

MoPaHyb - Modular Production Plant For Hybrid High-Performance Composites

*M.Sc. Tobias Joppich, M.Sc. Sascha Kilian, Prof. Dr. Frank Henning
Fraunhofer Institute for Chemical Technology ICT, Polymer Engineering / Injection and
Compression Molding
Joseph-von-Fraunhofer-Str. 7, 76327 Pfinztal, Germany*

Abstract

Hybrid components based on a multi-material approach are one of the most promising lightweight technologies for structural applications. However, current batch sizes, part derivatization and plant investment costs for individual products reduce economic feasibility and thus inhibit transfer to series application.

Within the MoPaHyb project, fourteen partners developed a modular and reconfigurable production plant generation which allows easy adaptation to produce a wide spectrum of individual hybrid components, also taking into account economic targets. The key is a plug & work architecture that connects production modules to a base control unit. The engineering language AML and the communication interface OPC UA with unified status models are used as standardized communication channels. A reference production plant including the cutting edge technologies of tape placement, press forming, long fiber injection molding as well as metal working, laser treatment and insert provision was set up to demonstrate the new plant generation. The concept has been validated by means of two different demonstrator parts and several hundred produced parts, also taking into account modular safety aspects and integrated quality assurance.

Background and Requirements

Many research activities, especially in the automotive and supply industry, are currently driven by overarching trends such as increasing energy and resource efficiency as well as the internet of things [1]. This is due to increasing dynamic product cycles, variant diversity and smaller batch sizes which lead to the economic and competitive challenges that many companies are currently facing [2].

One highly promising approach to save weight and therefore energy is the utilization of new lightweight material combinations. By combining fiber-reinforced plastics (FRPs) with metallic components, high-performance hybrid structures can be achieved [3]. These unite several advantages of the individual materials and exhibit the properties of the single components [4] [5]. When these composites are produced in a single step process through direct forming and over-molding processes, they are commonly referred to as intrinsic hybrids. The advantages of such a process layout are the reduction of additional joining operations and dependent processes. Additionally, integrated functions and potential component substitutions may be achieved.

However, the production of intrinsic hybrids poses significant challenges to the industry. Mechanical engineering and plant construction approaches have not yet achieved economically viable production plants for this growing market that can also meet the specific requirements for processing or integrating FRPs and metallic structures. The manufacturing process has so far been adapted to component-specific requirements, or carried out on specialized and investment-intensive production lines. The industry asks for high flexibility and modularity, and ultimately economical production lines for this kind of construction material. To achieve this aim

the publicly funded “MoPaHyb” project was initiated.

Control architecture

The key to the newly developed modular production plant is a service-oriented architecture (SOA) implemented within a centralized base control unit in combination with several production modules. A unique feature of the approach is that each production module can be operated as a stand-alone production unit. As a result it is possible to separate the module engineering from setting up the production line. Nevertheless, it is obvious that a standardized communication interface is mandatory to assure smooth operation of the system. This includes a standardized status model, safety protocol and control interface.

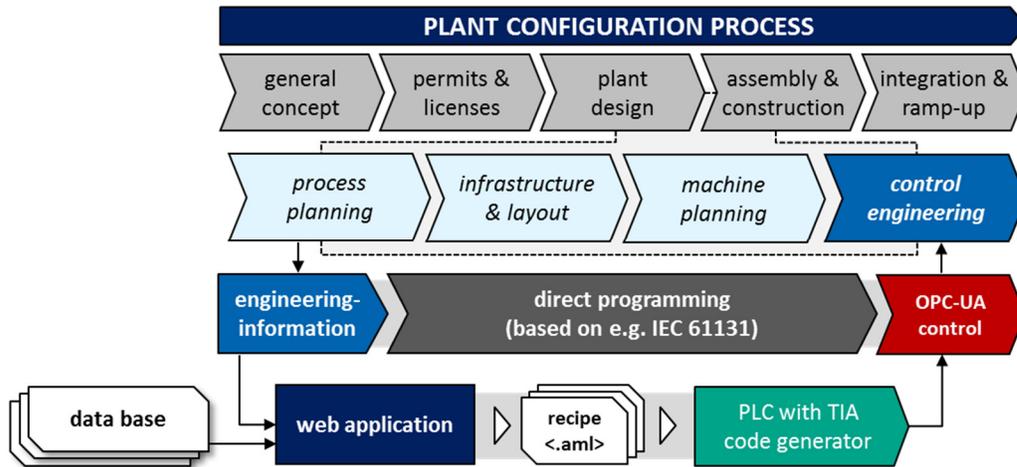


Figure 1 Plant configuration process [6]

Service-oriented architecture

Compared to classic production line coding, service-oriented architectures separate the coding process from the line setup itself. It is therefore possible to implement an offline engineering step to set up the overall production line. This was achieved within the project in the so called “*module kit*”, which is an operating-system-independent interactive web application.

All functions offered by a production module are capsuled in services. Hereby it is possible to separate and secure the know-how included in the machine source code, as this is not needed to setup the overall production process. Furthermore, each module supplier can take individual decisions about the granularity of services they offer to customers. As an example, an injection molding equipment supplier could either offer the services of “*plasticization*”, “*injection*”, “*cooling*” and “*demolding*” or all process steps combined within one service “*injection molding*”. Crucial process parameters are individually included in each service, e.g. “*plasticization*” might contain specific process parameters such as *cylinder temperature*, *dosing volume* and *back pressure*.

Production planning and PI sheet generation

The production planning begins using the “*module kit*”. A data base was developed in which module manufacturers describe their production modules including the services the module offers, possible system boundaries and necessary mechanical interfaces. Apart from the module library the data base also contains helpful information such as material data sheets or

manufacturing recommendations to support process engineers.

Depending on the part to be manufactured, the user individually decides which process technologies are needed. Using the interactive user interface it is possible to configure a production line by first selecting feasible production modules and second linking the offered services within the data base. To finalize the production planning, specific process parameters supplement this drag'n drop engineering step. At the end a description in the form of a PI sheet in platform-independent Automation ML is generated. This file contains all information needed, such as necessary production modules, soft- and hardware interface description and process parameters.



Figure 2 Engineering work-flow to set up production line [7]

As soon as the production line is set up in hardware, the PI sheet is used to generate the higher-level line control. The Automation ML file is converted using the code generator developed by Siemens which is specialized for PLCs with TIA.

Communication protocol and unified status model

As a basis for the service-oriented architecture the server-client-principal of the OPC UA (unified architecture – IEC 62541) communication protocol was chosen. Here every production module acts as an OPC UA server and the higher-level line control represented by the basic module as an OPC UA client. The OPC UA interface developed within the project is designed for easy integration into the production modules as a reduced set of 16 additional parameters. These are clustered in “*generalParameters*”, which are the same for each module and “*specificParameters*” which can be designed by each module manufacturer individually.

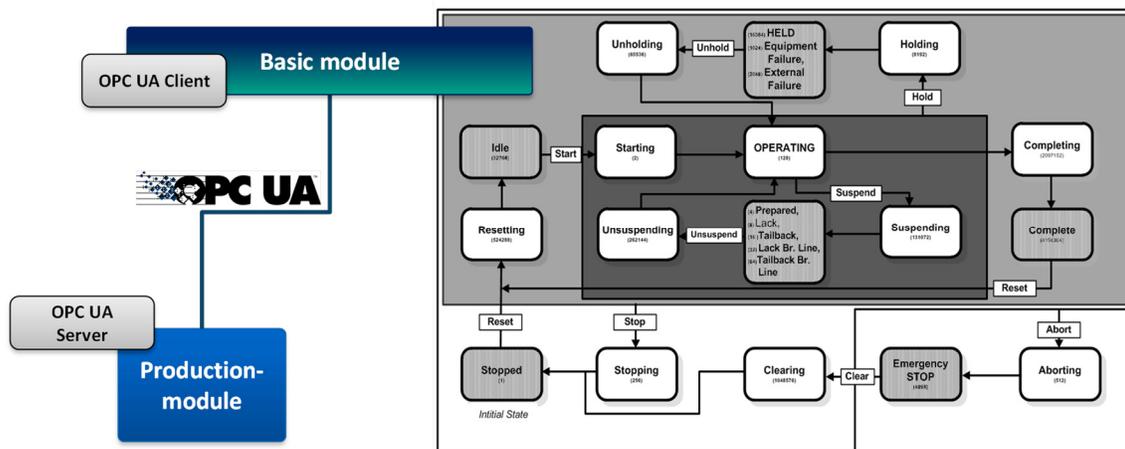


Figure 3 OPC UA communication structure and unified status model [7]

To assure smooth and safe operation of all linked modules, a unified status model according to ISA-88 was implemented which is conterminous with a state based control. To start a service six variables in a certain predefined sequence are written and read using the OPC UA client on the basic module. To start a service the modules need to be in idle state.

Safety

During the project period a focus was set on the adaptability of the new control architecture into industrial applications. One of the main tasks was to integrate a holistic safety concept right from the beginning. As the OPC UA standard is not dedicated to exchanging safety-related data, fail-safe communication in the form of PROFINET IO was chosen and integrated not only into every single production module but also to all software interfaces.

Adaptability of production plant

Through the use of the service-oriented architecture, a re-configuration of an existent production plant to manufacture different parts is simplified. This can be achieved by relocating time consuming engineering and line control coding to an offline tool represented in the MoPaHyb “module kit”. Furthermore the implemented plug’n work architecture allows an easy exchange of production modules within hours. As the automatized code generator is capable of interpreting the PI sheet and uploading it to the line control even faster, the time for commissioning and starting manufacturing can be reduced to a minimum.

Pilot line at Fraunhofer ICT

To show the full potential of the newly developed approach a production process in an industrial scale was chosen. Several production modules were developed and integrated into one highly complex pilot line. Table shows a list of all production modules developed and used to set up a production plant for intrinsic hybrids.

Table I: Modules developed and integrated within pilot line

No. (see Figure 4& Figure 5)	Module name	Function	Manufacturer
1	Tape laying module	production of laminar semi-finished products from composite laminates with patched, local UD tape reinforcement	Dieffenbacher GmbH Maschinen- und Anlagenbau
2	Injection molding module	forming and co-molding of hybrid parts in combination with hydraulic downstroke press from Dieffenbacher	Arburg GmbH + Co KG
3	IR-heating module	heating laminar semi-finished products	KIT-wbk
4	Feeding module for metallic load introduction elements	supply of metallic load introduction elements	A.Raymond GmbH + Co KG
5	Feeding module for metallic reinforcing elements	supply of metallic reinforcing elements	Trumpf GmbH + Co KG
6	Handling module	robot in combination with grippers to handle inlays and inserts	Kuka AG & J. Schmalz GmbH & KIT-wbk
7	Quality assurance modules	process quality monitoring	Vitronic Dr.-Ing. Stein Bildverarbeitungssysteme GmbH
8	Basic module	centralized line control of the reference plant	Siemens AG

Two hybridization technologies – injection molding and compression molding - were the

primary focus of the investigations, both utilizing direct processing of long-fiber thermoplastics (D-LFT). The main process step of intrinsic hybridization is carried out within the mold cavity. For this purpose a clamping unit - in this case a hydraulic press - is obligatory and represents the center point where all materials are combined.

One special feature of the built up pilot line is the integration of conventional equipment in the form of existing plant components, e.g. Dieffenbacher hydraulic press, which were not developed within the project. Through minimal adaptations these could be upgraded to meet the “MoPaHyb communication standard”. This again shows the potential of the developed approach for industrial application.

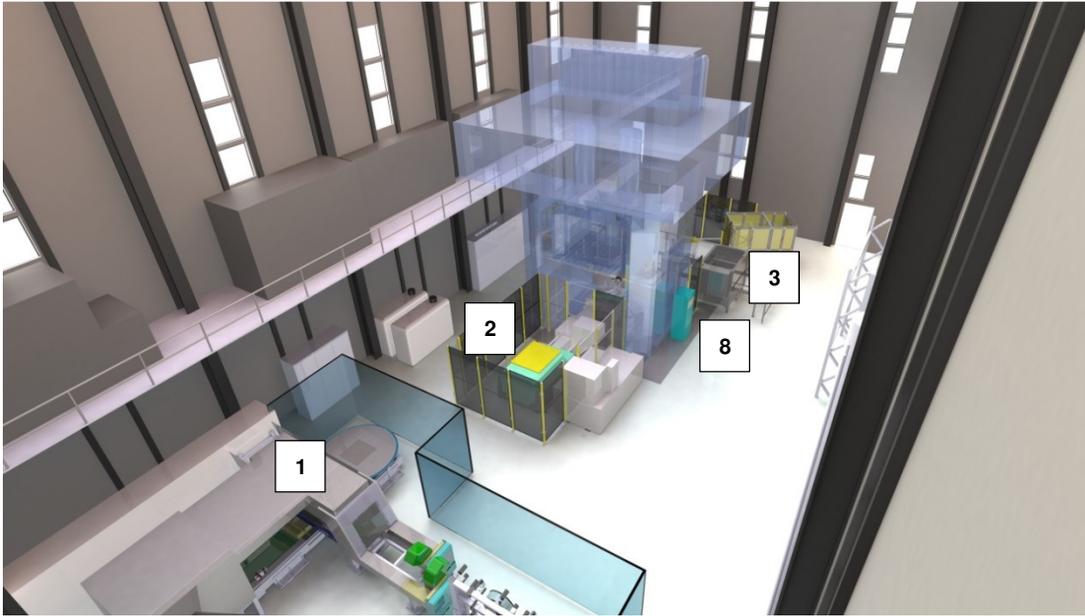


Figure 4: Rendering of pilot plant.

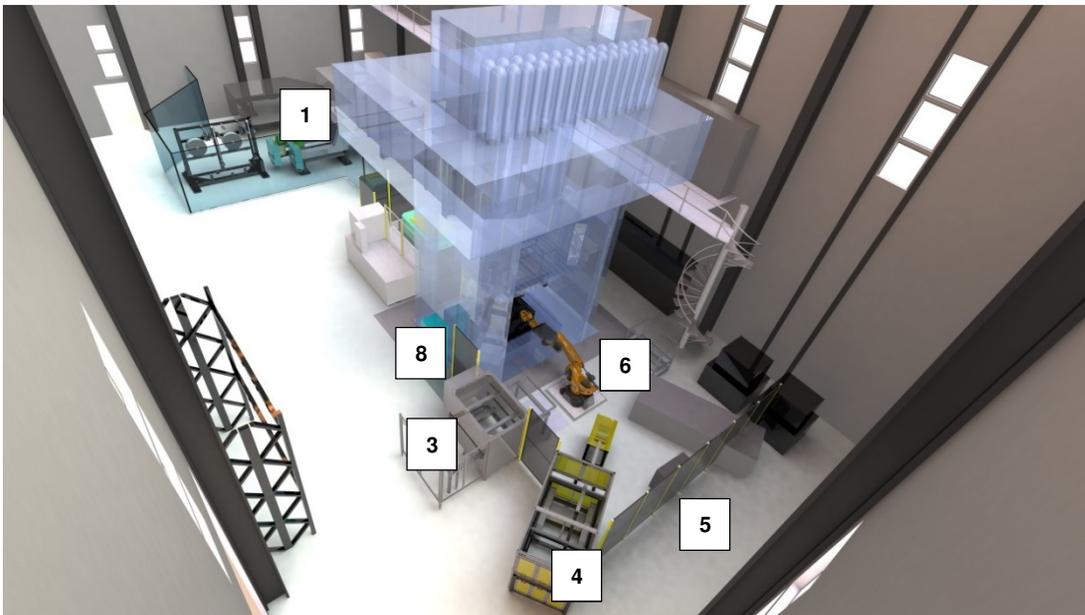


Figure 5: Rendering 2 of pilot plant



Figure 6 Dieffenbacher Fiberforge (left); hydraulic press with bold-on Arburg injection unit (middle); automatized production cell (right)

Demonstration and Validation

In order to show the full potential of the newly developed control architecture and its applicability in terms of manufacturing complex hybrid parts, two different demonstrator parts were chosen. The aim was to exchange not only the geometry of the produced parts but also the necessary production modules and therefore manufacturing processes. On the one hand an automotive seat backrest at which an injection molding process was used as the main hybridization process served to validate the new approach. On the other hand a compression molded substructure of an automotive underfloor was chosen. In this section both process routes as well as demonstrator parts will be introduced.

Seat backrest – process route 1

In the following the individual components of the hybrid seat backrest will be described. The technical design was developed within the preceding also publicly funded project BMBF CAMISMA [8].

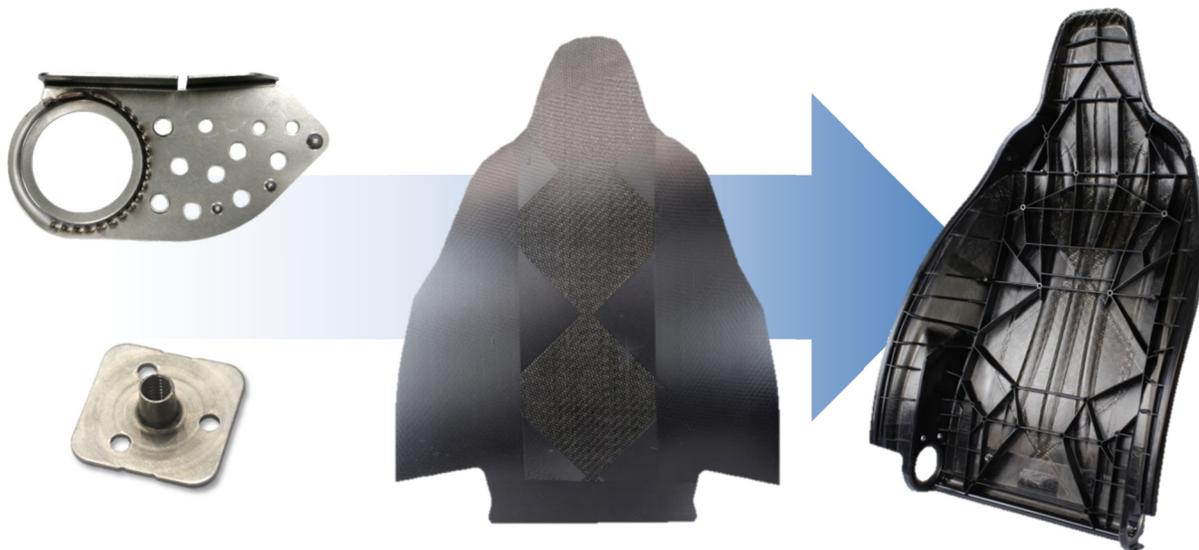


Figure 7 Recliner (top left); load introducing element (bottom left); locally patched organo-sheet (middle); final part with injection molded ribs (right)

The backrest consists of a thermoformed organo-sheet with polyamide 6 matrix and woven glass fabric. This structure is locally patched with unidirectional continuous carbon fiber reinforced tapes (UD tapes) and also with polyamide 6 matrix to strengthen the highest loaded

areas during crash load cases. The tape laying process was carried out using the Dieffenbacher Fiberforge. Furthermore two different metal inserts are integrated. These are firstly two recliners which act as a stiffening structure and load introduction at the connection to the car structure, and secondly load introducing elements with threads to attach further seat structure components. The last component is an injection-molded long-fiber-reinforced thermoplastic (LFT) rib structure for geometrical stiffening, integration of metal inserts and functional integration. The LFT is also used to overmold the edges of thermoformed fabric. It has been produced by utilizing Arburg's FDC unit, a direct compounding unit to reinforce non-reinforced pellet material with fiber rovings.

The described assembly structure defines the necessary process steps and manufacturing processes. Accordingly the following processes and production modules are needed.

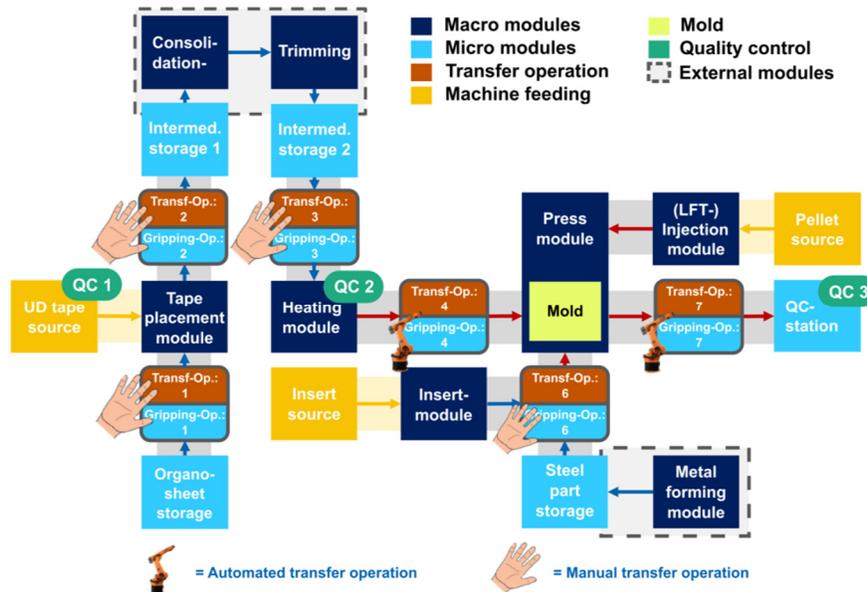


Figure 8 Process route 1 including necessary process steps and modules

Using the MoPaHyb prototype pilot line a total cycle time of 220 s per part in a fully automated production process could be achieved. Further improvements to the handling and gripper system might reduce the cycle time to 2 min or even less.



Automotive underbody segment

The second demonstrator part is a car underbody segment developed within the BMBF MAI qfast project including a stiffening structure made from UD tapes in combination with D-LFT compression molding [9]. It represents the seat attachment with the center tunnel and sill of a car. One major challenge of this structure is a possible displacement of the UD tape structure during mold filling with D-LFT [10]. A constantly controlled temperature management must therefore be used. The transfer of the UD tape laminate from the IR heating oven to the mold is especially important, which is why additional IR-heaters were integrated into the gripper. As D-LFT process equipment for compression molding is commonly set up with twin-screw extruders, this leads to a further challenge. The reason is that twin-screw extruders are based on continuously running processes, whereas thermoforming and compression molding are sequential processes. Nevertheless it is possible to synchronize these processes using the MoPaHyb approach and the service-oriented architecture.



Figure 9: Car underbody subsegment: bottom view (left); top view incl. position of UD tape inlays (right)

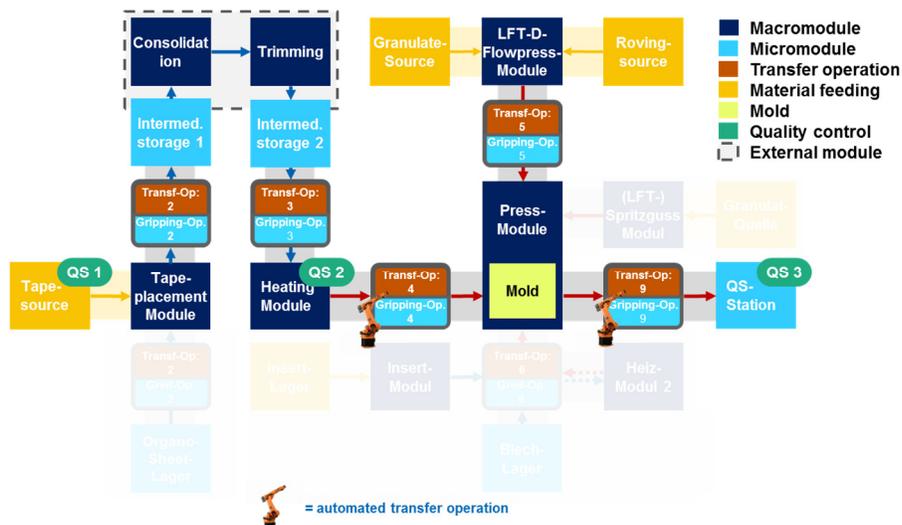


Figure 10: Process route 2 including necessary process steps and modules

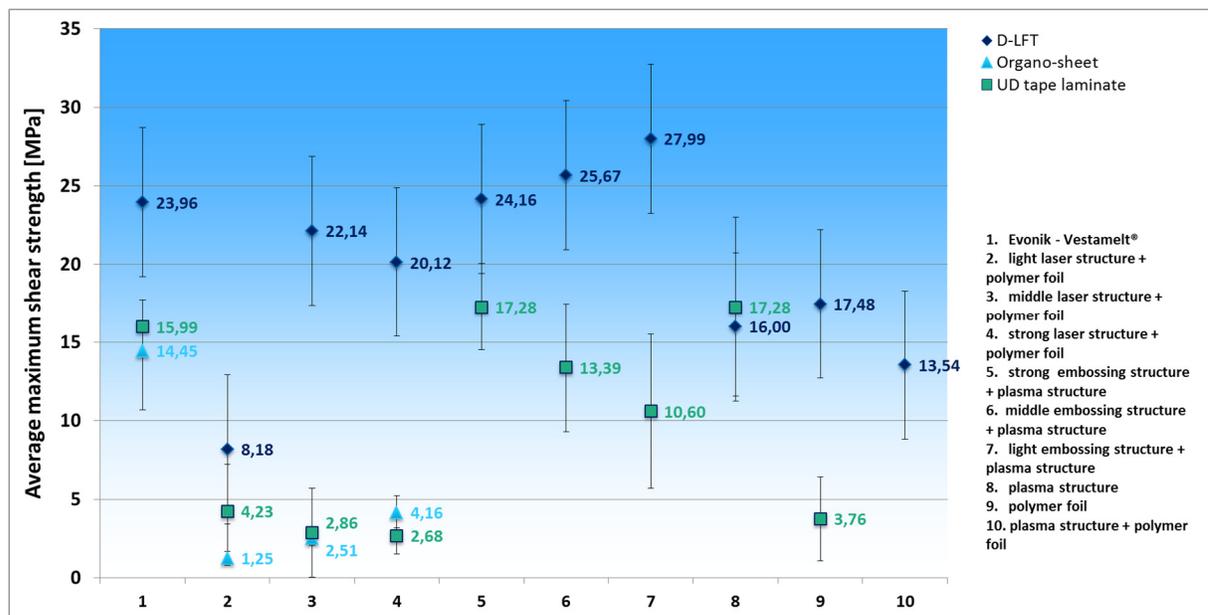
The re-configuration step of a pilot line from process route 2 back to process route 1 including exchanging production modules and commissioning was achieved within 3 hours.

Further investigation in hybrid structures

The most critical areas within a hybrid structure made from FRP and metal are the interfaces between the different components. For the recliners which are included in the seat backrest, the following interface material combinations take the highest loads:

1. PA6 – glass fiber (GF) organo-sheet & high-strength steel
2. PA6 – carbon fiber (CF) UD tape laminate & high-strength steel
3. PA6 – glass fiber (GF) D-LFT injection mold mass & high-strength steel

To further strengthen this critical interface, several basic investigations have been carried out. The focus of these investigations was possible metal surface treatments to enhance adhesion, e.g. plasma or laser treatment. The characterization method used to assess and quantify the adhesion was the edge shear test.



Summary and Next Steps

The modular plant architecture developed within the MoPaHyb project shows a significant improvement for an economic manufacturing of thermoplastic hybrid structures. Especially the flexibility regarding batch sizes as well as integrated engineering solutions help to save costs. A further benefit of the achieved solution is that the modular concept is not limited to intrinsic hybrids but can also be extended to any production plant. The integration of existing manufacturing equipment through hardware and software upgrades to meet the MoPaHyb requirements can be achieved easily and cost-effectively.

There is, however, room for improvement of the developed concept. One point of interest is the further integration of live process monitoring systems to meet industrial quality assurance regulations.

Apart from the technical point of view for such a modular concept, several business plans have been developed to offer the MoPaHyb approach to possible customers. For example new leasing models for production modules show a high potential for economic modular production plants.

Acknowledgements

The authors would like to thank the Federal Ministry of Education and Research and the Project Management Agency Karlsruhe for their support of the project, as well as the consortium leader Dieffenbacher. Special thanks go to the KIT-wbk for the development of the modular system, which was the central element of the project, to Siemens AG for the implementation of the code generator and the basic module, to all production module manufacturers for their outstanding commitment in the development and provision of the modules, and to Adient for defining the requirements of a modular production unit and providing the seat backrest mold.

Bibliography

- [1] VDMA, VDMA: Zukunftsfelder Elektromobilität - Chancen und Herausforderungen für den deutschen Maschinen- und Anlagenbau, Germany: Roland Berger Strategy Consultants, 2011.
- [2] VDMA, "Serienproduktion von hochfesten Faserverbundbauteilen - Perspektiven für den deutschen Maschinen- und Anlagenbau," Roland Berger Strategy Consultants, 2012.
- [3] F. Henning, J. Kuppinger and H. Paul, Examining Technologies for Composite Hybrids – A Multi-Material Approach to Eliminate Joining and Assembly Barriers Impacting Performance, Troy, USA: Global Automotive Lightweight Materials Assessing, 2012.
- [4] F. Henning, B. Hangs and M. Reif, "Funktionalisierung thermoplastischer UD-Tapegelege im Spritzgießverfahren – Untersuchung der Grenzflächenfestigkeit in Abhängigkeit der Prozessparameter," DVM Tag 2012, Berlin, 2012.
- [5] J. Staeves, "Highlighting OEM Experiences on the optimal multi-material-combinations including aluminium, magnesium and composites to reduce mass while limiting costs," Global Automotive Lightweight Materials 2013, London, 2013.
- [6] M. Schaefer, "webbasierte Konfiguration modularer Produktionsanlagen," in *public final symposium - MoPaHyb*, Pfintzal, Germany, 2018.
- [7] U. Krauter, "Plug'n Play Wandelbarkeit von Liniensteuerungen – Umsetzung in der Automatisierungstechnik," in *public final symposium - MoPaHyb*, Pfintzal, Germany, 2018.
- [8] M. Werhahn, "CAMISMA - Carbonfaser/Amid/Metall-basiertes Innenstruktur-Bauteil im Multimaterialsystem-Ansatz : Abschlussbericht," Evonik Creavis GmbH, Marl, 2015.
- [9] A. AG, "MAI qfast : Abschlussbericht für alle Projektpartner," Audi AG, Neckarsulm, 2015.
- [10] B. Hangs, M. Reif, F. Henning, D. Grauer, R. Jauch, S. Jespersen and A. Martsman, "CoCompression Molding of Tailored Continuous Fiber Inserts and Inline-Compounded Long-FiberThermoplastics," SPE ACCE 2012, Troy, USA, 2012.