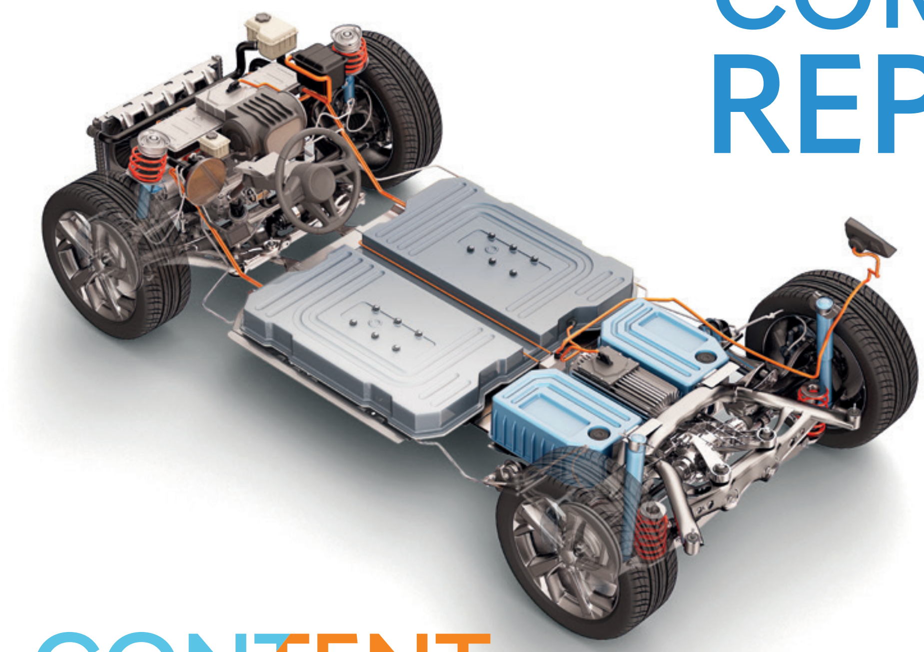
EDITION APRIL 2023

# AVK COMPOSITES REPORT 07

# Thermoplastic Composites
## INNOVATIVE APPLICATIONS AND Processes

## CONTENT

# COMPOSITES REPORT 07



## CONTENT

## Dear reader,

despite difficult and challenging times, there are also bright spots, because composites are on a positive path to the future.

Admittedly, the composites industry, like the industry in general, has had to overcome key challenges in recent years, such as the Corona pandemic, the semiconductor shortage, problems in the logistics chains and the sharp rise in raw material prices. All these factors have caused European - and also German - production volumes to slump by 20% in 2019/2020. However, due to a very strong market development, the previous level was almost reached again in 2021. For the past year 2022, the current market data show a strong development, especially in the first three quarters.

The main growth drivers for the composites industry are currently the wind energy sector and thermoplastic applications in the transport sector. The structural changes in the mobility sector often open up opportunities for composites to gain a foothold in new applications. The construction and infrastructure sectors as well as the electronics/electrical sector also offer great prospects. Here, in particular, there is clear added value in the use of composites beyond lightweight construction, for example against the background of the sustainability debate, Industry 4.0 and Smart Cities. Composites have been in industrial (series) use for many decades and yet there is still huge potential for opening up further fields of application in the future. In the current issue of our Composites Report, our member institutes show this time what is possible with thermoplastics, whether pultrusion or SMC, whether circular economy, mobility or digitalisation. Let yourself be inspired once again by the variety of composites.

Kind regards,

Dr. Elmar Witten
AVK Managing Director

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INSTITUT FÜR TEXTILTECHNIK OF RWTH AACHEN UNIVERSITY ITA

# MICROWAVE DRYING IN COMPOSITE PRODUCTION

*Reducing primary energy consumption and greenhouse gas emissions is a big challenge which is important from both an environmental and an economic perspective. However, the high production costs of composite materials in manufacturing and processing limit their wide use in certain applications. In the process chain, impregnation and drying consume the highest proportion of energy and the process is also crucial for the final product quality.*

*Author: Andreas Bündgens, M.Sc.*

There are different technologies for impregnating textile structures, which differ in the method of adding the matrix polymer to the reinforcing structure. In the production of thermoplastic fibre composites, the most important processes in which drying technology is needed are solvent impregnation and dispersion impregnation, compared to melt impregnation and hybrid yarn processing without a drying step. Currently, convection ovens are used as the most established industrial drying technology.

The comparison of energy efficiency of common convection ovens and microwave drying systems shows that microwave drying systems are much more energy efficient. For drying purpose, they couple the heat homogeneously across the entire cross-section. The power input is automatically adjusted based on the reflection signal of the microwaves and the shift in resonance frequencies, and the process is terminated as soon as all the free water has evaporated. This eliminates the need for preheating or running post-treatment steps overall. Microwaves can be used for both continuous and discontinuous drying and consolidation of fibre composite materials, as demonstrated by the "MicroCoat" project. The module that is developed uses microwave radiation to continuously heat the water molecules in the aqueous impregnated textile and to cause them to evaporate. Pressure is also used to consolidate the material and prevent a reaction with oxygen during microwave heating. The technology will be available as a modular system for drying fibre-reinforced materials and will soon be extended to drying other wet coatings in the textile industry.

In addition, a stationary pressing process is currently being developed in the "ISOWAVE" research project for the production of inorganic insulating materials for heat and sound insulation in cars, aircraft and machinery using microwave drying. This technology uses inorganic nonwovens such as silica fibres or glass fibres that are coated with an inorganic

| Impregnation methods | Advantages | Disadvantages |
|---|---|---|
| • Melt impregnation | direct process no drying | viscosity reduction |
| • Hybrid yarn | homogeneous mixing | long process time |
| • Solvent impregnation | low viscosity | damaging the environment |
| • Dispersion impregnation | only water is used | expensive and energy-intensive |

*Fig. 1: Types of impregnation and their advantages and disadvantages*

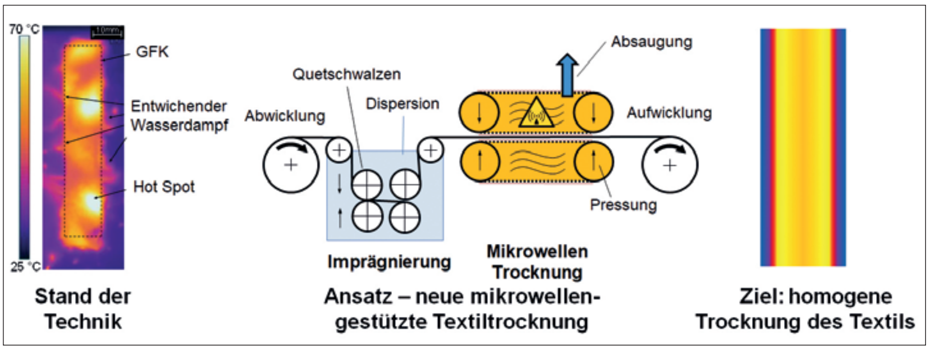


*Fig. 2: Approach of the new microwave-based textile drying process*

binder and formed into their final shape under pressure and heat. The new technology significantly reduces cycle time and energy consumption, because the thermal resistance does not have to be passed to heat the core. The microwaves mainly act on the water contained in the binder, raising the temperature and triggering gel formation, while excess water evaporates. In this way, energy surplus is avoided and only the energy that is actually necessary is used to realise the process.

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# *OVERMOLDING PROCESSES IN AVIATION*

FASERINSTITUT BREMEN E. V. (FIBRE)

# Simulation reduces development risks for OVERMOULDED AIRCRAFT STRUCTURES

*The overmoulding process allows hot-forming continuous fibre-reinforced laminates and functionalising it with short fibre-reinforced material by injection moulding in a single processing step. The automotive sector applies the technology in series production for several years already. The aircraft industry is currently working on increasing the technological maturity and is looking for possible applications.*

*Author: Robert R. Enderle*

In the recently completed LuFo V-3 joint project "ELTHEPLA" (FKZ 20W1726D), Faserinstitut Bremen e. V. (FIBRE) developed simulation methods for supporting the development of overmoulded aircraft structures. Together with the project partners Airbus Operations, Airbus Helicopters, Fraunhofer IWU and Neue Materialien Bayreuth (NMB), the outer skin of an emergency exit door demonstrator for passenger aircraft was also developed and manufactured by overmoulding.

Strict requirements apply to structural aircraft components, requiring the use of high-performance polymers with carbon fibre reinforcement. Besides the potential for reducing weight and costs, the overmoulding technology also involves risks for component development and production.

The interface between laminate and injection moulding is still too little understood and thus a challenge for design and sizing. At FIBRE, coupons for rib pull-off and tensile shear tests were therefore manufactured and tested. The material system consisted of short carbon fibre-reinforced PEEK (VICTREX® PEEK 90HMF40) and carbon fibre unidirectional tape with low melting PAEK matrix (VICTREX® AE™250). A fracture mechanical

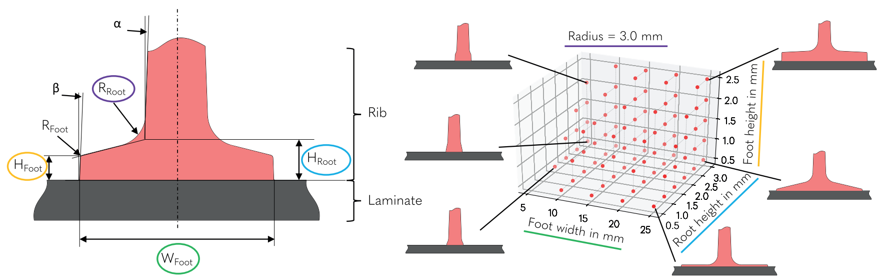



*Fig.1: Parameterised step-shaped overmoulding rib foot (left) and exemplary representation of the parameter space for rib foot optimisation (right). Each point in the diagram represents a specific rib foot geometry that was subjected to a virtual rib pull-off test to identify optimal shapes.*

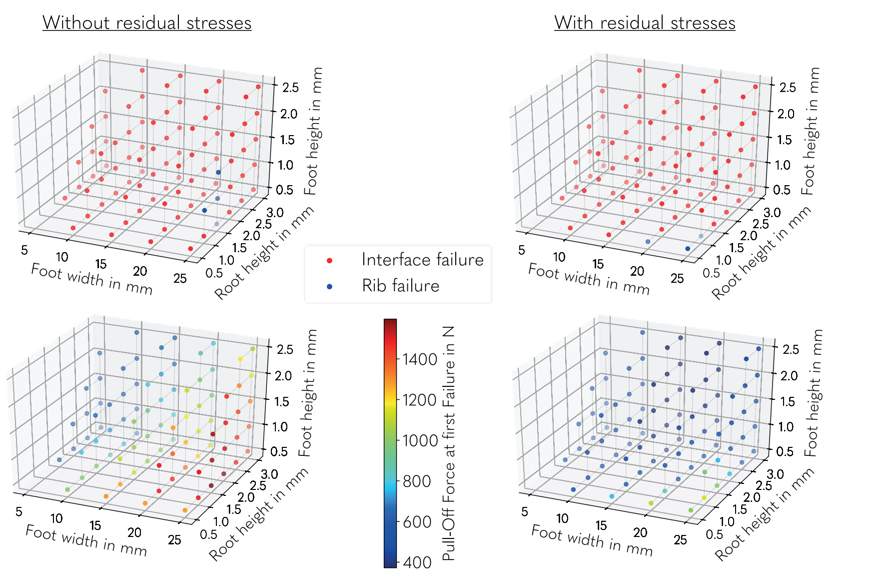



*Fig. 2: Results of the simulation-based parameter study for identifying the optimal rib foot shape. The failure location (within the rib or at the interface) is shown above and the maximum forces achieved in the virtual rib pull-off tests are shown below. The load-bearing capacity-reducing effect of material-related residual stresses can be clearly seen (left vs. right: without vs. with residual stresses).*

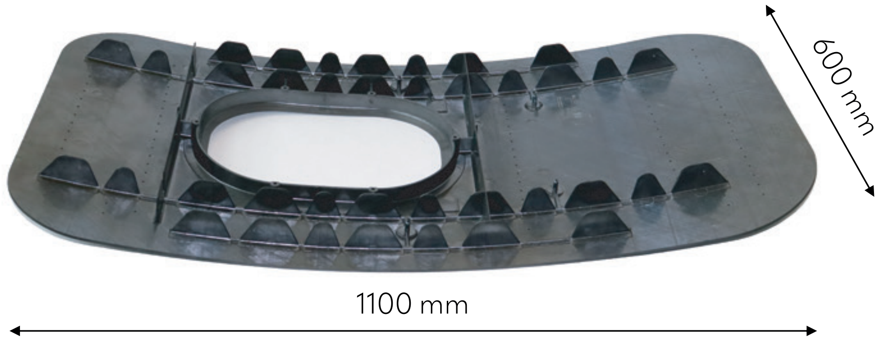
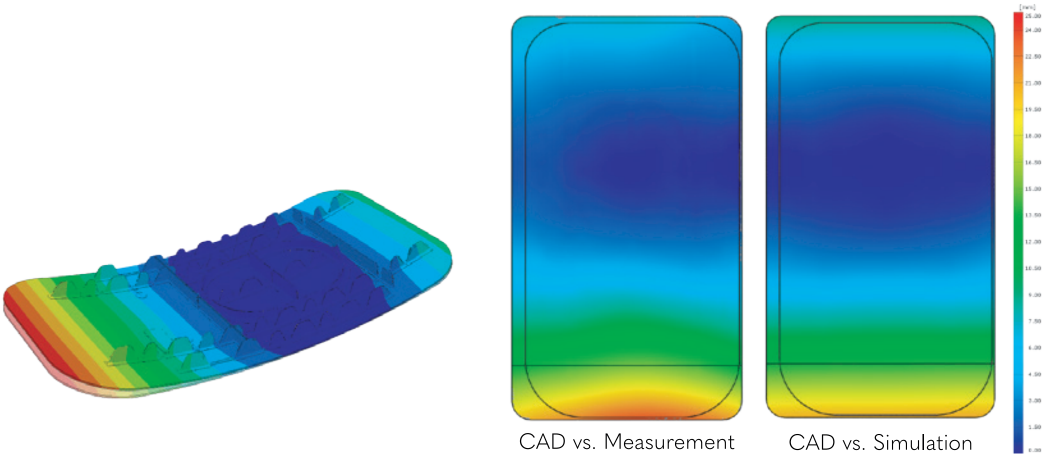



*Fig. 3: Outer skin of the aircraft emergency exit door demonstrator, made from carbon fibre-reinforced PAEK and manufactured in the overmoulding process by NMB.*

failure criterion was calibrated on the measured force-displacement data. Using the finite element method, this was applied to optimise the shape of the injection moulded rib structure of the emergency exit door outer skin demonstrator, see Fig. 1. Rib pull-off tests at NMB with an optimised rib foot shape yielded maximum forces differing by only 2 % from the simulated ones. The successful validation of the simulation model contributes to a reduction of risks for current and future developments.

Warpage is another risk in the development of an overmoulding application. Simulation-based predictions can help assuring the success of the component development by compensating the mould accordingly and maintaining tolerances without costly adjustments of the mould. For this purpose, an approach for rapid warpage estimation was developed at FIBRE, based on adjusted coefficients of thermal expansion. Although the method does not account for processing parameters, it captures quite well the magnitude of curvature deviation of the outer skin. Compared to more complex approaches, a result can be obtained in minutes to hours. Thus, the method can be used early in the design phase for a large number of geometries.

*Fig. 4: Comparison of measured and simulated distortion of the outer skin of the aircraft emergency exit door demonstrator. The simulation reproduces well the magnitude of the change in the curvature of the outer skin.*

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INSTITUT FÜR TEXTILTECHNIK OF RWTH AACHEN UNIVERSITY ITA

# Use of thermoplastic SANDWICH STRUCTURES in train interiors

*Autor: Boris Manin*

Trains play a central role in sustainable mobility of the future. With rising energy costs and requirements for fossil-fuelled vehicles, passenger transport in the rail vehicle sector is becoming increasingly attractive. Especially for wagon interiors, the components used must meet strict requirements regarding fire and scratch resistance, as well as hygiene. Fibre-reinforced phenol-formaldehyde resins are a material often used in train interiors. Since the production of phenolic resins produces harmful vapours, efforts are being made to reduce the use of such resin systems.

Therefore, novel materials for train interiors are being developed within the publicly funded IraSME project InnoSandwich. In order to successfully replace current materials, the new material must meet requirements for stiffness, low density, insulation and sustainability at low cost. Thermoplastic fibre-reinforced sandwich structures offer a high potential. Here, similar thermoplastic material is used for the core structure and as matrix material in the cover layers. To meet the requirements of fire resistance, additional functional layers are applied to the sandwich structure.

The processing of such sandwich panels differs from the currently used phenolic resin-based process chain. Therefore, a process for shaping the panel material into component geometry is being developed at the Institute of Textile Technology. The aims of the investigation are to determine the parameters for forming the sandwich material using a stamp forming process, to determine the defects that arise in the material, and to jointly scale

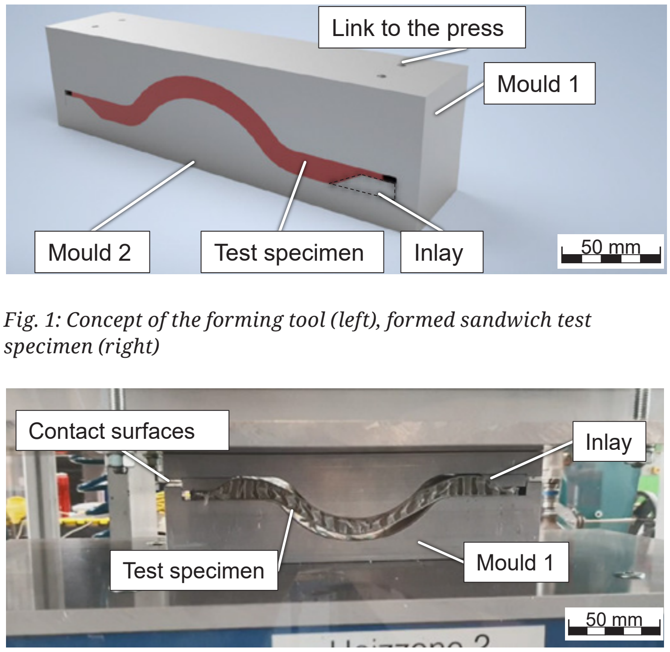


*Fig. 1: Concept of the forming tool (left), formed sandwich test specimen (right)*

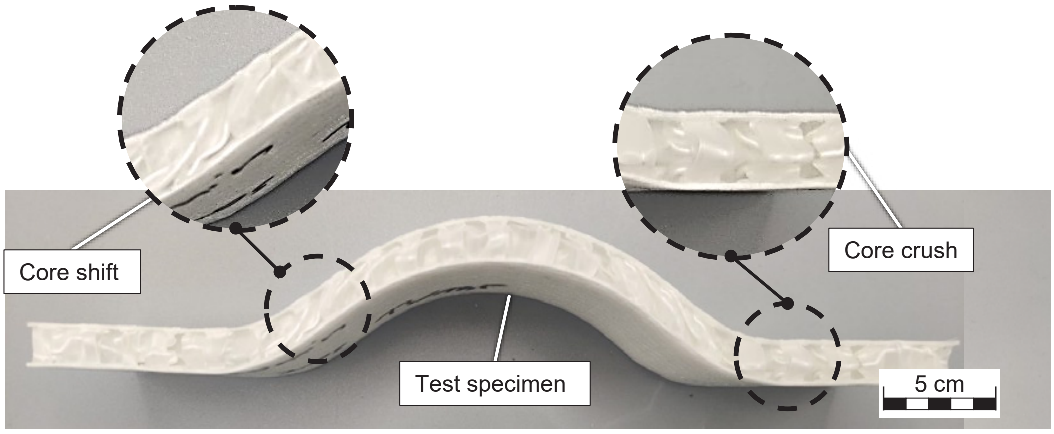


*Fig. 2: Material effects occurring in the forming process*

up the process chain for industrial application with the project partners. For this purpose, an omega-shaped tool for a stamp forming press is being developed (see figure 1). The tool is integrated into a press. The material is heated in an upstream convection oven.

In the investigations, it was found that the forming effects that occur during shaping can be attributed to two categories. In areas of high material compaction, material compression and associated core crush occurs. This is associated with a drastic reduction in mechanical properties and should be avoided if possible. In addition to core compaction, core displacement is observed (see Figure 2). Core displacement occurs particularly frequently when the plastic is heated close to its melting point. Therefore, the shift can be explained by the softening of the core material. The shear forces generated during forming are thus dissipated by deformation within the core.

Optimal forming temperatures could be achieved at 0.9Ts. Here, the material sample was warmed up for about 15 minutes and formed into the geometry within 10 seconds after removal. In summary, it can be said that the forming of sandwich test specimens into curved geometries is possible. The investigated mould radii are sufficient with the aim of later application. In the next steps, an upscaling of the process and production of the demonstrator component will take place.

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# THE PATH TOWARDS CLOSED LOOP RECYCLING

*Authors: Anna Krüger, M.Sc., Sascha Kilian, M.Sc.*

## MOTIVATION

For some time now, FRPs have been the first choice reducing $CO_2$ emissions in the mobility industry, due to their low weight. However, given the controversies and consumer criticism of plastics, the composites industry is confronted with increasing demands on the recyclability of its materials. Recycling approaches fail all too often because of one serious issue: the inevitable shortening of the fibres.

## APPROACH

In the conflict between lightweight construction and recyclability, thermoplastic self-reinforced plastics (SRPs) represent a promising alternative to conventionally reinforced materials. The use of the same basic polymer as fibre and matrix material enables material recycling. The reinforcing effect is achieved by stretching and the resulting high degree of orientation of the polymer molecules (see Fig. 1). Woven with non-stretched matrix filaments, semi-finished textile products are created and consolidated into organic sheets.

## MECHANICAL PROPERTIES

Comparing the mechanical properties of GRPs and SRPs (see Tab. 1), it can be seen that the former are initially superior due to their higher stiffnesses and strengths. However, as SRPs have a lower density, the differences in performance decrease when the same weight of material is considered.

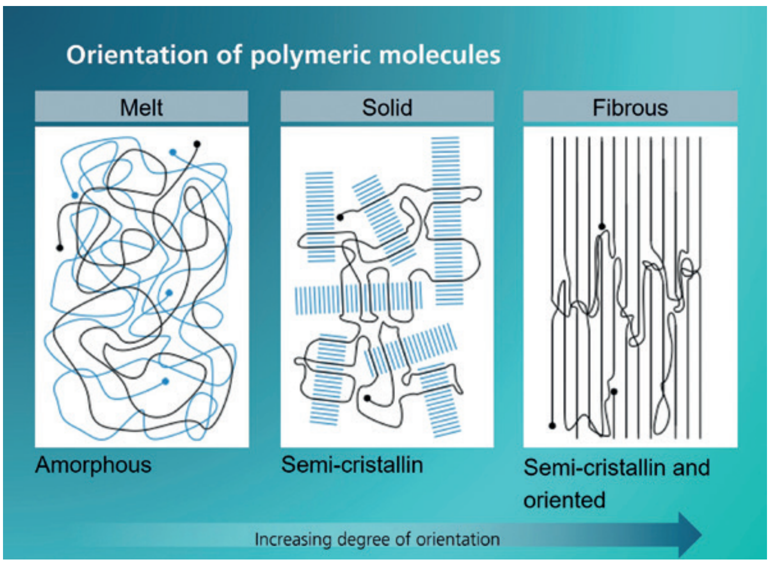



*Fig. 1: Illustration of the morphological structure*

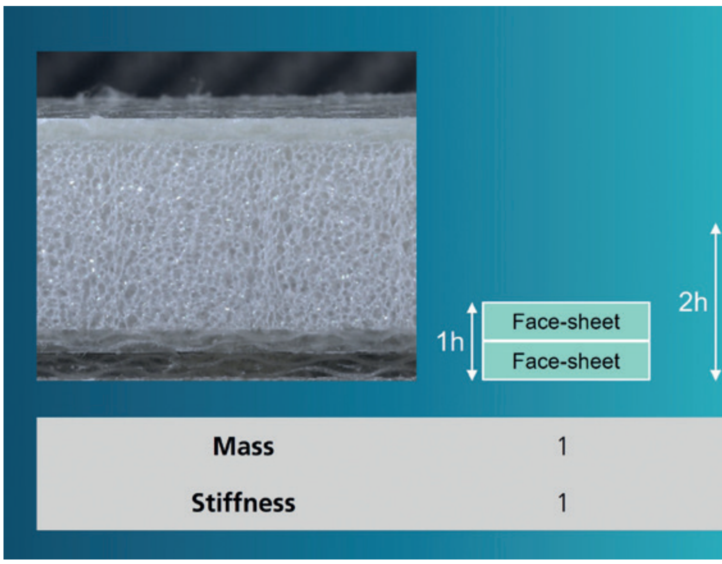



*Fig. 2: Effect of the sandwich structure on mass and stiffness*

| Property | Unit | PA6-GF47 Lanxess Tepex® | PP-GF47 Lanxess Tepex® | srPP DIT Weaving Pure®sheet | srPET Comfil srPET 50302 | srPET Comfil srPET 57 wt-% |
|---|---|---|---|---|---|---|
| Density | g/cm³ | 1,8 | 1,68 | 0,78 | 1,38 | 1,38 |
| Tensile modulus | GPa | 19,9 | 18 | 6,4 | 3,5 | 4,6 |
| Weight specific tensile modulus | GPa*cm³/g | **11,06** | **10,71** | **8,21** | **2,54** | **3,33** |
| Tensile strength | MPa | 343 | 383 | 215 | 143 | 195 |
| Weight specific tensile strength | MPa*cm³/g | **190,56** | **201,19** | **275,64** | **103,62** | **141,30** |
| Elongation at break | % | 1,9 | 2,1 | 7,7 | 22,8 | 24,7 |

*Table 1: Tensile properties according to DIN EN ISO 527-1*

## SANDWICH APPROACH

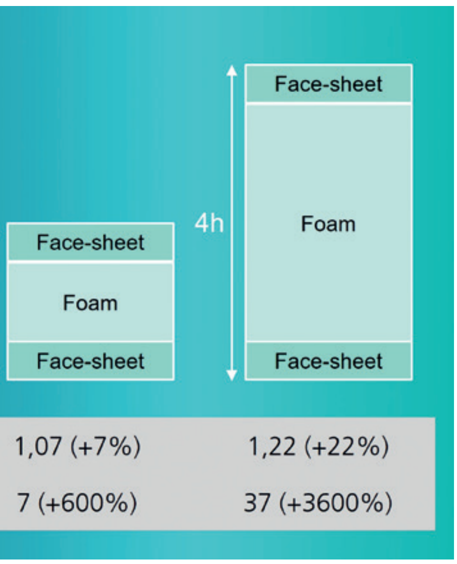
To compensate for the existing deficits in terms of stiffness, self-reinforced cover layers are joined with a shear-resistant core made of the same polymer to form a sandwich. This achieves a significant increase in stiffness with a relatively small increase in mass (see Fig. 2). Thermoplastic particle and extrusion foams as well as honeycomb and folded structures are suitable as cores. The sandwich composite is created by a melt joining process. The challenge in terms of process technology is to achieve good adhesion while at the same time preventing the temperature-sensitive core from collapsing.

## APPLICATION

Through further processing in thermoforming or co-injection, a wide range of applications from the aerospace, automotive, sports and leisure industries can be covered with monomaterial sandwiches. In addition, variably adjustable foam densities and component wall thicknesses enable optimization of load transfer through gradual compacting (see Fig. 3).

## OUTLOOK

In the future, a deeper understanding of the working mechanisms will be pursued through further characterization of the materials. Among other things, the creep and fatigue behaviour and the heat resistance will be investigated. The overarching goal is to conserve resources through the complete recycling of materials. In addition to recyclate-based PET structures, bio-based PLA systems are also being developed in current projects.

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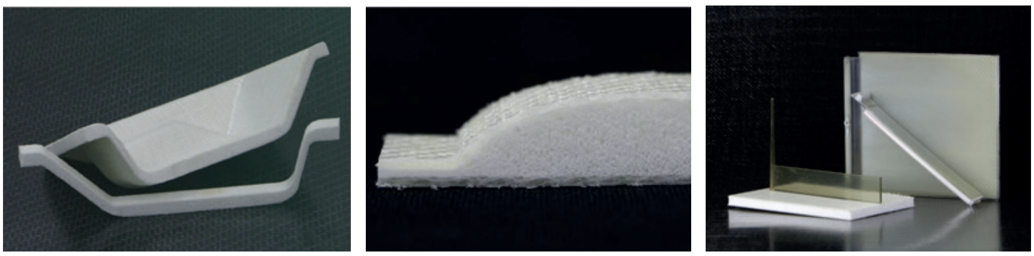

*Fig. 3: Functionalized sandwich structures: thermoformed component (left), variable wall thickness (middle), co-injected structure (right)*

FASERINSTITUT BREMEN E. V.

# Recycled materials for OVERMOULDING APPLICATIONS in aviation

*Author: Michael Petrich, M.Sc.*

In the overmoulding process, continuous fibre-reinforced structural components are stiffened or functionalised by injection overmoulding with a short fibre-reinforced compound. During the production of structural components, for example using the thermoforming process, off-cuts often accumulate, which are ideally suited for the production of high-quality recycling compounds for overmoulding. As part of an industrial project commissioned by Airbus Aerostructures GmbH (formerly Premium Aerotec GmbH), a process chain for the production of a recycling compound was investigated at the Faserinstitut Bremen e.V. and the bonding properties between structural insert and injection moulding component were compared to a virgin compound.

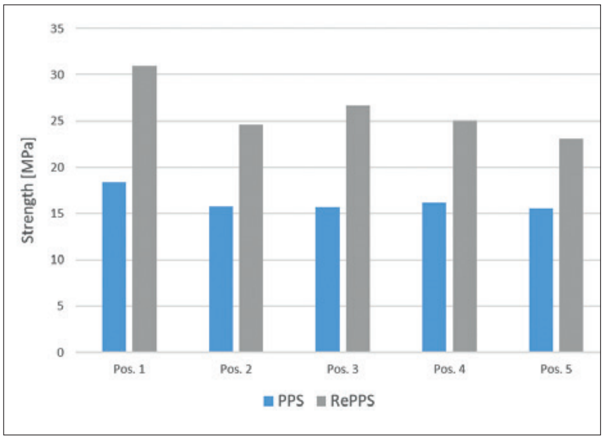


*Fig. 1: Comparison of bond strengths in overmoulding between recycled and reference material*

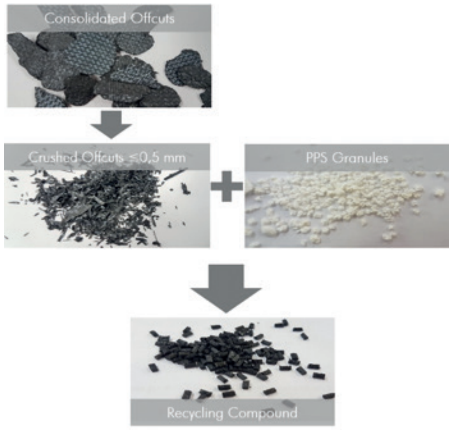


*Fig. 2: Process chain for the production of recycled injection moulding compound from off-cuts*

The offcuts from insert production are particularly suitable for the production of the recycling injection moulding granulate, since on the one hand, the fibres are already perfectly impregnated and on the other hand, the matrix material is identical to that of the insert component. Off-cuts from the production of thermoplastic aircraft components were used. These consist of PPS matrix with continuous carbon fibre reinforcement. When compounding the recycling granulate, unreinforced PPS granulate was added to achieve a fibre weight content of 25 %.

To compare the bonding properties, blanks of carbon fibre-reinforced PPS laminates were overmoulded with the recycled compound and a virgin reference material (30 wt.% carbon fibre). From the produced rib-on-plate geometry, 5 test specimens each were then taken along the rib and the bond strength between the insert and the overmoulding component was tested in a tensile test. The injection mould used is equipped with infrared sensors with which the material temperature of the injection moulding compound and its flow rate in the cavity can be measured.

The test results show that significantly higher strengths are achieved with the recycled compound, but these also vary more widely. For the specimens taken in the middle of the rib, the strength of the recycled specimens is 26.66 (± 6.26) MPa and that of the reference material is 15.69 (± 3.36) MPa. The results can probably be attributed to the greater inhomogeneity and resulting higher viscosity of the recycled material. The measured material temperatures are consistently higher for the recycled granulate, while the flow velocity is lower. The temperature in the joining zone is a decisive factor for the bond strength formed in overmoulding. Overall, the tests show the great potential for recycled materials in overmoulding, including for structural applications.

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INSTITUTE FOR PLASTICS PROCESSING (IKV) IN INDUSTRY AND CRAFT AT RWTH AACHEN UNIVERSITY

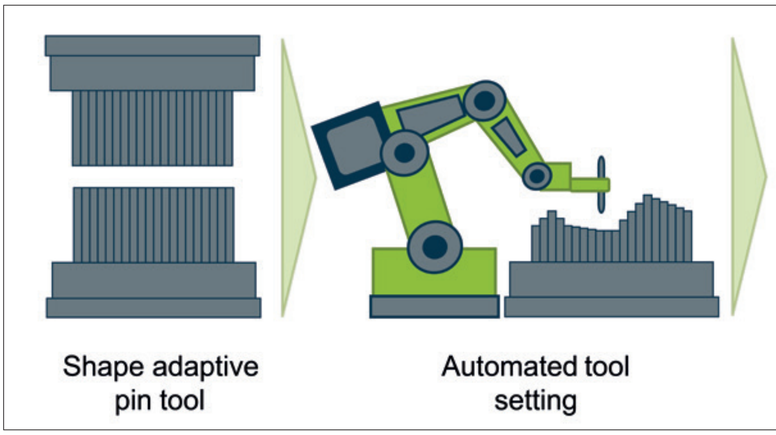
# DEVELOPMENT OF A NOVEL, DIGITALISED MANUFACTURING STRATEGY

## *for the automated design and production of FRP components in very small batches*

*Individualised components made of fibre-reinforced plastics (FRP) are an attractive class of components for applications in various industries. The use of unidirectional (UD) semi-finished products offers the possibility to adapt the fibre orientation and quantity in the component very individually to the specific load case, to combine semi-finished products of different shapes and material compositions and to increase the design freedom.*

Laminates made of pre-impregnated UD semi-finished products can be formed into the component geometry using the stamp forming process. However, the process is strongly tool-bound, with process and tool design being an elaborate process and subsequent changes to the physical tool being associated with high costs.

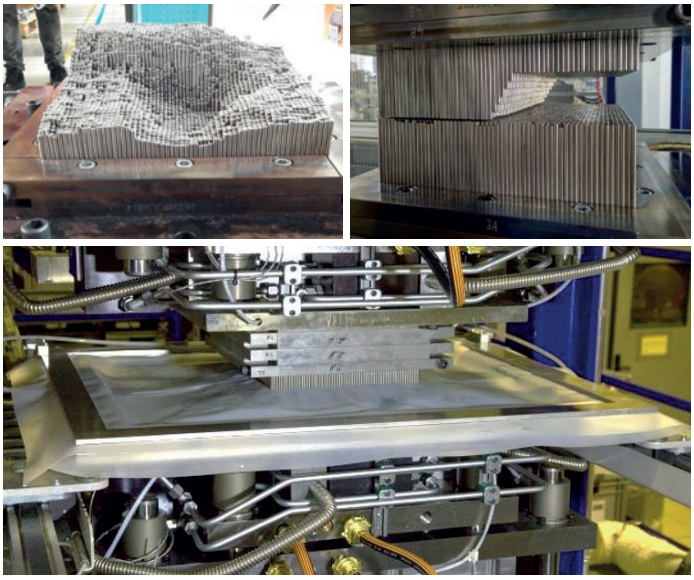
As part of the research project "Individualised FRP", a modular technology bundle is being developed for the resource-optimised development and production of UD-based FRP components in small and very small series. The developed process chain is implemented in a demonstration scenario.




With the help of a bidirectionally coupled structure and drape simulation, optimal laminate structures and essential forming parameters are identified. This is done with a view to ensuring that specified load cases and requirements for the component are fulfilled and that wrinkle-free forming can be guaranteed at the same time. A shape-adaptive pin tool is used to implement small series with a wide range of variants. In addition to the flexible mould surface, local mould inserts can be used. The cavity surface of the shape-adaptive tool is to be adapted fully automatically with the help of an industrial robot (see Fig. 1).

Furthermore, an expert system will be developed, which will provide a basis for decisions on the cavity design (direct surface impression versus local insert) and on the process control. The expert system takes into account additional selectable optimisation criteria, such as costs or surface quality. The selected laminate architecture, cavity design and process parameters form a production plan. Across all steps, a digital twin of the forming process is built up, which brings together all the data for the component to be produced, from the initial specification to the production plan selected on this basis to the production of the real component. In addition, the digital twin provides a holistic view of the product and the production process. In the case of new product developments, analogies can be made with production scenarios that have already been completed and iterations can be reduced.

The project is being carried out at the IKV together with the Institute for Human-Machine Interaction (MMI) at RWTH Aachen University and the Research Association for Programming Languages for Production Facilities (FVP), Aachen. The IKV is responsible for the practical mapping of the process chain as well as the simulative mapping of the process for the optimisation methodology. The MMI deals with the implementation of the digital twin and the expert system. The FVP takes over the path planning, and the robot control for automated tool setting.



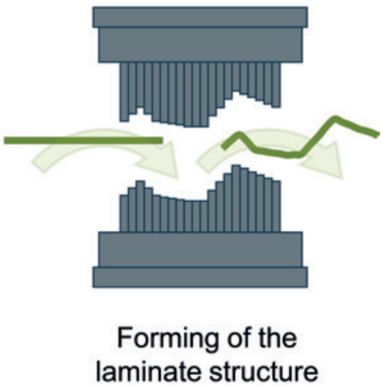



*Fig. 1: Automated adjustment of the shape-adaptive tool geometry*

## ACKNOWLEDGEMENT

The IGF project 22149 N "Individualisierte FVK" is funded by the Federal Ministry of Economics and Climate Action via the AiF as part of the programme to promote joint industrial research (IGF). We would like to take this opportunity to express our thanks for the funding. Additional thanks go to the project partners.

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AVK

# Composites Recycling Study

The study is now available from AVK in PDF format for 799 € (plus VAT) (for AVK members for a reduced price of 399 € plus VAT).

Please note: The study is only available in German language.

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Keyword: Recycling Study

The topic of sustainability and recycling has become increasingly important in industry and also in the plastics industry in recent years. Especially in the area of lightweight construction, composites have huge advantages. In addition, the materials can also deliver high added value in terms of sustainability. Why composites are advantageous has not been investigated systematically or rather in detail so far. The Composites Recycling Study, which has now been published and was compiled by IKK Institute Director Professor Hans-Josef Endres and Dr Madina Shamsuyeva with the support of industry representatives from the AVK Expert Working Group "Composites Recycling", is the first major study on the topic.

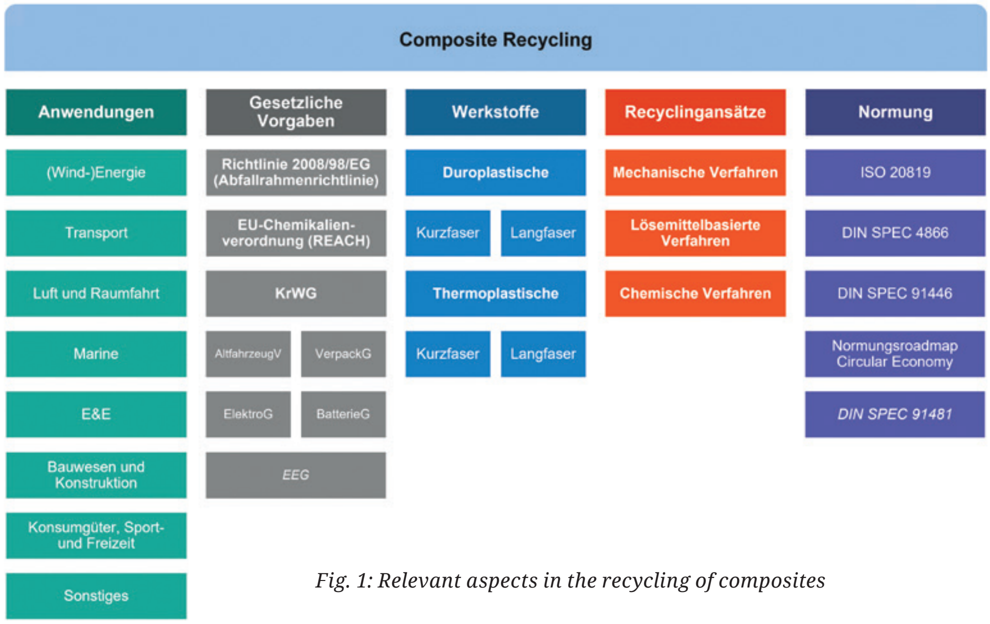



*Fig. 1: Relevant aspects in the recycling of composites*

For the first time, the study offers a systematic and comprehensive overview of the waste volumes generated in the composites industry and the solutions for high-quality recycling that are currently available and can be implemented in the future. The advantages and disadvantages of the various processes are also evaluated and relevant legal requirements and standards are considered.

"There is a high potential for composites in the field of sustainability, even if many believe that fibre-reinforced plastics are difficult to recycle. Nevertheless, one must not forget that not everything that is possible in recycling is also economical or sustainable. This is where it is important to take a close look. That is why this study is so important, to find out what the current status is, where the market can develop and where potential still lies dormant," states AVK Managing Director Dr. Elmar Witten. Prof. Hans-Josef Endres adds: "The study shows that more recycling is taking place in some areas, e.g. thermoplastics, but not yet in others. Especially in chemical recycling, the maturity of the technologies is not yet very advanced and sometimes plant capacities are not yet fully utilised. Pioneering work still needs to be done here, for example to work out interdisciplinary business models. At the same time, there are applications for composites that could already be easily recycled today from a technical point of view and 'only' lack the logistics and the will. But also a harmonisation of laws and standards as well as jurisdiction would be desirable to further advance composites recycling."

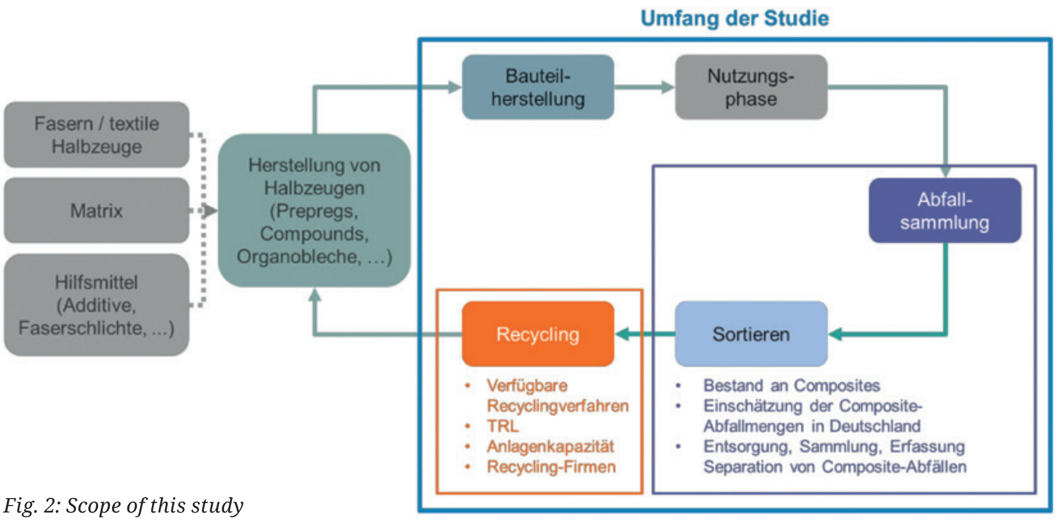



*Fig. 2: Scope of this study*

LEIBNIZ-INSTITUT FÜR VERBUNDWERKSTOFFE IVW

# Development of a novel process chain FOR THE DIRECT PRODUCTION OF NFPP TAPES

*Natural fiber reinforced polymer composites (NFRPC) have been used in the European automotive industry for decades and are mainly processed into semi-structural components such as door panels (see Figure 1), roof stiffeners and backrests.*

*Authors: Dr. Florian Gortner (IVW), Prof. Luisa Medina (HS), Martin Detzel (IVW)*

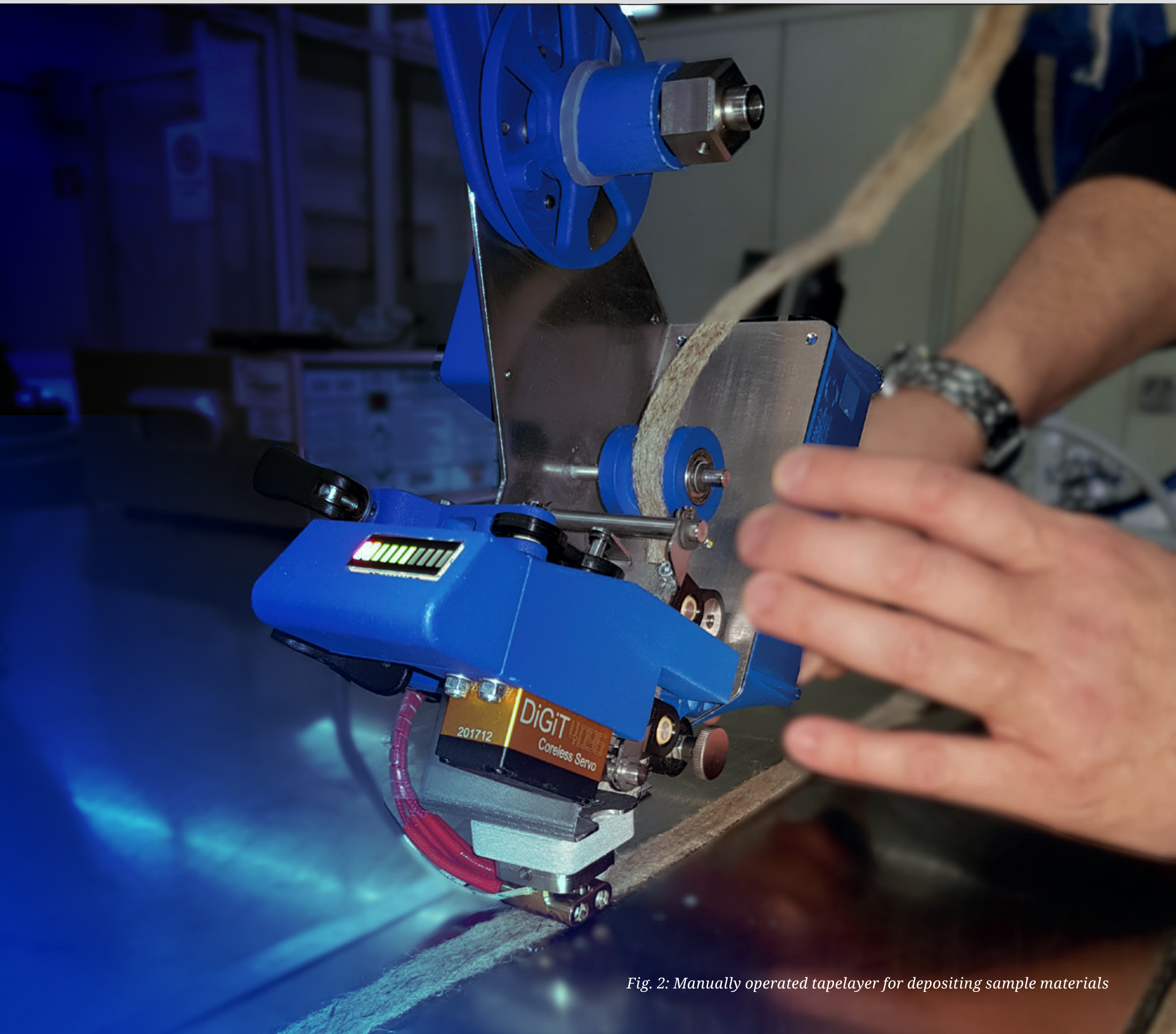


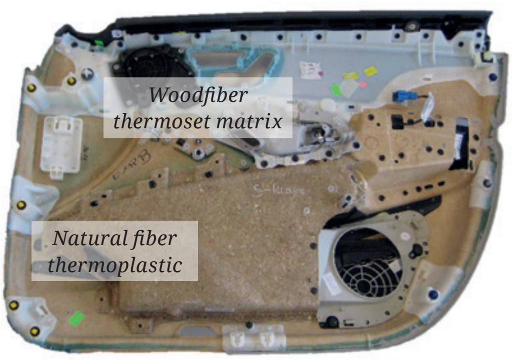

*Fig. 2: Manually operated tapelayer for depositing sample materials*

Here, the fibers are usually present as needled nonwovens and are combined with thermoplastic but sometimes also thermoset matrix systems. The specific mechanical properties of NFRPC are in some cases as good as those of glass fiber-reinforced polymer composites (GFRPC) but do not always fully attain their level. Nevertheless, they have great substitution potential and can already partially replace conventional expensive plastics as well as GFRPC structures today. Flax, hemp and kenaf are mostly used for the production of LFRP semi-finished products.

Compared to conventional reinforcing fibers such as E-glass, natural fibers have the advantage of significantly lower density (ρNF ≈ 1.5 g/cm³; ρGF ≈ 2.5 g/cm³) and thus outstanding lightweight properties. Furthermore, NFRPC are used due to their good mechanical properties, environmental compatibility, $CO_2$-neutral energy footprint, good crash and damping behavior and high dimensional stability.

Polypropylene (PP) is usually used as the thermoplastic matrix. In addition to its monetary advantages, PP has a very low density (~ 0.9 g/cm³), excellent processing properties, good mechanical performance and high impact strength.

In a joint project, Leibniz-Institut für Verbundwerkstoffe (IVW) and Kaiserslautern University of Applied Sciences - Pirmasens site (HS) - are researching the direct production of natural fiber tapes in combination with thermoplastic matrix. The aim of the research is to develop an alternative direct, cost-effective and efficient process for the production of unidirectionally oriented NFRPC semi-finished products, thus saving expensive and time-consuming process steps. At the beginning of the process, natural fibers and PP staple fibers are opened, mixed, homogenized by means of carding and processed into a fiber web. This is then merged to form a narrow strand and processed into a tape by means of a testing rig. In this tape, the fibers are aligned in the longitudinal direction of the tape and can then be laid down to form test specimen plates by means of a manual tapelayer (see Fig. 2). In the further progress of the project, the impregnation and depositing process will be optimized, mechanical parameters will be determined and tapes will be used for local reinforcement of components.



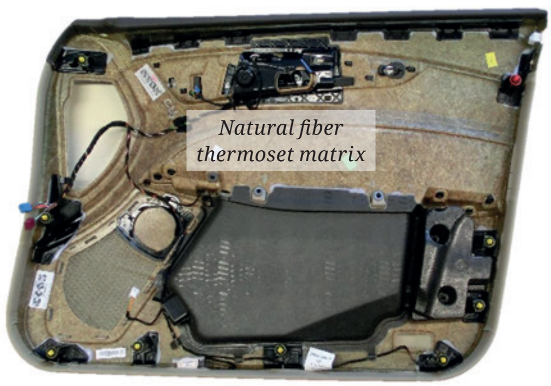




*Abb. 1: NFRPC door panel based on needled nonwoven*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INSTITUT FÜR TEXTILTECHNIK OF RWTH AACHEN UNIVERSITY ITA

# Development of bio-based thermoplastic natural fibre prepregs – BIO-YARN-COAT

*Natural fibres have comparable weight-specific mechanical properties to glass fibres, are locally available in Europe and have a neutral carbon footprint in cultivation. However, due to restrictions in the fibre digestion processes, only about 7 % of the harvested material can currently be processed into long fibres for the production of textile high-performance semi-finished products for fibre-reinforced plastics (FRPs).*

*Authors: Dr. Till Quadflieg, Lars Wollert, Carsten Uthemann, Prof. Thomas Gries*


The cost of these fibres is about 6 €/kg, which is significantly higher than that of glass fibres (2-3 €/kg). Substituting 5 % of the current annual production volume of glass fibre reinforced plastics (GRP) with natural fibre reinforced plastics (NFRP) could save up to 2.66 million tonnes of $CO_2$ per year and generate an annual turnover of up to 81.5 million € for German SMEs.

The aim of the Bio-Yarn-Coat project is to create the necessary conditions for the use of NFRPs with bio-based thermoplastic matrix systems in lightweight fibre composite construction. For this purpose, an innovative melt impregnation process for coating yarns is being developed using flax fibre yarns and polyamide 11 (PA 11) as examples.

Increasing ecological requirements are leading to the increasing use of bio-based matrix systems in addition to fibre materials. Biobased thermoplastics in particular offer the possibility of using plant-based resources. The use of thermoplastics in FRPs is limited by the low decomposition temperature of the natural fibres and the associated degradation of the mechanical properties. In addition, the high viscosity of thermoplastics is a key hurdle in impregnation. Therefore, in the impregnation and consolidation process, minimum flow paths and the lowest possible temperatures and exposure times should be aimed for. In order to ensure the use of natural fibres in sustainable and fully bio-based FRPs with high mechanical properties, further development of impregnation and consolidation processes is therefore required in particular.

Within the project, the basic working principle of impregnation is being researched. The aim is to improve impregnation with high-viscosity matrices by expanding the yarn by means of twisting during coating. This is investigated using a flax fibre yarn in combination with PA11 and the subsequent fabric production. The coating process is explicitly designed to reduce thermal damage to the natural fibres. This is achieved by minimising the contact time of the fibres with the hot polymer melt. Temporarily reducing the yarn twist during the coating process allows the polymer to penetrate the yarn structure. Renewed application of the yarn twist causes the yarn to be

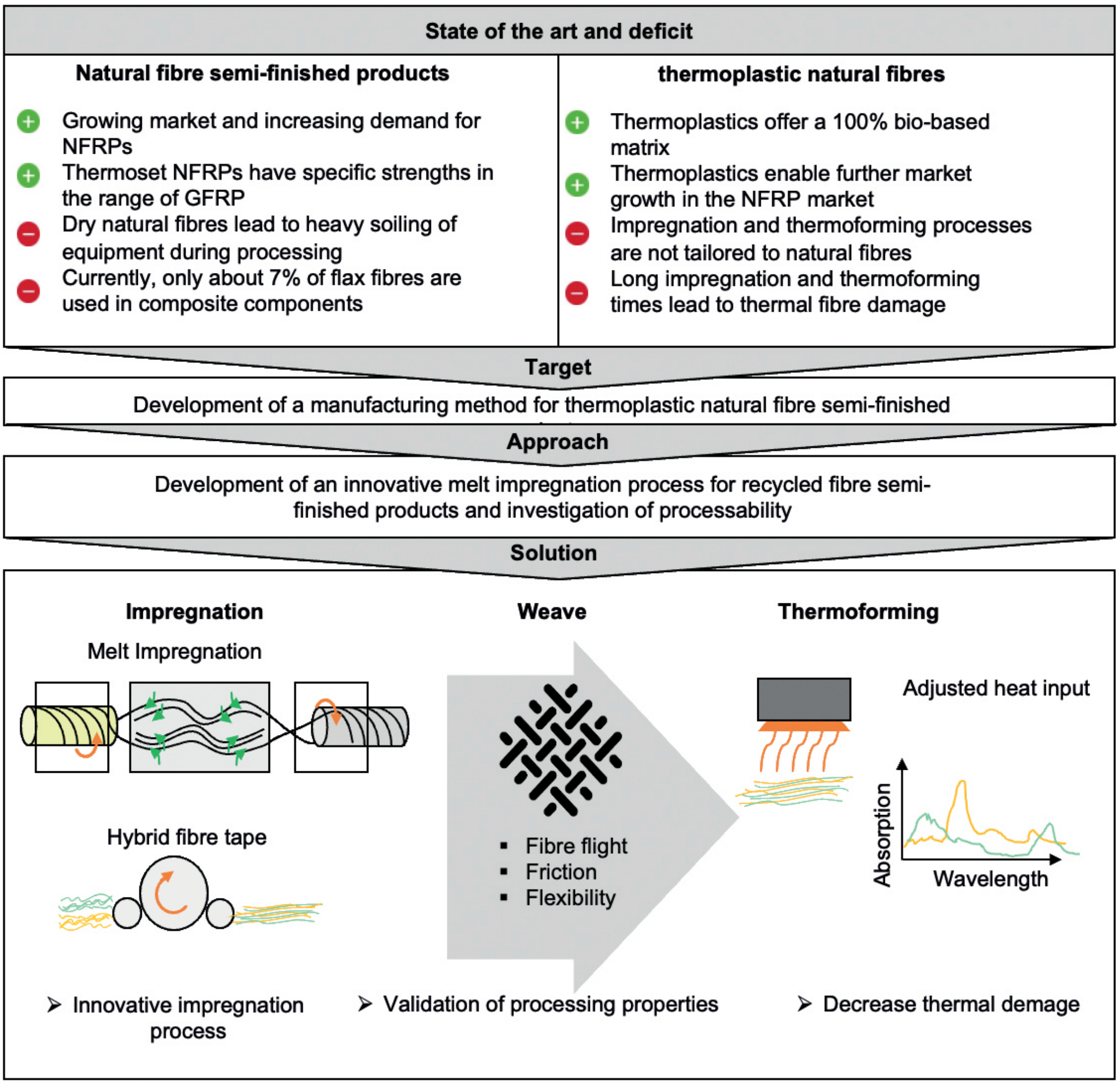
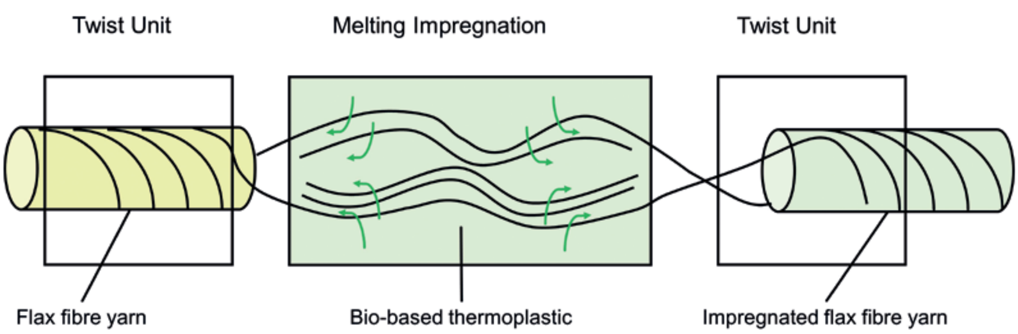



*Fig. 1: Mission statement of the project*

compacted up to a predefined fibre volume content.

Due to the very thin coating, the yarns are still flexible and can be processed into textile semi-finished products using common textile processes (e.g. weaving). In the present project, natural fibre yarns made from recycled fibres are to be used, which can significantly reduce material costs. The thermoplastic coating contributes to a reduction of fibre friction and damage in the weaving process and thus to a lower incidence of fibre fly. Cleaning and maintenance intervals can thus be significantly reduced. In contrast to fully consolidated thermoplastic FRP sheets (organic sheets), the semi-finished products produced have a textile character, which enables comparable forming properties as in the processing of thermoset pre-impregnated semi-finished products (prepregs). The semi-finished products can therefore be further processed



into complex LFRP components by hot forming. Due to the complete impregnation, the performance potential of the natural fibres is transferred to the composite material in the best possible way. The aim is to produce fibres including matrix below the current price of dry flax fibres and to offer comparable mechanical performance in the component.

The new process is characterised by the possibility of targeted energy input and short flow paths, which significantly reduces the thermal degradation of the natural fibre. The knowledge gained can be applied specifically to other material combinations (hemp, jute, PP, PA6) or alternative further processing routes (scrims, tailored fibre placement) in bilateral projects (e.g. ZIM) with the SMEs involved.

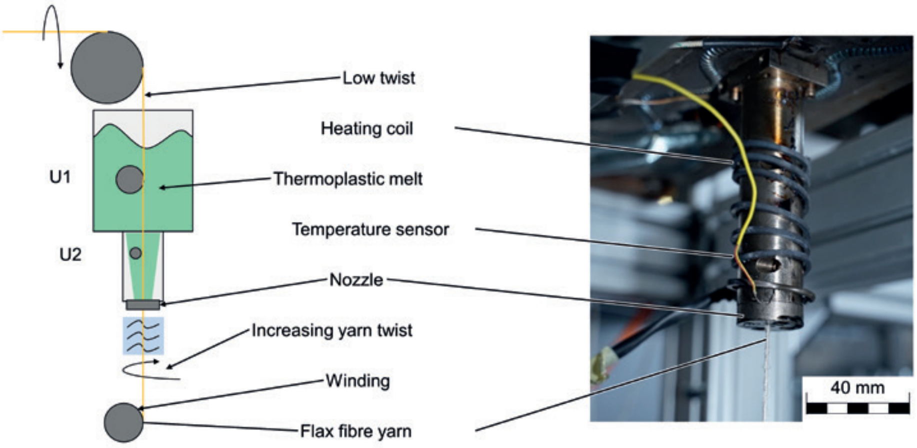



*Fig. 2: Bio-Yarn-Coat principle sketch*

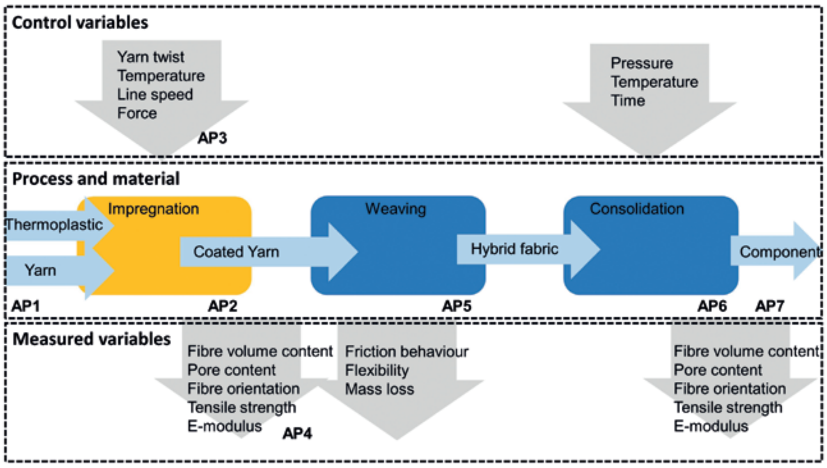



*Fig. 3: Process chain for thermoplastic NRP*

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INSTITUT FÜR TEXTILTECHNIK OF RWTH AACHEN UNIVERSITY ITA

# Pultrusion of fiber-reinforced thermoplastic profiles – RESEARCH AREAS, PROJECTS AND VISIONS

*Authors: Patrick Pasberg, Dominik Granich*

Pultrusion is a continuous process of processing plastics and is used to manufacture continuously fiber-reinforced semi-finished products. Thermosets are usually used as the matrix material. Thermoplastic composites, on the other hand, are rarely used, despite their many advantages. For example, if the thermoset is replaced by a thermoplastic, it is possible to recycle the semi-finished product. In particular, the possibility of post-processing such parts as joining and forming by, for example, bending the semi-finished product are of enormous potential for a wide variety of applications. A broad portfolio of applications is already offered by pultruded profiles in the automotive, construction, energy, marine and architectural sectors. Thermoplastic profiles with their low weight coupled with high strength and impact resistance would ideally expand the application profile here with these advantages.

*Fig. 1: Pultrusion plant*

At the Institut für Textiltechnik (ITA) of RWTH Aachen University, a pultrusion system has been developed that can continuously produce fiber-reinforced, thermoplastic semi-finished products with the aid of hybrid yarns. The hybrid yarns are unwound via a creel and drawn into a heating tool. Here, the matrix material is heated above the melting point to consolidate it with the reinforcing fibers. This technique minimizes the flow paths of the thermoplastic and prevents agglomeration. Last, it is drawn off after the pultrudate has cooled and can be cut to defined lengths. In addition to contact heating for materials such as glass, aramid and natural fibers, it is also possible at ITA to produce CFRP-profiles by means of induction. Here, the semi-finished product is heated from the inside, thus ensuring that the melt forms uniformly in the semi-finished product.

In addition to solid and hollow sections with unidirectional fiber orientation, braided and wound tubes made of hybrid yarn can also be consolidated at ITA. By adjusting the fiber angle as well as the choice of materials, semi-finished products can be produced here according to their application.

In current and future projects, it is planned to expand the heating equipment so that, among other things, a hybrid of PEEK and reinforcing fiber can be consolidated. Open to new applications and possible uses, the transition from laboratory scale to series production is currently in process. Forming tests and the joining of pultruded semi-finished products with subsequent mechanical testing are intended to reflect the range of possible applications and provide information about the load-bearing capacity during use.

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LEIBNIZ-INSTITUT FÜR VERBUNDWERKSTOFFE IVW

# HyBe in FRPC world

*Fiber-reinforced thermoplastics (TP-FRPC) are characterized not only by their fast processability and lower weight but also by good recyclability, making them an important alternative to thermoset FRPC.*

*Authors: Stefan Weidmann, Prof. Peter Mitschang*

These properties qualify TP-FRPC for a large number of lightweight applications, including the automotive industry. One way to optimize the properties of TP-FRPC components in terms of application is to combine them with metals. For example, metallic force introduction elements can be applied to TP-FRPC components by the use of suitable hybrid joining processes (Figure 1). In particular, hybrid joints that allow homogeneous force introduction lead to higher overall strenght of the component, which in turn can reduce the overall weight as a result of synergy effects.

HyBe is a current research project dedicated to the development of a fully automated joining process for the rapid and quality-assured joining of metallic fasteners to TP-FRPC components. The aim of the project is to develop an enabling technology that allows automated, digitized and energy-efficient inductive hybrid joining. By significantly reducing the cycle time using finite element methods to optimize energy input (Figure 2), in-line quality assurance, redundant process control and digital process chain modeling, the process will be taken to industrial maturity as a prototype. Metallic screw fasteners with a round connection surface are used as force introduction elements. The rotationally symmetrical geometry is particularly suitable for induction heating, whereby heating times of less than 5 seconds are achieved. After the fasteners have been picked up by the end effector (Figure 3), which can also be mounted on a robot, they are transported in a targeted manner to the joining position on the TP-FRPC component and joined. By using bonding agents (specifically

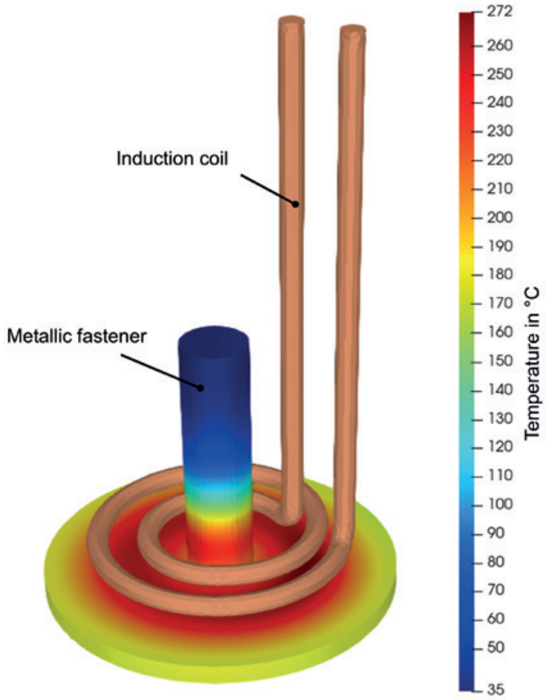


*Fig. 2: Heating behavior simulation of the metallic fastener by the alternating electromagnetic field*

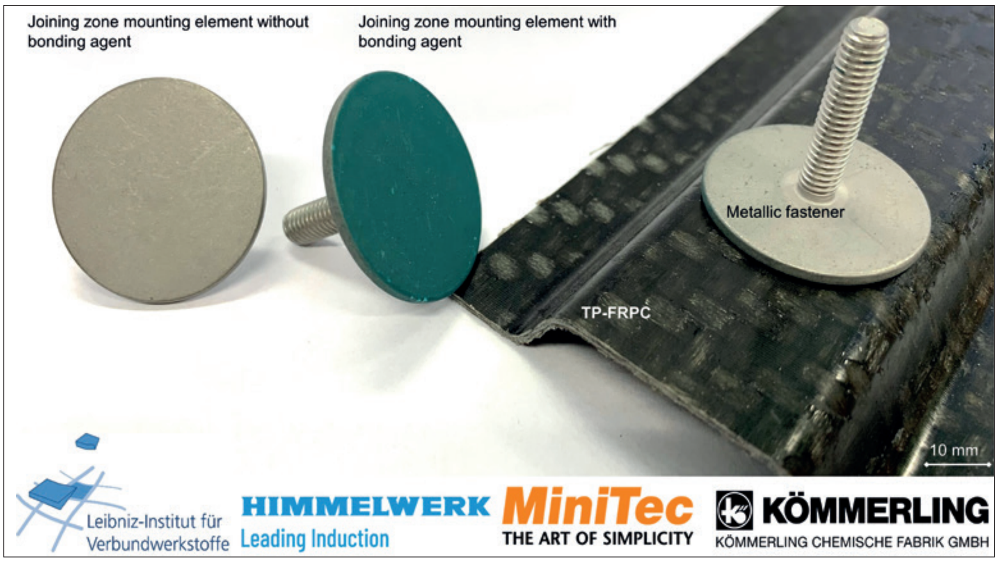


*Fig. 1: Metallic fastener with flat joining zone for homogeneous introduction of forces into the TP-FRPC*

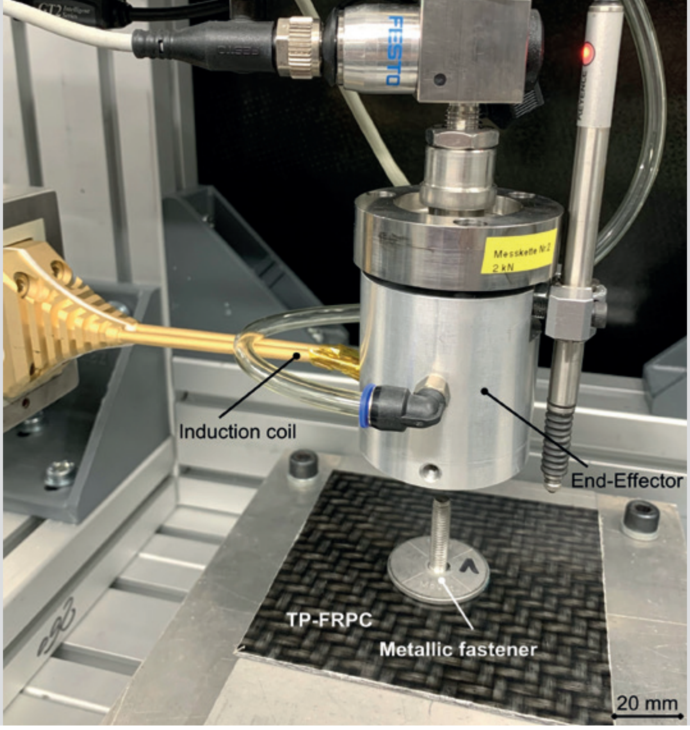


*Fig. 3: End effector at laboratory scale as a basis for further development to industrial scale and process optimizations*

developed for the project) on the joining surface of the fasteners, high joint strengths can be achieved even with matrix polymers such as polypropylene that are difficult to bond. In case of a hybrid joint of glass-fiber-reinforced polypropylene with steel, these are around 14 MPa (DIN1465) and thus exceed the strengths of conventional adhesives and TP-FRPC/metal joints. In addition, the fasteners coated with bonding agent are characterized by their uncomplicated processing and storage, e.g. in bulk form. Due to their industrial relevance, hybrid joints with fiber-reinforced ABS are also being investigated and optimized in the project.

In addition to process development, the characterization of the hybrid joints by means of material examples and studies on long-term durability is also an important part of HyBe project.

In the further course of the project, process time, energy input as well as bonding agents of the fasteners will be further optimized. Thanks to the close cooperation between the three industrial partners and Leibniz-Institut für Verbundwerkstoffe (IVW), a novel hybrid joining process that can be applied across all industries is being developed.

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FASERINSTITUT BREMEN E. V.

# THERMOPLASTIC COMPOSITES

## *Innovative applications and processes – HyFrame*

*Authors: P. Schwanemann, P. Schiebel, Faserinstitut Bremen e. V., Bremen, C. Sigolotto, ACE Advanced Composite Engineering GmbH, Salem M. Mechelhoff, MERKUTEC GmbH & Co. KG, Dinklage, Germany, D. Feltin, Hightex Verstärkungsstrukturen GmbH, Klipphausen, B. Staaks, SAERTEX GmbH & Co. KG, Saerbeck, Germany, R. Held, Megatherm Elektromaschinenbau GmbH, Hemer*

The textile processing of hybrid yarns by means of Tailored Fiber Placement (TFP) enables load-compliant preforms to be produced and further processed into complex structural components. The thermoplastic matrix of the structures then enables functionalization by means of injection molding (overmolding) and welding. This technological approach allows a significant reduction in production time and a reduction in component mass, and thus in emissions during the service life, compared with an RTM design of the same component.

In order to exploit the potential of the construction method described, a process chain was set up at the Faserinstitut Bremen e.V. in cooperation with industrial partners in the HyFrame project and an aircraft window frame was manufactured as a demonstrator structure.

The basis for this demonstrator structure is a hybrid yarn specifically developed for this application consisting of T700 carbon fibers from Toray Industries, Inc. and LM-PAEK fibers from Victrex Europa GmbH. The hybrid yarn production was followed by processing into the structural insert preform. Multiaxial fabrics (MAG) were processed as base material for local tailoring with UD layers via TFP. The major advantage of preforming with MAG over the TFP solution is the higher lay-up rate of the process. The subsequent consolidation of the preforms took place in a two-stage isothermal compression mold, which was equipped with a forming tool that goes through the consolidation process variothermally. After consolidation, the structural inserts can be stored or directly overmolded. Overmolding with short-fiber-reinforced PEEK enables integral stiffeners or functional elements to be integrated, which would be much more costly using continuous-fiber reinforcement. The cost-effectiveness of the process increases significantly here.

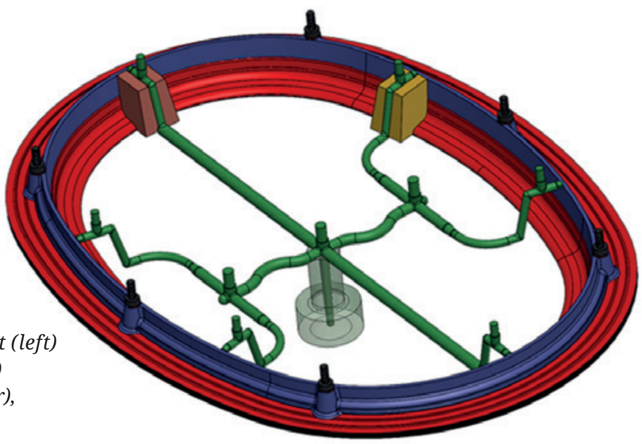
The window frame produced in this way can then be inductively welded into a fuselage skin.

The project has demonstrated that the use of high-strength thermoplastic materials can be used to manufacture geometrically complex primary structures for aerospace applications in high volumes in a lightweight and economical manner.

Gefördert durch:

Bundesministerium für Wirtschaft und Klimaschutz

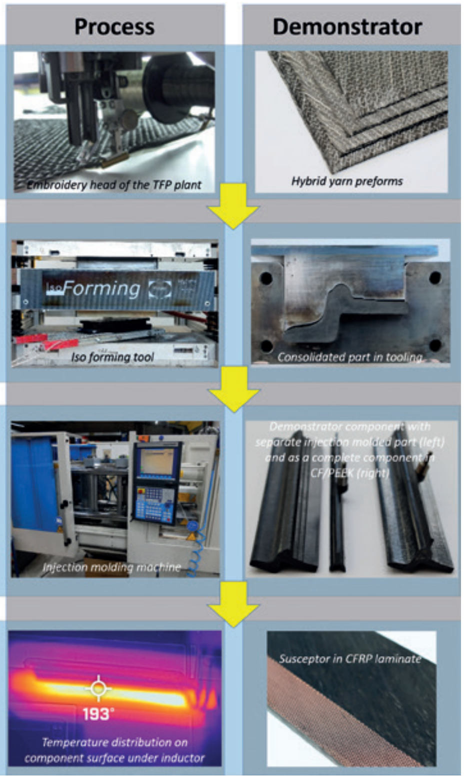
aufgrund eines Beschlusses des Deutschen Bundestages



*Component design with injection moulding gating concept (left) and Total window frame (outside) and straight test structure (center), with the same structure (right)*

## PROCESS CHAIN

| | |
|---|---|
| **Preforming** | First, a hybrid yarn was produced consisting of carbon (TORAY T700) and polymer (Victrex A250 PAEK) fibers. These hybrid yarns were processed into a multiaxial fabric, which was selectively thickened with UD layers by using Tailored Fibre Placement. |
| **Consolidation** | In order to keep the cycle time of the consolidation process as short as possible, a temperature control mold was developed which outsources the heating and cooling functions form the forming mold, resulting in a consolidation time of less than 20 min. |
| **Overmoulding** | The functionalization of continuous fiber reinforced structures was implemented by using injection molding.<br>Here, the AE250 matrix of the structural part was combined with a 90HMF40 injection molding granulate. |
| **Welding** | For induction welding, a stationary inductor was developed and a susceptor made of perforated copper foil was inserted in the joining zone for focused heating. |




*In HyFrame and ThermoTwin investigated process chain*

The process chain under consideration is being investigated in a further research project with regard to quality assurance and adaptive process control (ThermoTwin). For this purpose, the individual process steps will be sensorized and the measured parameters recorded in a digital twin. In addition, the process chain will be compared ecologically in order to determine the reduction in emissions in production and in the use and end-of-life phases.

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# THERMOPLASTIC BATTERY HOUSINGS FOR USE IN ELECTROMOBILITY

INSTITUTE FOR PLASTICS PROCESSING (IKV) IN INDUSTRY AND CRAFT AT RWTH AACHEN UNIVERSITY

# Thermoplastic composites – A CONTRIBUTION TO THE MOBILITY EVOLUTION

*Authors: Frederik Block, M.Sc.; Dominik Foerges, M.Sc.; Prof. Dr.-Ing. Christian Hopmann*

Electromobility for individual transport accounts for a large share of the developments in the mobility transition. The focus here is particularly on the integration of high-capacity battery systems in the vehicle underbody. The high mechanical demands on this component result in a high total weight of the battery system. Fibre-reinforced plastics have the potential to combine high mechanical properties with low weight. The aim is to develop a plastic battery housing that can absorb the small- and large-area loads that occur while at the same time keeping its own weight low. Further requirements regarding thermal management and shielding against electromagnetic radiation are to be addressed.

A solution approach for the production of large-volume battery systems was developed in cooperation with the project partners as part of the LightMat Battery Housing research project (EFRE-0801509). For the hybridisation of thermoplastic long-fibre-reinforced plastics (LFT) in the compression moulding process with continuous-fibre-reinforced semi-finished products (organosheet and unidirectional fibre-reinforced (UD) tapes), the process chain shown in Fig. 1 was used at the IKV. For the production of hybrid sheet components, the LFT plastic was pressed with preheated thermoplastic continuous

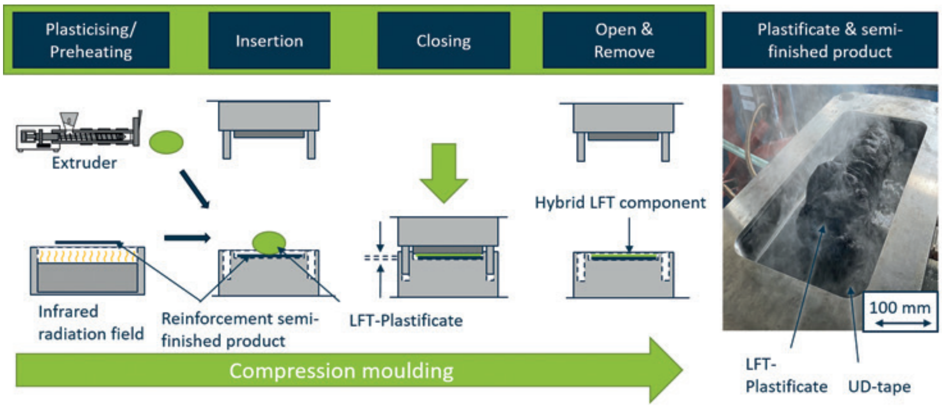


*Fig. 1: Schematic representation of the process chain for the production of hybrid LFT panel components in the compression moulding process at the IKV to characterise the process influences as well as the material combinations.*

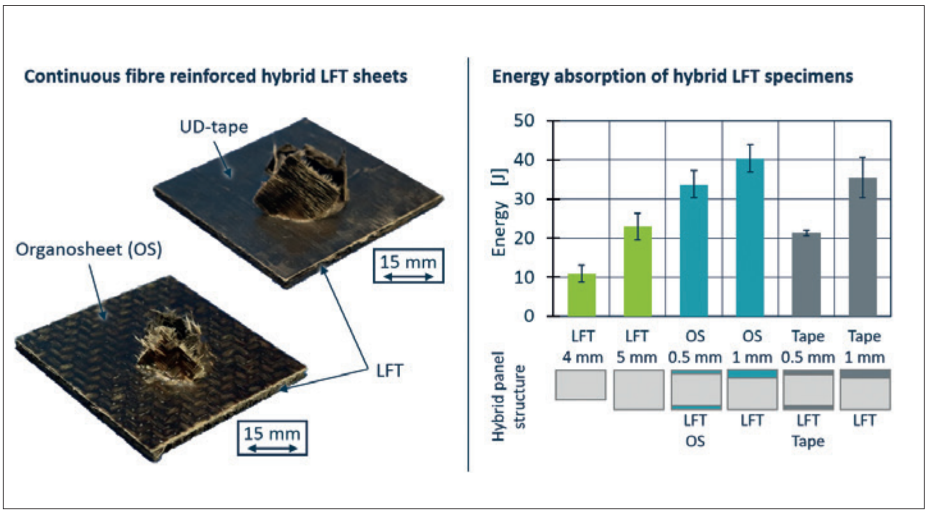


*Fig. 2: Use of thermoplastic continuous fibre reinforcements to increase energy absorption capacity (LFT: polyamide 6 & GF45)*

fibre reinforcements of the same type. The characterisation of the material and the process adjustment were carried out based on plate components. The potential of targeted reinforcement with UD tape laminates or organosheet is exemplarily shown in Fig. 2. By using organosheets, an increase in energy absorption of approx. 45 % could be achieved compared to pure LFT material. The findings of the investigations were used for the design and construction as well as for the validation of the structural simulation of a near-series demonstrator by the project partner PART Engineering GmbH. The knowledge gained was used by the project partner Kautex Textron GmbH & Co. KG, which produced a scaled version of a battery housing with full functional integration for use as an energy storage device in the underbody of an electric vehicle during the project. The demonstrator is formed as a hybrid component with metallic inserts and reinforcement with organosheet and UD tape structures (Fig. 3). The targeted use of UD tape structures allows the underbody to be stiffened to protect the battery cells from critical loads during an impact event. Organosheets in reinforcement structures showed the potential to improve the load distribution and thus the protection of the battery cells in the event of an impact. In further tests at component level, the near-series demonstrator was crash and impact tested at the Kautex Textron GmbH & Co. KG for further validation.

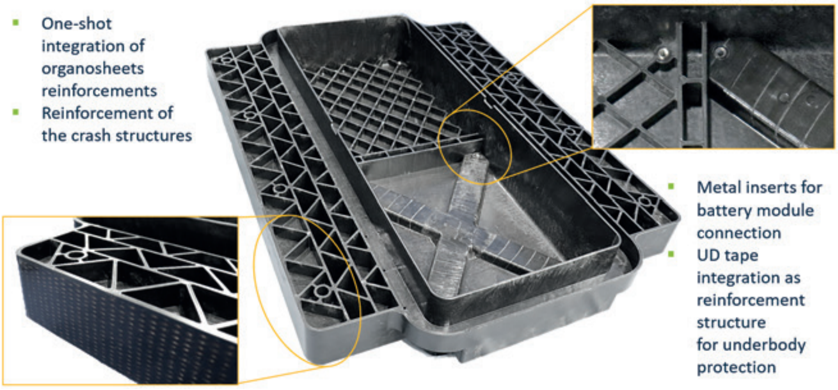


*Fig. 3: Demonstration component "battery housing" consisting of glass fibre-reinforced polyamide 6 (LFT) with thermoplastic continuous glass fibre reinforcement (UD tape structures and organosheet) and metallic functional elements produced in the D-LFT extrusion process.*

## ACKNOWLEDGEMENTS

The project "Development of functionalised, unidirectional fibre-reinforced semi-finished products for the large-scale production of novel, highly stressed plastic battery housings for electric vehicles" with the funding code EFRE-0801509 is funded by the European Regional Development Fund (ERDF). We would like to take this opportunity to express our thanks for the funding and support.

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### ABOUT THE IKV

The IKV is a research institute whose aim is to transfer the results of plastics technology research into the practice of industrial partners. The IKV is happy to help you with problems and development tasks in the field of "lightweight construction".

CHEMNITZ UNIVERSITY OF TECHNOLOGY –
INSTITUTE OF LIGHTWEIGHT STRUCTURES

# Development of a door structure made with thermoplastic composite construction for AUTOMOTIVE APPLICATIONS

*Authors: Dr. Jens Emmrich, Markus Layer, Prof. Wolfgang Nendel*

In the thermoPre® plus growth core, a door structure is developed by Chemnitz University of Technology, Elring-Klinger AG, the mold and tool maker Gebrüder Ficker GmbH, Mitsubishi Chemical Advanced Materials Composites GmbH and Fraunhofer IWU-STEX with application of continuous fiber reinforced thermoplastic materials.

The basis is formed also in thermoPre® plus, the newly developed, patented systems by Cetex Institut gGmbH for the production of final-contoured semi-finished textile products with load-oriented fiber orientation, the "effiLOAD technology". The effiLOAD preform is prospective produced in a fully automated, continuous "roll-to-roll" process. Half of it is made of a multi-layer stack of glass-fibre reinforced ThermoPre®-PA6 tapes and half of it is made of PA6-CF tapes that are locally suitable for the load path (Fig. 1 & 2).

The mirror-symmetrical arrangement of the halves to form the complete effiLOAD preform leads to a two-zone structure with near-net-shape, load-oriented fiber orientation and resource-efficient use of the carbon fibers placed in the middle. This structure leads to the effective use of glass fiber reinforced tapes in the hinge area subject to high loads and their reduction in areas subject to less stress. As a result, the volume fraction of the tapes was reduced by 46% compared to standard preforms, e.g. organo sheets.

The effiLOAD preform is processed using both hybrid injection molding and compression molding to create the load-bearing inner shell of the door (Fig. 3). Inserts made of sheet steel are implemented in the hinge area. The paintable interface to the exterior of the vehicle is realised in the subsequent process step by a bonded, non-load-bearing plastic panel (Fig. 4).

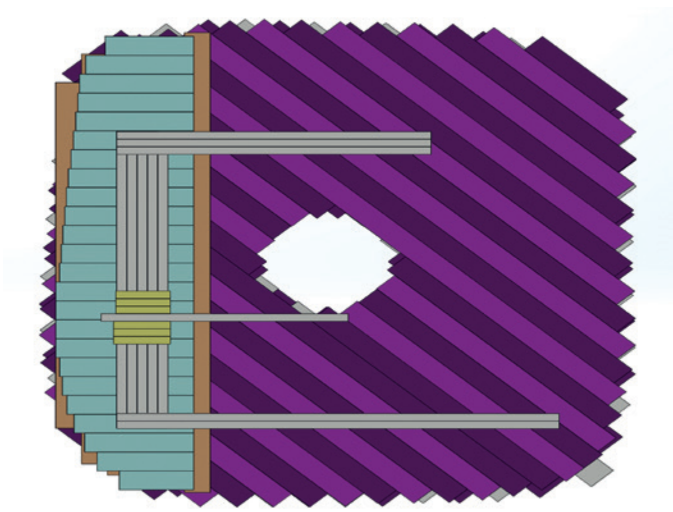

*Fig. 1: Half of the effiLOAD-preform for the demonstrator omponentl*

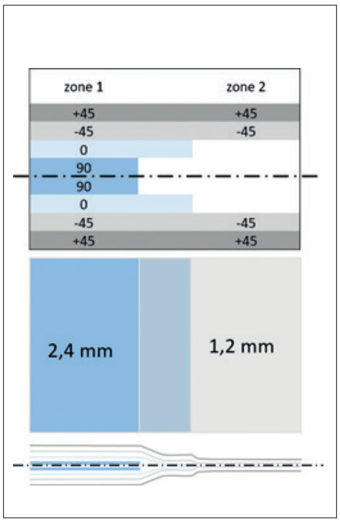


*Fig. 2: Mirror-symmetrical structure of the effiLOAD-Preform*

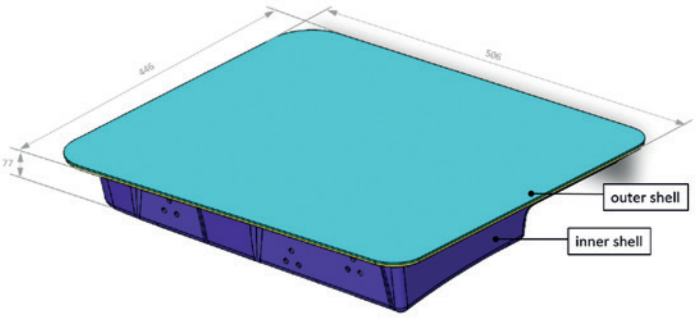


*Fig. 3: Complete door structure made of thermoplastic composite*

*Fig. 4: Painted outer shell of the composite door structure*

The mounting interfaces for the lock, rear window wiper and more are provided in the Inner shell (Fig. 5). The PA6-GF30 injection molded body shown in Fig. 6 consists of ribbing, trimming and screw boss.

The dimensioning was carried out using FEM based on defined load cases (injection molded body: "Van Mises" criterion, effiLOAD preform: interfiber fracture criterion according to Puck application). All simulations were approved on the test bench in the relevant load cases.

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*Fig. 5: Inner shell (outside view)*

*Fig. 6: Inner shell (inside view)*

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