# INDUSTRIALIZED MANUFACTURING OF CFRP REINFORCEMENT PROFILES

The current method of manufacturing composite structures, especially in aviation, is characterized by a variety of manual and semi-automated production processes. In order to satisfy the demand for an increased production rate in a manner that conserves resources and is cost-effective, while also taking into account a wide range of variants, novel automated technologies for the production of frames have been developed during the KOLIPRI project.

The objective of the KOLIPRI collaborative project (“Kosteneffiziente Lösungen für eine industrialisierte Fertigung von CFK-Versteifungsprofilen”) was the development of cost-effective solutions for the industrialized production of reinforcing profiles made of CFRP. A reduction of the production costs currently incurred for CFRP frames was achieved compared with current standards, with a simultaneous reduction in processing times. The process chain that was developed enables the automated production of CFRP frames with a large number of variants that can be used in modern passenger aircraft. Furthermore, these can also be used in vehicle manufacture as reinforcement elements in the passenger compartment, while simultaneously offering excellent cost efficiency. Using environmentally friendly and energy-efficient methods, innovative components can thus contribute to achieving future energy savings throughout the product life cycle, and thus also to reducing $CO_2$ emissions.

## APPROACH

In order to verify the technology, the typical curved Z-section frame, which is used widely in the aviation industry, was chosen as the reference geometry. This allows a comparison to be made with other technological developments and reflects various challenges relating to the production of CFRP components (such as local increases in the thickness of layers, as well as varying cross sections and curvatures). In current CFRP passenger aircraft such as the Airbus A350, over 300 different frames are used. Many of the frames that are built into the aircraft are similar, which makes it possible to consolidate a large number of these frames together into component families. Within these families, there are only small geometrical differences between the individual frame elements.

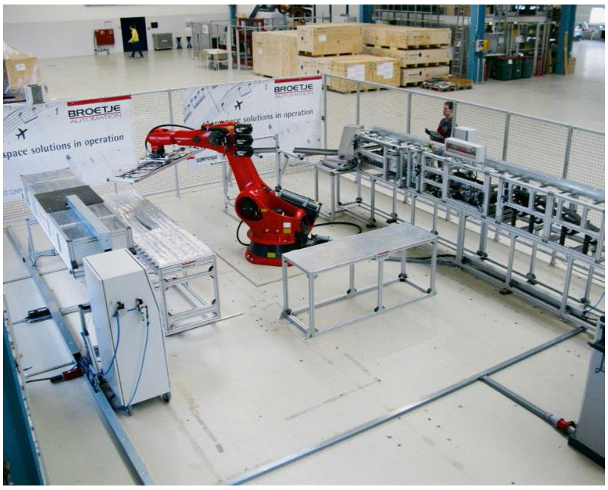


Figure 1 Composite preforming cell (© Broetje-Automation)

## TEXTILE DEVELOPMENT

The goal of the Textile Development subproject – led by SAERTEX – within the KOLIPRI project was the development and implementation of textile semi-finished products that could be used in an automated process chain for complex CFRP profiles in structural applications. The focus here was placed on achieving a large number of component variants, but only if these could be processed using complex, deformable carbon fiber non-crimp fabrics in automated manufacturing processes. The aim was thus to develop lighter, highly drapable non-crimp fabrics while employing innovative fiber orientations as well as applying a binder – which is adapted to the process – to the corresponding non-crimp fabric structures, in order to meet the requirements of automated preforming production processes. The non-crimp fabrics previously used in aviation have had a real weight that is significantly higher than is required for future CFRP components. Commonly used products are, for example, ±45° non-crimp fabrics with a real weight of about 540 g/m². These offer the advantage that they provide a closed fabric appearance and can be produced at a reasonable cost. When using a ±30° biaxial non-crimp fabric, it is possible to do without additional 0° layers in the web area of a frame; in the case of a curved frame with a varying web height, these cannot be deposited as a continuous layer. For such a ±30° non-crimp fabric and the desired low structural areal weight, existing products could not be used. Therefore, innovative approaches to product optimization had to be introduced. The goal was to achieve a product with a fiber angle of ±30° at a real weight of 380 g/m² with a closed surface, while at the same time achieving a high degree of drapability of the non-crimp fabric. For the automated preforming process, it is also necessary for the non-crimp fabric to be equipped with a preform binder. Within the project, the ambitious goal was set to find the lowest possible amount of binder with which the preforming process is still possible without complications arising. After extensive experimental draping tests [3], an epoxy resin binder proportion of 8 g/m² was selected. As a result, it was possible to ensure that the drapability is affected only slightly when the preform stability is sufficient.

## PREFORMING PROCESS

For economic reasons, aircraft and automobile manufacturers, in particular, will attempt to produce composite components using wet processes in future. Here, a component is first created from dry fiber-composite materials in the so-called preforming process; it is then infiltrated with resin and finally cured to become a usable part. Therefore, the goal of Broetje Automation was to develop an automated preforming cell, the so-called Composite Preforming Cell (CPC; Figure 1). With this unique pilot plant, the entire preforming process for a complex composite component can be demonstrated at series production level. Aircraft components such as frames and stringers can therefore be made in large numbers with significantly greater efficiency and 30% less expensively than with previous methods. One of the major results of these development activities was that, at an assumed series production of nearly 100,000 components per year, up to 80% of the production costs can be attributed solely to the cost of materials using the CPC. Within the CPC, numerous applications (Figure 2) that have been developed by Broetje Automation, and for which patents are pending, have been transformed into an automated overall system.

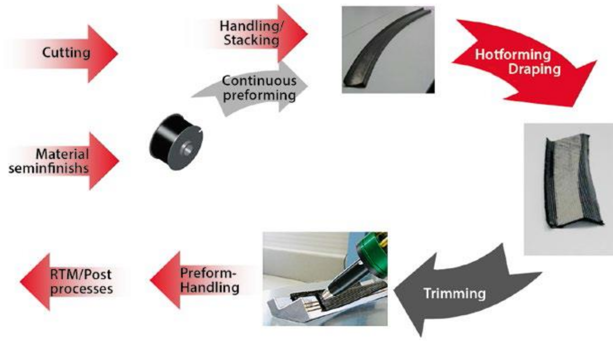


Figure 2 Production process within the Composite Preforming Cell (© Broetje-Automation)

The textile semi-finished products made of fiber material, which make up the target components in layers, usually go through a preforming process consisting of multiple stages. The systems integrated into the CPC are flexible and allow the production of a wide range of different component geometries. The production of the KOLIPRI "typical frame" reference component begins with molding a continuously produced preliminary profile which still has a relatively low structural complexity. The process extends through a second molding process for producing the complex component geometry as well as the precise trimming of the preform to achieve the contour of the finished profile preforms, close to the final geometry, for the subsequent infiltration and curing using resin. Within the framework of KOLIPRI, the system technology has evolved significantly. Whereas only profiles with a constant cross-section could be obtained previously, it is now possible to produce profiles with very high complexity. With the current CCPS (Figure 3), profiles with variable cross-sections, local reinforcing layers and a variable radius of curvature can now be produced in a single shot. Extensive system-specific extensions have been integrated in order to be able to implement all these component features reliably and reproducibly [4]. The other system technologies, such as the 3D Composite Handling System, the Composite Draping System, and the Composite Trimming System, complement the CCPS [5]. Using the CPC, complex composite preform structures can be produced to series production level. They therefore open up significant future potential for reducing previous production costs.


Figure 3 Preforms continuously manufactured with the Continuous Composite Preforming System (© Broetje-Automation)

## DEVELOPMENT OF THE CURING MOLD

In order to process complex textile preforms based on multiaxial non-crimp fabrics that have a high degree of drapability, fast automated curing and consolidation processes have been developed. In the KOLIPRI collaborative project, MBB Fertigungstechnik was responsible for the development of a cost-saving mold concept. The goal was to significantly reduce the cycle times and production costs of complex CFRP structural components with a wide range of variants. The mold concept is designed based on the component families described above. A two-part pressing mold (Figure 4) utilizes a basic mold for each component family.

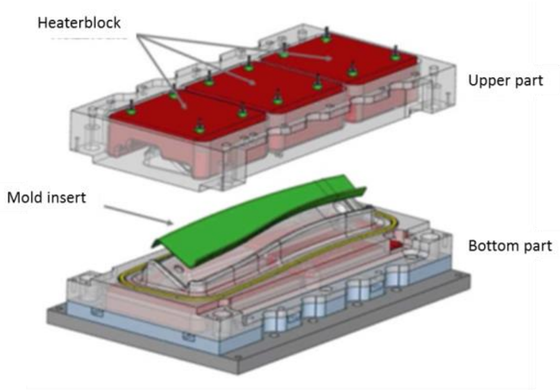


Figure 4 Two-part pressing mold consisting of a basic mold with applied mold inserts (transparent) (© MBB Fertigungstechnik)

The actual component shape of the frames is realized using applied mold inserts. The curing process can be implemented using various methods, such as infusion, RTM, gap impregnation and resin film pressing. For series production, the Fraunhofer IFAM – working as a subcontractor for MBB Fertigungstechnik – has developed a mechanically resistant plasma polymer separating layer that enables the transfer-free ejection of the CFRP profiles from the curing mold. This high-quality thin film, which is only mere microns thick, is suitable for multiple ejections, even for complex surfaces, and reduces the effort needed for cleaning the mold. In order to reduce the overall mold costs compared to an integral mold construction method, mold components with a high proportion of mechanical processing are integrated into the basic mold. This includes primarily the electric temperature control system. The temperatures of the individual heater blocks can be adjusted using several control loops, resulting in a homogeneous temperature distribution within the mold.

## OVERALL PROCESS CHAIN

The overall process chain for the production of typical frames was analyzed experimentally at the Faserinstitut Bremen (FIBRE). The curing mold was numerically investigated using finite element analysis and then given a preliminary design. The characterization of the curing behavior of certified aviation resin systems also revealed significant potential savings. It was possible to demonstrate here that production times can be reduced by up to 50% using a knowledge-based process design. As an aviation reference, airworthy frames were prepared at FIBRE using the infusion process and the developed curing mold concept (Figure 5). The selected manufacturing concept, consisting of process-adapted materials in combination with the automated continuous production of preforms as well as the novel mold concept, demonstrates a high degree of cost efficiency, even for small quantities. Using the example of the Airbus A350, assuming a future production rate of ten or more aircraft per month, a cost reduction of up to 42% is possible using the developed process chain (Figure 6).

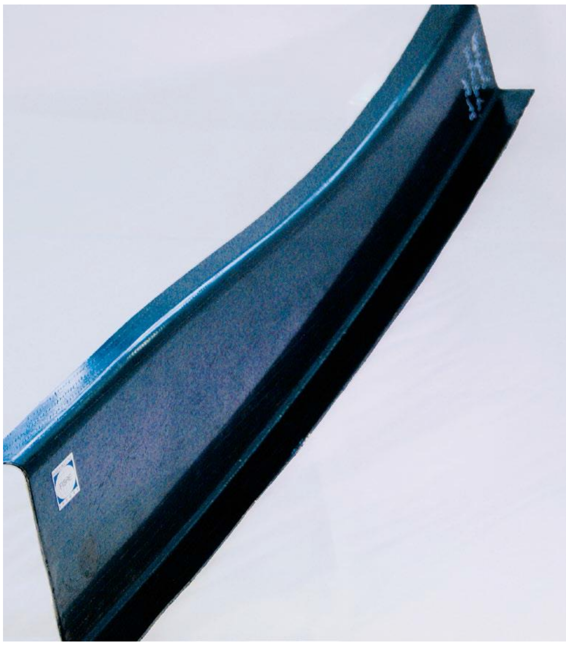

Figure 5 Typical frame section produced using the infusion process (© Faserinstitut Bremen)

By identifying further process limitations in the processing of current semi-finished products for the aviation industry, additional savings potentials can be shown [6, 7]. However, these must first obtain the necessary material and technology approvals over the medium term.

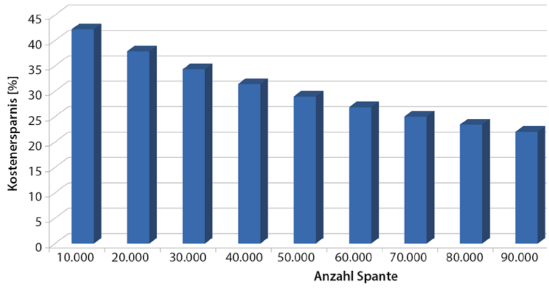


Figure 6 Estimated cost savings resulting from the developed process chain, depending on the number of frames produced (© Faserinstitut Bremen)

## SUMMARY

Using a knowledge-based method of process chain development, it was possible to achieve a significant savings potential compared to current processes. The development of process and structure-adapted semi-finished products has proven to be a crucial cornerstone of process development. The use of ±30° non-crimp fabrics with a high degree of drapability makes it possible to do without 0° layers, thus making layer overlaps in the web of the curved frame unnecessary. At the same time, preforms with varying curvature and local additional layers, as well as – for the first time – with a varying web height, can be produced continuously by developing the 3D preforming technology. The multi-part mold system for curing and consolidation that has been developed allows the use of basic molds for different but geometrically similar frames of a single component family. The basic mold only needs to be supplemented by a mold insert with individual frame geometry. As a result, investment costs for molds are reduced, especially in the case of a wide range of CFRP structure variants, as is common in the aviation industry. For the selected production scenario of an Airbus A350, a component cost reduction of up to 42% compared to current processes for frame production is assumed.

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## REFERENCES

[1] Purol, H.: Entwicklung kontinuierlicher Preformverfahren zur Herstellung gekrümmter CFK-Verstei- fungsprofile. Dissertation. Universität Bremen, 2011
[2] Meiners, D.: Beitrag zur Stabilität und Automatisierung von CFK-Produktionsprozessen. Dissertation. Technischen Universität Clausthal. Fakultät für Natur- und Materialwissenschaften, 2007
[3] Christ, M.; Herrmann, A.S.: Influence of Textile Design Parameters on Drapeability of Warp-Knit NCF, Kopenhagen, 2015
[4] Focke, O.; Miene, A.; Koerdt, M.; Evers, J.F.; Herrmann, A.S.: Automated quality inspection in a continuous preforming process for Non Crimped Fabrics (NCF). 11th International Symposium on Measurement Technology and Intelligent Instruments (ISMTII), Aachen, 2013
[5] Reinhold, R.: Innovative Automatisierungslösung zur Composite-Serienfertigung, lightweight design 3/13, Springer Fachmedien, Wiesbaden
[6] L arsen, G.: Cure Kinetics and cure modelling of epoxy/ amine resin systems. Universität Bremen/ University of Santa Catarina, Bremen, 2010
[7] Sluzhivtsev, I.: Charakterisierung verschiedener Epoxidharzsysteme und Ableitung von Verarbeitungszyklen. Faserinstitut Bremen, 2013

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