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Hubert Borgmann

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Welcoming Remarks

Dear Ladies and Gentlemen,

We are pleased to present the Conference Proceedings of ITHEC 2016, 3rd International Conference & Exhibition on Thermoplastic Composites. With the 2016 event we continue a unique event series launched in 2012 focusing on the most promising aspects of lightweight constructions.

Manufacturing technologies for composite parts based on thermoplastic matrices have gained a tremendous maturity during the past decades. Even though enabling enormously shorter cycle times in comparison with thermoset equivalents, thermoplastic composites are still cost-expensive due to the high costs for semi-finished products like organo-sheets or fibre-reinforced thermoplastic tapes.

For this reason, well-established production technologies for polymer processing (e.g. injection moulding, plastics extrusion processes) have become a focal point for composite part manufacturers within the past years. These processes have the potential for cost-efficient productions urgently needed to establish composite parts in series applications. With respect to the components' performance, pure polymer products cannot compete with structural metallic parts. For this reason, part manufacturers have been modifying existing technologies to integrate reinforcements with short, long and continuous fibres. The latest developments and currently available composite parts clearly show that overmoulding technologies are well on the way to enter the mass markets, especially in the automotive sector. Further investigations in part manufacturing show trends to deploy load-optimised fibre directions by using tailored blanks. Fibre-reinforcements are locally attached to not reinforced surfaces in areas, where load introductions and higher stiffness are needed in order to fulfill the demands. We are sure that targeted investigations as well as the implementation of additional functionalities will enable thermoplastic composite parts to compete with their metallic pendants in terms of costs and performances.

Thanks to our international Programme Committee for their enormous engagement to ensure a competent evaluation procedure to compile a high quality conference programme selected from the 65 submissions received in response to our first Call for Papers. In six sessions, 25 well selected oral presentations, two additional industrial keynote lectures as well as 20 poster presentations will showcase the latest results, highlight the new perspectives and give clear impulses for all the branches. As usual, the manuscripts published in these proceedings help to document the content for the delegates and to make it available for the interested public later on. Special thanks to the authors who went through the additional trouble and prepared their manuscripts in time.

Furthermore, again severe thanks to our financial and non-financial sponsors as well as our media partners, who enabled us to arrange such a unique conference and to disseminate the information on it all around the world.

We are sure you will have an interesting event with stimulating discussions, lots of ideas and inspirations as well as a pleasant stay here in the Hanseatic City of Bremen.

Enjoy your conference!

Axel S. Herrmann
Conference Chair ITHEC
Universität Bremen

Hubert Borgmann
Project Manager ITHEC
MESSE BREMEN
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Design and Engineering of Structural Applications Based on Thermoplastic Composites

A. Erber, S. Janetzko
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Abstract:
Carbon Fiber reinforced Thermoplastics can be a solution for high volume production in the future due to their capability of realizing fast manufacturing processes. In order to produce structural parts optimized for lightweight it is necessary to have a comprehensive material portfolio available as well as design concepts which focus on a design to manufacturing approach on a highly economic basis. This paper shows development activities in the field of thermoplastics along the entire value chain. The main focus is on advanced design concepts based on load path-optimization using a comprehensive fiber reinforced material toolbox.

Keywords: UD-Tapes, Organic Sheets, Over Molding, Load-Path Oriented Reinforcement

Introduction
New lightweight design concepts and high-performance materials like Carbon Fiber Reinforced Polymers (CFRP) will be used to address the challenges of the automotive industry in the future. For mass production of CFRP’s, in particular, there is continuing high demand for cost-efficient materials and process technologies. Composite materials are already used today in many high-performance applications like aerospace, wind energy or based on limited lot sizes also in the automotive industry. These materials offer advantage properties compared to other materials like high specific strength and stiffness together with excellent crash and fatigue behavior [1, 2].

Challenges
In the past few years, composites have penetrated the automotive industry on a broader front but still in limited lot sizes. This is due to a number of challenges within the CFRP value chain.
Unlike metals, composite materials are created during the actual production process. Depending on the manufacturing technology used, the reinforcing fibers may be pre-impregnated with the polymer (Prepreg) or placed as a textile in a mold and impregnated with the polymer via infusion, followed by a curing process. It is therefore necessary to harmonize material and semi-finished product properties and behavior with the manufacturing process. This is also true for the design of the component. The design has to address the load and application requirements of the structural component but also the characteristics and constraints of the manufacturing process. A ‘design to manufacturing’ approach for CFRP materials is required, when it comes to cost-sensitive high-volume applications like automotive.
A further challenge for today’s composite technology is the material utilization ratio. With a high-performance reinforcing yarn like a carbon fiber, a mechanical performance potential of 4.000 MPa strength and 240 GPa stiffness in the case of, for example, a 50k heavy tow (Sigrafil® CT50-4.0/240-T140) is offered. This potential can be utilized by advanced material technology involving fiber/matrix interaction and load path-oriented fiber architecture within the composite.
High-volume production processes, in particular, require fast material systems in order to reduce processing times and therefore production costs. In this respect, thermoset materials and their related manufacturing technologies are limited by polymer chemistry and the processes required, such as infusion and injection.

Thermoplastic Composites
The above challenges confronting today’s composite technology can be addressed by thermoplastic materials which offer different advantages. Thanks to their ability to deliver fast manufacturing processes, Carbon Fiber Reinforced Thermoplastics (CFRT) can be a game changer in terms of production costs for high-volume industries in the future. Besides their potential for cutting costs CFRT’s also offer recycling possibilities that enable sustainable lightweight products. Furthermore thermoplastic composite materials have the potential to interact with other materials in hybrid systems. In addition the thermoplastic material behavior enables well established joining technologies such as welding and introduces the possibility to new repair concepts for composites. In comparison to thermoset materials thermoplastic composites do not have to be cooled during transport and storage which offers again a high cost savings potential.

One key element within CFRT’s is the interface between the carbon fiber and the matrix material. Standard carbon fiber materials with their epoxy
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based sizing formulations lack in mechanical performance. Hence the full potential of the material cannot be utilized. In that respect SGL Group developed a sizing system especially designed for thermoplastic matrices. With this new carbon fiber for thermoplastic applications a substantial benefit in mechanical performance can be achieved.

Aimed at high-performance continuous fiber-reinforced parts for optimized lightweight designs, most thermoplastic composites are reinforced by low-tow aerospace-grade carbon fibers (3k to 12k) that are relatively costly. By using larger industrial-grade carbon fibers (heavy-tow carbon fibers like 50k SIGRAFIL CT50-4.0/240-T140) both the reinforcing fiber and the manufacturing processes for the thermoplastic component can be optimized in terms of total material costs.

Processing of Thermoplastic Materials

Organic sheets with their individual properties are the backbone of highly integrated parts for serial production of thermoplastic CFRP parts. In respect to the part design the sheets can be customized in stacking sequence, fiber orientation, thickness and textile architecture.

Based on the UD-tapes different stacking sequences can be realized by automated tape laying (ATL) processes. Furthermore customized lay-ups with local reinforcements can be produced by ATL processes using UD-tapes in order to realize lightweight optimized structures.

Thermoplastic UD-tapes can also be processed in various textile technologies. One example is the weaving process that can process UD-tapes in widths from 12 mm to 24 mm. These fabrics manufactured on industrial type weaving machines can be consolidated to organic sheets as shown in figure 1. Sheets based on a textile (weaving) architecture offer typical advantages of textile structures such as improved drapeability. 

Fig. 1: Organic sheets based on tape weaving

The pre-manufactured organic sheets, with customized stackings and textile architectures, are heated above the melting point of the polymer by infrared or hot air ovens in a first process step. The heated sheets are transferred into the forming tool which is assembled to a press or is integrated in an injection molding machine. The handling process is usually done by a robot with special gripping units that hands over the organic sheets to the blank holders and fixation needles of the tool. Before the material cools down below its melting point, the tool closes and drapes the sheet into the 3D geometry of the mold. If the tool is integrated into an injection molding machine the injection process of e.g. Long Fiber reinforced Thermoplastic material (LFT) is started to overmold the sheets in order to produce complex formed structures. A few seconds later a finished part, without the necessity for a trimming process, can be taken from the machine.

Generation of mechanical stiffness

Mechanical stiffness can be generated by superior materials or by an advanced geometrical design using ribs or crimps. As shown in figure 2 ribs can be processed using press and injection materials like LFT. In order to gain the benefit of a customized sizing and an economic fiber base SGL developed LFT semi-finished materials using 24k and 50k heavy tows – “Sigrafil C T24-4.8/240-T140” and “Sigrafil C T50-4.0/240-T140”. These carbon fibers can also be used in a direct LFT process (D-LFT) [3]. Both the semi-finished materials process and the D-LFT process enable the production of components with a high geometrical stiffness and material performance in parallel.

Fig. 2: LFT based ribs reinforcing organic sheets

Design methodology

The chemistry of thermoplastics offers the possibility to use this material class in a toolbox approach. UD-tapes can be used for local reinforcements of organic sheets as long as if the semi-finished materials are based on the same matrix polymer. Furthermore LFT materials formed into ribs can generate geometrical stiffness as described above. Here the same polymer matrix is also a prerequisite.

Using a harmonized material portfolio as described previously enables the engineering to go for load path optimized designs. Therefore a structured approach based on an advanced design methodology
Coupled Heating-Forming Simulation of the Thermoforming of Thermoplastic Composites

T. Baumard, Institut Clément Ader, Albi, France, and Queen's University Belfast, Belfast, United Kingdom
O. De Almeida, Institut Clément Ader, Albi, France
G. Menary, Queen's University Belfast, Belfast, United Kingdom
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P. Martin, Queen's University Belfast, Belfast, United Kingdom
J. Bikard, Solvay R&I, Saint-Fons, France

Abstract:
A strategy for the simulation of the whole thermoforming process, from the infrared heating to the stamping, is presented here. Two loosely coupled simulation tools are being developed: the first one computes a realistic 3D, transient temperature field of the composite stack inside an infrared oven, considering the radiative, conductive and convective heat transfers; the temperature distribution is used as an input for the second that aims at simulating the thermomechanical behaviour of the composite during the forming step via a non-orthogonal constitutive model. The steps for the identification of the model parameters are introduced. Initial validation tests show realistic results in term of shear angle distribution.

Keywords: Forming, Thermoplastic Composites, Infrared Heating, Process Simulation, Thermomechanical

Introduction
Thermoplastic composites structural parts have recently started to make their way into the transportation sector [1], but the use of composites in the automotive industry is currently mostly limited to low volume production parts for luxury cars, due to high manufacturing costs and cycle time.

Manufacturing processes such as thermoforming seem well adapted for high volume parts, but to reach the production rates required by the automotive industry, those processing techniques must be optimized to understand and avoid the apparition of defects. In order to avoid expensive trial-and-error procedures after the mould fabrication, robust virtual manufacturing schemes are needed to efficiently find the best process parameters (pre-heat temperature, punch speed, consolidation time ...), and predict the resulting mechanical properties of the part [2].

The thermoforming process consists in heating a laminate above the melting temperature of the thermoplastic matrix in an oven; it is then transferred to a press where it is formed and cooled down before demoulding. The sequential steps are presented in Fig. 1. Originally developed for thermoplastic sheets, it is now used for manufacturing thermoplastic composites parts as high production volumes are in demand.

Most of the current simulations of the thermoforming process consider only the mechanical draping of the part, while the effect is rarely investigated. It has been evidenced in recent research [3] [4] that the forming cannot be considered adiabatic: when the laminate contacts the mould, its temperature rapidly decreases which induces local rigidification that can lead to wrinkles. These heat transfer effects need to be studied as they represent a limit of the stamping process. The control of the laminate temperature during the entire process is therefore critical to ensure a good part quality.

This work adopts a comprehensive approach for the simulation of the thermoforming of thermoplastic preimpregnated composites. Two coupled simulation tools are being developed for the preheating phase and the forming phase respectively.

Heating simulation
The first stage of the thermoforming process aims at bringing the composite laminate to the processing temperature in an oven. Infrared oven are favored in industrial composite applications for their fast heat-up
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Fig. 1: Thermoforming process steps: (a) infrared heating, (b)-(c) forming and consolidation, (d) demoulding

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A full pdf version in print quality is available here!
QSP®: How to Produce a Netshape Thermoplastic Composite Part in One Minute

C. Callens, F. Bordellier
CETIM, Nantes, France

Abstract:
The Quilted Stratum Process® (QSP®) is a revolutionary approach for high performance thermoplastic composites and multi material parts design and production. This global breakdown concept reaches the goal of combination of High Performance, Low Cost and Short Cycle Time simultaneously. This new QSP® line can produce complex multi-thickness, multi-material, and multi-orientation parts in a short cycle time (40 to 90sec), starting from raw material to final netshape part. With a budget around 5M €, all this process was developed with university and industrial partners to get a final result close to real needs of the industry. With 6 patents and a JEC award received in June 2015, the QSP® is "ready to use" for the industry. It shows that we can now produce optimized thermoplastic composite parts, ready for assembly in a very short cycle time for high volume capacity, with quality repeatability and robustness at global cost efficiency.

Keywords: QSP®, Quilted Stratum Process®, Multi-Material, Low-Cost Process, Pultrusion, Lightweight, Thermoplastic Composite.

Introduction

The outstanding properties of composites and the advantages of using these materials in industry to lower the weight of structures are well established. The choice of process to enable optimized production is an issue for which there have been no viable solutions so far. On behalf of the French mechanical industry, CETIM worked on many different parts to propose solutions to reduce weight of structural applications based on continuous fiber reinforced composites. However, technologies compatible with small series or high-performance (and high-cost) applications could not meet the mass industry’s needs. There have been many attempts to optimize the productivity of existing technologies. The German car industry, for example, reached a high level of automation, substantially reducing the processing time for RTM parts. Unfortunately, the middle-class cars of tomorrow will not use many carbon-epoxy parts because the process concept itself generates high costs. We have to keep in mind that for traditional industry, the challenge is to mute from metallic solutions using steel at less than 1€ per kilo to composite solutions. The QSP® concept has been defined in 2012 by Cetim and Ecole Centrale de Nantes. Three years later, a QSP® pilot line funded by Cetim and Region des Pays de la Loire with 3 SME’s (Pinette Emidec Industries, Compose, Loiretech) supported by 3 main research laboratories (ECN, ENS Cachan and Onera) is ready for industrial validation. This pilot line is part of the French composite pilot line project under the M2P & JV IRTs authority in accordance with the French automotive industry.

A new process for new opportunities

To reach the goal of designing and producing high-performances thermoplastic composites and optimized multi-material parts, the QSP® is based on three concepts:
- integration of the global process “from raw material to net shaped part”, where the maximum added value is focused on the final part, with no semi-product procurement, but maximum automation and maximum raw-material standardization for a worldwide procurement capability;
- giving priority to production efficiency, with cost and cycle time becoming the main driver for the part design. For a given cost and cycle time performance, the final part has a reproducible quality level that provides material characteristics, rules and method for robust design;
- the design of multi-material, net-shape preforms for net-shape final parts, with the right material at the right place, with a minimum loss of material.

QSP®, how does it work?

As shown in Fig. 1, the process makes possible the production of parts with short cycle times, using steps described below:
1 – Pultrusion + extrusion: starting from continuous fibers combined with a thermoplastic material, tapes are produced at optimized cost in terms of width, thickness and fiber reinforcement (UD, weaving, glass and/or carbon).
2 – Cutting: tailored patches defined by a specific FEA analysis method are cut from different continuous pultruded tapes.
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2 – Cutting: tailored patches defined by a specific FEA analysis method are cut from different continuous pultruded tapes.
the adequate control means, and then set the process
rules and parts acceptance criteria needed for robust
mass production.

What kind of parts and what results with QSP®?
The pilot line is ready to use in Cetim's workshop at
Technocampus Composites (Nantes), and many
parts can be produced to evaluate the potential. The
Fig. 5 gives an overview of results we can achieve
based on a real suspension arm. It compares a
conception made in 2012 with mono-thickness
organosheet plates [2-3] ("current composite
prototype" in Fig. 5), with a new multi-thickness
and netshape conception with QSP®.

Fig. 5: Example of results (cost, weight, material
loss) / carbon suspension arm

Some parts have more potential on the QSP®, like
the composite seat backrest made of 9 patches
designed and manufactured by Cetim, under the
Demos collaborative project funded by Ademe and
led by Faurecia. The backrest is 30% lighter than the
original steel version for the same maximum load.
This backrest is a good example of a part feasible
with QSP® at high production rates (see Fig. 6).

Fig. 6: Multi-thickness Demos backrest

QSP® has been developed to answer to the question
of mass, cost and cycle time reduction for
mechanical engineering and automotive applications
made of composite materials. It is not limited to
these application areas. Indeed, it is totally usable by
the actors of the aviation industry faced with
significance growth of aircraft production rate (from a
few planes a month today to a few dozen aircraft per
month at very short term). The line has to
adapted to these kinds of application:
- Certified composite materials have to be used. It
means that the starting point of the QSP® line is the
cutting machine feed with tapes of certified
materials bought on the market,
- A particular attention has to be paid to the
behaviour of thermostable polymers during all the
manufacturing cycle,
- The process has to be optimized in order to
generate the minimum of defects.

Beyond these specific items, the line is adapted.

A new process ready for the industry

Based on a development linked with strong
industrial partners, this new process is ready for the
industry. Awarded by JEC organisation in 2015 in
Houston – USA (Process category), the QSP® opens
new opportunities for the production of
thermoplastic composites and multi-material parts,
combining high performance, low cost and short
cycle times.

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Nantes, April 2016
The infrared oven is to get a good homogeneity on temperatures between surfaces and through the multi-thickness preform. The system developed here can reduce significantly this issue, reducing also the cycle time with a better quality on the final heating. For example, for a multi-thickness preform PA6 Glass fiber, with thicknesses between 1.5mm and 3mm, the process can heat it in about 60 seconds at the right temperature everywhere, reducing at the same time oxidation for this material. With this innovative heating operation, a consolidation step is useless to achieve final quality specifications (porosity for example); this is a real breakthrough to reduce production's costs.

Finally, the fast transfer system with needles allows the use of netshape preforms. After stamping, there is no more operation needed to finish the part. Moreover, during the stamping, many operations are done at the same time (one shot operation) to get a maximum added value on the part:

- Overmoulding to add reinforced ribs or any other plastic functions, and to have a final netshape part ready to use
- Creation of high performance holes to prepare future assembly, with or without inserts
- Integration of multi-material assembly inside the mould, to make assembly during the forming step for a perfect connection

All the bricks of the process are working at the same time. Each one was defined and optimized to achieve a final short Takt Time as required for the automotive industry, between 40 to 90 seconds per cycle.

How do we design parts for the QSP®?

QSP® is not the result of a dogmatic material approach, it gives the capacity to the engineer to design an integrated multi-material part with the right material at the right place. The mechanical strength envelop shows the local areas where you need anisotropy resistance or not and the level of stress:

- For areas with high level of anisotropy, carbon fibers are usually used for high resistance or stiffness and glass or bio sourcing fibers for lower requirements.
- For areas without anisotropy, steels, aluminium and magnesium can be used as well depending on the level of stress.
- For areas with specific functionality, short fibers reinforced polymers can be used.

The QSP® provides the right solution of mixing all these requirements and materials for an optimized result in performance, cost and cycle time. Studying the potential for a process requires the existence of a numerical design chain. Cetim proposes a methodology using the best available tools, and focuses its R&D work on further improving simulation quality (see Fig. 3). Developing a new process goes hand in hand with the development of design know-how to understand how stresses are transferred from one patch to another.

Fig. 3: integration of multi-objectives for the design

Design robustness is assessed by integrating the harmfulness of the discontinuities in the part. The tools developed are:

- Optimization software (in collaboration with French aerospace lab Onera) to help identify the mechanically optimal zones and orientations for the patches, based on the functional specifications [4-5].
- Design software to help validate the feasibility of a part. Among other things, the tool enables linking the final 3D shape and the initial flat preform (see Fig. 4). In this way, the designer has all information needed for designing to cost. Equivalent tools exist for other processes (e.g. the wound composite modeler for the filament winding process) and can be integrated into simulation software like DS CATIA.

Fig. 4: Forming process simulation [6]

The design code, for which the pilot line at Cetim is used to determine the process capability, identify...
Automotive Crash Beam from UD Tapes by Tailored Blanks Production and its Optimisation

R. van den Aker, Van Wees UD and Crossply Technology BV Tilburg, The Netherlands

Abstract:
Van Wees has made UD and Crossply machines since 1993. The first machines were built for the ballistics industry in which it has become a benchmark and leading technology. More than ten turnkey production lines have been built producing millions of square meters per year. In 2006 the first prepreg machine for thermoset resins was built for the composites industry and in 2007 Van Wees started with the thermoplastic resin based equipment. In 2010, the first Multi-axial UD machine was built. A turnkey line is made up of creels, impregnation machine, crossply and/or Multi-axial UD machine.

Van Wees presents a study, being performed in cooperation with TPRC in the Netherlands and Kraus Maffei in Germany. The product which is chosen for this study is a crash beam, to be mounted in an automotive door. This product is originally designed with a Glass-PA fabric reinforced blank, so-called “Organic Sheet” from the demonstration project LIPA-series www.lipa-series.com

Keywords: Thermoplastic Composites, UD Tapes, Composite Tailored Blanks, Crossply, Multi-Axial, Automation

1. Introduction
High volume production of automotive parts made from composite materials are a big challenge for the industry, in particular for carbon fiber based materials. In this study, a comparison is made between fabric- and UD tapes based composite blanks. It will give the result of how to reduce weight of the part, use as much of the base material as possible and make the part just in time downstream the injection molding machine.

2. Crash beam for an automotive door
The crash beam’s function in a car door is to protect driver and passengers in case of intrusion by impact forces. Stiffness, strength and energy absorption are therefore important for the part. Furthermore an extra requirement is given by the relatively high displacement of 300 mm which needs to be possible without dangers of wounding passengers in the car. In case of steel this is easy to be realized due to the high elongation which is possible with the steel qualities being used.

In the Lipa-series feasibility project a consortium of companies worked together for the demonstration of the production of the crash beam, reference 1. The crash beam is made from fabric reinforced PA6 panels, 47% fiber volume fraction and a thickness of 3 mm. The size of the product is approximately 700 x 120 x 40 mm (see fig. 1). The glass fabric based panels are made by for example Bond laminates in Germany and Quadrant in Switzerland.

The fabric panel based part can withstand a force of 9 – 10 kN. The requirement is 8 kN. The absorbed energy is 200 Joule at a deformation of 60 mm. Deformation till 300 mm depth is not tested and/or reported.

Fig. 1: Crash beam, glass fabric based

3. Composite UD chips based products
Composite UD chips are defined as UD tapes which are cut to maximum sizes of 50*50 mm. and may have irregular shapes. The chips can be formed into parts in one operation. This will always be the case with thermoset resins composite chips. In case of thermoplastic resins, the intermediate step of making panels can be chosen.

The composite UD chips are an interesting option for making automotive parts. These materials are characterized by their high performance, isotropic nature, good formability and the chips can be made from the residue of UD tape and tailored blank production.

Examples are shown in figures 2, 3 and 4 with different resin types.
Automotive Crash Beam from UD Tapes by Tailored Blanks Production and its Optimisation
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Examples are shown in figures 2, 3 and 4 with different resin types.
For the configuration of the tailored blank line, the following ply-books are used. The glass fiber PA based design is composed of 10 layers of 0.3 mm thickness. Orientation is 45/135/0(3)/90/0(2)/135/45.

The carbon fiber based crash beam is made from 12 layers of 0.25 mm thickness with an orientation of 45/135/0(4)/90/0(3)/135/45.

In the third composition, the 4 middle layers 0/90/0/0 are replaced relative to the carbon fiber UD tapes based design by the carbon chips layers. The thickness corresponds with the 30% residue from the nesting and cutting. The ply-book is therewith 45/135/0/carbon chips/0/135/45.

Nesting of the tailored blank patches

In figure 8 the nesting of the patches is shown. The patches have a length of 687 mm and a width of 143 mm. The nesting results in a residue of 30% of the material surface.

Fig. 8: Nesting of the patches

By overlaying a grid of 50 x 50 mm it is shown how the residue can be cut into composite chips which have a considerable length and therewith will result in high performances in composite panels (see fig. 9). The chips are not or only partly connected by the spot-welds and therefore free to move when the material is pressed into shape.

Fig. 9: Nesting including a composite chips pattern of 50 mm

Configuration of the line and production process

Production line for tailored blanks

The process starts with the production of the UniDirectional tape on the impregnation machine. The Van Wees process is based on unwinding the tows from the creel, spreading the fibers and impregnation on the impregnation roller. The molten polymer is metered direct from an extruder with slot die on the impregnation roller where it meets the spread tows after which the UD tape is post impregnated and cooled in a calander before being wound on drums. Figure 10 gives an impression of the impregnation machine.

Fig. 10: Impregnation line for UD tapes production

The required numbers of UD tape rolls are placed on the Multi-axial UD and Crossply machine(s) where the UD tapes are positioned in multiple directions and layers. The plies are fastened by spot-welds. From this assembly, rolls can be made or patches which are cut in line with the Crossply machines, (see fig. 11).

Fig. 11: Tailored blank production line

Production of the patches

The UD tape based crash beam products have a ply book of 10 and 12 UD layers, total thickness is 3 mm. The production line dictating ply-book is the one for the carbon fiber product, being...
Influence of the Cathodic Dip Painting Process on Fibre-Reinforced Thermoplastic Composites

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Technische Universität Chemnitz, Germany

Abstract:
Fibre-reinforced thermoplastics are increasingly coming to the fore for automotive applications. Already in use for mounting parts like the diffuser frame in BMW i8 or the infotainment carrier in Audi A6 the next step is to employ this material in structural applications. Since car body structures are passing through a conventional automotive process chain and rearrangements of or adjustments to it include additional costs, it is the OEM’s intention not to make changes. Due to this fact fibre-reinforced thermoplastics must be capable of running through the existing automotive process chain including distinct influences. As little is known about the correlation of cathodic dip painting and the properties of fibre-reinforced thermoplastics, the author’s ambition is to gain an elementary understanding of it. Therefore tensile tests are conducted before and after the cathodic dip painting process with different fibre-reinforced thermoplastics. The results show that while the fibre-dominated properties are not influenced by the cathodic dip painting process the matrix-dominated properties increase.

Keywords: Fibre-Reinforced Thermoplastic, Cathodic Dip Painting, Mechanical Properties, Organosheets

Introduction
Introducing BMW i3 and BMW i8 the BMW Group became a pioneer in the field of mass production of thermoset fibre-reinforced plastics (FRP) for car bodies and hence also took over the technological leadership in this discipline. A key driver whether or not fibre-reinforced plastics can be established in the automotive sector on an even larger scale is the production costs [1]. Fibre-reinforced thermoplastics (FRTP) with advantages like faster manufacturing processes compared to thermoset systems can be a solution to this problem [1-2]. A further important factor for an increasing application of FRP parts in cars is the possibility of combining them with other established materials. The new BMW 7 series, shown in Fig. 1, proves that hybrid material solutions consisting of FRP, aluminium and steel in car body structures are possible.

Fig. 1: FRP, aluminium and steel in the body structure of the new BMW 7 series

FRTP are becoming an even more interesting alternative due to additional advantages like high functional integration by injection moulding [3]. Consequently, the next logical step must be to develop new multi material designs composed of FRTP, aluminium and steel to merge their benefits. That way it is possible to meet automotive demands of weight reduction and cost-effective mass production.

As the conventional automotive process chain involves press shop, body shop, paint shop and final assembly the processed materials are exposed to most diverse influences. The industrialisation of the new BMW 7 series with new hybrid setups showed that the paint shop with its considerable chemical and thermal loads presents a distinctive challenge. Since FRTP parts are intended for structural applications and can therefore not be seen, it is not necessary to paint them. Accordingly, the cathodic dip painting process (CDP) represents the most chemical loads and is therefore investigated in this paper. As little is known about the correlation of CDP and the properties of FRTP the author’s ambition is to gain an elementary understanding of it.

Cathodic dip painting process
The cathodic dip painting process is necessary to protect metal-based materials from corrosion by applying a diffusion layer. Furthermore it ensures a smooth surface and thus an adhesion base for the following lacquer coats [4-5].
The first process steps are several cleaning and pretreatment steps, where oils or other contaminants from the prior press and body shop are removed. After phosphation and passivation which is i.a. necessary for good adherence, a paint film is deposited on the body in white (BIW) by applying a voltage between 300 V and 450 V in the CDP-tank, see Fig. 2. That way the car body acts as a cathode and positively charged particles can be deposited on it.

In the CDP-dryer the applied e-coat is dried at maximum temperatures between 170 °C and 190 °C [6]. Figure 3 shows an exemplary temperature profile.

**Materials Used**

The materials used for this paper are organosheets with different matrix systems but identical fabrics, see Table 1. All organosheets are made of four plies of woven fabrics with 600 g/m² area weight resulting in a nominal thickness of 2 mm and a fibre volume content of 47 % endless glass fibres. The matrices are dyed black with carbon particles.

**Table 1:** Materials used

<table>
<thead>
<tr>
<th>Material</th>
<th>Matrix</th>
<th>Fabric</th>
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<tbody>
<tr>
<td>A</td>
<td>PA 6</td>
<td>Twill</td>
</tr>
<tr>
<td>B</td>
<td>PA 66</td>
<td>Twill</td>
</tr>
<tr>
<td>C</td>
<td>PPA</td>
<td>Twill</td>
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</table>

**Material Characterisation**

To characterise the effects of the CDP treatment several mechanical tests were conducted first. For analysing the fibre-dominated properties tensile tests were done according to DIN EN ISO 527-4 in fibre direction. The ± 45° tensile test method DIN EN ISO 14129 was used to determine matrix-dominated properties. To reproduce production conditions as good as possible and to create equal original conditions, all specimen were conditioned according to DIN EN ISO 1110 to equilibrium moisture content.

Specimen running through CDP were conditioned before CDP and tested without further conditioning afterwards. To apply the required voltage two 3 mm diameter holes were drilled to the CDP samples and M3 screws were used for attachment.

Differential scanning calorimetry (DSC) provided the difference of degree of crystallinity before and after CDP and thermogravimetric analysis (TGA) the fibre volume content. Karl Fischer titration was used for the determination of moisture content.

**Results and Discussion**

Figure 4 shows that there is no significant change in tensile strength in fibre direction due to CDP treatment. It is notable that the tensile strength of material B is clearly lower compared to material A and C which was not expected.

**Fig. 4:** Change in tensile strength before and after CDP in fibre direction (DIN EN ISO 527-4)
Overmoulding – An Integrated Design Approach for Dimensional Accuracy and Strength of Structural Parts

M.M. Bouwman, T.G. Donderwinkel, S. Wijskamp
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Abstract:
Overmoulding of thermoplastic composites combines the benefits of thermoforming and injection moulding to create structural parts with a high level of function integration. Work is performed in order to create proper design tools that can be used for a right-the-first-time design strategy. These tools take into account the evolution of residual stresses during forming, the development of the interface between the polymer and the composite during injection, and the warpage of the final part after cooling and release from the mould. A model is proposed for the prediction of the bond strength between an injected polymer and a composite insert. A test method has been developed to validate this bond strength under tensile loading conditions. A numerical strategy is proposed for the coupling between a forming and an injection moulding simulation. The spring-forward of different continuous fibre reinforced thermoplastic V-shapes was evaluated showing a good correlation between experimental work and a theoretical model.

Keywords: Thermoplastic composites, Press Forming, Injection Moulding, Interface, Residual Stress, Warpage

Introduction

Overmoulding of thermoplastic composites is a hybrid process that combines thermoforming of a continuous fibre reinforced thermoplastic blank with an injection or compression moulding process. The process allows for complex parts with high structural performance due to the continuous fibres that can be positioned along the load paths in the part. Further advantages are the potential for high level of function integration, net shape processing and large series production. A schematic representation of the overmoulding process is shown in Fig. 1. The process consists of the melting and forming of a blank, which is consequently over injected with a polymer that is compatible with the polymer matrix of the composite blank. This allows, for example, the addition of reinforcing ribs to increase the geometrical stiffness.

Combining the forming and injection moulding process requires an integration of the design tools that are already available for the separate processes. Multiple mechanisms that determine the final part quality occur nearly simultaneously. Forming-induced fibre reorientation and fibre stress build-up have to be taken into account together with the melt flow front evolution and shrinkage stresses for a proper mould design. Additionally, the formation of a bond between the injected polymer and the composite insert, which is a function of temperature at the interface of the two materials, needs to be known.

The objective of the current study is to qualify and quantify 1.) The formation of the interface between the injected polymer and the composite insert, and 2.) The evolution of the residual stress build-up and warpage of the overmoulded structure in order to implement these in commercially available numerical design tools. Polymers under consideration are polyamide 6 (PA6), polyetherimide (PEI) and a polyaryletherketone (PAEK).

Interface model development

The establishment of a bond between the composite insert and the injected polymer comprises two different phenomena: 1.) development of intimate contact between the insert and polymer melt, and 2.) interdiffusion of polymer chains across the interface. The latter is also known as healing and can only occur once intimate contact has been achieved. It is assumed that the time required to achieve full intimate contact is negligible compared to the required time to heal the interface [1]. Therefore, only
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The degree of healing $Dh$ can be defined as the fraction of the maximum attainable bond strength $\sigma_\infty$. The development of the degree of healing over time $t$ under non-isothermal conditions yields [2]:

\[ Dh(t) = \frac{\sigma(t)}{\sigma_\infty} = \frac{1}{T(t)} \int (1)
\]

with $T(t)$ and $\sigma(t)$ being the time dependent temperature and bond strength, respectively. For healing of amorphous polymers, the interface temperature needs to exceed the glass transition temperature $T_g$. For semi-crystalline polymers, the polymer chain mobility can still be severely obstructed by the presence of crystalline regions at this temperature, which prohibits healing. Therefore, it is generally assumed that the melting temperature $T_m$ has to be exceeded upon heating for healing to occur [3]. During cooling, healing is assumed to be possible until the polymer starts to crystallise [4].

It was observed that the reptation times of the semi-crystalline polymers PA6 and PAEK are very short above the melting temperature. This results in an almost instantaneous transition to full healing above the melting temperature and, consequently, a 'binary' output of the model with either full healing or no healing. Therefore, a more accurate description of the melting behaviour is considered of greater importance than the reptation times of semi-crystalline polymers.

Instead of using a single melting point, a melting trajectory is defined based on a DSC analysis. A baseline is fitted on the heating curve and the cumulative surface area of the melting peak is normalized. The resulting curve, representing the degree of melting $D_m$ of the material, i.e. the crystalline fraction that is melted with respect to its original state at room temperature, is shown in Fig. 2. An exponential function is fitted for numerical modelling purposes. Subsequently, this degree of melting is correlated to the degree of healing assuming a linear dependence.

Fig. 2: Melting curve of PA6 (Ultramid B3K) based on DSC measurement

Numerical implementation of the healing model

A Iosipescu specimen geometry was chosen for the numerical and the experimental validation of the healing model, see Fig. 3. It can be used to characterise the interface strength at the edges of the composite insert (Fig. 3, left), or the strength of a rib moulded to the surface of a composite laminate (Fig. 8, right). The test fixture is designed to apply a shear loading, but the specimen can also easily be clamped in standard tensile testing fixtures.

Fig. 3: V-notched specimen for interface strength characterisation; the right configuration is used for rib-on-plate testing

Autodesk Moldflow(R) was used to simulate the injection of a PA6 polymer on a PA6 insert. A finely meshed geometry is shown in Fig. 4.

Fig. 4: Overview of polymer flow and insert mesh.

The resulting degree of healing on the interface using the melting model of Fig. 2 is depicted in Fig. 5.

Fig. 5: Predicted degree of healing $Dh$ for overmoulding PA6. Overall $Dh = 0.64$

The tensile strength of a PA6 polymer insert overmoulded with the unfilled PA6 polymer was measured for the different temperatures of the injected polymer melt (Fig. 6). A slight increase in strength is visible for an increase in injection temperature and thus interface temperature. The strength is, however, limited to around 30% of the performance of the benchmark, which is the tensile strength of an injection moulded V-notch specimen.
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Efficient Laser Cutting of High-Performance Thermoplastic Composites

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Abstract:
In the European ‘Co-Compact’ project the partners LASER on demand GmbH, Element Materials Technology Hitchin and Laser Zentrum Hannover e.V. developed efficient laser cutting processes and adapted system technology for thermoplastic composites and proved the mechanical properties and industrial suitability by performing extensive tests on both coupon level and demonstrator parts. In this paper an overview of the innovative achievements is presented.

Keywords: Laser, Machining, Cutting, Drilling, Efficient, High-performance

Introduction
The widespread use of thermoplastic composite (TPC) structures within the aerospace, energy and transportation sectors leads to an increasing demand for economic, fast and reliable cutting and trimming processes. Predominantly these requirements are difficult to meet by conventional technologies, e.g. milling, drilling and water jet cutting. Laser cutting as an alternative technology offers outstanding advantages, such as no contact between tool and material, resulting in no tool wear and no moisture uptake of the materials. In order to be able to integrate laser cut TPC components into reinforced composite structures, a sound and comprehensive knowledge of the influence of the laser cutting process on the material characteristics is essential. Furthermore, a key factor in the acceptance of laser processes is the provision of adapted, automated and easy-to-operate processing and handling systems. The achievements within the European ‘Co-Compact’ project (‘Cost Effective Laser Cutting Of Thermoplastic Composite Materials For High Performance Applications’) provide answers and solutions for a large part of these questions, bringing the laser machining technology closer to industrial application.

Laser machining basics
A typical CFRP laser machining setup offering high flexibility in terms of the cutting geometry and high potential for damage-free cutting is remote cutting (see Fig. 1). The radiation is guided from the laser source through a fibre or by mirrors to the main part of this setup, a scan head. The scan head mainly consists of two dynamic mirrors enabling a fast beam movement (scan speed) across the material surface. The beam is focussed on the material surface by telecentric focussing optics. Since the working field is limited in this setup, a stage system can be used for extension when machining larger parts or multiple parts at once.

Fig. 1: Schematic laser remote cutting setup

Laser machining parameters and strategies
Lasers that use localised heat to remove material may influence the fibre-matrix-structure at the cutting kerf. A major objective within the project was the development of a comprehensive understanding regarding the effect of processing
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Efficient laser cutting of high-performance thermoplastic composites

Various laser types were studied and a main focus was placed on the use of industrially available, compact and easy to integrate lasers. The best compromise between cutting rate and cutting quality was found for continuously emitting, high power single mode fiber lasers which offer a high beam quality. The high beam quality allows for very small spot sizes which in turn lead to narrow and rectangular cutting kerfs, as shown in the cutting kerf micrograph of laser-cut CF/PPS in Fig. 2b).

The remote cutting setup enables the application of multipass cutting strategies in which the material is cut stepwise by multiple passes on the same cutting contour with very high scan speed. This strategy was identified to offer higher cutting quality and lower thermal load than processes with only a single pass for a full cut. Moreover, with increasing scan speed and by applying additional delay times for heat dissipation between the passes, a further improvement in the cutting quality was achieved (see cross-sections in Fig. 3).

Simultaneously, the application of these multipass cutting strategies with higher scan speeds leads to increasing process times due to a higher number of passes required for a full cut. To maintain a sufficient processing efficiency, specialized cycle processes were developed.

The combined use of the scan head and dynamic and precise stage systems allows for a continuous parallelized cycle processing, leading to improved cutting rates whilst maintaining high dimensional accuracy (see Fig. 4) [1].

Besides the quality evaluation by cross-section micrographs, the absence of cracks which can reduce the mechanical properties dramatically was proved by dye penetrant testing on laser cut parts, as shown in Fig. 5 for a structure in an efficient cycle process. In this example, which was processed by multipass cutting, no differences can be found between the surface and the cutting kerf.

To demonstrate the industrial applicability, process emissions, which are often mentioned as a problem with laser cutting, were investigated during cutting processes. Hazardous emissions, such as carbon monoxide, volatile organic compounds or hazardous particle sizes, were shown to dramatically decrease with multipass strategies which were previously identified for high quality processing [2].

Demonstration of mechanical properties

The full processing strategy development was accompanied by an extensive mechanical test program, including static, dynamic and ageing standard test methods, which were applied to identify the effects on the material performance. These tests included tension, compression, in-plane shear, open hole tension and open hole compression tests for both standard and ±45° test directions. The test program also covered very small specimen sizes such as interlaminar shear strength and flexural tests, which react very sensitively to potential modifications at the edges. Mechanical tests were also performed after the conditioning of samples with thermal cycling and after exposure to oil, water and humidity for up to several months. The mechanical properties of laser...
Hybrid Structures - The Novel Way of Forming High-Performance Thermoplastic Composites for Primary Structure

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Ferdinand Stükerjürgen GmbH & Co. KG, Rietberg-Varensell, Germany
C. Laugwitz, HBW-Gubesch Thermoforming GmbH, Wilhelmsdorf, Germany
A. Wegner, Karl Mayer Technische Textilien GmbH, Chemnitz, Germany
M. Würtele, KraussMaffei Technologies GmbH, München, Germany
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Abstract:
In the context of the LuFo IV-Project “VIA-Hybrid” a new technology for the manufacture of highly integral components with endless- and short-fibre reinforcement for aircraft primary structure is developed. The demonstrator consists of a structural insert, combined with an overmoulded component. The components form a window frame for aircraft applications. To combine endless-fibres, a complex fibre orientation and thermoplastics, hybrid textiles, consisting of carbon and PEEK-fibres, are processed to create a preform for the structural insert. For consolidation, a variothermal tooling concept is developed achieving up to 400°C. After consolidation the subsequent process step of overmoulding is performed. Pre-Heating concepts and material variations are carried out to evaluate parameters to achieve a reliable substance-to-substance bond.

Keywords: Window Frame, Overmoulding, PEEK, Hybrid Textiles, Thermoforming

Introduction
To meet the needs of emerging markets the CFRP manufacturing processes require significant cost reduction. Especially complex structural components in aviation application often are produced in RTM-processes, since the processed reinforcement fibres offer the great potential of being drapable into complex geometries. However, long cycle times reduce the process efficiency remarkably.

A promising strategy is processing of thermoplastic composites due to their short consolidation times. Nevertheless thermoplastic CFRPs are usually manufactured with prepreg or organo sheet materials which results in limited drapability. This disadvantage can be obviated by hybrid textiles consisting of thermoplastic- and carbon fibres. This class of reinforcements combines the drapability of dry textiles with thermoplastic matrices. To hold down tooling costs especially flat parts are desirable.

To increase the level of geometrical complexity, overmoulding with short-fibre reinforced thermoplastic material is a promising approach. Here the process development to create reliable interface strength between short- and endless-fibre reinforcement poses a key challenge.

Consequently the steps of creating endless fibre reinforced structural inserts combined with overmoulded short fibre-reinforcements were performed during the LuFo IV-project VIA-Hybrid to create a thermoplastic window frame.

Fig. 1: Process Chain

Development of hybrid textiles

Hybrid textiles for thermoplastic composite structures consist of a combination of reinforcement fibres and thermoplastic fibres that supply the matrix during consolidation. This class of textiles offer drapability of dry textiles combined with thermoplastic matrices. Furthermore the process stability increases, since the process step of matrix-integration is transferred to the textile manufacturer. To benefit from these advantages a hybrid non-crimp fabric (NCF) was developed by Karl Mayer Textilmaschinenfabrik GmbH and FIBRE.

Fig. 2: Hybrid Non-Crimp Fabric
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For manufacturing hybrid textiles a suitable combination of reinforcement - and thermoplastic fibres has to be found. In this context the chosen reinforcement fibre is TohoTenax HTS 45 12K with P12 sizing which has advantageous adhesion properties in combination with thermoplastics [1]. As matrix- and sewing yarns, fibres from VIC TREX PEEK 151G were developed. The realised construction enables Fibre Volume Contents of 54% and an engineered ply thickness of a single ply carbon fibre of 0.23 mm. Furthermore first prototype fibres from VICTREX PAEK AE250 were spun. PAEK AE250 yields an equivalent Glass Transition Temperature as PEEK 151G while providing a reduced Melting Temperature at 305°C. This enables significantly improved processing conditions regarding time and process induced internal stresses.

**Process development**

**Preforming**

Two different principles were combined for preforming.

- **Tailored Fibre Placement (TFP) of hybrid-rovings for circumferential deposition of fibres**
- **Draping of hybrid-NCF for +/-60° orientated fibres**

Both textiles were fixed by a PEEK sewing-yarn onto a PEEK-film. Consequently the consolidated structure will not be disturbed by any foreign material. Although the TFP-unit is only able to deposit single hybridrovings, the process efficiency is high, due to the possibility of multiple parallel running stitching units. Fig. 3: Preform

For depositing fibres with other than continuous 0° -direction, the efficiency of the TFP process would be reduced due to required loops that decrease the process velocity. Hence fibres with ±60° direction were integrated by draping the hybrid NCF. To evaluate an appropriate NCF, different configurations, produced by Karl Mayer Textilmaschinenfabrik GmbH, have been investigated. The objective was to configure a textile with a high degree of in-plane drapability and a low tendency to narrow while being draped. To examine the most promising configuration, three NCF with different stitching pattern and stitch distances were compared by DRAPETEST studies and picture analysis of the fibre orientation [2].

The developments for preforming resulted in a flat preform with multi-orientated fibres along the oval shape of the part. Cutting scrap is minimised to less than 5% which is advantageous regarding prices for carbon-fibre and PEEK.

**Thermoforming**

A major challenge for processing hybrid textiles is the mechanical and thermal design of the press tooling, which in this context was developed by HBW-Gubesch Thermoforming GmbH and FIBRE. The heat management of the press tooling follows a variothermal approach. For melting PEEK processing temperatures up to 400°C are required to reduce the melt viscosity and improve fibre bundle impregnation. In this case heating is supported by electric cartridges and cooling by oil. Electric cartridges provide the advantage of fast and precise heat transfer into the tooling and minor costs, whereas cooling of the tooling from 400°C requires pressurised oil. Fig. 4: Thermoforming Cycle

The layout of the cooling system is designed based on simulation results, giving recommendations for the optimum positioning of cooling channels for oil and the heated zones of the flexible tubular heaters close to the cavity. The knowledge of the temperature distribution is very important to predict the local thermal expansion of the tooling to prevent contact of upper and lower die and to achieve a uniform heat transfer into the laminate. Fig. 5: Consolidated Structural Insert
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Sequentially Coupled Material Flow and Multi-Scale Stress Analysis of Discontinuous Long-Fiber Composite Helicopter Fairing Rib

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S.R. O’Neill, Greene, Tweed & Co., Nottingham, United Kingdom

Abstract:
Discontinuous long-fiber (DLF) thermoplastic composites have been developed to replace complex-shaped metal parts. However, due to the random fiber structure of the material, analysis and prediction of part performance had been a challenge in the past. A sequentially coupled material flow and micromechanics-based multi-scale stress analysis is presented for the fiber orientation, nonlinear and progressive damage analyses of a compression molded DLF composite aerodynamic fairing rib for the landing gear skid of an eco-friendly helicopter. Predicted fiber orientation distributions are validated through the injection molding process tool. The sequentially coupled analysis approach shows very good predictive capabilities for the fiber orientation distributions, nonlinear response, and please load of the DLF composite rib. The DLF composite rib offered a 55% weight saving compared to the original metallic design along with the reduced machining operations.

Keywords: Discontinuous Long-Fiber, Thermoplastic, Composite, Micromechanics, Progressive Damage, Compression Molding, Fiber Orientation, Multi-Scale

Introduction
Composite materials continue to displace metal on new aerospace platforms due to recognized performance, life-cycle, and manufacturing advantages. Composites are commonly specified for large primary and secondary structure applications based on cost-effective benefits from weight reduction, design freedom, and service life. However, many metallic components still remain on the aircraft, at least in part due to a product capability gap for replacement of 3-dimensional (3D) complex-shape metal parts such as structural brackets, fittings, clips, or other components where injection molding lacks sufficient performance, but use of traditional continuous fiber composite materials is impractical (or impossible) due to the complex component geometry. Discontinuous long-fiber (DLF) composite materials are targeted to fill the metal replacement application gap for semi-structural or structural complex parts.

Most DLF thermoplastic products are produced by chopping carbon fiber reinforced prepreg unidirectional tape into “flakes” or “chips” with predefined dimensions to manufacture net-shape compression molded parts (see Fig. 1). The result is a complex 3D geometry with high fiber volume content (~57%) [1]. DLF components are compression molded using matched-die tooling, with high molding pressures to ensure part quality. Heat and pressure from the molding process are used to melt the thermoplastic matrix for flow. The high viscosity of PEEK thermoplastic resin carries the reinforcement fibers uniformly throughout the mold, resulting in a random-fiber oriented composite with consistent fiber/resin fraction. Highly complex shapes can be produced in this process without the need for traditional hand lay-up procedures, and many components can be molded net or near-net shape with reduced machining and finishing requirements. Threaded inserts, bushings, or other metallic components, if required, can also be incorporated into the molding process, further reducing the need for secondary operations (see Fig. 1).
Sequentially Coupled Material Flow and Multi-scale Stress Analysis of Discontinuous Long-fiber Composite Helicopter Fairing Rib
Sequentially Coupled Material Flow and Multi-scale Stress Analysis of Discontinuous Long-fiber Composite Helicopter Fairing Rib

The structural performance prediction of DLF components is more challenging than the performance prediction for traditional continuous fiber composite or metal parts due to a number of factors, including random fiber orientations, effects of material flow on fiber orientation, limited material data, and nonlinearity in material behavior.

Sequentially coupled analysis methods are, therefore, used to combine the material flow and micromechanics-based multi-scale stress analyses for the fiber orientation, nonlinear, and progressive damage analyses of DLF composite parts.

Carbon/PEEK DLF Fairing Rib Manufacture

One example of a complex-shape DLF application is an aerodynamic fairing rib for the landing gear skid of an eco-friendly helicopter. Activities in a demonstrator project, part of the Clean Sky Programme [2], undertaken by Greene, Tweed & Co. for its customer, focused on demonstrating suitability of DLF ribs for production service. In this demonstrator project example, an existing machined aluminium fairing rib was redesigned for manufacture with compression molded carbon/PEEK DLF thermoplastic composite material. Pairs of ribs are used to form bolted assemblies that clamp around the aluminum cross-tube of the landing skid (see Fig. 2). The fairing skin is then formed around the rib couples to give the required aerodynamic profile. Ten rib-couples are used per aircraft (three for each front fairing and two for each rear fairing). The fairings improve efficiency in forward flight by reducing aerodynamic drag. However, they add weight, which is detrimental to performance during hover maneuvers. A weight-optimized rib design was therefore required to replace the existing machined aluminum parts.

Fig. 2: DLF Helicopter Fairing Rib

The manufacture approach employed Greene, Tweed's ProFusion® compression molding to produce a near-net molded blank incorporating a sacrificial web of material across the inner radius (see Fig. 2). Although it is normally feasible to produce a net-molded part, the near-net molding approach provided a number of advantages in the case of the fairing rib. Firstly, it allowed individual DLF flakes to remain in-plane with respect to the sacrificial web. Secondly, machining the web and inner radius allowed a tighter tolerance than could be achieved with net-molding, as required in this area. Lastly, the sacrificial web reduced the likelihood of spring-out or twisting in the part as it cooled, which was a concern due to the nature of the geometry. The degree of design flexibility afforded by DLF allowed the part to be optimized within the loading constraints to minimize the finished weight of the rib. The redesigned DLF rib weighs 81.5 grams, which enables a potential saving of almost 2 kilograms per aircraft, a 55% weight saving compared to the original metallic design in addition to the reduction in machining operations.

Sequentially Coupled Analysis Framework

Fig. 3 illustrates the sequentially coupled analysis framework used to accurately predict the structural performance of DLF parts. It includes compression molding flow analysis using Moldflow software, mapping of fiber orientations to FE mesh using Digimat-MAP software, transfer of mapped fiber orientations for FE analysis using the in-house developed plug-in, predicting the 3D micromechanics-based nonlinear material behavior with progressive damage using the internally developed DLF material model, and FE analysis using Abaqus software.
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In-Situ Strain Monitoring-Based Simulation of Residual Stress/Strain Due to Skin-Core Effect in Thick CF/PPS Laminates

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Abstract:
When a thick CFRTP laminate is manufactured by practical high-rate processing conditions with rapid heating/cooling, thermal skin-core effects are induced by non-uniform temperature distribution in the through-thickness direction, causing non-uniform residual stress/strain. There are only a limited number of reports about estimation of residual stress/strain development in rapidly cooled laminates because of the difficulty in determining material properties for the simulation and these results have not been sufficiently validated by experimental results. This current study demonstrates a high accurate residual stress/strain simulation under a rapid cooling condition based on in-situ strain measurement using optical fibre sensors and clarifies the development process and distribution amount of residual stress/strain in a thick UD CF/PPS due to thermal skin-core effects. The simulation results are finally validated by experimentally-measured in-plane transverse strain.

Keywords: Residual Stress/Strain, Skin-Core Effect, Process Monitoring

Introduction
Considering high-rate manufacturing of thick thermoplastic composites for aircraft structures, the products must be heated and cooled rapidly. This results in thermal skin-core effects due to non-uniform temperature distribution in the thickness direction. The formation process of internal strain distribution due to skin-core effects was measured and non-uniform mechanical properties were confirmed by the authors in a previous study [1]. When skin-core effects are significant, there is a risk for premature failure due to non-uniformity of residual stress/strain. Thus, precise evaluation of generation and development of residual stress/strain due to skin-core effects is necessary. However, previous simulations have been performed based on many assumptions of material properties [2-3]. Furthermore, these simulation results were validated only by the shape comparison after moulding and internal strain changes through the cooling process have never been compared with experimental results. So, the accuracy of these simulations has not been evaluated sufficiently. This current study utilizes a new simulation scheme based on in-situ strain monitoring using optical fibre sensors [4] to determine material properties during solidification and perform residual stress/strain simulation of thick UniDirectional (UD) CF/PPS laminates under a rapid cooling condition that can induce thermal skin-core effects. The simulation results are discussed and validated based on in-plane transverse strain measurement.

Influence of Shear-Lag in Fibre Bragg Grating sensors on Measured Strain
Fibre Bragg Grating (FBG) sensors are a type of optical fibre sensor widely applied to in-situ process monitoring because they are highly sensitive to changes in strain and temperature. Furthermore, the FBG sensor can be embedded into composites in a minimally invasive manner due to its small size; the coating diameter is less than 150 µm. Strain generated in a composite differs from the strain measured by an embedded FBG sensor. Ref. [5] clarified that cure-shrinkage strain of thermosetting composites measured by an FBG sensor depends on the distance from the edge of the optical fibre to the point of FBG, which is called tail length, and the stiffness of matrix as described in Figure 1. This phenomenon is attributed to shear-lag generated at the edge of the optical fibre. Strain of the composite transfers to the optical fibre mainly through the interfacial shear stress arising at the edge of the optical fibre. The strain in the optical fibre reaches the far-field strain in the composite over the stress transfer length (d). The degree of shear-lag increases as the elastic modulus of the matrix resin decreases. So the resin modulus and cure-shrinkage strain can be simultaneously determined using two FBG sensors with different tail lengths (FBG-A and FBG-B in Figure 1) [4]. In this study, the authors applied this approach for determining CFRTP material properties. In the next section, process monitoring for determination of material properties is conducted.
Fig. 2: The stacking sequence was [0/8/FBG-90/0]°/8 where FBG-90 denotes optical fibres with an approximately 700 μm tail length. The initiation temperature was defined as the solidification temperature of 217.5 °C. This trend was also confirmed by our previous work [6]. The difference reached a constant value of about 90 °C. In other words, the both sensors measured almost the same strain without shear-lag. Although the strain difference between the two sensors increased as temperature decreased, the long-tail sensor measured less strain than the short-tail sensor due to shear-lag below k = 0.979 [4]. Since the strain measured by the embedded FBG sensor was set to 0 at the glass transition temperature (εμ = 0) and (2), the total shrinkage strains of the long-tail and (2) can be given by:

\[ \varepsilon_{LT} = \varepsilon_{MT} - (1 - k) \varepsilon_{ST} \]  

\[ \varepsilon_{ST} = \varepsilon_{MT} - (1 + k) \varepsilon_{LT} \]  

where \( k \) is the strain transfer coefficient of the laminate. From equations (1) and (2), the total shrinkage strains of the long-tail and short-tail sensors are given by the following equations:

\[ \varepsilon_{LT} = \frac{(1 - k) \varepsilon_{MT}}{2 - k} \]  

\[ \varepsilon_{ST} = \frac{(1 + k) \varepsilon_{MT}}{2 + k} \]  

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Recycling of Thermoplastic CFRP with Electrodynamic Fragmentation

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Abstract:
By having the ability to re-melt the matrix, thermoplastic carbon fibre reinforced polymers (CFRP) are interesting candidates for recycling. A novel approach to separate thermoplastic CFRPs into fragments using electrodynamic fragmentation (EDF) is presented. The method was applied to a complex structural part which was made from unidirectional chopped tapes of 20 mm length (PEEK/AS4 55 Vol%) using a non-isothermal compression moulding cycle. The specimens made with chopped tapes were subsequently dissociated in a high voltage fragmentation lab unit. The ultimate load the parts made with recycled thermoplastic composites were comparable to the ones made from virgin chopped tapes with a reduction of only 17% of the maximal strength [1]. It was noted that smaller fragments considerably reduce the coefficient of variation of the ultimate strength while lowering the mean value to a limited extend only.

Keywords: Thermoplastic Composites, CFRTP, Recycling, Electrodynamic Fragmentation, High Voltage Fragmentation

Introduction
For thermoset CFRP considerable effort is being made to recover the carbon fibres [2] by removing the thermoset polymer by means of mainly thermal pyrolysis processes [3]. The recovery rate is thus limited to less than 50 percentage in volume (vol%), and the resulting recovered carbon fibres are often short in length with reduced quality and mechanical properties which consequently limit their applications and their economic value. Even if new methods are being developed with the aims of reducing the energy consumption of CFRP recycling, a direct re-use of the recycled material to produce new parts is still not possible. In contrast to CFRPs with a thermoset matrix, thermoplastic composites have better perspective of recyclability with theoretical recovery rates up to 100%. Indeed thermoplastic polymers can be re-manufactured through reversible thermal processes while the curing process of thermoset polymers is considered as non-reversible. The thermoplastic CFRP parts have to be grinded down to small fragments prior reprocessing. While fragmenting aerospace CFRPs, the main problem comes from the high content of carbon fibres which dramatically damaged the shredder blades [4]. Furthermore, important amounts of harmful carbon powder are produced. Given that no solution was proposed in the industry to grind down efficiently high performance thermoplastic CFRPs, the authors choose a novel approach to separate TPC into its constituents without tool wear using high voltage pulses through a technology known as electrodynamic fragmentation (EDF).

The aim of this work was to demonstrate the applicability of EDF to thermoplastic CFRP.

![Breakdown Voltage as a function of the pulse rising time. Solids have breakdown voltages lower than water below rising time of 5\(\mu\)s.](image)

Materials and Methods
The thermoplastic matrix selected in this study was a polyether-ether-ketone (PEEK) from VICTREX ®. The CFRP was supplied in unidirectional directional (UD) 55 vol% AS4 high modulus carbon fibres (Hexcel) pre-impregnated and chopped into 20 mm long “chips” by SUPREM AG, Switzerland.
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These chopped tapes where compression moulded using a non-isothermal process. The raw material was dropped into the tool cavity and then pressed using a vertical hydraulic press (Schwabenthan 200T, Germany) with 20 tons clamping force and heated up at 360°C. The parts were finally cooled at a rate of 20°C/min and ejected from the cavity. The authors [6] already performed a complete study investigating the influence of the process parameters, the size and type of material used.

Fig. 2: Compression molded door hinge demonstrator used for this study, the part on the left is made from chopped tapes, the part on the right is made from recycled fragments.

The EDF equipment was a lab-scaled unit, Selfrag Lab manufactured by Selfrag AG, Switzerland. The fragmentation was operated in a 3 to 4 litres water closed vessel. For a single door hinge, 6 cycles of 100 pulses each with an applied discharge voltage of 180kV at a frequency of 5Hz were sufficient. Between each cycles the content of the vessel was filtered using at first a metallic sieving grid having a mesh interspace of 4mm, fragments passing through are separated whereas the rest is put back into the vessel. Finally the smallest fragments and the carbon powder generated were separated with respectively a sieving grid having 1mm interspaces and a filter with mesh around 15 µm.

Fig. 3: Evidence of fragmentation with increasing number of pulses.

Results & discussion

The ultimate failure load, shown in Table 1, of the door hinges made with recycled thermoplastic composites were comparable to the ones made with virgin chopped tapes with a reduction of only 17% of the maximal strength. The decrease of mechanical properties is attributed to two reasons: the fragments coming from fragmentation process are shorter than the original ones, and the discharge led to a localized pyrolysis of the polymer at the surface of the fragments, similar to observations made in lighting strike experiments on CFRP [7]. This results in a fracture surface where, adversely to virgin parts, not the entire fracture surface is showing by cohesive failure of the matrix, but also displays small areas of adhesive failure.

Table 1: Mechanical properties of specimen

<table>
<thead>
<tr>
<th>Version</th>
<th>Fibre length (mm)</th>
<th>Ultimate Load (kN)</th>
<th>Standard deviation (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>virgin</td>
<td>20</td>
<td>4.15</td>
<td>±0.94</td>
</tr>
<tr>
<td>recycled</td>
<td>1-4</td>
<td>3.46</td>
<td>±0.29</td>
</tr>
</tbody>
</table>

Conclusion

In this report, the recycling feasibility of high contents carbon fibre reinforced thermoplastic parts is demonstrated without the typical tool wear known from shredders. Structural parts were successfully produced with 100% of recycled materials using the same compression moulding unit as for the original hinges and without any post processing applied on the fragments between the recycling and the re-processing and with a reduction of only 17% of the mechanical performance compared to novel chopped tapes door hinges. After fracture analysis, it has been clearly demonstrated that this reduction of mechanical performance came from smaller fragments and from a partial reduction of polymer on the fragment surface due to thermal pyrolysis reducing the fibre/matrix adhesion and load transfers [1].

Acknowledgement

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References


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Abstract:
Within the frame of the research project RecyCarb a qualified value-added chain shall be initiated for recycled carbon fibres (rCF), enabling the high-quality and sustainable re-use in sophisticated fibre-reinforced plastics in the area of transportation, sports equipment or medical technology. The technological gap between the actual rCF available at the market and the functional re-use as reinforcing elements in high-quality parts has to be closed. This will be achieved by developments in all parts of the process chain, combined with the initiation of a reliable scheme of quality assurance. Based on this information, a monitoring system will be realised, comprising the whole process. The results will contribute to largely preservation of fibre properties and functionality. This avoids downcycling and enables multiple use of the energy-intensive produced carbon fibres. The research project RecyCarb has been initiated in 2016; this presentation comprises results of the preliminary work, the project structure and first project results.

Keywords: Recycled Carbon Fibres (rCF); Quality Monitoring; Nonwoven; Lightweight Construction

Introduction
Due to the growing markets increasing amounts of carbon fibre-reinforced plastics (CFRP) are reaching the ‘end-of-life’. State of the art for recycling of dry carbon fibre waste is treatment by milling or shredding technology and pyrolysis. As a result of this process products of inhomogeneous morphology are entering the markets for recycled carbon fibres (rCF). These mixtures comprise roving residues & filaments in wide length distribution. The only established industrial standard is use of short fibres or milled material for injection moulding – a cheap product, more for improving the antistatic properties than the mechanical properties of plastics. For long fibres (>10 mm) up to now there are no definitions for:

- Necessary qualities (length distribution, minimum tenacity, homogeneity, ...)  
- Sampling in process (sampling locations, modality of sampling, reproducibility, ...)  
- Quality of the final products compared to factory-new fibres

For these reasons the commercialisation is hindered or impossible.
Consequently, the research project RecyCarb has been initiated with special focus on:

- Process scale-up for waste recovery and nonwoven production into industrial and economical relevant scale with respect to the quality requirement
- Set-up of a process-integrated monitoring of quality parameters, starting with waste recovery and reaching to the high-quality re-use of rCF in suitable parts
- Evaluation of the effects of different nonwoven technologies, first-time application of a combined nonwoven process for generating quasi-isotropic nonwoven structures
- Specific application-oriented adaption of technology and products to the different requirements of the target applications and potential end-users

The project team consists of two research institutes and four industry partners, covering the desired value-added chain (see Fig. 1).

Aim of the project work is to set up a qualified value-added chain for recycled carbon fibres (rCF) by closing the technological gap between rCF und functional high-value re-use. The work will comprise the definition of necessary initial quality &

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WP1 & 2: preliminary work, Q-monitoring, test parameters, test methods and regulations
Concept by FIBRE, STFI, TENOWO

WP3 & 4: advancement of the processing technology, tests in technical scale
STFI, AUTEFA

WP5: integration of testing methods
STFI, FIBRE, AUTEFA, TENOWO

WP6: composite production
COTESA, SCHMUHL, (STFI, FIBRE)

WP7: development value-added chain → all partners

Aim of the project work is to set up a qualified value-added chain for recycled carbon fibres (rCF) by closing the technological gap between rCF and functional high-value re-use. The work will comprise the definition of necessary initial quality &
In addition, by SEM analysis it was possible to identify other artefacts of the pyrolysis easily (if present), e.g. matrix residues. Summing up the tenacity and SEM analysis, the samples comply in these terms more or less to the supplier declaration. Damages by pyrolysis like crater formation and matrix residues could easily be identified.

Concerning the fibre processing, successful attempts have been made to prepare different CF waste/cutting scraps or CF from pyrolysis using a modified cutting and tearing processes. The resulting average fibre length was 60 mm, i.e. 85% of the pre-cut. This work was combined with technical and technological developments for transfer to the industrial scale. This enabled the processing of long, but not endless carbon fibres by means of the carding principle, using either 100% carbon fibres or blends with natural fibres and/or synthetic fibres (see Fig. 6).

Fig. 6: Nonwovens line and product [2], modified presentation
Web formation was followed by in-line entanglement using stitch-bonding technique MALIWATT or needle-punching. Furthermore, the combination of CF-nonwovens with other textile structures is possible (see Fig. 7).

Fig. 7: Available textile structures from rCF.
Finally these rCF nonwovens were processed into composites using epoxy resin as matrix. The technical data were: fibre volume content approx. 24%, Young’s modulus approx. 16/31 GPa (MD/CD) and tensile strength: approx. 200/500 MPa (MD/CD).

For comparison, an organosheet, based on a hybrid nonwoven fabric (40% rCF/60% PET) was produced. The technical data were: Young’s modulus approx. 18/40 GPa (MD/CD) and flexural strength approx. 340/660 MPa (MD/CD). The results depict the advantages of carding compared to the known milling process: less fibre damage and therefore retaining maximum fibre length as well as cost-efficiency. Woven and web structures made from carbon filaments can easily be pre-cut and then processed in a preferably one-step recycling process.

Conclusions
Pyrolysis is a suitable process for recovering carbon fibres from CFRP parts. For the extracted rCF new process pathways are necessary to enable their re-use in high-value parts. First steps of this work have been carried out in preceding projects: a first process for production of carded nonwovens from rCF has been developed, and basic principles for characterisation of rCF are known. These initial results depict clearly, that web formation is possible from 100% primary carbon fibres as well as from 100% recycled carbon fibres via mechanical carding. This will open up new potential for the industry. With their high formability and sufficient strength, these carbon fibre nonwovens are very suitable as semi-finished products for CFRP-structures.

The RecyCarb project start is scheduled for September 2016. Main targets are: process scale-up into industrial and economical relevant scale with respect to the quality requirement, and set-up of a process-comprising quality monitoring/quality management.

The expected results of this project are not less than upcycling of rCF into high-grade composite parts, e.g. in vehicle manufacturing, sports equipment, boat building etc. in an industrial viable scale.

Acknowledgement
Financial support by the German ministry of education and research (BmBF) within the framework Entrepreneurial Regions, project FutureTex, no. 03ZZ0608A is gratefully acknowledged.
A Technique for the NDT Inspection and Reparation of a Manufacturing Process for the Offshore Oil and Gas Industry

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GE Oil & Gas, Newcastle upon Tyne, United Kingdom

Abstract:
Hybrid un-bonded flexible pipe, designed using thermoplastic matrix composite layers for the offshore oil and gas industry is manufactured continuously with the inherent potential of any continuous process that simple defects can lead to large sections being scrapped. Removing the affected area and grafting in a replacement section is not economically desirable and/or technically viable. For that reason, it is essential during the production run of a pipe, to detect and address any problems that can affect its structural performance and service life. Focussing upon the thermoplastic composite layer, the challenge is to address any defects in the affected area without introducing significant changes in the mechanical properties of the pipe structure.

Keywords: NDT, Composite, Thermoplastic, Repair, Tape Winding, Pipe

Introduction
The introduction of composite materials technology to unbonded flexible pipe systems effectively facilitates weight reductions, which enable flexible solutions to challenging deep water applications and advantageously reduce installed cost in more conventional applications. Unbonded flexible pipe is a composite structure, combining the chemical resistance of thermoplastic polymers with the high stiffness and strength of functionalised layers of metallic reinforcement. Selective replacement of some or all of the metallic structural layers with fibre reinforced composite materials, provides a means to tailor the mass of the pipe system balancing the pipe properties with the demands of the installation logistics and the long-term dynamic environments. Composite materials providing both the enabling and optimisation tools in the structural design.

One specific design is to replace the conventional steel hoop reinforcement layer with a bonded thermoplastic composite. This can provide a significant and tailored weight saving of between 25% and 35% on a conventional steel design. The composite hoop layer is manufactured by a simplified tape placement technology which is continuously monitored for consolidation quality. However if defects or voids are introduced during manufacture they can be detected and the thermoplastic nature of the structural composite layer enables a reconsolidation step or inline repair. The thermal reconsolidation demands careful control of both the pressure and temperature; any change during this procedure could affect the quality of the pipe by introducing further voids or delamination rather than repairing the existing defects. One such technique is a proprietary control application that takes the mapped data from the phased array NDT element, allowing users to convert the defects into pixels or zones and apply complex thermal profiles controlled by functions and equations to maintain precise control of externally applied directed re-heating, consolidation and cooling of the pipe defect in real time, whilst the continuous production remains in motion. This real-time solution means that areas of the pipe must be processed with totally different thermal parameters rather than arbitrary global constants.

Surface Generation’s PtFS process technology has been used to manage the thermal and positional control in relation to the pipe defect whilst the pipe is in motion. A physical representation of this digital control, coupled with a multi-channel control system has been created to allow manipulation of all variables within the software, creating a unique intelligent thermal environment.

Thermal Performance Simulations
By investing heavily in thermal performance computer simulations and working closely to calibrate these virtual models with empirical data, both steady-state and transient models have been built. These have been used to optimise control of the repair of thermoplastic continuous fibre composites. With the need to locally re-heat regions of the deep well riser to address consolidation issues, Surface Generation has also developed models that allow it to simulate active thermal management of the target region and the adjacent areas such that these are not affected by the repair.

Some initial simulations undertaken by Surface Generation investigated using directed heat at the
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conventional Ultrasonic inspection techniques can identify and characterise the controlled defects in the lab scale samples very accurately. However in poorly consolidated laminates even larger defects, approaching the critical size are difficult to identify due to the difficulty in transmitting the ultrasonic signal through the poorly coupled material. This work also reported the initial demonstration of an inline/NDT system to continuously assess the quality of the composite pipe as it is manufactured. Here we present the next stage, looking at controlled defects introduced to pipe samples during manufacture using the production scale thermoplastic composite tape placement process. A study has been conducted to determine the optimum ultrasonic probe settings suitable for inspection of the thermoplastic composite laminates produced by the tape placement process.

Fig. 2: Schematic of typical controlled defect layout

Controlled defects were introduced throughout the thickness at defined locations in prototype thermoplastic composite pipe samples as illustrated in figure 2. A number of defect shapes have been considered with emphasis on 'strip' shaped defects anticipated through loss of consolidation during the tape placement process.

Fig. 3: Introduction of a strip defects prior to overwinding.

The defects were introduced by including a thin PTFE film to prevent bonding between subsequent layers as illustrated in figure 3. The depth of the defect was specified and controlled production parameters employed to ensure full consolidation of the rest of the laminate.

Fig. 4: Pipe samples containing controlled defects. (some coupling agent visible on the surface)

NDT implementation

A number of different ultrasonic probe configurations have been assessed for application as in-line inspection tools for the go/no-go assessment of possible processing defects, based upon the critical defect size criteria for manufacturing. The study has also included an assessment of high resolution probes to assess the suitability of the technique for detailed inspection of samples for assessment of small defect sizes and their possible evolution due to combined ageing and mechanical loading. Post testing in environmental fatigue for example.

A range of UT frequencies has been studied to find the optimised signal transmission though the materials, this being both a function of the thermoplastic resin and the fibres, the interfacial bonding and the level of consolidation achieved during the specific pipe manufacturing process. Further variables for high resolution probes include; the pitch between phased array elements, elevation or stand-off from the surface for roller configured probe systems. See figure 6 for examples of roller probe configurations.

Fig. 5: Multi-element UT roller probes.

F. Rapp, B. Beck, T. Huber
Fraunhofer ICT, Pfinztal, Germany

Abstract:
Wind energy is generally considered to be the most promising renewable energy source. In order to improve the technological and economic efficiency, the blade length has to be increased. However, a major challenge is the total weight of the blades, which limits this enlargement.

The four-year European-funded project WALiD, which started in 2013, combines process, material and design innovations in an integrated approach. The core innovation is the use of advanced thermoplastic composites. This creates cost-efficient, lightweight, durable and recyclable blades with a beneficial weight/performance ratio, making wind energy more affordable and competitive. WALiD will introduce a holistic concept focusing on the areas of blade root, tip, shell core, spar and coating in an automated production process. The current material developments in thermoplastic composites, foams and sandwich parts are described in the present paper.

Keywords: Thermoplastic Composites, Thermoplastic Foams, Sandwich Materials, Wind Blades

Introduction
Compared to conventional thermoset materials which are used in state-of-the-art wind blades, thermoplastic composites show improved properties in terms of impact strength, processing times, automation, recyclability and chemical resistance. A wide range of properties enables components to be tailored to meet the individual requirements of specific sections of an offshore wind turbine blade. These requirements can be contradictory: for example, the light shell on the outside, which consists of a sandwich construction with thin biax layers and a foam core, and the highly-loaded root area on the inside, made of thick laminates where high local stresses of the bolt connection occur.

As most state-of-the-art production processes are carried out manually, the laminate quality of current blades depends on the workers’ qualifications. The lack of automated processes for thermoset materials can lead to subsequent problems during operation and maintenance [1]. This instability must be compensated by extensive safety features, which also increase the weight of a wind blade.

The core innovation of the WALiD project is the use of thermoplastic material with tailored properties instead of thermoset components in wind turbine blades. The project focuses on several blade sections (see Fig. 1) in which the development of materials, design and process are strongly linked. The use of an automated fibre placement (AFP) process enables a modular, lightweight, stiff and load-optimized design.

![Fig. 1: Blade sections developed in WALiD](image-url)

As using thermoplastic materials in a wind turbine is a new approach, new materials and processes must be developed for different blade sections. For the laminates, new hybrid fibre tape materials were developed which can be processed in AFP and fulfil the requirements of blade components. The tapes were also used to manufacture sandwich structures based on newly-developed thermoplastic foam materials. A further development was a new wear-resistant coating that can withstand the harsh environmental conditions faced by offshore wind turbines, which is compatible with the underlying thermoplastic structure. The integrated approach with all these developments is illustrated in Fig. 2.

![Fig. 2: Material and process development in WALiD](image-url)

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Blade root connection
to the hub
Coating
Shell core
Shear web

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Material and process development

Polymers & fibres
UD - tapes
Automated lay-up process
Laminates
Polymers, fibres & Additives
Tailored compounds
Foaming process
Foams
Sandwich structures
Polymers & fibres
Coating compound
Application process
Coated laminates
Coating
Foam
Tape material

Fig. 2: Material and process development in WALiD

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Foam development

WALiD developed new light and stiff thermoplastic foam materials which can meet the requirements for sandwich cores in large offshore wind turbines.

Nanoscaled additives (carbon nanotubes (CNTs) and platelet nanoscaled structures (graphene)) for reinforcement in combination with modified polymer matrices were incorporated in a continuous foam extrusion process (laboratory tandem foaming line with a throughput of 30 - 60 kg/m³). An evaluation was carried out to determine the foaming behaviour of four different thermoplastic polymers.

For the foaming process different physical blowing agents (e.g. carbon dioxide, nitrogen, hydrocarbons or alcohols) are dosed into the polymer melt in different concentrations and compositions by membrane pumps or compressor stations. The nanoscaled additives are dosed in a high and low concentration.

Results

The foaming behavior of different raw materials was studied. It was found that polyethylene terephthalate PET shows the best expansion behavior of the materials selected. The density of the foam could be lowered to 85 kg/m³. All foams are produced in nearly the same density range in order to generate a comparable basis.

The nanoscaled particles influence the expansion behavior of the foam. It could be observed that the expansion ratio and consequently the density of the foam are affected by the particles. The higher the concentration of nanoscaled particles, the worse is the expansion ratio. This must be compensated by the process settings.

Fig. 7 shows an example of a foamed PET board.

The cell morphology analysis also showed the influence of the nanoscaled particles on the cellular structure. The small particles act as nucleation agents, which is a starting point for a further cell growth. The average cell size for the pure material is 258.5 µm, while for the reinforced material it is 243.9 µm, which is a small reduction in cell size.

The mechanical properties of the foam are evaluated by compression testing (ISO 844). The two major properties that are analyzed are the E-Modulus and the compression strength. As a reference a commercial PET core material was analyzed in three directions in space.

In Fig. 8 the values of the commercial samples are shown. It can be seen that the E-Modulus and compression strength have the highest value perpendicular to the surface. The E-modulus reaches 34,561 kPa and the compression strength 845 kPa. There is a large decrease for the remaining directions. The individual values are at least 56% lower than the highest values perpendicular to the surface.

The compression testing was also carried out with nanoscaled reinforced foam (see Fig. 9). It was determined that due to the incorporation of CNTs the compression strength is increased up to 10%. The compression strength of the graphene-filled foams is also higher than that of the commercial foams. For CNTs the values increase at a higher filler content; for graphene the reverse is true. A further increase can be shown in the E-Modulus of the foam, which can be increased by up to 20% at a higher CNT concentration. For graphene this effect could not be observed. At a higher concentration of graphene the E-modulus decreases again. For both nanoparticles it can be shown that there is an optimal concentration in an average level of fillers.
Resource-Efficient Production of Large-Scale Lightweight Structures

S. Nendel, H.-J. Heinrich, L. Kroll
Cetex Institut für Textil- und Verarbeitungsmaschinen gemeinnützige GmbH, Chemnitz, Germany

Abstract:
Within the BMBF-funded innovative regional growth cluster thermoPre® new processes were developed: for the single, direct impregnation of the unidirectional (UD) fabrics with a thermoplastic matrix and for the continuous production of multi-layer, load-capable optimized organic sheets as continuous fibre-reinforced semi-finished products. By means of using this new semi-finished part in the example of an engine subframe of VW e-Golf, the proof was provided that it is possible to substitute a die-cast aluminium component with additional steel elements for glass fibre-polypropylene in a pure thermoforming process. This does not only considerably reduce weight but, by means of functional integration and a new production technology, also save costs significantly.

Keywords: Thermoplastic UD Tapes, Lightweight Structures, Large-Scale Production, Resource Efficiency, ThermoPre®

Building bridges between basic and applied research allows to establish series-near innovation chains for fibre-reinforced products and to implement the knowledge acquired in practice as quickly as possible. The close cooperation between the Institute of Lightweight Structures (IST) and the Cetex institute as an affiliated institute of the Chemnitz University of Technology (CUT) in the field of special textile machines for the large-scale production of fibre-reinforced structural components is an example for such a bridging function. The jointly developed automated process chains and the related machines and interfaces allow it to reduce the production costs and are already being used by industrial partners in pilot lines.

Fig. 1: Single-stage direct processing – new process for the production of continuous fibre-reinforced prepregs and components (Source: thermoPre e.V.)

The gap-free feed of the reinforcing fibre tape is guaranteed by the appropriately designed fibre tape guidance directly before entering the impregnating tool. The final consolidation of the thermoplastic prepreg is realized by using a specially designed tempered ΩEGA calendar system.

Fig. 2: Contitaping plant for the production of load-adapted organic sheets (Source: thermoPre® e.V.)

In a contitaping plant, the thermoplastic UD tapes are processed into an organic sheet with a variably-axial laminate construction designed according to the load.

The reinforcing fibre, as unidirectional aligned and spread fibre tape according the required mass per unit area, has to be provided as a continuous material flow in the process step of thermoplastic matrix impregnation.

Fig. 3: Thermoplastic UD Tapes, Lightweight Structures, Large-Scale Production, Resource Efficiency, ThermoPre®
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Within the framework of the BMBF-funded innovative regional growth cluster “thermoPre® - Fibre composites for large-scale production”, it was the aim to manufacture continuous, fibre-reinforced, thermoplastic, semi-finished products in a continuous, single-stage, direct process “only heated once”. In order to realize this, new processes were developed: for the single, direct impregnation of unidirectional (UD) fabrics with a thermoplastic matrix and for the continuous production of multi-layer, load-adapted organic sheets as continuous fibre-reinforced semi-finished products.

The reinforcing fibre, as unidirectional aligned and spread fibre tape according the required mass per unit area, has to be provided as a continuous material flow in the process step of thermoplastic matrix impregnation.

The reinforcing fibre structures can be fed as already spread, prepared UD fibre tapes on sectional beams via a turret winder with following laying unit or from a roving creel with online spreading.

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Structural Joining of a Steel Insert with a Thermoplastic Organic Sheet

T. Renault, FAURECIA, Nanterre, France

Abstract:
Macro-textured metal inserts were developed and successfully integrated in a one-step thermo-stamping/overmolding process to yield highly structural assemblies with a thermoplastic organic sheet. The technology was demonstrated on a composite automotive seat backrest side flange with integrated steel recliner mechanism and has the potential for high series applications in the automotive industry. The development was done within the LIMECO project, a collaborative project of the French Institute of Technology IRT Jules Verne in Nantes (France).

Keywords: Multi-Material Joining, Insert, Thermo-Stamping, Overmoulding, Thermoplastic Composites

Introduction - LIMECO Project
Joining technologies must be developed to create multi-material structures and enable the introduction of composites into vehicles. Currently available technologies to assemble metals and composites for structural applications are very limited and not attractive for very large series.

Project LIMECO (Links Metal to Composites) took place from 2012-2015 as one of the first project of the then newly created French Institute of Technology IRT Jules Verne. The project enabled the design, test, and validation of structural multi-materials joining. Steel and thermoplastic composites (polyamide) were the selected materials. The molding processes that were considered in this project are thermoplastic injection and thermostamping, whereas the joining technologies that were developed are over molding, adhesive bonding, mechanical assemblies, and their combinations in synergy. Welding technologies were not considered in this project.

The project partners were IRT Jules Verne, Faurecia, Compose Tools, Cetim, and Ecole Centrale Nantes (ECN). Compose Tools designed and manufactured the molds that were used in the project. Manufacturing and testing of the demonstrators were done at CETIM. Faurecia designed and manufactured the seat prototype. ECN and IRT Jules Verne developed the simulation of the multi-material joining (presented in [1] and [2]).

Description of the case study
An automotive seat backrest was used as a case study for the project. A key challenge for a composite seat is how to join standard steel recliner mechanism to the composite backrest?
A demonstrator was designed to evaluate and compare several solutions of joining a steel recliner mechanism and a plate of organic sheet (fabric of continuous fibers impregnated with TP resin). A recliner mechanism is basically a steel disk with a diameter of 80 mm but unfortunately it is not exactly flat. It is designed to be laser welded to a steel part (welded area has the shape of a ring with a few millimeters of width). The torque that the assembly has to resist is 2500 N.m. The two technologies that are currently the most used for multi-material joining are mechanical fastening and adhesive bonding. Due to the functionality of the recliner and the fact that it is made of hardened steel, it is not possible to design a mechanical joint (with either screws or rivets) to assemble the mechanism on the composite without degrading its function. Also, due to its geometry, it is not possible to design an efficient adhesive bond: the contact area is too small for adhesive bonding and the surface is not flat. To solve the problem, it was decided to laser weld the recliner mechanism on a steel ring that will then be interfaced with the composite. The challenge is now to limit the weight of this ring by limiting its surface as small as possible.

Design and manufacturing of a demonstrator
The concept that was invented, developed, tested, and validated in the project consists in the combination of anchoring the steel ring on the composite (by creating a macro-texture on the metal that can penetrate the composite on a thickness of 2 to 3 mm) and overmoulding to limit the peel effect between the metal ring and the composite. Anchoring the ring on the organic sheet has the objective to increase the shear resistance of the assembly. To avoid the peel between the metal ring and the composite, a plastic ring is over molded on the metal and composite. To anchor the steel ring on the organic sheet, CMT (Cold Metal Transfer) pins were welded on the steel ring and the pins were pressed in the composite. CMT pins were developed by Fronius [3] which allows the fast texture of a metal surface. This
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The demonstrators were tested for their resistance to torque. A test bench was designed to enable the test in torque until failure of the samples. The torque was recorded as a function of angle until failure of the assembly.

The samples were tested at room temperature without ageing and the results are shown in Fig. 5. The torque at failure and the stiffness of the assembly are compared.

The first conclusion is that the torque at failure of the demonstrator can be increased from a baseline of 1200 Nm for a non-textured metal disk by a value of 100% to 200% when textured disks are used (3100 to 3550 Nm). Similarly, the stiffness of the assembly is improved from 500 Nm/° by more than 200%.

The effect of the height of the pins (from 2 to 3 mm) can be compared between Sample 1 and 2 and the main effect is on stiffness that increases with pin height. It is also demonstrated that the number of pins can be decreased without significant decrease of performance (Sample 2 and 4) and that the number of pins can be tuned to the desired performance (Sample 4 and 5).

The samples were then tested to evaluate the influence of moisture and temperature on the assembly performance. Samples were tested after conditioning the samples during 10 days at 70°C and 62% of relative humidity. They were also tested new at 80°C. Sample 2 with 168 pins of 3 mm were tested.

Due to the fact that the matrix of the composite that is used is polyamide, both the effects of moisture and temperature are important. For the samples with CMT pins, the effect of moisture is less than 5% due to the high content of fibres in the polyamide, whereas the torque at failure at 80% is reduced by about 25%. These values are expected when polyamide is used.

The assembly of Sample 2 was also tested in endurance. The test was started with conditions that are used in seats validation (30000 cycles) as shown in Table 1 and was progressively increased (torque value and number of cycles) to reach a value of -500 Nm / +250 Nm and 2 million cycles without failure.

Table 1:

<table>
<thead>
<tr>
<th>Torque Number of cycles</th>
<th>Test results</th>
</tr>
</thead>
<tbody>
<tr>
<td>-274/+137 Nm  30,000</td>
<td>No failure</td>
</tr>
<tr>
<td>-548/+274 Nm 30,000</td>
<td>No failure</td>
</tr>
<tr>
<td>-500/+250 Nm  2,000,000</td>
<td>No failure</td>
</tr>
</tbody>
</table>

The sample that was tested in endurance with 2 million cycles was then tested for its torque at failure and it was verified that the value was not decreased after endurance.

The joining concept is very robust and performant. It was therefore decided to develop a seat prototype that integrates this technology.
On the Use of Flexible Intensity Distributions for Thermoplastic Tape Placement by Means of Vertical-Cavity Surface-Emitting Laser (VCSEL)

T. Weiler, M. Emonts,
Aachener Zentrum für integrativen Leichtbau, Aachen, Germany
H. Janssen, Fraunhofer IPT, Aachen, Germany

Abstract:
This paper introduces the potential use of flexible intensity distributions for thermoplastic tape placement. The enabling tool for this technology is the Vertical-Cavity Surface-Emitting Laser (VCSEL). VCSEL make it possible to electronically control laser-emitting lines independently for the required intensity. Several potential fields of action were identified and are presented. One exemplary case will be considered in detail: the radiant exposure for the case of tape placement around edges with conventional (homogeneous) laser spots.

Keywords: Automated, Thermoplastic, Tape, Placement, Flexibility, Intensity Distribution, VCSEL, Vertical-Cavity Surface-Emitting Laser

Introduction
The Vertical-Cavity Surface-Emitting Laser (VCSEL) is not one single laser, but many thousands of micro lasers, which emit perpendicular from its surface. They are made out of wafers and cut into single chips. Several of these chips are connected with each other in-series onto emitter lines. These can be controlled independently by a driver rack [1].

It offers the possibility to change the intensity profile within micro seconds, which allows highly flexible process control. This new possibility is now being investigated by AZL and Fraunhofer IPT on its potential use for thermoplastic tape placement.

The VCSEL module can be arranged in two principle configurations: a) by placing the emitting lines in the direction of the material feed (see Fig. 1) or b) parallel to the direction of the material feed, by mechanically turning the module by 90°.

The Optimal Intensity Distribution
Before answering the question of what is the optimal intensity distribution in laser-assisted tape placement, one first has to consider what is the optimal thermal process condition (for low-cost production of laminates with high mechanical performance)? More precisely: what is the optimal temperature distribution in the tape and the substrate before the point of bonding (see Fig. 2)?

Interestingly enough, this question is not very well defined in the literature, probably because the heating process is a transient thermal problem, difficult to describe by simple equations and difficult to obtain by measurements. Instead, several thermal values are mentioned, which are only partial aspects of the temperature distribution:
- Surface temperature $T_s$ of tape and substrate at the point of contact [has been considered a lot]
- Melting depth $\delta_m$ [2]
- Time interval after bonding $\Delta t_{B > T_{crit}}$ for which the contact temperature $T_B$ is above a critical temperature $T_{crit}$

The first value, surface temperature $T_s$, is by far the most often mentioned and most often investigated on its effect on the laminate quality. It is also easy to measure and therefore used in control loops [see Fraunhofer IPT]. Nonetheless, it seems that the time interval after bonding $\Delta t_{B > T_{crit}}$ is the more critical value for the bonding process, but it is more difficult to predict and difficult to measure.

Fig. 2 shows a lateral view and a cross section of the tape with a typical temperature distribution in three dimensions, representing also the heating of the substrate. The temperature distribution in thickness and feed direction correlate, due to the internal transient heat conduction.
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Fig. 1: VCSEL-assisted tape placement

The Optimal Intensity Distribution
Before answering the question of what is the optimal intensity distribution in laser-assisted tape placement, one first has to consider what is the optimal thermal process condition (for low-cost production of laminates with high mechanical performance)? More precisely: what is the optimal temperature distribution in the tape and the substrate before the point of bonding (see Fig. 2)?

Interestingly enough, this question is not very well defined in the literature, probably because the heating process is a transient thermal problem, difficult to describe by simple equations and difficult to obtain by measurements. Instead, several thermal values are mentioned, which are only partial aspects of the temperature distribution:

- Surface temperature $T_T$ of tape and substrate at the point of contact [has been considered a lot]
- Melting depth $\delta$ [2]
- Time interval after bonding $\Delta t$ for which the contact temperature $T_T$ is above a critical temperature $T_C$

The first value, surface temperature $T_T$, is by far the most often mentioned and most often investigated on its effect on the laminate quality. It is also easy to measure and therefore used in control loops [see Fraunhofer IPT]. Nonetheless, it seems that the time interval after bonding $\Delta t$ is the more critical value for the bonding process, but it is more difficult to predict and difficult to measure.

Fig. 2 shows a lateral view and a cross section of the tape with a typical temperature distribution in three dimensions, representing also the heating of the substrate. The temperature distribution in thickness and feed direction correlate, due to the internal transient heat conduction.
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Each and every one of the identified cases requires deeper explanation and analysis. One of the cases (A4) was analysed and will be presented in this section: First we will introduce the general geometrical values, important to understand the problem.

Fig. 5 shows two situations of a manufacturing process, where tape is placed onto a random edge with the angle $\alpha$:

- Local change in intensity, caused by the part geometry and the laser beam, which moves ahead of the bonding point

The edge is representative for any part shape, differing from a flat surface. First thing to consider is that the radiant flux $\phi$ (energy) per differential angle element $d\theta$ is constant:

$$\frac{\phi}{d\theta} = c$$

Therefore, the laser intensity per differential angle element $I$ is also constant.

On the other hand, the intensity on the part surface $I_{PP}$ is not constant. It is a function of the irradiated surface $dPP$ per differential surface element $d\theta$:

$$I_{PP} = d\theta \phi \cdot PP \cdot d\theta = d\theta \phi \cdot PP \cdot d\theta \cdot d\theta$$

with $PP\theta$ for the overall laser power and $\phi\theta$ for the beam angle of the laser. The following correlation applies for the local change in process intensity:

$$C = \frac{I_{PP}}{I_{PP}} = \frac{d\theta \phi \cdot PP \cdot d\theta}{d\theta \phi \cdot PP \cdot d\theta} = d\theta$$

due to a change of the part geometry. To keep it simple we assume the bonding width $d\theta$ to be constant. The larger the irradiated length $d\theta$ per $d\theta$, the lower the intensity.

We can go further and describe the problem in more general terms, by analysing the effect of the laser system angle $\beta$ and the angle of the part edge $\alpha$ on the local change of intensity $C$. The geometrical correlation between $d\theta$, $d\theta$ and the angles $\alpha$ and $\beta$ can be described as follows with the law of sine:

$$d\theta \approx \sin(\pi - \alpha - \beta) \sin(\beta)$$

(This is only true for collimated laser beams with a low angle of divergence.)

Fig. 6 shows the result:

Influence of the parts' edge angle and the laser system angle on the local change in intensity

It becomes obvious that every deviation from a flat part surface inevitably leads to a local change in the process intensity. Trying to change the process speed or laser power to compensate this effect does not help, as this simultaneously affects other areas of the heating zone.
Individualised Production of Thermoplastic Composite Parts - Combining Additive Manufacturing and Thermoforming

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Abstract:
The manufacturing of functionalised thermoplastic composite parts (TPC) is most often done in a back-moulding process. However, especially for the production of individualised parts with high variability or the production of small 3lot sizes this production process shows disadvantages due to the cost-intensive mould technology. Using an innovative processing route, combining additive manufactured structures (ribs, fastening elements, mounting devices) and continuous fibre reinforced TPC sheets, the BMBF funded project Lightflex offers an economic solution. Therein, a combined forming and joining process was setup in which a laser scanning system melts the surface of the 3d-structure. After the preheating of the structure a molten TPC sheet is formed onto the structure using a one-sided diaphragm based forming process. By using a cost-effective supporting structure the mould costs can be reduced significantly and thus, part development process can be accelerated and new areas of applications for TPC parts can be opened up.

Keywords: Additive Manufacturing, Individualised Production, Tape Production, Thermoforming

Introduction

The serial production of technical products in large-series is now more than ever influenced by the increasing diversification and individualisation of products. The customer demand for customised, functionalised products at low prices causes challenges for the manufacturers in the fields of product development, process flexibility and cost. This individualisation trend can in principle be served particularly well by fibre-reinforced plastics (FRP), since FRP can be adapted by freely combining a variety fibre and matrix materials to meet the requirements of the final part. In addition to the wide adjustability of the resulting spectrum of properties, the good forming properties allow for displaying complex product geometries. However, the production of small and variable series is still economically challenging today.

Therefore, the development of more flexible, resource-efficient production technologies for the individualised production of functionalised, high quality FRP-parts is in the foreground of current research approaches at the Institute for Plastic Processing (IKV) in Industry and the Skilled Crafts at RWTH Aachen and the Fraunhofer Institute for Production Technology IPT. In this paper a highly innovative approach is presented, which allows for a tool-independent manufacturing of functionalised thermoplastic FRP (TPC) components based on unidirectional tapes, locally reinforced TPC sheets and additively manufactured structures.

The production of functionalised TPC components is currently carried out usually in a matched-die-forming process with subsequent injection molding process (2-shot process) or a combined forming and back molding process (1-shot process). Regardless of the process variant, the functionalisation of the part is done via injection moulding (e.g. ribs, fastening elements) [1]. The cost-intensive tools for the injection-molding process represent a huge cost factor in particular for the production of prototypes and small series or the partly iterative component development process. Additional costs can derive from potential changes to the tool geometry during the part development process.

In the BMBF-funded project Lightflex this deficit regarding the individualised production of functionalised TPC parts is to be resolved. Therefore, geometric complex additively manufactured structures are joined with load optimised TPC sheets using a mould independent combined forming and joining process. The combination of additive manufacturing with continuous fiber reinforced TPC-sheets should widen the range of applications of TPC towards individualised and functionalised components currently produced in the back-moulding process. For this purpose, the advantages of the processes additive manufacturing (direct production of complex geometries in small numbers) and laser-assisted tape laying (individual laminate production
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A New Generation of Aesthetic Composites Based on Styrenic Co-Polymers

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INEOS Styrolution Group GmbH, Frankfurt am Main, Germany

Abstract:
Today’s continuous fiber reinforced thermoplastic parts usually allow only a very limited surface quality caused by imprint of the fiber reinforcement, inhomogeneous surface areas and the “read-through” of opposing ribs. The present work proves that styrene copolymers represent a promising new candidate for matrix polymers in fiber reinforced thermoplastics, providing both, structural performance and aesthetic appearance. Besides high gloss and low surface waviness, the styrene copolymer based system also allows high quality surface decoration, such as printing, foil lamination or conventional painting. To validate the complete processing chain, a close-to-production prototype was designed and will be exhibited.

Introduction
Continuous fiber reinforced thermoplastics are gaining growing importance in various industries due to their lightweight potential, high freedom of design and applicability in mass production.

Apart from their exceptional mechanical performance, however, composite thermoplastic parts currently based on semi-crystalline polymer matrices (PA, PP) usually allow only a limited surface quality. The imprint of the fiber reinforcement due to shrinkage/ warpage of the matrix and “read-through” of the back molded structural ribs are major reasons. Hence, the applications of composite thermoplastics are so far focused on structural parts without particular aesthetic value.

In a R&D project with partners from academia and industry, a new generation of high strength fiber-reinforced composites based on styrenic copolymers was developed.

This project focused on the evaluation of specific styrene copolymers as a lightweight, robust and aesthetic component, has been supported by the research institutes NMF (Neue Materialien Fürth GmbH) as well as NMB (Neue Materialien Bayreuth GmbH), which joined the INEOS Styrolution research network in 2013.

In a second step of this project, INEOS Styrolution decided to validate the product development and created a prototype mold to evaluate the processing behaviour as well as the surface quality which can be achieved with this new material employing different types of surface decoration.

Performance of styrenic copolymers composite in semi-structural applications

The project showed that specific styrenic copolymers represent promising new candidates as a composite matrix polymers as it combines structural and aesthetic excellence.

Styrenic resins have a very high flow and hence enable complete impregnation of the fibers, being present typically from 45% to 60% by weight. As the sizing of common glass or carbon fibers are not designed for styrenic polymers in particular, modifications were carried out to make the styrenic polymer matrix more compatible to the fiber surface.

These measures led to composite sheets based on glass or carbon fiber fabrics featuring an excellent mechanical performance profile (stiffness, strength, impact strength), being on a par with today’s most advanced (PA6 or PC based) thermoplastic composites in the market place for woven Glass reinforced Thermoplastic (see Fig. 1) [1]. StyLight is the Brand name of this new generation of the thermoplastic composite from INEOS Styrolution.

![Stress deflection curve](image)

Fig. 1: Stress deflection curve StyLight vs PA & PC

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Moreover, the low water absorption of the amorphous styrenic copolymer, combined with its high glass transition temperature of 110°C, provides high mechanical stability over a large temperature range. The good stability of styrenic copolymers versus environmental conditions makes this new class of products ideal for technical part design requiring stable properties and dimensions.

Nevertheless, in a three-dimensional part used for automotive or sport applications, the composite sheet does only represent the surface layer. Consequently, the mechanical properties of the organosheet skin should be combined with the back injected molded ribs material to better determine the finished part performance. For that purpose, different materials with different property performances have been developed within different rib design (see Fig. 2) [2] and the adhesion of the Rib on the StyLight* sheet has been measured to find the optimum material combination, resulting in a portfolio of short Glass Fiber reinforced PA/ABS blends (Terblend N®) and ABS (Novodur®).

Finally, above and beyond the static mechanical performance of StyLight*, INEOS Styrolution performed fatigue tests to evaluate the long term resistance of this new type of styrenic composite in comparison to alternative thermoplastic-based composites, as well as epoxy-based composites showing excellent performances of StyLight*. Surface aesthetics: Although StyLight* show a higher stiffness and a high performance stability versus other currently available thermoplastic composites on the market, these advantages would not justify alone the investment to develop and launch a new composite thermoplastic type on the market. But the StyLight* composite is adding another significant advantage: its surface properties. Outstanding surface quality inherent to a styrenic matrix makes it possible to extend the application scope of composite thermoplastic to visible aesthetic parts at a competitive price level.

The lower shrinkage during the consolidation step of our styrenic copolymer matrix based on a modified SAN reduces the surface roughness (“waviness”) significantly, offering a superior surface quality compared to most existing standard thermoplastic composites based on PP, PC or PA (see Fig. 3) [3]. Although we do not claim to achieve a high-end “Class A” surface in one single compression/injection shot at this point (see paragraph “Demonstrator”), the surface quality achieved with StyLight* combined with the high polarity of its surface allows an easy surface decoration process such as coatings, painting or foil decoration.

Beside the surface “flatness” advantage, the low shrinkage of our styrenic copolymer matrix is enhancing the dimensional stability of the finished parts and reduces the risk of warpage. Moreover, styrenic copolymers’ water absorption is extremely low; as a matter of fact, the part dimension remains stable after manufacturing making it suitable for applications in vehicle interior requiring a good fit and finish. In combination with its good chemical resistance (environmental stress crack resistance, “ESCR”), StyLight* is a robust and versatile composite solution suitable for aesthetic semi-structural high performance applications.

Since this newly developed styrenic-based composite neither contains semi-crystalline polymer domains nor requires any additional impact modification or plasticizers, the resulting sheets reinforced with Glass fiber fabrics appear translucent with a high gloss surface finish. This is adding an interesting feature to StyLight* which could be used for backlighted decorated applications at a competitive price level versus PC, PMMA or a TPU-based thermoplastic composite. The transparent nature of the StyLight* matrix, reinforced by a textile, offers as well an interesting design solution to produce a “composite look” for decorative applications (see Fig. 4) [4].
New Reactive Resins for Thermoplastic RTM and Pultrusion

M. Glotin, ARKEMA, Colombes, France

Abstract:
Continuous Fiber Reinforced (CFR) Composites are seen as key future contributors to weight reduction targets in the automotive industry. Due to a greater maturity of the technology, epoxy or polyurethane based composites have already been introduced in high end and small series vehicles. In such applications, the production of structural parts is mostly carried out using High Pressure Resin Transfer Molding (HP-RTM) processes. One of the remaining challenges for this technology to enter the automotive mass market is to reach an overall part production cycle time well below 2 minutes.

Moving to Thermoplastic Composites offers several advantages on final part properties and recyclability, but also on cycle time reduction. Current thermoplastic technologies are mainly focusing on thermo-stamping of CFR-TP organosheets, but the use of reactive resins processed by RTM or Pultrusion would allow to reduce cost in by-passing one step in the value chain, i.e. the production of the semi-finished products, but would allow also to increase the fiber content and give access to more complex 3D parts.

The recent development of the Elium® reactive resin by Arkema is answering this unmet need, and various manufacturing and process technologies such as Thermoplastic RTM and Thermoplastic Pultrusion offer new solutions for lightweighting structural automotive parts.

Introduction
Due to the very high melt viscosity of thermoplastic matrices, Continuous Fiber Reinforced Thermoplastic Composites production is not readily amenable to RTM or pultrusion processing technologies. Moreover, among engineering thermoplastics which are cost-compatible with high volume production such as is needed for the auto industry, the water uptake of most of these polymers leads to poor mechanical performances with time.

The new thermoplastic Elium® resin, developed by Arkema, overcomes these issues and makes it possible to mold large thermoplastic composite parts using thermoset-like processes showing low water uptake. For example, the low resin viscosity at 20 °C allows a fast and complete part infusion or the use of a room temperature light RTM process. With similar basic mechanical properties than epoxy, but higher toughness, the Elium® technology is today mostly focused on the manufacture of structural parts. Tables 1 and 2 below summarize the main properties of the Elium resin and those of a typical glass reinforced composite with Elium® matrix.

Table 1: Main properties of Elium neat resin.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Deflection Temperature</td>
<td>109 °C</td>
</tr>
<tr>
<td>Maximum Continuous Temperature Service</td>
<td>85 °C</td>
</tr>
<tr>
<td>Water Uptake (8 days)</td>
<td>0.5 %</td>
</tr>
<tr>
<td>Coefficient of Linear Expansion</td>
<td>0.065 mm/m/°C</td>
</tr>
<tr>
<td>Fracture Toughness Stress Intensity, KIC</td>
<td>1.2 MPa m(^{1/2})</td>
</tr>
</tbody>
</table>

Table 2: Main properties of Elium®-based composites with plain weave glass fabric.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength</td>
<td>557 MPa</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>27 GPa</td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>700 MPa</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>27 GPa</td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>347 MPa</td>
</tr>
<tr>
<td>Compressive Modulus</td>
<td>28 GPa</td>
</tr>
<tr>
<td>In-plane Shear Modulus</td>
<td>5600 MPa</td>
</tr>
<tr>
<td>Charpy Impact Strength (un-notched)</td>
<td>206 kJ/m²</td>
</tr>
</tbody>
</table>
Due to the thermoplastic nature of the Elium matrix, the toughness is intrinsically higher than that of epoxy or polyester based thermoset composites. This is illustrated in figure 1, in which the interlaminar fracture toughness energy of an Elium-based composite is compared with that of an epoxy-based composite with similar fiber reinforcements (in this comparison, fiber sizings are optimized for Elium and Epoxy resin respectively).

Fig. 1: Toughness - crack propagation properties Elium vs Epoxy composite

Processing by Light RTM or Resin Infusion

Initial developments of Elium have targeted applications such as transportation or marine, in such applications, the processing is carried out using room temperature processes such as Resin Infusion and Light-RTM. Typical cycle times for the production of such parts are typically of the order of 30 minutes to more than one hour depending on part size. Figure 2 shows a front bus part made using a light-RTM process with a mould at room temperature and a 6.5 meters long prototype sail boat with a full Elium based carbon fiber hull and deck made by a vacuum assisted resin infusion process.

Fig. 2: Bus front part (by light-RTM process) and sail-boat carbon hull and deck (by VARI process) made of Elium resin

High rate processing by C-RTM process

In the last 3 years, research has been carried out to improve the Elium chemistry as well as the tooling and the composite manufacturing process in order to target high production rates of structural parts for automotive applications. The initiation and polymerization formulation of the 2K Elium resins have been optimized to shorten the polymerization kinetics, a total polymerization time below 3 minutes has been achieved at an isothermal mold temperature of 95°C, this is illustrated in figure 3 where the heat-flux during the polymerization of a 50x50 cm² composite sheet is measured against time.

Fig. 3: Optimization of the Elium resin formulation for fast polymerization as measured by a heat-flux sensor during the production of 50x50cm² composite sheets. 50x50 glass fiber reinforced Elium composite sheet (left) and its C-Scan quality control showing > 99.3% of surface with less than 1.1db attenuation (right)

Interlaminar Fracture Toughness Energy (mode I), GIc from DCB specimen (ISO 15024)

Elium resin / UDT (Glass Fiber with suitable sizing)

Epoxy for wind blade (CeTePox AM3320) / UDT (Glass Fiber SE2020)

GIc = 1370 ± 21 J/m²

GIc = 697 ± 11 J/m²
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Lightweight Thermoplastic Composite Fuel Tanks for Space Applications

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D.M. Grogan, National University of Ireland, Galway, Ireland
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Abstract:
Composite overwrapped pressure vessels (COPVs) have become a critical component in the storage of cryogenic fuels aboard rockets, satellites and spacecraft. Recent research has focused on reducing the cost of COPVs by replacing the inner metallic liner with a low cost alternative, or by removing the liner in its entirety. An integrally heated rotational moulding tool has been constructed and used to produce PEEK polymer liners which have been permeability tested using helium gas. PEEK samples have been overwrapped in a laser-assisted tape placement (LATP) process with a CF-PEEK tape. Cryogenic cycling of liner-overwrap samples has shown crack resistance over multiple cycles. A combined experimental and numerical approach to the design of linerless CF/PEEK LATP composite cryogenic tanks is also presented. Defect characterisation using 3D X-ray CT scanning, optical microscopy and cryogenic cycling has been undertaken. A novel XFEM cohesive zone methodology is used to predict damage in an internally pressurised cryogenic tank, to define an optimised tank lay-up which is resistant to microcrack formation.

Keywords: COPVs, PEEK, Carbon Fibre, Tape Placement, Polymer Liners, Permeability, XFEM, Cryogenic Cycling, X-Ray CT

Introduction
Composite overwrapped pressure vessels have become a critical component in aerospace applications since their initial introduction in the early 1970s [1]. Their ability to store highly permeating fuels at high pressures under cryogenic conditions makes them an integral part of propulsion systems, breathing systems, environmental control systems, and specialised research and analysis equipment aboard rockets, satellites and spacecraft [2]. Recent research has focused on reducing the costs of COPVs by either replacing the standard metallic liner with a low cost polymer liner, or by removing the liner in its entirety, and improving the crack resistance of the carbon fibre overwrap in a linerless COPV design [3-8].

In both cases, the new COPV design must ensure that an adequate level of permeability resistance is maintained while the tank is in operation. COPVs experience an internal pressurisation (5 - 300 bar) and cryogenic temperatures as low as -250 °C during operation, and as such must retain structural integrity while also limiting fuel leakage. These extreme conditions can lead to liner debonding, microcracking and delamination formation within the polymer liner [3, 4] and CFRP overwrap [5-8], which, in severe cases, can result in permeation of the cryogen through the fuel tank walls. Therefore a precise understanding of the material structure and damage accumulation underpins the potential use of these new designs in COPV applications.

In the current paper a modified rotational moulding process is presented as an alternative manufacturing method for thermoplastic polymer (PEEK) liner production [3]. Liner samples, formed using this tooling, have been permeability tested to determine the ability of these materials to store highly permeating fuels. These samples have then been overwrapped in a Laser-Assisted Tape Placement (LATP) process to form liner-overwrap samples for cryogenic testing and X-ray CT scanning tests.

For the linerless tank design, a detailed material and defect characterisation of CF/PEEK thermoplastics was undertaken using optical microscopy and 3-D X-ray CT scanning, as well as cryogenic testing to investigate damage formation in CF/PEEK samples [5]. Resulting material data is used as inputs to a novel XFEM-cohesive zone methodology which is used to predict intra- and inter-ply damage in an internally pressurised cryogenic tank [6-8]. An optimised tank lay-up is presented and tested using the numerical method to ensure both resistance to microcrack formation and fuel leakage through the tanks walls under operating loads [8].

Polymer Lined COPVs
Polymer-lined COPVs have been proposed as a viable alternative to metal-lined COPVs due to their low cost, low weight, resistance to chemical attack, and low permeability characteristics [3, 4]. A modified rotational moulding process (Fig.1) is
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Presented here as an alternative manufacturing method for the production of polymer liners for COPV applications. The modified tooling consists of electrical heating lines dispersed around the metal mould tool, in a segregated pattern, that allows for increased control of temperature distributions across the mould surface. The tool is powered via slip rings at the main rotating joints and the removal of the surrounding oven, common in traditional rotomoulding processes, allows for temperature readings to be taken from multiple locations around the tool. This gives increased control of temperature distributions within the tool and hence increases the dimensional accuracy of the formed part. Multiple prospective liner materials have been tested as part of this analysis with flat panel sections taken from PA11, PA12 and PEEK moulded liners.

Fig. 1: Modified Rotational Moulding System and Electrically-Heated Tooling.

Flat panel sections have been extracted from the rotomoulded polymer liners for helium permeability testing, to determine if they can achieve the acceptable levels of fuel containment needed for the COPV liners. A helium permeability test rig, following ASTM D1434 [9] and using a Leybold L200 leak detector, has been used to determine the leak rates of all materials. The sample is placed between two aluminium chambers and a vacuum is applied to both sides. The leak detector is then engaged and helium gas is introduced to the upstream side of the sample. The leak rate through the sample is measured over time to determine the steady state leak rate of the sample and its permeability coefficients. Three samples have been tested from each rotomoulded liner.

Fig. 2: Laser-Assisted Tape Placement (LATP) of CF/PEEK Tape over Polymer Liner Samples. These samples, once permeability tested, were then overwrapped with a CF/PEEK tape by a Laser-Assisted Tape Placement (LATP) process using a robotic arm and a laser welding head at the ICOMP Centre, Limerick, Ireland, Fig. 2. It uses a 0.125 mm thick by 14 mm wide CF/PEEK thermoplastic tape that is built up on the part over multiple passes and layers to create an overwrapped part. Once overwrapped the parts were thermally cycled in liquid nitrogen and assessed using X-ray CT scanning techniques to map crack growth in the liner-overwrap configuration.

Linerless COPVs

The second part of this research focuses on linerless cryogenic tanks manufactured using the aforementioned LATP unit. A detailed analysis of CF/PEEK laminates was conducted using X-ray CT scanning and microscopy techniques [5]. Samples of different materials, in varying ply thicknesses, were processed in an autoclave and then machined and polished for further analysis. Cryogenic cycling was undertaken in liquid nitrogen, at temperatures near -196 °C, with a 2-15 minute immersion and a 6-30 minute warm up cycle (dependent on the laminate thicknesses). X-ray CT scanning and microscopy were then used to map crack growth over subsequent cryogenic cycles.
Joining of Light Metals to Fiber Reinforced Thermoplastic Composites by Power Ultrasonics for the Application in Hybrid Aircraft Structures

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J. Born, Composite Technology Center GmbH, Stade, Germany
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Abstract:
Multi-material-design offers high potential for weight saving and optimization of engineering structures but inherits challenges as well, especially robust joining methods and long-term properties of hybrid structures. The application of joining techniques like ultrasonic welding allows a very efficient design of multi-material-components to enable further use of material specific advantages and are superior concerning mechanical properties.

The Institute of Materials Science and Engineering of the University of Kaiserslautern (WKK) has a long-time experience on ultrasonic welding of dissimilar materials, for example different kinds of CFRP, light metals, steels or even glasses and ceramics. The mechanical properties are mostly optimized by using ideal process parameters, determined through statistical test planning methods.

This gained knowledge is now to be transferred to application in aviation industry in cooperation with CTC GmbH and Airbus Operations GmbH. Therefore aircraft-related materials are joined by ultrasonic welding. The applied process parameters are recorded and analyzed in detail to be interlinked with the resulting mechanical properties of the hybrid joints. Aircraft derived multi-material demonstrators will be designed, manufactured and characterized with respect to their monotonic and fatigue properties as well as its resistance to aging.

Keywords: Ultrasonic Welding, Hybrid Structures, Mechanical Properties Of Joints, Multi-Material-Design

Introduction
After the consequent evolution of CFRP usage in primary aircraft structures Airbus settled the A350XWB as the first composite aircraft within the Airbus family. Reviewing the material breakdown of the aircraft with a structure weight share of 47% for titanium alloys, aluminium alloys, steel alloys and other material it can be concluded that the A350 is also one of the most sophisticated hybrid structures in the civil aerospace industry [1].

There are some key challenges arising from the hybrid aircraft design defining also the future development needs such as joining of hybrid material stacks, the tolerance and gap management, stress optimized designs, robustness of joining method and NDT evaluation, automation and process costs [2]. So one of the main drivers for the development of next generation aircraft structure is the joining technology. The state of the art methods are mechanical fastening like riveting as well as adhesive bonding both for metallic and composite structures. Regarding performance, costs and certification limits these methods leave potential for alternative joining techniques such as the ultrasonic welding especially for hybrid structures. These could enable new disruptive structural concepts based e.g. on new integration sequences and efficient joint geometries with regard to structural mechanics.

The technology of ultrasonic welding
The ultrasonic welding process is basically divided into two technologies regarding the sonotrode’s oscillation direction in relation to the joining area (see Fig 1). A perpendicular oscillation of the sonotrode finds application as ultrasonic plastic welding in joining of thermoplastics.

Fig. 1: Different ultrasonic (US) welding technologies: Left: US spot welding for polymers, middle: US spot welding for metals, right: US torsion welding. (Courtesy: Telsonic Ultrasonics)

Ultrasonic metal welding is a solid state welding technique, where the formation of the bond occurs as a result of a moderate static pressure and a superimposed ultrasonic oscillation, which is parallel to the interface between the parts to be welded without fusion of the metals. The high frequency relative motion between the metallic parts
forms a solid state weld through progressive shearing and high plastic deformation between surface asperities that disperses oxides and contaminants. Consequently an increasing area of pure metallic contact and finally welding of the adjacent surfaces will be realized. The main influencing parameters can be split into process-related as well as materials-induced limits of ultrasonic welded joints, see Figure 2.

Fig. 2: Significant influencing parameters for ultrasonic metal welding

Ultrasonic welding of aerospace materials

Ultrasonic spot welding (see Fig. 1 middle) is the most common technology and was investigated for the first time to join different aluminum alloys (AA1050, AA5754 and AA2024) to carbon fiber reinforced polymer (CFRP) [3-5]. A constant thickness of 1 mm for all aluminum sheets and 2 mm for the carbon fiber fabric reinforced polymer with PA66 matrix and a fiber volume fraction of 48% were chosen [3].

Ultrasonic metal welding is characterized by ultrasonic oscillations parallel to the metal surface. In case of metal to CFRP joints, the polymer matrix is softened and squeezed out of the welding zone underneath the sonotrode. For ultrasonic metal welded joints it could be proven that both an intermolecular contact and a mechanical interlocking of the load bearing carbon fibers of the CFRP and the aluminum surface developed during ultrasonic metal welding, see Figure 3.

Fig. 3: Interfacial microstructure of an ultrasonic metal welded Al-alloy/CFRP-joint

Furthermore, no damage of the carbon fibers was observed in the cross section [4]. Based on this experience, the joining of light metals to fiber reinforced polymer composites by ultrasonic metal welding is being pursued for the introduction in hybrid aerospace structures. The high joint quality as well as the applicability to several material combinations makes the process interesting for future multi-material concepts. Looking at both primary and secondary structure parts of an aircraft material combinations of interest for an extensive parameter study are aluminum alloys, titanium alloys and high performance thermoplastic composites like carbon fiber reinforced PEEK or PPS.

First experimental results show successfully welded AA7075/CF-PEEK-joint realized by ultrasonic torsion welding as depicted in Figure 4. Ultrasonic torsion welding is another variant of US metal welding (see also Fig 1 right) with some advantages like maximum generator power and more freedom of design compared to US spot welding.

Fig. 4: Ultrasonic torsion welding system (Telsonic Ultrasonics TSP 3000) for hybrid joints

Figure 5 summarizes and compares selected Al/CFRP joints with respect to automotive or aircraft applications [5]. The achievable tensile shear strengths are shown as function of ultrasonic spot and torsion welded untreated specimen. The nominal joining area is kept constant for both variant with a sonotrode tip of $A = 100 \text{mm}^2$. Both joining partners, the alloys AA2198 and AA5024 as well as the carbon fiber reinforced polyether ether ketone (PEEK) find broad application in aerospace construction.
Modified Thermoplastic Foam Cores for Structural Thermoplastic Composite Sandwich Structures

J. Grünewald, T. Orth, P. Parlevliet
Airbus Group Innovations, München, Germany
V. Altstädt, Universität Bayreuth, Bayreuth, Germany

Abstract: Composite sandwich structures offer excellent lightweight properties for the aviation industry. Up to today most sandwich structures are based on fibre reinforced thermoset composite skins, which are adhesively bonded to a honeycomb core. The production costs of these structures are high, since the production is time consuming and the production method requires high machine investment. Therefore the aviation industry is seeking for alternative technologies for the production of sandwich structures. This paper deals with the development of novel thermoplastic composite (TPC) sandwich structures based on modified thermoplastic foam core structures, which are suitable for the aviation industry and could be an alternative for honeycomb sandwiches in certain applications. The lower mechanical performance of the foam core compared to a honeycomb structure is countered by the development of a foam reinforcement structure. Production times can be reduced by fusion bonding of skins and core.

Keywords: Sandwich Structures, TPC Sandwiches, Foam Core, Modified Foam Core, Core Reinforcement

Introduction

Due to the excellent performance to weight ratio, a wide range of sandwich structures is applied in aircraft vehicles of the Airbus Group. In aircrafts typical external sandwich structures are aerodynamic fairings, covers and doors (1). Applications inside of an aircraft are fairings and floor panels. In helicopters sandwich structures can be found for example in floor panels, cowling, beams and frames, as well as rotor blades (2).

Up to today predominant skin materials are glass fibre or carbon fibre reinforced pre-impregnated (prepreg) materials with epoxy or phenolic resins. As the core material mostly honeycombs are applied, even though they may be overdesigned and too costly in some cases. Typical honeycombs consist of Aramid paper which is impregnated with a phenolic resin (1). They feature excellent stiffness and strength characteristics and have good FST properties for interior applications. In spite of the excellent performance, honeycombs also show various drawbacks such as: anisotropic behaviour, required potting and sealing, telegraphing effect, and water accumulation in the cells (3,4). Moreover, the production of honeycomb core sandwiches is time and cost intensive. A typical production process takes up to 10 hours, where the curing of the resin in autoclave governs the cycle time with up to 6 hours. Foam cores are also used in the aviation industry, though they find fewer applications than honeycomb structures. A good example for successful application of foam cores is Polyethyleneimide (PMI) foam in rotor blades (2). In general, foam cores feature a lower mechanical performance than honeycomb structures, but they are cheaper, as can be seen in Fig. 1. In (4) a detailed comparison of several foam and honeycomb sandwiches for aviation applications, all produced by means of an autoclave, is given.

Fig. 1: Performance vs. price of core materials

Besides the lower price, foam core structures offer further advantages. Closed cell foam cores feature an even distribution of pores leading to an isotropic behavior. In addition the closed cell structure leads to minimal water absorption. Moreover, foam cores can be shaped easily and in case of thermoplastic materials even thermoformed.

There is a wide range of different foam cores available, though only a few are suitable for the aviation industry due to the requirements concerning FST characteristics, chemical resistance and possible service temperature. In addition due to the lower mechanical performance foam cores are only applicable in low-loaded structures.

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In this paper a manufacturing approach is presented, where thermoplastic materials are applied to shorten the cycle times of the production of sandwich structures.
Another concept for reinforcing foam core was stitch the skin-preforms directly onto the foam core. In previous studies concepts were developed to impregnate fibre reinforced rods, referred to as Z-pins (9). The pins are introduced into the foam with riveting as an example. In the first step thermoplastic reinforcement element to the skins as well as to the core? After several investigations a thermoplastic sandwich structure. It is noticeable shear strengths for some core structures, suitable for shear stresses caused by bending moments acting on sandwich structures in this study. However, the idea of reinforcing the core was adapted to the TPC technology (10). A dry carbon fibre roving is introduced by Airbus, known as the tied foam core structures. In Table 1 the compression strengths and shear strengths for some core structures, suitable for compression and drum-peel strength. The best results were achieved where the skin-preforms were connected to the skins. An overall bond between thermoplastic composite skins are heated ultrasonic support and bended afterwards or directly pins (9). The pins are introduced into the foam with 1 pin/100 mm. The pins have a rectangular cross sectional area of 1.7 mm x 1.7 mm and are introduced into the foam with 1 pin/100 mm. The results were achieved where the skin-preforms were connected to the skins. In addition sandwich structures often have modification of foam cores. Endres (10) showed that the performance of PMI foams was improved significantly concerning tensile, compression strength according to DIN 53294 and tensile strength investigation the core was additionally reinforced with roving s implemented under different angles (45°, 60° and 75°). The best results were achieved where the skin-preforms were connected to the skins and the reinforcing roving is realised. Therefore the question arose, how to connect a thermoplastic composite skins and the reinforcing roving is realised. Thereafter, the result that both ends protrude on both sides of the foam, pins and skins is achieved by the introduction of 45° rovings. The introduction of the pins under various angles (45°, 60° and 75°). The best results were achieved where the skin-preforms were connected to the skins and the reinforcing roving is realised. The pins are impregnated with the resin and cured separately, placed onto the core and fusion bonded to the foam core (refer Fig. 5: Realization of rivet heads/ fusion bond to core).

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Hybridisation of Organosheets; Tuning of Composite Properties

H. Luinge, TenCate Advanced Composites BV, Nijverdal, The Netherlands
L. Warnet, University of Twente, Enschede, The Netherlands

Abstract:
This paper describes the efforts to use hybridization to further optimize laminate properties by the combination of different reinforcement styles. The optimization is targeting improved properties at locations where they are needed and cost optimization where possible. In addition, hybridization is a potential tool towards improved processing routes. The study addresses various forms of reinforcement, combining glass and carbon fabrics, tapes and moulding compounds, acclaimed from processing scrap. The hybridization is evaluated in terms of processing and mechanical properties.

Introduction
Thermoplastic composites are gaining importance in various structural light-weight applications due to their combination of specific mechanical properties and ease of processing, i.e. thermoforming, thermoplastic welding. Applications include automotive, oil&gas, civil infrastructure and aerospace. With the increased use of thermoplastic materials, hybridisation is required. Hybrid Materials is a broad scope, Figure 1 depicts some examples of hybrid materials related to organosheets. This paper will focus on hybrid organosheets.

Fig. 1: Hybrid Composites

A designer has several parameters to choose from in order to have its fibre reinforced product fit to the part specifications. These parameters typically include type of fibre, matrix, fibre structure and lay-up of the laminate. Most applications to date are based on a single choice of the first three parameters, while varying the lay-up (amount of plies and orientation) for optimising the part. This paper investigates possibilities to further optimise a Thermoplastic composite part by varying the parameters typically fixed, i.e. the fibre, matrix and fibre structure, which can be called lay-up hybridisation. An overview of current hybrid laminate will be given first, followed by two illustrations, targeting improved or kept properties, and improved processability while adding geometrical functionalities.

Potential and need for hybridisation
Thermoplastic composites are processed using a variety of techniques, from the traditional high performance autoclave, thermoplastic-specific thermoforming, to since recently pultrusion. Thermoforming, also called stampforming is currently a well-developed production technique and is used to produce thermoplastic composites parts of various complexity. This technique is unique to thermoplastic composite, making use of the possibility to re-melt the matrix at different stages of the production or assembly. The basis of such a product is mostly a flat laminate, also called organosheet. Such a laminate can be produced in large surfaces, before being cut to dimensions, thereby producing a blank for the thermoforming step. Thermoforming is then performed by heating up the flat blank, which makes it deformable, before pressing the blank into shape between a positive metal mold and a rubber counterpart, or between matched metal tools.

Efforts have been set in the understanding of the interrelation between performance, design, material and processing in the last two decades, easing the job of the designer. It means that developments are observed towards tailored blanks, with for example varying locally thickness and orientation of the blank by using tape placement. Tailoring can also mean varying the material within the laminate in order to reach locally alternative properties. A typical example is the well-known sandwich material, consisting of thin, in-plane stiff skin, with a light core able to transfer shear through the thickness, thereby creating a bending stiff material with a low density.
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Further mechanical properties which should be maintained are the bearing strength and the out-of-plane tensile strength, which are the main properties being addressed when bending a corner. These criteria are used as a basis to select a number of potential solutions or concepts.

Materials and testing methods

Based on the criteria proposed last paragraph, a selection of materials is proposed, in order to modify a CETEX TC1100 5H Satin T300 reinforced PPS, based on a quasi-isotropic \[(0,90)/(+/-45)/(-/+45)/(MidLayer)\]s. For the midlayer, different types of reinforcements were chosen: Glass fabrics, recycled C/PPS flakes and a nonwoven material.

Three types of tests are proposed at this stage to evaluate the validity of the concepts proposed:

1- A three point bending test (EN2562), in order to show the independence of the chosen mid-layer on both bending stiffness and strength.

2- An interlaminar shear strength test based on a 4-point curved beam test (ASTM D6415), in order to evaluate the influence of the mid-plane layer on the structural performance after forming, as the specimens need to be thermoformed in this case.

3- A bearing strength test (AITM 1-009), in order to consider the fastening capacity of the bracket to other parts.

Laminates were pressed according to standard procedure for all specimens. The curved beam test specimen were thermoformed at TPRC in a metal matched tooling set-up.

Example of a processability optimisation related hybrid organosheet

The following example illustrates that organosheets can also be optimised for a processability purpose, leading to more function integration within a single pressforming step.

For example, ribs are common sights in thin structures in order to locally enhance bending properties against a very low weight penalty. This sort of features are regularly used in injection moulding products but also for compression moulding composite products, commonly integrating skin with ribs and bosses. Such features are uncommon for stampforming products, as it is difficult to obtain enough flow of the standard material in the rib cavities in a process having a high cooling rate.

The idea to enable adding stiffeners on pressformed products is to add a layer of materials having a low viscosity, making it possible to fill the mould features meant at creating such stiffeners.

Experiments have been performed by first pressing organosheets based on TenCate Cetex TC1100 5H Satin T300 – PPS, with a top layer of A-Moulding compound MC1100A; B-Purpose produced short fibre moulding compound MC1100B, which could be made from recycled materials. The organosheets are then stampformed between two flat moulds, one having the necessary mould cavities on the moulding compound side. Fig. 4 shows the results with three stiffeners having different width, as well as a close up of the edge of the stiffener.

Both types of ribs are well filled, resulting in a stiffened panel in one processing step. This example shows that it is possible to add functionalities to stampformed products when combining different material formats.

Fig. 4: Ribs on pressformed laminate based on a layer of UD moulding compound

Fig. 5: Ribs on pressformed laminate based on a layer of Short fibre reinforced injection moulding compound

This example can be extended to different geometries and functionalities, modifying top as well as middle layers. Examples of such a function integration is provided in Figure 6.
Additive Manufacturing of Aerospace Composite Structures

Z. August, R. Marcario, D. Hauber
Automated Dynamics, Niskayuna, USA

Abstract:
The ultimate goal for manufacturers of aerospace composite structures is a fully automated process like additive manufacturing. In-situ automated fiber placement (AFP) of thermoplastic composites (TPC) achieves this goal but aerospace industry acceptance has been slow. The industry standard process of thermoset composite layup followed by an autoclave cure is inefficient but well understood after decades of use. Thermoplastic composites offer process and property improvements over traditional thermosets that require a new mindset for designing, manufacturing, and testing advanced composite structures. This paper describes recent work to advance the state of the art in additive manufacturing of aerospace composite structures.

Keywords: Additive Manufacturing, Automated Fiber Placement, Thermoplastic Composites, Aerospace

Introduction:
Rapid Prototyping (RP) or three dimensional printing (3DP) has come a long way in the 30 years since its invention. We are now moving from prototypes to additive manufacturing (AM) of functional structures. This paper outlines approaches for the additive manufacturing of high performance composite structures.

One approach is to additively manufacture tooling for use in conventional composite manufacturing such as hand layup (HLU) and autoclave cure. Another relatively straightforward approach is to selectively reinforce much weaker additively manufactured structures with composite materials. Alternately, in-situ AFP of TPC can be used to additively manufacture high performance thermoplastic matrix composite structures on conventional hard tooling. A more advanced approach is to additively manufacture high performance TPC directly onto additively manufactured tooling. Such AM tooling can be “fly away” or used as a structural component of the finished part, especially if it is topology optimized for the in-service loads.

Additively Manufactured Composite Tooling:
Traditional composite tooling is labor intensive to manufacture with long lead times and is prohibitively expensive for small production runs. Large scale additive manufacturing such as the Oak Ridge National Laboratory (ORNL) big area additive manufacturing (BAAM) system can be used to rapidly and cost effectively produce composite tooling. Michael Kline of LM Aero has demonstrated millions of dollars in savings with composite tooling printed using BAAM. Additively manufactured tooling can be used directly for prototype or small production runs, forming dies, drill jigs or tool verification/fit check fixtures. AM tooling can be plated for larger production runs as shown in the figure below.

Fig. 1: BAAM layup tool and layup tool with nickel plating at LM Aero

Although AM tooling for legacy composite manufacturing process is an important step forward, a truly additive manufacturing process for high performance composite structures is the ultimate goal.

Composite Reinforced AM Structures
Composites can be used to selectively reinforce AM structures to greatly improve their performance. Dan Campbell of Aurora Flight Sciences (pictured below) used composite spars to strengthen the wings of his jet powered UAV. Notice the 3D printed cores in the 3D wings in the figure below.
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Fig. 5: In-situ TCP AFP concept sketch and early implementation with hot gas torch (HGT).

The figure below illustrates a more recent Automated Dynamics in-situ TCP AFP workcell with an articulated arm robot. The use of commercial off-the-shelf robot arms significantly reduces the workcell cost over earlier custom made robotic manipulators.

Fig. 6: In-situ TPC AFP with articulated arm robot

The latest generation of workcells replace the hot gas torch heating shown above with the laser heating system (LHS) shown below.

Fig. 7: Modern workcell with laser heating system

The LHS offers real time closed loop temperature control for improved bond quality and higher energy density for increased throughput over the legacy HGT system as illustrated in the figure below.

Fig. 8: LHS temperature vs. bond strength for different process speeds with carbon/PEEK composites

The workcell is housed in a laser safe enclosure as illustrated below. This fully automated workcell achieves the goal of additive manufacturing of high performance composite structures.
The Development of a Virtual Engineering Approach to Find Cost-Effective Solutions for Hybrid Composite Structures

D. de Vries, H. van Aken
Code Product Solutions, Schinnen, The Netherlands
W. Schijve, G. Francato, S. Kulkarni
SABIC, Geleen, The Netherlands

Abstract:
Driven by regulations focused on lower emissions, automotive OEMs are targeting weight reduction. Recognizing this challenge, SABIC has developed new thermoplastic hybrid composite material forms for use in an overmoulding process. This paper contains a research study showing a semi-automated method that selects the right fibre type for every single part or ply in an assembly, such the cost per kg weight saved is minimized. The focus is on the development of a methodology for cost-optimization, using finite element analysis.

Keywords: Cost Optimization, Hybrid Thermoplastic Composites, Research Study, Finite Element Analysis, Multi Material Optimization, Methodology

Problem description
The need to reduce the car fleet carbon emissions is one of the key drivers for new developments in the automotive industry [2]. Manufacturers and their development partners are working on multiple options such as reducing aerodynamic drag, enabling electrification or using alternative fuels. In addition, most automakers believe that models coming to the market after 2021 will need to show substantial weight savings [1].

The main inclination of most OEMs in the industry is to increase the use of high strength steels and aluminum instead of composite materials because the latter are perceived as too expensive. Put differently, the premium paid for weight savings (expressed in Euros per kilogram of weight saved) is too high. The cost would typically be about 15 to 20 €/kg for a carbon composite part, which is significantly higher than the maximum increase manufacturers of mass produced cars would be willing to pay (e.g., a solution in aluminum).

Recognizing this challenge, SABIC has developed new affordable material forms that can be used in an overmoulding process to significantly reduce the amount of composite material, as shown in Fig. 1. In the latter figure, it is shown that the cost effectiveness of “hybrid” plastic parts is achieved through selective localized use of reinforcements (i.e. with clever design, composite laminate is used only where the load paths require it and the overmoulding resin is maximized to achieve the highest functional integration potential and cost effectiveness. Additionally, thermoplastic composites, when compared to (traditional) thermoset composites, can be processed much faster, making them a better fit for mass production.

Fig. 1: Thermoplastic composite sweet spot
The material forms developed by SABIC for automotive applications are constant thickness fully consolidated multi-axial laminates manufactured by stacking unidirectional (UD) tapes (see fig.2)

Fig. 2: Unidirectional and multiaxial laminates
SABIC has initiated a number of research studies to be able to predict the mechanical behaviour of components or assemblies and the cost to produce them. The analysis pointed out that in order to keep the cost of the component in an affordable range the use of the carbon fibers have to be carefully considered during the design phase. A cost analyses performed by SABIC focus on several automotive component indicated that the current carbon fiber price level constitutes a challenge for the car manufacturers willing to use thermoplastic composite
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A full pdf version in print quality is available here!
COMPOSTAMP

F. Ravisé, B. Duthille
Airbus, Bouguenais, France

Abstract:
Application of mix process, also known as stamping-overmoulding process is one of the ways to reach the expected level of functionalization. Stamping-Overmoulding process is developed to minimize non-adding value steps and reduce lead time by integrating functions to an elementary part. This is a true design-to-manufacture and design-to-cost way of thinking, organized around a clear goal: obtain a “plug and play” structural thermoplastic composite elementary part, right after its manufacturing. Especially edge sealing operation will be integrated to the over moulded elementary part, as a replacement of today cost and time expensive operation. Develop and manufacture industrial thermoplastic composites with stamping-overmoulding process is one of the key levers to reach high rate production together with high performance thermoplastic composites.

Keywords: Thermoplastic, Aeronautics, Structure, Stamping, Injection, Overmoulding, Design-to-Cost, Design-to-Manufacture

Unfortunately, the final manuscript has not been received by the printing date. Please contact the authors for more detailed information.
Production Optimization of High Performance Carbon Fiber Reinforced Thermoplastic Composite Crash-Elements

M. Beyrle, F.J.C. Fischer, M. Endraß, L. Häberle, T. Stefani
Deutsches Zentrum für Luft- und Raumfahrt (DLR), Augsburg, Germany

Abstract:
The production of carbon fiber reinforced thermoplastic (CFRTP) parts consists of time and energy consuming steps that have great potential for optimization and automation. The research at the DLR in Augsburg aims at efficient thermoplastic composite production utilizing the advantages of a hot press that is integrated in a flexible robot cell.
The potential for improvement is analyzed along the whole process chain from as-delivered material to the finished part. This paper presents a set of optimization approaches along this process chain. The investigated process steps include preforming, transfer of ply-stacks, and consolidation of ply-stacks to organo sheets. Special focus will be given to the reduction of process steps and an optimized vacuum consolidation.
At the DLR in Augsburg an efficient CFRTP-production has been setup, optimized and verified.

Keywords: Carbon Fiber Reinforced Thermoplastics (CFRTP), High Performance Thermoplastic Composite, Preforming, Vacuum Consolidation, OOA, Thermoforming, Automated Process Chain

Introduction

Thermoplastic composites (TPC) attract great interest in aerospace industry due to their great potential for efficient processing compared to their thermoset counterparts. They may be formed under temperature and pressure and hence allow fast process cycles.
The usage of press formed thermoplastic composites has proven to be suitable for small parts with high output numbers like the TPC clips that are produced by the thousands for the A350 XWB. [1] For these parts the necessary high output rate can be reached by an optimized thermoforming process.

At the Center for Lightweight Production Technology (ZLP) of the German Aerospace Center (DLR) the whole production process is screened regarding automation and optimization potential for the production of carbon fiber reinforced thermoplastic (CFRTP) composites.

Typical matrices used for a thermoforming process in aerospace applications are polyetheretherketone (PEEK), polyphenylene sulphide (PPS) and polyetherimide (PEI). Another advantage of these materials comparing to their thermoset counterparts is their capability to be stored at room temperature.

For the analysis of the complete production process the demonstrator assembly Wellholm was chosen. The assembly consists of 7 parts with 3 different, partly rather complex geometries (see Fig. 1).

Fig. 1: Single components of the sine wave beam

The central element of the assembly is the sine wave web that is connected to the upper and lower cap by edge links. This so called sine wave beam can be used as a crash-absorber, e.g. in helicopter floor structures.

As materials Cetex TC1200 CF-PEI (5 harness satin) from TenCate and ULTEM™ 1000 PEI film from SABIC Innovative Plastics GmbH was used.

Automated Production

The process chain for the sine wave beam production at DLR in Augsburg is illustrated in Fig. 2. The production of the thermoplastic parts is done in an industrial environment by using a flexible robot (KUKA KR210 R3100 Ultra F) in combination with a hot press (Wickert 4400 S) that can be heated up to 450°C.
Excerpt only, page has been blanked! A full pdf version in print quality is available here!
Fig. 2: Process flow of the automated thermoplastic composite production at the DLR ZLP. The first step of the process is the generation of cut pieces by an automated cutter (1). After the transport of these cut pieces to the robot cell, an automated pick and place end-effector is able to generate ply stacks autonomously (2).

The laminate stacks then undergo vacuum consolidation rendering so-called organo sheets (3). For this production step, the laminate stacks are vacuum bagged (see Fig. 3) and heated up to 320°C with a dwell time of 20 min.

Fig. 3: Vacuum bag configuration for consolidation

The organo sheets are inserted into a so-called clamping frame (4). This clamping frame, activated by a docking station, is able to keep the organo sheet in a defined orientation throughout the whole thermoforming process step (5). It is designed to resist the high process temperatures. At the pre-heating step, the organo sheet is heated up to process temperature by infrared radiation, i.e., up to approximately 320°C for PEI and approximately 400°C for PEEK (6). The surface temperature is measured by pyrometers and used for the regulation of the heaters. After reaching the required process temperature, the organo sheet is transferred into the hot press. This transfer takes about 7 s and will further be optimized in future. At the pressing step, a pressure of 15 MPa is applied to the organo sheet while the tooling temperature is kept at 270°C for around 3 min. After that, the temperature of the tooling is cooled down to 180°C while the pressure is kept constant. When the press process is finished, the clamping frame with the formed part is transferred out of the hot press (see Fig. 4) to the next process steps.

Fig. 4: Clamping frame with sine wave web after press process

During the next process step, the single parts are trimmed to net shape. The final trimmed parts (see Fig. 5) are finally joined by implant resistance welding, a technology established at the DLR Institute of Structures and Design in Stuttgart (7)(8).

Fig. 5: Final trimmed sine wave web and edge attachments

Results

At the DLR ZLP in Augsburg, the automated flexible production of thermoplastic composite parts, i.e., sine wave web and edge links with CF/PEI has been established with good quality. Organo sheets were produced by vacuum consolidation, a flexible out of autoclave (OOA) technology. The developed clamping frame shows good resistance to the high process temperatures up to 450°C (for PEEK) without losing its functionality. It maintains the required tension on the organo sheet and guarantees a defined positioning during the entire press process.

The surface quality of the pressed parts was excellent. The components were successfully joined to the assembly sine wave beam (see Fig. 6) by implant resistance welding.
Processing UD-Thermoplastic Composites for Local Reinforcement

C. Götze, Georg Kaufmann Formenbau AG, Busslingen, Switzerland

Abstract:
For a better combination of lightweight potential and cost efficient part production, it is required to think of hybrid part structures, where the reinforcing material is minimized to the locations of the load paths and consisting of only unidirectional fibers. The individual behaviour of this unidirectional reinforced composites while processing is a huge challenge for a tool maker. Different successful projects prove that the processing of unidirectional reinforced composites in a One-Step injection moulding process, including shaping and overmolding, is possible.

Keywords: Lightweight Structures, Local Reinforcement, UD-Laminate, Injection Moulding, Mass Production

Introduction
Especially in automotive industry, the pressure of reducing CO2-emissions is one of the driving factors for reducing the weight of the vehicles. Therefore one solution is the usage of thermoplastic processing technologies as e.g. injection moulding, which is state of the art for mass production applications. In combination with high performance composite materials the injection moulding process offers the advantage of producing parts with enormous strength and stiffness in combination with a maximum level of functional integration. The first applications of this so called LIPA-technology are already in serial production [1]. But it is still a hard challenge to meet the economic targets of the OEMs. Therefore the development target needs to be to change the part design, so that the usage of reinforcing material is reduced to the minimum, ideally only placed along the load paths. But having numerous small lightweight inserts in the production process for one part, challenges especially the handling- and toolmakers for developing new technologies.

Objective
The target of the project was to develop a production process and an injection moulding tool, so that the demonstrator beam structure (Fig.1), reinforced with 3 unidirectional thermoplastic composite laminates, can be moulded in a One-Shot-Process, with a maximum cycle time of 60s. As the demonstrator beam has a specific design for various testing methods [2], the tool needs to be able to create 7 different reinforced variants of the part. Also the evaluation of injection compression moulding in comparison to injection moulding was a target of the customer.

Process and tool development
For developing an injection moulding tool for the specific insert material, a detailed analysis of the production process was necessary. With the focus on a One-Shot-Process it was required to insert the UD-laminates into the tool at a preheated stage above the glass transition temperature. The temperature level is necessary, so that the shaping of the inserts can take place in the tool, and that a chemical bonding between the over moulding material and the matrix material of the laminate can be achieved.

For choosing the correct tooling technology, especially for fixing and clamping the hot laminate, a pre-development project was carried out. Various trials were performed with a separate test tool, until one concept was proven feasible. The main challenges were not to deforming the UD-laminate while overtaken from the gripper but at the same time, fixing it in the cavity so that no displacement happened during the over moulding. In the last stage, this concept was transferred to the demonstrator part tool.
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Fig. 1: Demonstrator-beam of SABIC, Source: SABIC

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Near Net Shape Thermoplastic Preforming with Continuously Automated Cutting and Robotic Pick and Place Processes

M. Kuehnel, A. Schuster, C. Raehtz, M. Kupke
Deutsches Zentrum für Luft- und Raumfahrt (DLR), Augsburg, Germany

Abstract
Today's automated production lines for carbon fiber reinforced thermoplastic (CFRTP) parts of the aerospace industry are mostly designed for one special part or application. Changing part geometry or material would lead to a complete re-design of the whole process chain. Here comes the flexible and highly automated the DLR process into game: A continuously automated production line “from fabric delivery to the near net shape preform – ready for consolidation”. With the paper and presentation, the authors would like to contribute to the industry’s increasing needs of continuously automated but highly flexible process chains for variable high volume CFRTP parts.

Keywords: CFRTP, Preforming, Draping Simulation, Forming Simulation, Near Net Shape, Nesting, Cutting, Robotics, Pick And Place, Ultrasonic Welding, Automation

1 Introduction
In modern helicopter industry production rates for one model typically vary from 50 to rarely 100 helicopters per year. Considering such low production rates it is mostly not possible to justify an extensive invest in automated production lines. The degree of capacity utilization of such lines, being specialized on the production of one single part, hardly can be shown. [1]

The same applies for aircraft manufacturers with a high part variety, such as e.g. the so called A350 clips, where more than 2500 different clip designs among 5000 clips exist. These designs can differ e.g. in the outer contour, laminate thickness, stacking sequence matrix material, folding angles or foot radii. [2]

In contrast to existing, costly production lines and with respect to the above mentioned industry’s needs DLR invented a highly flexible and continuously automated process chain "from fabric delivery to the tailored preform" with comparably low invest.

2 Production engineering and preparation
Prior to the “first ply cut”, cut piece geometries as well as pick (in 2D), drop and weld positions (in 3D) for the cut-pieces to be laid down have to be defined.

2.1 Near-net-shaped and performance optimized cut-piece geometries with draping and forming simulations
In order to get a near-net part shape the single cut-pieces making up its laminate have to comply with this near net shape. As the cut-pieces usually are cut out of flat (e.g. rolled out) fabrics, the manufacturing engineering has to consider the draping of the cut-pieces from two to three dimensions. Therefor the authors used draping simulations in Dassault’s CATIA R23 Composites Part Design (CPD) with a kinematic approach in case of low deformation degrees, which cause only low stresses during draping (comparable to a manual draping process). [3]

Hereby the flexibility of the later described lay down process allowed the engineering to optimize the part by its performance and not restricting it for a better producibility (demonstrator part for draping by gripper and vacuum bag with performance optimized ply endings see Fig. 1). The near-net shape was generated by using the flattening and geometry transfer functions, which consider the internal kinematic mesh used for draping.

Fig. 1: Draping simulation of a 45° cut-piece of a fuselage skin part preform (A350 curvature radius) out of CF/PES UD tape (top). Tooling surface (green) reconstructed out of laser measurement. Diamond shaped ply endings from thicker to thinner laminate region (bottom) [4]
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Automated supply of cut-pieces to robot cell

As soon as the drawer storage device mentioned in 3.1 is completely filled with cut-pieces, it can be driven to a receiving robot cell with a mobile logistic unit. The mobile logistic unit can be either an automated guided vehicle (AGV) or a manual controlled platform (see Fig. 6). By using multiple drawer storage devices a continuous flow of cut-pieces can be provided to one or more robot cells.

Fig. 6: Drawer storage with cut-pieces on its way to a robot cell (above) and picking out of drawer storage (below)

Robotic pick and place process

A robotic pick and place process with a cut-piece detection camera, material friendly vacuum gripping and ultrasonic (US) fixation units then detects, grips, stacks and fixates the cut-pieces to point-welded stacks ready for consolidation with e.g. thermforming or vacuum consolidation (see Fig. 7).

Fig. 7: Robotic pick and place end-effector

The system layout of the end-effector is shown in Fig. 8. The vacuum is generated centrally in a Schmalz X-Pump nozzle and distributed via a FESTO valve cluster to the gripper units, which sit on spring followers, to have lateral stability and longitudinal draping or adapting functionality. In the current configuration a maximum of 24 grippers can be operated. The grippers sit on an aluminium frame made of WITTE profiles to assure fast and reproducible reconfigurations. The US horn is supplied by a US generator from Branson and moved to its place of operation by a pneumatic feeder unit sitting on FESTO linear axis. All systems are linked via EtherCAT.

Fig. 8: System layout of the end-effector

4.1 Automated cut-piece detection system

One major advantage achieved by the use of tailored preforms is the enhanced degree of freedom in part design. This comes with additional requirements for automation, because now there is a multitude of individual cut-pieces that causes conventional automation concepts, like aligning the cut-pieces by stoppers, to fail. A good concept is to store position and orientation of the cut-pieces after cutting (compare section 3.1). A better concept, that also compensates mechanical deviations due to machine imperfections or uncontrolled movement of cut-pieces e.g. during transport, is to equip the production system with computer vision capabilities. In our use case we mounted an industrial GigE vision camera together with a powerful flash illumination to the robot's gripper. Software for identifying cut-pieces and determining their positions was developed and thoroughly tested in combination with the industrial robot. The preferred method concerning robustness and accuracy was rotational template matching in combination with border following.

[13] The 2D-shapes of the cut-pieces are used for generation of rotated, correctly sized bitmaps which are matched to the camera image, what yields good true positive detection rates but has difficulties in distinguishing similar cut-pieces, what can be compensated by a subsequent border following step. Robustness of the detection is very important due material undulations we experienced in our samples. After transformation to the robot's coordinate system...
Performance and Simulation of a Thermoplastic PAEK Hybrid Composite System

F. Ferfecki, M. Tanaka
Victrex plc, Thornton Cleveleys, United Kingdom
S. Chung, D. Hayduke
Materials Sciences Corporation, Horsham, USA

Abstract:
The paper presents the results of a commissioned study with Materials Sciences Corporation (MSC) that looks at material behaviour and the development of simulation methods for modelling a thermoplastic polyaryletherketone hybrid composite system. The study focuses on the behaviour and simulation of the interface between the injection moulded material and the continuous composite laminate. The results present test data and simulation results for both plaques and a bracket constructed using the hybrid technology.

Keywords: Hybrid Moulding, Thermoplastic Composites, Aerospace Brackets, PAEK Polymers

Hybrid Moulding Concept

The continuous carbon fibre VICTREX AE™ 250 UDT tape is fabricated into the desired laminate structure. The layup is heated and compressed into a laminated composite panel with multiple layers of continuous fibre. The composite panels are then thermoformed into shapes using standard industrial equipment. The final mould blank form is then cut using standard equipment such as a water jet.

The formed shapes are then inserted into a standard injection mould and over-moulded with a short carbon fibre reinforced VICTREX PEEK resin using standard injection moulding processing methods. Additional inserts, such as threaded metal inserts can also be placed into the injection moulding tool. Once the inserts are properly loaded thermoplastic injection moulding is used to create the net shape part.

When the PAEK composite insert is overmoulded with the short-fibre injection-moulding PEEK resin a bond develops at the interface of the two components. The bond is a result of the differential in melt temperature. The molten PEEK melts and fuses with the low-melt PAEK matrix composite laminate.

The system does not require preheating of the composite insert. The resulting hybrid component is a continuous structure that has the three-dimensional shape of an injection moulded part and the structural backbone of a continuous composite laminate. The entire matrix material is a PAEK family resin having the benefits of PEEK such as chemical resistance and high temperature capability.

Project Scope

Materials Sciences Corporation was selected by Victrex plc to characterize the mechanical performance of the hybrid composite structures. The focus of the study is placed on the development of a methodology to quantify the bond strength between the injection moulded and continuous fibre composite components of the hybrid structure. The goal of the initial effort is the generation of preliminary data necessary to provide a basic understanding of the overmoulded composite structure performance. Results from the study are discussed in this paper. The work includes:

- Coupon fabrication
- Mechanical testing
- Modeling to characterize the performance of the overmoulded hybrid composite structure

A building block approach is utilized such that coupon fabrication and testing was first performed to gather the fundamental properties of the structure, with a focus on model development to assess bond strength. The study looks at various processing parameters such as injection temperature, tool temperature, and hold times. While processing parameters effect performance, it will not be discussed in detail in this paper as we are focusing on parts that are properly processed. The process study is to determine processing windows and is outside the scope of this discussion.

The paper focuses on structural performance of the hybrid sample; in particular results are presented for overmoulding of a woven composite panel moulded with a random-oriented injection-moulded layer, and an uni-directional composite panel overmoulded with a direction fiber injection-moulded layer.

Panel Fabrication

Hybrid panels were fabricated at MSC using in-house moulds to produce the overmoulded configurations. Two different moulds are used as shown in Fig. 1,
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A full pdf version in print quality is available here!
Fig. 2: Illustration of improper processing and proper processing

Flexural bending results for the centre gate panels are shown in Table 2. With IU (injection side up) test setup, failure occurred at the composite due to tension (plus some delamination between composite plies). The interface appeared fully intact. The failure load was 1895 N (426 lb.), relating to a 551 MPa (79.9 ksi) tensile stress on the tension side. With the continuous composite side up, failure occurred due to tension of the moulding compound and eventually propagated up towards the interface as shown in Fig. 2. The moulded compound failed at a higher stress level than a random orientated injection moulded bar, 233 MPa (33.8 ksi) per Victrex allowable data at 45º using a fan gated plaque.

Table 2: Flex test results of Configuration 1 (weave panel – centre gate)

<table>
<thead>
<tr>
<th>Test</th>
<th>Orientation</th>
<th>Span (mm)</th>
<th>Specimen Width (mm)</th>
<th>Specimen Thickness (mm)</th>
<th>Ultimate Load (N)</th>
<th>Ultimate Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IU</td>
<td>127</td>
<td>19.4</td>
<td>5.82</td>
<td>1895</td>
<td>1895</td>
<td>551</td>
</tr>
<tr>
<td>CU</td>
<td>127</td>
<td>19.4</td>
<td>5.79</td>
<td>1272</td>
<td>1272</td>
<td>378</td>
</tr>
</tbody>
</table>

The next set of data presented is for Configuration 2, which uses a unidirectional composite panel overmoulded in the fan gate tool. The injection direction is aligned with the unidirectional composite orientation. Flex tests are run with the fibres aligned with the direction of bending. Results are shown in Table 3. Similar to the Configuration 1 specimens, flex strengths were overall higher when tested with IU (injection side up). All specimens here showed good bond strength, where initial and final failure occurred at the same time. Under IU test set-up, failure occurred at the composite due to tension near the surface (the interface appeared fully intact). Under a CU (continuous side up) test set-up, failure occurred due to tension of the moulding compound and eventually propagated up towards the interface. Fractures are shown in Fig. 3. As in Configuration 1, the moulding compound failed at higher load than a random orientated injection moulded property, 473 MPa (68.6 ksi) compared to 364 MPa (52.8 ksi) per Victrex allowable data at 0º using a fan gated plaque.

Table 3: Flex test results of Configuration 2 (unidirectional panel with fan gate mold)

<table>
<thead>
<tr>
<th>Test</th>
<th>Orientation</th>
<th>Span (mm)</th>
<th>Specimen Width (mm)</th>
<th>Specimen Thickness (mm)</th>
<th>Ultimate Load (N)</th>
<th>Ultimate Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IU</td>
<td>127</td>
<td>19.3</td>
<td>5.99</td>
<td>3326</td>
<td>3326</td>
<td>916</td>
</tr>
<tr>
<td>CU</td>
<td>127</td>
<td>19.1</td>
<td>6.02</td>
<td>1713</td>
<td>1713</td>
<td>473</td>
</tr>
</tbody>
</table>

Modelling Results

The initial effort is focused on the modelling of Configuration 2 – unidirectional laminate overmoulded using the fan gate mould. The first step in modelling is to determine the constituent properties. Properties of the unidirectional continuous fibre material are based on tensile and compression data. Additional parameters needed for the model, such as shear stiffness and Poison’s ratio are estimated using classical micro-mechanics models. The populated model parameters for the unidirectional composite are presented in Table 4.

Table 4: Constituent properties for unidirectional panel

<table>
<thead>
<tr>
<th>Experimental Strength</th>
<th>Material Model</th>
<th>Parameter</th>
<th>MPa</th>
<th>Parameter</th>
<th>GPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 Tension</td>
<td>micro-mechanics</td>
<td>E1</td>
<td>127.5</td>
<td>E2</td>
<td>10.0</td>
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<tr>
<td>S1 Compression</td>
<td>micro-mechanics</td>
<td>E3</td>
<td>10.0</td>
<td>NU 12</td>
<td>0.335</td>
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<td>G12</td>
<td>5.76</td>
<td>G13</td>
<td>5.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G23</td>
<td>3.47</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For the moulded layer, key stiffness/strength values are primarily based on moulded tensile test specimens. Additional parameters, such as shear stiffness and Poison’s ratio, are computed using classical micro-mechanics models. The models assume 73% of the fibres are aligned along the length of the specimen, and 13.5% of the fibres...
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tool with a composite side up test configuration are shown in Fig. 6. Axial stresses (in respect to the fibre direction, S11 or S22) are plotted in the composite, the core region of the injection moulding material, and the skin region of the moulding material. Analysis indicates a tensile failure of around 269 MPa (39 ksi) occurs in the lower skin of the moulding material at an applied load of around 1560 N (350 lb) which correlates well with the experimental results.

Fig. 6: Predicted stress of overmoulded specimen when tested CU

Computed stresses of a 3-point flex specimen of the unidirectional panel overmoulded in the fan gate tool with the injection side up test configuration are shown in Fig. 7. Axial stresses (in respect to the fibre direction, S11 or S22) are plotted in the composite, the core region of the injection moulding material, and the skin region of the moulding material. Analysis indicates an onset of nonlinearity around 345 MPa (50 ksi) occurs in the upper skin of the moulding material at an applied load of around 1780 N (400 lb) which correlates well with the experimental results.

Fig. 7: Predicted stresses of overmoulded specimen when tested IU

To approximate nonlinearity, the overmoulded material stiffness is reduced by 50%, which corresponds to a 70-75% reduction in the 3-point bending stiffness, as seen in Fig. 8. Analysis suggests that a ductile, nonlinear response of the overmoulded material in compression results in a redistribution of the load that causes ultimate failure in the laminate. A nonlinear material model could be employed in future efforts to verify the accuracy of the simple, uniform stiffness reduction applied in this initial effort.

Fig. 8: Predicted stresses of overmoulded specimen when tested IU with reduced stiffness of moulded material to capture nonlinearity

Lateral Load Test Results on Hybrid Part

A lateral load is applied to the bracket as shown in Fig. 9. The load-displacement curve for the bracket under the applied load is shown in Fig. 10. A minor drop is seen in the load-displacement curve around 978 N (220 lb) although no damage was seen or detected. A subsequent load drop was seen at 1348 N (303 lb) possibly due to some dislocation of the moulded material at the interface. At 1468 N (330 lb), a significant load change is seen where cracks were visually seen forming around the interface of the moulded material. This was confirmed in the DIC measurements, shown in Fig. 11. Subsequent loading beyond this point yielded distinct progressive failure events that resulted in unloading and reduced stiffness.

Fig. 9: Load description and part dimensions
**Thermoplastic Multi-Tows Winding Placement**  
**WOLF_TP Project Preliminary Results**  
E. Soccard, Airbus Group Innovations, Nantes, France  
Agreement and courtesy of:  
Y. Hardy, Coriolis Composites, Queven, France  
P.-A. Vetter, Irepa Laser, Illkirch-Graffenstaden, France  
A. Barasinski, Ecole Centrale Nantes, Nantes, France  
M. Krezminski, B. Defoort, Airbus Safran Launchers, Saint Médard en Jalles, France  
C. Collart, E. Petiot, Airbus Operations, Bouguenais, France  
Y. Grohens, Université Bretagne Sud, Lorient, France  

**Abstract:**  
WOLF_TP project, funded by French government, has been running for almost 3 years in partnership with Coriolis, Ecole Centrale de Nantes, Irepa Laser, Airbus Operations, Airbus Safran Launchers, Université Bretagne Sud with the leadership of Airbus Group Innovations.  
The main objectives developed are:  
- a disruptive thermoplastic multi-tows winding machine with high tows tension  
- a new Laser technology (compact / high energy efficiency 90% / individual tow heating / high power),  
- a monitoring solution for in-situ process  
and an ongoing process modeling (in order to improve understanding of consolidation during fiber placement) with the final demonstration of revolution part with local double curvature and tank parts manufacturing. The project has almost reached the end of its last year and ITHEC 2016 is a good opportunity to present to the community the first promising results.  

**Keywords:** Winding, In-Situ Process, Laser, Monitoring, Modelling, Thermoplastic  

**Introduction**  
First of all, we have to keep in mind that to industrialize TP materials on complex shape, we do need to have a complete automated placement process, because it’s the only way to get a reproducible process on complex and large parts with acceptable no recurrent cost.  
In-situ process is obviously the dreamt industrial process targeted to manufacture parts without final consolidation. In one “shot” with low cost tools, without bagging and without oven or autoclave, we would be able to get the desired structures.  
During the last years, we demonstrated that two steps process [1]: automatic lamination by fiber placement machine with laser heating followed by oven final vacuum consolidation has been successful at an industrial maturity level.  
Next and last step is to develop the multi-tows thermoplastic winding in a one-step process in order to industrialize it, in short time, for Airbus targets and needs.  
Winding process with high tow tension, associated with good material quality is maybe the only process able to get the dreamt one.  

**New laser solution**  
Main objective of this task is to develop a multi-lasers head adapted for both multi-tows fiber placement and winding machines. Irepa Laser has developed the best innovative solution (see Fig. 1) in order to shape each optical laser beam according to process requirements.  

**Fig. 1: Optical shaping principle**  
Users could illuminate and heat the chosen tows without overheating and re-heat others already laid down. We can report a lot of advantages of this technology: high energy availability for each ¼” tow, up to 1 kW, compacity, low energy loss (less than 10%), high deep laser field and easy automation.
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Residual Strain Monitoring During Hot Pressing of Thermoplastic Composites by a Distributed Fiber Optic Sensor

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N. Takeda, The University of Tokyo, Chiba-ken, Japan
H. Kojima, SOKEIZAI Center, Tokyo, Japan

Abstract:
This paper investigates the relationship between consolidation processes and mechanical properties of carbon fibre reinforced thermoplastics (CFRTPs) by monitoring residual strain during the processes. In order to monitor the solidification behaviours during the process, the authors use a distributed fibre optic sensing technology, the Brillouin optical correlation domain analysis (BOCDA). In this study, a fibre optic sensor (FOS) was embedded into a quasi-isotropic carbon fibre (CF) / polyetheretherketone (PEEK) laminates. This CFRTP was fabricated by hot press with three cooling speed. Strain changes during the process and residual strain after cooling were measured by the embedded FOS. Temperature was monitored by a thermocouple which was embedded in the molding tool for compensating temperature effects of the FOS. Firstly, as for the cooling speed, residual strain value was lower as the cooling speed was faster. This is because the crystallinity of the materials affects the residual strain. To determine the relationship between crystallinity and the cooling speeds, differential scanning calorimetry (DSC) was carried out. From the DSC results, crystallinity of CFRTP laminates fabricated under faster cooling speed was lower than that under slower cooling speed. Secondly, there was no distinct differences on mechanical properties of the laminates that were fabricated under faster and slower cooling speed in this study. In summary, the authors show the feasibility of CFRTP process monitoring technique by using a distributed fiber optic sensing technology to understand the internal strain behaviour during the process. This will contribute largely to set an optimum process for each consolidated products.

Keywords: Residual Strain, Process Monitoring, Fibre Optic Sensor

Introduction
Carbon fibre reinforced composite materials, especially thermoset carbon fibre reinforced plastics (CFRPs), are recently used for aircraft structural components because of their high specific strength and stiffness. While primary structures of new generation aircrafts are made of thermoset CFRPs, the used of carbon fibre reinforced thermoplastics (CFRTPs) is limited to secondary structures. CFRTPs have big advantages on manufacturing rate, durability to impact loadings, thermal stability and process reversibility. The last one is the most distinct feature of CFRTPs, these will enable to be repaired by reheating and reprocessing when some kind of damage will be detected. On the other hand, CFRTPs have less reliability on mechanical properties due to their strong dependence on the consolidation process. A variety of trial-and-error approaches, which are high cost and time consuming approaches, still need to set an appropriate manufacturing process because the most optimal processing parameters differ according to parts size and geometries. In order to make the features of CFRTPs, it is expected to understand the relationship between consolidation process and product quality by in-situ monitoring.

Fiber optic sensor (FOS) is one of the most feasible sensors for in-situ monitoring of composite products because these have very small diameter which has no effect to the composite mechanical properties by embedding it into laminates [1]. In-situ monitoring techniques using dispersed FOSs such as fiber Bragg grating (FBG) sensors and using refractive index changes in a FOS have already been studied [2-4], however, these techniques can monitor fragmentary information. Furthermore, these studies mainly focus on thermoset CFRPs not on CFRTPs due to in-situ measurement difficulties. In this study, residual strain changes, not secondary parameter such as temperature and pressures, in carbon fiber / polyetheretherketone (CF/ PEEK), which is mainly used for aircraft structures, were monitored directly by embedding a distributed FOS. Brillouin optical correlation domain analysis (BOCDA) was used for measuring axial strain of the FOS [5]. To obtain cooling speed dependence of crystallinity and mechanical properties, differential scanning calorimetry (DSC) and mechanical tests were carried out, respectively.
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Distributed fiber optic sensor

The authors have been developing a distributed fiber optic strain sensing technology, BOCDA, for structural health monitoring of aircraft structures [6].

BOCDA measures axial strain changes in a FOS by utilizing a stimulated Brillouin scattering (SBS) phenomenon. SBS occurs when two light waves, the pump light and the probe light, counter-propagate inside a FOS, and the probe light frequency is lower than the pump light frequency by $\nu_B$ called as the Brillouin frequency shift (BFS). Its spectrum is called the BGS. When an axial strain is loaded to a FOS, the BFS changes, that is, the strain changes of an OFS (see Fig. 1).

$\nu_B = \frac{\lambda V}{n^2}$(1)

where $n$ is the refractive index of an optical fiber core, $V$ is acoustic wave speed in an optical fiber and $\lambda$ is pump light wavelength. Furthermore, the stimulated position is limited by optical correlation domain analysis.

In-situ monitoring

Quasi-isotropic CF (T800S) /PEEK laminates were fabricated with [(45/0/-45/90) 2S] stacking sequence. The size and curvature radius of the specimens were 300 × 300 mm and 1128.1 mm, respectively. A polymide coated FOS was embedded into each specimen in the middle layer (90º) parallel to the reinforced carbon fiber (see Fig. 2). In the experiments, hole-assisted FOSs were used in order to suppress the optical loss in the FOSs due to the micro-bending by reinforced carbon fibers.

According to the measured strain at the center of the specimen during the process (see Fig. 4), residual strain decreased as the cooling speeds faster. There was no significant changes of measured strains at the glass-transition temperature (143 C) and at the recrystallization temperature (160 C). From the distributed strain measurement results (see Fig. 5), residual strains near the center of the specimen were smaller than that near the edge of the specimen. This is because tensile strain which was due to the molding pressure at the center of the specimen counteracted the residual compressive strain. This measurement results indicate that it would be possible to understand the residual strain distributions of final products. That will contribute to assure the quality which varies by the size and configuration effects of the products.
Thermoplastic Composite Fusion Welding (CoFusion)

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Abstract:
This paper describes the development of a form of resistance welding for thermoplastic composite materials and assemblies (Patent Applied For). The welding element consists of a polymer-impregnated light weight discontinuous carbon fibre mat that is sandwiched between two layers of electrically isolating glass fabric which allows the technique to be used for welding carbon fibre based laminates. The welding process involves positioning the element between the surfaces that are to be welded, pressure is applied and an electrical current passed through. The welding element heats up rapidly and melts the thermoplastic both in the element and of the laminate either side of the element. This process can be completed within 3 minutes. The assembly is allowed to cool and the weld is formed. Welded test coupons and components have been evaluated and shown to have consistent high strength and fatigue properties.

Keywords: Thermoplastic, Resistance, Composite, Fibre, Welding, Joining, Fatigue

Introduction
The thermoforming of thermoplastic composites is a rapid technique for manufacturing aerospace components with typical cycle times of 3-7 minutes. However this technique is limited to simple shapes as it is a pressing process. Currently these simple shapes are assembled using traditional metal fasteners which are structurally inefficient and heavy. These components could potentially be welded using induction welding which is slow, plant intensive and has geometrical constraints or by using metal mesh resistance welding which has associated strength, fatigue and lightning strike issues. The lack of suitable welding techniques has limited the application of thermoplastic composite materials mainly to simple brackets and clips.

This paper describes the development of a form of resistance welding for thermoplastic composite materials and assemblies. The welding ‘element’ consists of a light weight discontinuous carbon fibre mat that is sandwiched between two layers of glass fabric, the fabric and carbon mat are impregnated with the same thermoplastic matrix and at the same concentration as the laminate to be welded. The glass fabric electrically isolates the carbon mat from the substrate and therefore allows the technique to be used for welding carbon fibre based laminates.

The welding process involves positioning the element between surfaces that are to be welded, pressure is applied and an electrical current passed through. The welding element heats up rapidly and uniformly as shown in Fig. 1.

![Fig. 1: thermal image showing even temperature distribution of heated welding element](image)

The thermoplastic of both the element and of the carbon laminate surface either side of the element is melted and inter-diffuses. The assembly is allowed to cool and the weld is formed as shown in the micro-section Fig. 2. This process can be completed within 4 minutes.

![Fig. 2: Micro-section showing a void-free weld between two laminates](image)

Previous work has demonstrated that this process is feasible for both carbon and glass reinforced laminates using polyetherimide, (PEI), polyphenylenesulphide (PPS) or polyetheretherketone (PEEK) matrices.

The process has been verified by welding joints which when analysed have been void free and which pass standard aerospace ultrasonic NDT criteria.
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Welding Elements

The welding elements as shown in Fig. 3 are manufactured using a pressing process where strips of lightweight carbon fibre mat are placed between two glass fibre fabric insulating facings. The elements are then consolidated by hot pressing an appropriate volume of thermoplastic polymer into the dry fibre and into the mat, the polymer is matched to that of the parent matrix in the substrates to be welded.

Fig. 3: Multiple elements manufactured in one pressing process and then extracted into strips ready for use

Manufactured elements have been assessed by micro-section and by ultrasonic NDT and shown to be well consolidated and void free.

Welding Process

The elements are placed between the two substrates to be welded and an electrical attachment is made to the element. Bespoke fixtures as outlined in Fig. 4 have been designed to enable safe operation of the welding process.

A repeatable set of welding parameters suitable for TenCate Cetex™ TC1100 Carbon Fibre PPS laminates has been defined as follows:

- Load material into welding fixture under a pressure of 1 to 2.5 MPa
- Apply electric current to the element and heat at a rate of ~75 °C/min to a process temperature of 330 °C
- Dwell at process temperature for 1 min
- Turn off power and naturally cool
- Isotherm stages can be applied during cooling to preserve crystallinity (as required)
- Demould welded substrates at below glass transition temperature (Tg) ~90 °C

Fig. 4: 1&2) Carbon fibre reinforced thermoplastic substrates to be welded 3) AC power supply 4) Connecting electrodes 5) Heating element 6) Electrodes integrated into the PTFE tooling 7) Plunger operated electrical safety switches

The thermal profile of the welding process is outlined in Fig. 5. The full process can be completed within 10 minutes however this cycle time may be reduced if a cooling system is used.

Fig. 5: Thermal profile showing temperature (°C) vs time (sec) for a typical welding process

Weld Properties

The single overlap shear, torsion and 3-point bending performance of welds for both static and fatigue load cases has been determined. Both coupon and sub-assembly levels have been tested in terms of strength and stiffness. Where possible the weld performance has been benchmarked against equivalent tests on mechanically riveted joints.

Single overlap shear testing in accordance with ASTM D5868-01 has shown that an average single lap shear strength of 14.3 MPa can be achieved. The maximum single lap shear strength recorded was 15.7 MPa.

3-point flexural testing in accordance with ASTM D7264 has shown that an average flexural strength of 779.8 MPa can be achieved which is compared to only 511.9 MPa for an equivalent riveted joint. Fig. 6 shows the stress / strain response for the welded and the riveted coupons.
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SOFIA - Structural Organic Sheet Components for the Integration in Automobiles

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Abstract:
Fibre reinforced lightweight materials in structural automotive components are limited to niche sectors like luxury and sports applications due to high costs. Mixed material designs offer weight savings which result in enhanced performances and less fuel consumptions. Reduced manufacturing costs for fibre reinforced car components and the design of hybrid material car concepts enable to go down market with new products. A great challenge is to enhance quick and reliable joining technologies for structural mixed material products, especially for high performances in the aviation or in the automotive sector. The research project SOFIA aims at the development of hybridised organic sheets by integration of metal elements, which can be welded to metallic car body structures, using spot-welding processes in serial productions.

Keywords: Spot-Welding, Mixed Material Design, Automotive Lightweight Structures, Organic Sheets, Thermoforming

Motivation
The fabrication of automobiles for the mass market is significantly dominated by automated manufacturing technologies where single process steps infrequently take longer than one minute. Since the reduction of fuel consumption became more and more important for the eco efficiency of automobiles in the past years, weight savings are a priority for automotive engineers. Many concept cars of OEMs as well as future prospects show the strategy to substitute single metallic components or subassemblies by fibre reinforced polymers (FRP) in areas with the highest lightweight- and cost potential [1], [2]. The joining of different materials and the realisation of hybridised car structures are key elements to mature new multi material designs in the automotive mass market. Actual joining technologies for different materials consider adhesive bonding and mechanical fasteners, which are often time-consuming and cost-intensive. The conventional spot welding process offers strong joints between metallic parts as well as quick, economical process cycles with huge maturity. The aim of SOFIA is to enable the usage of the spot welding process to join a fibre reinforced thermoplastic (FRTP) part with a metallic structure. Due to the short achievable cycle times, an organic sheet blank is applied as semi finished product.

Process description
The joint between the metallic structure and the FRTP is realised by using metallic inserts, integrated in the thermoplastic fibre reinforced semi-finished blank (see Fig. 1). The metallic inserts form a flat surface and fit into prefabricated holes in the FRTP part. This metallic surface is in plane with the reinforced final component's surface to be welded on the metallic structure. For demonstrating the joining strength and the process integrity for existing spot welding plants, a metallic car body part is substituted in a fibre reinforced thermoplastic component. Depending on the applied load and boundary conditions, mechanical and geometrical insert designs are investigated to transfer tension, shear and torsion loads.

Fig. 1: Principle of integrated metallic insert in FRTP part

With respect to manufacturing costs, the inserts can easily be produced by die cutting in a one step process. The stamped metallic inserts in load-dependent geometries are shown in Fig. 2.

Fig. 2: Metallic Inserts in different geometries

Taking into account the process surroundings (e.g. the accuracy of robotised spot welding plants, acceptable cycle times) as well as locally restricted joining spots, the FRTP blank is prepared with several drill holes to be equipped with the metallic inserts (see Fig. 3).
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Mechanical Behaviour of Short Entada Mannii - Glass Fiber Hybrid Polypropylene Composites

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Federal University of Technology Akure, Akure, Nigeria

Abstract:
The quest for high performance biodegradable plant and synthetic fiber for the reinforcement of hybrid polypropylene based composites has continued to attract interest among researchers. The structural characteristic and mechanical behaviour of short Entada mannii- glass fiber hybrid polypropylene composites was investigated. Entada mannii / glass fiber were prepared by different weight ratios using a twin screw extruder and follow by compression moulding. Tensile properties, impact strength and flexural properties of the composites were evaluated. Surface morphology of the fractured composites was performed using scanning electron microscopy. Tensile strength and Young’s modulus of the pure polypropylene was improved by adding short Entada mannii-glass fiber into the matrix. Addition of 5wt% Glass- Entada mannii fiber reinforced composites showed higher hardness and impact strength than other composites by about 58% relative to the hybrid composites. Fiber pullout and debonding was characterized with the single short Entada mannii- glass fiber reinforced composites. Morphological studies revealed that glass – Entada mannii fiber have good interfacial adhesion with the matrix supporting the improvement of the mechanical properties of the hybrid composites. Increase in the fiber loading decreases the degree of the crystallinity of the composites. This could be attributed to poor interfacial adhesion between the fibers and the matrix.

Keywords: Entada Mannii Fiber, Debonding, Fiber Ash, Mechanical Behaviour, Polypropylene, Compression Moulding

Unfortunately, the final manuscript has not been received by the printing date. Please contact the authors for more detailed information.
Study and Simulation for the Effect of Interface Microstructure on the Press Forming of Thermoplastic Composite Laminate

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W. Ba, Henan University of Technology, Zhengzhou, China

Abstract:
Insufficient interface strength between polymer matrix and carbon fiber (CF) is the main reason that causes damage of composites, especially thermoplastic composites. In this paper, we discussed a method for improving the interface strength of the composites by coating carbon nanotube (CNT) hybrid graphene onto the CF. We studied how the interface microstructure changed during press forming of the composites, and we found that dendritic interface morphology might prevent the inter-ply debond of the laminate which was relevant to the thickness and the stretchability of the interface layer. Hybrid graphene with CNTs presents better strengthening effect on the composites due to easily forming dendritic interface morphology. Based on the findings, we simulated various effects interface microstructure has on the press forming of CF-reinforced PA6 laminate.

Keywords: Thermoplastic Composite, Interface Strength, Press Forming, Simulation

1. Introduction
Thermoforming of thermoplastic composites (TPC) laminates is potentially a fast and low-cost production technology for the manufacture of high quality advanced composite components. Above the matrix melt temperature, inter-ply sliding in these materials is restricted only by the limited adhesion provided by the molten matrix layer connecting consecutive two plies. The properties of fiber/polymer composites depend naturally on the properties of the two main constituents. It is nowadays well-known that the strength of the fiber/matrix interface is important in determining the mechanical performance of a composite [1,2]. In practice coupling agents (or sizings) are applied on the fibers for promoting the bond between fiber and matrix.

Sizing is commonly applied for CFs in order to introduce oxygen containing functional groups [3]. The presence of functional groups governs the surface energetics (polar components) and improves the wettability [4]. For CF sizing the knowledge gained with thermoplastic modified EPs was adapted recently. Various thermoplastic polymers, including polyacryletherketones (PAEK), can be used as disperse phase tougheners for EP [5]. When such polymers are used in the sizing then the interfacial fracture toughness may also be improved. Tensile tests on single fiber indicated that PAEK coating eliminated the surface defects and improved the interfacial toughness.

This has been proved by analyzing the force displacement curves monitored in microbond tests [6]. Incorporation of nanofillers into sizing formulations was pushed forward recent years. Its main advantages are to enhance the surface roughness of the fiber, to increase the local modulus of the interphase and hence shear strength (thus decreasing the stress transfer length at a broken fiber). Surface roughening is beneficial not only for improving the frictional component of adhesion, but also for toughening. The crack developed at the interface or in the interphase is forced to follow a zig-zag route owing to the nanofiller particles acting as obstacles. The higher the aspect ratio of the filler, the higher the crack deviation efficiency is. It is obvious that higher energy dissipation is involved in a zig-zag crack path (involving debonding, pull-out, fracture and various matrix-related failure events) rather than in a planar one. It has been already emphasized that, because stress transfer occurs through shear at the interface, the thermomechanical properties of the interphase determine the stress range which the composite can withstand before fracture [7-8].

In this paper, we discussed a method for improving the interface strength of the composites by coating carbon nanotube (CNT) hybrid graphene onto the CF. We studied how the interface microstructure changed during press forming of the composites, and we found that dendritic interface morphology might prevent the inter-ply debond of the laminate which was relevant to the thickness and the stretchability of the interface layer. Compare to CB hybrid graphene, coated CNT presents better strengthening effect on the composites due to easily forming dendritic interface morphology.
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Resistance Welding of Carbon Fiber Reinforced Thermoplastic Composites Using Carbon Fiber Heating Element

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Kindai University, Higashiosaka-shi, Japan
T. Kurashiki, Osaka University, Suita-shi, Japan

Abstract:
This study aims to develop the resistance welding method for continuous fiber reinforced thermoplastic (CFRTP) composites using spread carbon fiber as resistance heating element. The material for the experiment was woven CF/PPS laminates. The effects of processing conditions such as applied voltage, time and pressure, and also material conditions such as thickness of the inserted PPS films on the fusion behavior of CFRTP composites were investigated to get the optimum condition for electro-fusion joining. The contents for evaluation were surface condition of joint section peeled off after applying current and welding area obtained from those images. The experimental results revealed that electro-fusion behavior was influenced significantly by thickness of PPS films and electric resistivity of CFRTP laminates. From the result of the single lap shear strength (LSS) test, it was revealed that the LSS value was achieved over 28 MPa. Moreover, CFRTP pipe joint using carbon fiber heating element was developed in this study.

Keywords: CFRTP, Resistance Welding, Spread Carbon Fiber, Pipe Joint, Single Lap Shear Strength

Introduction
Carbon fiber reinforced thermoplastic (CFRTP) composites which can be manufactured by press-forming, hybrid injection molding and auto tape laying are attracting attention recently in aircraft and automobile applications. However, CFRTP components have rather simple geometry due to the limited deformation allowed for the reinforcing fibers and high viscosity of thermoplastics. Thus, a joining technology is necessary for the manufacturing process of CFRTP composite structures. The demand of on-site joining without large facilities is also expected for a large-scaled CFRP composite structures [1]. Conventional joining methods used for thermosetting composites such as mechanically fastening and adhesive bonding are unreasonable of applying for CFRTP composites, because those methods have some drawbacks in strength and reliability. In addition, the adhesive bonding is difficult to bond chemically between thermoplastics [1]. To solve the above-mentioned problems, the fusion joining technologies such as ultrasonic welding, resistance welding and induction welding have been proposed for high performance CFRTP composites [2]. Especially, the resistance welding method has applicability to a large structure, and it is cost-effective compared to other fusion joining methods. Therefore, it was applied to joining between large scaled structures made of GFRTP such as A340 J-nose parts. It has also been widely used for polyethylene pipe systems of gas and water. In those applications, the heating element made of stainless steel mesh and Ni-Cr wire has been used by inserting between joint surfaces [3,4]. However, the heating elements are undesirable materials which has disadvantage on recyclability, stress concentration and corrosion resistance because the metallic heating elements remains into joining parts. Therefore, the material used for heating element is prefer to be made of the same material as CFRTP. A authors have been proposed the use of heating element made of carbon fiber to solve these problems in resistance welding. In this study, the electro-fusion joining method for CFRTP was developed using spread carbon fiber as resistance heating element. The effects of processing conditions such as applied current, conducting time and pressure, and also material conditions such as PPS layer thickness of fusion part were investigated, the optimum condition was obtained to improve the joining strength for resistance welding. Moreover, CFRTP pipe joint using carbon fiber heating element was developed in this study. The CFRTP pipe joint was manufactured by insert injection molding method.

Experimental Materials and Procedure

Materials
Fig. 1 shows the surface images of material used. The materials used for the experiment is CF/PPS laminate (TenCate, CETEX®). This laminate has 5H sateen weave construction with a resin content of Vr=45 vol.% and a thickness of r=1.2mm (woven-CF/PPS). The PPS polymer is semi-crystalline
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polymer. The result of differential scanning calorimeter (DSC) analysis of PPS polymer shown that the glass-transition temperature is $T_g = 90 \, ^\circ C$, and the melting temperature is $T_m = 290 \, ^\circ C$. The result of thermogravimetric analysis (TG) also shown that the decomposition temperature is $T_d = 410 \, ^\circ C$. A spread carbon fiber sheet (Mitsuya Co., Ltd., $t = 0.03 \, mm$) was used as resistance heating element.

Fig. 1: Surface images of material used.

Resistance welding and evaluation method

Fig. 2 shows the appearance of resistance welding device for CFRTP. The test specimens with $W = 20 \, mm$ in width and $L = 60 \, mm$ in length were prepared. The welding area is insofar as $L_f = 20 \, mm$ from the end of laminates. A spread carbon fiber sheet with $W_{CF} = 40 \, mm$ in length was mounted between laminates to work as the heating element. To investigate the effects of thickness of PPS films on electro-fusion behavior, the PPS films (Toray Co., Ltd., TORELINA®, $t_{PPS} = 0.1 \, mm$) with various sheet number were inserted between laminate and heating element. The spread carbon fiber was also inserted in $0^\circ$ direction as shown in Fig. 2(b).

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New Self-reinforced Polymeric Composites Made Of Biobased PLA Commingled Yarns

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Abstract:
Lightweight design is in the key interest of the mobility sector, e.g. the automotive industry. Additionally, the worldwide demand for replacing fossil-based with biobased materials has led to a significant growth of bioplastics in terms of technological developments. Due to their low mechanical performance and durability, their use is still limited. Therefore, it is necessary to develop biobased, sustainable polymeric materials with high stiffness, high impact and high durability without impairing recyclability at a similar price level of non-biobased solutions. The development of such self-reinforced polymeric composites (SRPCs) is shown. This includes a hybrid yarn based approach for producing biobased PLA composites. Finally an outlook on further development of reinforcing biobased SRPCs is given.

Keywords: Self-Reinforced Composites, Biobased Materials, PLA, Commingled Yarns

Introduction
In SRPCs the same polymer is used for the reinforcing and matrix phases. SRPCs combine high stiffness, high impact and high durability. However the density is lower compared to traditional filled polymers. Using the same polymer also eases the recyclability of such composites. [1]

SRPCs can be manufactured using commingled yarns. The use of commingled yarns allows the combination of a large variety of fibres and therefore a wide range of material properties. The production process of SRPCs using commingled yarns is illustrated in the following figure 1.

Fig. 1: Production process for sel-reinforced self-reinforced polymeric composites made of biobased PLA Commingled yarns

Experimental
For developing the PLA SRPCs part of the PLA material is procured directly in the filament yarn form. The other part of the PLA is procured in granulate form. Using a melt spinning plant fibres are spun with this PLA grade in order to assess the effect of spinning parameters on composite properties. The materials used are presented in table 1.

Table 1: Materials used for experiments

<table>
<thead>
<tr>
<th>Product</th>
<th>Company</th>
<th>Material form</th>
<th>SRPC phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingeo™ 6302D</td>
<td>NatureWorks LLC, Minnetonka, USA</td>
<td>Fibre</td>
<td>M matrix phase</td>
</tr>
<tr>
<td>Ingeo™ 6201D</td>
<td>NatureWorks LLC, Minnetonka, USA</td>
<td>Granulate</td>
<td>Reinforcing phase</td>
</tr>
<tr>
<td>Biofront J-20</td>
<td>Teijin Limited, Osaka, Japan</td>
<td>Fibre</td>
<td>Reinforcing phase</td>
</tr>
</tbody>
</table>

To consolidate the composite a heat pressing process is being used. However, the temperature causes thermal distortion in the reinforcing fibre. Therefore, the essential requirement for the selection of the polymers for reinforcement and matrix is the difference in the melting point. The reinforcing polymer should have a melting point of approximately ΔT 50 °C higher than the matrix component. This difference in the melting points allows the use of a heat pressing process for consolidation without thermal distortion of the reinforcing component.
The Ingeo 6201D PLA is melt spun with a spinning plant in technical-scale (30 kg/h) plant from Fourné Polymertechnik GmbH, Alfter. A schematic view of the machine is shown in figure 2.

![Fig. 2: Melt spinning of multifilament yarns](image)

The extruder is equipped with 5 individual temperature zones (red). The zones 1 to 5 are kept at 200 °C, 210 °C, 215 °C, 220 °C, 225 °C respectively. The temperature of the spinning head is kept at 230 °C. The spinneret selected for the experiments has 48 holes each with a diameter of 0.25 mm with a 2:1 L/D ratio. The melt spinning is performed at constant winding rate of 2500 m/min [2].

The reinforcing fibres have to be commingled with the matrix fibres in the next process step. During the commingling process, the filament yarns are mixed together in a mixing box and later wound on a separate bobbin. The process is shown in figure 3.

![Fig. 3: Commingling process](image)

Inside the mixing box the yarns are fed through the commingling nozzle. The nozzle has one or more additional openings transverse to the yarn path, through which compressed air passes into the yarn path. The compressed air creates turbulences that mix the filaments of both components (reinforcement and matrix). The intensity of the turbulent flow is increased or decreased by changing the air pressure. Increasing the air pressure also results in rising filament breaks and increases the production cost [3]. In addition to the pressure, the quality of the yarn (fibre distribution) is also influenced by the overfeeding rate. Overfeeding is generated by the relative speed between delivery godets (see figure 3). The overfeeding allows sufficient movement of the filaments in order to be mixed in the commingling nozzle. Furthermore, the production speed is a relevant process parameter for the quality as well as production costs.

During the commingling trials speed, pressure and overfeeding rate are varied to identify a parameter set that offers best properties for the commingled yarn. The properties are determined by evaluating the mixing behaviour of the single components in the commingled yarn cross section (see figure 4).

![Fig. 4: Microscopy of cross sections](image)

Analysing the cross section the blending coefficient can be calculated. The blending coefficient indicates the filament distribution in the cross section of the commingled yarn [3]. Low coefficients stand for a homogenous distribution, which results in the least movement of the matrix filaments during heat pressing of textile preform.

The yarn damage is assessed by tensile testing. In addition the process ability by examining production speeds is evaluated. The aim is to achieve well-blended yarns, with the lowest fibre damage possible at the highest production speeds.
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Research of Carbon Fiber Non-Woven Fabric Reinforced Thermoplastic Composites Through Press Molding

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Abstract:
In this research, the non-woven fabric by carding method was chosen for its ability to enable usage of longer carbon fiber. That was used as Carbon Fiber Reinforced Thermoplastic (CFRTP) material. It was investigated the influence of the molding conditions of heat press molding process on the mechanical properties of the nonwoven fabrics. Moreover, the non-woven fabric without needle-punch by carding method was developed and examined the spring-back phenomenon rate and the mechanical properties. As the results of this research, the mechanical properties of such composites are yet to be investigated regarding the link between processing conditions on the mechanical properties under heat press molding. Therefore, the non-woven fabric without needle-punch made by carding method was developed and examined the spring-back phenomenon rate and the mechanical properties in the cold press molding.

Keywords: Carbon Fiber Non-Woven Fabric, Press Molding, Spring-Back Phenomenon

Introduction
In recent years, CFRTP have been drawing as much attention in composite materials for their short production cycle and recyclability. However, impregnation process was a problem. It is difficult to impregnate matrix resin to carbon fiber because the thermoplastic resin has high melt viscosity. Therefore, the carbon fiber non-woven fabric that can omit the impregnation process was interested. In addition, this method also has a short process that it only used press molding.

The carbon fiber non-woven fabric is fabricated by mixing of thermoplastic fiber and carbon fiber together. Then that fabric is heated in the mold to make a composite material. By the thermoplastic fibers are melted and become a matrix resin. In this research, the carding method non-woven fabric that was chosen for its ability to enable usage of longer carbon fiber, instead of air-laid non-woven fabric or paper-making method non-woven fabric was used. It was examined the influence of the processing conditions on the mechanical properties under heat press molding process.

On the other hand, the cold press molding, the needle-punched non-woven fabric has the problem as it was difficult to the introduction to a die because it is easy to having the spring-back phenomenon at the process of heating. This is because the carbon fiber in the needle-punch non-woven fabric has the strain because the carbon fiber is entangled. While having the strain in the needle-punch process and the spring-back phenomenon occur because its strain is released when the thermoplastic fiber started melting in the heating process.

Therefore, the non-woven fabric without needle-punch made by carding method was developed and examined the spring-back phenomenon rate and the mechanical properties in the cold press molding.

Experiment
Material
Two kinds of non-woven fabrics were used in this research. Firstly, Carbon fiber (T700) was made by Toray, which has fiber length 50 mm. And secondly, maleate modified polypropylene fiber was made by Daiwabo, which interface adhesive property was suitable with carbon fiber. The two materials were coded as carbon fiber and polypropylene fiber. They were mixed at ratio of 50:50 then it was formed into web through the carding method. After that, they were prepared to needle punch nonwoven fabric and sheet-press nonwoven fabric by using two different process. For needle punch nonwoven fabric, it was interlaced through needle-punch. However, sheet-press nonwoven fabric was prepared by suppressed the spring-back phenomenon without needle-punch. Its weight per area equal to 250g/m².

Sample preparations
Both types of nonwoven fabrics were prepared to composite sample. Three layers of the non-woven fabrics were molded by heat press molding process under the conditions as listed in Fig.1. However, the
The molded temperature was designed based on the thermal properties of maleate modified polypropylene fiber as shown in Fig. 2. By DSC data of maleate modified polypropylene fiber indicate the melting temperature at 167.9°C. After heating process, samples were cooled down by cold press molding process for 3 minutes under the pressure of 25 kgf/cm².

**Fig. 1:** Processing Conditions of Press Molding process

**Fig. 2:** DSC of Polypropylene Fiber Characterization

Tensile and bending testings were carried out by using universal testing machine (Instron 55R4206). The broken points of tensile samples were observed by using an optical microscope and SEM. The spring-back phenomenon was evaluated by measuring the thickness after heating in 200°C for 20 sec.

**Results and Discussion**

**Influence of Molding Conditions on the Mechanical Properties**

Fig. 3 shows density, tensile and bending results. The comparison of density, tensile and bending properties at different processing conditions are shown in Fig. 4 – Fig. 6, respectively. These show existence of difference that depended on the molding conditions. The density is higher with increasing of molded temperature or the increasing of longer molding time. The tensile strength and bending strength increase with the increasing of temperature, pressure and time. The biggest contribution ratio to mechanical properties is the molding time.

**Fig. 7** shows the optical photographs at the broken point of tensile samples. It can be seen that it shows a lot of the bunch of the carbon fiber when the mechanical properties were lower. There was not the big bunch of the carbon fiber when the mechanical properties were higher.

**Fig. 8** shows the photographs of the broken point of tensile specimens that were observed by using SEM. It shows that the adhesion of the carbon fiber and the matrix resin was difference. Which led to the difference in melting condition of the resin.
Experimental Investigation and Numerical Modelling of the Bonding Strength of Full-Thermoplastic Hybrid Composites

R. Giusti, G. Lucchetta
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Abstract:
New design approaches and new technologies are focused on production of hybrid parts in order to lighten them and increase their proprieties by integrating different materials. The In Mold Forming technology was recently proposed for manufacturing full thermoplastic hybrid composites by coupling thermoforming and injection overmolding process. Knowing the part performances is crucial to justify the initial investment of the production system. The ability to define the boundary conditions that take into account this phenomenon is extremely important in order to develop accurate numerical models. In this work a Cohesive Zone Modelling approach was proposed to describe the damage phenomena at the crack tip by means of a stress-opening relationship, which is the principle of the cohesive phenomena. A hybrid T-joint specimen, in full thermoplastic composite, was manufacture and tested. Experiments were scheduled in accordance to a DOE approach by varying the process parameters and tensile test of the samples were performed. CZM models was calibrated on experimental data.

Keywords: Lightweight Structures, In Mold Forming, Polypropylene Matrices, Full-thermoplastic Composites.

Introduction

Lightweight design is becoming more and more important since regional regulations move to the improvement of energy efficiency and reduction of local CO2 emission [1]. New design approach and new technologies are focused on production of hybrid parts in order to lighten them and increase their proprieties by integrating different materials. [2] To satisfy this requirement, the In Mold Forming technology was recently proposed for manufacturing full thermoplastic hybrid composites by coupling thermoforming and injection overmolding process [3]. In general, plastic hybrid composite parts consist in an outer shell in glass-woven reinforced sheet and an internal overinjected ribs system. The adhesion between the two parts is due to an auto-healing phenomenon, which takes place at the interface between two similar thermoplastic matrices.[4-5]

In general, when polymeric matrices come in contact, reinforcement fibres rest confined without crossing the interface [6]. Therefore, the interface consists in a polymeric layer without reinforcement and it is usually the weaker point of the part. Moreover, a delamination failure between the first polymeric and glass woven layers has been noticed, indicating that the weaker point can shift inside the composite sheet [7-8]. Especially for technology such as IMF, knowing the part performances is crucial to justify the initial investment of the production system. The ability to define the boundary conditions that take into account this phenomenon is extremely important in order to develop accurate numerical models. The overall goal of this work is to provide designers with a useful tool for virtually optimizing their products [9]. To this aim in this work a Cohesive Zone Modelling approach was proposed to describe the damage phenomena at the crack tip by means of a stress-opening relationship, which is the principle of the cohesive phenomena [10]. The cohesive model was calibrated on experimental data obtained from tensile test of an hybrid T-joint specimen. Specimens were manufactured by varying process parameters as melt temperature, holding pressure and mold temperature. In particular, the mold temperature was controlled by mean of a variothermal system in order to better heat the welding area, and the laminate was pre-heated by infrared lamps. Experiments were scheduled in accordance to a DOE approach and the result from the best and the worst setting was considered for numerical modelling.

Experimental

The hybrid T-joint specimen is made of a 2 mm thick composite laminate base with area of 22 mm x 42 mm and an overinjected stem with area of 4 mm x 20 mm x 50 mm (see Fig. 1). The interface has a nominal area of 4 mm x 20 mm.

The material used for the base is a polypropylene matrix reinforced with 50-wt% glass fibres with balanced woven fabrics. The material used for the stem is a polypropylene matrix reinforced with 30-wt% long glass fibers. All the samples were molded on a 1000 kN electrical injection molding machine.
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A two-cavity mold was designed to realize a T-welding joint at the end of the filling phase. A full factorial design was selected with three parameters at two levels as reported in Table 1. Each experiment was repeated 7 times. The temperature of the laminates at the beginning of the filling phase was 160°C.

Table 1: Factor levels of the in-mold forming process.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Low level</th>
<th>High level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melt temperature</td>
<td>220 °C</td>
<td>260 °C</td>
</tr>
<tr>
<td>Packing pressure</td>
<td>10 MPa</td>
<td>20 MPa</td>
</tr>
<tr>
<td>Mold temperature</td>
<td>80 °C</td>
<td>130 °C/80</td>
</tr>
</tbody>
</table>

The tensile tests of the T-specimens were performed on a universal tensile testing machine MTS with load cell of 5kN. The basis was not clamped but it was secured using a steel plate with a central rectangular hole having sides 1 mm longer than the sides of the interface area.

Fig. 1: T-Joint Specimen and the clamping system for tensile tests.

DCB specimens were manufactured for determining the strain energy release rate $G_{Ic}$. The shorter border of a rectangular cut out of dimension 4 mm x 25 mm x 200 mm was heated over the melting temperature. The crack was obtained from the opening of the interface between the 4th and the 5th woven layer. Finally, the crack was expanded until the required length by applying a cyclic load. Tensile tests were performed controlling the displacement with a rate of 0.5 mm/min. The tests were performed on a CETR UMT machine with load cell of 1000 N and the crack propagation was visually monitored. The load and the overture was acquired at each step of propagation in accordance to the standard ASTM D5528 and $G_{Ic}$ was calculated.

Fig. 2: DCB specimen

Modelling

The 3D FE simulations were performed in Ansys APDL environment. The experimental results were fitted on the basis of their behaviour: bilinear law, which is a linear cohesive law, was used when the breakage was brittle otherwise, when fiber bridging occurs, the trilinear law allows to represent its effect [11]. The schematic traction-separation laws are reported in Figure 3.

Fig. 3: Example of linear damage cohesive law for Mode I and in presence of fibers bridging.

Where $T_n^{\text{max}}$ is the maximum normal cohesive stress, $\delta_n^*$ the normal displacement when $T_n = T_n^{\text{max}}$, $\delta_n^c$ is the normal displacement at total damage, $K_n$ is the normal cohesive stiffness ($K_n = T_n^{\text{max}}/\delta_n^*$). Moreover, the value $T_{n fb}$ is the cohesive stress corresponding to the displacement $\delta_n^{\text{fb}}$ at which the fiber bridging occurs. The area of the triangle corresponds to the energy required to get a complete damage of the sample that is assumed equal to the strain energy release rate $G_{Ic}$. The CZM parameters were determined performing a sensitivity analysis on experimental data. A double symmetry was used to simulate the T sample. PLANE182 elements were used for the two parts and INTER202 elements were used for the interface. The interface-elements were 0.02 mm width (along the 4 mm side) and 0.1 mm long. The meshing type was mapped. The behaviour of the injected material was assumed as linear elastic with an elastic modulus of 4.2 GPa and a Poisson's ratio of 0.4. Otherwise, the laminate's behaviour was assumed as orthotropic and an elastic modulus of 17.5 GPa was assumed for both the principal direction and a modulus of 2.5 GPa for the third direction. The Poisson's ratio are: XY = 0.4, YZ = 0.05, XZ = 0.25.

Results

The analysis of variance results of the tensile tests, which are reported in table 2, indicate that both melt temperature and holding pressure contribute in increasing the performances of the bonding resistance. Unexpectedly, the mold temperature provided a decrease of the performances and has a negative interaction with the melt temperature. It was supposed that this effect could be related to the mold architecture and to a higher increased residual stress induced by the higher temperature.
Investigation of the Processing Time of Fibre Reinforced Thermoplastic Composites with Improved Thermal Properties

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RWTH Aachen, Aachen, Germany

Abstract:
Both the automotive industry as well as the aerospace industry aim to achieve the lowest possible weight at maximized mechanical properties. In order to achieve the mentioned efficiency while staying profitable, fibre reinforced thermoplastic composites (FRTCs), are being developed. These can be produced by commingling thermoplastic fibres with reinforcement fibres to hybrid yarns and weaving these into fabrics. The textile structures are subsequently heated and consolidated through compression moulding. However, the heating and cooling times of the organic sheets are the cycle-time determining factors. The shortening effect of nanoscale fillers on the heating and cooling times of hybrid yarn based thermoplastic composites was observed at the Institute for Textile Technology, Aachen. The goal of the presented work is the characterization of the potential of this effect for industrial applications. This work will focus on the influences of the investigated particles on the processing of Polyamide 6 and the resulting cycle times for the production of FRTCs.

Keywords: Fibre Reinforced Thermoplastic Composites, Heat Pressing, Commingling, Nanoscale Fillers, Thermal Conductivity

Introduction
The importance of light weight construction in the mobility sector has increased throughout the recent years. Both the automotive industry and the aerospace industry aim to achieve the lowest possible weight, whilst maximizing mechanical properties [1]. A reduced weight leads to higher energy efficiency, thus decreasing operating costs. In order to achieve this goal, fibre reinforced thermoplastic composites (FRTCs) are being developed [2]. FRTCs are made out of two or more components. The reinforcing fibres define the mechanical properties of the composite. Commonly used fibres are carbon, glass, aramid or basalt fibres. The matrix component defines the thermal properties, as well as enables a force distribution between the reinforcing fibres. Typical thermoplastic matrix components are polyamide 6 (PA6), polypropylene (PP) and polyether ether ketone (PEEK). FRTCs can be produced using the film stacking method. This involves stacking the two components into a sandwich structure and consolidating them through compression moulding. Alternatively, FRTCs can be produced by commingling thermoplastic fibres with reinforcement fibres into hybrid yarns or rovings and weaving these into fabrics. The textile structures are subsequently heated and consolidated through compression moulding. For an optimal consolidation, the temperature distribution needs to be homogenous throughout the organic sheets, as excessive temperatures can lead to degradation of the polymer and low temperatures lead to consolidation constraints. The heating and cooling times are an essential component to this process, but are also the cycle time determining factors to the production chain. Shorter cycle times lead to higher outputs, thus reducing the costs per part. Thus the goal is to find the shortest cycle time, without compromising the consolidation quality. During the course of the “NanoOrgano” project for the Federal Ministry of Education and Research (BM BF) of the German government, nanoscale titanium dioxide (TiO2) fillers were added to the thermoplastic component and a shortening effect on the heating and cooling times of the hybrid yarn based thermoplastic composites was observed [3]. The production chain suggested by this study is pictured in Figure 1. The goal of the follow-up project “VIP Organo” is the validation of the innovation potential of this effect. As a first step in the project, studies looking into Polyamide 6 (PA6) compounds containing different concentrations of TiO2 are being conducted.

![Production chain NanoOrgano](image)

Fig. 1: Production chain NanoOrgano [3]

The modification of PA6 with nanoparticles of TiO2 has several effects. A small increase in the concentration of titanium dioxide (TiO2) leads to an increase in the thermal conductivity and decrease in the heat capacity [4]. This leads to shorter heating and cooling times, which in turn have a significant
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regards to the first (industrially produced) composite
between the second (film stacking) and third (hybrid
during pre-tests. This enables a direct comparison
produced FRTC while using the production
production process (film stacking) of the industrially
 needed to be created. This is done by replicating the
Since the production parameters of the industrially
PA6 used has been modified with 5 wt.-% of TiO2.
the same material properties as the first. However, the
using the commingling method. This composite has
properties of the other two. The second is created
as reference and thereby defines the material
industrially produced FRTC. This composite is used
compare it with the industrial standard this study
In order to assess the effect on the cycle time and
Method
PA6 on the mechanical properties, consolidation and
utilised is the nano-modified PA6 with 5 wt.-% TiO2,
roving with a fineness of 1200 tex. The PA6
has a fibre weight percentage of 63 % and a plate
matrix material is added as foils. The resulting FRTC
with a glass roving fineness of 1200 tex. The PA 6
thickness of 5 mm [5][6].

The second method is the micro computed
microscope and the visible consolidation is evaluated.
Afterwards the probe is analysed under the light
enables equal probe qualities in a test series.

During this process the probes are placed in epoxy
resin. The epoxy resin fixates the different
components during probe preparation (polishing) and
inferences to be made regarding the industrial process
between the two production types and allows

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Multiaxial Non Crimp Fabrics for Reinforcing Thermoplastic Composites

S. Bakker, K. Suhre
SAERTEX GmbH & Co. KG, Saerbeck, Germany

Abstract:
Thermoplastic composite materials are now more and more in focus as a weight-saving alternative for sheet metals, and also to enhance the mechanical property of component made by injection or compression moulding. Here the use of Multiaxial Non-Crimp Fabrics as textile reinforcement for thermoplastic composites creates a widely untapped opportunity. In order to improve the specific mechanical properties significantly, thermoplastic composites are often reinforced by continuous glass or carbon fibres. These fibres are mainly in the shape of a woven fabric or as unidirectional tapes and impregnated by molten polymer to a composite.

Non-Crimp Fabrics (NCF) offer optimal fibre orientations and area weights per layer in a multi-layer structure. And these can be manufactured in a single step. Additionally spreading rovings enables to produce fabrics with a very smooth surface. Thermoplastic composite material reinforced by Non-Crimp Fabrics form an excellent supplementary product to currently available composites. Furthermore Non-Crimp Fabric reinforced composites are suitable for components with high demands concerning surface quality and mechanical properties at the same time.

Keywords: Non Crimp Fabric, Organic Sheets

The Challenge
Reduction of CO2 emissions by increasing the vehicle efficiency is a key issue in the automotive world for a long time. The weight of a vehicle is responsible for approximately 25% of its total fuel consumption. Therefore reducing the vehicle weight can be an effective approach to reduce polluting emissions. Thermoplastic composite materials are now more and more in focus as a weight-saving alternative for sheet metals. But even conventional fibre reinforced plastics, like SMC or GMT, are no longer safe for substitution in their established fields of applications. The challenge is to develop the suitable composite for specific applications.

State of the Art
In order to improve the specific mechanical properties significantly, thermoplastic composites are often reinforced by continuous glass or carbon fibres. These fibres are mainly in the shape of a woven fabric or as unidirectional tapes and impregnated by molten polymer to a composite. To orient these fibres optimally along diverse load paths further steps are necessary.

By skewing a woven fabric its weft threads move into their final orientation (see Fig.1). Woven fabrics need a special preparation for an optimal use of the fibre corresponding to the respective load path. The originally 90° oriented weft threads are being skewed, for instance to 45°. The skewed fabrics are very fragile though and difficult in processing, furthermore the freedom in layer thickness is limited. Finally stacking of different woven fabric creates the structure of a multiaxial reinforced composite.

Fig. 1: Skewing woven fabric

Unidirectional tapes have to be laid up in accordance to different load paths (see Fig.2). These stacks are very vulnerable during the part pressing stage and are therefore limited to certain geometries.
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State of the Art

In order to improve the specific mechanical properties significantly, thermoplastic composites are often reinforced by continuous glass or carbon fibres. These fibres are mainly in the shape of a woven fabric or as unidirectional tapes and impregnated by molten polymer to a composite. To orient these fibres optimally along diverse load paths further steps are necessary.

By skewing a woven fabric its weft threads move into their final orientation (see Fig.1). Woven fabrics need a special preparation for an optimal use of the fibre corresponding to the respective load path. The originally 90° oriented weft threads are being skewed, for instance to 45°. The skewed fabrics are very fragile though and difficult in processing, furthermore the freedom in layer thickness is limited. Finally stacking of different woven fabric creates the structure of a multiaxial reinforced composite.

Fig. 1: Skewing woven fabric

Unidirectional tapes have to be laid up in accordance to different load paths (see Fig.2). These stacks are very vulnerable during the part pressing stage and are therefore limited to certain geometries.
Mechanical Behavior of Novel Organo-Sandwich Components for Lightweight Structures in Automotive Applications

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Abstract:
In this work novel semi-finished Organo-Sandwich material combinations consisting of a thermoplastic honeycomb core and fiber reinforced thermoplastic face sheets are characterized in terms of their mechanical and thermal properties to gain fundamental knowledge for their later processing in conventional thermoplastic injection molding technology. Therefore specific mechanical properties are measured at room temperature and process relevant temperatures to investigate the influence of cell width, core height and density of the thermoplastic honeycomb core. Additionally thermal properties linked to the pre-heating process step of Organo-Sandwich material combinations are measured via instrumented specimens in an infrared radiation oven.

Keywords: Organo-Sandwich, Hybrid Injection Molding, Lightweight Structures

Introduction
Lightweight design is a common philosophy which enables engineers to keep the mechanical performance and functionality of a structure while reducing its weight. Continuous fiber reinforced plastics (FRP) have high specific mechanical properties and are predestined for lightweight structural applications. The restricted industrial processability of FRP is a cost driving factor which reduces the scope of applications actually to some premium components for example in aviation or automotive industry.

Knowing these challenges, FRP with thermoplastic matrices are a potential alternative [1]. Compared to thermosets thermoplastic components can be processed with short cycle times and a high reproducibility which are main advantages for cost and production [2]. Furthermore the meltability of thermoplastics leads to further process relevant advantages like thermoformability and a high recyclability. These positive features give reasons for the increasing demand on continuous fiber reinforced thermoplastics. Therefore there is also a growing market for new developed and improved thermoplastic semi-finished products.

Hence EconCore (Leuven, Belgium) developed a novel and innovative semi-finished material combination, called Organo-Sandwich which combines the advantages of a sandwich structure with the high specific mechanical properties of a thermoplastic FRP composite which enhances light weight potential and production effectiveness significantly [3,4]. An Organo-Sandwich consists of a continuously produced thermoplastic honeycomb core and continuously fiber reinforced thermoplastic organo sheets as cover layers. The good meltability of the thermoplastic materials enables the production in a continuous fully automatic production process, shown in Figure 1. Therefore this novel material combines a continuous production of the thermoplastic honeycomb core with an inline lamination of the organic sheets. The honeycomb core is produced in the patented ThermHex (owned by EconCore) process by extruding a thermoplastic film with subsequent vacuum rotation thermoforming and folding to a honeycomb core. This continuous and fully automatic procedure enables a very cost efficient production of sandwich panels. Furthermore, the sandwich design and FRP design enables a significant enhancement of the specific bending stiffness compared to conventional organic sheets and composites. Thus higher bending stiffness makes the Organo-Sandwich suitable for flat or thin component areas which are especially sensitive to stability failure like buckling or kinking.

Fig. 1: Automated in-line production of semi-finished Organo-Sandwich Sheets [ThermHex].
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The different core types were tested and compressive strength ($R_C$) at maximum load and compressive modulus ($E_C$) from the slopes of the technical stress strain curves were evaluated. These results are given in Table 2 for comparison.

Table 2: Compressive strength and modulus.

<table>
<thead>
<tr>
<th>Identifier</th>
<th>$R_C$ [MPa]</th>
<th>$E_C$ [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>THPP60-10-8-RT</td>
<td>0.52 ± 0.02</td>
<td>12.41 ± 0.39</td>
</tr>
<tr>
<td>THPP80-10-8-RT</td>
<td>1.03 ± 0.03</td>
<td>35.20 ± 1.87</td>
</tr>
<tr>
<td>THPP80-4.5-4.5-RT</td>
<td>1.30 ± 0.14</td>
<td>15.84 ± 1.65</td>
</tr>
<tr>
<td>THPP80-20-9.6-RT</td>
<td>1.05 ± 0.09</td>
<td>62.27 ± 5.98</td>
</tr>
</tbody>
</table>

Also by comparing the plotted stress-strain data in Figure 5 it is obvious that there are differences between them. Firstly a rise in compressive strength with increasing density of the core is noticed. Comparing THPP60-10/8 and THPP80-10/8 with identical cell size and core height, a doubling of compressive strength is recognized, which corresponds to the thicker cell walls used at higher density. Besides that also a correlation between cell size and compressive strength as well as the compressive modulus is slightly obvious. Keeping the density equal and varying cell size and core height leads to a different compressive strength as well as a different slope of the stress-strain curves and with that to different compressive moduli.

Fig. 5: Averaged stress-strain curves with scatter bands.

To get a deeper look into behavior of the honeycomb core during the thermoforming process, all core types were also tested at a temperature of 80°C. A comparison of the results at room temperature (RT) and at 80°C for specimen type THPP60-10/8 is exemplarily illustrated in Figure 6. It shows that an elevated temperature leads to a significant loss in both compressive strength and compressive modulus.

Fig. 6: Averaged stress-strain curves with scatter bands at RT and 80°C.

Summing up the results of the performed compressive tests a strong influence of the used core type and test temperature is recognizable. That means on the one hand that each core type has to be characterized and evaluated separately and one the other hand that the processing temperature and the pressure in mold within the thermoforming process step has to be attuned to the used core type. To avoid long and cost intensive experimental tests to get a fitting thermoforming temperature a thermal characterization of the Organo-Sandwich with a finite element simulation of the heating and temperature distribution was done.

**Thermal Characterization**

The results of thermoforming as well as of functionalization by injection molding are deeply influenced by the previous heating process with IR. This heating process is characterized by superimposition of different heat transport mechanisms, like thermal conduction, heat radiation and thermal convection. To integrate the semi-finished parts into the process chain it is also necessary to examine the thermal behavior of Organo-Sandwich pre-forms. Therefore specimens of this material were loaded with medium waved IR on both sides. While emitting electromagnetic waves within a range of 1.4 µm to 3.0 µm [5] most of emitted energy can be absorbed by the thermoplastic matrix material (PP) of the top layers converted into heat. Only a small amount of radiation is lost due to transmission and diffusion. These enable an accurate control of surface temperature by controlling the radiation performance. Figure 7 shows the temperature the top layer differs from the temperature in core center while heating the Organo-Sandwich up from 30°C to 150°C. It could be examined that the slope of temperature is well controllable which enables the adjustment of specific and individual heating and holding phases.
Manufacturing of a UD-Tape Reinforced Hybrid Thermoplastic Composite Test Component

B. Rietman, E. Boxus, S.M. Kashif, N. Verghese
SABIC, Geleen, The Netherlands

Abstract:
The regulations for reduction of fleet emissions stimulate the increasing use of lightweight materials in the automotive industry. Continuous fibre reinforced plastics feature excellent mechanical properties combined with a low density. Thermoplastic composites, in which an engineering thermoplastic is used as the matrix material, additionally allow for fast processing cycles in the order of one minute. Although the inherent properties of thermoplastic composites principally match well to the requirements from industry confidence still seems to be lacking. The main reason is that the simulation methods for composite design are not yet matured and design data is not available.

To address the aforementioned needs a technology demonstrator has been designed with the goal of testing the failure limits of the used thermoplastic composites under different loading conditions on the component level. By doing so, the developed simulation approaches for tensile, compression and shear failure, static as well as dynamic, were successfully validated.

The test component consist of unidirectional (UD) tape based laminates overmoulded with a long fibre injection moulding grade. In the one-step fashion of the overmoulding process the insert is pre-heated to forming temperature, transferred to the mould, shaped by the closing stroke of the moulding tools and subsequently overmoulded. To investigate the manufacturability different composite inserts have been used, starting from UD strips towards full-width multi-directional laminates. Since the coherence of UD materials perpendicular to the fibre direction is poor, especially in melt state, dedicated clamping and fixation devices have been developed. This paper addresses the main challenges in processing UD based laminates in an overmoulding cycle.

Keywords: UD-Tape, Overmoulding, Mould Design, Thermoplastic Composites, Production Technology

Introduction

One of the possibilities to comply with current and upcoming legislation on emission reduction of cars is to reduce their weight. Continuous fibre reinforced plastics, generally referred to as composites, feature excellent mechanical properties with a low density. Thermoplastic composites, which are based on continuous fibres in a thermoplastic matrix, furthermore feature the advantage of short processing cycles. Especially the possibility of hybrid overmoulding to make very complex parts in a cost-efficient way is one of the main drivers to adopt thermoplastic composites. Thermoplastic composites can also be recycled with relative ease. Semi-finished products like unidirectional prepreg tapes and laminates can be processed by heating and shaping, which is due to the nature of the thermoplastic matrix. This same feature also allows for the integration of different processing steps like consolidation, forming, welding and overmoulding in a single process. This is hard to find in other composite material systems.

A direct comparison between fabric and UD based laminates, as has been done for instance in [1], shows that UD’s outperform fabric based laminates in terms of stiffness and strength. This is attributed to the geometric undulations of the fibre bundles due to the fabric architecture. Furthermore laminates using UD plies offer greater flexibility with respect to the orientation of the fibres. UD prepreg tapes and laminates are therefore ideally suited to align the reinforcement structure to the local load path and thus allowing for optimal light weighting.

Unidirectional tapes and laminates feature excellent mechanical properties in fibre direction; however in transverse properties are reduced significantly. This is especially the case at typical forming conditions where the temperature in the laminate is above the melt temperature. Small loads in transverse direction may therefore lead easily to unwanted deformations, like splitting of the laminate. Current systems like vacuum or needle grippers often result in defects of the laminate that can negatively influence the performance of the final part. For this reason new gripping and fixation systems have been developed that are applied during the critical stages of heating, handling, forming and overmoulding of the laminate.

This new technology will be demonstrated on the basis of a large hybrid overmoulded beam.
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Handling of UD laminates

The laminates based on UD tape feature excellent performance in fibre orientation. The reduced properties at forming temperatures, however, pose a challenge for handling and fixation during the process of overmoulding. Available gripping solutions such as needle or vacuum grippers have proven effective for woven fabric based laminates and dry fabric, but do not give feasible results for UD laminates at elevated temperatures. Trials have shown that the use of these systems results in severe damage of the insert. Defects like fibre movement and buckling, delamination and ply splitting could be observed. Therefore, new gripping devices have been developed that are able to handle UD laminates without significant damage.

In order to reduce the deformation of the laminate, the local pressure is reduced by using flat grippers with large surface areas. In this way the forces needed to hold the laminate are introduced in a large area. The grippers are positioned opposite to each other, again to reduce the risk of deformations. The same principle is used to hold the laminate in place within the mould.

Fig. 3: shows the developed solution for fixation and positioning of the composite insert in the mould. The robot that holds and transfers the heated laminate positions the laminate between both mould halves. In a next step, the tool grippers are moved out of the mould halves and take over the laminate. As all tool grippers are in position, the robot grippers release and the robot is getting ready for a new cycle. Now the tool is closed and the laminate is positioned to its final position in the mould, using the controlled movement of the tool grippers.

During overmoulding of the resin, the mould grippers at the cavity side are retracted one-by-one in order to allow the flow front to pass and fill the cavity. The resin pressure is able to keep the laminate at the right side of the cavity such that underflow of the laminate can be prevented. After cooling, the mould is opened and the part is ejected.

Manufacturing

A number of variants using different types of inserts have been produced on FiberForm equipment at KraussMaffei Technologies in Munich. For each of the variants, the process settings and the timing for the grippers were determined on the basis of short shots and filling simulation results.

Fig. 4: technology demonstrator including full UD-laminates

Thanks to the new gripping technology, it was possible to produce high quality demonstrator parts that could meet the requirements on accuracy. The parts have been tested and the results could successfully be used for experimental validation of the simulation chain [2].

Conclusions

In this paper, a new technology for enabling the use of UD laminates in overmoulded parts was presented. This new technology allows for the handling and fixation of hot UD inserts without introducing defects and is an enabler for hybrid overmoulding processes for automated mass production of weight optimized composite parts.

Acknowledgements

The authors wish to recognize the contributions of Georg Kaufmann Formenbau AG and KraussMaffei Technologies.
Innovative Hybrid Thermoplastic Composite Test Beam to Validate All Failure Modes for Automotive

W. Schijve, R. Yaldiz
SABIC, Geleen, The Netherlands

Abstract:
Today, carbon emissions reduction is one of the key drivers for new developments in the automotive industry. Amongst others, one solution is to reduce the weight of a vehicle significantly. Composite materials can offer these weight savings, yet widespread adoption is still not there. Besides cost, a major hurdle is the lack of confidence in performance predictability. Especially for the more cost efficient hybrid combinations of UD tape based laminates with overmoulding material robust predictability procedures are not yet state of the art. For this reason a test component was designed that can be produced in a representative production process and is able to validate all of the many different composite failure modes. The main purpose here being to have sufficient process and simulation validation for any yet to be designed component. At the same time the design takes care to have actual failure in the continuous fibre composite material and not in the much weaker short/long injection overmoulding material.

Keywords: Continuous Fibre Thermoplastic, Predictive Engineering, Simulation, Design, UD Tape, Laminate, Hybrid, Overmoulding

Introduction
Continuous fibre reinforced thermoplastic materials are attracting automotive industry attention for several years already. They are attractive due to their high mechanical performance and low weight. These new materials require however new robust manufacturing processes that have to comply with the short cycle times of around 1 minute required for the mass production in this industry. In addition, new predictive methods need to be developed providing the necessary confidence for accurate predictability of the manufacturing process and (mechanical) part performance. A few years ago, SABIC has interviewed most major OEM’s, tiers and equipment suppliers, asking them what they see as the main hurdles for composites introduction. This resulted in a clear top three:
1. Design predictability.
2. Cost
3. Cycle time
Of much less importance were the following items:
- Material properties characterisation
- Joining predictability / performance
- Quality and consistency
- Recycling
We believe that the issue of cost and cycle time can be handled especially well by clever design and making use of the hybrid overmoulding technology as explained elsewhere [1, 2]. The hybrid overmoulding process itself is schematically explained below (see Fig. 1). In this process, continuous fibre reinforced thermoplastic laminates are applied only at those locations where there is a high load, while structural details are moulded in short or long fibre reinforced material via an injection moulding process.

Fig. 1: Hybrid overmoulding technology for thermoplastic hybrid components. 1: Pick up of composite blank. 2: IR-heating. 3: Blank fixation in the mould. 4: Thermoforming of blank. 5: Injection overmoulding. 6: Part demoulding.

Although the cost and cycle time hurdles can be overcome, confidence in predictability still needs to be gained.
For this reason a beam like test component was designed that would tackle variations in process and validates predictions of actual in-part composite material performance.

Validation test component
Confidence in predictions of composites can be obtained at various levels. E.g. one would usually start with testing material properties on laminates, and end up with testing a final component until failure under realistic application conditions. This could be e.g. a side door in a car, tested in a crash situation. This is illustrated below (see Fig.2).
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Asymmetric insert layout was chosen (see Fig. 6). In this way the neutral axis in bending is shifted towards the thick insert, causing the stresses in the thin insert always to be much more than twice that of the thick insert. In this way the thin UD strip can be tested either in compression or in tension always.

Fig. 6: 3D cross section showing highly asymmetric UD insert layout.

As can be seen in Fig. 2, the beam is quite slender. Actual length is 1000 mm while the height is only 40 mm. The reason being that in this way the shear stresses in the overmoulding material remain quite low, and can be as low as around 20 MPa depending on the resin. By increasing the length of the beam, it will be certain that the beam can be tested to e.g. 1000 MPa tensile failure in the composite and not fail in the overmoulding material.

Similarly, when one wants to test the shear strength, it is easy to reduce the distance between the load point and supports, which will result in relative high shear stresses.

Apart from UD strips also multidirectional laminates or joined components can be tested for validation purposes (see Fig. 6).

Fig. 7: Various layout configurations.

Example validation

At the moment of writing an elaborate test program is still under way. It includes testing of beams at typical temperatures required by the automotive industry, such as -40 and +85°C. Also it will include both static and dynamic testing. Below a first example of a multi angle laminate beam is shown. In this case a full width hat section shaped laminate having the following layup: [+45, -45, 02]s. Total thickness being 2.0 mm. In this example the flanges were loaded in tension. A comparison of predicted versus measured force displacement curves is shown below (see Fig. 8).

Fig. 8: Comparison predicted (dashed line) versus measured (solid lines) force-displacement curves. Agreement is quite good both in stiffness and failure prediction. Note that post failure prediction was not attempted here.

Integrated simulation chain

Today several software packages are available for simulation of different composite manufacturing processes and for mechanical analysis. For hybrid processes, fibre orientation of both the short and continuous fibre is especially important for the mechanical (or warpage) simulation. The continuous fibre material orientation can change due to the draping process, which can be simulated with software like AniForm† or PAM-FORM†, while the short or long fibre orientation resulting from the filling process can be predicted by e.g. Moldflow† or Moldex3D†. Software packages such as Digimat† can transfer fibre orientation from Moldflow to Abaqus, used for mechanical performance prediction. Nevertheless, today there is no software that couples any step in the manufacturing process towards the mechanical simulation. At SABIC newly developed software SIMAN† Mapper is used that takes care of all these tasks. (See Fig. 9, 10).

Fig. 9: Integrated simulation chain, using mapping software.
Manufacture and Testing of Thermoplastic UD Tapes for Serial Production – How to Produce Cost Efficient UD Tapes

M. Risthaus, Evonik Resource Efficiency GmbH, Marl, Germany

Abstract:
The trend is unstoppable: Demands for comfort and safety in vehicles are increasing while at the same time environmental impacts are to be reduced. Vehicle producers have to continuously develop lighter components in order to meet the specified targets.

Keywords: Thermoplastic UD-Tapes, Design, Processing, Testing, Quality Assurance

Endless fiber-reinforced polymers offer a promising and innovative solution with a high potential for lightweight construction. The composites consist of carbon or glass fibers and a matrix of high performance polymers. The properties of the two materials are combined optimally in UD tape, which allows the development of innovative construction materials for new paths in component design. Several layers of UD tapes in a laminate form what are known as organosheets, which considerably surpass the mechanical properties of metal sheets with the same thickness. The organosheets can be thermoformed and, consequently, assume many different component geometries. They also offer the possibility of integrating more functions or components when the components are overmolded with a plastic in an injection molding tool. It seems natural to use the same polymer class as that used for the matrix in the UD tape so that the two components bond well - this is absolutely necessary for dynamic load cases. With the matrix of high performance polymers developed especially for these applications with a high glass transition temperature and, consequently, good heat resistance, which are coordinated optimally for high-strength endless fibers, it is possible also to use components in high temperature installation spaces.

Quality Assurance

These days, one of the challenges facing industry is reliable testing of the semi-finished products, but also the finished composite components. It must be ensured that the components have no cavities and that the fiber-matrix connection is complete. As a result, each single fiber - with carbon fibers, just 7 μm thick - must be completely enclosed with polymer. If this is not the case, you get dry patches, which reduce the load-bearing capacity. From the component design aspect, this must be avoided: Only completely consolidated composites ensure a failsafe design and simulation of component properties. Therefore, test standards to guarantee constant material quality are vital to gain confidence in the new technology. As a leading producer of specialty chemicals, Evonik is a driving force in the development of corresponding standards. Working groups established for this purpose consider standards that create a common understanding of quality in the producing and processing industries and that are intended to ensure the high quality standards.

Production of UD tapes

In the relatively new composites industry, several production processes have become established for UD tapes. Probably the most economic process is direct melt impregnation, since this uses granulate as it occurs in the production process. Some alternative methods, such as dispersion impregnation or spread processes, need very fine powder, which is obtained by expensive grinding of the initial granulate. At present, reactive in-situ processes are still at the development stage, although from these we can expect relatively low production rates.

Fig. 1: Example of a direct melt impregnation line
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parameter study to get sufficient results. laminate. Each material combination needs its own bonding to get out the best performance of a laminates without lunkers and optimal fiber matrix shown in the table below. Finding the correct An example for suitable processing parameters are increased to 15 - 20 bar and maintained at this value In the consolidation phase the pressure should be heating phase, pressures of 1 - 2 bar are sufficient to structure is adequately heated through. In the extended to 5 - 10 minutes; this ensures that the UD cannot be recorded the pressing time shall be any reason the temperature inside the laminate applied to achieve good bonding of the layers. If for laminate, a pressing time of 1 - 2 minutes shall be rates of the press to 10 - 15 K/min. Once the target may be advisable to limit the heating and cooling over the pressing surface during the cooling phase, it To ensure a homogeneous temperature distribution includes comprehensive technical support during the design phase of particular components, detailed solutions in collaboration with our customers. This develops technologically sophisticated system and modern simulation software tools are needed. For an adequate prediction of UD tape processing and component properties powerful material models and non-linearity and dependence on temperature and simulation software such as LS-Dyna, ABAQUS. In the design phase, we use state of the art numerically via integrative simulation to support the optimize the part design and describe the behaviour of the composite and overmolding materials overmolding process from the filling phase to the and technical services include recommendation for tape materials are fully utilized. Furthermore, our Hereby, the strengths of endless-fiber reinforced tapes as well as onsite technical support during piloting and manufacturing. CAE support is an and challenges with the customer to develop and process development discusses all objectives and essential element of all customer projects. We pilot and manufacturing. CAE support is an appropriate solutions.
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List of Exhibitors

A

Automated Dynamics
2 Commerce Park Drive, Niskayuna, NY 12309, USA
T +1 (0) 518 377 6471
sales@automateddynamics.com
www.automateddynamics.com

For over 30 years, Automated Dynamics has been a global leader in automated composite production. We specialize in the manufacturing of high-performance composite structures, development of advanced automation equipment, and solution-based engineering services. Through the use of a true out-of-autoclave (OoA) process, we bring additive manufacturing to continuous-fiber thermoplastic composite parts; saving weight and improving reliability in today’s most demanding engineering environments. We offer patented Automated Fiber Placement (AFP) technologies, and, as recognized innovators, we have produced hundreds of thousands of composite parts for over 500 clients in 17 countries.

B

Barrday Composite Solutions
86 Providence Road, Millbury, MA 01527, USA
composites@barrday.com
T +1 (0) 508 581 21
www.barrday.com

Barrday is a leading North-American based advanced material solutions company whose product lines encompass applications for the composite and protective markets. Our growth strategies are based on developing technologically advanced fiber reinforcement, prepreg and other material solutions for our customers in the aerospace, military/defense, transportation, energy and protective markets. Barrday has a manufacturing and sales presence in North America and Europe.

Barrday has developed expertise and performance differentiation in the following areas:
• Woven reinforcements
• Thermoplastic tapes and semi-preg
• Thermoset prepreg systems
• Adhesive films and specialty tapes

C

Cetex Institut für Textil- und Verarbeitungsmaschinen gemeinnützige GmbH
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nendel@cetex.de
F +49 (0) 371 5277 – 100
www.cetex.de

Cetex is the research institute in Germany for new technologies and machines for manufacturing technical textiles, textile-based semi-finished products, functional components and high-performance structures. Its work centres on developing processes, materials and machines for continuous fiber-reinforced semi-finished products and complex preforms. The design and the testing of technologies for major production runs for multi-functional lightweight applications are essential for this. Research focal points include the processing of carbon fibers, the fiber deposition according to the flow of forces, new technologies for fiber spreading and the production of near net shape preforms.
CFK Valley e. V.
Ottenbecker Damm 12, 21684 Stade, Germany
T +49 (0) 4141 40740 – 0
F +49 (0) 4141 40740 – 29
info@cfk-valley.com
www.cfk-valley.com

Success by Innovation – The Network for Composite Technology

The CFK Valley e. V. is an established competence network for carbon fibre reinforced plastics (short CFRP, German abbreviation = CFK). The association was founded in 2004 and is located in Stade, a city close to the region of Hamburg. More than 100 international companies, research facilities and universities are organized in the non-profit association. Inventing future orientated designs, automated manufacturing processes and part production are the purposes of the CFK Valley. The versatile competences of market leading experts allow the covering of the entire value chain. It starts with educating of highly skilled employees and spreads over the part design and serial production towards the recycling of CFRP-components after use. All mobility branches like aerospace, automotive, rail way, marine systems, transportation as well as wind energy and mechanical engineering in general lie in the focus of the activities of the CFK Valley. CFRP allows lighter and fuel saving airplanes, motor vehicles and ships as well as bigger and more powerful blades for wind energy power stations. The carbon fibre reinforced polymer “CFRP” has the biggest potential beyond the materials of the future. To successful face these challenges, it is essential that different partners cooperate within a network. The CFK Valley e. V. provides its members and partners an ideal cooperation platform. The purpose is to develop innovative products and place them in the different markets.

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CompositesWorld - the industry’s leading technical information resource.
High-Performance Composites – expert coverage on continuous carbon fiber & other high-performance composites & on the associated end-markets of aerospace, automotive, ballistics/military & more.
Composites Technology – compelling, trusted content on fiberglass & similar FRP composites & the associated end-markets of ground transportation, marine, energy, industrial applications & more.
SOURCEBOOK – the directory of record for the international composites industry.
CompositesWorld.com – comprehensive & authoritative content, industry updates & product research.
CompositesWorld Weekly and CompositesWorld EXTRA e-newsletters – the latest in news & developments in the industry & related end-markets, as well as access to the CompositesWorld.com blog.
CompositesWorld Conferences – timely & high-quality content focused on business trends, strategy, technology & market forecasts.

E

EcoMaT - Center for Eco-efficient Materials & Technologies
c/o WFB Wirtschaftsförderung Bremen GmbH
Langenstraße 2 – 4, 28195 Bremen, Germany
bastian.mueller@wfb-bremen.de
T +49 (0) 421 9600 – 349
www.ecomat-bremen.de

For pooling existing expertise in Bremen from industry and science in the field of innovative materials and lightweight structures will the technology center EcoMaT arise in Bremen in close proximity to Airport and to major industrial partner Airbus. In EcoMaT the research topic deals with the question of the efficient and effective use of materials and the development of new materials. Short distances and joint projects can be used to accelerate innovation processes across industries already in an early stage of development. The proximity also allows the sharing of laboratories and facilities. Under one roof, around 500 people from the business and scientific will research and develop together.
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martin.risthaus@evonik.com
www.evonik.com/composites

Evonik is one of the world’s leading specialty chemical companies offering creative and innovative product solutions for the Composite Industry. Its solutions comprise thermoplastic matrix systems processed in glass fiber and carbon fiber UD tapes. Resulting laminates with VESTAKEEP® and VEST-AMID® high performance polymers exhibit mechanical properties in the magnitude of steel but significantly lighter. With a high glass transition temperature and good heat resistance adjusted optimally for high-strength endless fibers, components can even be used in high temperature applications.

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www.faserinstitut.de

The Faserinstitut Bremen e. V. (FIBRE) is a successful research institute for the development of high-performance fibre reinforced composites, processing technologies, fibre development, quality control and material characterisation. An institute with this combination of core competencies is unique in the German research landscape. Partners are research institutes and companies from various industries like aerospace, automotive and wind energy. Since 1989 the institute cooperates with the University of Bremen and is active in research and teaching. FIBRE trains skilled employees in manufacturing of fibre composite components and trains skilled employees in the production of CFRP components. FIBRE employs 45 highly skilled engineers, scientists and technical staff in different disciplines. FIBRE is certified according to DIN EN ISO 9001 and EMAS III and is integrated in an international network of industrial partners, research Institutes and Universities.

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F +49 (0) 6192 900 316
gschenk@gtweed.com
www.gtweed.com

Greene, Tweed is a world-class leader in the design and manufacture of high-performance materials and custom-engineered solutions for the Aerospace, Semiconductor and Energy industries. For more than 150 years, we have partnered with global leaders across the markets we serve, working collaboratively to identify critical challenges and solve them with advanced technologies. Greene, Tweed is Market Leader in Hydraulic seals for Landing gears. Focusing on collaboration with Airframers and leading tier 1 companies in the Aerospace Industry, we have developed high-performance thermo-plastic composite solutions and advanced processing techniques that deliver components with dramatic weight savings, increased efficiency and reduced part-count. Headquartered in the suburbs of Philadelphia, PA, Greene, Tweed maintains a global presence throughout North America, Europe and Asia.
GRIP Metal Inc. was founded in 2013 as a subsidiary of NUCAP Technologies Inc., a major manufacturer to the automotive braking industry. GRIP Metal™ technology is a derivative of the NUCAP Retention System (NRS), which is a process that extrudes a unique hook pattern on metal to allow for an extremely strong physical bond without the use of adhesives.

What is GRIP Metal™?

GRIP Metal™ is a proprietary mechanical interlock bonding technology that aims to augment or replace the traditional adhesive bonding between two materials. It is an innovative and cost-effective way to create high-performance and lightweight structures.

GRIP Metal™ process allows the mass production of consistent small-scale metal hooks that are uniformly distributed on the surface of a thin gauge sheet metal. The modified metal sheet is then pressure bonded or molded into weaker substrates forming a superior structure through the performance of the mechanical interlock bonding connection. The GRIP hooks can be produced in heights up to 4 times the base materials thickness on either one side or both sides of sheet metal simultaneously. Hooks are drawn from the base metal in a proprietary manufacturing process without having to perforate it. GRIP Metal™ can be processed on almost any coiled metal in a thickness range from 0.25 to 10 mm.

The hook structure creates a mechanical bond with the laminate surface or between two surfaces, offering both adhesive-less bonding and a mechanical strength increase of 2 to 3 fold, and potentially higher, by creating a depth to the shear line. The increase in shear strength can allow for up to a 50 % material savings, reducing weight. Hook geometry, height, and density are variable, ranging from 0.30 to 2.41 mm, and are offered with varying degrees of curvature from a wave-like crest to a more vertical spike. Bending, forming, punching and shaping can be applied before or during the bonding process. Applications include automotive, aerospace, wind energy, 3D printing, oil & gas, piping, composite laminating, and concrete reinforcement.

Ideally suited for production with thermoplastics and fibre-reinforced polymers (FRP), it can also be used with thermosets, phenolic resins, and coatings. Even a metal-to-metal bonding is available.

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INEOS Styrolution is the leading, global styrenics supplier with a focus on styrene monomer, polystyrene, ABS Standard and styrenic specialties. With world-class production facilities and more than 85 years of experience, INEOS Styrolution helps its customers succeed by offering the best possible solution, designed to give them a competitive edge in their markets. The company provides styrenic applications for many everyday products across a broad range of industries, including automotive, electronics, household, construction, healthcare, toys/sports/leisure, and packaging. A highlight at ITHEC 2016 will be the presentation of a first demonstrator of the company’s first thermoplastic composite.
J

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With a network of 250,000 professionals, JEC Group is the largest composite organization in the world. It represents, promotes and helps develop composite markets by providing global and local networking and information services. For the past 20 years, JEC has achieved continuous growth and acquired an international reputation. It has opened offices in North America and Asia.

After successfully winning over the composites industry, JEC Group is now enlarging its scope to the next segment of the value chain, i.e. manufacturers and end-users. Through Knowledge and Networking, JEC’s experts offer a comprehensive service package: the JEC publications - including strategic studies, technical books and the JEC Composites Magazine - the weekly international e-letter World Market News and the French e-letter JEC Info Composites. JEC also organizes the JEC World Show in Paris – the world’s largest composites show, five times bigger than any other composites exhibition –, JEC Asia in Singapore and JEC Americas in Atlanta; the Web Hub www.jeccomposites.com; the JEC Composites Conferences, Forums and Workshops in Paris, Singapore and Atlanta and the JEC Innovation Awards program (Europe, Asia, America, India and China). The composites industry employs 550,000 professionals worldwide, generating 69 billion USD worth of business in 2015.

L

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The Laser Zentrum Hannover e. V. (LZH) participates in research and development projects for laser development and laser applications. One exploratory topic of the LZH is the laser treatment of fiber reinforced materials. This subject is investigated by the Composites group with the focus on repairing and cutting of carbon fiber reinforced plastics like demonstrated in the projects Holquest 3D and Co-Compact. In addition, laser transmission welding processes for joining thermoplastic composites are developed to provide the possibility of manufacturing parts.

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The magazine lightweight design is aimed at promoting the use of lightweight materials and structures for the purpose of reducing weight and saving energy. It reports on the implementation of lightweight design principles in the development and manufacturing of new products along the entire value creation chain, from materials technology and design techniques to simulation and optimisation processes, to manufacturing, quality assurance and recycling.
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With more than 1,900 staff worldwide, Pilz operates internationally as a technology leader in automation technology. In this area Pilz is consistently developing a role as a total solutions supplier for safety and automation technology. In addition to the head office in Germany, Pilz is represented by 31 subsidiaries and branches on all continents.

Products include sensor technology, electronic monitoring relays, automation solutions with motion control, safety relays, programmable control systems and an operating and monitoring range. Safe bus systems, Ethernet systems and industrial wireless systems are also available for industrial networking.

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Plastics. Our profession. Since 1949, Pöppelmann has developed five production sites with 550 injection moulding and thermoforming machines and extruders, growing into one of the leading manufacturers in the plastics processing industry. Our customers operate e.g. in the automotive industry, renewable energies, machine or equipment engineering. “Made by Pöppelmann” quality is valued in over 90 countries worldwide. The business division Pöppelmann K-TECH® develops solutions regardless of what requirements our customers have for their components. Pöppelmann K-TECH® is expert in weight-reduction. Paths we take to reduce weight are e.g. the implementation of composites or organic sheets. From development through to serial production, Pöppelmann K-TECH® takes over all those numerous jobs which a project involves - the requirements of our customer always in focus. Those jobs consist e.g. in simulations, creation of moulds, production and assembly. The earlier you integrate Pöppelmann K-TECH® in the project, the quicker it is done.
Procotex Corporation S.A. is a subsidiary of the holding company, Dolintex. NV with HQ in Belgium and factories in Belgium, Lithuania, France and Turkey.

Philosophy:
Sustainability and conversion of raw material have always been the cornerstones of our company philosophy. The second generation of the family behind Procotex is proud of the fact they recognize that their commitment to sustainable profitable growth also has to take into account the broader economic, environmental and social impact of their products and operations.

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Produktion addresses the entire range of the decision-making chain in the manufacturing industry with its mix of engineering and business topics. Production managers and heads of departments integrated in the production process are the main target group. Also members of design and logistics departments belong to our readership, as well as directors and CTOs. Produktion provides helpful engineering expertise and product information for the shopfloor, real-life examples and management tips for process optimization, and competitor and market analyses for business decisions.

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Reinforced Plastics magazine reports on all the latest business and technology developments in the global composites industry in all industrial markets – automotive, aerospace, construction, boat building, military / defense, and more.

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RUCKS Maschinenbau GmbH has more than 170 years of experience in the manufacturing of press systems! Its production range extends from the design and manufacturing of complex production lines including handling equipment and high-precision laboratory presses. Press forces are from 0.01 kN to 100,000 kN and heat plate dimensions from 200 x 200 mm to 5,000 mm x 3,000 mm. RUCKS also offers different automation solutions.

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With approximately EUR 320 million of annual revenue, the family-owned company SAERTEX® is the global market leader in the manufacture of multi-axial fabrics (non-crimp fabrics) and core materials for the production of fiber-reinforced composites. Customers in the wind, aerospace, automotive, sports and boat building industries rely on SAERTEX® reinforcement materials made from glass, carbon and aramid fibers to achieve lighter weights, enhanced stiffness and corrosion resistance. Particularly in segments like shipbuilding, railways, oil & gas and construction, the company offers additional services to support customers in the transformation of components from steel to composite – from calculations and process development to serial part production. With some 1,200 employees and twelve production sites on five continents, as well as an active distribution network in more than 50 countries, the SAERTEX® Group is globally positioned, to satisfy the rising demand for advanced-technology composite solutions.

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SAMPE is a global organization devoted to the promotion of technical excellence in materials and process engineering, totalling around 15,000 engineers, technologists and materials scientists world-wide. The organization – founded in 1946 – has spread all over the world and is today divided in about 40 chapters over the continents. SAMPE EUROPE was formed to become an association of persons of like interests in the field of material and process engineering for all types of advanced materials in all markets. Aerospace, automotive, constructions and energy have been the main targets in the last decade. In Europe, we have activities in more than 25 countries, organized predominantly in national associations like those of France, Germany, Italy, Switzerland, Spain, Russia or in international groups like Benelux, UK & Eire, Scandinavia a. o.

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Surface Generation is a world leader in the design and manufacture of advanced Plastics, Composites, Metals and Glass processing solutions based around its patented PtFS technology (Production to Functional Specification) for the Aerospace, Automotive and Consumer Electronics industries. Founded in 2002, the company has an extensive technology portfolio and offers a product range including advanced thermal and process control systems specifically designed to maximise performance in turn-key or retrofitfitted applications. Ideally suited for production with low and high temperature engineering thermosets and thermoplastics in single sided, matched Autoclave and Out-of-Autoclave applications, PtFS can also be used to process aluminum and titanium in hot forming and 3D printing.

With over 90 % exports, the company’s customer base includes blue chip OEM’s, Tier 1’s and Materials Suppliers around the world. By precisely controlling temperatures during manufacturing, Surface Generation offers a step change in processing accuracy, speed, economics and part performance even with the most challenging materials, designs and applications.

Using state-of-the-art technologies, Surface Generation has challenged convention and gone back to first principles to design PtFS from the ground up to work at temperatures up to 1000 °C powered only using air. This innovation combined with custom hardware and software provides the first ‘digital moulding environment’ where ‘active thermal management’ gives massive reductions in energy consumption, cycle time and pressures needed to process even the most complex material and part combination.

T

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t

In TAPAS – the Thermoplastic Affordable Primary Aircraft Structure Consortium – Dutch industrial companies and research institutes work together with aircraft manufacturer Airbus. TAPAS 1 has nine partners in its collaboration. In the TAPAS 2 project the total number of partners expanded to twelve.

Together, the eleven Dutch partners are commercially active in the Dutch aerospace industry and work closely with Airbus in the field of material-, production- and connection technology and design. The technology is targeted for future Airbus-developed applications, including primary structural components as fuselage and wings.
The focus of our scientific work lies on the development and research of integrative plastic technologies for the resource-efficient production of lightweight structures and systems. The starting materials include both specifically modified high-performance polymers and compounds made from renewable resources as well as novel thermoplastic prepregs and bionic customised textile semi-finished products. In various thermoplastic and thermoset-based manufacturing processes a merger of currently separate processes takes place to energy-efficiently produce complex components with high-power density and high functional integration. For this purpose, the coupled component and process simulation provides vital information for the optimal adjustment of structure parameters and process windows using analytical and numerical methods.

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The TenCate Advanced Composites Group is a global supplier of advanced composite materials for the space and aerospace industry, anti-ballistics and a broad range of industrial applications. The company combines its fibre expertise with smart polymer, chemical, and engineering technology. This synergy gives a true meaning to Ten Cate’s slogan „Materials that make a difference”.

TenCate’s thermoplastics are branded under the name ‘TenCate Cetex®, a high strength/low weight sheet or tape material combined with thermoplastic resin systems. This advanced fiber reinforced thermoplastic composite is used for many structural and semi-structural Aerospace parts as well as a variety of demanding applications like in Automotive or the Oil & Gas Industry. TenCate Cetex® can be specifically engineered for automated processing and tailored to meet thermal, mechanical, chemical and electrical properties whilst maintaining highest safety requirements. No compromises.

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The ThermoPlastic composites Research Center (TPRC) is a consortium of industrial and academic members active in the thermoplastic composites industry. We believe in thermoplastic composites as the material for lightweight manufacturing in large volumes. Our primary aim is to enable a more widespread use of thermoplastic composites by eliminating technological barriers.

For this purpose, the consortium as a whole defines and executes a research roadmap aimed at generating the fundamental knowledge required to optimize existing and new manufacturing processes in terms of quality and productivity. The developed knowledge is put to use through process design tools which allow design for manufacturing for thermoplastic composites, taking into account the material and processing capabilities and limitations.
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Toho Tenax Europe GmbH is one of the leading manufacturers of carbon fibers world-wide. Our thermoplastic products, combined with rapid production processes, allow short processing times, low scrap rates, as well as high mechanical performance, chemical resistance and recyclability. Tenax® Thermoplastics are available as:

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V

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Victrex is an innovative world leader in high-performance polymer solutions. With more than 35 years of experience, we are delivering technical excellence and cutting-edge composite solutions to the Commercial Aerospace market including the new VICTREX AE™ 250 composites and hybrid moulding technology.

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The WICKERT WKP S presses are designed for manufacturing mouldings in composite materials. Out of modular standard components, WICKERT produces a wide range of presses, either standard or adapted to the clients individual tasks requirements. The product range of WICKERT consists of press systems incl. automation for RTM, HP-RTM, wet-lay up, prepreg, thermoforming, compression moulding as well as all related processes. The WICKERT modular system includes presses with a clamping force from 20 to 110,000 kN for a variety of product dimensions and product types.
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