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Fully bio-based epoxy thermosets for high performance composites: chances and challenges

K, Resch-Fauster¹

Polymer composites contribute significantly to technological advances and more important, to increased resource efficiency and hence to a sustainable development. Today, most polymer composites are produced from petrochemical resources. However, initiatives of the European Union (EU) towards a resource efficient and sustainable low-carbon economy require the development of new materials and new consumer products from European biomass, avoiding the need for fossil-based inputs. In terms of polymer composites, this transition into bio-based industry while meeting the EU's plastics circular economy directives requires interdisciplinary research covering complex interrelations of bio-based polymer building-blocks, polymer-physical performance, efficient processability and recyclability. With respect to these aspects, the lecture will address the development of high-performance epoxy resins based on renewable resources. Specific focus is on obtaining cost-efficient resin systems with a bio-based carbon content of 100% which exhibit properties that are competitive to those of conventional resin systems. Application potentials and challenges, recyclability and future perspectives are outlined.

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Hierarchical Composites with HIgh Carbon nanotube Loading

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We define hierarchical composites (HC) as composites consisting of at least two reinforcements of very different sizes embedded in a matrix. The two main routes for reinforcing continuous carbon fibre reinforced polymers with carbon nanotubes (CNTs) involve either growing or attaching CNTs to the fibres or dispersing them into the matrix. Although both methods have had some success in improving matrix dominated properties, the latter process was proven to be more amenable for scale-up as conventional composite manufacturing processes can be adapted. Attempts to produce hierarchical composites by further reinforcing the matrix with CNTs have been hindered by processing difficulties caused by the increased matrix viscosity caused by the presence of CNTs and self-filtration.

Multiwalled nanotubes (MWNTs) were shear mixed with a solid epoxy resin with an uncured glass transition temperature of 39°C in concentrations ranging from 1 to 20 wt%. This process was optimized for maximum dispersion and distribution, which should, in turn, eliminate stress concentrations and maximize mechanical performance. The resulting nanocomposite was milled into a fine powder. This powder was used in a wet powder impregnation process to produce fibre reinforced thermosetting nanocomposite prepregs with a fibre volume content of 58%. The HC prepregs were laid up and press-claved to produce HC laminates, which were characterized with respect to their electrical conductivity and mechanical properties.

Matrix dominated properties, such the interlaminar shear strength, compression strength and through thickness electrical conductivity, improved significantly with the introduction of nanoreinforcement. Furthermore, we will show that composite toughness can be improved by creating hybrid composites with consisting of unreinforced matrix zones and nanoreinforced matrix regions. Electron microscopy shows not only that the presence of CNTs induced toughening mechanisms, but also the inhomogeneity of the matrix.

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Silica-based CMC-prepreg: Industrialization issues

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Executive Summary

A cost-effective Ceramic Matrix Composite (CMC) prepreg is presented. Since the major cost driver of CMCs are the raw material costs, a best-cost material needs to compromise on the fibres and matrix ingredients, which furthermore results in a narrow processing window, where the matrix can already sinter, but the reinforcement fibres do not relax yet. In combination with the aim to produce a prepreg, which can be manipulated using an epoxy-based part manufacturing line, several failures are presented.

CMCs: Applications and market segments

Ceramic Matrix Composites (CMC) are generally used in high temperature [>1100°C], high mechanical load environments (especially bending and impact requirements) and/or highly corrosive media. The usual components used are Al2O3-fibres in combination with a matrix blend of SiO2 and Al2O3, with the Aluminum-oxide based materials being the main cost driver. [1]

This requirement profile has led to a narrow niche of usecases (e.g. ultrahigh performance friction discs, jet engine applications, military applications), therefore also led

to boutique manufacturers with low volumes focusing on high yield products and subsequently into a market with no budget options, mainly driven by the fact that metallic solutions offer a compelling value preposition for applications below 1000°C.

Since the temperature limit of the polymer matrix based composites (e.g. Cyanatester) is limited to around 350°C operating temperature, the lightweight performance materials market can be divided in three categories:

- Organic matrix composites (-50 to 400°C)
- Lightweight metal alloys (-50 to 1100°C)
- Ceramics composite (>1000°C)

These performance metrics have left the 400-to 1000°C-bracket almost exclusively to metals, with no developments in the last years to push either organic matrices up in service temperature or ceramics down, in both costs and temperature resistance.

In order to industrialize the use of a CMC, several prerequisites need to be fulfilled:

- The total cost of production needs to be competitive against a metallic solution. Since the raw materials are more expensive (70% of the, CMCs start with a cost disadvantage, which they need overcome with lower manufacturing costs.
- The production setup needs to be generic. Special equipment with high upfront investment makes the usage of CMCs unlikely from a business perspective.
- Environment, Health and Safety: Conventional CMCs use solvent-based chemistry to keep the material in a processable state. Most of the currently used solvents require personal worker protection, adding to the complexity of the manufacturing process.
- Transport, storage, shelf life: cooled or chilled storage and transport requirements add additional costs, with no direct benefit for the end user.

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An industrialization approach for a CMC-prepreg

A low(er) cost CMC prepreg concept is presented. With the restrictions outlined above, the following initial development constraints were established:

- * service temperature of 950°C max.
- * water-based formulation with a two stage curing cycle (drying at 110°C, sintering <1000°C)
- * restricted use of expensive Al₂O₃-ceramic components in both fibre and matrix
- * the product shall be processable in a conventional CFRP-/GFRP-prepreg-production line, with the additional sintering stage
- * non-military grade fibres

The constraints directly point at a SiO2-based fibre, and ideally (from a cost perspective), processed in combination with a SiO2-based matrix.

Several trial stages were concluded, with mixed results. The main problems derive from the similarity between matrix and fibres, which results in damaging one when optimizing the process for the other. Manually impregnated prepregs could be successfully manufactured early on in the trials, but showed non-satisfying mechanical strength, impregnation and draping behavior (see Fig.1)



Fig. 1: Initial draping trial, with flakes of the matrix falling of the fibre reinforcement (bottom right)

The self-imposed avoidance of solvents and the therefore waterbased solution led to a wetting of the fibres during storage, reducing the strength of the fibres and increasing the variances of the test specimens.

After optimizing for impregnation behavior and delamination stability, the prepregs lost the fibre-derived mechanical strength due to thermally induced relaxation after the sintering phase. By adopting to a different curing cycle by improving the matrix additives in order to allow for high speed sintering, manual impregnated samples could finally exceed the expected 40 [MPa] flexural strength, only to being non-processable in an impregnation machine, due to higher viscosity of the matrix at room temperature.

Finally, a product could be finalized, which fulfilled all criteria and was still processable, only to be found unusable after shipment, because the release film drew water out of the uncured prepreg, drying out the matrix and becoming unreleasable.

After several iterations on the release films and the matrix system, the final product has been established after almost 2 years of unsuccessful trials.

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Thermoplastic Infusion and In-Situ Polymerisation of PA-6 and Acrylic Composites

C.Ó. Brádaigh*

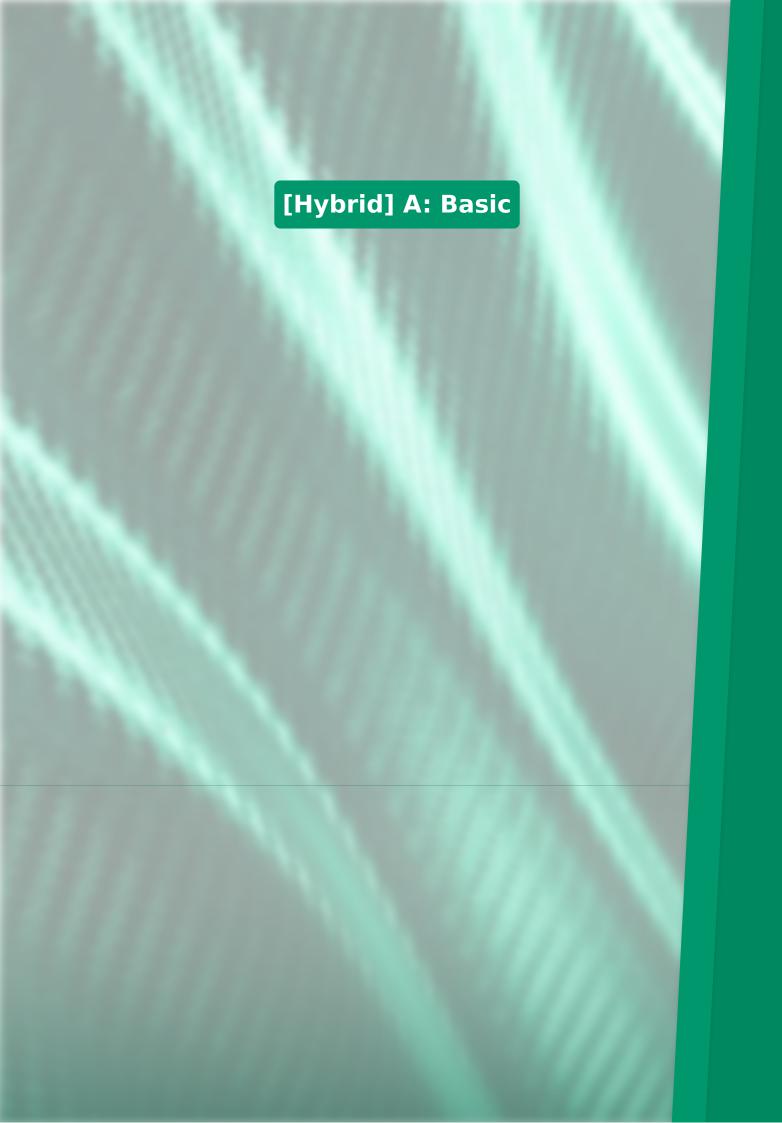
In recent years, the fibre-reinforced polymer composite industry has faced strict global targets to address the end-of-life challenges posed by thermoset polymer matrix composites. Thermoplastic composites, despite their well-demonstrated improved recyclability, thermoformability and weldability, are yet to attain the same technological maturity as thermoset composites. In situ polymerisable thermoplastic resins have been identified as attractive emerging solutions for improving the processibility of thermoplastics. This lecture covers two important families of thermoplastic infusible monomer systems for high fibre volume-fraction composites, namely polyamide-6 (PA-6, processed at temperatures above 150°C) and acrylics (processed at room temperature). A brief survey of active research in these fields is presented, together with some emerging industrial applications for the technologies.

Reactive thermoplastic resin transfer moulding has been used to produce stitched-unidirectional glass fibre reinforced PA-6 composites by employing a simple 2-part injection of low viscosity monomer precursors and in-situ polymerisation. The low monomer viscosity resulted in injection pressures of around 10% of that required for a typical thermoset RTM resin, thus negating the need for expensive equipment. A specially-developed novel reactive fibre sizing was used to compare to a standard silane glass fibre sizing. Transverse mechanical properties of the composites reinforced with the novel reactive sizing were 20–28% higher than those with the standard fibre sizings, demonstrating improved fibre-matrix interfacial properties. Average mode I fracture toughness was also measured to be 10–30% higher. Drop-weight impact testing showed that the different fibre sizings had little effect on the post-impact compressive properties.

Acrylic polymers can be used to infuse composites at room temperature, followed by a chemically-activated polymerisation reaction. This offers potentially recyclable materials for large composite structures, for instance in renewable energy, marine and infrastructure applications, where elevated tooling temperatures would be economically prohibitive. The mechanical and thermomechanical characteristics of acrylic matrix composites have been benchmarked against an epoxy composite reference. The acrylic composite exhibited superior tensile (90°), flexural (0°), interlaminar shear and fracture toughness properties. Thermomechanical characterisation also revealed marked superiority in the damping behaviour of the acrylic composite. Acrylics, however, as amorphous thermoplastic polymers, are highly susceptible to solvent attack which makes them unsuitable for application in particular environments. It has been shown that incorporating up to 5% of an engineering thermoplastic, such as poly(phenylene ether) (PPE) into a reactive acrylic resin to produce a hybrid-matrix system is a simple, yet effective strategy towards enhancing solvent resistance of this family of infusible thermoplastic composites.

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Corrosion prevention in multi-material automotive structural components

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Manufacturing sector is constantly in demand for superior composite materials that can cope with the requirements for increased mechanical qualities to create wide applications in various industries [1], such as automotive structural body parts (fig. 1). New automotive structural components made of carbon and glass fibre preforms in combination with metal (aluminium and steel) sheets were developed in this study with the goal of reducing component weight and CO_2 emissions, increasing component strength, improving failure characteristics, offering better joining techniques, and lowering costs.

The interface region plays a significant role in defining the ultimate properties of the multi-material-composite as it occupies a large area in structure [2]. The contact between carbon fiber and metal plate at the interface is a challenge with these materials. Because carbon fiber is electrically conductive and has a higher electrochemical potential than both aluminum and steel, galvanic corrosion can occur, resulting in the metal plate's slow destruction. This, in addition to reducing part-to-part adhesion, has a negative impact on the overall properties of the composite material, resulting in failure to meet mechanical requirements during the service cycle.

A unique functionalized interface film with integrated spacer fabric is designed and incorporated into the composite structure to avoid this electrical contact. To assess corrosion behavior, samples with various structure designs are subjected to a corrosive environment inside a corrosion chamber and being extracted at predetermined time intervals. Following, light microscopy is used to examine how corrosion affects the surface of the samples. Finally, scanning electron microscopy is used to investigate changes in surface topography and element compositions.

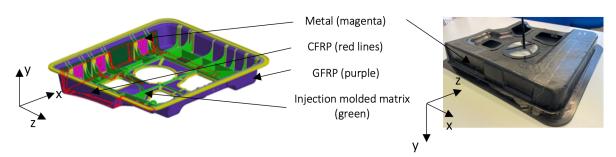


Figure 1. Delivery van rear door: CAD design (left) and the final part.

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3D reconstruction of hierarchical nanoporous gold from FIB tomography data using deep neural networks

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Hierarchical nanoporous gold (HNPG) is a uniform network of ligaments with a typical ligament size of 15-110 nm and pore size between 5 to 20 nm. This material exhibits unique mechanical properties, e.g. enhanced stiffness and strength in comparison to geometrically similar structures with only one characteristic length scale [1]. However, materialographic investigation of the HNPG is challenging and requires its accurate reconstruction.

Focused ion beam (FIB) tomography is a destructive technique used to collect three-dimensional (3D) structural information at a resolution of a few nanometers. For FIB tomography, a material sample is degraded by layer-wise milling. After removing each layer, the new surface is imaged by a scanning electron microscope (SEM), providing a consecutive series of cross-sectional images of the HNPG structure.

For nanoporous materials, the reconstruction of the 3D microstructure of the material, from the information collected during FIB tomography, is impaired by the so-called shine-through effect. This effect prevents a unique mapping between voxel intensity values and material phase (e.g., solid or void) and often substantially reduces the accuracy of conventional methods for image segmentation.

In this poster, we demonstrate the use of machine learning-based algorithms in the 3D reconstruction of HNPG. A significant bottleneck in using machine-learning models is the availability of sufficient training data. To overcome this, we present an approach to generate synthetic training data in the form of FIB-SEM images generated by Monte Carlo simulations [2]. We show that machine learning-based methods enhance the segmentation performance significantly.

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Comparison of 3D CT image processing and experimental methods to obtain local fiber volume contents of carbon-fiber-reinforced polyamide 6 plate

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When investigating the mechanical behavior of fiber-reinforced polymers (FRP), the distribution of fibers across the manufactured part plays an important role. The fiber distribution is typically measured in the form of fiber volume contents (FVC). Average fiber volume contents can be determined generically by the amount of fibers added during the process. However, local differences in any coordinate axis of the plate can lead to anisotropic and varying mechanical properties and are therefore of interest in terms of material characterization. Measured, locally dissolved FVC values from finished plates are therefore essential. In order to measure the FVC, volumetric μ CT (computed tomography) scans and consecutive image processing methods have become one of the leading non-destructive testing (NDT) methods. There are several destructive experimental methods to determine FVC as well.

The investigated material is carbon-fiber-reinforced polyamide 6 processed in a LFT-D compression molding process [1]. The influence of flow behavior on the fiber volume content across the plate is investigated for this specific material combination and process. The FVC is computed from CT scans of small volumes at selected coordinates of the plate through a local gray-value thresholding method based on the Otsu threshold [2] but with a self-developed adjustment (cf. Figure 1). The FVC can be additionally determined after dissolution of the matrix material. This is conducted with two different dissolution methods: pyrolysis- and acid-based. The authors compare and interpret the different fiber volume content results and were able to reproduce the acid-based, experimental FVC results with deviations of less than 5.2 % with the algorithm.

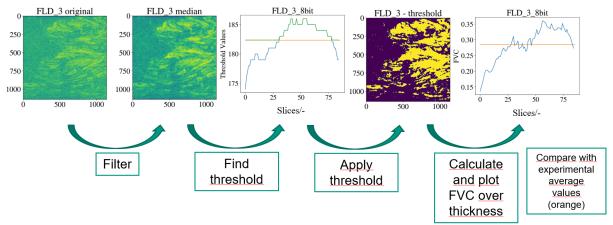


Figure 1: Representation of the self-implemented algorithm.

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Fracture Mechanisms of Nanostructured Cu/Ni Metal Laminate Structures

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Nanostructured metal multilayers have been known to possess exceptional material properties regarding strength, magnetism, radiation resistance, fatigue resistance, corrosion resistance and abrasion resistance. Since there are a lot of governing factors for the material properties of nanostructured metal multilayers (NMMs), i.e. global composition, local composition, used metals and interface strength, NMMs can be tailored to specific needs. [1]

Cu/Ni NMMs have seen special interest in the scientific community for the wide variety of possible applications and the possibility to synthesize with a single-bath electrodeposition process. [2]

Current research at the University of Hamburg is focusing on the strengthening of welded steel structures against fatigue, by coating the surface with a nanostructured Cu/Ni-metal laminate patch. [3] The findings are in accordance with other studies that studied the fatigue properties of Cu/Ni nanolaminate coatings. [4]

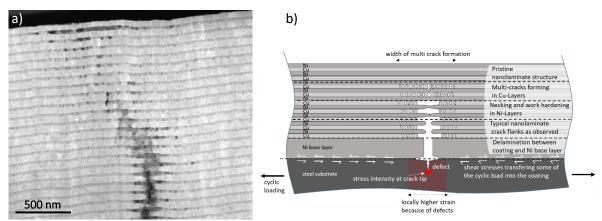


Figure 1. a) HAADF TEM image of the crack tip closure in the top part of the TEM-lamella with multi-cracks forming in the Cu-layers and crack bridging of the Ni-layers; b) schematic crack propagation [5]

The surface roughness is measured with AFM before and after fatigue loading. The nanolaminate Cu/Ni coating on the fractured fatigue samples are examined with serial FIB cross sectioning. Subsequently a TEM-lamella is taken from the crack tip to investigate the crack initiation and assess the fracture mechanisms of the Cu/Ni NMM. The Cu-layers experience multi-crack formation and the initial multi-cracks are arrested at the interfaces. The Ni layers bridge those cracks and each layer ruptures individually, resulting in a distinctive crack pattern.

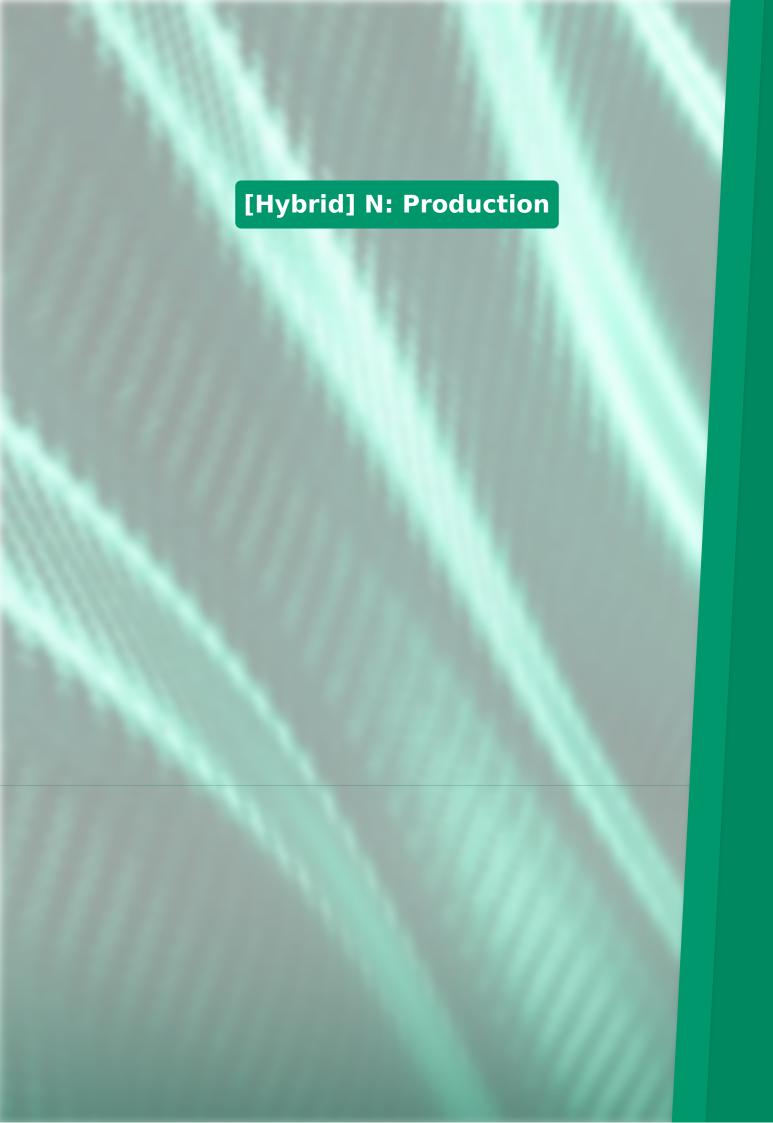
The lifetime enhancement of the welded sample are linked to the fracture mechanism of the NMM and can thus be attributed to the following five mechanisms: reduced surface roughness, micro-crack bridging, energy dissipation, crack arrest at interfaces and changes in surface tribology. [5]

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Concept for a Customized Production System for flexible Manufacturing of individualised Multi Material Structures with specific Lightweight Specifications and Loads

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Aim of the paper is to show a new concept for a customized production system for flexible design and manufacturing of individualised multi material structures with specific lightweight specifications and loads. Motivation of this work is the trend of individualisation of consumer products and production batches even of complex products down to one. Ideas of the new solution is to develop a solution for a profile based lightweight frame design for variable applications e.g. for medicine products, sport vehicles and mobility systems. Additive manufacturing is one possible solution for this but the bigger sized structures are ineffective and cost intensive for this manufacturing processes.

So basis of the new production chain are incremental forming methods flexible shaped thin walled metal profiles of high strength steel and aluminium alloys. The forming processes are incremental tube and profile forming and allow to manufacture flexible bends, cross-sections geometries, wall thicknesses and surface structures over the longitudinal axis [1, 2].

The second fundamental step of the manufacturing chain is a joining system realized by a robot based 6 axis polymer printing method. So nods and other details of the profile based structures can be manufactured with the flexibility of additive manufacturing. This makes it possible to design a composite metal polymer frame within a customized approach. The individual design specifications are integrated in a special optimisation concept that connects the lightweight and load requirements with the process limits of the manufacturing and automation technology.

For a demonstrator for this study an individual designed lightweight bicycle frame is used.

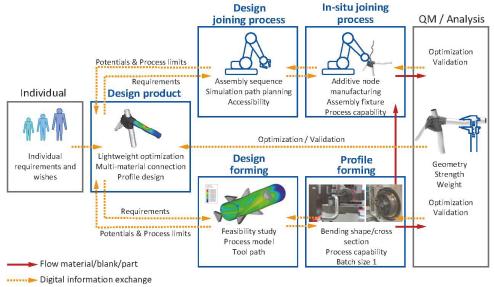


Figure 1. Concept of the new process chain.

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Contribution to the development of a setup for the efficient production of high-performance composite parts based on hybrid textiles

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Keywords: Thermoplastic composites, Compression moulding, Tooling setup

In recent years, interest in thermoplastic composites for future aircraft applications has grown steadily. In particular, the possibility of out-of-autoclave processes, short process and cycle times, weldability and recyclability are the key drivers for thermoplastic composites in addition to high corrosion resistance, impact tolerance and ductility.

Hybrid thermoplastic and carbon fibre-reinforced textiles are promising because they offer high drapability, a wide range of matrix systems and lower costs compared to consolidated pre-impregnated materials. While film stacked or powder coated preforms are mostly used for the industrial production of organo sheets, hybrid-yarn-based preforms are suitable for more complex geometries. [1]

The most common variants for hybrid yarn textiles are hybrid rovings (e.g. commingled yarns: mixture of matrix and reinforcing fibres in one roving) and side-by-side arrangements (e.g. fabrics made of reinforcing fibres and thermoplastic fibres on top of each other). [2]

The use of thermoplastic fibres improves the evacuation of the mould and the textile character increases the draping properties compared to films. However, hybrid textiles are rarely used for primary structures, because today's simulation models cannot predict the component quality and possible defects (e.g. fibre distortion or porosity), especially for complex parts.

In addition to the insufficient simulation, the consolidation itself needs to be more efficient. During the processing of hybrid textiles, the parameters of time, pressure and temperature must be optimised to each other for high-quality components. In particular, the high process temperatures (up to 400 °C) pose a challenge to the existing presses. On the one hand, the hot presses are often limited in terms of temperature, and on the other hand, the thermal mass of the moulds must be reduced in order to make production more environmentally friendly and faster. [1]

Therefore, our research project aims to develop a 3D consolidation model for hybrid textiles which defines the optimal process and material settings for compression moulding of high-performance carbon fibre-reinforced thermoplastics for the aerospace industry. Furthermore, we aim to develop a versatile and efficient compression moulding setup to enable existing presses to manufacture parts based on these high-performance composites. The presented work focuses on the manufacturing of the parts using the developed 2-stage isothermal compression moulding setup – see figure 1.

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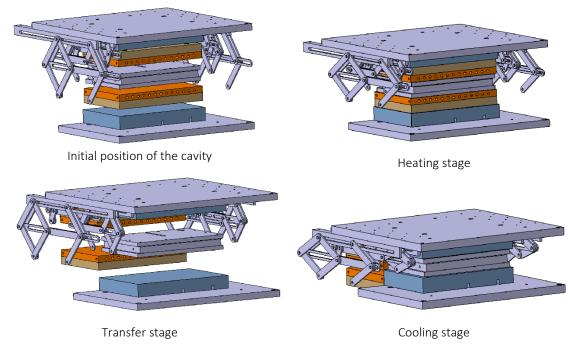


Figure 1. Press-independent 2-stage compression moulding setup for processing high-performance composites.

It enables the separation of the heating from the shaping function of the moulds. The aim is to reduce the thermal mass of the cavity. In the present setup, the cavity is positioned centred in the press area. By closing the press, the cavity is heated by direct contact to the hot stage. Whereas in the system presented by Koerdt, the cavity is moved manually [1], in this system the hot stage is moved out of the press area. This allows the process to be carried out in a more defined and reproducible manner as there is no manual transfer of the cavity. Furthermore, existing heating elements of the press or their cooling system can be used for temperature control of the cold stage. In this way, the cooling temperature is ensured throughout the entire production day.

We demonstrate the performance advantages of manufacturing high-performance fibre-reinforced composites using high-temperature thermoplastics (such as PEEK, PEI) and compare the process times with conventional variothermal processes.

In conclusion, this study shows how existing presses can be upgraded for the production of high-temperature fibre-reinforced composites. In addition, the setup allows a flexible production with different cavities. Furthermore, the follow-up non-recurring costs are reduced by separating the shaping from the heating function of the moulds.

Acknowledgement

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Efficient hot forming of prepreg stacks by means of liquid contact heating

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The development and production of civil aircraft and their individual components are increasingly determined by the need to adapt cost and weight targets to increasing competition and existing profit expectations while at the same time reducing CO₂ emissions.

Although the conventional autoclave prepreg process delivers high load-bearing structural parts, their production in the ply-per-ply lamination process is very time-consuming and cost-intensive. Thus, weight-reduced components can only be produced at increased costs.

The production of flat preforms in the form of primary layers (e.g. biaxially oriented primary layers) or complete stacks brings a significant improvement. These can be deposited more easily and quickly and facilitate automation significantly. The flat preforms are then draped or shaped into the 3D geometry of the part. Due to changes in curvature, each layer in the laminate is subject to a different change in arc length. By introducing heat into the preform, interlaminar sliding between the layers in the forming process is promoted. Forming can then be initiated via vacuum and an elastic membrane. According to the current state of the art, the process step of heat input is carried out via hot air blowers or infrared radiators. This is precisely where the new development comes in, as these processes have very high energy consumption and long cycle times. In addition, there is a risk of overheating the preform. These disadvantages are eliminated by the newly developed hot forming process.

In this process, heat is transferred by a heat-storing and heat-conducting fluid (water) via a membrane located directly on the preform. As a result, the heating time can be reduced by a factor of 3 compared to infrared radiation and by a factor of 11 compared to hot air blowers. Another positive effect of this novel hot forming process is the uniform temperature distribution over the entire semi-finished product surface ($\Delta T < 5$ K) with simultaneous very simple process control. Partial temperature maxima, so-called hot spots, can thus be avoided and heating that is gentle on the material can be realized. With an efficiency of well over 85 %, this new technology offers numerous areas of application in the processing of thermoset semi-finished products into high-performance components.



Figure 1: Hot forming plant with hot water process tank

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Environmental barrier coatings deposited by different coating technologies

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Environmental Barrier Coatings (EBC) are critical to protect Ceramic Matrix Composites (CMC) from water vapour corrosion in a gas turbine environment. In this work, the state of art EBC material $Yb_2Si_2O_7$ which is usually applied on SiC-based CMCs is taken as an example. The major challenge is to obtain dense and crystalline $Yb_2Si_2O_7$ coatings. The $Yb_2Si_2O_7$ coatings were deposited with different coating technologies: Very Low-pressure Plasma Spraying (VLPPS), Suspension Plasma Spraying (SPS), Atmospheric Plasma Spraying (APS), High-Velocity Oxygen Fuel spraying (HVOF) and Aerosol Deposition (AD). The microstructure features of coatings deposited with different coating technologies mainly with respect to crystallinity and porosity will be discussed. By using a high deposition temperature, dense and fully crystalline $Yb_2Si_2O_7$ coatings can be obtained with VLPPS and SPS. However, vertical penetrating cracks and a large amount of amorphous phase can only be avoided in APS coatings by using specific spray conditions. A highly crystalline dense coating can be obtained with HVOF, but the high kinetic energy of particles can introduce a high-stress level leading to a high risk of delamination of the coatings and also some remaining porosity is present. As AD is a room temperature coating technology, melting of feedstock can be fully avoided. A crack-free, fully crystalline $Yb_2Si_2O_7$ coating can be obtained. Also here the high porosity level is certainly an issue.

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Manufacturing hybrid ceramic components by combining CIM and VPP

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Ceramic injection molding (CIM) is an efficient way to manufacture ceramic components with limited complexity in large quantities [1]. In contrast, additive manufacturing offers enormous design freedom and individualization, but at lower productivity [2]. There are approaches to join ceramic components, e.g. by active metal brazing or adhesives [3]. Usually, this involves auxiliary materials limiting the component properties, for example in terms of strength or applicability at high temperatures [3]. The aim of this research is to join ceramics produced by CIM and the additive manufacturing process vat photopolymerization (VPP) without using function-limiting auxiliary materials. In a first approach, CIM components in their green state are used as inserts and individualized structures are printed on them using VPP. Afterwards, a co-debinding and co-sintering takes place. By varying the CIM feedstock composition and performing mechanical pre-treatments of the CIM green parts, the process is optimized.

The results showed that VPP printing on CIM inserts is possible in principle. A glass bead blasting of the CIM inserts prior to the VPP process had no significant effect on the connection of CIM and VPP sections. As expected, co-debinding and co-sintering revealed different shrinkage coefficients and defects in the component. The closer the shrinkage compensation factors match, the better the joining quality and the higher the degree of sintering. Almost identical compensation factors lead to nearly complete sintering (Fig. 1a and 1b). The larger the printed geometry, the larger the influence of a mismatch (Fig. 1a vs. 1b). With small deviations, cracks and partial delamination appear especially in the edge area (Fig. 1c). If the deviations are too large, complete delamination occur (Fig. 1d).

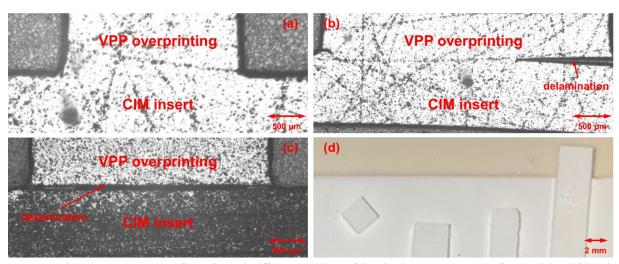


Figure 1. Light microscope images of samples with different matching of the shrinkage compensation factors: (a) and (b) with almost identical factors, (c) with bigger differences, (d) with too big difference.

Combining ceramic parts produced by different manufacturing technologies enables a cost-efficient production of complex and individualized components with superior properties.

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Strain gage technique to quantify manufacturing-induced residual stresses in fiber metal laminates

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The predominant use of FBG sensors to monitor the strains evolving in a fiber metal laminate (FML) during the manufacturing process does not permit absolute strain measurements. The reason for this is the loss of the connection between the sensor and laminate during phase transitions of the resin. Thus, points of significant changes in the measurement signal (e.g. bonding temperature) are used for the residual stress evaluation. In FML, however, the metal partner behaves purely elastic over the entire manufacturing process. Thus, process strains recorded in the metal can be used for the absolute residual strain evaluation and residual stresses can be quantified directly.

The approach in this work uses strain gages that are bonded to the top metal layer of a CFRP-steel laminate and monitor the strains during manufacturing. The cure strains are measured for different cure processes that differ in their time-temperature profile and are developed to reduce the final residual stress level in the laminate. The strain gage technique shows that the residual stresses in a specimen can be reduced by up to 50% by modifications in the cure cycle.

Despite the sensors being applied to the metal layer, the presented strain gage technique allows analyzing the cure state of the resin by changes in the gradient of the strain readings. Particularly, the interference of the free thermal expansion of the CFRP and metal layers is identified. Hence, the bonding temperature, from which, the previously independent layers start to form a laminate is exactly determined. It was shown that assuming the bonding temperature to be equal to the stress-free temperature, overestimates the residual stresses for the laminate at hand when compared to the absolute residual strain measurements.

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Technology platform for the development of application specific ceramic temperature cyclers

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A large number of technical manufacturing processes are based on the specific temperature control of process goods or chemical reagents. Due to their technical properties, ceramic materials and technologies are suitable for implementing selected heater applications in the geometrically mesoscale range. One example is a highly dynamic and actively cooled matrix heater for the generation of fast temperature cycles. These consist of individual pixels that are combined to form a matrix. Supported by a simulation-based design of these components, well-known technologies such as thick film technology are symbiotically combined with modern techniques of additive manufacturing of ceramic materials at the Fraunhofer IKTS.

The production of the basic structures is based on ceramic materials and technologies. Ceramic materials can only be machined at great expense due to their typical high hardness and low ductility. Here, additive manufacturing processes represent "game changers", since complex geometries can be realized close to the final contour and functions, such as cooling channels, can be realized even in small volumes. The use of these methods results in increased geometric degrees of freedom and completely new areas of application. The optimized and additively manufactured ceramic components are functionalized using the well-known thick-film technologies. Electrical circuits, heating elements and sensors are printed in a structured manner and fired onto the ceramic basic structure. Electrical contacting is achieved by means of advanced assembly and connection technology. Solutions up to temperatures of 350°C have been successfully realized. Applications up to 600°C are currently being tested. Temperature gradients of up to 70 K/s have been demonstrated successfully.

The presentation will demonstrate the current possibilities concerning the materials and technologies for creating this type of element. Two implementation examples are discussed in the contribution.

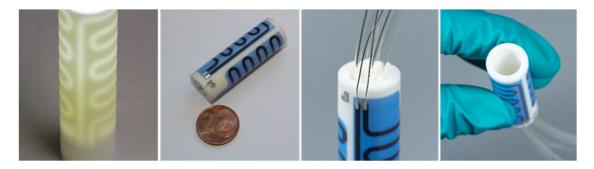


Figure 1. μ PCR-reactor developed at Fraunhofer IKTS; Al₂O₃ substrate with integrated cooling channels (left), functionalized component (middle, left), fluidic and electric connections (middle, right), final component (right)

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[Verbund] A: Polymermatrix-Verbundwerkstoffe (PMC)

Cellulose aerogel-based fiber reinforcement – towards thermoformable composite materials

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Cellulose is renewable and characterized by a strong polymeric backbone. Thus, it is increasingly gaining attention as functional additive in polymers. Melt blending thermoplastic polymers with nanocellulose yields cellulose nanocomposites. However, nanocellulose particles tend to aggregate making a homogenious nanofiber distribution challenging. [1]

Cellulose aerogels (CA) consist of a 3D randomnly arranged cellulose nanofibers and therefore isotropic by preparation. These open porous aerogels can be prepared by various routes that mostly involve the dissolution of the native cellulose (e.g. in aqueous salt hydrate melts such as ZnCl₂) followed by regeneration and drying in supercritical CO₂. [2]

In order to overcome aggregation, cellulose aerogels can be used as a preformed nanofiber felt. By means of capillary force-assisted infusion molding of the pore structure with a thermoset matrix, light and faultless nanofiber-matrix composites are achieved. Such composites are called cellulose aerogel reinforced polymers (CARPs). CARPs having fiber fractions ranging from 6 to 22 vol.-% considerably affect the resulting mechanical properties and formability. Fiber fractions as low as 14 vol.-% yield composites with multiplied Youngs' moduli observed with epoxy, phenolic and unsaturated polyester resins. Although, the composites were cured in a final processing step, CARPs show significant formability at elevated temperatures. The interface of CA and matrix combines friction, mechanical interlocking, and chemical fiber-matrix bonding yielding complete stress transmission and thus, joint deformation of both composite phases, the fiber and the matrix.

In conclusion, CARPs appear as a single component material making it impossible to attribute the resulting properties to either the fiber or the matrix phases.

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Diffusion and Degradation Mechanisms in Thermoset Composites

23. Symposium Verbundwerkstoffe und Werkstoffverbund

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Motivation

Polymer composites as high-performance materials are widely used and very specific for numerous applications. In building science, connecting and sealing joints with particle-filled thermoset polymers is a beneficial option due to their high mechanical properties and customization ability. It is therefore important to systematically estimate the long-term performance of various composite systems.

Environmental exposure causes degradation in composites among which moisture and temperature play dominant roles. Diffusion determines the rate of moisture uptake and hydrolysis the severity of mechanical reduction. The chemical composition, degree of cure, void fraction, filler ratio and size distribution determine diffusion and degradation rate. The extent of these parameters on mechanical properties under various environmental conditions is investigated.

Study design

Three different particle-filled composites were stored at temperatures from 21 °C to 40 °C and relative humidities from 25 % to 100 % and characterized within defined time periods. Two **bisphenol-based epoxy polymers** with low filler content and one **vinyl ester-based polymers** with high filler content were studied.

Applied characterization methods:

- Electron Microscopy
- Energy dispersive X-Ray Spectroscopy
- X-Ray Diffractometry
- Differential Scanning Calorimetry
- Mechanical Tests

Results and Discussion

Moisture diffusion for the epoxy- and vinyl ester-composites followed a Fickian-type of diffusion. Diffusion mechanisms and kinetics were defined based on the type of filler, the filler ratio and the matrix-filler interphase. A novel Isotherm-Model for moisture saturation was established.

The decline of mechanical properties (tensile strength, shear strength, Young's Modulus) was directly connected to the moisture, the temperature and the composition and design of the composites.

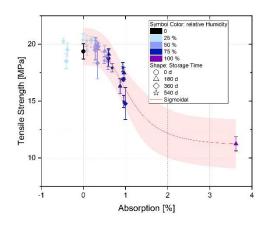


Figure 2 Reduction in Tensile Strength as a function of Moisture absorbed

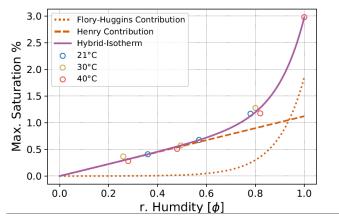


Figure 1 Novel Hybrid-Isotherm for Quartz filled composite

Direct ultrasound dispersion of carbon nanotubes and carbon nanofibers in low viscous resin

Affiliations

B. Zanghellini, P. Siedlaczek, S. Schörpf, Maria Omastova, K.-H. Semlitsch, H. Lichtenegger, H. Rennhofer

Nowadays carbon fiber composites represent the state-of-the-art high-performance materials in terms of outstanding mechanical properties in combination with low densities. Nevertheless, also in those materials, failure mechanisms, e.g., delamination, are occurring. One way to decrease such failures is to implement nanofillers with high aspect ratios into the polymer matrix of the composite, like carbon nanotubes (CNT) or carbon nanofibers (CNF). Compared to neat carbon fiber reinforced polymers (CFRP) samples, the addition of 0.7 wt% oxidized CNT to the resin increased the tensile strength and the flexural strength of CFRP by 18% and 15%, respectively [1]. Not only CFRP, but also the polymer alone shows enhanced fracture characteristics due to the addition of nanofiller. In our previous work we produced epoxy samples with 0.5wt% oxidized CNT by using a new vacuum-casting technique and compared to neat epoxy samples both, tensile and flexural strength, improved by 44% and 48%, respectively [2].

Several dispersion methods exist, that allow excellent dispersion quality [3-5]. Since most of those are very time consuming, they are not suitable for a scale-up production of CFRP. Thus, finding fast and scalable routes for dispersion, i.e., methods that are also applicable in the industrial sector, with comparable results is still a challenge in this sector.

Recently, we developed an efficient but simple approach to disperse CNT and CNF directly in a low viscous resin— i.e., without the use of additional solvents - through an ultrasonication system. This setup works time-efficient, allows a very simple handling and is thus also suitable for industrial use [6]. It is crucial to avoid or control cavitation during sonication, which otherwise induces unwanted length reduction and even chemical modification of the nanofillers, which again reduces the benefit from nanofiller application [7].

Currently we work at tailoring the process parameters during ultrasound dispersion in solvent systems, allowing to achieve good dispersion quality while inducing only minimal amount of damage. When finally established, this method extends the existing dispersion routes of nanofillers in polymers and has the potential to be used for a scale-up production of CFRP.

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Experimental validation of the porous tube model for capillary rise

S. Neunkirchen^{1*}, Y. Blößl¹, R. Schledjewski¹

In liquid composite molding processes (LCM) the capillary driven flow is, next to the permeability, determining the filling behavior of the composite. To optimize flow speed and thus efficiency, these parameters have to be determined for the given textile and a good balance between the flow forms needs to be found. Considering capillarity, the Lucas-Washburn equation is the basis for the description of capillary flow in tubes. It can be observed that for polymer composites this equation has its limitations. Consequently, it was modified by a regression-based porous tube model considering the peripheral fluid through the tube walls as well as the gravitational force. Compared to other extensions of the Lucas-Washburn equation, this approach is designed to be simple considering testing and calculation effort while still being accurate and close to the process.

In this work, capillary rise experiments were performed to evaluate the proposed model. Figure 1 shows a test fluid, here n-decane, immerge in the textile. The capillary flow is then determined based on the weight loss of the fluid container as well as by visual evaluation of the flow front progression. Glass and carbon reinforcements, each in four different forms, were tested repeatedly to establish a broad database.

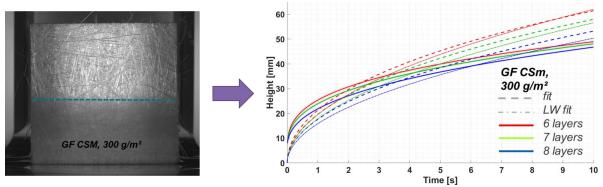


Figure 1. Capillary rise experiment of a glass fiber chopped strand mat and evaluation of the Lucas-Washburn (LW) and the porous tube model.

Comparison with the modeled results shows good conformity. A high number of intersections, high fiber volume content, and a regular shape of the textile improve the accuracy of the model predictions. The estimation of the capillary radius and the term describing the peripheral fluid flow are identified to be the most important factors.

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Implementing a multi-material window frame

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The development of hybrid yarns (CF/LM-PAEK) and related processing is the focus of the work and enables the implementation of a window frame with complex geometry to meet the mechanical requirements. The manufacturing process being developed will make it possible to produce load-bearing lightweight structural components more efficiently.

The process chain should reduce the manufacturing time significantly (-50%), consume significantly less energy (-50%), and increase the geometric complexity at lower costs and reduced mass.

The hybrid construction combining endless fibre CFRP with injection molding in functional areas with low mechanical stress and load introduction via induction welding and metallic inserts. This allows a post-processing free process chain with high automation potential. In addition, the use of thermoplastics allows a simple recycling without separation of fiber and matrix.

For insert production, both MAG and TFP preforms based on adapted hybrid yarns are used, thus achieving a high degree of automation and online quality assurance. The preforms are then isothermally pressed, which enables short cycle times and high laminate quality

Overmolding is used to stiffen the overall structure and integrate functions (integration of load introduction elements and sensors). The basis for the necessary connection strength of the individual components is the use of special PEEK variants from Victrex.

Weight and cost reductions are to be achieved in particular by welding the window frame to the fuselage structure, which is implemented in currently used window frames by Hi Lock connections. Costly work steps for the rivet connection can be saved and so the shown construction can compete with RTM and aluminum window frames, despite high material costs.

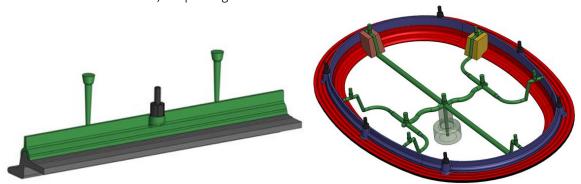


Figure 1. Hybrid material Window frame with metallic retainer elements, injection-moulded functional and stiffening elements and a continuous-fiber-reinforced structural inlay

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Investigation of the binder, preform and infusion properties of different multifunctional non-woven fabrics

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The prepreg-autoclave process is the state-of-the-art technique to manufacture fibre composite parts for the aircraft industry due to their high-quality standards. The disadvantages of this process are high energy consumption and high process costs. Therefore, many researches are carried out in order to improve out-of-autoclave processes, like the resin transfer moulding (RTM) process. One research topic is the production of parts in comparable quality to the autoclave-process. A promising way to improve the quality of the RTM process is the integration of non-woven fabrics. Therefore, the aim of the project NICItA is the development of multifunctional non-woven fabrics, which act as a binder- and flow-aid and as an improvement of the impact behaviour [1], [2] of the fibre composite part.

Manufacturing

Main advantages of the nonwoven production process are excellent economic efficiency due to high production output and high flexibility regarding properties like areal weight, isotropy and degree of compaction. The compact carding process combines several conversion steps to produce a homogeneous textile surface from a fibre blend. Three thermoplastic fibres (TP) and one type of recycled carbon fibres (rCF) are used within different blends in this study. The TPs are polyamide 6 (P300, K140) and PET (Cetex) fibres.

The fibres are processed at ITA Augsburg on the non-woven line KC11 2-4 SD / MEK 11 from Dilo Systems GmbH, Eberbach with different trial setups. Carding is a trade-off between different properties like fibre damage or homogeneous mixture. The influence of the machine setup is investigated in a later stage of the project, that's why the first trails are produced using a fixed set of machine parameters. First pure TP-blends are processed to determine the influence of different areal weights and blend mixtures for the following process steps. Secondly, different fibre blends including rCF are produced (cf. Figure 1). These semi-finished products form the basis for the subsequent hot press process (thermal consolidation). The thermal consolidation improves handling and influences the infusion functionality.

pure thermoplastic fiber

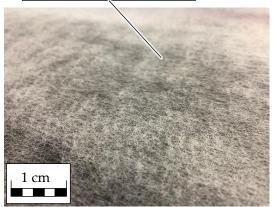
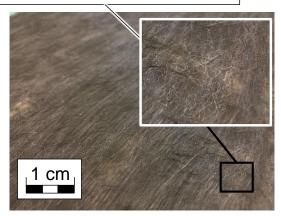


Figure 1. Different semi-finished Materials

carbon fiber + thermoplastic fiber blend



These semi-finished materials were investigated at the FIBRE institute. The aim of the research is to deduce the optimal binder properties and permeability of the non-woven fabric. As baseline material a unidirectional carbon fibre non-crimp fabric (NCF) is used in the experiments. The semi-finished non-woven fabrics are integrated between each NCF layer.

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Binder and preform properties

In the semi-finished non-woven fabrics, the low melting TP (K140 or Cetex) works as binder for the preforming process. A low mass fraction of binder material is preferable, therefore the minimum amount of low melting TP fibre in the non-woven fabrics has to be determined.

In the first step, flat preforms are produced to investigate the binder functionality of different blends (fibre composition) and different areal weights (20gsm and 40gsm). In the following step, 90 degree preforms are produced with blends, which have shown good results. Almost all blends show a good binder property (flat preforms). Only blends with very low percentage of melting fibres (<10% of K140 or < 20% of Cetex) are not suited for preforming. For a good preform stability (90 degree preforms), the experiments show three major parameters: melting fibre type, amount of melting fibre within the blend and areal weight. Additionally, preform temperature is also a crucial parameter for good preform quality (cf. Figure 2). Overall K140 blends lead to a better preform stability.



Figure 2. Comparison of preform stability after different preform temperatures with K140 blends.

Permeability

Permeability describes the textile induced flow resistance. A high permeability leads to a low infusion velocity. Normally, non-woven fabrics are used in vacuum infusions to speed up the production process. Afterwards, these layers are removed due to their inferior mechanical properties compared to the non-crimp fabrics [3]. The multifunctional non-wovens in this study are integrated in between each layer of the NCF to fulfil the binder functionality and to improve the impact behaviour. The different functions of the multicomponent non-woven fabrics interfere with each other. A high content of binder material can lead to a worse permeability compared to results without non-woven fabrics. The aim of the permeability investigations is to identify non-woven material characteristics, which are improving the impregnation behaviour.

The permeability is measured with a radial infusion measurement setup [4]. With the integration of the Cetex non-woven fabric the flow front progression is improving in fibre direction and transverse to the fibre. For the K140 blends only the impregnation transverse to the fibre is improving. The influences of areal weight, amount of rCF and ratio of melting fibre within in the non-woven blends are investigated (cf. Figure 3). The permeability enhancement by the Cetex blends is superior.

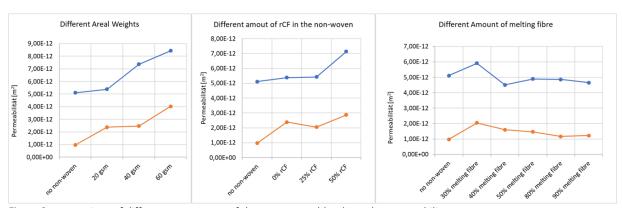


Figure 3. Comparison of different parameters of the non-woven blends on the permeability

The different behaviour of the two melting fibres (binder vs. permeability) are investigated in detail via a CT-scan (cf. Figure 4). The images show the structure of the non-woven fabrics after the preforming process. The K140 non-woven fabric tends to form agglutinations (better binder), while the Cetex non-woven maintains its primary structure (better permeability).

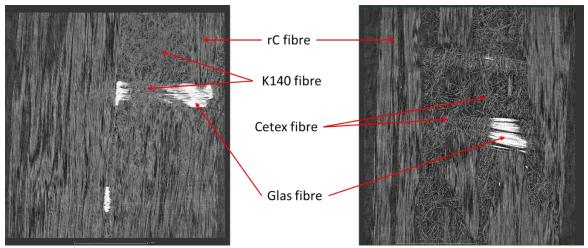


Figure 4. CT-images of two preforms with a K140 (left) and Cetex (right) non-woven

Outlook

So far, the achieved results show that the developed multicomponent non-woven fabrics can fulfil different functionalities in the RTM process. The investigation about the improvement of the impact behaviour by integrating the developed non-woven fabrics is the next step in the project. With these results, the non-woven fabrics can be optimized depending on the preferred functionalities.

Acknowledgment

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Geschichte der Verbundwerkstoffe

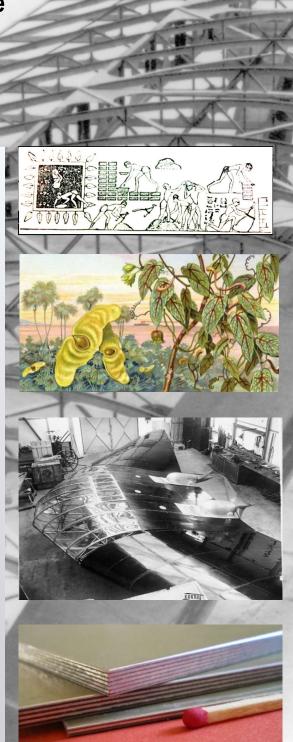
Wie lange gibt es schon Verbundwerkstoffe? Woher kommt die klassische Laminattheorie?

Wer baute den ersten modernen Faserverbund?

Wissen Sie die Antwort?

Über die historische Entwicklung von Verbundwerkstoffe ist bisher kaum etwas bekannt. Obwohl immer wieder bruchstückhaft einzelne Episoden Erwähnung finden, werden sie in der Regel nur im Rahmen von werkstofftechnischen Leistungsparametern als Mittel zum Zweck kontextualisiert. Eine Fokussierung auf das Material selbst findet kaum statt.

In seiner Darstellung zur Geschichte der Materialforschung hat der Stuttgarter Wissenschafts- und Technikhistoriker Andreas Haka erstmalig werkstofftechnische Forschungs- und Entwicklungsstrategien zu hybriden Werkstoffen des 19. und 20. Jahrhunderts untersucht. Dabei stieß er auf eine Vielzahl von Fakten, welche einen Pendelgang zwischen konstruktiver Anwendung und werkstofftechnischer Sondierung bei diesen "Baukastenwerkstoffen" konstatieren. Bereits 1794 hielt ein Wittenberger Hochschullehrer die technische Nutzung von Faserstoffen fest, deren Wirkprinzipen zu Beginn des 20. Jahrhunderts erstmals im Zusammenhang mit frühen Verbundwerkstoffen thematisiert wurden. Und eine bionische Vorlage war die Basis der ersten dynamisch belasteten Konstruktion, welche komplett aus einem Faserverbund in der ersten Hälfte des 20. Jahrhunderts gefertigt wurde. Die umfassende Untersuchung stellt die Entwicklung und Bedeutung der Verbundwerkstoffe in einem historischen Kontext dar.



Demnächst als Buch:

Konstruierte Stabilität: Die Geschichte der Verbundwerkstoffe.

Dr. Andreas Haka Universität Stuttgart

Lehrstuhl Geschichte der Naturwissenschaften und Technik

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(Hintergrundfoto: Unbeplankte Tragflächenstruktur aus dem Jahr 1936, welche komplett aus Faserverbund bestand. Quelle: Nachlass W. Radinger)

Novel Silicone Resin Binder and Compound for Thermally Highly Stressed Applications

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Silicone resins binders are used for impregnation, lamination and coating applications, with the main aim to show stability against high thermal stresses. Electrical motors, mainly for traction applications, as well as mica- and other laminates and pultruded products represent the main markets for silicone resins. Silicone resin compounds for molded parts are not commercially offered in quantities relevant to the market yet. Driven by the expected outstanding resistance to thermal stress and UV-radiation, a novel, solvent free, low viscous phenyl-methyl-silicone resin binder has been developed and used to iteratively create reinforced compounds, optimized for the manufacturing of moldings by press forming and pressure gelation [1]. General information on silicone resins can be found [2].

The paper deals with the chemical composition and the resulting properties of both binder and cured compounds. Like liquid-silicone-elastomers, the novel material contains highly reactive Vinyl-groups (Si - CH = CH₂), which, in the presence of a suitable catalyst and Si-H-units, form the crosslinking Ethylene-bridges [Si - CH_2 - CH_2 - Si] by the so called hydrosilylation process. Standard, methyl-polymer based additive masterbatches were found to have a negative influence in the resulting mechanical properties of the cured parts. Therefore new, special additives have been developed to meet optimum properties. The curing speed was found to be well adjustable by using these additives. An example of a DSC-graph is shown in [Figure 1]. The curing enthalpy of a typically filled compound was measured to be about 250 J g⁻¹ which is slightly less than that of a typical epoxy resin (300 – 500) J g⁻¹ [3].

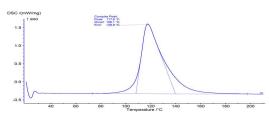


Figure 1. DSC plot of the Pt-catalysed hydrosilylation of the new silicone resin binder with a temperature rise of 10 $\rm K^{-1}$

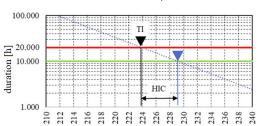


Figure 3. Typical thermal long-term diagram of a compound made from the novel silicone resin binder and suitable mixture of fillers

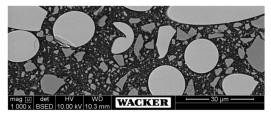


Figure 2. electron micrograph of silicone resin binder reinforced with glass fibers, quartz and silica (not visible)

Thermal class [°C]	Code	Typically used materials
90	Υ	Polypropylene
105	Α	Phenolic resin
120	E	Paper, Epoxy resin
130	В	Polyester, Epoxy resin
155	F	Aramide
180	Н	Polyimide, Glasssilk with silicone elastomer binder
200	N	Polyimide, PTFE
220	R	PTFE, PEEK
250	-	PEEK

Table 1. Typical thermal classification data for comparison (as sourced from literature)

It was found that compounds with the novel binder can be cured rapidly in the presence of peroxides as well which allows the formulation of one-component, ready-to-use, label-free products. This material is applicable with existing machinery to mold thermally extremely stable moldings for sustainable future

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solutions like electro-mobility. Selected results with respect to the combination of reinforcing fillers as well as to the processability are presented. Optimization of the mechanical properties was achieved by compounding the binder with combinations of fiber- and particle-shaped fillers (Figure 2). The fiber reinforcement allows a modification of the typically rather brittle compounds towards a more elastic material that can be repeatedly deformed to a certain extend.

Compounds have been evaluated with respect to their thermal stability acc. to [4] by using the mass reduction of the binder as evaluation criterion. The 10%-threshold for each storage temperature has been extrapolated from measured data. The resulting thermal long-term diagram is shown above [Figure 3]. The thermal index is higher than 220°C, the halving interval is about 5K. The material meets the thermal class R acc. to [5] and therefore represents a material with a very high thermal stability in comparison to other materials (Table 1). Additional advantages of the manufactured silicone-resinmoldings have been found to be a very high stability against UV-stress, a perfect mechanical durability and an easy processability with existing devices (pressure gelation, injection molding). Molded parts are easily removable from the mold without release agent. First injection molding trials have been successfully finished. In comparison to earlier presented formulations [6] the latest materials show the desired mechanical properties without an extended obligatory post curing.

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Online Process Monitoring in Hybrid Injection Overmoulding

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Keywords: Thermoplastic Composites, Quality control, In-cavity monitoring

1 Introduction

The overmoulding process for thermoplastic fibre composites combines the excellent mechanical properties of continuous fibre reinforced laminates with the high degrees of geometric freedom and short process times of injection moulding. Flat or thermoformed continuous fibre composites can be stiffened or functionalized by overmoulding with a short fibre reinforced thermoplastic. The compound strength of these hybrid structures, which is essential for the properties of the components produced, is determined primarily by the interface between the continuous fibre-reinforced insert and the injection moulding compound. [1]

The use of this technology for highly stressed components or safety-critical parts, such as aerospace primary structures, is currently prevented mainly by an incomplete understanding of the process and resulting properties, as well as a lack of process and quality assurance.

The formation of the interface is influenced by a multitude of process parameters. As a result of these parameters, certain process variables occur in the mould cavity during the filling process, which are decisive for the bond forming between insert and injection moulding compound as well as the resulting component properties. It is known from previous work at the Faserinstitut Bremen e.V. (FIBRE) that in particular the temperatures of melt, insert and mould, as well as the flow rate of the melt and the distance from the gate are of vital importance. [2]

Since the correlations between adjustable machine and process parameters and the process variables that arise in the mould cavity are extremely complex due to the large number of parameters and interactions, it is advisable to use the process variables recorded directly in the cavity, and thus at the point of interface forming, for monitoring of the process. [3]

2 Tool design

For this purpose an overmoulding tool with an array of sensors within the cavity was developed at FIBRE. This tool allows the fabrication of test specimen, with which the bonding properties at the interface can be determined as a function of the process variables. The components consist of an organosheet insert, onto which ribs made of short-fibre reinforced thermoplastic are overmoulded on both sides. Tensile specimens can then be taken from the components and tested in a tensile testing machine. Compared to a one-sided T-geometry, the placement of ribs on both sides prevent the organosheet from bending upwards in the tensile test, which would lead to a peeling load. Due to the wider base of the clamping rib, compared to the testing rib, a failure in the target interface is ensured. The test specimen is shown in figure 1.

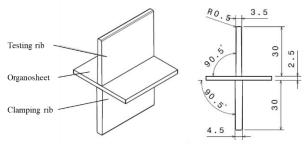


Figure 1. Overmoulding test specimen.

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A variable design of the tool makes it possible to vary the thickness of the insert and the sequence in which the two ribs are injected. In addition, test specimens can be taken at different distances from the gate and a weld line can be created by activating a second gate channel. It is also possible to process high-temperature thermoplastics such as PAEK or PEEK. By using a total of 8 individual sensors, the temperatures of mould, insert and melt can be measured. The sensors and their positions along the overmoulding part are shown in figure 2.

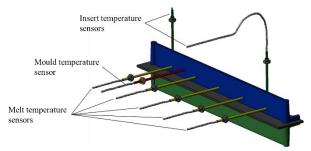


Figure 2. In-cavity sensors.

The mould temperature is determined by a gradient thermometer, which measures the temperature at three different distances from the cavity, so that the heat transfer into the mould can also be determined. The temperatures of insert and melt are measured by IR sensors, whose extremely short response time of 10 ms makes it possible to determine precisely the time of the melt front reaching individual sensors. In this way, the flow rate of the melt can also be determined from the signals of the individual sensors placed along the cavity. All sensors were provided by the FOS Messtechnik GmbH as part a the cooperation in the research project QuaSimOdo, funded by the German federal ministry for economic affairs and energy (BMWi). [4]

Figure 3 shows the principle of the melt front flow rate measurement, using the temperature sensors.

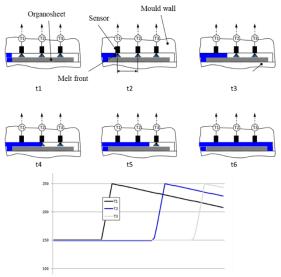


Figure 3. Principle of melt front speed measurement.

3 Experimental Procedure

A statistical test plan was carried out to evaluate the tool and the sensor system. The effects of various machine and process parameters on the process variables measured in the cavity and the resulting bonding properties were determined. As a material system inserts of a glass fibre fabric with a PP matrix and a short fibre reinforced PP glass fibre injection moulding compound were used.

The results were used to define a process window within which, given the material and mould used, a complete formation of the bond between insert and injection moulding compound can consistently be expected and which can thus be used as a basis for quality assurance.

4 Conclusion

In conclusion, this study presents the design of an overmoulding tool with an array of sensors for the determination of in-cavity process values, which can be used for monitoring of the process and the validation of the tool for a PP-GF material system.

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Influencing Parameters on the Crash Tube Deformation Behaviour in - Laboratory Scale

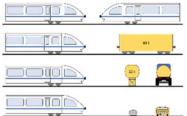
23rd Symposium on Composites and Composite Materials

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As a result of comfort requirements or driver assistance systems, the complexity of rail vehicle construction increased. This is associated with increases in vehicle mass, some of which are considerable. The safety technology housed in the vehicles also contributes to this trend. Crash elements and crash structures are usually made of metallic materials. A disadvantage is the high dead weight of these structures. In vehicle construction, especially in rail transport, lightweight structures are preferred in order to relieve tribological systems and to reduce the acceleration energy of the vehicles. For use in rail vehicle construction, energy dissipating systems must absorb high amounts of energy in a short time in the event of a collision. It The requirements of DIN EN 15227 specify that crash elements must operate at as constant a force level as possible in the event of a train collision so as not to endanger the static integrity of the vehicle structure Fiber-reinforced plastics (FRP) can be used to design lightweight and inflexible structures. Due to their high specific energy absorption capacity, they are also suitable for energy dissipating systems in lightweight vehicle construction. [1,2]



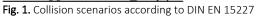




Fig. 2. Defibrated test specimen with tapered section

In this research project, influencing parameters on the specific energy absorption capacity of side crash elements of rail vehicles are investigated. Object of investigation in the laboratory are geometrically similar FRP crash tubes which are pressed through a telescopic guide. In this guide there is a conical ring-shaped taper (conical ring). When exposed to high pressure in the axial direction, the FRP crash tube must pass through this constriction, where it deforms. Since the material does not behave ductile, it fibrillates into discrete fragments, some of which remain connected to each other by fibers. When passing through the conical ring, the degree of deformation is so high that interlaminar fracture of the fiber layers in the tube may occur. When passing through the conical ring, the degree of deformation is so high that interlaminar fracture of the fiber layers in the tube may occur. In order to optimise the fracture behaviour, different ring geometries are tested. The influence of the material pairing between the conical ring and the FRP tube can have an impact on the load level.

Quasi-static series tests are carried out on a universal testing machine. The optimum conical ring geometry and the optimum layer structure of the fiber composite structure are determined in order to achieve the highest possible specific energy consumption. The results, in which the crash tube models have a quasi-isotropic layer structure, show a significant increase in energy absorption capacity when the geometry of the conical ring is modified.

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[Verbund] B: Metallmatrix-Verbundwerkstoffe (MMC)

High-speed laser melt injection for reinforcing steel and copper tools

P. Warneke^{1*}, A. Bohlen¹, T. Seefeld¹

Laser melt injection (LMI) is used for reinforcing tools with hard particles. In contrast to competing technologies for generating metal matrix composite (MMC) tool surfaces, LMI uses the substrate as a matrix. By this, the properties of the substrate and the hard material can be combined individually. For pressure die casting pistons, highly conductive copper alloys such as Hovadur® CNCS are used in order to ensure high cooling rates and short process cycles, consequently. By injecting spherical fused tungsten carbide (SFTC) particles into the surface, a high thermal conductivity can be preserved in the piston while the wear resistance is significantly improved at the same time [1]. Furthermore, tool steels such as 1.2362 which are used for skin-pass rolls can be reinforced by SFTC particles in order to improve the wear resistance and the service life of the rolls.

Until now, due to low process speeds, the use of LMI is limited to a small number of applications. Usually, process speeds below 2 m/min are used [2]. To increase the process speed, a model for the hard particle movement from leaving the powder nozzle until the incorporation into the weld pool has been designed, see Figure 1. The distance travelled by a particle can be divided into s₁, s₂ and s₃. On s₁ and s₂, the average particle velocity $v_{1,2}$ mainly depends on the volume flow rate of the feeding gas $\dot{V}_{\text{feeding gas}}$ and the weight force F_g whereas the average particle velocity v_3 is strongly affected by the surface tension force F_s, the drag force of the weld pool F_d, the weight force F_g and the initial kinetic energy E_{kin}. The kinetic energy Ekin depends on the average particle velocity v_{1,2}. Hence, both the travel time t_{travel} and the incorporation time $t_{incorporation}$ depend on the average particle velocity $v_{1,2}$. The particle only interacts with the laser beam during s2 and s3. Experiments showed that high laser intensities are necessary to maintain a continuous melt pool at high process speeds. As a consequence, strong interactions with the laser beam lead to a partial melting and undesired deformations of SFTC particles. Furthermore, agglomerates of various particles are formed. In LMI at regular process speed, feeding gas volume flow rates below 5 l/min are used [3]. To avoid the partial melting of SFTC particles, a new approach with significantly higher volume flow rates was taken. Experiments showed that the average hard particle velocity $v_{1,2}$ is a key factor for enabling high-speed LMI (HSLMI).

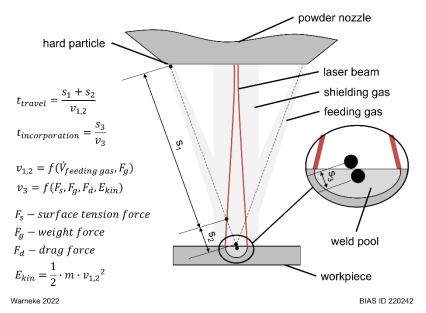


Figure 1. Model for the hard particle movement in LMI.

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With this approach, a process speed of 30 m/min could be reached on the copper alloy Hovadur® CNCS. Figure 2 shows that only a few particle deformations can be identified at a laser power of 10 kW. At a laser power of 6 kW, no particle deformations were detected.

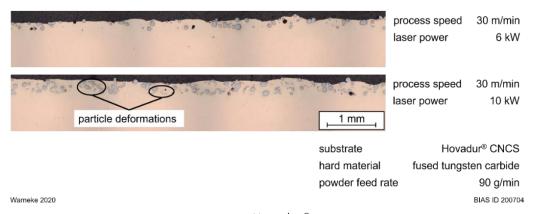


Figure 2. Cross sections of SFTC particle reinforced Hovadur® CNCS by HSLMI.

Due to the better absorption efficiency of steel against copper, higher process speeds for LMI are possible with the same laser power. Process speeds of up to 100 m/min were reached on the tool steel 1.2362, see Figure 3. The MMC layers provide a small layer thickness and a smooth surface with a low waviness. Consequently, with HSLMI, near-net shape MMC layers can be generated minimizing the costs of final machining. Furthermore, it was shown that the crack susceptibility can be reduced by increasing the process speed.

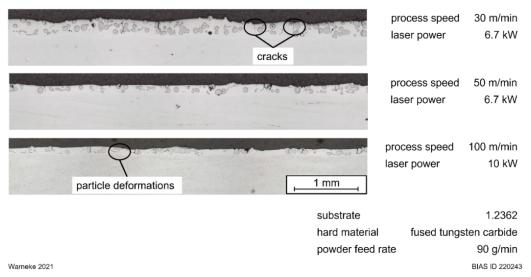


Figure 3. Cross sections of SFTC particle reinforced 1.2362 by HSLMI.

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Mechanical and microstructure characterization of particle-reinforced AlSi10Mg aluminum alloy produced by means of high-energy ball milling and field-assisted sintering

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AlSi10Mg is precipitation hardenable aluminum alloy widely used in the melt metallurgy and additive manufacturing and highly demanded for diverse lightweight applications for example in aerospace and automotive. However, the manufacturing method and thus the microstructure, silicon phase size/morphology, and precipitation hardening significantly affect the mechanical properties of this alloy [1]. Furthermore, the reinforcement of aluminum alloys with hard particles represents a possible approach to fully exploit the potential of AlSi10Mg and its mechanical performance. For this reason, this work aims to produce particle-reinforced AlSi10Mg alloys containing aluminum oxide (Al₂O₃) and silicon carbide (SiC) by means of powder metallurgy route including high-energy ball milling (HEBM) and fieldassisted sintering (FAST) with subsequent precipitation hardening. In this context, the influence of milling and reinforcement upon the hardening behavior of AlSi10Mg are presented. HEBM-experiments were conducted in Simoloyer CM08 (Zoz GmbH, mill tank capacity of 8 l, powder amount 800 g, ball to powder ratio 10:1) with a with 4.4 mm stainless steel balls. It included the milling of AlSi10Mg without and with particle reinforcement under rest air, argon atmosphere, and menthol as process control agent (PCA). The milling duration was limited to 7 h. The powder variants were consolidated under vacuum (p. < 1 mbar) by field-assisted sintering with a spark plasma sintering system HP D 25-SI (FCT Anlagenbau GmbH). The amount of 50 g of powder is heated in a steel tool (D=50 mm) at 100 K/min to 500 °C and held for 10 minutes. The pressing pressure is 100 MPa over the entire duration. The water-cooled stamps ensure a cooling rate of 50 K/min in the range between 500 and 250 °C. The sintered samples are then subjected to a heat treatment with solution annealing at 500 °C for 1 h and subsequent artificial aging at 160 °C for 5 h.

The sintering of the as-received AlSi10Mg dissolves the fine eutectic structure and leads to the precipitation of Si particle in the α -Al grains. The result is low hardness of 54 ± 1 HV1, but comparable with as-cast AlSi10Mg (43 – 67 HV) [2, 3]. A typical artificial aging (T6) improves the hardness remarkably to 101 ± 2 HV1. According to several previous investigations, this hardness increase is mainly attributed to the formation of Mg₂Si precipitates within the Al phase (Mg content in the alloy 0.25 - 0.5 m%) [4, 5]. In comparison, the as-build AlSi10Mg (produced by laser powder bed fusion (L-PBF)) delivers high hardness value of 134 ± 2 HV1 exciding that of sintered AlSi10Mg in both condition (without and with T6). This high hardness correlates with the unique ultrafine microstructure of the as-build L-PBF sample characterized by supersaturated Al phase and fine network of Si particle (fine eutectic silicon phase) all caused by the high cooling rate (Figure 1, microscopic Image 2). However, the L-PBF AlSi10Mg is usually subject to T6 heat treatment for a useful balance between strength and ductility.

To separate the effects of milling and particle reinforcement on the properties of sintered AlSi10Mg, a field-assisted sintering (FAST) of the unreinforced AlSi10Mg alloy was conducted after milling under different milling conditions (rest air + menthol as PCA, without PCA under argon). As can be seen in the Figure 1, the hardness of the sintered milled powder is comparable to that of the as received powder in the FAST state. On the contrary, after T6 treatment no change in the hardness can be observed, i.e. no hardening occurred in the Al phase. Based on the Mg₂Si precipitation mechanisms, this could mean that the building of Mg₂Si phase is suppressed e.g. through the oxidation of Mg by oxygen from the milling process. With regard to milled powder under menthol, the analysis of O-content in the powder could support this theory (0.321 m% milled vs 0.034 m% as-received). In addition, higher amount of magnesium and oxygen could be detected on the grain boundary of heat-treated cross section in case

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of milled powder (SEM). Overaging due to the milling process can also contribute to lower strength. For samples from milled powder, the hardness maximum of 80 HV1 war observed only after 0.5 h during artificial aging, which indicates an accelerated precipitation owing to higher defect density caused by milling. The larger silicon precipitation can be also a consequence of this effect (Figure 1, microscopic images). By means of X-ray diffraction, only Al and Si phase could be detected apparat from the powder or heat treatment state, probably due to low fraction of Mg_2Si or possible oxides.

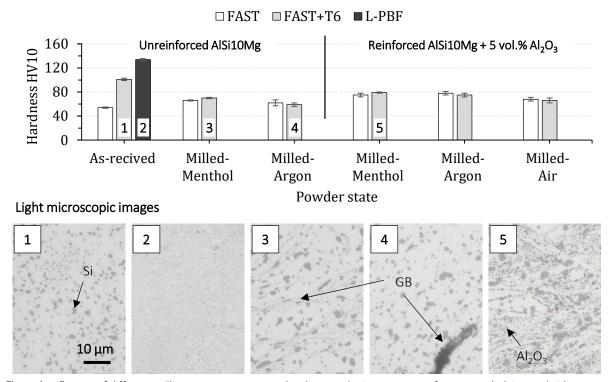


Figure 1. Influence of different milling parameters on HV1 hardness and microstructure of compacted AlSi10Mg (without and with particle reinforcement (Al_2O_3)). GB = Grain boundary.

However, milling under argon reduces the O-content to 0.088 % and in spite of that there is no change in hardness after T6 treatment. Microstructural investigation showed that the samples were highly contaminated during the milling process so that a high proportion of cracks appeared in the microstructure (on grain boundaries) after heat treatment. A high N-content measured in the milled powder (0.1 m% vs. 0,012 m% in as-received powder) and Si-N Phase in the compacted samples (EDX-SEM) refer to contamination due to the abrasion of the Si_3N_4 rotor during milling. This makes a final conclusion at this point difficult whether the absence of aging hardening is due to the partly or completely consumption of Mg by oxidation so that it is not available for the precipitation hardening. The particle reinforced composite possesses a higher hardness in the FAST state around 80 HV1 due to reinforcement, but show a similar behavior when heat-treated, which according to the current investigation caused be the milling process itself and not by the reinforcement. Similar behavior is also observed with SiC reinforcement, however with higher average hardness values. Higher Al_2O_3 proportion of 15 vol.% led to hardness of 111 \pm 4 HV1 in the sintered samples without heat treatment.

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Preconditioning of aluminium matrix composites for brake disc applications

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The demand for lightweight construction concepts and statutory requirements to minimise environmentally harmful emissions accelerate the development of new material concepts. Hard particle reinforced aluminium matrix composites (AMC) with a high reinforcement content are predestined for wear applications where the above requirements are placed on. Since this material shows similar braking behaviour to grey cast iron in friction pairing with conventional brake lining material [1] and can exhibit higher wear resistance [2], AMCs are suitable for use as brake discs. The prerequisite for this is the formation of a tribologically conditioned surface (tribo surface, also known as friction layer or tribo film). This builds up in front of the protruding reinforcement particles and ensures low wear and low noise emissions as soon as it is extended over the entire friction surface [3]. Under normal loading, abrasion can be reduced by at least 85% [3]. However, AMC brake discs cannot be used directly after manufacturing and finishing. Since in braking applications of non-preconditioned AMC brake discs there are locally different contact pressures and temperatures caused by friction, the tribo surface is formed at different rates depending on the location. If the tribo surface is irregular, areas of tribo surface failure can occur locally [3]. Due to these undefined processes, the use of AMC brake discs is currently still under development, as local failure quickly leads to failure of the entire system and represents a safety risk. For the use of AMC brake discs in serial applications, a defined generation of the tribo surface, the "preconditioning", is therefore necessary. The aim is to create a stable adjusted tribo surface as quickly as possible by sliding brake lining material against the turned AMC surface. In this study, preconditioning is carried out using the pin-on-disc test and the parameters contact pressure and pin speed are varied. Optical investigation show that the tribo surface becomes consistent faster, meaning a smaller number of passings is needed, with increasing pressure and speed, see Figure 1.

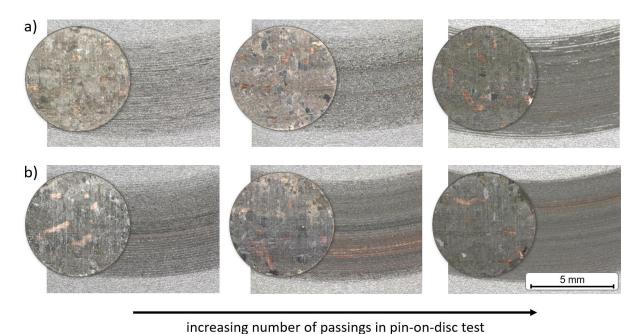


Figure 1. The friction tracks on the AMC surface with differently formed tribo surfaces and the surfaces of the brake lining pins rubbed against them are shown with increasing number of passings from left to right. Compared to the parameter set with the lowest selected pressure and speed (a), the tribo surface becomes visually consistent faster at high pressure and speed (b). Due to the irregular composition (phases and phase contents) of the brake pad pin, it is not easy to evaluate the build-up of the tribo surface.

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Data recorded during the tests, such as the system wear and the coefficient of friction, could not show any trends with increasing number of passings. Once the test parameters were set, the coefficient of friction and the wear rate, expressed as the slope of the wear curve, did not change significantly. Therefore, it was sought for other ways to quantify the observations. The irregular distribution and content of phases in the brake lining pins (see Figure 1) always poses a difficulty. The common surface characteristics determined by the 3D surface measurement also showed no correlation in the surface shape with increasing number of passing during the pin-disc test. But the basis for determining the surface characteristics is the Abbott curve, also known as the material proportion curve. The development of a new routine using MATLAB makes it possible to evaluate the curve using a new approach. V_{surf} is the new surface parameter that shows trends for the first time. Depending on the set contact pressure and the pin speed during the test, V_{surf} decreases more or less rapidly with increasing number of passings and runs in a saturation range. It is assumed that the running-in phase is completed at the latest when saturation is reached. However, depending on how large V_{surf} of a surface is, the number of passes required to reach the saturation area changes. A calculable prediction is possible and will be discussed. The surface characteristic value V_{surf} before the test (initial state), the difference of V_{surf} that results until the test parameters are set and the rate of change of V_{surf} until the saturation range is reached enter the equation. In summary, it can be said that by knowing the initial surface characteristics (V_{surf}), the run-in phase can be planned as a production step. However, it is not possible yet to say which parameter set is the most suitable and economical. In addition, further tests on real brake discs are necessary to determine when preconditioning has actually taken place.

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23. Symposium Verbundwerkstoffe und Werkstoffverbunde 2022 Topic: B - Metallmatrix-Verbundwerkstoffe (MMC)

The effect of milling time on the microstructural and mechanical properties of SiCp reinforced AA2017 composites powder produced by high-energy ball milling

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Abstract - The purpose of this study is to characterize the microstructural and mechanical behavior of Al-SiC composites produced by the high-energy ball milling process (HEBM). Gas atomized AA2017 aluminum alloy powder with the particles size of <100 and silicon carbide (SiC) powder particles with an average particle size of <1 µm composites were successfully produced using HEBM process. The milling process was performed using the laboratory scale HEBM machine called Simoloyer CM08 ZOZ GmbH for 5 h. The effect of milling time on the microstructure and mechanical properties of AA2017-SiC composites during the mechanical milling process was investigated. The microstructures of the composite powder samples at different milling times were examined using optical microscopy (OM), Scanning electron microscopy (SEM), and X-ray diffraction (XRD) technique. The OM and SEM investigation confirmed that the SiC particles were homogeneously dispersed in the AA2017 matrix material after 5 h of milling. The XRD analysis was carried out to determine the phase constituents and crystallite size of the composites powder at various milling times. The XRD results showed that the crystallite size of the Al matrix reduced and the lattice strain increased with increasing milling time. So, the average crystallite size and lattice strain of the AA2017 + 10 vol.% SiC composites were reduced from 300 nm to 64 nm and increased from 0.1 to 0.5 %, respectively after 5 h of milling. The microhardness of the powder particle samples was measured using the Wilson Microhardness tester with an indentation load of 10 gf. It was observed that hardness increased for all samples with increasing the milling time. The average microhardness of the AA2017-SiC composites obtained after 5 hours of milling was higher than the unmilled powder particles.

Keywords: Al-SiC composites, High-energy ball milling, crystallite size, lattice strain, microhardness

[Verbund] C: Keramikmatrix-Verbundwerkstoffe (CMC)

Characterisiation of Unidirectional Minicomposites as an Efficient Tool for SiC/SiC-CMC Development

A. Konschak^{1*}, M.Hartbauer², J.Schmidt¹, J. Vogt¹,

SiC/SiC fibre reinforced Ceramic Matrix Composites (SiC/SiC-CMC) are high-performance ceramics serving applications up to 1200 °C and well beyond. E.g., SiC/SiC is a material of choice for hypersonic applications or in the hot section of aircraft engines, where high mechanical and thermo-mechanical stresses prevail. However, it is very tedious to develop SiC/SiC-components with suitable mechanical strength and fracture toughness. In particular, the SiC/SiC-CMC development is time consuming, since a multi-step process chain must always be performed to obtain standard samples for the mechanical testing.

The goal of this work was to identify a time and cost-efficient way to reduce the number of steps in the material development while increasing the number of test specimens. High efficiency in the SiC/SiC development was achieved by the use of unidirectional minicomposites with a maximum length up to 200 mm.

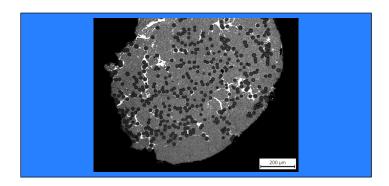


Figure 1. Microscopic image of a polished cross section at 119mm of a 200mm minicomposite 69 with SiC-fibers with CVI-BN/SiC interphase in SiSiC matrix with residual silicon (magn. 100x).

All rovings were first coated by an interphase (CVI-BN/SiC layer) and then embedded in a SiC rich matrix. The matrix composition was tailored by the adaption of a water-based suspension. In the first step, the dry rovings were impregnated by a slurry cast technique. These minicomposites were pyrolized and infiltrated by the silicon melt, doped with Boron to lower the maximum siliconization temperatures. The microstructure after the siliconization was investigated by light microscopy. A correlation between the fibre coating thickness and the fibre attack by the silicon melt was established. A specific test set-up was developed for the tensile testing of the minicomposites. Moreover, the microstructure could be correlated with the mechanical strength.

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Development of C/C-SiC via Fiber Patch Placement zum 23. Symposium Verbundwerkstoffe und Werkstoffverbund an

J. Riesner^{1*}, F. Böck ¹, D. Koch¹

Carbon fiber reinforced silicon carbide, so called C/C-SiC materials, were manufactured via Fiber Patch Placement (FPP). At FPP an unidirectional fiber tape is cut into defined pieces, so-called patches, and placed on a negative mold by a robot gripper. The structure of the patched carbon fiber reinforced polymer (CFRP) is typically realized with the help of a thermoplastic binder located on the bottom side of the patch. The binder melts due to a heating wire installed in the gripper during placement and provides the necessary fixation of the individual patches after cooling. The preform created in this way is then infiltrated with a resin. The great advantage of this process is that each patch can be placed independently to other patches in position and direction. This provides a high degree of flexibility and allows the production of load-path optimized and reproducible 3D components. The main disadvantage, on the other hand, is that a gap is formed between two adjacent patches due to the discontinuous fiber. This gap is the weakest link in the composite and must be compensated via an optimized lay-down pattern of the individual patches across all layers. [1,2]

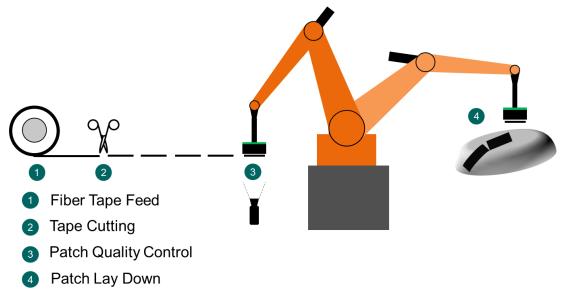


Figure 1. Schematic representation of the Fiber Patch Placement process

In this study, two-dimensional C/C-SiC plates are manufactured via a three-step liquid-silicon-infiltration process (LSI), which consists of CFRP fabrication, pyrolysis, and silicon infiltration. The primary goal is to demonstrate that patched CFRP components can be successfully converted to a ceramic matrix composite (CMC). This is done by adjusting the material and the process parameters under the continuous analysis of the state of the material by scanning electron microscopy. Furthermore, the mechanical properties are investigated with the focus on the influence of discontinuous fiber reinforcement due to the patches. Tensile tests are used to characterize and compare the mechanical properties of continuous fiber reinforced and patched C/C-SiC.

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Development of composite implants based on metallic support elements and ceramic bionic guide structures for high-strength ingrowing of bone tissue

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Abstract

Fehler! Linkreferenz ungültig.

Approximately 5 % of the adults in Germany over the age of 60 suffer from hip joint arthrosis. Today, the implantation of a hip endoprosthesis is one of the 20 most frequently performed operations in Germany, with more than 200,000 primary operations per year [1].

Depending on the age of the patient, the current gold standard for the use of hip endoprostheses is the cemented or cementless anchoring of the prosthesis stem in the femur. Deficiencies of cementless prosthesis anchorage are based on the fact that the stability and durability of the endoprosthesis is based on the bone ingrowth of the surrounding tissue. In addition, the life expectancy of prosthesis wearers has increased steadily in recent years. These patients have the demand for unrestricted activity despite hip endoprosthesis. Therefore, further improvements of existing prosthesis concepts with regard to bone ingrowth are inevitable.

The aim of the "BioniCera" research project is to develop a hip endoprosthesis with a bionic ceramic guide structure that enables high-strength bone ingrowth. To realize the innovative composite material of the implant, the conventional titanium prosthesis stem is combined with an alumina-based ceramic. The ceramic contains a bionic guide structure of branched channels that enable bone ingrowth and thus

long-term anchoring of the prosthesis in the bone.

In the presented study, the focus is on the selection of the fiber material to create the capillaries of the bionic guidance structure, as well as the ceramic.

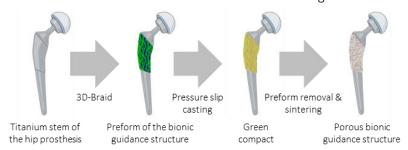


Fig. 1: Development within the BioniCera project

The fabrication of the prosthetics is done by pressure casting of a corresponding ceramic composite. For this purpose, individual filaments are first embedded in an alumina matrix and then pyrolytically removed to form the capillary structure. Within the framework of empirical tests, suitable fibre materials (investigated material: PA66, PP; fibre diameter $d_f = [0.2; 0.35; 0.45]$ mm) as well as a pyrolysis programme (determination of firing temperatures, heating rates and holding times) for the formation of the capillary structure are determined. The characterisation of the macro-structure produced (capillary diameter depending on the fibre material used, pyrolysis-related damage to the ceramic microstructure) is carried out using optical and radiological examinations (CT, SEM, micrographs).

We would like to thank the German Federal Ministry for Economic Affairs and Energy for funding the research project "BioniCera" within the framework of the Central Innovation Program for SMEs.

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Enhancing the microstructural stability of oxide ceramic composites by matrix doping

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The main limitation of oxide ceramic matrix composites (Ox-CMCs) is related to their thermal stability. At temperatures above 1000°C, fiber grain growth and matrix densification lead to loss of strength and embrittlement. To improve the thermal stability of Ox-CMCs, the use of matrix doping is analyzed in this study. Minicomposites containing Nextel 610 fibers and alumina matrix with and without 450 ppm of MgO doping were evaluated before and after different thermal exposures to 1300°C and 1400°C for 2 h. Both minicomposite types have very similar as-produced properties. Nevertheless, MgO-doped minicomposites show much lower fiber grain growth during the subsequent thermal exposures. The differences in microstructural evolution are associated with elemental diffusion between fiber and matrix at high temperatures. In this sense, the MgO doping from the matrix can diffuse to the fibers and also influence fiber grain growth. As a result, MgO-doped minicomposites show much higher strength retention than non-doped mminicomposites after the thermal exposures. Hence, doping the composite matrix can increase the overall thermal stability of Ox-CMCs.

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Fabrication and mechanical properties of nacre-like hydroxyapatite ceramic composites for load-bearing bone implants

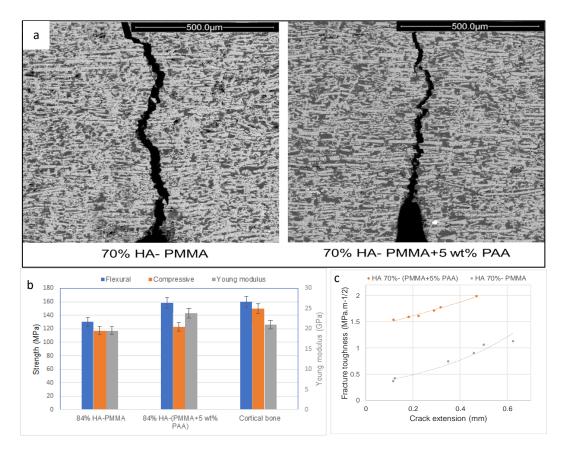
Parinaz Tabrizian^{1*}, Sean Davis², Urangua Jargalsaikhan³, Tan Sui³, Bo Su¹

After more than five decades of research on load-bearing bone implants, replicating the mechanical strength and toughness of cortical bone is still a challenge for engineers and clinicians.

Cortical bone or dense bone consists of 70% hydroxyapatite (HA) and 30% collagen having hierarchical structure resulting in extrinsic toughening mechanisms. Nacre-like ceramic composites have opened new horizons for the fabrication of biomimetic bone implants with high strength and toughness [1].

Various methods have been used to develop nacre-mimetic composites with hierarchical "brick-and-mortar" architecture, among which bi-directional freeze-casting has proven to be a powerful method to produce bulk composites with excellent mechanical properties [2].

The main aim of this work is investigating and preparing of long-range aligned lamella hydroxyapatite (HA) scaffold by bidirectional freeze-casting which can be further densified and infiltrated with polymethyl methacrylate (PMMA), and PMMA + 5wt% acrylic acid (AA) to evaluate the capabilities as load-bearing bioactive implants. Based on the microstructural and mechanical analysis (Figure 1) nacrelike HA composites with PMMA and PMMA + 5wt% AA displays a rising R-curve behaviour; however, by adding 5wt% PAA the average values of fracture toughness increase to 2 MPa.m $^{1/2}$ at the ceramic fraction of 70 wt% and , flexural strength and young modulus increase to 158 MPa and 24 GPa at the ceramic fraction of 80 wt%, suggesting these bioactive composites are potential candidates as bone implants [3].



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Figure 1. The effect of adding PAA on the microstructure and mechanical properties of HA-PMMA at the same ceramic fraction composite. a) . Representative SEM images taken during the in-situ imaging of composites under loading in bending. b) The flexural, compressive strength and young modulus increases to 158, 123 MPa and 24 GPa, respectively. c) The fracture toughness increases to 2 MPa.m^{1/2}.

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Fracture mechanics of all-oxide ceramic composites – development of reliable testing methods

Michaela Janowski^{1*}, Katrin Bock¹, Judith Moosburger-Will¹, Dietmar Koch¹

Composites made of ceramic fibres and ceramic matrices (CMC) show a high thermal and chemical stability and high mechanical properties, including a damage tolerant failure behaviour caused by microscopic failure processes such as controlled crack evolution and fibre pull-out. This allows their use in high temperature applications under aggressive atmosphere and high load, e.g., in turbine engines. While the widely used and investigated SiC/SiC-compounds are affected by oxidation embrittlement, limiting their service lifetime, all-oxide CMCs provide a higher chemical resistance in oxidative environments [1, 2].

Until today no specific tests for determination of crack propagation and fracture mechanical behaviour of ceramic matrix composites exist, complicating the characterization of the failure behaviour of different materials or processing methods. To develop a reliable testing routine, the applicability of the Norm ASTM-E 1820, suited for metals and monolithic ceramics, was investigated. Single-Edge Notched Bend-Tests (SENB) were performed on samples of all-oxide CMC based on Al₂O₃-SiO₂-systems (Keramikblech Typ FW12, Walter E.C. Pritzkow Spezialkeramik), prepared according to the geometric requirements of the norm. Focus was set to the determination of crack length, which is an important parameter in calculation of J-Integral, used to quantify the strain energy release rate. Other than metals or monolithic ceramics, CMCs show complex crack formation, namely multiple microcracks, crack branching, or fibre failure behind the crack tip [3]. To estimate the real crack length with respect to the expected crack branching, the SENB-tests were in-situ monitored with an optical system (ARAMIS 12M), to calculate the strain-distribution on the sample surface based on the displacement of a speckle-pattern (see [Fig. 1]). It was found that the regions of maximum strain (red) coincide with the main crack paths formed during crack opening with increasing load.

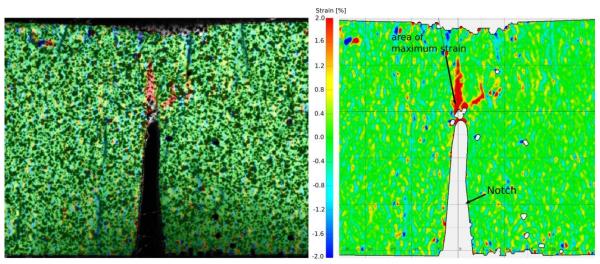


Figure 1. Strain distribution on SENB sample surface: directly shown on sample (left) and extracted strain calculation (right). The maximum strain (red) shows similar branching as the expected crack opening.

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The obtained crack paths are compared to the crack tip opening displacement calculated by the compliance-method according to ASTM-E 1820. In addition, ultrasonic microscopy and x-ray computed tomography are used for high resolution investigation of the crack geometry, allowing determination e.g., of the crack length and the number of large cracks. Combining all experimental results, calculation of the J-Integral can be adapted for all-oxide CMCs to proceed in the development of a specific fracture mechanics testing procedure for these materials.

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Green Carbon / Carbon with CVI – possible or not?

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In recent decades, the development efforts on ceramic composites (CMC) have focused mainly on improving the mechanical, chemical and thermal properties as well as on optimizing cost-effective production routes. Recently, more and more application areas for CMC have opened up outside of aerospace engineering, where environmental impacts and emissions are also relevant. These impacts have hardly been studied so far but are attracting growing interest due to the increasing awareness of environmental impacts. The project team of the CU EcoCeramic [1] joint research project is now focussing on these questions using C/C (carbon fiber reinforced carbon) as a generic example to show what the environmental footprint of C/C manufacturing looks like along the chemical vapor infiltration (CVI) route.

On the one hand, the key performance indicators (KPI) are considered. Secondly, realistic future scenarios are calculated, such as the use of regenerative process energy or the further development of manufacturing technology.

Finally, current approaches and ideas are discussed as to what a holistic regenerative approach to C/C using CVI might look like when biobased carbon fibers and green process gases are used. The environmental impact will be determined by a life cycle assessment (LCA) using SimaPro software and interpreted in comparison with properties of C/C.

CO₂ Technological CO₂ Capture

Co₂ Capture

Chemical Precursors

By Plants

Crüne

Fibers

Figure 1. Schematic representation of a regenerative CMC production [2].

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Low-Cost Ceramic Matrix Composites for Applications at Aluminum melting Processes

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For the transport and processing of aluminum melts, hand pouring crucibles and other production aids are currently used. However, these materials have weak points: The high level of wear and tear on the metal hand-held pouring crucibles is a serious problem. The wear is due to the high reactivity of the aluminum melt and the associated formation of intermetallic phases [1].

A low weight of the pouring crucible is in the foreground; therefore, the lining is made from high-purity, polycrystalline Al_2O_3 and amorphous Al_2O_3 -SiO₂ wool [2].

This lining meets the requirements of the aluminum casting industry, where temperatures of up to 800 °C occur. However, the short service life of the hand pouring crucibles has a disadvantage, as the lining wears out during the production process and has to be reapplied regularly (Figure 1). The resulting repair costs have a negative impact on production costs.



Figure 1. Used casting crucible with ceramic fabric lining (Source: Metallgießerei Chemnitz).

An alternative to this are hand pouring pots made of oxidic ceramics. However, these monolithic materials are brittle and not resistant to temperature changes. For this reason, hand-held casting pots made of fiber-reinforced oxide ceramics are increasingly being used.

Based on the model of a metallic pouring pot, a ceramic composite material is being designed in the ZIM-BaMOx project. The choice of materials and the manufacturing processes to be used are largely based on their cost factors, but also on their sustainability. Energy-intensive sintering processes should be avoided. In order to be of economic interest as a casting aid, the future product must be inexpensive in all of its components. Particularly, when it comes to the fiber material to be used, it is important to ensure that low-cost melt-spun fiber types are used. Expensive high performance ceramic fibers are not considered. The composite matrix used should also consist of cold-curing geopolymer; here, too, energy and material costs for the process are taken into account. If the fiber material or composite surfaces require a protective layer, favorable wet chemical processes are also used here. As part of the investigations, various cold-curing ceramic systems (geopolymer) were tested with regard to their mechanical properties up to 800 °C. Fiber materials made from basalt and glass were also examined and selected based on their thermomechanical properties. The interaction of fiber and matrix material was specifically characterized mechanically in the following on the basis of test CMCs before and after thermal stress.

The poster presented at the conference will give an overview of the project and its main findings.

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Low-Cost Manufacturing of Fiber Reinforced Ceramic Matrix Composites for Intermediate Temperatures

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Today, the use of CFRP and GFRP composites is limited to low temperature applications up to about 200 °C. On the other hand, high-priced and high-performance fiber-reinforced ceramics are available that can be used for applications up to 1200 °C and above. However, there is still a great need for lightweight and low-cost materials for applications in the temperature range between 300 and 800 °C, e.g. in metal and glass casting or melting industry as well as in chemical engineering. Polymer-based composites (PMC) cannot be used in such industrial environments, and conventional Ceramic Matrix Composites (CMC) are usually too expensive due to high-priced fibers and complex processing.

The basis for successful material development to reduce the cost of CMCs is to use low-cost and temperature-resistant basalt or glass fibers instead of ceramic or carbon fibers. Composites based on these fibers with high thermomechanical stability can only be achieved in combination with specific ceramic matrices. These matrices can be made, for example, from ceramic precursor resins or geopolymers. In contrast to conventional CMC, no high-temperature sintering step is required, which on the one hand enables the use of cost-effective fiber types with lower maximum operating temperature and on the other hand allows energy and cost savings to be realized.

To ensure cost-effective and reproducible component production, prepreg processes based on prefabricated textiles are proposed. The main advantage here is a high degree of automation in the production of fiber-matrix semi-finished products. For their further processing into components, cost-intensive process steps such as autoclave processing or post-infiltration must be avoided. In this context, automated winding and laying of prepreg fiber tapes has great potential for cost-effective and scalable production of low-cost CMC components [1].

This manufacturing concept was successfully demonstrated using the example of metal-CMC hybrid tubes (see fig. 1) consisting of a gas-tight metallic inner tube body and a creep-resistant ceramic fiber jacket [2, 3].

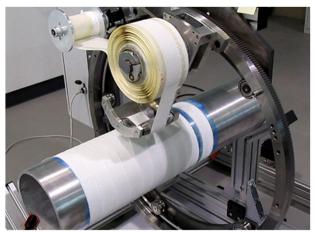


Figure 1. Metal-CMC Hybrid tube manufactured by the automated tape-winding process.

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Reinforcing injection moulded LSI-based CMC with chopped fibres: Process analysis and material properties

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Ceramic-matrix composites (CMC) made of carbon and silicon carbide dual matrix reinforced with carbon fibres (C/C-SiC) have exceptional heat, thermal shock, creep, and wear resistance, while also having little density and high strength. In comparison to monolithic ceramics, CMC possess ductility and damage tolerance, which opens this material for severe applications. Starting in space applications, this material is today well established in friction applications, where lightweight high-performance brakes securely decelerate e.g. luxury cars or elevators. The high production costs still limit the broad application like as brake discs in standard passenger cars, although less weight, better performance and longer life-time. The industrial used production process is the liquid silicon infiltration (LSI) with it three steps: preform shaping, pyrolysis and silicon infiltration. In this work, the shaping process of the carbon fibre reinforced plastic CFRP preform, is done by thermoset injection moulding. The application of plastic production processes like compounding and injection moulding in the liquid silicon infiltration process route, enables large-scale manufacturing. However, the screws and high shear forces inside the plastic processing machines significantly shorten the fibres. [1-3]

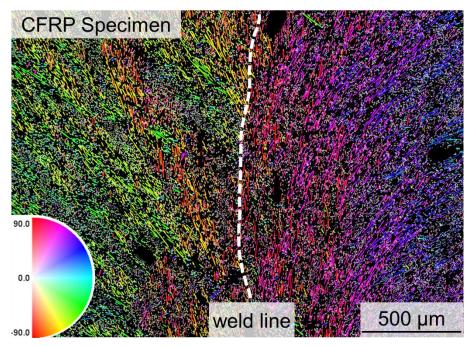


Figure 1. Fibre orientation in the middle of a CFRP specimen. Fibres coloured according to their alignment. [6]

To overcome the disadvantage of fibre length reduction, chopped carbon fibres are into the injection moulding process. This roving-based reinforcement is intended to ensure ductile material behaviour with tolerant failure. For this purpose, the chopped fibres with different length and mass shares are embedded into the CFRP preform during injection moulding, then pyrolysed and infiltrated with silicon. The chopped fibre bundles withstand the shear forces during the injection step and increase the mechanical properties of the plastic and ceramic parts. The test specimens are examined microstructurally and mechanically. Additionally, the influence of the flow direction on the orientation of the fibre bundles and their influence on microstructure and mechanical properties is shown. [4-6]

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Electrochemical metal recovery from chrome plated PC/ABS

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Decorative chrome plated plastics are widely used on household appliances and automotive parts, and are mostly composed of a plastic substrate such as ABS or PC/ABS, and an electrodeposited metal layer that contains mostly Cu, Ni and Cr. One of the challenges is the recovery of those metals without the formation of the toxic hexavalent chromium (Cr [VI]). Current studies focus mostly on the recovery of the plastic substrate and obtain mainly a mixed metal residue after separation. [1,2] An alternative method for the metal/plastic separation and the recovery of single metals is presented. It involves the electrochemical degradation of the metal layer and the parallel separation and recovery of each metal through electrochemical deposition and centrifuge filtration. Chrome plated PC/ABS samples were electrochemically processed using a methane sulfonic acid solution and set at a constant potential. Under these conditions, it was possible to recover Cu via electrodeposition at the cathode while Cr remained in its reduced form. Ni was found to be contained in the remaining electrolyte in ionic form which could be separated via chemical precipitation.

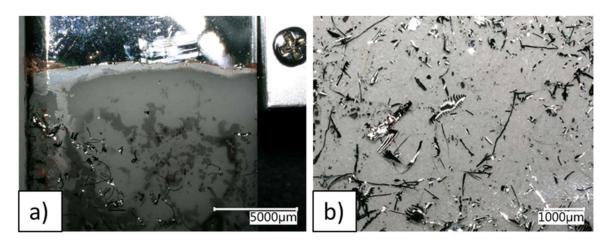


Figure 1. a) Microscope images (20x) of the treated plated PC/ABS part after the electrochemical treatment and b) recovered metallic chrome through filtration.

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Layer separation of thermoplastic composites at room temperature by power-ultrasonics

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Laminated carbon fibre reinforced polymers (CFRP), are materials providing exceptional mass specific mechanical properties and are therefore intensively used in the aeronautical and aerospace industries (certain modern aircrafts are made of more than 50 % of CFRP). Recycling methods for these materials including thermal (pyrolysis), chemical (solvolysis) or mechanical (cutting, shredding) methods exist. Nevertheless, they all have the disadvantage to start with the part size reduction and lead to a loss of the length and the orientation of fibres which in turn induces a down cycling of the material. A successful attempt to recover complete fibre layers embedded in matrix was performed by initiating a crack by an impact loading and by propagating the crack using a dynamic peel-like loading at a few meters per second at Fraunhofer EMI [1]. A good preservation of the mechanical properties of the recovered single layers could be demonstrated. Nevertheless, alternative methods for both crack initiation and propagation might also produce promising results and be more suitable for small size specimens. In this context, a novel mechanical method is proposed to separate the laminated CFRP layer-by-layer by cutting the interface between the layers using power-ultrasonics.

Experimental tests were conducted to evaluate the feasibility of this novel proposed method. A special cutting sonotrode made of CPM-Steel, with a resonance frequency of 20 kHz was fixed to an Ultrasonic plastic welding setup, which had been adapted to realise cutting experiments. The investigated specimen was a multilayer carbon-fibre PEEK (poly-ether-ether-ketone) composite material in the shape of rectangular specimen featuring a length of 70 mm, a width of 30 mm and thickness of 1,8 mm. The specimen was clamped with an inhouse constructed anvil and successive cuts, featuring a depth of 25 mm (maximum depth of cut which could be achieved from the ultrasonic cutting setup) were initiated starting from one edge of the sample. Interlaminar cracks were successfully induced and a propagation 10 mm further than the edge of the ultrasonic tool could even be observed. In order to propagate the crack through the whole specimen and thus to reach complete layer separation, a dedicated setup has been developed at INATECH in cooperation with Fraunhofer EMI and was adapted to the existing tensile testing machine Zwick-Z20 with a 20 kN load cell. The layer separation setup consists of a base plate, above which the specimen is placed. One end of the specimen is fixed with a wedge-shaped clamp penetrating into the crack and the other end is fixed with a toggle clamp. The base plate is fixed to one side of the tensile testing machine. A pyramid surface profiled clamp is used to firmly grip the single layer which was partially delaminated with the cutting sonotrode. This profiled clamp is then fixed to the other end of the tensile testing machine. The separation force was measured during the delamination of each single layer and the mechanical properties of the recovered single layers were determined in a second step to evaluate the damage induced by the layer separation process. This concept will be extended to other organic composite laminates for a layer-bylayer separation and it will be also adapted to process larger specimens in the future.

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Manufacturing and de-hybridisation of fibre-metal laminates with activatable interface

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An important goal of modern material science is to overcome the restrictions and limitations of homogeneous and monolithic materials. This is often achieved by combining various materials to hybrids for example in fibre-metal-laminates [1]. As the interface between metal and fibre-reinforced polymer is designed to transfer high loads such as fatigue loads [2], it is very difficult to separate or recycle fibre-metal laminates at the end of the component's life cycle without decomposing the polymer matrix.

One possible solution to this recycling problem is an additional layer of a thermoplastic material between the metal and the fibre-reinforced thermoset polymer which can be "deactivated" after the component's life cycle. This study shows the feasibility of processing such a deactivatable fibre-metal laminate. It considers in detail Aluminium (AlMg3) combined with a thin layer of thermoplastic sheet (polypropylene or polystyrene) and a carbon fibre reinforced epoxy.

To increase the adhesion to the thermoplastic layer via undercuts and increasing the surface, the metal sheet is pre-treated using a Nd:YVO4 laser (30 W, MOPA) as proposed by [3] before the different constituents are in-situ consolidated via hot-pressing.

Mechanical performance of the interface is characterized with a specially designed shear edge testing device [4] and a Zwick universal testing machine. SEM images of the metal sheet, before and after the test, enable to have a closer look at the interface and to assess the quality of impregnation of the thermoplastic polymer on the metal surface. After comparison of shear properties of specimens with and without additional thermoplastic sheet, de-hybridisation is realised by heating the fibre-metal laminate.

It can be shown that activatable fibre-metal laminates can be manufactured by laser pre-treatment and hot pressing. Material combination and laser parameters have a significant influence on the interlaminar shear strength of the fibre-metal laminate. By using heat, a de-hybridisation assisting the recycling process after usage is feasible (c.f. Figure 1).

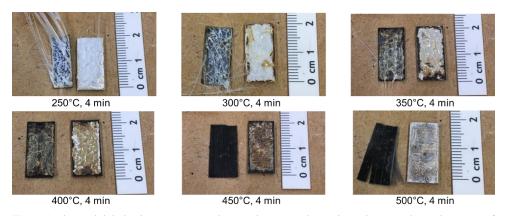


Figure 1. Thermal dehybridization using a thermoplastic interlayer shows best results in the range of 400 to 450 °C.

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3D wire structures for graded property transition in injection molded metal / plastic hybrid compounds

S. Palaniyappan^{1*}, A. Todt¹, M. Trautmann¹, G. Wagner¹

Owing to the demand for improved load resistant and low-cost lightweight structures in automobile and aerospace applications, a trend in the production of hybrid metal/plastic material compounds has substantially increased. By producing such hybrid compounds, the properties of both the plastic and metal part are optimally combined together, and it results in attaining the synergistic effects which cannot be fulfilled by either of them separately. In this research work, three-dimensional (3D) macroscopic transition wire structures (strucwire®) are used in the metal / plastic interface to generate a graded property transition between the sheet metal and the plastic component that allow significantly higher loads on the hybrid compounds. A galvanized steel sheet (HX340LAD+Z100) and transition wire structures were mechanically blasted to improve the interlocking mechanism before they were brazed together using ZnAl based brazing alloy. In particular, the Zn layer on the galvanized steel sheets was used to join the transition structures with or without electroplated Zn coatings on the transition structures. The brazed metal components were then injection molded with short glass-fiber reinforced polyamide through the permeable transition wire structures to produce the hybrid metal / plastic compounds. New insights into the shrinkage behavior of glass-fiber reinforced thermoplastics in permeable transition structures as well as the alignment behavior of the short fibers when flowing through the structures depending on the materials, the permeability and the process-technological parameters were analyzed. In addition, the microstructural, mechanical and intermetallic phase characteristics of the produced hybrid compounds were evaluated using light microscopy, shear tests and scanning electron microscopy respectively.

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A gold-steel composite produced by forging

W. Scheiblechner¹, S. Strobl², R. Haubner²

For decorative applications a gold-steel composite material was manufactured by forging. Sheets made of steel K110, with a thickness of about 0.8 mm, and gold sheets, with a thickness of about 0.5 mm, were put together and forged approximately at 800 °C. Afterwards this bar was twisted in hot stage (Figure 1a). To obtain a 4 mm thick composite sheet two longitudinal cuts were performed. The end pieces of this bar were examined by metallography.

Forging of different steels together is called Damascus technique [1], forging different non-ferrous metals is called Mokume Gane [2], but there is no proper name for the composite made of gold or copper and steel [3].

The steel K110 shows deformation structures, because broken carbides are detected (Figure 1c, d). Earlier this was observed as well in medical drills [4, 5].

The soft gold was partially pushed out at the ends of the sample (Figure 1b). The grain size in gold can reach up to 1 mm (Figure 1e, f). It is supposed that gold recrystallizes during cooling after the hot treatments.

An approximately 10 μ m thick diffusion zone can be seen at the interfaces between steel and gold. According to the phase diagram at 800 °C 20 wt.% Fe is approximately soluble in gold and about 3 wt.% Au in iron.

The production of this gold-steel composite has thus succeeded in a satisfactory manner.

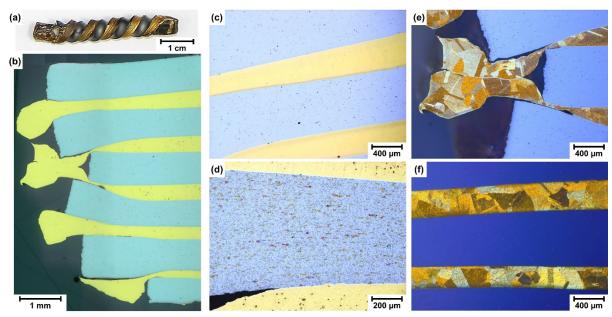


Figure 1. Gold-steel composite. (a) composite after forging and twisting, (b) overview of the sample, (c) polished sample, (d) after etching the carbides with Murakami solution, (e, f) etching of gold with KCN- H_2O_2 .

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Advanced long-time stability of copper-coated CFRP using pulsed laser

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Replacing metal components with fiber-reinforced plastic (FRP) components offers great potential for lightweight construction, especially in the automotive and transportation industries, aerospace and more. This is due their excellent stiffness-to-weight ratio. Furthremore, to improve certain properties, such as their low wear resistance and thermal conductivity, metal coatings can be applied to the FRP, for instance by thermal spraying. Functional coatings on FRP show enormous application potential, but so far offer insufficient adhesive strengths [1-3]. While sandblasting on metallic substrates can be used for the roughening of the surface resulting in high adhesion strength, plastic subsrtates become contaminated with the blasting material (Figure 1a). Additionally, in the case of FRP, the high acceleration of the blasting particles leads to irreparable damage to filaments close to the surface, which weakens the adhesive strength of the subsequent coating. [1] Consequantly, a material-sensitive surface pre-treatment is necessary to improve the adhesion strength of metallically coated FRP. In this work, the surface of the carbon fibre-reinforced epoxy is pre-treated with pulsed laser-based methods (Figure 1b). The used process chain, the resulting surface conditions and their effect on the adhesion strength of wire arc sprayed copper coating (Figure 1c and d) is described in detail in this study. It was found that pulsed laser radiation enabled an increase in adhesion strength of up to 19.3 MPa in pull-off tests [4]. Furthermore, the hybrid metal-plastic parts achieved a flexural stress of 1128.0 MPa in four-point-bending test without coating-impairment. After 1000 hours of salt water aging, the copper coating showed surface corrosion effects, while the joining zone remained unaffected. The adhesion strength between the metallic sprayed layer and the CFRP substrate was doubled compared to sandblasting. The long-term durability of the hybrid was demonstrated with an intact coating after flexural loading and an unaffected interface after aging.

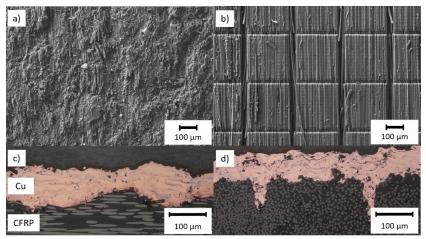


Figure 1. SEM images of CFRP substrate' surface after a) sandblasting and b) laser pre-treatment and cross-sections of the copper-coated c) sandblasted and d) laser pre-treated sample.

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Advances in the development of polymer coated bioactive glass composite foams for regenerative medicine

23. Symposium Verbundwerkstoffe und Werkstoffverbunde

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The production of engineered porous three-dimensional scaffolds is a field of extensive research for regenerative medicine especially in bone tissue engineering to repair critical bone defects. The use of bioactive glasses (BG) as scaffold material has been considered particularly promising due to their reactivity with the surrounding environment, which allows having a strong bonding to bone and inducing the formation of new tissue led by the biological activity of the released ions during the dissolution process [1]. Nevertheless, BG scaffolds are brittle constructs with poor resistance to crack propagation which is a challenge for load-bearing applications where the scaffolds are under mechanical loads not only in the tissue regeneration process but also during implantation. Therefore, polymer coatings have been considered an interesting approach to overcome the lack of mechanical properties of BG scaffolds, while providing additional functionalities, for example, as therapeutic drug carriers [2].

Natural polymers and proteins such as gelatine, collagen, soy and zein have been considered as coating materials for BG-based scaffolds produced via the foam replica technique [3-6]. Moreover, combining traditional herbal medicine or phytotherapeutics with biomaterials is gaining attention to obtain multifunctional 3D scaffolds. For instance, to tackle bacterial infections in the implantation site. Recently, the antibacterial properties of Manuka Honey (MH) in combination with BG based scaffolds were investigated [6]. In this study, we evaluated the incorporation of MH in a coating made of zein, a natural protein derived from corn with great potential for applications in tissue engineering due to its properties in terms of biocompatibility and degradability. Figure 1 shows the surface of BG scaffolds before coating and after coating with zein and MH. MH was visible as dark regions on the surface. The release of the honey was measured by means of UV-vis spectroscopy and the antibacterial activity against the gram-positive bacteria *S. Aureus* was evaluated. Regarding the mechanical properties, the coated scaffolds exhibited superior compressive strength than the non-coated BG scaffolds.

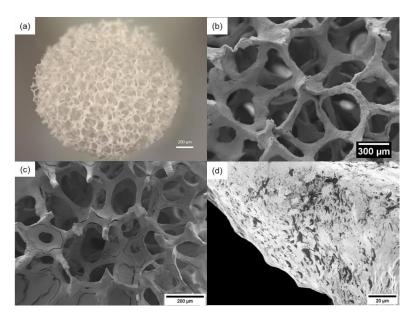


Figure 1. Optical microscope and SEM images of coated and non-coated scaffolds. a,b) 45S5 BG scaffold, c) zein coated BG scaffold, d) zein and MH coated BG scaffold.

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Composite wire for use in additive manufacturing and thermal spraying made from layered and jointly formed strips

A. Oswald^{1*}, H. Saleh¹, T. Stuth¹

hpulcas GmbH has developed a process for the production of compound wires from metal strips [1]. The method enables a wide range of material combinations to be produced in wire form without conventional alloying procedure. These wires can be used as feedstock for thermal coating processes and additive manufacturing processes as well. The basic concept of the technology is the folding of the layered metal strips in a specific sequence by roll profiling. While the outer material forms the sheath of the compound, the inner metal strip replaces the material usually introduced in powder form in conventional cored wires, as can be seen in the Figure below.

In this way, a compact, bimetallic bulk wire can be produced that bypasses the disadvantageous properties (i. e. porosity, high oxygen content due to large specific surface, splashing tendency during welding) of powder-filled wires. Nickel/Aluminum wires are one possible application, enabling the supply of filler metals for the build-up of nickel aluminides by welding. They are known for their beneficial properties (high hardness, low density, good resistance to high-temperature oxidation, corrosion and wear resistance) but also for their room temperature brittleness, that makes conventional wire production via melting and forming impossible. Due to the lack of powder filling and the low recrystallization temperature of the high purity nickel sheath, the layered stack Ni/Al-wire can be softening annealed at any point during processing. Therefore, the wire can be offered in hard, semi-hard and also in soft condition even in the lower dimensional range (Ø 1.6 ... 1.0 mm) and is suitable for welding operations requiring tight bending radii, too.

The method enables a wide range of possible material combinations and their supply in welding wire form, especially, alloys which form brittle and non-ductile intermetallic phases. So far, the process has been proven not only for the production of NiAl composite wire, but also for FeAl-compounds. Further material combinations and material ratios are under development.

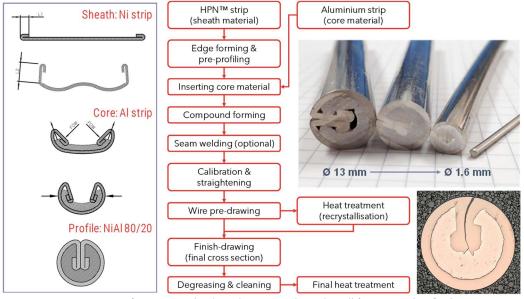


Figure 1: Mean processing steps to form a Ni80Al20 (wt.%) compound wire by roll forming and its further processing to thin wires. Wire cross sections after profiling (\emptyset 13 mm) and several drawing operations down to \emptyset 1.6 mm.

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Deep Drawing of Thermoplastic Fiber Metal Laminates

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Thermoplastic fiber-metal-laminates (TFMLs) are the materials composed of metal sheets as outer and intermediate layers as well as fiber-reinforced thermoplastic polymer (FRTP) core. Due to their promising lightweight potential and improved mechanical properties, these materials have recently been increasingly developed and investigated.

Forming of TFMLs into complex geometries through conventional forming (e.g. deep drawing) methods at room temperature is limited, where the forming potential of the fibrous structure is restricted and the metal/FRTP interface strength cannot withstand the shear stresses due to forming leading to delamination problems. Moreover, further kinds of failures arose during warm forming of TFMLs semi-products, such as significant core thickness irregularities. Therefore, the current study offers a novel processing method - namely one-step thermoforming process - for producing complex TFMLs components in which bonding and forming of the unbonded TFMLs layers take place simultaneously. With this process, arbitrary metallic sheets and FRTP thicknesses can be processed with improved forming potential due to the continuous sliding of the unbounded layers during the forming step. Further advantages of this process are the reduction in energy consumption and in the amount of waste of the cut-to-size mono materials, which can be easily recycled.

For this purpose, the study focuses on two aspects: a) developing the tools required for a robust thermoforming process and b) developing several forming scenarios aiming at achieving defect-free components, which can be reached by varying the temperature profile and holding force utilizing a universal sheet metal testing machine. So, heatable/coolable tools for axis-symmetrical circular deep drawing operations are firstly developed and experimented. TFMLs blanks with different thicknesses and fiber orientations were investigated.

With the developed tools, homogenous temperature distribution was reached. Moreover, defect-free 40-mm deep-drawn TFMLs cups could be achieved at the optimal process parameters. A further development of the forming tools in modular shapes is foreseen to produce further complex geometries.

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Design, Manufacturing and Testing of a Metal-Ceramic Hybrid Brake Disc

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Future mobility concepts like electric powered vehicles demand for new braking technologies and brake disc concepts. Due to the technological progress regarding the recuperation capabilities of electric vehicles, friction brakes are merely needed for complementary braking and more importantly for emergency braking manoeuvres. Consequently, new brake disc designs are viable in which for example the mass of the brake discs can be reduced. Due to the fact, that the brake discs in electric powered vehicles aren't used as frequently, the corrosion of the brake discs and brake pads are problems which have to be coped with. Thusly the use case or rather the (performance) requirements for brake discs for electric powered vehicles are very different compared to brake discs for cars with internal combustion engines.

A new concept in the form of a metal-ceramic hybrid brake disc is propagated for the use in electric powered vehicles. It consists of an aluminium carrier body which is lined with ceramic friction segments on the friction surface of both sides. For the friction segments a short fibre reinforced ceramic matrix composite (in particular a carbon fibre reinforced silicon carbide: C/SiC) is used. The outlined concept allows for a light-weight, corrosion resistant and economically viable emergency brake with outstanding friction properties for the use in electric powered vehicles. An overview is given on the potential application areas and on the design, construction, manufacturing (esp. joining) and testing of said hybrid brake disc.

A potential use case of a mid-class sedan with a mass of around 1.8 t and maximum travelling speeds of up to 200 km/h is taken as a basis for the design and construction of a metal-ceramic hybrid brake disc prototype (Figure 1). This prototype was tested on the dynamometer test bench at the University of Bayreuth under emergency braking conditions. Different characteristic values like wear, coefficient of friction and different temperatures were measured. Furthermore, possible joining methods were evaluated and thermomechanical characterisations of different joints were conducted.



Figure 1: Metal-ceramic hybrid brake disc prototype (outer diameter = 410 mm): Individual parts (left), assembly (middle), prototype during tribological testing (right). [1]

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Hybrid Processing of Coupling Rods

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A hybrid process is being developed within the project "pro-TPC structure", in which continuous fiber-reinforced, tape-layed structures are overmolded with discontinuous (short fiber) injection molding material on all sides (see figure 1). This provides major advantages in terms of economy and cycle time - making the process suitable for high-performance components with large volumes, such as those required in the automotive sector for example.

The manufacturing technology at the IVW includes a production cell on an industrial scale, which stands in direct comparison with the conventional metal component forming process. The suitability for industrial application is proven by a continuous process control starting from the semi-finished product to the preform, via preheating and insertion step up to the injection molding process.



Figure 1. Continuous fiber-reinforced loop as insert in injection mold with force introduction sleeves

In a first step, a topology-optimized structure was developed and designed according to component and process requirements - such as load introduction and flow front problems. For this purpose, the raw materials were analyzed mechanically and thermally (DSC/TGA) and transferred to the simulation models.

The subsequent tape-laying process for the structurally optimized reinforcement structure, in this case a loop insert, was realized on a heated winding mold. The injection molding process was carried out on an ENGEL Victory 1560/400.

The results of an initial component test show, that the static requirements are achieved, while the component weight is more than 16% lower than that of a conventional metal coupling rod. It should be noted that the results shown in the poster were obtained in static tension and compression tests, using a convection oven to preheat the inserts. The failure force in tension and compression in the preliminary study is 115 kN and -74.6 kN, with one demonstrator for each test assembly.

In the outlook of the poster, the main test series is described, which uses a fully automated IR radiation field to preheat the insert loop and tests the hybrid coupling rod in detail both, statically and dynamically, with larger sample size.

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Influence of contaminants on the aluminum oxide - niobium phase boundary chemistry in refractory composite materials

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Coarse-grained refractory ceramics based on α -Al₂O₃ are common materials for linings in high-temperature processes such as steel casting technology but suffer from failure by thermomechanical stresses. Likewise, refractory metals have been employed but lack sufficient resistance to chemical and oxidative attack. Coarse-grained composites produced from both material classes promise an outstanding combination of thermomechanical and additional functional properties such as low shrinkage, excellent resistance to thermal shock, and high electrical conductivity.

Technical grade raw materials of α -Al₂O₃ and Nb contain impurity elements that induce the formation of secondary phases such as carbides and complex oxides during the synthesis of conventionally sintered bulk composites. These phases further develop while exposed to typical application temperatures of 1500 to 1800°C and affect the phase boundary cohesion. To understand the principles of formation, we investigate model materials, such as α -Al₂O₃ substrates sputter-coated with Nb, in addition to the technical grade material. This allows to independently study the influence of impurity elements on the chemistry of the ceramic-metal interface. Electron microscopy methods elucidate the microstructure, while transmission electron microscopy and atom probe tomography (APT) advance the understanding of nano-scale segregation and phase formation at the phase boundary. APT data (Figure 1) show the presence of a thin oxidic layer at the interface of the as-deposited composite. Investigation of the phase evolution after heat treatment reveals the interface to be altered by C and O presence. The addition of further impurities provides a road to modify the interface chemistry and, thus, the material's behavior.

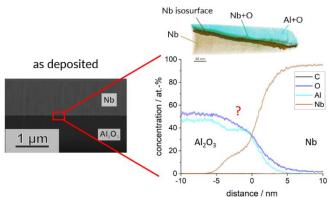


Figure 1: APT analysis of the Al₂O₃-Nb interface.

Acknowledgments

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Investigation of the Interfacial Adhesion of Thermoset-Metal-Hybrids using Injection-Molded Single Lap Shear Specimens

N. Schmeißer^{1*}, Michael Gehde¹

Multi material design combines the positive material properties of the composite partners. In the case of plastic-metal-hybrids, they combine the low density of the polymer component with the high strength and stiffness of the metal component. Hybrids based on thermoplastic materials represent the state of the art and are used in numerous series applications in the industrial environment. In contrast, the use of thermoset-metal-hybrids for series components is often limited by the complex production of such composites, e.g. using autoclave technology. In order to make the excellent properties of thermoset materials, such as good temperature and chemical resistance and a low creep tendency, usable for series applications, a method and technology development along the entire product cycle is necessary. This topic is being addressed by the TU Chemnitz in cooperation with an industrial project consortium as part of a project funded by the German Federal Ministry of Education and Research. A first step is the development of a suitable test method to evaluate the adhesion strengths. In this publication, the possibility of producing thermoset based single lap shear specimens in the injection molding process will be presented. Thermoset molding compounds based on epoxy resin and phenolic resin as well as different types of steel are used to produce these test specimens. Furthermore, the influence of various surface treatments on the adhesive strength of the thermoset-metal-hybrids is investigated. The focus of the investigations is on increasing the adhesive strength by using different surface coatings and textures.



Figure 1. Test specimen based on DIN EN 1465 "Adhesives - Determination of tensile lap-shear strength of bonded assemblies"

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Investigation on Self-Healing Mechanisms in Metal-Polymer Structures

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In mechatronics technology, plastic housings are used to protect components from harmful environmental influences, such as moisture, media, or reactive substances. Connections, preferably in the form of metallic lead-frame structures, through the housing wall, are required for their electrical supply or control. In this system, an insufficient connection between the plastic component and the metal surface due to the incompatibility between the two materials is often observed. In industrial applications and due to the thermal-induced stress, cracks in the polymer can be formed leading to leakage. Therefore, an adhesion promoter is implemented in the metal-polymer interface. This layer should flow into micro-damage such as interface, cracks, inhibit them from growing and close them. Based on that self-healing mechanisms can be created. The selected primer is an epoxy form DELO (DUALBOND LT2266). It is an adhesion promoter with two reaction stages. In these, the first stage provides fixation to the lead frame directly after the coating step. This can be done within seconds using UV light (UV light with 365 nm). In the second stage, the material will be thermally hardened during the injection moulding process.

In this study, the primer fluidity and ability to fill micro-cracks are investigated. For these characterizations, a pressing test was carried out using a cylindrical piston with a pressing ram. Several pistons were produced with different die diameters. The pistons and the ram were installed in a universal testing machine. The tests were done on completely cured primer at different temperatures and with different pressing speeds (100, 200, 300, 400 μ m/min). Fig. 1 shows the resulting stress-strain curves from the pressing test at 150 °C and with ram speed of 100 μ m/min.

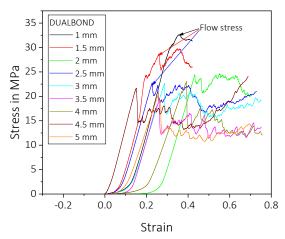


Figure 1. Extrusion stress-strain curves of primer at 150 °C using containers with different die diameters and ram speed of $100 \mu m/min$

Furthermore, the primer capability to fill micro-cracks has been characterized using negative polydimethylsiloxane (PDMS) templates with micro-meter holes. The PDMS stamps could be moulded negatively using a micro-structured silicon wafer (see Fig. 2 left). Using the PDMS templates and based on the stamping process, the ability of the primer (partially cured strips used as specimens) to fill the template holes was characterized. The characterizations were done on specimens with different

degrees of curing. The filling ability of the primer is then estimated by the filling depth which is here equal to the height of micro-structured of the primer surface. Using white light interferometry, a 3D-micro-profile of the primer micro-structured surface could be generated and the heights were measured (Fig. 2 right).

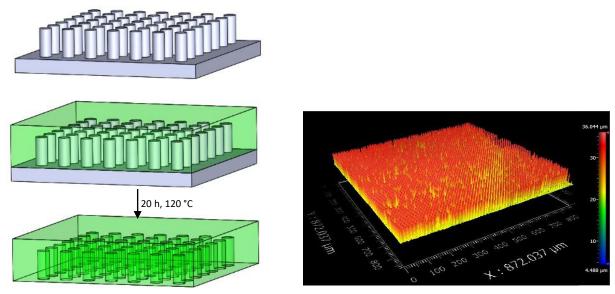


Figure 2. Left, schematic representation of the manufacturing process of PDMS templates by negative moulds of a microstructured silicon wafer; Right, 3D-Micro-profile of the micro-structured partly cured primer by white light interferometry

Finally, the penetration behaviour of the selected primer in defined capillaries made in Ultramid was investigated. Holes with a diameter of 0.3 mm were produced in injection-moulded A3EG7 plates with a thickness of 4 mm. A substrate coated with an adhesion promoter was placed on the test specimen with pressing forces determined by the piston pressing test and at different temperatures. Metallographic analyses were carried out to verify the filling grade (Fig. 3).

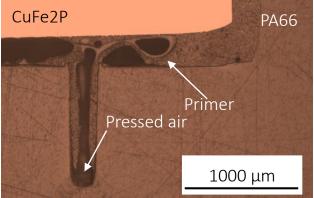


Figure 3. Cross-section of the pressed coated-copper on PA66 plate at 50 °C with 4 MPa

Due to the mismatch in the coefficient of the thermal expansion (CTE) in a hybrid system among the copper and the polymer, the stress is introduced in the system upon heating and cooling down, which should be the driving forces for the self-healing mechanisms. In this study, the ability of the selected primer to flow and fill micro-cracks as long as it is exposed to external impulse is proven meaning the primer can flow and fill the formed cracks in the metal-plastic system under the induced thermal stress.

Investigation on aluminum-aluminum hybrid cast nodes from low pressure die casting

R. Van der Auwera^{1*}, J. Clausen¹, S. Schmidt¹

Hybrid casings from the same material offer a high potential for lightweight construction and recycling.

Hybrid aluminum-aluminium cast nodes were produced via low pressure die casting. The alloys used were extruded aluminum EN AW-6060 and cast aluminum EN AC-42 100. The oxide layer was removed via brushing. Conventional T5 heat treatment on the hybrid cast parts was performed. To ensure a stable and reproducible casting process the filling parameters and melt and tool temperature and were kept constant. To evaluate the transition area characteristics micro indentation tests, mechanical wedge test and a combined three-point bending peel test of hybrid test parts were used. The results from micro indentation tests show that the heat treatment was successful. The mechanical tests prove that thinner aluminium inserts produce better material bonding through the casting process. Although the oxide layer of the insert still is a challenge to ensure overall material bonding. Secondary dendrite arm spacing sDAS were analyzed as a function of cast hight and cast wall thickness with respect to heat treatment.

To predict the melting of the extruded aluminum parts in the casting process a simulation of thermo couples in Magmasoft 5.4.1 was used. In order to determine the heat transfer coefficient between insert and casting different temperature curves were generated for temperature profiles within the insert an on the insert. Temperature curves with different heat transfer coefficients were simulated. The results of the simulation were compared to micro sections of the test specimen and a temperature-dependent heat transfer coefficient could be approximated. Furthermore, it is shown that different melting characteristics occur with respect to heat input in the simulation.

The results were used for the production of a demonstrator sub frame geometry with integrated aluminium profiles. The filling and solidification process of the demonstrator was simulated using casting software Magmasoft.

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Mechanical performance evaluation of carbon fiber composites equipped with an in-situ wireless sensor body

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In modern day structural engineering, fiber-composites play vital role in various industries for light-weight constructions. These structures can also be equipped with multi-component sensor systems for various performance evaluations both during and post curing processes. In this work a novel method is developed to place a wireless sensor inside a fiber reinforced composite system to enable multifunctionality without much trade-off in mechanical performance. The aim of such system is to both observe curing kinetics during the curing process and to support the structure after curing by sensing stress concentration (post-curing) during dynamic loading process.

Key objective here was to optimize the sensor shape to minimize stress accumulation and crack propagation around the sensor geometry inside the cured composite sample under stress. A finite element simulation model is developed for this purpose and a parametric model for the sensor geometry provided better insight into the force distribution along the fibers around the sensor element. Mechanical performance of fiber composites equipped with sensor samples, which are extended by dielectric channels, were analyzed. Such channels facilitate transmission of sensor information through electrically conductive elements such as carbon fibers, which are widespread in today's industrial and consumer applications.

Consequently, different testing sample combinations were prepared, for which, fibers were either cut or bend around the sensors and dielectric channels. These modifications, results in a decrease in mechanical characteristics in the fiber composites and in this work a detailed comparison is made between different methodologies of sensor placement, in vacuum assisted resin infusion (VARI) process. The samples were tested under different standard loading conditions and the results were compared with simulation model to produce a reliable correlation. Eventually, the goal of this work is to train the system in VARI and transport the knowledge into various industrial standard manufacturing processes like press-forming, autoclave curing etc.

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Microstructural evolution of the bonding zone in TRIP/TWIP laminate produced by accumulative roll bonding

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The four-layered laminate made of X5CrMnNi-16-6-6 (TRIP steel) and X5CrMnNi16-6-9 (TWIP steel) was manufactured by accumulative roll bonding (ARB). An intermediate annealing between rolling passes allowed to achieve good bonding between the laminate layers. The microstructure of the laminate at each step of production was analysed with a main focus on the bonding interface and deformation lenses by means of scanning electron microscopy, including chemical and orientation mapping techniques, and microhardness measurements. Additionally, a special measuring routine was developed to reveal spatial distribution of the grain size along the cross section. Finally, tensile specimens were cut out from the laminate and tested under quasi-static loading with subsequent fracture surface analysis. Repeated rolling and annealing of the steel layers resulted in the alteration of the grain size and microhardness. The grain size in the layer of TWIP steel after first roll bonding and annealing was found to drop down near the surface, whereas no such effect was found in TRIP steel. The microstructure of a deformation lens was found to fully change from severely deformed brittle steel matrix with excessive oxygen content after rolling to a ductile mixture of sub-micron globular oxides and austenite grains after annealing. These ductile deformation lenses ensure excellent bonding of layers and microcrack blunting. This allowed to achieve a remarkable combination of mechanical properties of the four-layered TRIP-TWIP laminate with a yield strength up to 800 MPa and an elongation to failure up to 45 %, which resulted in the work of deformation up to 41 GPa·%.

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Nano-crystalline AlZrN coatings grown by CVD

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The unique microstructures of nanoscale coatings are the reason for their superior properties in wear applications like cutting tools. By using chemical vapour deposition (CVD) a nano-lamellar AlTiN coating consisting of TiN and AlN was achieved by spontaneous self-organization during layer growth [1, 2, 3]. These results suggested the investigation of the AlZrN system.

In this study, AlZrN coatings were deposited by CVD from ZrCl₄ and AlCl₃ precursors and reaction with NH₃ at 950 °C. By changing the AlCl₃:ZrCl₄ ratio various layers with changing chemical composition could be deposited. The layer thicknesses were determined gravimetrically and by means of dome grinding. To verify the microstructure of the coatings transmission electron microscopy (TEM) and X-ray spectroscopy (XRD) were applied. The coatings showed the formation of nano-crystalline phases but additionally some amorphous phases. Pillar structures were found throughout the coatings, with a higher crystallinity in the pillar compared with the surrounding material (Figure 1). Regarding the transition area between the substrate and the deposited coating, differences in the elemental composition as well as the crystallinity compared to the bulk of the coatings were observed. Depending on the elemental composition, the formation of hexagonal AlN or cubic ZrN was found. Additionally a shift of the respective lattice parameters was observed by x-ray diffraction, which indicates the incorporation of other elements in the crystal lattice.

With the obtained results new information on the microstructure as well as the crystallinity of AlZrN coatings with varied Al/Zr ratios was received, which can further help to customize coating properties such as the phase formation accompanied with different crystal structures.

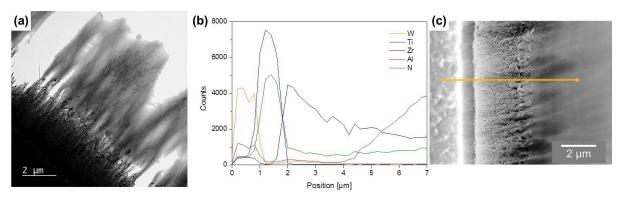


Figure 1. TEM and EDX results from AlZrN nano-crystalline coatings: (a) pillar structures throughout the coating, (b) EDX line scan showing a Zr-rich intermediate layer between the TiN and AlZrN, (c) TEM picture to the EDX line scan.

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Stress-dependent and spatially-resolved potential assessment of hybrid designs for a structural guide vane

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In hybrid lightweight structures, mass can be decreased while maintaining functionality by allocating materials to areas according to the prevailing stress conditions. This approach is interesting for structural guide vanes with limited design space due to aerodynamic requirements and simultaneous demand for mass savings. In this paper, a methodology is presented, which can be used to quickly assess the potential of a hybrid design for a component, using the example of an engine guide vane. [1]

The prevailing stress state is decisive for the material allocation. While isotropic materials are needed to bear the stresses in complex stress states, orthotropic materials can be used for axial or biaxial stress states. The stress analysis required for this classification is usually carried out by manual evaluation of principal stresses in component. [2]

A methodology for the automated evaluation of numerical simulation results (e.g principal stress) and for the spatially resolved derivation of materials suitable for existing stresses reduces the design effort and significantly increases the quality of the analysis results. First, a methodology for identifying similarly stressed areas is presented. Then, the relationship between stress states and the material selection is considered and rules for material assignment based on stress magnitudes and stress states are established.

The developed methodology is implemented using the example of a structural engine guide vane. The geometry of the guide vane generates complex stress states even in simple loading scenarios, making it very suitable for the application of the methodology. Based on the analysis carried out, the potential of implementing a hybrid design for the guide vane can be easily estimated by identifying sufficiently large areas with the same material allocation as depicted in Figure 1.

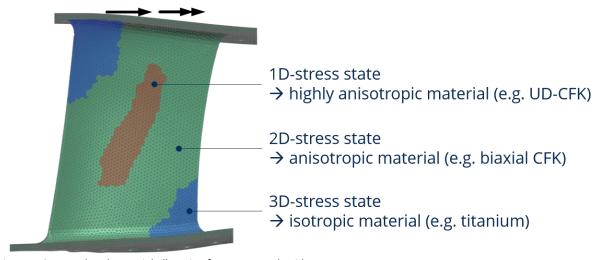


Figure 1: Stress-related material allocation for a structural guide vane

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[Verbund] F: Bio-inspirierte und Nachwachsende Rohstoffe, Nachhaltigkeit

A COMPARISON OF DIFFERENT NATURAL FIBRE REINFORCED COMPOSITES USING RTM & VARI PROCESS

B. Ravindran^{1*}, U. Kirschnick¹, M. Salzmann¹, G. Le Vely², M. Ekam¹, S. Schmid¹, R. Schledjewski¹

The increasing consideration of natural fibres as potentially sustainable reinforcements in Fibre Reinforced Polymer (FRP) composites needs to address several challenges to increase market readiness, one of them being composite manufacturing [1-3]. Due to the commercial applications of NFRPs in predominantly small-sized with medium to high component complexity, high-volume, non-structural components (e.g. decking for construction industry, and interior panels for automotive industry), liquid composite moulding are suitable manufacturing technologies [4]. Especially, resin transfer moulding (RTM) and vacuum assisted resin infusion (VARI) are widely used methods that has been reported to produce natural fibre composites with reasonable mechanical properties.

In this present study, two different textiles, namely hemp in plain weave and flax fibres in 4x4 twill weave are used as the reinforcements together with a partially bio-based epoxy matrix to manufacture NFRP plates using two different LCM processes RTM and VARI. The materials and processes are compared in regards to density, mechanical properties of the plates are examined by tensile tests and their thermal properties that is examined by Differential Scanning Calorimetry (DSC). In conclusion, it is visible that the RTM offers better impregnation with greater fibre volume fraction over VARI. Nevertheless, the flax NFRP from RTM process exhibits favorable material properties and suitable for a wider range of application.

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Bioinspired nacre-like zirconia/PMMA composites for dental CAD/CAM restoration

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Zirconia, with outstanding mechanical strength, wear resistance, and biocompatibility, has been considered as a promising material for dental computer aided design/computer aided manufacture (CAD/CAM). However, high hardness and brittleness, pale appearance, and aging cause clinical issues such as potential chipping and fracture, unwanted wear of the opposite teeth, and poor machinability, which limit the long-term performance of zirconia restoration. Materials with both high strength and toughness is still in need for dental CAD/CAM restoration[1].

On the other hand, the polymer-infiltrated-ceramic-network (PICN), with a sintered porous ceramic matrix infiltrated with polymer showed great potential for dental CAD/CAM application with a balance of machinability and mechanical property. Moreover, to fabricate better dental restoration, efforts of bio-inspiration has been made to fabricate composite mimicking the 'brick and mortar' microstructure of nacre, which has both high strength and toughness. As a result, zirconia could be incorporated into PICN with nacre-like microstructure to fabricate dental CAD/CAM restoration[2][3].

In this study, bioinspired nacre-like zirconia/PMMA composite has been fabricated via bi-directional freeze casting. This composite showed a similar 'brick and mortar' microstructure as nacre. The flexural strength ranges from 150MPa to 290MPa depending on different kinds of zirconia and different ceramic fractions, which could support the clinical use of this composite. Also, Young's modulus of this composite is within the range of human enamel, which ensures the safety of functioning in the oral cavity. Moreover, this composite shows great fracture toughness indicated by an increasing crack-resistant behaviour, which ensures a better long-term clinical performance. (Figure 1.)

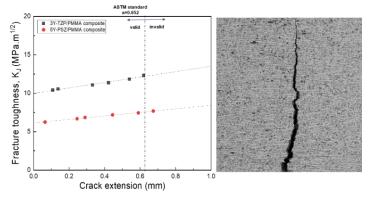


Figure 1. Crack growth resistance curves (R-curve) of 3Y-zirconia/PMMA and 5Y-zirconia/PMMA composite with 75% ceramic fraction. Both 3Y-zirconia/PMMA and 5Y-zirconia/PMMA composite present an increasing R-curve and deflecting crack propagation.

These results illustrated this bioinspired nacre-like zirconia/PMMA composite is promising for dental CAD/CAM restoration.

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Fully bio-based high-performance composite

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The interest in high-performance composites based on renewable resources is growing vigorously. Recently, the authors presented 100% bio-based epoxy resin produced from epoxidized linseed oil (ELSO) and pure crystalline citric acid (CA) ^[1]. The main objective of the present study is now to produce a composite based on the novel ELSO/CA resin matrix and flax fibers, which exhibits a high stiffness and strength.

To transform the ELSO into a curable resin, a defined amount of CA (100:25) was added and grinded in a bead mill. Prior to processing, reinforcing flax fabric Biotex 400g/m² 2x2 Twill (5 layers; Composites Evolution, Chesterfield, UK) was dried at 120 °C (1 h). Composite plates were manufactured by Resin Transfer Molding (RTM) and cured for 24 h at 80 °C followed by 24 h at 120 °C. Composite specimens were cut out and analyzed by 3-point bending tests at room temperature. The produced composite exhibits a flexural modulus of 5500 MPa and a flexural strength of 80 MPa. Thus, regarding the mechanical properties, the composite represents an interesting alternative to conventional composites.

By RTM a novel, high-performance composite with a bio-based carbon fraction of 100 % was produced, which is uncritical in terms of environmental and safety issues. Since CA is solid, a homogeneous fiber impregnation and the manufacturing of large components is somewhat challenging. Thus, we currently work on an innovative ELSO/CA production process without solid content. This research project is funded by the Austrian Ministry for Transport, Innovation and Technology in framework of the program "Produktion der Zukunft" under contract no. 858688, within the context of the project "Reliable and Sustainable Composite Production for Biobased Components."

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Manufacturing of cellulose-based composites with two-step extrusion

23. Symposium Verbundwerkstoffe und Werkstoffverbund

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Cellulose fibres from regional plants like miscanthus have gained a lot attention as a replacement of synthetic fibres due to their eco-friendly nature, abundant local availability, low cost, reducing "food versus fuel" competition and their application in bio-based composites [1–3]. Typical ways to obtain the natural fibres in practice are mainly refining and/or cooking processes [4]. In our study, extrusion technology was used for fibrillating the fibres for preparing the reinforcement of cellulose-based composites.

Using a twin-screw extruder, miscanthus was extruded in different swelling media. The extrudates were purified and analysed for fibre morphology and chemical composition. It could be shown that the swelling media significantly influences the fibrillation process, leading to different fibre morphology. In a second extrusion step, selected extrusion-fibrillated fibre materials were compounded with cellulose-based matrices such as cellulose acetate (CA) and cellulose acetate butyrate (CAB) to produce injection-mouldable cellulose composites. The mechanical properties of the compounds were compared to the unmodified grades and to compounds made with the drop-in biopolymers bio-PP und bio-PE as matrices. The rheological and morphological properties were characterized as well. It is shown that the mechanical properties of cellulose-fibre reinforced CA prepared this way are comparable to those of glass fibre-reinforced polypropylene (GF-PP) with similar fibre content (20 wt. %).

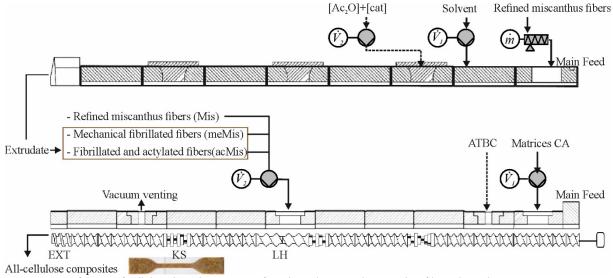


Figure 1. Manufacture of cellulose-based composites from biopolymer and miscanthus fibres through 2-Step extrusion

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Mechanical flexible composites from renewable resources

M. Schwaiger^{1*}, M. Bender¹, J. Taesler², K. Resch-Fauster¹

Conventional fibre reinforced composites are usually considered as high-performance materials with high specific stiffness and strength. In contrast mechanical flexible composites can combine high strength with high flexibility regarding bending. Thus, this material class brings a lot of new possibilities. They can cover potential applications in apparel, furniture and sporting goods but also as technical leather, technical canvas and damping elements. By further using renewable resources, the ecological aspect is improved and the enormous innovative capacity is combined with high resource efficiency. This work addresses the development of such mechanical flexible composites from renewable resources. As matrix system a polymer based on epoxidized vegetable oil with 100 % bio-based carbon content was developed without the usage of catalysts or solvents. The used reinforcements were knitted textiles made of rayon fibres. Composites were successfully manufactured by applying Vacuum Bagging. In Figure 1 the developed matrix (left) and a produced composite (right) are visualized to demonstrate the flexibility.

For the pure matrix system, a glass transition temperature of 2,5°C was observed by Dynamical Mechanical Analysis. The flexible composites were characterized regarding mechanical properties and morphology. They exhibit strong anisotropic properties, due to the knitted structure of the textile. In knitting direction, the composites were less mechanical flexible (> 4x higher bending stiffness) but exhibited more than 3 times higher tensile strength values.

The next step is a systematic material optimization based on the established processing-structure-property relationships in order to tailor the composite's properties for different applications. This includes especially the adjustment of the reinforcement layer (e.g. knitting structure, variation of fibre materials).

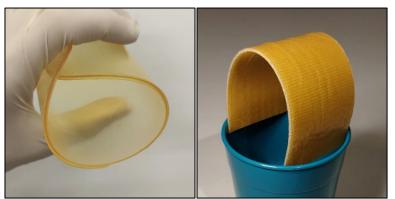


Figure 1. Demonstration of mechanical flexibility of pure matrix system (left) and composite material (right).

The research project is funded by the Austrian Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology in frame of the program "Produktion der Zukunft" under contract no. 871403, within the context of the project "Semiflexible and flexible composites based on renewable resources".

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Timber and mycelium-based composites for load-bearing building components (Komponenten aus Holz-Myzelium-Kompositen für tragende Konstruktionen)

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According to the DGNB (German Sustainable Building Council), the construction industry is responsible for more than 38% of CO² emissions worldwide. Furthermore, 80-90% of these resources are used in buildings. Additionally, after a building's life cycle, only a minor part of the demolition waste is fully recyclable and causes a significant impact on landfills. These facts make an urgent demand obvious for innovative bio-based and non-mineral construction materials with controlled properties, applicable also for load-bearing structures. The development of innovative, cradle-to-cradle materials based on fungal mycelium could replace traditional oil-based construction materials, e.g., thermal insulation, lightweight fill, or noise absorption. Mycelium-based composite materials combine lignocellulosic substrates with the vegetative component of filamentous fungi, which form hyphae, growing into a close-meshed network, that give the resulting material a solid structure, carrying compressive and minor tensile stresses. Fungi belonging to the genus Basidiomycetes, such as *Ganoderma lucidum*, *Ganoderma applanatum*, or *Fomes fomentarius*, are commonly found in forests, decomposing there deciduous wood, which may even be chemically contaminated. Therefore the use of wood as a substrate for the bio-fabrication of mycelium-based composites represents a significant advantage to the circular economy, extending the life cycle of old and contaminated wood or using wood waste form timber

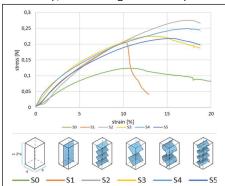


Figure 1. Shear resistance of mycelium composite matrices with different imbedded boundary areas.

industry. In order to achieve a mycelium-based composite material with controlled mechanical characteristics, various research on the symbiotic combination of mycelium and lignocellulosic substrates as well as material tests on the mechanical behaviour and the strength were carried out. For the replacement of plastics or mineral materials in common construction systems and construction materials a systematic material design based on composite models (*Werkstoffstrukturmodelle*) and based on three components as mycelium, timber substrate and different types of aggregates was conducted. The research aimed for the optimization of mycelium composite materials from different points of view: 1. the manufacturing methods, based on lignocellulose and fungal mycelium

and various strategies for influencing positively the hyphal growth and meshing. 2. The improvement of strength of mycelium composite materials: as conglomerates with timber aggregates and natural tissue (e.g. he fmp) for brick-like masonry systems or as laminates, consisting of mycelium plus wood chips for OSB-like timber plates. The strength of a mycelium conglomerate consisting of mycelium and a wooden substrate in the form of a grain of 5mm max. size is fairly similar PU-foams with a strength of 1,5N/mm² and a Young's Modulus 4N/mm² and suitable to replace this artificial component in different construction contexts. The high shear strength of mycelium composites joined with timber opens a wide range of biobased timber preproducts. Two replacing construction systems were developed: a masonry system based on a classical brick-format and a KS-format brick and a sandwich-wall-system with laminated veneer plates and mycelium composite core.

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Symposium Verbundwerkstoffe und Werkstoffverbunde - Verbund 2022, Leoben

ABSTRACT

Wood in Top Form - New Perspectives in Wood Construction

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Moulded wood profiles from solid wood are novel structural elements for architecture, civil and mechanical engineering. The idea is based on wood as a cellular material that undergoes large deformations when heated and compressed. With the help of moisture and temperature the deformation can be released and used for shaping.

The presentation will show the thermo-hygromechanical behaviour of wood and its particularities such as recovery when moistened and fixation when dried. For structural use wooden tubes can optionally be reinforced with technical fibres and textiles from glass, aramid and carbon.

Within this research particular attention is paid to the use soft and hardwood such as beech. It could be shown that this specie is suitable for moulding perpendicular to the grain. Consequences regarding sylviculture and environment are being discussed.

Experimental test results of components and connections will be presented as well as environmental impact assessments.

Structural tubes showed outstanding load bearing capacities. Special applications from the building sector and plant engineering such as solar and wind power stations are also dealt with. Within the project BEECHPOLE, a lightning pole is being developed. The study of its impact behaviour on a test track with a car showed excellent results regarding the frangibility criteria.

The same physical principles are used for the shaping of sandwich cores from wood, especially Balsa. This approach uses end grain panels from bi-axially compressed wood that allow the manufacturing of double curved shells. In addition with high performance fibres one obtains sandwich elements with a high potential in lightweight design.

Dresden, November 27th, 2021

Professor Peer Haller

[Verbund] G: Fertigung (inkl. Additive Verfahren, Fügeverfahren, Beschichtungsverfahren)

Additively manufactured precast concrete elements with fibre-based reinforcement

M. Lindner^{1*}, R. Gliniorz¹, H. Funke¹, S. Gelbrich¹

Rapidity, precision, economics and resource saving are the most important requirements of the construction industry of the future. Modern lightweight construction technologies can implement these requirements and add the aspect of design freedom, efficiency and sustainability. Therefore, the development of new manufacturing technologies for highly stressable, durable and free-forming prefabricated concrete components with low material and energy input is the focus of research at the research group LBW [1,2]. The high-performance material concrete is the most widely used building material worldwide because it is durable and – in combination with steel reinforcement – has very good mechanical properties. Due to the tendency of steel to corrode, however, massive concrete constructions result, since reinforcing steel has to be protected against corrosion by being coated with concrete. Here, new steel-free reinforcement systems made of innovative fibre-reinforced plastics (FRP) offer great potential with regard to lightweight designs [3,4]. The implementation of the lightweight construction principles goes hand in hand with new solutions in terms of materials, technology and component design.

A forward-looking lightweight construction technology is additive manufacturing with mineral-bound materials, which stands for a continuously digitally controlled value chain. The current focus of research is on the additive manufacturing processes that involve processing of fresh concrete/mortar in the extrusion process.

Within this work, a new process was developed in which high-strength fibres with a not yet polymerized resin system are defined in an extruded concrete matrix for reinforcement. Two robots working simultaneously, consisting of a concrete extruder and a Fibre-laying-impregnation-unit (FLIU), implement this automated joining process.



Figure 1. Robots work together as a team [5,6,7].

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The technology of the FLIU realizes the fibre conveying and the simultaneous tension-free resin impregnation. The polymerisation of the plastic matrix takes place at the same time as the hardening of the concrete layer. As a result, in addition to the positive fusion, a material connection between the concrete matrix and reinforcement fibres is generated and the fibre-concrete matrix connection has been proven four times higher than the conventional textile reinforcement technologies. This increase in bond stress goes hand in hand with an improvement in load-bearing capacity, thereby the use of high-strength lightweight structures in civil engineering is allowed.

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Aging behavior of extruded TPU components on enamel surfaces under static load

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Direct additive manufacturing of thermoplastic components on glazed surfaces by material extrusion using an adhesion promoter could open up new design and repair opportunities for white goods in kitchens and bathrooms, for ceramic screen-printing in the automotive industry or for enamel surfaces in the chemical industry. It also combines the different material properties of ductile thermoplastics with the hardness of glazed surfaces. Environmental conditions affect both the thermoplastic component and the adhesion-promoting aminosilane coating, e.g. through absorbed humidity, which causes generally reduced adhesion. Kitchen or bathroom items that can be suspended from the generatively manufactured elements, for example, also lead to a static load on the joint, which reduces the lifetime of the joint between the plastic and the glazed surface.

The research presented focuses on the reduction of critical static loads under defined climatic conditions and the aging process in the interface between an extruded thermoplastic polyurethane (TPU) head tensile specimen and an enamel surface created using (3-aminopropyl)trimethoxysilane (APTMS) as an adhesion promoter.

The compounds were characterized by using a constant load test comparing acetone cleaning and additionally applied amorphous silica coatings as different surface pretreatments for wet chemical APTMS coatings based on methanol, butanol and isopropanol, respectively. The aim of this approach is to evaluate the surface pretreatment in the context of aging in humid climates and the influence of the alcohols used on the kinetics of the polycondensation reaction as well as their influence on subsequent aging.

Ceramic-Ceramic Multi-material components by Lithography-based Ceramic Manufacturing (LCM)

S. Nohut^{1*}, S. Geier¹, I. Kraleva², M. Schwentenwein¹, R. Bermejo²

The continual need for new materials and their combinations that can tolerate different conditions by providing properties and functions at different positions led to the design of multi-material components [1]. Significant developments in manufacturing technologies especially in additive manufacturing (AM) enable us nowadays to manufacture multi-materials that can improve functionality and performance by combining different material properties in a single component. Lithography-based Ceramic Manufacturing (LCM), a method developed by Lithoz GmbH as an enhancement of stereolithography and digital light processing (DLP) technology, offers layer-by-layer printing by curing a photosensitive formulation with a mask-exposure process using the concept of DLP in the required areas through selective light exposure [2]. A newly developed 3D printer type allows the deposition of multi-materials by simultaneous processing of two photocurable feedstocks [3, 4]. The setup in the process chamber of this novel 3D printer based on the LCM concept is shown in Figure 1.

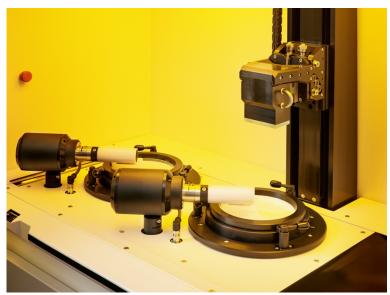


Figure 1. Two-vat system in multi-material LCM printer

Various methodologies have been introduced that enable multi-layered and functionally graded ceramic-ceramic multi-material combinations (see Figure 2) that have different compositions, microstructure, and porosity.

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Figure 2. Possible multi-material combinations

This study investigates the performance of printing methodologies of ceramic-ceramic multimaterials in terms of printability, precision, and functionality.

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Efficient hot forming of prepreg stacks by means of liquid contact heating

S. Nendel^{1*}, S. Voigtländer², Dr. Udo Berthold ²

The development and production of civil aircraft and their individual components are increasingly determined by the need to adapt cost and weight targets to increasing competition and existing profit expectations while at the same time reducing CO₂ emissions.

Although the conventional autoclave prepreg process delivers high load-bearing structural parts, their production in the ply-per-ply lamination process is very time-consuming and cost-intensive. Thus, weight-reduced components can only be produced at increased costs.

The production of flat preforms in the form of primary layers (e.g. biaxially oriented primary layers) or complete stacks brings a significant improvement. These can be deposited more easily and quickly and facilitate automation significantly. The flat preforms are then draped or shaped into the 3D geometry of the part. Due to changes in curvature, each layer in the laminate is subject to a different change in arc length. By introducing heat into the preform, interlaminar sliding between the layers in the forming process is promoted. Forming can then be initiated via vacuum and an elastic membrane. According to the current state of the art, the process step of heat input is carried out via hot air blowers or infrared radiators. This is precisely where the new development comes in, as these processes have very high energy consumption and long cycle times. In addition, there is a risk of overheating the preform. These disadvantages are eliminated by the newly developed hot forming process.

In this process, heat is transferred by a heat-storing and heat-conducting fluid (water) via a membrane located directly on the preform. As a result, the heating time can be reduced by a factor of 3 compared to infrared radiation and by a factor of 11 compared to hot air blowers. Another positive effect of this novel hot forming process is the uniform temperature distribution over the entire semi-finished product surface ($\Delta T < 5$ K) with simultaneous very simple process control. Partial temperature maxima, so-called hot spots, can thus be avoided and heating that is gentle on the material can be realized. With an efficiency of well over 85 %, this new technology offers numerous areas of application in the processing of thermoset semi-finished products into high-performance components.



Figure 1: Hot forming plant with hot water process tank

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Development of a modular, research-oriented RTM injection system for insitu polymerizing thermoplastics

J.E. Semar^{1*}, D. May¹, P. Mitschang¹

Fiber-reinforced thermoplastics (TP) offer a number of advantages compared to thermosets (TS): For example, they can be melted, thus enabling forming and welding processes as well as recycling. The processing by thermoforming – which is common for continuously reinforced TP – is suitable for large-scale production, but the high investment costs represent a hurdle to entry. In-situ polymerizing thermoplastics provide a potential link that can be used for entry into TP technologies or within the context of prototype construction and series ramp-up. In this process, equivalent to thermosetting process chains, the low-viscosity monomers or oligomers are injected into a mold containing the fiber preform. Only there, they polymerize into the finished thermoplastic (Figure 1). In this context, intensive research is being carried out on polyamide 6, for example, which is formed from the monomer ε-caprolactam by anionic polymerization [1].

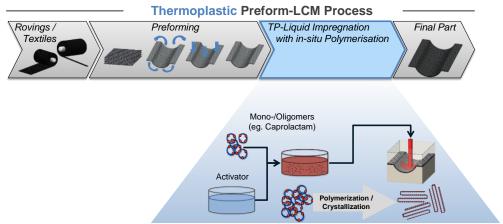


Figure 1. RTM process chain for in-situ polymerizing thermoplastics

As part of a project supported by the European Regional Development Fund, the Leibniz-Institut für Verbundwerkstoffe is currently building up expertise in the field of in-situ polymerizing TP. In this context, a novel injection plant for the resin transfer molding (RTM) process has been developed, which is suitable for processing ε -caprolactam and other in-situ polymerizing thermoplastics. In contrast to commercially available equipment, the use for research is focused here. The system is therefore modular in design and can thus be adapted to other process parameters or material compositions with little effort if required. In addition, the system has a large number of sensors and configuration options. Other key aspects in the plant development were the special challenges of processing ε -caprolactam: corrosiveness, very low processing viscosity and a high sensitivity of the polymerization reaction to moisture and oxygen. Complementary to the plant, an injection tool was developed, which is also modular in design and can continuously measure and record all relevant process parameters for process control.

In this presentation, the relevant development steps and use cases are discussed.

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Field-assisted foaming

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Powder-metallurgical aluminum foams are based on preform materials with dispersed particles of a foaming agent inside of them. The blowing agent releases the porosity-producing gas during specific heat treatment while the matrix material is at least in a semi-solid state. Once the foam has reached the desired density, the heat supply has to stop, and the material temperature is brought as quickly as possible to a range below the melting point. The process is usually carried out as an oven process and thus presents a corresponding challenge in thermal management [1]. The present article deals with the qualification of field-assisted sintering for this task to achieve more sustainable and safer process control. A powder metallurgical processed AlMgSi-alloy with 0.8 wt% TiH₂ was foamed in a graphite tool as a cavity inside the sintering device FCT HP D25 from FCT System GmbH. The process was executed by applying the direct current in two different methods. In the indirect heating method (Fig. 1a), the graphite tool was heated until 800 °C, controlled by a thermocouple (TC) at the wall of the tool. The process was stopped after a certain temperature was reached were measured by TC inside the preform material. The second method is direct heating (Fig. 1b). The DC was applied directly through the preform material controlled by a pyrometer in the tool lid. An isolation ring prevents the conduction of electricity through the graphite tool.

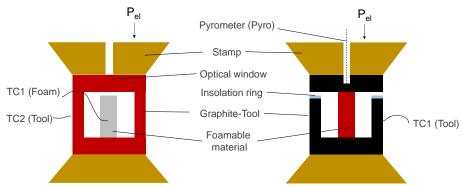


Figure 1. Shematic view of field-assisted foaming: a) Indirect method by heating the tool; b) direct method by joule heating of the preform material.

If we use the indirect heating method, a typical plateau occurs at about 660 °C. It marks the alloy's melting range begin. Dehydrogenation of the process during the plateau leads to a swelling of the preform material (point A in Fig. 2). The swelling starts at the lower area of the specimen, where the maximum heat transition is to be expected due to the direct contact of the material with the tool. The plateau ends with a rapid temperature rise. Interrupting the process during this temperature rise often produces an excellent foaming result (point B in Fig. 2). Complete mold filling can be achieved, although drainage effects have often already set in at the bottom. The expansion of the foam leads to direct contact with the molding tool at a temperature of approximately 800 °C. The aluminum alloy over-heats very quickly, and the foam collapses. It results in compact, flat test specimens without significant porosity (point C in Fig. 2).

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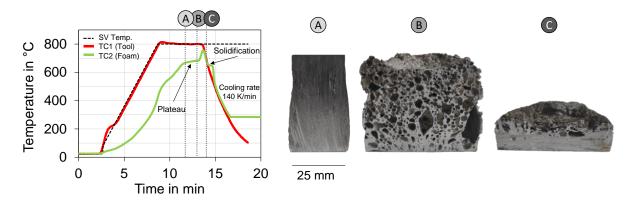


Figure 2. Temperature curves during foaming by indirect heating method and cross section of foams, when the process is interrupted at different points

The direct heating method (Fig. 3) leads to an early swelling at the top of the specimen, where the current is initiated in the conductive material. The hydrogen release starts at 500 °C and causes longitudinal cracks in the solid aluminum. At a temperature of about 700 °C, the material reaches the melting range of the alloy. The expansion runs from top to bottom, which leads to a mushroom shape of the specimen if it is stopped prematurely. Continuing the process in this way results in good foam quality in the upper areas, while the melt already collects in the near-to-bottom area due to drainage effects.

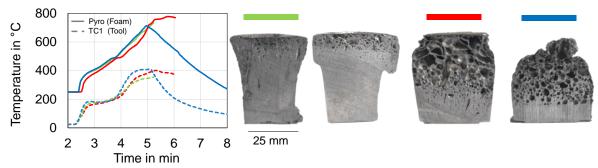


Figure 3. Temperature curves during foaming by direct heating method and cross section of foams, when the process is interrupted at different points

Both methods can be used in principle. So far, no suitable stop criteria for optimum foam results have been found. In particular, suitable tool concepts must be developed for homogeneous temperature distribution. In the future, the advantages of field-assisted foaming lie in higher efficiency due to the direct heating of foamable material from inside and the protection of the surrounding material through targeted cooling. The latter is a considerable advantage in producing sandwich materials with aluminum foam core and aluminum sheets as outer cover layers and could revolutionize it.

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Flexible injection solutions for large thermoplastic structural components

23. Symposium Verbundwerkstoffe und Werkstoffverbund

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Demands for lightweight moulded parts for vehicles and aircraft in order to reduce their CO2 footprint during production and use cannot ignore the thermoplastics material group. Injection moulding has proven to be an effective process for manufacturing these components.

If, in addition to an attractive design and high surface quality, these moulded parts also have to meet special requirements in terms of thermal, mechanical and chemical properties, combinations of different thermoplastics, the incorporation of different fibre materials (e.g. glass, carbon, basalt, bamboo.....) and/or the overmolding or gating of organic sheets and UD tapes are conceivable. Injection moulding machines with vertical clamping units are particularly suitable for "insert moulding", as the force of gravity makes it easy to place the parts in the open mould. Vertical presses with horizontally arranged plasticising and injection units, are also suitable for this purpose. In order to increase the flexibility of these machines or systems, hot runner deflection plates have been developed which can guide the injection flow of the injection unit from the plate edge to any point on the clamping surface of the clamped mould.

These hot runner deflection plates can be mounted on the press table or also on the upper movable press platen.



Figure 1. Hot runner intermediate plate $2,000 \times 1,400 \times 240$ mm with spacer plate $2,200 \times 1,400 \times 270$ mm. Heat insulation plate (red) between hotrunner and spacer plate.

In addition to a "simple" transfer of the thermoplastic melt in the hot runner from the nozzle of the injection unit to the mould sprue bush, it is also possible to measure process parameters with sensors and to influence the injection flow:

- Feeding of another thermoplastic melt to the injection stream to increase the injection volume or to implement sandwich injection moulding (Coinjection) [1]
- Installation or mounting of sensors to record process parameters of the melt flow, e.g. viscosity and shear.
- Feeding of fibre material, colour batch
- Homogenization of the injection flow by static mixers
- Opening and shut-off elements for the melt flow

In the lecture the advantages of this technology are presented on the basis of realized projects and practical experiences are reported.

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[1] Reichert, V.; Nendel, W.

Nozzles and hot runner systems for injection moulding machines for the production of thermoplastic composite mouldings with skin-core structure (sandwich mouldings)Composites, 21st Symposium on Composites and Composite Materials, 2017, Bremen; Deutsche Gesellschaft für Materialkunde e. V.

Heißkanal-Zwischenplatten für Spritzgießmaschinen mit vertikal angeordneten Schließeinheiten und Spritzgießanlagen bestehend aus Vertikal-Pressen in Kombination mit horizontal angeordneten Plastifizierund Einspritzeinheiten

Ausgewählte Referenzen

Hot runner intermediate platens for injection molding machines with vertically arranged clamping units and injection molding systems consisting of vertical presses in combination with horizontally arranged plasticizing and injection units

Selected references

A&E Produktionstechnik GmbH Gostritzer Str. 63 D 01217 Dresden www.a-e-produktionstechnik.de



Heißkanal-Zwischenplatten für Vertikalmaschinen Hot runner adapter plates for vertical machines

Die Distanzplatten dienen zur Überbrückung der minimalen Werkzeugeinbauhöhe (Abstand der oberen Werkzeugaufpannplatte zum Maschinentisch)

The spacer plates are used to bridge the minimum mold installation height (Distance of the upper mold clamping plate to the machine table)

Distanzplatte (Distance plate)

Abmessungen (dimensions): 2.000 x 1.680 x 400mm und 2.000 x 1.680 x 200mm Für die Montage der Distanzplatte an der oberen Werkzeugaufspannplatte waren zusätzliche Distanzsäulen erforderlich.

Additional spacer columns were required for mounting the spacer plate to the upper mold fixing platen



Bildquelle (source) http://open-hybrid-labfactory.de/medien-infos/bilder/ (28.06.2018)



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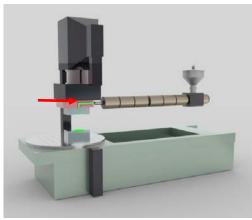


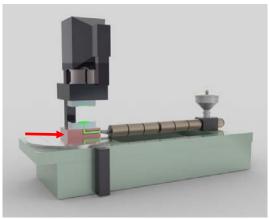
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Heißkanal-Zwischenplatten in Vertikal-Spritzgießmaschinen Hot runner intermediate plates in vertical injection molding machines







Schematische Darstellung der Einbauvarianten von Heißkanal-Zwischenplatten in Spritzgießmaschinen mit vertikalen Schließeinheiten.

Die Heißkanal-Zwischenplatten können mit verschließbaren Düsen und Angießbuchsen ausgestattet werden. Weitere Optionen sind auf Anfrage lieferbar.

Schematic representation of the installation variants of hot runner intermediate platens in injection molding machines with vertical clamping units.

The hot runner intermediate platens can be equipped with closable nozzles and sprue bushes. Other options are available on request.

Für eine Vertikal-Spritzgießmaschine mit horizontal angeordneter Spritzeinheit wurde eine Zwischenplatte, Abmessungen LxBxH 1.020x750x150mm, gebaut, die dem Kunden das mittige Einspritzen und das seitliche Einspritzen ermöglicht. Über dieses Projekt wurde auch in der Zeitschrift "Plastverarbeiter" – berichtet: "Spritzen und Pressen", Plastverarbeiter 02-2015, S. 35-37, Hüthig-Verlag.

For a vertical injection molding machine with horizontally arranged injection unit, an intermediate plate, dimensions LxWxH 1,020x750x150mm, was built, which enables the customer to inject in the center and laterally. This project was also reported in the magazine "Plastverarbeiter" - "Spritzen und Pressen", Plastverarbeiter 02-2015, p. 35-37, Hüthig-Verlag.

Heißkanal-Zwischenplatte

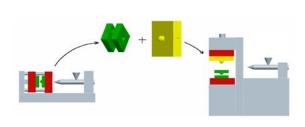
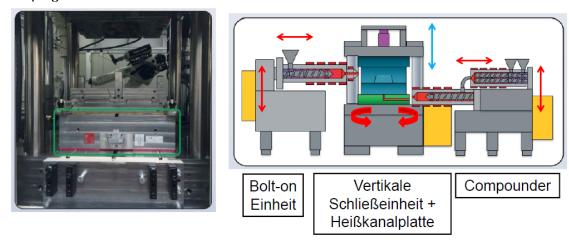


Foto: ENGEL

Heißkanal-Zwischenplatte 900x900x265mm für einen Spritzgießcompounder mit Spritzgieß-Beistell-Aggregat, Bolt-On - Bezeichnung des Maschinenherstellers. Diese Platte kann in der Schließeinheit um 180° um die vertikale Achse gedreht werden, so dass die Heißkanal-Angießbuchse entweder mit dem Spritzgießcompounder oder mit dem Bolt-On-Spritzaggregat verbunden ist. Die Formteil-Entnahme erfolgt hier bei geöffnetem Werkzeug innerhalb der vertikalen Schließeinheit.

Hot runner intermediate platen 900x900x265mm for an injection molding compounder with injection molding auxiliary unit, Bolt-On - designation of the machine manufacturer. This platen can be rotated by 1800 around the vertical axis in the clamping unit, so that the hot runner sprue bush is connected either to the injection molding compounder or to the Bolt-On injection unit. The molded part is removed here with the mold open inside the vertical clamping unit.



Heißkanal-Zwischenplatte für Spritzgießmaschine KM41-400 GXV mit Bolt-On-Aggregat, Fachhochschule Rosenheim Kunststofftechnik

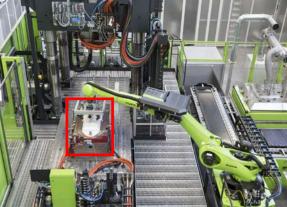
Hot runner intermediate plate for KM41-400 GXV injection molding machine with bolt-on, Fachhochschule Rosenheim Plastics Engineering

Heißkanal-Zwischenplatte 2.180x1750x120mm auf Schiebetisch gleicher Größe.

Ein Vorteil von Vertikalmaschinen besteht darin, diese mit einem Schiebetisch zu kombinieren, so dass Formteile außerhalb der Schließeinheit aus dem geöffneten Werkzeug entnommen werden.

Hot runner intermediate platen 2,180x1750x120mm on sliding table of the same size. One advantage of vertical machines is to combine them with a sliding table so that molded parts are removed from the open mold outside the clamping unit.





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Heißkanal-Zwischenplatte 1.020x650x15mm in Vertikal-Spritzgießmaschine mit Drehtisch und Bearbeitungsstationen zum Pressen und Spritzgießen für das Thermoformen von Organoblechen und nachfolgenden Anspritzen von Thermoplast-Formelementen. Der Heißkanal leitet Schmelze leckagefrei von horizontal angeordneter Spritzeinheit in die Plattenmitte der Bearbeitungsstation. ("Gespritzt und gepresst" – Fachaufsatz in Kunststoffe 3/20216 Seiten 90 – 93, Carl Hanser Verlag)

Hot runner intermediate plate 1,020x650x15mm in vertical injection molding machine with turntable and processing stations for pressing and injection molding for thermoforming of organic sheets and subsequent gating of thermoplastic mold elements. The hot runner directs melt leakage-free from horizontally arranged injection unit to the plate center of the processing station. ("Sprayed and pressed" - technical article in Kunststoffe 3/20216 pages 90 - 93, Carl Hanser Verlag)





Foto: TU Chemnitz, SLK Foto: A&E

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Heißkanal-Zwischenplatte 2.000 x 1.600 x 200 mm mit Distanzplatte 2.000 x 1.600 x 470mm Seitliche Ausfräsungen in der Distanzplatte zum Spannen der Platten auf einen Schiebetisch, der in den Werkzeugraum einer Presse gefahren wird.

Hot runner intermediate plate $2,000 \times 1,600 \times 200$ mm with spacer plate $2,000 \times 1,600 \times 470$ mm. Lateral cut-outs in the spacer plate for clamping the plates on a sliding table, which is moved into the die area of a press.



Montage der Düsenanfahrzylinder der Spritzeinheit an die Heißkanal-Zwischenplatte. Die Verbindung Düsenanfahrzylinder – Heißkanal-Zwischenplatte ist prozessbedingt lösbar, die Verriegelungsposition wird überwacht.

Mounting the nozzle start-up cylinder of the injection unit on the hot runner intermediate plate. The connection between the nozzle start-up cylinder and the hot runner intermediate plate can be released during the process, and the locking position is monitored.



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Heißkanal-Zwischenplatte 2.000x1.400x240 mm mit Distanzplatte 2.200x1.400x270mm Seitliche Nuten in der Distanzplatte zur Befestigung auf dem Pressentisch.

In der Distanzplatte ist der doppeltwirkende Hydraulikzylinder für den Heißkanal-Düsenverschluss eingebaut. Zur Wärmeisolation dient eine Wärmedämmplatte zwischen Heißkanalund Distanzplatte. Beide Platten werden fest auf dem Pressentisch einer Presse montiert. Hot runner intermediate plate 2,000x1,400x240 mm with spacer plate 2,200x1,400x270mm. Lateral grooves in the spacer plate for mounting on the press table.

The double-acting hydraulic cylinder for the hot runner nozzle connection is installed in the spacer plate. A thermal insulation plate is used between the hot runner plate and the spacer plate for thermal insulation. Both plates are firmly mounted on the press table of a press.



Weitere Informationen zu den technologischen Möglichkeiten der Zwischenplatten für Spritzgießmaschinen und Spritzgießanlagen finden Sie in folgenden Veröffentlichungen: For more information on the technological possibilities of intermediate platens for injection molding machines and injection molding lines, please refer to the following publications:

Flexible Technology Module - Hot Runner Intermediate Plates Allow Injection Molding Machines to Be Deployed Cost Effectively for Special Processes Nendel, Wolfgang, Reichert, Volker, Kunststoffe International 08-2016, Seiten 56-58, Carl Hanser Verlag München

Flexible Hot Runner Adapter Plates for Injection Molding Machines and Their Potential for Polymer Development

Zimmermann, Phillip; Reichert, Volker

Polymertec 2018, Merseburg - Macromol. Symp. 2019, Band 384, Heft 1, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

Impact of ultrasound enhanced friction stir processing on microstructural and mechanical properties of an aluminum matrix composite

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Friction stir processing (FSP) is a solid-state process with the ability to affect the microstructure and mechanical properties of materials in locally defined areas, creating efficient crack deflection or reinforcement structures. Regarding high-performance materials such as aluminium matrix composites (AMC) friction stir processing additionally offers the possibility to enhance the distribution of particles and reduce remaining pores resulting in a more homogeneous AMC. To further improve this homogeneity, the friction stir process was combined with the transmission of power ultrasound leading to the hybrid process of ultrasound enhanced friction stir processing (USE-FSP). In the present work an aluminium matrix composite consisting of AA6061 reinforced with 10 % particles of silicon carbide was manufactured in house by spark plasma sintering and afterwards processed by FSP as well as USE-FSP. The resulting microstructural and mechanical properties were investigated and compared in detail.

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Influence of the wire strand surface on the joining process during ultrasonic metal welding of aluminum wires and copper terminals

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Requested presentation mode: poster

Keywords: ultrasonic metal welding, aluminum, copper, stranded wires, dissimilar joints

Abstract. Ultrasonic metal welding is a joining method, which sees widespread application in the manufacturing of similar as well as dissimilar joints of electrical conductors, e.g. stranded wires and terminals for usage in wire harnesses. As joining takes place below the melting temperature of both joining partners it is classified as a solid-state welding technique. Due to this, the formation of brittle intermetallic compounds at the interface which exhibit poor conductivity can be prevented to a large extent. Additionally, due to its energy efficiency, short process times and the avoidance of process gasses or additives ultrasonic metal welding is being adopted in more and more industrial branches. Although this technology features many advantages over conventional joining methods it is highly sensitive to the surface conditions of the joining partners. In these investigations focus lies on the surface conditions of the stranded aluminum wires used for joining with copper terminals. Five different states of the stranded aluminum wires were produced and ultrasonically welded to copper terminals. The produced joints and single strands were examined via light as well as scanning electron microscopy, x-ray photoelectron spectroscopy and tensile testing. Inter alia the examinations have shown that artificially generated surface layers of AlO(OH) are not broken up by the ultrasonic oscillations thus impeding with inter-strand connection and adhesion of the aluminum wire to the copper terminal, which led to a decrease of joint strength by 90 %.

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Innovative, resource-saving production process for online impregnated textile preforms

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The usage of prepregs is nowadays an essential part of the production strategy for a multitude of industrial high-performance applications. The primary aspect for the application of prepregs is a high, consistent quality, as well as a certification of the materials that has already taken place in advance. Likewise, the competences for the production of fibre-reinforced materials and their processing can be separated from each other.

However, the advantages of this class of materials are also opposed by a number of disadvantages. For example, the energy-intensive cooling and the comparatively limited storage capacity. Disposal of the offcuts is also problematic, as the already impregnated textiles are difficult to recycle.

The innovative, resource-saving production process for online impregnated textile preforms developed at Clausthal University of Technology was able to address the disadvantages mentioned. The resulting process culminated in the development and production of the online prepreg-machine at the Clausthal Centre for Material Technology.

This paper deals with the detailed description of the process chain; starting with the automatically nested cutting of dry textiles of choice, a subsequent temperature-controlled textile drying; via the contour-accurate direct impregnation of selected individual textiles, up to the optional B-staging.

With regard to this future-oriented, climate-friendly process, which is excellently integrated into the now indispensable, interdisciplinary research field of the Circular Economy, we hereby offer an adaptable key technology for industrial high-performance applications.

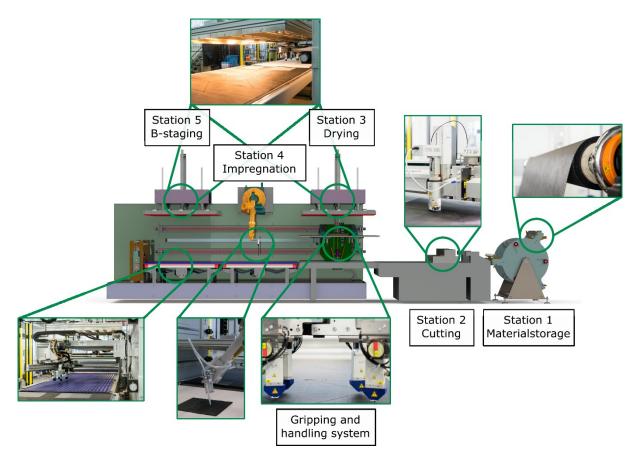


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Interface Modification in the Production of Multi-Material Structures in a Continuous Metal Die-Casting-Plastic Injection-Molding Hybrid Process

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Abstract

The production of modern multi-material structures is currently characterized by separate individual processes, which often result in extensive process interruptions due to unnecessary transport routes. For example, longer transfer times for insert elements made of aluminum or magnesium, which are integrated into a polymer injection molding process, present the risk of increased oxide formation and possible contamination. This makes additional, usually aggressive cleaning steps necessary. With the help of a continuous hybrid process, the metallic components are to be produced in an aluminum diecasting process and functionalized with fibre-reinforced polymer structures within the same processing system (Fig. 1, left) in a resource-saving manner. The aim is to manufacture innovative and complex multi-material components in a single production step, thereby saving energy, storage costs and transfer paths in particular. Improved efficiency and cost-effectiveness of the new hybrid technology compared to standardized individual processes result from the reduction of pre-treatment and cleaning steps, supplemented by optimized cycle times and a significantly reduced space requirement due to only one hybrid production plant.

The development of a stable connection of the hybrid materials with high mechanical stability and durability, especially in the modification of the interphase, requires further research. A promising approach is the surface treatment of the metal component using laser beams. This creates defined microstructures on the metallic component and geometrically extended bonding zones (Fig. 1, right).

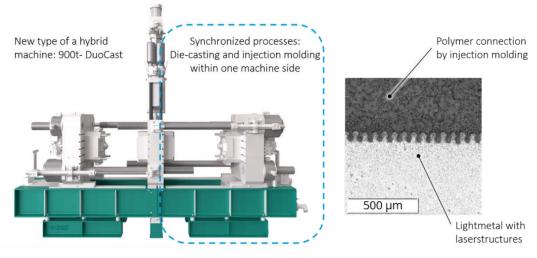


Figure 1: new type of DuoCast hybrid machine (left) and analysis of laserstructures for hybrid processes (right)

The analysis and optimization of the inserted laser structures as well as the targeted identification of process parameters are the subject of the preliminary investigations of the so-called HyDrun project. In order to identify significant dependencies, the bonding strength of the generated metal-polymer hybrid joinings will be correlated with the structure parameters (structure depth and pattern spacing), different shapes of possible laser structures as well as relevant parameters of the plastic injection molding process. Furthermore, current insights into the development activities in the areas of the required hybrid mold technology, the unique plant technology and the modified, novel process within the HyDrun project will be provided.

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Irradiation induced crosslinking in thermoplastic polyurethanes for structural applications

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Heat treatment of steels and other structural metals is common practice to enhance the performance of the material without drastically increasing the materials cost. Therefore, from one material bought a great number of properties can be derived downstream of the material supplier. Furthermore, it is possible to restrict the improvement to certain areas where it is needed. Polymers are another material class, which can be used for structural applications. Benefits like good corrosion resistance and good mechanical properties are only some reasons for the use of polymers instead of metals. Especially for thermoplastic materials there are only a few ways to fit the mechanical properties to application requirements, e.g. by using reinforcing materials. Additionally, it is possible to use polymer blends or switch to a completely different thermoplastic polymer. All three strategies involve major effort either for the user of the material or for the material supplier. This effort is mainly concerned with finding the right processing parameters to use the reinforced thermoplastic or to find the right blend composition. Additional to those efforts the material cost usually increases. Nevertheless, many manufacturers downstream of the raw material supplier often face changed loading scenarios, which have to be incorporated under cost and time limitations.

One possible solution for slight changes in the materials performance is the use of irradiation to change material properties by crosslinking in the solid state. As irradiation sources gamma radiation and high velocity electrons can be used to induce crosslinking. This strategy is widely used to improve the performance of insulation materials like PE in the electronic industry. Three main factors contributed to the widespread application in this industry. One is the highly scalable irradiation process, which can be applied with little additional cost and in large quantities. Therefore, the raw material and manufacturing process can be unchanged for products with enhanced performance requirements compared to those in standard applications. The only difference is an additional processing step. However, the main reason for a broad application in the electronics industry is a better creep resistance of a low-cost polymer like polyethylene. Even though this strategy is long known, only very few applications of irradiation enhanced polymers can be found for mainly structural applications. Even though in this type of application additional benefits could be realized by localized property modification of the polymer (e.g. locally enhanced toughness to restrict crack initiation). However, not all polymers can be modified, and only slight changes are possible. The presented work investigates the irradiation modification of thermoplastic polyurethane (TPU) for structural applications. Some research can be found on the irradiation effects on rubbery TPU's but rarely on materials with higher stiffness. It is the aim to show the potential benefits of irradiation induced crosslinking in structural polymers. The investigated material is an ether-type TPU. For this material class it is sometimes possible to induce crosslinking without the use of any additional crosslinking agents. This makes the material class to a potential candidate for irradiation modification after the injection molding, for organo sheets (continuous fiber reinforced thermoplastic sheets) or the final product without any changes in earlier processing steps. A wide variety of mechanical and thermal tests like differential scanning calorimetry (DSC), dynamic thermal mechanical analysis (DTMA) were used to better understand the material changes under irradiation. Static and fatigue experiments have been undertaken to show the influence of irradiation on the mechanical properties. The comparison of different dose levels shows the competing effects of crosslinking and chain scission, which can lead to deterioration of the material as well as a property improvement. In addition to the mechanical characterization, the material was evaluated with regard to the impregnation behavior of glass fiber fabrics as prerequisite for organo sheet manufacturing. The results promote further research into the use of irradiation crosslinking for thermoplastic polymers in structural applications.

Microthermoforming: A low cost process for automated small-scale production

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Introduction

Microthermoforming is an enhanced variant of blister technology[1,2] adapted and improved at Hahn-Schickard to produce microfluidic cartridges e.g for diagnostic purposes.[3,4] These cartridges feature a great variation in aspect ratios ranging from microchannels (μ m range, see Figure 1 d) to large chambers (mm range). Apart from material variations, geometric aspects are one of the major challenges in process automation. Here we present the adaption of the manual sheet-by-sheet process to a fully automated "roll-to-sheet" variothermal replication process to produce structured films as a low cost alternative to injection molding.

Process and Material

The thermoplastic polymer film is pulled from feeding roll in the process chamber (see Figure 1 a) over the metal tool (Figure 1 b), which subsequently is closed and evacuated followed by heating (130 - 165°C*) and application of air pressure (2 - 5 bar*) to pre-form the polymer film. Afterwards the final forming step is initialized by increasing the air pressure (≥ 7.5 bar*) and heating (≥ 180 °C*) followed by cooling (to 50 - 80°C*) and air-pressure supported de-molding (≥ 1.5 bar*) as well as cutting of the structured polymer film into single sheets (see Figure 1 c). Overall cycle time ranges from 2 - 8 minutes / per part.

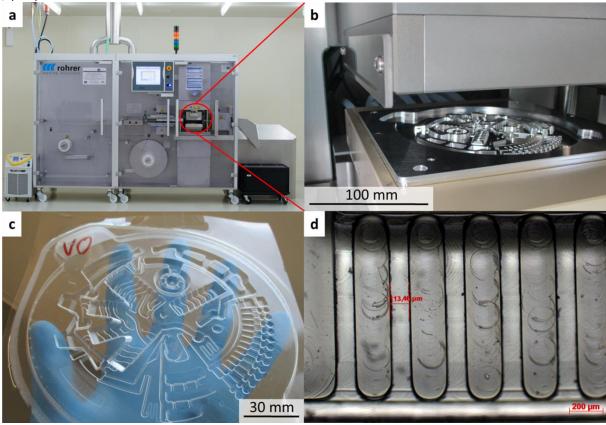


Figure 1. a: Thermoforming machine Rohrer R760S b: Aluminum tool (lower tool with positive mold) in the process chamber c: Image of thermoformed functional packaging with microfluidic structures and d: Microscope image of a thermoformed structure made from PC (Makrofol®)

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Conclusion and Outlook

This technology allows for fast development cycles and highly precise replication of small and medium numbers of parts at low cost (compared to injection molding) from various tools. Turn-around times from final design to the first thermoformed parts are possible within approx. 2 weeks with low tooling costs ($< 6,000 \in$). This enables the scale up of functional prototype production e.g. for pre-clinical studies of diagnostic point-of-care applications.[5,6,7]

* depending on the polymer film type and thickness (e.g. COP (ZEONOR® films), PC (Makrofol®, Covestro AG) or custom-made COC 6013/8007 bilayer film (Tekni-Plex, Inc.))

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Non-Impregnated Glass Fibres for Microfluidic Applications

23. Symposium Verbundwerkstoffe und Werkstoffverbund

C. Doerffel^{1*}, H. T. Schicktanz², J.Nestler³, F. Schubert⁴, M. Spieler¹, W. Nendel¹, L. Kroll¹

Glass fibres are of great interest for microfluidic applications. The high density of their bundles makes them good to use for filtration of fluids. Their surface properties and high surface area can be used to separate for example DNS-molecules from a fluid sample. The best way to integrate them into a microfluidic system is a fully automatized process. This process creates a compound material of the fibres and thermoplastics. In opposite to standard compound material, which are used to retain high mechanical loads, it is not the aim of the process to create textiles, that are fully impregnated with the matrix material. The free space in the fibre bundles is used to create a big surface area for filtration - and interaction processes of the fluid samples.

The process to create hybrid parts consisting of this kind of compound is a complex three-step injection moulding process. It is based on the high viscosity and its wall sticking behaviour of the thermoplastic melt. This production process creates a hybrid part with a compound of glass fibres and thermoplastics and only the areas for interacting with fluids are accessible from the outside. Therefore, no further joining processes or additional materials are needed to integrate the fibres into the microfluidic cartridge. This reduces the risk of soiling or damaging sensitive microfluidic structures. It allows the placement of the fibres in any layer of the cartridge not depending on assembly -, joining - and covering processes.

The combination of different plastic materials gives the opportunity to increase the functions of the cartridge. The great variety of fibre materials and textile structures, that can be processed, allows the design of many different functional elements, that can be integrated into the cartridge design.

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Novel Process for the Wet Filament Winding

Bergmann, Benedikt^{1*} (B Bergmann), Schlimbach, Jens¹ (J. Schlimbach)

Due to its potential for efficient manufacturing of rotationally symmetrical bodies, filament winding is a widely used and long-established process producing components such as pipes, pressure vessels, or shafts. The most common method within the winding process is wet winding. Winding with wet fibers has advantages, but also clear disadvantages. Working with liquid resins leads to contamination along the production line which is a particularly known problem. Much more critical, concerning the mechanical properties of the component, is the wet filament, which tends to slip off the roving of the mandrel. One possibility to solve the slipping problem is separating impregnation and fiber lay-down. With this pre-impregnated Towpregs slipping can be decreased. This separated process typically leads to higher overall costs.

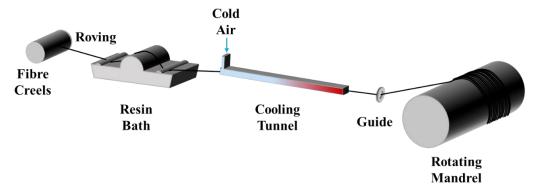


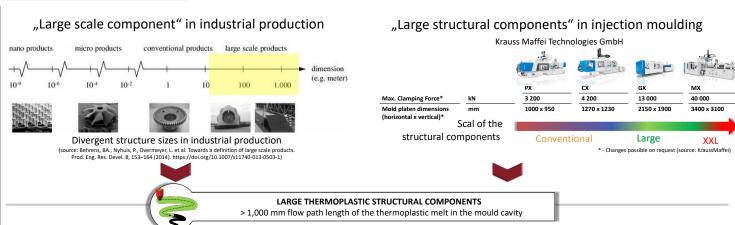
Figure 1. Schematic illustration of the novel winding process.

This work shows a novel wet winding process that allows to significantly improve the precision of the roving deposition without using an additional process step. To achieve this goal, a coordinated process and resin system combination was selected and optimized. In-line to the winding process, the roving is impregnated with resin in a conventional impregnation bath. The resin is then thermally treated to achieve Towpreg-like properties. After fiber deposition, the novel system is processed like conventional resins. In the project, the mechanical properties of the composite produced using the new process were determined with the aid of test specimens and compared with reference materials. At the end of the project, several full-scale pressure vessels were produced to confirm the process reliability. Maximum winding speeds of up to 150 m/min were achieved.

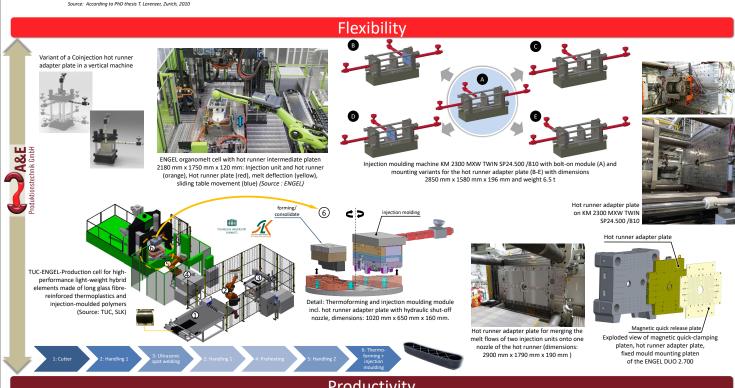
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Flexible injection solutions for large thermoplastic structural components



- Special Universal Flexibility
- The flow properties of thermoplastic melts, the flow path length and the wall thickness of the moulded part limit its size. Already from 1,000 mm one might refer to thermoplastic largestructure components.
- A solution for the contradiction of manufacturing technology: Flexible modules = hot runner adapter plates for injection moulding machines/plants
 - High flexibility and productivity



Productivity

Summary

- Hot runner adapter plates:
 - **▶** Extension of the application possibilities of injection moulding machines/plants
 - Easy installation and removal comparable with mould changes
 - Combination with special injection moulding processes, e.g. coinjection, chemical and physical foaming simple and cost-effective
- Technology, economic efficiency consulting and trials in the Lightweight Construction Technical Centre at Chemnitz University of Technology

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Residual strain and structural health monitoring for automated tape layup using HiBi FBG sensor

Neha Yadav^{1*}, Karol Wachtarczyk², Pawel Gąsior², Ralf Schledjewski¹, Jerzy Kaleta²

Residual stresses generated during automated tape layup process adversely affect the layup quality and have detrimental effect on the mechanical properties. These stresses may result in various defects arising in the laminate such as delamination, matrix cracking, fiber buckling and shape distortion [1, 2]. Tensile and flexural properties and fracture toughness during service life might also be impaired [3]. Shape distortion for flat parts happens in the form of warpage and so far, trial and error approach is used to rectify such distortions [4], which is both expensive and time consuming.

Inline monitoring of residual stress is crucial to understanding the relationship between distortion and process parameters. Recognizing such parameters will help in minimizing stress and limiting the laminate distortion. To further assess the effects of these stresses on mechanical properties structural health monitoring (SHM) is required.

For the present work, fiber Bragg gratings (FBG) sensors are integrated inside the laminate as they can be used for both inline measurements during the process and SHM. Regular FBG sensors are used to evaluate the effect of tool temperature on residual stress for unidirectional layup. Highly birefringent (HiBi) FBG sensors are used to assess both axial and transverse stress for cross-ply layup. It is found that tool temperature has a direct effect on the residual stress. As the cooling rate decreases, so does the residual stress, leaving the laminate distortion free. The effect on mechanical properties of such stresses is also discussed.

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Simultaneous electrophoretic deposition of polymer-ferroelectric ceramiccomposites

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In the case of functional ceramics, it is not only the performance of the materials themselves that is important but above all the processability of the materials plays a very important role for industrial applications. One possibility for the production of ceramic layers is electrophoretic deposition (EPD). In this work, Niobate (KNN) - polymer (PMMA) composite layers were deposited simultaneously with a PMMA content of up to almost 35 vol%. Those ceramics can act as dielectric components or maybe as a highly sensitive sensor layer for humidity sensors. The BaTiO $_3$ samples are designed for piezoelectric applications where a layer thickness of 50-150 μ m is requested.



Titanate samples were deposited on a fine-grained and sanded graphite electrode and afterward sintered at various temperatures in a chamber furnace. The sintering program included the steps of debinding the polymer binder, burning the graphite, and sintering the 200 nm-sized ceramic particles in only one run. For the intended piezo-electric application a layer thickness of about 100 μm was achieved with only minimal bend layers and a roughness minor than 5 μm without any supporting material.

Figure 1. Thin Layer of BaTiO₃ a) as deposited after the EPD Process and b) with no supporting structure after sintering.

The KNN samples with an area of 1x1 cm² and a thickness of 25-200 µm were deposited on a nickel-plated steel sheet and vapor-deposited with a silver electrode for the capacitance measurement. For industrial applications, a high polymer content can be beneficial when it is possible to get mechanical stable layers at room temperature which don't need a high-temperature treatment. Figure 2 shows the posibility of adjusting the polymer content in the composite material in a wide range. By combining the two shown effects a really high PMMA content can be acieved.

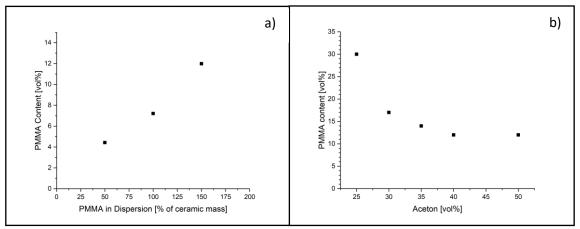


Figure 2. Polymer content in the composite layer as a function of the process parameters a) PMMA content in the suspension and b) acetone content in the solvent of the suspension.

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VliesSMC – Processing of recycled carbon fiber nonwovens in sheet molding compound



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STFI e.V. and Fraunhofer ICT are investigating new ways to process rCF-nowovens. For this a new SMC technology is currently being set up at the Fraunhofer ICT. The processabilty of rCF-nonwovens in the SMC process chain was successfully demonstrated in a first test campaign.

Within the research project VliesSMC, the suitability of different types of nonwovens based on recycled carbon fibers (rCF) for processing in the SMC process chain is investigated. In particular, open questions regarding the different textile manufacturing processes, production and handling of SMC semi-finished products, as well as the flowability in the compression molding process are addressed.



Figure 1. Nonwovens production at STFI (Source: STFI/D. Hanus)

The following research topics are being pursued in the project:

- Development of adapted nonwovens made from recycled carbon fibers
- Influence of different web formation methods on the impregnation quality and the flowability of the SMC semi-finished product
- Equipment and process development with the aim of automated processing of rCF-nonwovens in the SMC process chain
- Limits of part complexity in the molding process of rCF-SMC depending on the achievable fiber volume content
- Cost analysis and economic feasibility study of the VliesSMC recycling process

The mechanical entanglement of the individual fibers due to the bonding of the nonwoven material represents a fundamental difference to conventional SMC materials based on cut fibers. Unhindered fiber transport during compression molding is consequently not possible. To minimize the influence of mechanical fiber entanglement, investigations are carried out along the entire process chain.

Regarding the SMC semi-finished product production step, the focus is on the handling and impregnation of the nonwovens. An automatic, speed-controlled unwinding ensures that the fabric is fed into the system without tension. This enables the use of very low-strength nonwovens with little mechanical entanglement of the individual fibers. Rheological characterizations support the development of semi-finished products. The impregnation quality is ensured by a complete monitoring of the system parameters as well as microscopic examinations of the semi-finished products and cured materials.

To evaluate the fiber transport during compression molding, flow tests are carried out to determine the maximum flow distance. Using in-mold sensors, pressure and material progress in the mold are monitored.

The VliesSMC materials are mechanically characterized and compared to conventional SMC. Furthermore, investigations of the achievable surface quality are carried out.





Figure 2. SMC line at Fraunhofer ICT [nonwoven feed (left); SMC semi-finished product (right)] (Source: Fraunhofer ICT)

A project-accompanying committee, which includes material and equipment manufacturers as well as processing companies, ensures that the developments are relevant to industry and that they can be directly implemented.

Acknowledgement

The IGF project "VliesSMC" (No. 21124 BG) of the research associations DECHEMA Society for Chemical Technology and Biotechnology e.V. and Forschungskuratorium Textil eV is funded by the Federal Ministry for Economic Affairs and Energy through the AiF as part of the program to promote industrial community research (IGF) funded by a resolution of the German Bundestag.

[Verbund] H: Industrie 4.0, Digitalisierung

The path to CO2-neutral production – setting up an energy-coordinated process network for multi-material composite components

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Abstract

The increased demand for individual products in our fast-moving society requires flexible, manufacturing processes that are efficient and and conserve resources at the same time. In order to achieve internationally set climate targets, it is also necessary to drastically reduce CO_2 emissions for all manufacturing processes. However, well-established industrial processes are very energy consuming with partially high CO_2 emissions for which an improvement is urgently needed. Nevertheless, to achieve the set climate targets, new types of manufacturing and production chains must be developed that fulfill the climate protection requirements on the one hand through an energetically appropriate combination of the individual processes and on the other hand through the use of sustainable energy generation (such as solar thermal and/or photovoltaic).

This is where the national joint project "METEOR" initiated by the TU-Dresden comes in. By developing methods and technologies to validate and optimize the resource efficiency of process networks, the objective is to demonstrate possibilities for reducing CO_2 emissions in the production of lightweight structures. Using the example of a thermally optimized combination of a light metal die-casting and plastic injection moulding process for the production of multi-material lightweight components, a novel, energetically improved production network (Fig. 1) will be set up and validated. In this process, both the waste heat of the die casting process and the thermal energy of solar thermal support processes are used directly for the injection moulding process in a so-called tempering cascade. The evaluation of the resources which will be saved that way is to be demonstrated by an energy analysis (LCA) accompanying the project.

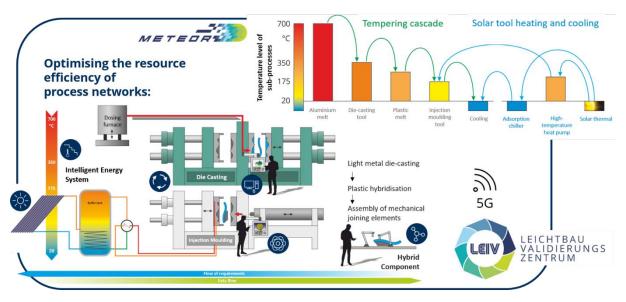


Figure 1: Modern process networ for saving CO₂ emissions based on the example of the METEOR project

The subject of this publication is the concept and the status of the development of the novel process network as well as the results of the current analysis of the energy consumption with the preview of potential optimization methods.

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[Verbund] I: Modellierung, Simulation, Auslegung

Application Oriented Thermal Shock Testing of Ceramic Matrix Composites

23. Symposium Verbundwerkstoffe und Werkstoffverbund

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Sustainability and long life-duration products in combination with efficiency improvement and reduction of CO_2 emissions are getting more and more important. Many high temperature processes are realized only by use of technical ceramic or ceramic matrix composites. Examples can be found in space and aeronautical applications driven by weight saving and increasing gas temperature or thermomechanical loads in brake discs. In these processes, high thermal gradients or fast temperature changes occur leading to high thermo-mechanical loads.

Thus, thermal shock has been investigated since decades. Testing of composite material with small dimensions leads to an overestimation of properties because of lower failure probability. Cracks in ceramic matrix composites are stopped or redirected by fibres. The cracking behaviour depends on fiber matrix interface. In general, several testing procedures have been proposed allowing the qualitative comparison of materials regarding their thermal shock resistance. However, they do not yield quantitative results usable to lay-out components. Furthermore, sample dimensions typically are intended for lab tests. Additionally, the use of known thermal shock parameters has been shown to be not sufficiently reliable for component design. Earlier the authors proposed a thermal shock test set-up for ceramic materials that delivers quantitative results [1,2,3]. By thermo-mechanical simulation test results are utilized for component design.

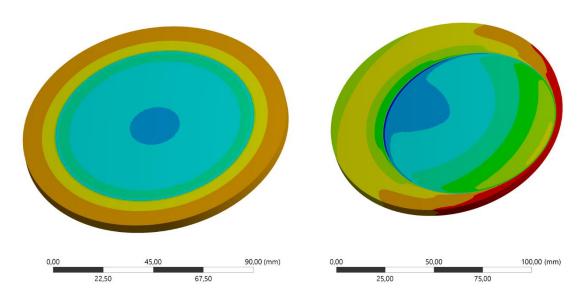


Figure 1. Simulation of Maximum Principal Stress for centric (left) and eccentric (right) heated area. Same stress scale for both plots.

It is shown that this proposed process is also suitable for ceramic composites materials. As such materials are more stress resistant than classical technical ceramics, sample geometries and test set-

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ups have to be chosen deliberately. In a simulation-based study, a variety of test set-ups is investigated. For example, a centric position yields a homogeneous stress distribution at the sample edge, whereas an eccentric position leads to stress increase in certain areas enabling cracking of higher stress-resistant materials. Figure 1 compares First Principal Stresses for both configurations for the same sample and heating area size.

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Bauteil 4.0: Verfahrensentwicklung und Festigkeitsbewertung von Bauteilen in Sandwichbauweise mit integrierter Elektronik für die Luftfahrtanwendung

D. Ernst¹, M. Heckert³, D. Melzer², R. Koschichow^{2*}, R. God³, T. Zerna¹

Zusammenfassung

In der Luftfahrttechnik werden Komponenten und auch ganze Systeme traditionell hierarchisch nach dem Grundsatz "eine Funktion = ein Bauteil" konzipiert. Ein jedoch stetig steigender Funktionsumfang, der heute insbesondere zur Erhöhung des Passagierkomforts in der Kabine realisiert werden muss, ohne gleichzeitig das Volumen und vor allem die Masse der Bauteile überproportional zu erhöhen, verlangt neue Konzepte. Im Rahmen des Forschungsprojektes "Bauteil 4.0" wurde ein Aufbaukonzept für eine hochintegrierte und -funktionalisierte Leichtbaukomponente für Kabinen aus dem Flugzeugbau entwickelt. Für dieses Konzept wurde ein Testvehikel einer solchen Leichtbaukomponente in Sandwichbauweise mit integrierter Elektronik entworfen, wobei zunächst eine einfache Energie- und Datenversorgung betrachtet wurde.

Zur Bewertung der Zuverlässigkeit und Sicherheit dieser Leichtbaukomponente insgesamt, aber auch der integrierten Elektronik, wurde ein Testprinzip erarbeitet und umgesetzt. Diese Tests wurden mit Hilfe numerischer Simulationen nachgebildet, so dass durch eine virtuelle Analyse mittels Finite-Elemente-Methode (FEM) eine Abschätzung der Zuverlässigkeit bzw. des Bauteilversagens vorgenommen werden kann. Dafür wurde eine geschlossene Modellierungsstrategie entwickelt, die neben der detaillierten Berücksichtigung der Topologie der untersuchten Leichtbaukomponente auch alle relevanten Werkstoffkennwerte beinhaltet, um die komplexen Schädigungsmechanismen bei einem Festigkeitsnachweis von Bauteilen in Sandwichbauweise abbilden zu können.

Projekthistorie

In der vergangenen Dekade hat das Bundesministerium für Bildung und Forschung (BMBF) unter anderem mit dem Förderprogramm "Zwanzig20 – Partnerschaft für Innovation" die überregionale Kooperation und Vernetzung zwischen Kompetenzzentren in Deutschland unterstützt. Speziell wurden dabei auch Kompetenzen aus der Luft- und Raumfahrtentwicklung mit dem Schwerpunktgebiet "Elektronik und Halbleitertechnik" gebündelt. In einigen Projekten ging es dabei vordergründig nicht um die inhaltlich fachliche Projektarbeit, sondern um die Vernetzung der entsprechenden Unternehmen in den Regionen und den Forschungsreinrichtungen aus den bis dahin separat agierenden Netzwerken. Im Einzelnen wurde eine engere Zusammenarbeit der Netzwerke "Berlin-Brandenburg Aerospace Allianz (BBAA e.V.)", "Hamburg Aviation e.V." und "Luft- und Raumfahrttechnik Sachsen/Thüringen e.V. (LRT)" zum Thema Luftfahrtforschung und -technik einerseits mit dem Netzwerk "Silicon Saxony" zum Thema "Elektronik und Elektronikintegration" andererseits angestrebt. Aufbauend auf die ersten Machbarkeitsstudien zur Integration von Elektronik in Luftfahrtstrukturen seitens des Zentrums für mikrotechnische Produktion der TU Dresden entstand die Idee das Projekt Bauteil 4.0: "Funktionsintegrierte Sandwich-Bauteile für die Flugzeugkabine als Voraussetzung für Industrie 4.0 und innovative Betriebs- und MRO-Prozesse" als ein Kooperationsprojekt aufzubauen. Schließlich wurde das Projekt für die beteiligten Einrichtungen: IMA Materialforschung und Anwendungstechnik GmbH Dresden, Technische Universität Hamburg, Institut für Flugzeug-Kabinensysteme, und Technische Universität Dresden, Zentrum für

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mikrotechnische Produktion, im 3. Aufruf des Luftfahrtforschungsprogramms V (LuFo V-3) des Bundesministeriums für Wirtschaft und Energie (BMWi) genehmigt.

Motivation

Visionäre Konzepte seitens der Flugzeughersteller oder ihrer Zulieferer zum Thema Funktionsintegration existieren schon seit langer Zeit. Besonders im Kabinenbereich stehen dabei die Erhöhung des Funktionsumfangs und des Komforts für die Passagiere im Vordergrund (Abbildung 1 und Abbildung 2). Die zurecht sehr strengen Zulassungsbedingungen und umfangreichen Zulassungsprozesse erlauben oft nur kleine Entwicklungsschritte und sind meist auch der Grund für eine vergleichsweise konservative Haltung der Hersteller, wenn es um die tatsächliche Umsetzung geht. Auf Grund der besonderen Anforderungen an Elektronikbaugruppen in der Luftfahrt sind zunächst grundlegende Fragen zu klären:

- 1. Wie können Elektronikmodule unterschiedlicher Komplexität in den Herstellungsprozess typischer Kabinenbauteile integriert werden?
- 2. Welchen Beanspruchungen sind diese eingebetteten Elektronikmodule im Betrieb ausgesetzt?
- 3. Inwieweit beeinflussen die eingebetteten Elektronikmodule die Stabilität der Kabinenbauteile?
- 4. Welche Konzepte sind denkbar, um funktionsintegrierte Kabinenbauteile montage- und wartungsgerecht bezüglich der eingebetteten Elektronik zu gestalten?

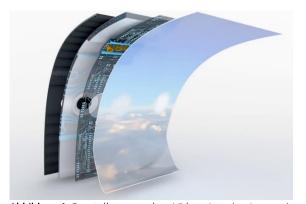


Abbildung 1. Darstellung aus dem Video "Imagine Innovations Flying Tomorrow" von Airbus und dem Cabin & Cargo Netzwerk des Bundesverbandes der deutschen Luft- und Raumfahrtindustrie zu aktiven Oberflächen [1]



Abbildung 2. The Future by Airbus in 2050: The Concept Plane Cabin. Die "Smart Tech Zone" mit holographischen Bildschirmen [2]

Herstellung typischer Kabinenbauteile

Kabinenbauteile werden im Interesse der Gewichtsreduzierung in Leichtbauweise hergestellt. Eine Gewichtseinsparung von nur 10 kg am Leergewicht eines Kurzstreckenflug-

wichtseinsparung von nur 10 kg am Leergewicht eines Kurzstreckenflugzeugs vom Typ A320 führt zu einer jährlichen Treibstoffeinsparung von etwa 2000 Litern. Bei diesen Leichtbauteilen handelt es sich meist um Bauteile in Sandwichbauweise. Derart aufgebaute Leichtbauteile (Abbildung 3 A) für die Flugzeugkabine werden häufig als Verbund aus Laminaten aus CFK-(Kohlenstoffaser verstärkte Kunststoffe)- oder GFK-(verstärkte Kunststoffe)-Decklagen (Abbildung 3 B) und einer sogenannten Nomex-Papierwabe (Abbildung 3 C) gefertigt. Diese werden nach dem Legen unter Druck und Temperatureinwirkung zu Sandwichbauteilen verarbeitet. Die Temperatur wird dabei in Form einer Rampe in einer Aufheiz- und Abkühlphase eingebracht. Dabei ist zwischen der Fertigung im Autoklav mit der Unterstützung von Unterdruck und in einer Presse zu unterscheiden. Autoklav-Verfahren kommen für Formbauteile zum Einsatz, im Vergleich dazu werden Pressen vorwiegend für die Fertigung von plattenförmigen Bauteilen genutzt.

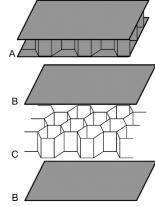


Abbildung 3. Leichtbaukomponente in Sandwichbauweise mit Wabenkern

Im Verlauf des Projektes konnten Proben solcher plattenförmigen Bauteile unter Nutzung des im Produktionsprozess eines Herstellers von Kabinenbauteilen (3D ICOM GmbH & Co. KG, Hamburg) vorhandenen Equipments und damit unter produktidentischen Bedingungen hergestellt werden. Die folgenden Prozessparameter wurden dabei genutzt und vermitteln einen Eindruck von den Lastbedingungen, die durch das Einbetten von Elektronikmodulen in Sandwichbauteile auf diese Module bereits im Produktionsprozess wirken:

- Druck in der Presse bis 1,9 MPa, wobei ein auf Untermaß gefertigtes Aluminiumformwerkzeug die finale Höhe (Dicke) des Sandwichbauteils limitiert,
- Aufheizgradient: zwischen 3 und 5 K/min,
- Peaktemperatur: zwischen 120 und 135 °C, bei einer Haltezeit zwischen 1 und 2 h,
- Abkühlgradient: zwischen 3 und 5 K/min.

Es wird ersichtlich, dass ein eingebettetes Elektronikmodul dabei eine nicht unerhebliche Belastung erfährt.

Hinsichtlich der Fertigbarkeit der Sandwichbauteile mit integrierter Elektronik und Validierung der numerischen Modelle, die mittels FEM durchgeführt wurden, werden Prüfkörper mit einer geometrisch einfachen Struktur gefertigt. Als Elektronikmodule kamen dabei Komponenten mit reduziertem Funktionsumfang, etwa Radio-Frequency Identification (RFID)-Module, zum Einsatz (Abbildung 4).

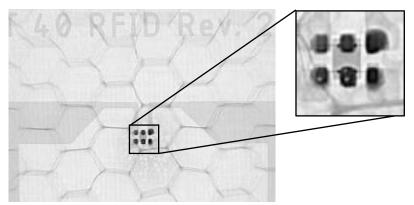


Abbildung 4. Röntgenmikroskopieaufnahmen einer Leichtbaukomponente gefertigt in Sandwichbauweise mit integrierter Elektronik

Prüfkonzept

Zur Entwicklung eines geeigneten Teststandes wurden mehrere Belastungsszenarien analysiert. Allgemein gültige Normen für die Durchführung solcher Prüfungen sind nur vereinzelt in der Anwendung, z. B. für Biegeversuche [3]. Vielmehr gibt jeder Flugzeughersteller vor, welches Bauteil welchen Belastungen ohne Schaden widerstehen soll. Beispielhaft darf für ein etwa 180 cm x 180 cm großes Paneel bei einer flächigen Lasteinleitung von 680 N am lastkritischen Punkt die Durchbiegung maximal 25 mm betragen. Bei Partition Walls gilt max. 25 mm Durchbiegung bei einer Kraft von 900 N. Mit den genannten geometrischen Parametern ergibt sich bei der zulässigen Maximaldurchbiegung von 25 mm ein Biegeradius von ca. 16,2 m. Aus diesen und anderen Angaben in Firmennormen wurden folgende Lastfälle abgeleitet:

- Flächige Krafteinwirkung auf das Sandwichbauteil zu dessen Durchbiegung (Vier-Punkt-Biegeversuch),
- Punktförmige Krafteinleitung mittels Druckkalotte mit einem Radius von 5 mm (z.B. sich aufstützender Ellenbogen auf einem Tray-Table oder Schuhabsatz auf Bodenplatten),
- Punktförmige Krafteinleitung mittels Druckkalotte mit einem Radius von 37,5 mm (z.B. sich aufstützender Handballen auf einem Tray-Table).

Der Teststand muss demnach in zwei Modi betreiben werden können (vgl. Abbildung 5). Für beide Lastfälle bzw. Modi werden die eingebrachten Kräfte mittels Kraftmessdose überwacht.

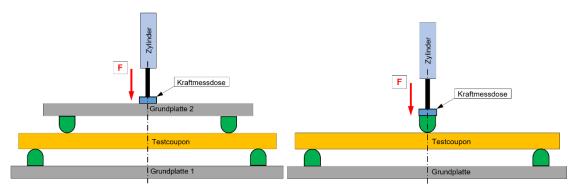


Abbildung 5. Prinzipskizze der beiden Teststand-Modi, links: Vier-Punkt-Biegung, rechts: Punktbelastung

Bei der Vier-Punkt-Biegung wird zusätzlich die erzielte Verformung durch einen Wegaufnehmer erfasst. In **Abbildung 6** ist der realisierte Aufbau des Prüfstandes zu sehen. Darin befindet sich der genannte Wegaufnehmer mittig unterhalb des Prüfkörpers. Bei einer Punktbelastung wird die Beschaffenheit der Probe nach Belastung charakterisiert. Der realisierte Prüfstand ist modular aufgebaut und ermöglicht es Prüfkörper bis zu einer Länge von 350 mm zu testen.

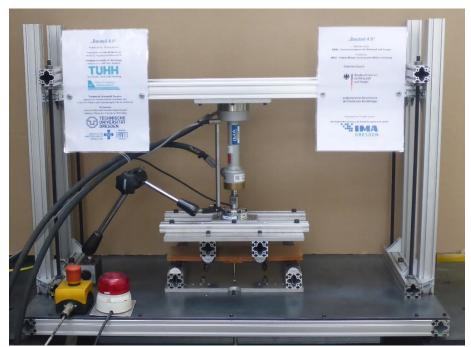


Abbildung 6. Realer Prüfstand aufgebaut für den Modus: Vier-Punkt-Biegeversuch

Herstellung von Prüfkörpern

Die Fertigung der Testvehikel erfolgte mit Hilfe einer Aluminiumrahmen-Form zur Begrenzung der äußeren Abmessungen, um ein Verrutschen des Geleges sowie ein Eindrücken des Nomex®-Wabenkerns zu verhindern. Das Werkzeug weist drei Kavitäten auf, die den geometrischen Abmessungen der Prüfkörper entsprechen, sodass für die damit hergestellten Prüfkörper keine nachfolgenden Bearbeitungsschritte notwendig sind. Die geometrischen Abmessungen der Prüfkörper betragen 350 mm / 100 mm / 11 mm (L/B/H). In Abbildung 7 links ist die CAD-Geometrie des Press-Werkzeuges, das bestückte Werkzeug (mittig) sowie die hergestellten Prüfkörper (rechts) dargestellt. Zur Gewährleistung vergleichbarer Prüfkörperqualität wurden während eines Fertigungsdurchlaufes zwei Prüfkörper (Kavität 1 und Kavität 3) mit Elektronikmodul und ein Prüfkörper ohne eingebettete Elektronik (Kavität 2) hergestellt. Dadurch kann sichergestellt werden, dass alle Prüfkörper einer Charge mit vergleichbaren Prozessparametern

gefertigt wurden, sodass es möglich ist einen Einfluss der eingebetteten Elektronik, als Störstelle im Prüfkörper, auf die mechanischen Eigenschaften zu untersuchen.

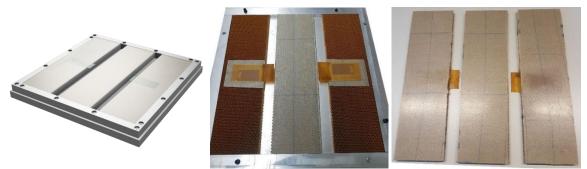


Abbildung 7. CAD-Geometrie des Press-Werkzeuges, bestücktes Werkzeug, Prüfkörper nach Herstellprozess (v. l. n. r.)

Der gewählte Aufbau der Prüfkörper ist wie folgt:

- Decklage oben: zwei Lagen Gurit PHG600-68-50 (0,3 mm)
- Wabenlage: Schütz Coremaster C1 4,8 Wabe hexagonal (10,4 mm)
- Zusatzlage (Prüfkörper 1 und 3): Gurit PHG-600-68-50
- Elektronikmodul (Prüfkörper 1 und 3): RFID-Chip
- Decklage unten: zwei Lagen Gurit PHG600-68-50 (0,3 mm)

Alle Prüfkörper wurden nach der Herstellung visuell analysiert und bewertet. Des Weiteren wurde die Funktionalität der eingebetteten Elektronik überprüft. Dazu wurden die RFID-Chips ausgelesen und teilweise beschrieben. Weiterhin wurde die Struktur zerstörungsfrei untersucht. Dazu wurde die Röntgenmikroskopie eingesetzt. Durch den hohen Anteil konstruktionsbedingter Lufteinschlüsse und durch die Materialkombination selbst ist die alternativ mögliche Ultraschallmikroskopie nicht hinreichend geeignet, um Defekte oder gar Eigenschaften des Aufbaus zu analysieren. Die Röntgenmikroskopie ist dagegen sehr gut geeignet. Mit jeweils angepassten Parametern ist es möglich, sowohl die Elektronik als auch die Wabenstruktur zu analysieren. So konnte gezeigt werden, dass keine signifikanten Strukturveränderungen aufgrund der Fertigung erzeugt wurden. Es wurde jedoch beobachtet, dass einige RFID-Komponenten direkt auf einer Wabenkante liegen. Sie waren dennoch nach der Fertigung funktionstüchtig. Dieser Umstand kann jedoch im weiteren Verlauf zur Herabsetzung der Zuverlässigkeit, vor allem hinsichtlich der Elektronik führen, da hier ggf. höhere und undefinierte Spannungen auftreten können. Ebenfalls konnte eine leichte Verschiebung der Wabenkanten im Bereich der eingebetteten Elektronik beobachtet werden. Ein signifikanter Einfluss dieser Unregelmäßigkeiten auf die Zuverlässigkeit konnte in den folgen-den Belastungstests nicht nachgewiesen werden.

Vier-Punkt-Biegeversuch

Zur Bewertung der mechanischen Eigenschaften wurden die hergestellten Prüfkörper im Vier-Punkt-Biegeversuch experimentell untersucht. Bei allen Prüfungen wurden 1,9 mm starke Gummiunterlagen auf den Auflagern sowie unterhalb der Prüfstempel verwendet, um eine mögliche Initiierung der Prüfkörperschädigung in diesen Bereichen, die aufgrund starker Steifigkeitsunterschiede erfolgen kann, zu verhindern. Alle Prüfungen erfolgen bis zum Totalversagen der Prüfkörper weggesteuert mit einer konstanten Prüfstempelgeschwindigkeit von 3 mm/min. Die Vorspannkraft beträgt 10 N. Untersucht wurden jeweils Prüfkörper mit und ohne der eingebetteten Elektronik. In der Abbildung 8 ist eine Prüfkonfiguration gezeigt bei der ein Prüfkörper ohne eingebettete Elektronik dargestellt ist. In der Abbildung 9 ist das entsprechende Schadensbild des geprüften Prüfkörpers dargestellt. Auffällig ist das typische Ablösen der druckseitigen Decklage von dem Wabenkern mit nachfolgendem Knickversagen dieser Lage. Bei allen durchgeführten Prüfungen an Prüfkörpern mit und ohne Elektronik konnte ein vergleichbares Verhalten beobachtet werden. In Abbildung 10 ist eine

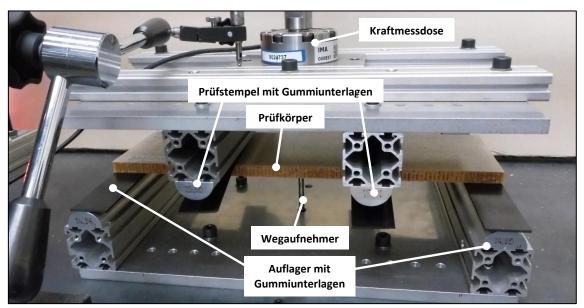


Abbildung 8. Bestückter Prüfstand zur Durchführung eines Vier-Punkt-Biegeversuchs

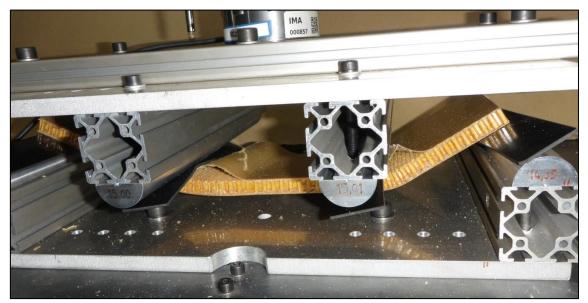


Abbildung 9. Bruchbild eines Prüfkörpers im Vier-Punkt-Biegeversuch

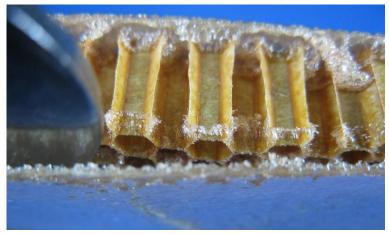


Abbildung 10. Interfaceversagen zwischen Decklage und Wabenkern eins Prüfkörpers im Vier-Punkt-Biegeversuch

Nahaufnahme des Schadensbildes eines Sandwichbauteils mit Wabenkern im vollständig entlasteten Zustand dargestellt. Bei visueller Bewertung des Sandwichkerns konnten keine bleibenden Deformationen bzw. erkennbaren Schädigungen der Wabenstruktur festgestellt werden. Das Ablösen der Decklagen trat in Abhängigkeit von der Prüfkörpergüte teilweise großflächig auf. Diese Erkenntnisse verstärken die Annahme, dass die Decklagen erst nach Ablösen vom Wabenkern ausbeulen und versagen. In der nächsten Prüfreihe wurden Prüfkörper mit eingebetteter Elektronik untersucht. Dabei wurden sie so eingespannt, dass das RFID-Modul sich untenliegend befand und während der Prüfung auf Zug beansprucht wurde (siehe Abbildung 11). Die Funktionsfähigkeit des RFID-Moduls wurde während der gesamten Prüfdauer protokolliert und konnte auch nach dem Versagen des Prüfkörpers nachgewiesen werden. Auch bei einer Prüfkonfiguration mit obenliegendem RFID-Modul (Abbildung 12) konnte die Funktionsfähigkeit der Elektronik nach Versagen der Prüfkörper nachgewiesen werden. Das Schadensbild der Prüfkörper der beiden Prüfkonfigurationen ähnelte dabei dem Bruchverhalten der Proben ohne die eingebettete Elektronik und äußerte sich in Form einer lokalen Ablösung der oberen Decklage mit anschließendem Knickbruch.

Im direkten Vergleich der Kraft-Weg-Verläufe zeigen die drei unterschiedlichen Prüfkonfigurationen ein annährend vergleichbares Steifigkeitsverhalten auf (Abbildung 13).

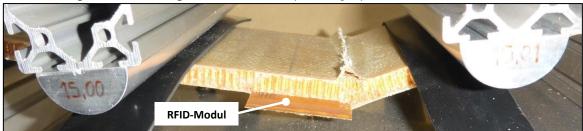


Abbildung 11. Schadensfall bei untenliegendem RFID-Tag, Bruch in der oberen Decklage



Abbildung 12. Schadenfalls bei obenliegendem RFID-Tag, Bruch in der oberen Decklage

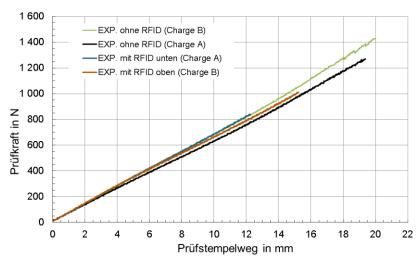


Abbildung 13. Kraft-Weg-Verlauf der drei untersuchten Prüfkonfigurationen

die von Charge zu Charge große Schwankungen aufwies, konnte keine abgesicherte statistische Auswertung der maximal ertragbaren Last durchgeführt werden. Vielmehr konnten Bereiche identifiziert werden, in den sich die Festigkeiten der Prüfkörper (mit und ohne Elektronik) bewegen. Bei Prüfkörpern ohne ein eingebettetes RFID-Modul lag die maximal ertragbare Last zwischen 1200 N und 1550 N. Bei Prüfkörpern mit integrierter Elektronik lag sie zwischen 800 N und 1150 N.

FE-Analysen

Ausgehend von den gewonnenen Erkenntnissen der ersten Biegeversuche wurde ein zwischenzeitlich verfolgtes Konzept der komplexen Modellierung eines eingebetteten Elektronikmoduls im Zusammenspiel mit dem umgebenden Sandwichaufbau zunächst zurückgestellt. Der Simulationsansatz wurde also dahingehend vereinfacht, die eingebettete Elektronik als "Black Box" zu betrachten und sie lediglich als entsprechende Störstelle mit homogenen Eigenschaften im Sandwichaufbau modelltechnisch abzubilden. Die Modellierung und Simulation erfolgte im System ABAQUS. Unter Nutzung der Probensymmetrie für eine Modellvereinfachung (eine übliche Methode in der FEM zur Aufwandsreduzierung) entstand das in Abbildung 14 gezeigte Modell des Vier-Punkt-Versuchs. Der Wabenkern wurde geometrisch detailliert im Modell abgebildet und mit Schalenelementen diskretisiert. Die Decklagen aus glasfaserverstärktem Kunststoff wurden ebenfalls mit 2-D Schalenelementen diskretisiert.

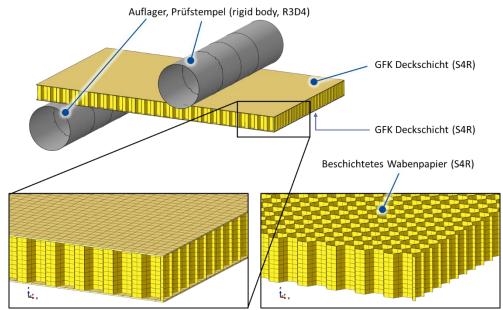


Abbildung 14. FEM-Modell eines Bauteils in Sandwichbauweise im 4-Punkt-Biegeversuch mit Glasfaserverstärktem Kunststoff (GFK) als Decklagen und einem Wabenkern aus Phenolharz getränktem Aramidpapier (in Klammern ABAQUS spezifische Elementtypbezeichnungen)

Zwischen der GFK-Deckschicht und der Wabenschicht wurde im Modell eine feste kinematische Kopplung angenommen (in ABAQUS: TIE-Kontakt). Als Decklagenmaterial wurde ein Prepreg aus E-Glasgewebe und Phenolharz (Interglas 92626, Aero) mit 0,3 mm Dicke angenommen, als Wabengewebe Nomex® T412, DuPont mit 0,1 mm Wandstärke. Es standen Materialparameter aus Datenblättern der Hersteller sowie aus ähnlichen Versuchen zur Verfügung. Alle FE-Analysen wurden mit einem explizit Solver gelöst. Abbildung 15 zeigt Simulationsergebnisse der Durchbiegung (links im Bild) und der Werkstoffanstrengung (rechts im Bild) für zwei Zeitpunkte während eines Vier-Punkt-Biegeversuchs, und zwar im oberen Teil vor dem Reißen der Decklage und im unteren Teil unmittelbar danach.

Durch Verwendung kohäsiver Kontakte bzw. kohäsiver Elemente in ABAQUS kann die Steifigkeit bzw. Festigkeit der Klebstoffschicht (Interfaceschicht) zwischen Decklage und Wabenkern in einer numerischen Simulation berücksichtigt werden. Bei Definition einer Schädigungsinitiierung sowie des Schädigungswachstums kann darüber hinaus der komplexe Mechanismus des Ablösens und des plötzlichen

Versagens der Deckschichten realistisch berücksichtigt und bewertet werden. In der Abbildung 16 ist die Auslastung der Interfaceschicht (links) sowie die Werkstoffanstrengung der GFK-Decklagen, vor (oben) und unmittelbar nach dem Totalversagen der Klebstoffschicht (unten) dargestellt. Der entsprechende Vergleich der Kraft-Weg-Verläufe aus FE-Analysen und Experiment ist in der Abbildung 17 dargestellt.

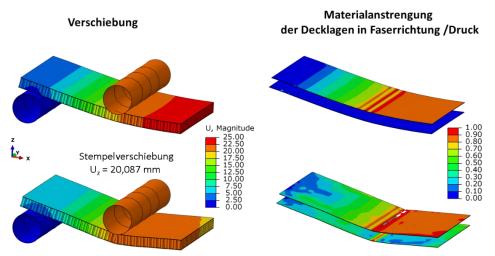


Abbildung 15. Durchbiegung und Werkstoffanstrengung als Ergebnisse aus einer FE-Analyse, oben vor und unten nach dem Reißen der Decklage (ohne Interfaceversagen)

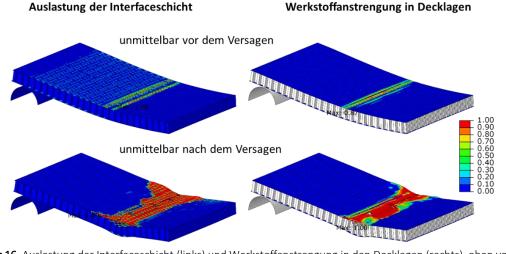


Abbildung 16. Auslastung der Interfaceschicht (links) und Werkstoffanstrengung in den Decklagen (rechts), oben vor und unten nach dem Versagen der Interfaceschicht

Des Weiteren wurde die eingebettete Elektronik, wie bereits anfangs erwähnt, als eine Störstelle zwischen einer der Decklagen und dem Wabenkern in der Mitte des Prüfkörper modelliert und numerisch untersucht. Ein signifikanter Festigkeitsabfall des Verbundes, der in den experimentellen Untersuchungen auftrat, konnte mittels der durchgeführten FE-Analysen nicht reproduziert werden. Die Ergebnisse der numerischen Untersuchungen zeigen, dass die maximal ertragbaren Lasten der Prüfkörper mit und ohne eingebettete Elektronik vergleichbar sind, wobei die Verbundsteifigkeit mit RFID-Modul geringfügig höher ist (Abbildung 18). Insgesamt ist eine exzellente Übereinstimmung zwischen Modellierung/Simulation und Experiment festzustellen, so dass die erarbeitete Modellierungsstrategie für weitere Un-

tersuchungen verwendet werden kann. Zum Beispiel kann per Simulation gezeigt werden, dass bei unverändertem Wabenkern eine Verdoppelung der Decklagendicke (oder -anzahl) sich nahezu linear auf die Ergebnisse auswirkt (Abbildung 19).

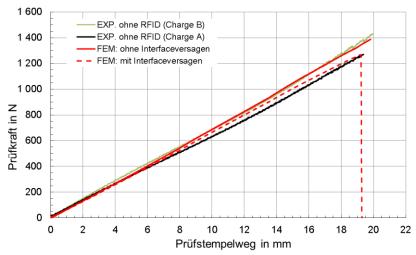


Abbildung 17. Vergleich der Kraft-Weg-Verläufe aus FEM und Experiment, mit und ohne Interfaceversagen

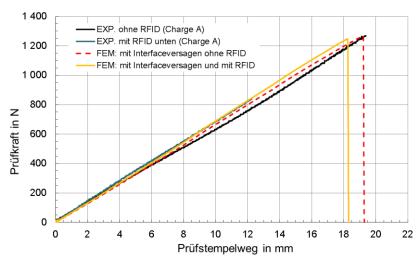


Abbildung 18. Vergleich der Kraft-Weg-Verläufe aus FEM und Experiment, mit und ohne Interfaceversagen/RFID-Modul

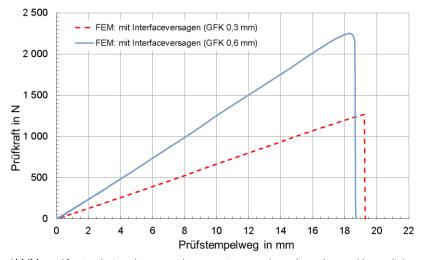


Abbildung 19. Simulation der Auswirkungen einer Verdoppelung der Decklagendicke

Zusammenfassung und Ausblick

Im Projekt "Bauteil 4.0" konnten Kompetenzen aus dem Flugzeugkabinenbau und der Elektronik-Technologie zusammengeführt werden. Die prinzipielle Machbarkeit des Einbettens einfacher und komplexerer Elektronik-Module in Leichtbauteile konnte demonstriert werden. Die Anpassung zwischen den Verbundmaterialien und den Elektronikmodulen ist möglich. Für die eingebettete Elektronik wurde bewusst auf Standardtechnologien der Aufbau- und Verbindungstechnik gesetzt. Diese sind weiter eher den Avionik spezifischen Zulassungsverfahren für Bauteile zugänglich als High-End-Technologien z. B. des additiven Aufbaus von Elektronik-Komponenten.

Die typischen Belastungen, die auf Kabinenbauteile wirken dürfen, können für die innenliegende Elektronik als undramatisch eingestuft werden. Zu beachten ist eher die potenzielle Schwächung des Strukturbauteils durch die "Störgröße" Elektronikmodul. Statische Belastungstests haben gezeigt, dass diese Schwächung des Strukturbauteils beherrschbar ist. Diese Tests wurden mit Hilfe numerischer Simulationen nachgebildet, so dass auch durch virtuelle Analyse mittels Finite-Elemente-Methode eine Abschätzung der Zuverlässigkeit bzw. des Bauteilversagens bei modellierten Leichtbaugruppen mit integrierten Elektronikmodulen vorgenommen werden kann. Dafür wurde eine geschlossene Modellierungsstrategie entwickelt, die neben der detaillierten Berücksichtigung der Topologie der untersuchten Leichtbaukomponente auch alle relevanten Werkstoffkennwerte beinhaltet, um die komplexen Schädigungsmechanismen bei einem Festigkeitsnachweis von Bauteilen in Sandwichbauweise abbilden zu können.

Ausgehend von den Ergebnissen aus einem 4-Punkt-Biegeversuch der zum Bauteilbruch führenden maximalen Kraft von geometrisch einfachen Prüfkörpern konnte eine sehr gute Übereinstimmung mit den Ergebnissen aus einer expliziten FE-Analyse festgestellt werden. Sowohl qualitative als auch quantitative Güte der mittels der FE erzielten Ergebnisse bezogen auf das Experiment zeigen eindrucksvoll (Abbildung 5), dass die entwickelte Modellierungs-strategie ein geeignetes Werkzeug ist, um auch an geometrisch komplexen Bauteilen in Sandwichbauweise mit integrierter Elektronik eine Festigkeitsabschätzung numerisch durch-führen zu können. Darüber hinaus stellt der entwickelte Ansatz eine gute Ausgangsbasis für eine numerisch gestützte Auslegung und Dimensionierung von Leichtbaukomponenten mit integrierter Elektronik in der Luftfahrttechnik dar.

Danksagung

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FEM modeling of combined debonding and bulk crack propagation in a rubber-matrix composite

S.M. Frankl*, M. Pletz, C. Schuecker

Composite materials are widely used in highly stressed and lightweight structures. Their further improvement is therefore essential to meet new and higher load requirements. The debonding of the matrix from the reinforcement and crack propagation within the matrix are two key mechanisms in a composite's failure. For rubber-matrix composites, the development of such cracks is more complex because of the large deformations occurring in the rubber. This work introduces a concept to predict the crack path, capturing both interface debonding and crack propagation in the matrix of a rubber-matrix composite based on the criterion for maximum energy release rate. The concept is based on a fracture mechanics concept using configurational forces and implemented within the Finite Element Method (FEM) following Müller et al [1]. Starting from an initial debonding, the method predicts the further propagation, which can either continue in the rubber reinforcement interface, or kink into the rubber matrix. The crack propagation angle is found in an iterative manner using the Targeted Angle Correction (TAC) method proposed by Frankl at al. [2], which is an efficient implementation to yield the crack growth angle for maximum energy release rate.

To apply the TAC concept in a FEM model, the load is increased incrementally, and in each load increment, the existing crack is checked for crack growth using the above concept. Once the crack arrests for the applied load, the load is increased by one increment and the crack is checked again. This incremental crack growth concept is applied for a plane strain model of a shear specimen, where rubber is embedded between steel plates (see Figure 1). Due to the specimen's symmetry, only the region in the magenta frame needs to be considered. Starting from initial steel-rubber debonding on the left side, the crack paths for various ratios of interface rubber fracture toughness are computed. The location where the crack starts to grow into the rubber is determined by the G_c -ratio defined as the ratio of fracture toughness of the interface and the rubber material, respectively. If the ratio is slightly below a value of 1, the crack grows into the rubber rather early. Decreasing the G_c -ratio, the location shifts to the right as it becomes easier for the crack to propagate in the interface. The TAC concept can be adapted to describe any type of heterogeneous material where debonding and crack growth play a role. Such materials could be particle-reinforced polymers, additively manufactured parts where interfaces with lower fracture toughness than the bulk material occur, or classical fiber-reinforced composites.

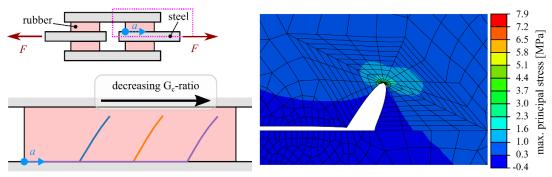


Figure 1. Predicted crack paths in a shear specimen for varied G_c -ratio and a contour plot of the maximum principal stress for one position of the crack tip.

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Kontaktbedingungen der Grenzschichten ultraschallgeschweißter Verbindungen für rechnerische Auslegung von Bauteilen in der Finite Elemente Simulation

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Hybride Verbindungen sind neben der Steigerung der Leistungsfähigkeit durch gezielte Werkstoffkombinationen häufig unvermeidlich, um Bauteilkomponenten miteinander zu verbinden. Das Ultraschallschweißen ist eine innovative und vielversprechende Fügetechnologie für genau solche hybriden Werkstoffsysteme. Das Verfahren ist kostengünstig und kann ohne Zusätze wie Klebstoffen, Nieten oder Bolzen realisiert werden. Die Erfassung und Bewertung relevanter Prozessparameter ermöglicht die Prozesssicherung im Betrieb. Ein vielversprechendes Potential dieses Verfahrens gegenüber anderen Fügeverfahren ist die stoffschlüssige Verbindung verschiedenartiger Werkstoffe, beispielsweise Metalle mit faserverstärkten Kunststoffen, Gläsern oder Keramiken.

Die meisten Bauteile werden bei der entsprechenden Anwendung multiaxial beansprucht. Der Spannungszustand innerhalb der Komponenten ist daher oftmals komplex. Aus diesem Grund erfolgt die Auslegung moderner Bauteile häufig mit Hilfe von Finite Elemente Simulationen. Zur rechnerischen Auslegung ultraschallgeschweißter Komponenten müssen die Kontaktbedingungen zwischen den Fügepartnern berücksichtigt werden. Der Verbindungsmechanismus ultraschallgeschweißter Verbindungen ist allerdings größtenteils noch ungeklärt, bestimmt aber Kontaktbedingungen, die bislang im FE-Modell für rein wissenschaftliche Zwecke vereinzelt durch Hilfsmodelle ersetzt wurden.

Im Zusammenhang mit der Verbundfestigkeit können anhand systematischer Untersuchungen der Mikrostruktur im Bereich der Grenzflächen zwischen den Fügepartnern und der Bruchflächen weitere Erkenntnisse über den Verbindungsmechanismus gewonnen werden. Basierend auf diesen Erkenntnissen sind Rückschlüsse auf die Kontaktbedingungen möglich, die auf ein FE-Modell übertragen werden und rechnerisch validiert werden. Neben der Erweiterung des Kenntnisstandes auf wissenschaftlicher Ebene leisten die durchgeführten Untersuchungen zu den Kontaktbedingungen ultraschallgeschweißter Hybridverbunde und die darauf basierenden FE-Modelle einen wertvollen Beitrag für eine effizientere und sichere Bauteilauslegung.

Modeling of the consolidation process during the processing of thermoplastic UD tapes

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The processing of thermoplastic continuous fiber reinforced materials has become increasingly important in recent years. Reasons for this include the high automation potential during processing and the recyclability at the end of the product life cycle. In addition, the use of unidirectional fiber-reinforced (UD) tapes can achieve a local, load-path-compatible orientation of the fibers. On the one hand, this reduces the use of valuable raw materials and, on the other, further lowers the component weight, which subsequently leads to a reduction in the CO_2 footprint over the product life cycle.[1-5]

Consolidation plays a key role in the processing chain, as this is where air pockets between the individual paper layers, which later act as defects in the product, are eliminated.[6-8]

In this process, the layup is first brought under pressure in a heating press to a temperature higher than the glass transition or melting temperature and then cooled in a cooling press, again by means of applied pressure, to below the glass transition or melting temperature (see Figure 1). Direct measurement of process and product properties during processing is only possible to a very limited extent due to the boundary conditions in the process.

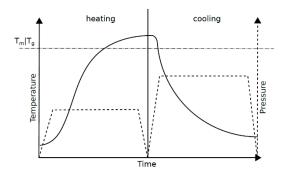


Figure 1. Sketch of temperature and pressure during the heating and cooling phase of a consolidation process.

In order to predict the influence of the process parameters (heating temperature & pressure, as well as cooling temperature & pressure) on the semi-finished product quality, a digital model of the process is being developed, which should subsequently also serve to reduce the cycle time and thus increase the efficiency of the process.

The modeling presented considers the thermodynamic aspects of consolidation, which influence the viscosity of the matrix material and thus affect the displacement (squeeze flow) and compression of the material as well as the bond strength between the individual layers. Significant here are the influences on heat conduction during heating and cooling of the layup, such as the applied pressure and the prevailing machine-dependent conditions.

For this purpose, a multi-region, multi-phase and multi-component-mixture model was developed using the simulation toolbox OpenFOAM®. Experimental data are used to validate the results obtained from the model.

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Modelling of the manufacturing process of TRIP/TWIP steel laminates

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Abstract

Production of roll bonded metal composites is gaining more interest due to the possibility of combining different material properties for special needs application. The combination of high alloy transformation induced plasticity (TRIP) steel and twinning induced plasticity (TWIP) steel resolves in a metal composite with outstanding strength and elongation characteristics. The production of this compound was first investigated by Qui et al. Qiu et al. [1] where the author faced difficulties in finding stable processing conditions. To further understand the production process and to optimize the current processing conditions Qui et al. Qiu et al. [1] stated, that simulative tools should be used. In the present paper the production process of TRIP / TWIP metal laminates was investigated using suitable numerical models. The used model was first published by Zhang et al. Zhang and Bay [2] and was already extended by Schmidtchen et al. Schmidtchen and Kawalla [3]. For the current research this model was also extended to take into account the elastic material behavior. It is shown that through usage of the model the current processing conditions for TWIP/TWIP and TRIP/TWIP combinations could be optimized and a theoretical bond strength could be calculated. Also the results of the extended model fit good with measurements from the actual production process.

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Numerical development and experimental validation of the crash behaviour of a composite ultra-light aircraft

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The popularity of ultra-light aircraft has been increasing in the recent years among private hobby pilots, due to its lower maintenance costs and good flying properties. The use of high performance materials like carbon fibre and the integration of rescue systems, for instance airframe parachute system, have improved the acceptance of this type of aircrafts. However, this type of rescue systems requires a minimum altitude to guarantee a proper deployment. Moreover, statics show that the most accidents take place near the ground during take-off or landing, where the use of the most rescue systems is not any more possible.

In order to improve the crashworthiness of ultra-light aircraft and due to the limited space and allowed MTOW, an integral design approach shall be followed, and the crash behaviour of the structure shall be investigated in early stages of the development. This approach was applied to the development of the AIRector aircraft and validated within the project ULtrasicher funded within the EFRE-program. The crashworthiness of the initial design was numerically investigated and structure weak points were identified. Afterwards modification of the laminate lay-up and the use of new materials, like carbon-aramid hybrid layers, in critical areas were investigated using the explicit solver Abaqus. After various iterations, a crashworthy design of the structure was reached and the integrity of the structure was proven numerically. Afterwards a test structure was manufactured and a pendulum test set-up consisting of three auto cranes to create the pendulum swing was planned and realised to verify the proposed design. The crash test was performed successfully, high accuracy with the numerical results was reached and the structure showed the expected crash behaviour.

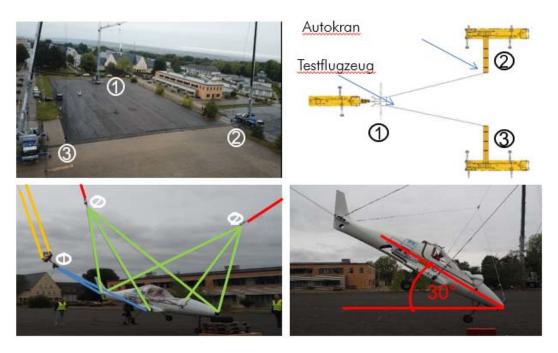


Figure 1. Test set-up with three truck-mounted cranes. Crash speed 65 km/h; test weight 323 kg.

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Investigation and simulation of the crushing behaviour of veneer-based wood composites under crash loading

Thomas Feser^{1*}, Giovanni Piazza¹, David Heyner¹, Elmar Beeh¹

In the field of lightweight structural design, outstanding results have already been achieved through the development of particularly lightweight CFRP structures and corresponding simulation methods and models. Not only the high strength and stiffness and the associated significantly lower structural mass of CFRP materials should be emphasised, but also the high mass-specific energy absorption in the event of a crash load. On the other hand, CFRP structures require a great deal of manufacturing and are therefore expensive to produce. In addition, lightweight vehicle construction has been undergoing change in recent years. In order to reduce CO₂ emissions, the sustainability of the materials used is becoming increasingly important in addition to the lightweight construction potential. The reduction of CO₂ emissions through the use of sustainable materials is thus increasingly becoming the focus of research and development [1]. The use of wood as a renewable material is a promising approach to reduce CO₂ emissions along the life cycle of vehicle structures due to its excellent specific mechanical properties and the resulting high lightweight construction potential [2].

A prerequisite for the transfer of wood to industrial application in vehicle structures is the development of suitable simulation methods that correctly represent the anisotropic material behaviour of wood under various loads.

This presentation will show how modelling, simulation and validation methods developed for CFRP materials can be transferred to wood veneer-based material systems.

The starting point of the considerations are extensive expiremental investigations of the failure behaviour as well as the specific energy absorption (SEA) under crash loading on a generic omega profile made of CFRP, see Figure 1, pefromed at DLR in the past [3]. On the basis of the determined data, characteristic values for numerical material models could be calibrated and simulation methods for the representation of crash load cases could be validated.

Based on this, this work investigates the transferability of the developed methodology to veneer-based wood material systems. For this purpose, layered veneer laminate was used in the omega segments instead of CFRP, see Figure 2. In addition to investigating the failure behaviour, the aim was to estimate the potential of such veneer-based materials in comparison to CFRP, as well as to map the crash behaviour in the numerical simulation.

In initial investigations, the similarities in the failure behaviour of the omega segments under crush loading between CFRP and veneer-based wood laminates could be shown. With the correct choice of lamiante layup, the veneer-based omega profiles showed progressive failure behaviour, a prerequisite for high specific energy absorption. The specific energy absorption of the veneer-based wood laminates determined in this first experimental investigation was about 30 % of the reference made of CFRP. With regard to the simulation methods developed, the similarities in the modelling between CFRP and veneer-based wood laminates could be shown. The work is concluded with a quantification of the potential of wood-based structures compared to the reference made of CFRP with regard to energy absorption and the validity of the simulation. In this way, an initial basis for veneer-based materials in lightweight construction applications is to be created and, in addition, the transferability of the developed simulation method to other material systems is to be demonstrated.

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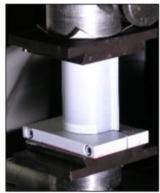






Abbildung 1 Test setup, execution and crushed CFRP omega specimen after the quasi-static compression test, from [3].







Abbildung 2. Test set-up, execution and crushed omega specimen from layered wood veneer laminate after the quasi-static compression test.

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A Microscale Experiment for Characterizing the Viscoelastic Fiber-Matrix-Interaction during Cure

M. Müller-Pabel^{1*}, I. Koch¹, J. Kuhlmey¹, M. Gude¹

Thermosetting polymers are widely used as matrix material for high performance lightweight structures made of fibre-reinforced polymers (FRP). During processing, material-inherent properties, like resin shrinkage, cure-dependent viscoelasticity and anisotropy of the composite provoke the build-up of residual stresses that may lead to micro-cracks and reduced lifetime [1]. In order to improve understanding for the complex interaction of manufacturing and laminate properties, process simulation has established as essential tool in both scientific and industrial environment [2]. For this purpose, usually multi-scale approaches are adopted that combine a range of material input data with different homogenisation steps. While the neat resin is often thoroughly analysed in dependence on the process parameters like time, temperature and cure, the resulting composite behaviour is often only validated on macroscopic scale. As a consequence, the microscopic contribution of the fibre-matrix-interface to the effective composite properties during cure remains an unknown variable. Until the present, only few data regarding the influence of process relevant parameters like cure and temperature on fibre-matrix-interaction is available [3,4].

For this reason, we suggest a novel microscale experiment, which is dedicated to the in-situ analysis of the cure-dependent fibre-matrix-interaction, Fig. 1. It is inspired by the previous work of BRODOWSKY et al. which was performed to assess microscopic fatigue effects of single fibre model composites [5]. Based on the selection of a model resin material, basic characterisation by rheological and calorimetric experiments is performed. First experimental results of the novel test setup are presented that highlight the impact of matrix viscoelasticity and cure on the interface behaviour.

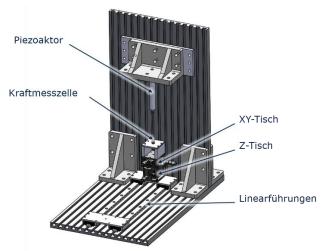


Figure 1. Novel microscale test setup

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Analysis of the influence of impact damage on fatigue properties of carbon fiber-reinforced polyurethane by 3D digital image correlation

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Fiber-reinforced polymers are widely used in automotive and aerospace industries following their excellent strength-to-weight ratio and also corrosion resistance. Due to their increasing use a holistic material characterization, based on different loading conditions, is necessary. Especially laminates are sensitive to out of plane loading, which is due to their anisotropic or quasi-isotropic properties. [1] This kind of loading may result from crash loads due to bird strike, hail or smaller accidents during the manufacturing process, e.g., tool drops. Besides generating characteristic values from impact tests, a suitable method for damage detection and observation of damage evolution in subsequent loading is mandatory. Often, the key component for the mentioned loading conditions is the investigation of residual strength in tension after impact (TAI), compression after impact (CAI) or fatigue after impact (FAI) tests.

In order to achieve qualified knowledge of impact and after impact strength properties, different damage detection methods were compared regarding their level of detail and reproducibility. Most commonly used methods are ultrasonic C-scans, thermography and computed tomography. [2,3] Within this paper, active and passive thermography, ultrasonic C-scans and computed tomography are used for quantitative and qualitative damage description of impacted specimens. The specimen geometry was specially designed in order to be used in both impact and fatigue testing. The material used is a quasi-isotropic carbon fiber-reinforced polyurethane (CFR-PU) with symmetrical layer setup [+45/-45/0/90]_{2s}. At first the impact tests were carried out at 10, 20 and 30 Joule. Subsequent fatigue tests, after non-destructive testing for damage detection, were performed as multiple amplitude tests with stress ratio of R = -1 at a test frequency of f = 5 Hz, beginning at a maximum stress of $\sigma_{max,start}$ = 10 MPa with a stepwise increase of $\Delta\sigma_{max}$ = 10 MPa every ΔN = 2500 cycles (Figure 1).

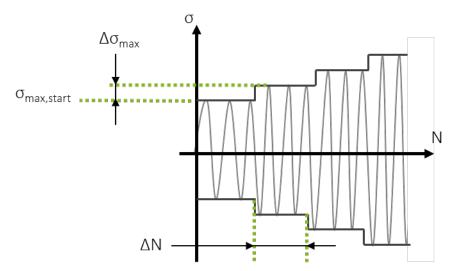


Figure 1. Schematic method for multiple amplitude tests (MAT).

Moreover, the fatigue tests were instrumented with thermocouples and 3D digital image correlation (GOM ARAMIS SRX 3D, 12 MP) so the evaluation of dynamic stiffness C_{dyn} with the help of piston stroke and test force, change in surface temperature ΔT and engineering surface strain $\epsilon_{x/y/z}$ was enabled.

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By the determination of impact energy, impact force and penetration depth correlations between test parameters and damage area were carried out. The damage detection methods were evaluated based on a medium impact energy of 20 J and showed a significant difference between detected areas of up to 63%, which was determined by means of the two methods with lowest and highest capability for damage detection, ultrasonic scans and passive thermography. At the same time, the results are presenting the requirement for a separation of damage modes, such as delamination, fiber breakage and matrix cracks. The fatigue after impact tests resulted in a decrease in lifetime with increasing impact energies by 18 to 82%. The evaluations of dynamic stiffness and temperature are suggesting that a critical stress level exists, on which the materials shows degradation within one step. At the same time, the DIC-analysis presented a pronounced dependence of the failure behaviour on the prevailing loading condition. Especially the deformation in out-of-plane (z-) direction during compression phases supports this assumption and also the need for a 3D DIC-analysis (Figure 2).

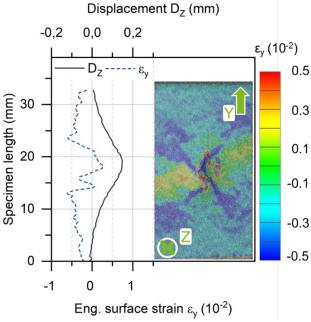


Figure 2. Engineering surface strain in y-direction and displacement in z-direction exemplary for impact damage of 30 J.

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Characterisation of fibre alignment within discontinuous carbon fibre nonwovens using eddy current technology

V. Schumm^{1*}, M. Sauer¹, B. Leitner¹, J. Wölling¹, R. Kupke², A. Oerder³

Nonwoven reinforced composites arise as an innovative material class, especially in the field of carbon fibre recycling. These semi-finished products consist of staple fibres of finite length. In the simplest case, all single filaments are randomly distributed in isotropic orientation. In the context of high-performance lightweight designs, however, it often is more suitable to present a (partial) alignment specifically in the nonwoven material, so that the anisotropic fibre properties can be utilized most effective. [1] The alignment of the fibre can increase the packing density of the composite, which results in a reduction of fibre breaks during the consolidation. Therefore significantly higher fibre volume contents as well as impregnation quality can be achieved using this approach. [2] Corresponding technical implementations are the subject of current research projects along various processing routes.

Reliable measurement of fibre orientation within a discontinuous products is thus essential for further development in this field. In the present approach, the anisotropic conductivity of the carbon fibre base is utilized to define a measurand for fibre alignment by means of non-destructive eddy current technology. For this purpose, a magnetic field is induced in the nonwoven or nonwoven based composite. The magnetic field is distorted due to the conductive filaments and can be recorded as a quantifiable signal by a receiver coil. In addition to the orientation of the fibres, local information on the grammage and the homogeneity of the product can be derived simultaneously. The principle of the measurement can be seen in figure 1 below. [3]

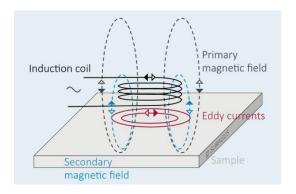


Figure 1. Principle of non-destructive eddy current technology [Suragus GmbH]

The material used in this study is developed as part of the publicly funded project MAI ScrapSeRO. The feedstock consists of recycled pyrolyzed carbon fibres with an average cutting length of approx. 6 mm, featuring a pronounced fibre length distribution. Using the pilot line of the project partner Voith, the fibres are further processed into high-quality partially aligned wetlaid nonwovens with a grammage of 50-100 gsm. These semi-finished products are further manufactured into composites by two processing routes. For version 1, a polycarbonate matrix system from the project partner Covestro is used and consolidated with a variothermal hot pressing cycle. Version 2 is processed by wet compressing moulding using an epoxy-based prepreg system from the project partner Sika. The aim in each case is initially to produce high quality test panels and subsequently to demonstrate the potential within technical demonstrators.

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The eddy current measurement is realized at three different points in the process: On the semi-finished product during the wetlaid production (inline), on the semi-finished product after nonwoven production (offline) and on the composite of the consolidated test panels (offline). For the inline measurement, a customized system from the project partner Suragus GmbH was integrated into the wetlaid pilot line. Four fixed-axis sensors with an elliptical coil shape are applied at 0°, 45°, 90° and 135° to enable the measurement at operation speed. The sensors are linked to each other in order to record a constant measuring point during production. For continuous monitoring of the process, a measured value is recorded every 40 mm by each sensor. For the offline measurement basically the same principle was used, but with utilization of only a single sensor while moving the sample orientation below a fixed setup. This allows for more detailed measurements, especially with regard to the angle-dependent resolution. In order to also obtain detailed local information, specimens were scanned at nine spots. A central measurement point then is rotated in 5° intervals generating polar-type diagrams (see figure 2).

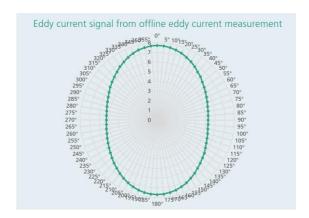


Figure 2. Wetlaid pilot line from Voith used in this project [J.M. Voith SE & Co. KG]

The evaluation of the test method is based on the MD/CD ratio between measured values in 0° (machine direction) and 90° (cross direction). The collected MD/CD ratios during wetlaid production are on a very consistent level with a mean value between 1.43 and 1.47 for five production batches (up to 600 running meters per batch). The standard deviations are rather low with 0.067 to 0.076. Fibre orientation degrees of the offline measured wetlaid nonwovens reach about 5 % higher values. The MD/CD ratios of the consolidated composites are between 1.40 and 1.52 over 14 test panels. The standard deviation vary between 0.014 and 0.077. Thus, the offline measurement also achieves very uniform values, which are quite reproducible to those of the inline measurement. Based on the results of 4-point-bending test, ratios of 1.97 (bending strength) and 2.23 (bending modulus) are achieved on average.

The work in the MAI ScrapSeRO research project confirms that both the homogeneity and fibre orientation of wetlaid nonwovens can be reliably quantified in the case of semi-finished products as well as products based on recycled carbon fibres using non-destructive eddy current measurement. This is an important contribution to advance the processability of recycled carbon fibres in the future.

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Continuous analysis of production-related imperfections in thick-walled composite

Richard Protz^{1*} (R., Protz), Eckart Kunze¹ (E., Kunze), Maik Gude¹ (M., Gude)

For the transmission of extreme mechanical loads in multi-layer fibre-reinforced plastic composites (FRP) structural components with high wall thicknesses are required (Figure 1). However, with increasing composite thickness, production-related imperfections such as fibre misalignment also occur more frequently [1, 2]. Their formation mechanisms and influence on the resulting material behaviour are being fundamentally analysed in the DFG research project PAK 988 "DIWA". For this purpose, glass fibre-reinforced polyurethane resins are produced using braiding technology and the high-pressure resin transfer moulding process (HP-RTM), characterised using non destructive testing methods and subjected to thermo-mechanical load tests.

In this paper, the formation, expression and evolution of fibre misalignment in the sequential manufacturing steps are continuous examined in more detail. For this purpose, a synergetic combination of in-situ process monitoring, structure elucidation and accompanying numerical simulation is carried out. By producing different laminate structures with different fibre orientation, thicknesses and process parameters, a thickness-dependent imperfection classification is possible, which can be evaluated in follow-up investigations at the project partners. The results of DIWA can be used to derive evaluation criteria and process control strategies that will make it possible to evaluate and minimise composite imperfections in thick-walled laminates in the future.



Figure 1. Example of a thick-walled drive shaft.

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Detection of damage in continuous fiber-reinforced polymers by acoustic emission

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Typically occurring microscopic damage mechanisms in fiber-reinforced polymers (FRPs), such as matrix cracking, fiber-matrix debonding or fiber breakage, generate elastic waves. These waves travel through the test specimen and can be detected by piezoelectric sensors, that are attached to the specimen surface. The sensors convert mechanical surface vibrations to electric voltage signals, which are processed by the acoustic emission (AE) system. By comparing the voltage signal to a set threshold, the AE system manages to determine transient signals, also referred to as "hits", originating from damage events in the material [1, 2].

Detected hits can be analysed in many ways. The simplest approach is to count them in order to gain information about the occurring AE activity. Hence, initiation of damage and damage progression can be detected. For a more detailed interpretation of hits, features can be extracted from the recorded waveforms. Typically used features include max. amplitude, energy, duration or frequency related parameters. For example, AE signal amplitude or energy can be used to quantify the intensity of the occurring damage mechanisms. Figure 1 shows cumulative AE signal energy during tensile loading of a $\pm 45^{\circ}$ carbon fiber-reinforced epoxy laminate. The rapid increase of cumulative energy at sensor 1 at approximately 470 s correlates with the formation of cracks in the laminate close to this sensor.

AE data can also be used to gain detailed information about the underlying damage mechanisms. When choosing the right features, detected hits can be classified according to their similarity. After identifying groups of signals, it can be attempted to correlate them with certain damage mechanisms. This can, for example, be done by comparison with other non-destructive testing methods, that are performed simultaneously [2].

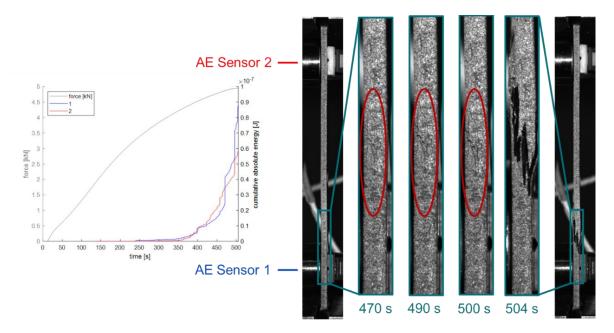


Figure 1. Cumulative AE signal energy acquired during tensile loading of a ±45° carbon fiber-reinforced epoxy laminate.

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Digital Image Processing for Textile Characterization of Flax Yarn Utilized in Natural Fiber Reinforced Plastics

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Due to low environmental impact and inexpensive cost, natural fibres like flax fibre (FF) increasingly gain interest as reinforcement structure for composite materials [1]. The properties of FF reinforced plastics (FFRP) highly depend on the textile composition of the FF-semi finished product, fundamentally on the FF-yarn structure. For load bearing FFRP applications only a homogeneous distribution and unidirectional orientation of the fibres will result in an optimal utilisation of the FFs' advantageous strength and stiffness properties. Due to the natural growth of the fibres, irregularities like uneven length and thickness occur. Textile yarn spinning normally requires applying yarn twist to ensure sufficient tensile strength and level compaction for follow-up processes. The resulting influences on the yarn structure must be characterised to take the effects on the FFRP in consideration.

Important structural-textile features of FF yarns are thickness, hairiness, twist angle, twist direction, and number of twists [2]. For some of these characteristics standard physical tests and according test devices exist. Yet, most of these tests are not suitable for inline-testing. This work introduces methodologies of characterizing these characteristics using digital image processing in Python to achieve fast, accurate, repeatable and non-destructive tests. Appropriate methods of image segmentation and feature extraction for the FFs' natural character are introduced and compared. To determine yarn twist related features, a novel application of Fast Fourier Transformation in combination with magnitude spectra is developed. A comparison of the results to physical tests reveals the accuracy of the introduced methods of digital image processing.

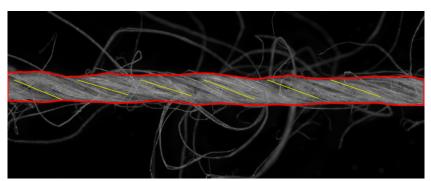


Figure 1. detected yarn core and indicators of yarn twist angle.

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Einfluss des Fasertyps auf die Prozess-Struktur-Eigenschaftsbeziehungen von langfaserverstärktem Polyamid 6

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Langfaserverstärkte Thermoplaste (LFT) haben sich aufgrund ihrer hervorragenden Verarbeitbarkeit, ihrer geometrischen Flexibilität und ihren hohen spezifischen mechanischen Eigenschaften als Leichtbauteile im Automobilbau etabliert. Zur Herstellung von LFT-Bauteilen im LFT-Direkt (LFT-D) Pressprozess können je nach gewünschter mechanischer Leistungsfähigkeit und tragbarer Kosten entweder Kohlenstofffasern oder Glasfasern eingesetzt werden. Dabei unterscheiden sich mechanische Eigenschaften und Kosten der beiden Fasern und der daraus resultierenden Strukturen erheblich. In vorherigen Untersuchungen konnte im LFT-Spritzguss mit Mischfaser-PA66-Granulat ein guter Kompromiss zwischen mechanischen Eigenschaften und Kosten erreicht werden [1].

Da es beim LFT-D Prozess schon im Imprägnierextruder zu einer Wechselwirkung der Fasern kommt, ist es besonders interessant, wie sich bei diesem Prozess eine Fasermischung auf die mechanischen Eigenschaften von Bauteilen auswirkt. Zusätzlich kommt es im Pressprozess bei Teilauslage der Form zu einer Orientierung der Fasern in Fließrichtung. Da die Faserorientierung einen erheblichen Einfluss auf die mechanischen Eigenschaften hat, ist es wichtig zu verstehen, wie sich die verschiedenen Fasertypen während des Pressprozesses im Fließweg ausrichten und ob die Kombination beider Fasertypen zu positiven Synergieeffekten führt.

In dieser Studie wird der Einfluss verschiedener Faserzusammensetzungen (Glasfasern, Kohlenstofffasern und eine Mischung beider Fasertypen) auf die resultierenden mechanischen Eigenschaften von LFT-Bauteilen auf PA6-Basis untersucht. Um die Faserorientierung in Betracht zu ziehen, werden Zugversuche an Proben durchgeführt, die an verschiedenen Positionen (Einlegebereich und Fließbereich) und in unterschiedlicher Orientierung zum Fließweg aus LFT Platten entnommen wurden.

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Experimental Characterization of Fluid Influence on Transverse Compressibility Behaviour of Technical Textiles Through In-Situ-Impregnation Method

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Transverse compaction behaviour of technical fabrics has been studied extensively in the scientific literature. Most experimental research was focused on the influence of fibre volume fraction, number of layers, loading speed or binder content. These aspects can be characterized on dry samples and thus, test-rigs were designed accordingly. Based on (a) the need for more extensive testing capabilities and (b) the results of an international benchmark exercise on textile compaction from 2021 [1], a novel test-rig was designed allowing for the characterization of dry and wet compressibility in a single experiment. For this purpose, in-situ impregnation of the samples under compressive load is realized in the experimental setup. This approach enables to reduce measurement time as well as measurement errors caused by fabric variability.

This paper introduces a novel test methodology for the measurement of textile characteristics at conditions equivalent to liquid composite moulding (LCM) techniques, through a test configuration of dry loading/dry relaxation/wet relaxation/wet unloading. Furthermore, the influence of different test fluids can be quantified. The work at hand utilizes the proposed novel test methodology to study the influence of different test fluids on a non-crimp-fabric (NCF) through comparison of characteristic stages of the relaxation process. The results of these measurements can be used to (a) improve existing material models of textile compaction behaviour and (b) predict the relaxation of fabrics relevant for LCM processes.

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Experimental investigation of the size effect on the mechanical properties of bi-axially braided glass fibre-polyurethane composites under tensile, compressive, and flexural loading.

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To transfer extremely high mechanical loads into multi-layer fibre-reinforced plastics (FRP), it is often necessary to design structural components as thick-walled composites. However, with increasing composite thickness, a disproportionate drop in various mechanical properties (e.g. compression strength) occurs [1]. In addition to statistical effects, there are other explanatory attempts that point to the influence of manufacturing-related imperfections such as fibre misalignments and undulations [2,3]. In the DFG research project PAK988 "DIWA", new evaluation criteria as well as process control strategies are developed through a synergetic combination of in-situ process monitoring, structure analysis and material tests with accompanying numerical simulations.

In order to gain a deeper understanding of the factors influencing the failure mechanisms of thick-walled composites, this paper describes an experimental study that examines the effect of specimen size on the compressive, tensile and flexural properties of bi-axially braided glass fibre/polyurethane composites. In the present experimental setups, specimen thicknesses of $t=4\,\mathrm{mm}$ and $10\,\mathrm{mm}$ were investigated. The braiding angles were $\pm\,30\,^\circ$ and $\pm\,45\,^\circ$, respectively. Furthermore, the results were compared to those of unidirectional laminates of the same material. Due to the high mechanical loads required for destructive testing, some compressive experiments were performed on a 1 MN universal testing machine. A modified clamping device has been used for these compression tests on a ICSTM test fixture. The gauge length of the compression tests is based on a standardised DIN-EN-ISO-527 specimen and is further compared with a 3D scaling of the gauge section of 20 x 20 mm ($t=4\,\mathrm{mm}$) and 50 x 50 mm ($t=10\,\mathrm{mm}$), respectively. Different gauge sections were used to differentiate volume and thickness effects. Flexural results were obtained by four-point bending tests with scaled support span while tensile tests were performed with a gauge section of 150 x 50 mm for both 4 mm and 10 mm thick specimens.

Further insights into the specimens of different size were gained by non-destructive testing via ultrasonic scans and computer tomography. The size effects that occurred were quantified in terms of strength and stiffness while the assessment of damage modes was performed optically using micrography.

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Fatigue behaviour of 3D-printed continuous flax fibre reinforced polylactide

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Additive manufacturing (AM) facilitates the production of industrial applications with different materials and complex structures. Fused filament fabrication is the most commonly used AM process when considering thermoplastic matrix materials. During this process, filament strands are deposited onto a built-platform layer-by-layer. The layer-wise deposition induces defects and anisotropy in the printed parts. The diffusion depth between adjacent strands significantly influences the resulting mechanical properties. In recent years, FFF is also performed with continuous fibre reinforced filaments. A currently highly researched fibre-matrix combination represents continuous flax fibre reinforced polylactide. This composite is used in this study as the interest in the commercial use of natural fibre-based composites is steadily increasing.

Since components for industrial applications often have to withstand several loading and unloading cycles, the fatigue behaviour of the material needs to be analysed in advance. In order to be able to describe components using numerical methods later on, the material is tested in the direction (UD0) and perpendicular to (UD90) the strands/fibres with tension (R=0.1) and alternating (R=-1) loads. The test setup is shown in Figure 1. The stress levels are set in a way to reach cycles to failure in the range of 10^3 to 10^6 . The loading frequency is selected in order to avoid excessive hysteretic heating. The evaluated fatigue curves for the two loading modes and strand/fibre orientations were compared.



Figure 1. Test-setup for fatigue testing of 3D-printed endless-flax fibre reinforced polylactide at different strand/fibre orientations and R-values (R): (a) UD0, R=0.1 and (b) UD90, R=-1.

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General effect of fibre misalignment in thick composites under compressive load and dependence of the environmental temperature

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The application of polymer-composites is consistently growing and leads to more complex applications and load cases. To endure the higher resulting forces the size and thickness of the composites get increased. Thicker specimens generally have more defects due to the size effect, but the increasing size can additionally lead to manufacturing deviations and thereby to further defects.

This study investigates how defects, fibre misalignment in particular, effect the mechanical behaviour of glass fibre composites under compressive loading. Fibre misalignment can be divided into in-plane and out-of plane misalignment, those failure types are in general randomly distributed in a thick composite [1]. To gain a better understanding of their effects on the mechanical properties, the defects get introduced intentionally into the composite, resulting in decreasing strength and a change in failure mode. To ensure that the specimen have similar magnitudes of fibre misalignments a new manufacturing procedure for low pressure RTM is introduced. As additional quality control, ultrasonic tests and CT scans were carried out, which supplementary allowed finding possible damage initiations. Besides defects the behaviour of a composite under compression load is also highly dependent on the properties of its matrix [2]. Changing the environmental temperature influences those properties massively, decreases the stiffness and ultimate strength and should in theory also influence the compressive behaviour of the composite [3].

All tests are carried out with five extends of fibre misalignment, in- and out-of-plane with two each and a combined superposition. To gain additional understanding the damage growth during testing gets monitored via acoustic emissions.

Concluding the investigation thick specimen from a high-pressure-RTM with randomly distributed defects get compared to the intentional fibre misalignments to transfer the knowledge into large industrial applications.

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Integration of sensor technology in thermoset sandwich composites for the detection of structural damage

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A decisive factor in achieving the climate targets of the German government is the reduction of CO2 through the gradual electrification of transport. In battery-electric vehicles, the energy storage system is typically positioned close to the ground under the passenger cell. Thus, the passage of ground level obstacles or typical load scenarios affecting the underbody are crucial for vehicle safety. Currently, such battery protection structures usually consist of thick-walled aluminum, steel or titanium constructions, which are associated with increased weight and manufacturing costs [1]. Larger moving masses in battery electric vehicles lead to high resource consumption during the usage cycle. Therefore, the battery protection structure represents a lightweight structure.

This paper addresses the development of a functionally integrative lightweight battery protection structure made of glass fiber reinforced plastic (GRP). In addition to the purely mechanical protection of the energy storage unit, this structure should be able to detect and classify any damage occurring to the battery module above during operation. A structure-integrated sensor system allows to automatically determine the extent of damage, which means that downtimes caused by service operations or component replacements are limited to cases of reliably detected damages and are not necessary within defined maintenance intervals or on suspicion.

Based on a detailed requirement profile for the structure, a comparison of selected sensor concepts is carried out. For further investigations, three sensor types (pressure sensor, strain sensor, inductive sensors) are examined in more detail and analyzed with regard to their positioning in the composite as well as their suitability for detecting different load cases. A further issue is the clarification of possible integration options in terms of production technology. For this purpose, the so-called e-preforming technology is used, which enables an automated application of functional elements. In this context, different types of conductor track manufacturing and contacting of electronic components within the sandwich structure is demonstrated.

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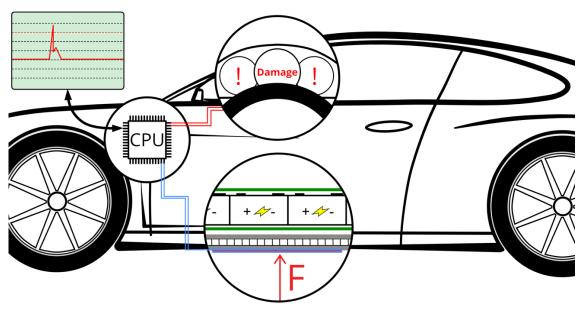


Figure 1. Principle illustration of an intelligent battery protection system for electric vehicles for detecting undesirable mechanical damages.

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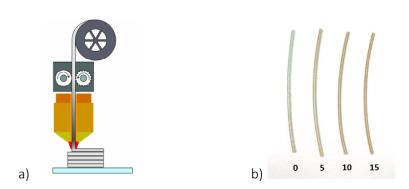
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Integrative material characterization of crystalline nanocellulose reinforced filaments for fused-filament fabrication

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Recently Crystalline nanocellulose (CNC) has received increased attention in the scientific community following a universal push for more environmetally conscious engineering and increased sustainability. Due to the combination of high stiffness and low density of CNC, a high specific modulus of approximately 90 MPa/(kg*m³)¹ is achieved. However, during processing via fused filament fabrication (FFF), the material is exposed to a series of thermal and mechanical loads. Therefore, the load history has to be considered when characterizing and predicting the composite's properties in the final 3D-printed construction part.

Figure 1. a) schematic of fused filament fabrication (FFF)² b) filaments with filler contents of CNC in vol% in a recycled polypropylene matrix.



A recycled 3D-printable polypropylene modified with CNC up to 15 vol% content was examined in this study. Since the CNC's reinforcement effect is mostly determined by the interactions between the cellulose and the matrix³, a maleic-acid-anhydride-based compatibilizer was used. To characterize the novel composite shear rheological investigations, dynamic-mechanical analysis (DMA) and measurements regarding shrinkage were performed.

An unexpected decrease in viscosity with increasing filler content was observed. This decrease was attributed to (I) the increased use of low viscosity compatibilizer with increased filler content and (II) the thermal degradation of the compatibilizer manifested in a colour change of the tested material. This hypothesis was verified by differential scanning calorimetry (DSC) measurements. This enabled a reliable material characterization, which can help to predict the properties of the final printed part.

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Investigation and optimization of UV curable resins via TMOR for the production of low-shrinkage glass fiber composites

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UV-curable resins and fiber-reinforced plastics thereof are particularly suitable for repairing defects due to their short curing time. They are already being used in the construction sector (e.g. sewer rehabilitation), the automotive industry (e.g. refinishing business) and in medicine (e.g. tooth repair). One type of UV curing polymerization is the radical polymerization. Radical polymerizing systems may undergo a considerable volume shrinkage. As a result, a rehabilitated defect may no longer be satisfactorily repaired after the resin has cured and shrunken. One variant for reducing polymerization-induced volume shrinkage is the addition of monomers with higher molecular weight. Another way is the introduction of prepolymers serving as volume constant units being covalently incorporated into the network. The classical prepolymers described in the literature are often linear in structure [1]. These lead, however, to a low crosslink density during polymerization with unfavourable effects on the mechanical material properties.

In this work, polymeric diphenylmethane diisocyanate (PMDI) was employed as a primary prepolymer building block. This still allows the formation of highly crosslinked plastics for mechanically demanding applications, which nevertheless possess strongly reduced shrinkage.

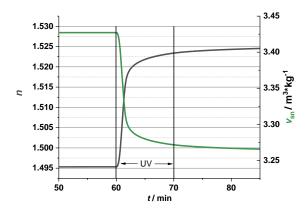


Figure 1. Measurement of refractive index and normalized specific volume during a UV curing reaction via TMOR.

Systematically both the influence of PMDI as a prepolymer building block and monomers with a higher molecular weight on the polymerization-induced volume shrinkage in an acrylic resin were investigated. The experimental results showed that volume shrinkage could be strongly reduced by prepolymerizing the acrylic monomer with PMDI. Depending on the selected PMDI content, volume shrinkage could be reduced by up to 30% during curing. A novel method of refractometry, the Temperature Modulated Optical Refractometry (TMOR) was employed to very accurately assess and monitor volume changes in situ during the polymerization process [2].

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Mechanical and thermokinetic characterization of innovative coating systems

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The efficient operation of thermal power plants such as gas turbine engines and the optimization of the underlying conversion processes are of high relevance concerning the increasing importance of environmental protection. Since this challenge is primarily to be tackled with higher operating temperatures, numerous research projects are designed to optimize or even reinvent novel coating systems, which is the main purpose of the RTG "MatCom – ComMat".

The development of novel diffusion and nanocomposite based coating systems requires advanced methods for material property characterization and the description of potentially occurring failure mechanisms. In order to assess the behavior under extremely high temperatures and in aggressive media, both the investigation of system-internal interactions between the individual layer components and the description of the macroscopic material system behavior are of essential importance.



Figure 1. Compression test rig and 3D camera system for mechanical characterization of investigated layer systems.

In order to make a decisive contribution to the RTG, mechanical bending and compression tests on first candidate systems in as-built and annealed conditions are being carried out and accompanied by advanced in-situ deformation and damage measurement techniques. This experimental study is supported by a code-based thermokinetic simulation approach to investigate the interdiffusion and oxidation behavior of the coating components.

NanoPul – A project to realize pultrusion with nanomodified resins

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The outstanding properties of carbon fibre composites can be enhanced by modification of the polymer matrix with Carbon Nanotubes (CNTs) and Carbon Nano Fibres (CNFs). The interaction between the nanofiller and the polymer matrix is mainly determined by the interface, which allows to control the load-transfer and thus the crack initiation, propagation and likewise the strength of the material. Three steps are necessary for successful processing: chemical modification of the nanofiller for easier separation of the nanofillers and likewise better bonding to the polymer, fine dispersion in the polymer in order to reduce inhomogeneities like large agglomerates and proper wetting of the carbon fibre fabrics or strands during production.

Previously we successfully modified and dispersed CNT and produced CFRP with enhanced materials properties. We followed a new route of simple and low toxicity modification of the nanofillers by oxidation with hydrogen peroxide (H_2O_2) at 80 °C and dispersed with the well-established three-roll mill into epoxy resin. CFRPs produced with 0.7 wt% addition of H_2O_2 -modified CNT showed increased mechanical properties, i.e. a 38 % increased tensile strength [1].

In course of the FFG project "NanoPul" we now work on all three process steps to enable future application of nanomodified resin in industrial scale pultrusion. Multi-walled CNTs and cup stacked CNFs are used in low viscous resin for the production of unidirectional carbon fibre reinforced plastics (CFRP). In a first step, the H_2O_2 -treatment was further developed for application at room temperature, resulting in a degree of oxidation of about 2 %. In a second step, we established a fast and easily applicable dispersion method by application of ultrasound instead of. 0.3-0.7 wt% of CNF or oxidized CNT were dispersed directly in a low viscous resin system, without application of additional solvent and avoiding unwanted damage of the nanofillers [2].

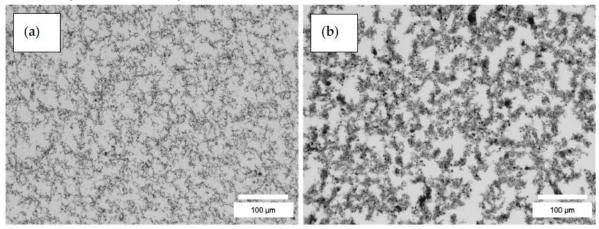


Figure 1. Light microscopy after ultrasound dispersion directly in hardener: (a) 0.5 wt% CNF; (b) 0.5 wt% oxidized CNT; [2].

These promising results show an easily scalable and non-toxic modification and dispersion strategy, which is crucial for industrial applicability and which will allow production of nanomodified pultruded CFRPs in the near future.

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Quality control of expired prepregs by Near-Infrared-Spectroscopy

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Prepregs are high quality semi-finished products out of a textile reinforcement structure impregnated with a resin matrix. As a reactive resin system is concerned, the prepreg is typically kept cold until its finishing process. The storage life of cooled prepregs adds up to 6-24 months. Expired prepregs are usually disposed of. Alternatively costly and time-consuming measurements are done to ensure the usability of the expired prepreg. Parameters used to ensure the usability are e.g., the degree of cure or bonding force to certain surfaces.

A fast, easy, and non-destructive technology to ensure the usability of prepregs already on site is Near-Infrared-Spectroscopy (NIR). Using light in the range from 800-2500 nm, characteristic molecular vibrations are created. The molecular vibrations result in characteristic spectra which can be used to determine the state of the prepreg. But to evaluate the spectra a valid calibration-model, based on reference data is mandatory.

In the last years so called NIR-Micro-Spectrometer have been developed. They differ from classical process spectrometers through low weight and volume as well as a significantly lower price. Equivalently there are some cutbacks e.g., in resolution. Nonetheless they seem suitable alternatives to the conventional spectrometers and enable the development of a hand-held tool, with which prepregs can be tested during their storage and processing. A fast, easy, and non-destructive check of the prepreg quality could initiate the renunciation of the time-based disposal of prepregs in favor of a quality-based disposal.

Spectra from prepreg samples at different age are recorded by a NIR-Micro-Spectrometer. As reference to develop a valid calibration model, the degree of curing and bonding force on copper are determined. Afterwards different approaches for calibration models are tested to predict the usability of the aged prepreg.

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Quantitative evaluation of void content in polymer matrix composites by means of X-ray computed tomography

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Voids in modern polymer matrix composites (PMC) can significantly influence the mechanical properties of the final products [1] and therefore play an important role in terms of quality assurance during the production process. As soon as the parts become more complex and larger, there are nearly no manufacturing methods that guarantee void free parts. Therefore the development of products in combination with new manufacturing technologies and material systems or new material combinations requires a detailed materials characterisation. By using X-ray computed tomography (CT) methods, it is possible to receive a relatively fast impression of internal microstructural materials composition of a certain volume.

Fig. 1 shows detailed images of CT cross sections (top row) and corresponding segmentations (bottom row) of different fibre reinforced PMCs. The investigated materials vary in terms of fibre material, such as carbon (a - e) or glass (f), as well in manufacturing process: (a) 0/90° UD prepregs [2] and (b) plain weave prepregs based on epoxy carbon fibre reinforced resin in autoclave; (c) epoxy resin based sheet moulding compounds (SMC) using carbon fibre UD tape prepregs [3]; (d) 3D printed carbon fibre reinforced PLA in fused deposition modeling (FDM) [4]; (e) carbon fibre reinforced PA1212 in selective laser sintering (SLS) [5] and (f) glass fibre reinforced PP sheets in compression moulding [6]. Especially geometry, size and distribution of voids vary strongly as revealed in this image.

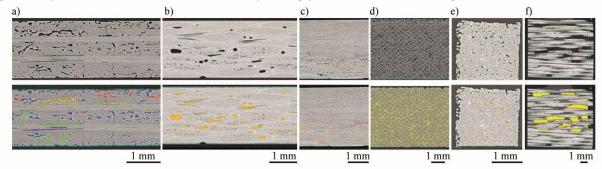


Figure 1. CT cross sections (top row) and corresponding segmentations (bottom row) of different fibre reinforced PMCs.

In this contribution, a multiscale approach [7] for quantitative evaluation of voids in PMCs by means of CT on a broad variation of different materials systems is applied and discussed. For detailed discussions, a series of standard methods such as standardized thermo-chemical analysis (DIN EN 2564:1998), thermo-gravimetric analyses (TGA) [8] together with the density measurement data as well as serial sectioning and light optical microscopy (LOM) are applied on certain specimens. For example, Fig. 2 shows the comparison of a segmented LOM image (top left) and the corresponding CT slice #3 (bottom left), as well as determined porosity values via CT or LOM are compared (right), showing nearly no significant differences, as long as the same exact slice in a certain volume is compared and the evaluation regions are identical.

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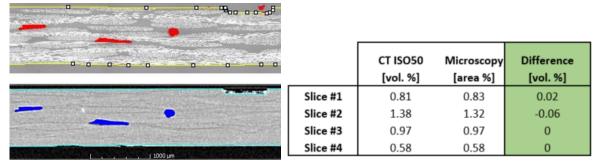


Figure 2. Comparison of one segmented LOM image (top left) and the corresponding CT slice #3 (bottom left) as well results from a quantitative comparison of both methods (table right).

By comparing different methods, a similar strategy must be used in dealing with deepings on the surface, open voids or voids very close to the surface to avoid misinterpretation of porosity values.

This work shows that CT is able to provide reliable porosity values and has high potential to replace certain well known standard methods. Using a multiscale approach to calibrate certain threshold values for image segmentations allows scanning larger sample volumes [9], typically in a range of 10 to 20 mm³. Seeing that CT is a non-destructive method, exactly the same specimens can be used for consecutive mechanical testing or additional experiments. If scan resolution and quality are high enough, other material characteristics such as fibre orientations or fibre length distributions can be evaluated in addition to the void content [3, 5, 10].

Acknowledgments

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Real-time flow front monitoring in HP-RTM molds using phased array ultrasonic testing

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To enable the transfer of extremely high mechanical loads in structural components made of fiber-reinforced plastic (FRP) composites, the use of increasing wall thicknesses is unavoidable. However, this increase leads to a reduction in the mechanical properties related to the cross-sectional area, which is due to various manufacturing-related defects such as fiber displacements and undulations. To minimize or avoid such defects, the manufacturing process must be well controlled. However, this requires precise process knowledge, especially of the flow front, which currently can only be obtained via simulative approaches.

The focus of this paper is on real-time flow front monitoring in a high-pressure resin transfer molding (HP-RTM) mold using phased array ultrasonic testing (PAUT). For this purpose, investigations were conducted during the production of test specimens made of glass fiber reinforced polyurethane resin with a wall thickness of 10 mm and a fiber orientation of $\pm 45^{\circ}$. A phased array ultrasonic probe was used to record individual line scans over a period of 200 seconds. By using different measuring positions of the phased array probe and thus the line scan, an approximate two-dimensional monitoring of the polyurethane flow front can be performed.

With these results, it is possible to determine the local flow velocities of the matrix system during mold filling, which have a significant influence on the occurrence of fiber disorientations in FRP, especially in the HP-RTM process. Furthermore, these results can be used to improve the prediction quality of conventional simulative methods for determining flow velocities.

This contribution was created within the framework of the DFG research project PAK988 "DIWA" to fundamentally investigate the development and influence of structural composite imperfections.

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Test specimen and accompanying test strategy for the comprehensive evaluation of moulding materials and produced hybrid composite structures

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Moulding is a common approach to protect components like electronic devices on circuit boards or coils in an electric engine from environmental influences and to increase their performance according to aspects like heat transfer. To ensure the correct design of the multi-material structure for long-lasting operation, the impact of the indivdual material parameters and their interaction on aging and failure mechanisms under different loads in service have to be considered and – in the best case - fully characterized before the component's final design. This creates demand for simple testing techniques that are able to map the multi-directional and multi-domain loads in a moulded hybrid part as accurately as possible. According to the current state of the art, different geometries and test strategies are suggested but seem to be limited in terms of flexibility, intensity, reproducibilty and the temporal distinctiveness between different materials.

The aim of this work is to present a test specimen together with a test strategy focusing on the comprehensive evaluation and characterization of moulding materials and the material combinations produced with them. For this purpose, a cylindrical test specimen using a specially shaped metal insert encased with the potting material was combined with different testing techniques. Mechanical stresses arising from exposure to temperature changes are concentrated and adjusted using different metal and geometry combinations. The amount of aging of the material combination as well as that of the potting material are characterized in particular in the form of delamination phenomena as well as crack initiation and propagation on the test specimen. In addition, the results of suitable test methods to use with the specimen, like vibration-based measurements and electrochemical impedance spectroscopy, are presented. Hereby, it is not only possible to extensively characterize the potting material, but also the interface between polymer and metal.

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Investigation on the moisture content and its influence on the curing behaviour of epoxy resins in rotor blade production

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Keywords: moisture, epoxy resin, balsa wood, dielectric analysis (DEA), vacuum infusion process

These days, rotor blades for wind turbines are mainly made of glass-fiber reinforced plastic and are manufactured in a shell-sandwich construction with stiffening spars. Industrial rotor blade production takes place using the vacuum infusion process. During this process, the non-impregnated fiber material, core material, and auxiliary materials are introduced into a single-sided mold and then infused with epoxy resin. Once the fiber material is completely saturated by the resin, curing of the polymer matrix begins, under an exothermic crosslinking reaction. Due to the current shortage of the core material balsa wood and the climatic ambient conditions in the countries of production, it is not always possible to ensure that balsa wood is sufficiently dried before placed into the mold in practice. As a result, moisture can get into the vacuum buildup and consequently comes into contact with the resin. In addition to the resulting optical defects, the so-called "champagne laminate", caused by a side chemical reaction of moisture, interacting with the hygroscopic amine cure agent [1,2], moisture can act as a catalyst for the curing reaction of the epoxy resin. Previous studies have shown that the influence of moisture accelerates the curing reaction and increases the reactivity of uncured epoxy resin systems. At the same time, samples cured under increased moisture content show a reduction of the glass transition temperature. [3-5]

This research study aims to investigate whether moisture from the balsa wood has an influence on the curing behavior of epoxy resins during rotor blade production. In addition, it should be examined, if the dielectric analysis (DEA), which is an established measurement method for tracking the degree of cure in situ, is a suitable measurement technique for measure this influence. For the experimental investigations, the epoxy resin systems EPIKOTE Resin MGS RIMR 035c, RIMR 135 and RIMR 1037 from Hexion are considered, which are relevant in rotor blade production.

In order to quantify the moisture input through the balsa wood into the epoxy resin during the vacuum infusion process, balsa wood samples are conditioned under various representative climatic conditions in a climatic chamber to simulate realistic wood moisture contents. The resulting moisture content of the balsa core range from about 9% (23,5°C, 75% RH) to 40% (23,5°C, 75% RH, heavy rain), depending on the conditioning conditions. Preliminary examinations are conducted to trace the moisture transport processes in different sandwich layer stacks during a representative vacuum infusion process. Based on these results, approximate moisture levels in the resin can be calculated. This way, realistic moisture contents of 1 wt% to 5 wt% in the epoxy resin are determined.

The qualitative moisture influence on the curing behavior of the epoxy resin is measured via the ion viscosity signal (DEA) on resin samples with different moisture contents.

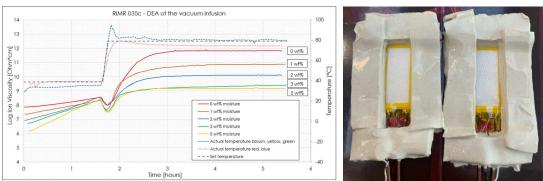


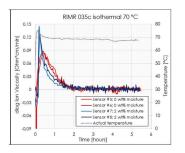
Figure 1. Influence of moisture on the ion viscosity of RIMR 035c and dielectric sensors.

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Dielectric tests show an increased reactivity in the initial phase of crosslinking with increasing moisture content (Figure 1). In addition, an earlier stagnation of the cure reaction for resin samples with higher moisture content is detected. This suggests an earlier attainment of the final cure level.

The dielectric measurements are validated using differential scanning calorimetry (DSC, Figure 2). Via the differential calorimetric studies, a decrease in the glass transition temperature can be observed for resin samples with moisture content.



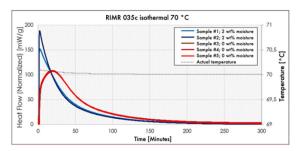


Figure 2. Comparison of DEA and DSC measurement.

Finally, process-oriented experiments are conducted, in order to show, that dielectric measurements are capable of predicting the real moisture content in epoxy resin during the production process (Figure 3). Although the in situ measurement underestimates the forecasted moisture content, the tests confirm the previous results. Reasons for the deviation might be simplifying assumptions for the calculation of the moisture content, such as homogeneous moisture distribution in-plane.

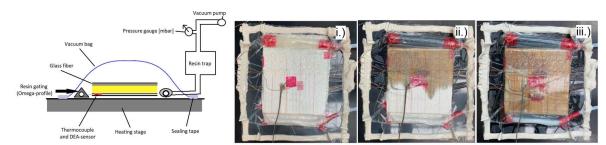


Figure 3. Process-oriented vacuum infusion process.

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[Verbund] K: Anwendungen

Development and applications of the composite material WC-ZrO2

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It has been possible to sinter the material system, consisting of 60 vol.-% ZrO2 and 40 vol.-% WC, without pressure in a nitrogen atmosphere. This composite material has excellent properties in terms of tribological and chemical resistance. Among other characteristics, the good thermal conductivity and low thermal expansion coefficient should be mentioned, which achieve excellent thermal shock resistance in the material. Also worth mentioning is the high hardness, which ensures low material wear. The development of the material arose from various research and development projects addressing different fields of application, which benefited from the above properties. Starting with the development of surgical electrodes in high-frequency surgery, through the application for grinding balls, which achieve extremely efficient grinding due to the high density and correspondingly high weight of the material, to tools used in friction stir welding of steel.

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Innovative High-Performance Rocket Engines Based on Hybrid Composites-Metal Design 23. Symposium Verbundwerkstoffe und Werkstoffverbund

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Abstract

Today space is significantly changing. In the past the responsibility for visions, goals, the implementation and the financing of capital rich space projects lay in the hands of states and their governments. Since the recent past, more and more private initiatives take responsibility for New Space activities.

In the field of space transportation and under the header 'Black Engine', DLR turns now and increasingly again to the research and technology development of transpiration cooled [1] ceramic high-performance rocket thrust chamber assemblies (TCA). For more than twenty years, the foundations of a completely new hybrid composites-metal design approach [2] have already been laid, which promise high future competitiveness compared to standard metal designs. The latter focus' primarily on significantly higher life-times and operational safety at high efficiency and lower cost.

Unaffected of <u>additive manufacturing</u> technology (AM), which improves in general the manufacturing of future metallic rocket engine designs, the application of high-temperature resistant <u>Ceramic Matrix</u>

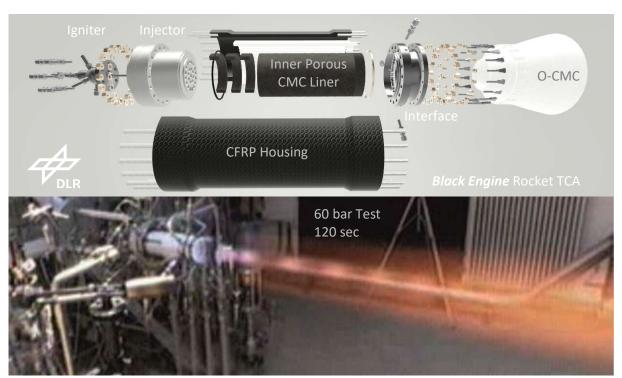


Figure 1. De-coupled structure principle of an innovative ceramic high-performance rocket thrust chamber (top), and cryogenic (LOX/LH2) high-performance operation at DLR's European Research and Technology Test Facility P8 (bottom).

Composites (CMC) and light weight Fibre Reinforced Plastics (FRP) opens in combination with suitable metallic interface technology new horizons for future New Space propulsion solutions. In a completely load de-coupled structural design, consisting of multiple not-bonded single structure components (see Figure 1), on the one hand sophisticated CMC material derivatives manage the heat balance at the inner hot gas surface against fluid temperatures of almost 4000 °C. On the other hand, light-weight carbon fibre reinforced plastics (CFRP) and conservatively or AM produced metallic parts carry the mechanical loads independently in the highly transient operation scenario of a cryogenic rocket engine.

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Besides the long-life capable TCA, highly reusable rocket engines require additionally a durable $\underline{\underline{u}}$ urbo $\underline{\underline{u}}$ ump $\underline{\underline{u}}$ nit (TPU). The life-time of cryogenic high-performance TPUs is typically limited by the use of metallic ball-bearings. Due to this systematic weak point and specific engineering challenge, DLR currently develops a highly innovative CMC journal bearing technology [3], based on transpiration-lubricated function and a structural design principle similar to the design of the micro-porous inner CMC combustion chamber liner in the engine's TCA.

This variety of potential hybrid composites-metal structure applications in future rocket engines will be presented in an overview on a corresponding poster.

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LEICHTBAU SPRITZGUSS-BATTERIEGEHÄUSE FÜR DIE ELEKTROMOBILITÄT:

WIE EIN VOLLSTÄNDIG REZYKLIERBARES BATTERIEGEHÄUSE ELEKTROFAHRZEUGE LEICHTER UND NACHHALTIGER MACHT

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Elektrofahrzeuge sind, je nach Fahrzeugklasse und Antriebsart (Hybrid, vollelektrisch), zwischen 100 bis 700kg schwerer als ein vergleichbares Fahrzeug mit reinem Verbrennungsantrieb. Auch wenn Energie rekuperiert werden kann, so spielt das Gewicht des Kraftfahrzeugs eine entscheidende Rolle bei Fahrdynamik und Reichweite. Daraus resultiert eine konsequente Forderung nach kosteneffizienten, serientauglichen und nachhaltigen Leichtbaulösungen.

Durch die Kombination endlosfaserverstärkter Decklagen (Natur- Glas-, Kohlefasern) mit einem geschäumten Kern (z.B. rezyklatbasiert), ermöglicht das im Rahmen des Vortrags vorgestellte Verfahren, die Herstellung höchstbelastbarer thermoplastbasierter hybrider Spritzgussbauteile in Form eines Sandwich-Verbund. Demonstriert wurde die Eignung des neuartigen Herstellverfahrens an einem Gehäuse für Traktionsbatterien.

Durch die Kopplung eines energieeffizienten und serientauglichen Herstellverfahrens, eines leichbauenden Design und einer Wiederverwertbarkeit der Komponenten, kann mit diesem Verfahren, im Sinne der Circular-Economy, ein klarer Beitrag zur Nachhaltigkeit im Bereich der E-Mobilität geleistet werden.

Die nachfolgende Abbildung zeigt den Aufbau der Traktionsbatterie. Das spritzgegossene Verbundgehäuse ist darauf gut zu erkennen.



Figure 1. Funktionsfähige Traktionsbatterie mit thermoplastbasiertem Gehäuse auf dem Batterieprüfstand am Fraunhofer LBF

Die Technologie ist jedoch nicht ausschließlich auf Gehäuse für Traktionsbatterien beschränkt, sondern hat ein hohes Potential für weitere Anwendungsgebiete, z.B. im Bereich des Unterbodenschutzes. Im Einsatz als Traktionsbatterie-Gehäuse kann durch das Leichtbaupotential eine Gewichtreduktion von bis

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zu 30%, im Vergleich zu klassischen Gehäusekonzepten, erreicht werden. Weiter ermöglicht das Verfahren den gezielten Einsatz von Rezyklaten und/oder naturfaserverstärkten Materialien sowohl als Kern- oder Deckschichtmaterial und bietet so das Potential, zur Herstellung nachhaltiger Strukturbauteilen.

Vergleichsweise kurze Zykluszeiten (Bauteilabhängig zwischen 60-120s), bietet die Chance hochbelastbare Strukturbauteile mit geringen Produktionskosten und CO_2 -Footprint serientauglich herzustellen. Durch die anforderungsgerechte Integration zusätzliche Funktionalitäten wie Flammschutz, Abschirmung und thermische Leitfähigkeit/Isolation können zusätzliche Vorteile integriert werden.

Die Eignung des Verfahrens zur Herstellung höchstbelastbarer und leichtbauender Strukturbauteile wurde bereits demonstriert und ein funktionsfähiger Technologiedemonstrator einer Traktionsbatterie aufgebaut. Dieser ist in nachstehender Abbildung, auf dem Batterieprüfstand am Fraunhofer LBF dargestellt.



Figure 2. Funktionsfähige Traktionsbatterie mit thermoplastbasiertem Gehäuse auf dem Batterieprüfstand am Fraunhofer LBF

Zukünftige Entwicklungsziele adressieren Untersuchungen zum Langzeitverhaltens, den Flammschutz, eine weitere Automatisierbarkeit des Verfahrens, die Untersuchung der Anbindungseigenschaften der Decklagen (speziell bei Einsatz von Rezyklaten), die Weiterentwicklung einer angepassten Auslegemethodik für hybriden spritzgegossenen Struktur-Leichtbauteile und die Steigerung der funktionalen Integrationsdichte zur Optimierung z.B. des Thermomanagement und der elektromagnetischen Verträglichkeit. Diese Punkte werden im Vortrag herausgearbeitet und Lösungsansätze aufgezeigt. Vereinfachte Flammschutzuntersuchungen weisen jedoch bereits jetzt schon auf eine hohe Flammwidrigkeit der hybriden Bauweise hin.

Optimized design for lightweight hydrogen pressure vessels

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With the ever intensifying CO_2 neutrality and ambitious climate agreements, alternative clean energies, in particular, hydrogen is gaining its momentum. The reason being carbon free energy conversion and high gravimetric energy density of hydrogen. In order to integrate compressed hydrogen into vehicles, lightweight, safe and inexpensive pressure vessels are necessary, which at the same time should be capable of serial production. [1]

Current state of the art carbon fibre reinforced plastic (CFRP) pressure vessels, consisting of carbon fibres, liner and metallic bosses, are produced by filament winding. These designs need huge amounts of CFRP-material around the dome area to transfer the axial forces into the lamina.

Primary objective of the project is to exploit the advantages of composite materials and thereby accounting to material reduction. To achieve this, the patented load introduction of the IVW is used to integrate the metallic dome in the CFRP-Material. With this load introduction developed for highly loaded tension rods, the axial loads of the dome can be introduced individually into the axial layers via single layer placement without having to wrap the entire dome. This distributed load introduction into the individual fibre layers avoids stress peaks and thereby ensures a high suitability for lightweight design. Because of its design, the lamina consist only of 0°-axial and 90°-circumferential layers and the fibres lie along the load path. This provides a high cost-saving potential for CFRP.

In addition, there is a wide range of pressure vessel diameters possible. This enables a high packing density and thus efficient use of design space. This gives a high degree of design freedom in the tank design.

The aim of this study is to use the concept of the IVW-load introduction for hydrogen pressure tanks and to verify the potential of this design.

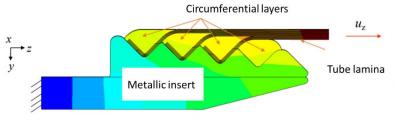


Figure 1. IVW load introduction for highly loaded tension rods.

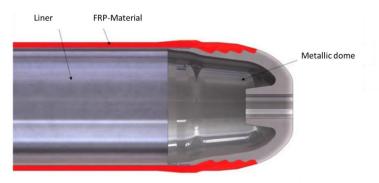


Figure 2. Hydrogen pressure tank with optimized connection between metallic dome and FRP-material via IVW load introduction.

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Untersuchung kosteneffizienter geflochtener und gewickelter Verbundrohrleitungen für Wasserstoffanwendungen

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Um bis zum Jahr 2050 eine treibhausgasneutrale Gesellschaft zu ermöglichen, wie bspw. im europäischen Green Deal angestrebt, ist die Verteilung von grünem Wasserstoff der Schlüssel für eine erfolgreiche Umsetzung. Dieser Beitrag behandelt Auslegungs- und Herstellungsansätze für Verbundrohrleitungen und deren Potenzial für den Transport von Hochdruckgasen wie Erdgas oder Wasserstoff. Da aktuelle Lösungen nur einen Bruchteil der notwendigen Anforderungen erfüllen, muss oft ein Kompromiss zwischen den verschiedenen Faktoren Kosten, Gewicht, Leistung und Machbarkeit gefunden werden. Anhand eines Benchmarking von duroplastischen und thermoplastischen Matrices in Kombination mit Glas-, Kohlenstoff- und Basaltfasern wird die Wettbewerbsfähigkeit von geflochtenen und gewickelten Verbundrohrleitungen für die Wasserstoffverteilung untersucht. Für die Verbundmatrizen wird Epoxidharz (EP) als duroplastisches Material ausgewählt und Polyamid (PA) sowie Polyethylen (PE) als thermoplastische Matrices gegenübergestellt. Aufgrund der Festigkeitsund Steifigkeitsunterschiede zwischen den Materialgruppen werden geeignete Laminatarchitekturen abgeleitet und gemäß ISO 14692 mittels Simulation validiert. Für die Herstellung werden die zwei produktiven Ansätze, Radialflechten und Multi-Filament Winding (MFW), untersucht. Für das MFW wird die Verarbeitung von vorimprägnierten Verstärkungsfasern, sog. Towpregs, untersucht. Da Towpregs Wickelgeschwindigkeiten von bis zu 5 m/s und eine Varianz des Harzgehaltes von nur ±2 Gew.-% ermöglichen, können kostengünstige und hochfeste Verbundwerkstoffe gewickelt werden. Zusätzlich erlaubt der MFW-Prozess die gleichzeitige Verarbeitung von bis zu 48 Towpregs sowie die Ablage von unidirektionalen Schichten. Durch Radialflechten kann die Anzahl der gleichzeitig verarbeiteten Rovings von 32 bis zu 144 variiert werden. Dabei wird die Harzinfusion entweder separat nach dem Flechten durchgeführt oder es werden Hybridmaterialien verarbeitet, die eine anschließende Konsolidierung erfordern. Basierend auf den experimentellen Ergebnissen aus den Wickel- und Flechtversuchen werden Simulationen durchgeführt, um verschiedene Verbundrohrleitungen berechnen zu können. Daraus ergeben sich Daten für die Auslegung von Verbundrohrleitungen in Bezug auf die erforderlichen Drücke und Diffusionsraten für verschiedene Gase wie Erdgas oder Wasserstoff. Anhand dieser Daten werden auf Basis der analysierten Materialkombinationen die Kosten für das Material und für die zugehörigen Produktionsprozesse untersucht und gegenübergestellt. Anschließend wird das

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vielversprechendste Design für die Herstellung von je einem Demonstrator mittels Radialgeflechten und MFW auf einem PA-Liner ausgewählt. Abschließend werden Empfehlungen für die industrielle Hochskalierung der Verbundwerkstoff-Pipelineherstellung vorgestellt.

[Verbund] L: Recycling, Reparatur

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INSTITUT e.V.

DuReNo – Untersuchungen zur optimierten, staubarmen Fertigung von Carbonfaservliesstoffen mit dem Fokus auf arbeitsschutztechnische Belange

Zielstellung

Kernaufgabe des Projektes DuReNo war es, den Herstellungsprozess von mechanisch verfestigten Vliesstoffen aus rezyklierten Carbonfasern dahingehend zu untersuchen und zu entwickeln, dass eine nahezu staubfreie Produktion ermöglicht wird. Betrachtet wurden hierbei die Prozessschritte von der Faseraufbereitung mittels Schneid- und Reißtechnologie über die Vliesbildung per Kardier- und Airlayverfahren bis zur Verfestigung mittels Vernadelung.

Ergebnisse

Im Rahmen des Projektes wurden erstmalig im systematischen Untersuchungen zu neuralgischen Punkten Staubentstehung sowie zu Maßnahmen zur Staubverminderung durchgeführt. Mit Hilfe eines im Projekt beschafften Probenahmesystems wurden in umfangreichen Versuchs- und Messkampagnen die Staubkonzentrationen von (Staubpartikel, die so klein sind, dass sie beim Einatmen über die Atemwege aufgenommen werden können) und A-Staub (Staubpartikel, die so klein sind, dass sie beim Einatmen über die Atemwege aufgenommen werden und bis in die Alveolen und Bronchiolen der Lunge vordringen können) aufgenommen. Die gemessenen Staubkonzentrationen dienten nachfolgend zur Bewertung der durchgeführten Parameteränderungen bzw. anlagentechnischen Modifikationen.

Das angestrebte Projektziel der Reduktion des Staubanteils um ca. 50 % in der gesamten Vliesstoffprozesskette am Beispiel der Carbonfaservliesstoffanlage im Zentrum für Textilen Leichtbau am STEI wurde erreicht.



Abb. 1: Mitarbeiter in Arbeitsschutzkleidung mit angelegtem Probenahmesystem.

Ausblick:

Die Ergebnisse bilden die Grundlage für weiterführende Untersuchungen an industrieller Anlagentechnik bzw. ermöglichen bei baugleichen oder vergleichbaren Maschinen eine unkomplizierte Adaption. Durch die Bereitstellung von Handlungsrichtlinien und Empfehlungen zur Parametrierung und maschinenbaulichen Modifikationen bestehender Anlagen können die Ergebnisse zeitnah in der Industrie umgesetzt werden.

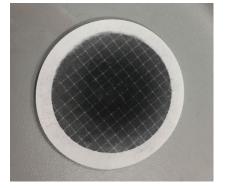


Abb. 2: Filter mit A-Staub-Fraktion

Forschungskuratorium textil





Gefördert durch:



aufgrund eines Beschlusses des Deutschen Bundestages



Danksagung

Wir bedanken uns für die finanzielle Förderung des Vorhabens 20295 BR DuReNo über das Forschungskuratorium Textil als Mitglied der Arbeitsgemeinschaft industrieller Forschungseinrichtungen (AiF) aus Haushaltsmitteln des Bundesministeriums für Wirtschaft und Energie im Rahmen des Programms zur Förderung der Industriellen Gemeinschaftsforschung (IGF).

Identification of CFRP-containing materials in waste streams using a novel inductive heating process

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Keywords: recycling, carbon fibre reinforced plastics, sorting, induction, inductive heating, active thermography

Currently, there is no industrial sorting process for separating fibre-containing material from waste streams. The aim of this study is therefore to identify carbon fibre reinforced plastic (CFRP) in different waste streams using an inductive heating method called active thermography. For this purpose, a conveyor belt transports different material fractions under a coil, whereby the materials are heated by induction, and reach into the visual field of a thermal camera, whereby the heating behaviour of the different materials is determined and compared.

The visual effects of different material combinations at different conveyor belt speeds, different height distances between the inductor coil and the specimen, and different specimen sizes are investigated. The material fractions investigated include various semi-finished CF products such as scrims, fabrics and nonwovens, as well as their combination with a plastic matrix (CFRP with multiaxial fabric, unidirectional (UD)-reinforced CFRP, and a nonwoven made of recycled CF and thermoplastic matrix). The research scope of the study also includes the investigation of different material combinations of CFRP, glass fibre reinforced plastic (GFRP), CFRP-aluminium hybrids, steel and wood.

The results show that CFRP structures heat up by induction. However, the heating behaviour is strongly dependent on the material and structure of the test specimen examined. A differentiation between CFRP and materials not containing CFRP is possible. This means that materials containing CFRP can potentially be sorted out from waste streams (both production and End-of-Life waste) coming from industries like aviation, wind or automotive. This can be achieved by using a novel sorting process by means of inductive heating and thus fed into a high-quality recycling path.

Introduction

Currently, the production of electricity has a high amount on the global CO_2 emissions [1]. An important building block to achieve climate neutrality in 2045 is to use renewable energy sources like wind and solar power. The design and manufacturing of wind turbine blades (WTB) cannot be imagined without the use fiber-reinforced plastics (FRP). This material consists of a fiber, which brings stiffness into the material and a matrix material, in which the fibers are embedded and protected against environmental impacts [2]. The continuing high demand for wind power is the main driver for the increase in length of WTBs and therefore high demand in FRP material. This helps in paving the way to a cleaner, more sustainable power production [3,4]. After the average service life of 30 years of wind turbines, they are usually dismantled and discarded [5,6] . Due to a high number of installations of WPPs in the 1990s and 2000s in Germany and Western Europe, increasing quantities of rotor blade material can be expected in the coming years. A forecast from 2015 expects about 30,000 tonnes of blade material appearing annually in 2025 [7].

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Figure 1: Global CFRP Demand from the years 2010 to 2019 and estimations for 2020 to 2023 [8].

The demand of carbonfiber-reinforced plastics (CFRP) has had a rapid growth in the last ten years and increased the amount of CFRP from 33 kt in 2010 to 92 kt in 2021. After a small decrease due to the Covid19 crisis, it is expected to increase again [8]. Besides others, the increasing demand of CFRP and the estimations for the End-of-Life (EoL) turbine blades show that in the near future there will be a high amount of FRP material, which needs to be recycled. The production of FRP material, in particular carbon fibers, is very energy-intensive [9] and, in order to reduce energy and resource consumptions, calls for an appropriate recycling process. An essential step of the recycling process is the sorting of different material types into single-origin fractions for the subsequent recycling process. Through this sorting step impurities can be discharged, which can have a negative effect on the quality and potentially downgrade the quality of the recycled material. As Table 1 demonstrates, many different materials occur in a shredded WTB, which makes it currently problematic to recycle. This makes a functioning sorting process urgently necessary.

Table 1: Overview of different materials which are used in the construction of a WTB [7,10–12].

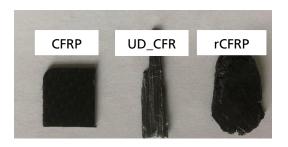
Material	Fraction [weight-%]
Fiber (Glas and carbon)	35-75
Resin	30-50
PU-Foam	<5
Metal	<5
Paint	3-5
Other plastic	<15
Wood	<5

Materials and Methods

The material tested in this study aims to represent the materials, which are used in the construction of a WTB. Furthermore different carbonfiber textiles have been tested to study and better understand the impact of the induction technology on the carbon fibre textiles. Table 2 shows the different materials tested and the abbreviations used in the following text to describe the materials.

Table 2: Overview over the material used in this study.

Material	Abbreviation
Multiaxial glasfiber-reinforced plastics (GFRP)	GFRP
Multiaxial CFRP	CFRP
Unidirectional CFRP	UD_CFRP
Recycled CFRP	rCFRP
Unidirectional carbon fibre fabric	UD_CF
Carbon fibre woven fabric	CF
Recycled carbon fibre nonwoven	rCF
Unidirectional GFRP	UD_GFRP
Wood	Wood
Steel	Steel
CFRP-aluminium hybrid	CFRP_Alu



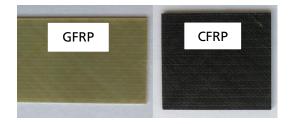


Figure 2: Different FRP materials used in sorting process.

The experimental setup exists of a conveyor belt with a thermal camera (FLIR A65, 30 Hz) placed in 30 cm height. An area of $10 \text{ cm} \times 10 \text{ cm}$ in the middle of the conveyor belt is covered by the inductor coil. The thermal camera is placed subsequently after the inductor coil over the conveyor belt. The inductor is operated by a frequency converter (1000 - 2000 kHz, 5 kW) and controlled via a raspberry pi with corresponding software. The inductor coil is cooled through a water cooler. The whole setup is shown in figure 3.

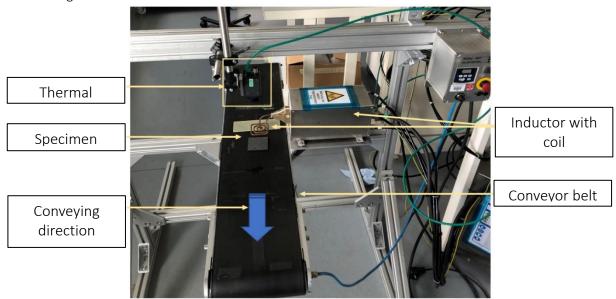


Figure 3: Experimental setup of the sorting tests with conveyor belt, thermal camera and inductor coil.

The test specimen is placed on the conveyor belt for the test procedure. The conveyor belt then transports the test specimen at a constant speed towards the inductor coil. While the test specimen passes through the area under the inductor, the test specimen is heated through the electromagnetic field. The thermal camera measures the temperature of the specimen as it passes through its visual field and passes its measurement data to the software, where the software displays a live thermal image of the camera's field of view and saves the measured data in a CSV file. Only the highest temperature measured is saved in the CSV file. When the test specimen has passed through the thermal camera's field of view, the test is terminated. The speed and performance is adapted to laboratory scale. The target temperature is 60 °C and the speed is set to 5 cm/s.

Results and discussion

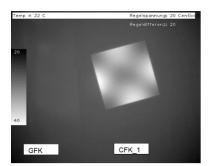
The results show that the heating pattern of the CFRP samples visually differ well from the other materials, but the heating behaviour is influenced by various parameter, which will be explained in more detailed in this section.

Power of inductor and conveyor belt speed

The power of the inductor has a decisive influence on the heating of the samples meaning that the samples at low power heat up more slowly and are unable to reach the target temperature. In addition, the heating of the samples is lower at higher conveyor belt speeds. This result can be described in general terms by equation [13]

$$E_{ind} = P \times t \tag{1}$$

Here, E_{ind} is the necessary energy to heat an ideally insulated conductive workpiece, P is the power introduced into the system and t is the time the workpiece is in the magnetic field [13]. The conveyor belt speed influences the heating of the samples to that effect that an increase in speed results in a decrease in heating, because the conveyor belt speed has an effect on the dwell time (t) during which the specimen is under the magnetic field. At constant power, the energy E is directly changed by the dwell time (t). At a higher conveyor belt speed, the dwell time is shortened, which reduces the energy E introduced and lowers the heating effect. Figure 4 shows a GFRP and CFRP sample at different conveyor belt speeds (5cm/s - 15 cm/s). The brighter the material is, the higher is the temperature of each specimen. It is recognizable that with increasing speed, the brightness of the material and thereby the heating decreases and consequently the maximum temperature reached decreases (from 40°C to 32°C).



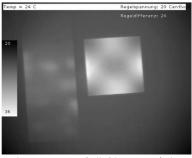




Figure 4: Influence of conveyor belt speed on heating, 5 cm/s (left), 7.5 cm/s (centre), 15 cm/s (right). The CFRP sample heats less with increasing speed, the GFRP sample shows almost no heating.

Distance inductor coil to specimen and size of specimen

Another important influencing factor is the distance between the inductor coil and the specimen, which has a great influence on the heating behaviour. A reduction in distance leads to a higher heating effect due to the magnetic field strength (H), which has a direct influence on the induced voltage. The closer the specimen is, the higher is the magnetic field strength resulting in a higher induced voltage and consequently causing the sample to heat up more when it is closer to the coil.

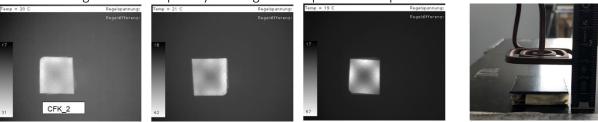
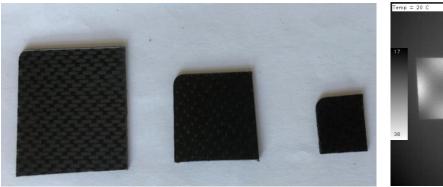


Figure 5: Influence of height difference on warming, 2 cm height difference (left), 1.5 cm height difference (second from left), 1 cm height difference (second from right). The temperature scale on the left side of the pictures shows clearly that with a reduced..

When testing three differently sized specimens made of CFRP, the influence of the specimen size on the heating was investigated. If the test specimens are of different sizes, the largest specimen heats up the most. The decisive factor for this effect is the area A_{ind} , through which a ring current flows. As seen in equation 2 does an increased size result in a higher induced voltage if the other parameters remain constant, which results in a stronger heating of the material [14].

$$u_{ind} = \omega \cdot B \cdot A_{ind} = 2\pi \cdot f \cdot \mu \cdot H \cdot A_{ind}$$
 (2)



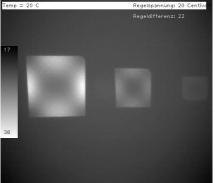


Figure 6: With an increased specimen size, the area A_{ind} grows and the heating increases.

Influence of textile structure and material composition on heating behaviour

CFRP samples made of a CF-nonwoven, a CF-fabric and a CF non crimp fabric were also examined. The CF nonwoven is heated the most, followed by the CF-fabric, while the noncrimp CF sample shows no visible heating pattern. This is due to the fibre structure, which is decisive for the effects of Joule heating and contact resistance heating. In the samples examined, contact resistance heating is decisive; the more fibre contacts there are in the sample, the more the material heats up. Considering this, it is understandable that the nonwoven materials heats up the most, due to the many cross-links of the carbon fibres and that the non-crimp CF material with its parallel aligned fibres has no contact resistance heating and therefore a weaker heating behaviour.

When testing the different semi-finished textiles reinforced in plastic matrices, an influence of the polymer on the heating behaviour is not found, the nonwoven material heats up the most. The main reason is that the magnetic field frequency of 1235 kH is too low to support dielectric heating, which is only possible at a magnetic field frequency in the three-digit MHz range [15]. Therefore,

it is not possible to assess whether the matrix of the samples is a dielectric and how it would influence the heating behaviour.

In another test, the skin effect [16] is also determined. This occurs with the textile semi-finished products as well as the CFRP. The skin effect, which is generated through the concentration of eddy-currents on the surface of the material, shows the typical heating pattern, which is visible in the images of the thermal camera. This effect decreases with higher frequencies of the electrical field and thicker material.



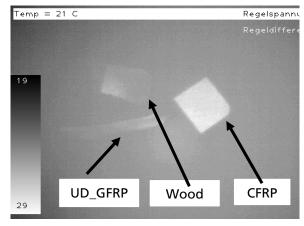


Figure 7: The heating behaviour of wood and GFRP clearly differs from the CFRP.

The comparison of the heating behaviour of CFRP, GFRP, CFRP-aluminium, wood and steel provides insights into the heating of common material flows coming from EoL-WTBs. Materials with a poor electrical conductivity like wood and GFRP show no heating patterns during the test, while the CFRP-aluminium composite heats up when the CFRP component is on the side facing to the inductor coil though the aluminium part is not visibly heated. The tests with CFRP and steel show that both materials heat up to approximately to the same extent. The heating behaviour of the steel sample is strongly influenced by the location of the sample under the inductor coil. The sample is visibly heated in the centre of the coil, but no heating is visible, if it is placed at the edges of the coil. The steel sample quickly gives off heat again when it is not in the centre of the coil; the magnetic field is stronger in the centre of the coil. Table 3 offers an overview of all material and its heating behaviour.

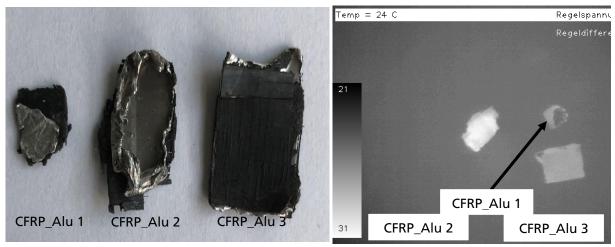


Figure 8: On the left different CFRP-Aluminium composites can be seen with the corresponding thermal image on the right.

Table 3: Overview of the characteristical heating behaviour of the tested material.

Material	Heating behaviour	Characteristic
Multiaxial GFRP		None
Multiaxial CFRP	++	Quick heating through contact resistance
		heating
Unidirectional CFRP	-	Slow joule heating
Recycled CFRP consolidated	++	Quick heating through contact resistance
		heating
Non-crimp carbon fabric	-	Slow joule heating
Carbon fibre woven fabric	++	Quick heating through contact resistance
		heating
Recycled carbon fibre	+	Quick heating through contact resistance
nonwoven (semi-finished		heating
material)		
Unidirectional GFRP		None
Wood		None
Steel	+	Strongly influenced by the location of the
		sample
CFRP-aluminium hybrid	+	CFRP parts heats more than aluminium

Conclusion

Basically, the CFRP samples differ well visually from the other materials in the thermal camera images. However, the CFRP samples also show different heating behaviours among themselves. While unidirectional material shows a weak heating behaviour, material with cross-links heat up very strongly due to contact resistance heating. Further investigations are necessary, if the sorting according to the fibre structure becomes necessary. However, the results show that similar CFRP structures display similar heating behaviour. At a constant power setting, UD-CFRP can be distinguished very well from the other CFRP structures such as nonwoven-CFRP or woven-fabric-CFRP. In any case, this type of thermography is in principle suitable for the sorting of shredded WTBs or Multimaterial-composites in general. Due to the good conductivity of carbon fibers and the metallic components, these materials show a definite, but distinguishable heating behaviour. Shredded WTBs also contain high quantities of GFRP and wood, which do not heat up in this process, which makes them clearly distinguishable from the CFRP and metallic components.

One challenge of this sorting techniques lies within metal-CFRP composites, which are not disintegrated in the prior shredding process. The thermography technique cannot easily distinguish this material from CFRP without metal attachment since the thermal camera recognizes the heating pattern of the CFRP itself. Hence, a detailed analysis on how to proceed with undamaged metal-CFRP composites needs to be conducted. A possible solution could be a determined fraction of this material group, which would be sorted out during the process. Depending on the amount, a specific recovery scenario (e.g. another shredding process) can be considered.

For a standardized procedure different aspects for machine setup as well as the material composition have to be considered. The machine set up has to consist out of an inductor with a higher power and higher magnetic field frequency than the set up used in this study to receive an optimal heating behaviour. The material samples need to have similar geometric dimensions to minimize the effect of sample size on the warming and to minimize the effect of the height difference between sample and inductor coil. A thermal camera with a higher frame rate will allow a higher speed of the conveyor belt, which is necessary for an industrial sorting process.

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Options to evaluate Glass Fiber Reinforced Polymer (GFRP) composite recycling from an environmental point of view

U. Kirschnick^{1*}, N. Krempl², R. Schledjewski¹

Circular economy of composites and especially recycling are gaining importance in science, politics and industry under the sustainability paradigm. Nevertheless, recycling of complex materials, such as glass fibre reinforced polymers (GFRP), requires life cycle assessment (LCA) to critically assess and verify the anticipated ecological benefit, and to analyse hotspots and identify optimization measures within the recycling value chain. The LightCycle project investigates various aspects of the circular economy of GFRP composites, such as i) the usage of mechanically recycled thermoplastic matrix material (polypropylene) and glass fibers, ii) technology optimization by a combined compounding and injection molding process (one-step process), iii) degradation behaviour and process control of the GFRP materials throughout multiple recycling cycles, and iv) the development of a demonstrator component for the identification of industrial substitution potentials.

This research presents different designs of LCA to evaluate the environmental performance and capture the impact of the project, which are depicted in Figure 1.

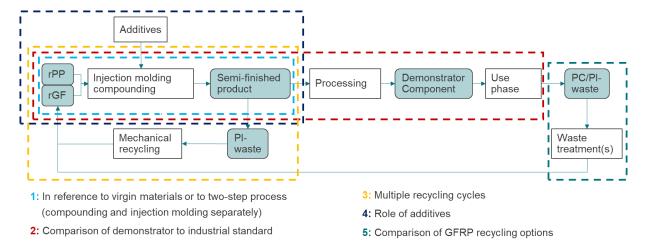


Figure 1. Different approaches for environmental assessment within the LightCycle project.

The identified approaches are i) comparison of virgin and recycled materials, ii) comparison of two-step compounding and injection molding with the one-step process, iii) benchmarking and substitution potential of the recycled demonstrator against industrial standards, iv) the determination of environmental and material performance of multiple recycling cycles, v) assessment of the role of additives, and vi) comparison of different GFRP composite recycling options, e.g. mechanical recycling, pyrolysis and solvolysis. Furthermore, it analyses the different LCA approaches' in terms of scientific relevance, significance to project results, feasibility and data requirements. Industrial benchmarking has the highest project and scientific relevance as previous research stresses out that there is a lack of examples for fields of application. From the project perspective, this approach combines material and process specific aspects to influence the environmental performance that can be captured per equivalent component. Difficulties arise from the high level of interdisciplinarity needed and feasibility of data collection.

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