# IMPROVING THE PROCESSING PROPERTIES OF HYBRID COMPONENTS USING INTERLOCKING EFFECTS ON SUPPORTING STRUCTURES

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**Abstract**
In order to enable fiber-reinforced plastics (FRP) and lightweight design to enter automotive volume markets, multi-material design aims at developing hybrid components to be produced by adapted large-scale manufacturing technologies. The combination of different materials opens possibilities to use their particular advantages to integrate material specific functions and to reduce cost of material and manufacturing.

The disadvantages of multi-material design effect automation and process challenges because of differing processing properties of materials. Therefore, the purpose of research is to provide automated and continuous process chains. This paper bases on an integrative approach in automated manufacturing of hybrid components and introduces a proposal for improving processing properties using interlocking effects between different materials.

## 1. Introduction

Today's aims in the transport sector to reach fuel savings and higher ranges for electric vehicles by reducing the vehicle's weight are demanding. Current lightweight strategies for automotive applications reach their economic limits trying to exploit the full weight saving potential and the implementation in large-scale production. Components made of FRP and composite materials, however, cannot be considered as an alternative for volume markets yet because of their high material and manufacturing costs.

One promising way to enhance both lightweight and economic potential is described as multi-material design. Hybrid components combine the advantages of different materials and material classes in a most efficient way to guarantee needed properties and specifications [1]. In this approach, materials such as metals, plastics, ceramics and fibers of different types, are applied in their most suitable function to integrate particular advantages in a single component. Besides cost advantages, hybrid design enables a material based function integration within lightweight construction and production.

For the production of hybrid metal FRP components there are two main processing routes as described in [2]. Figure 1 shows both possibilities, differing in the point of merging the materials. The conventional production way is to manufacture each part separately with specific and material optimized production technologies. The second and targeted route aspires to combine different materials in an early stage of manufacturing. The multi-material mix is consecutively processed jointly to the final product.

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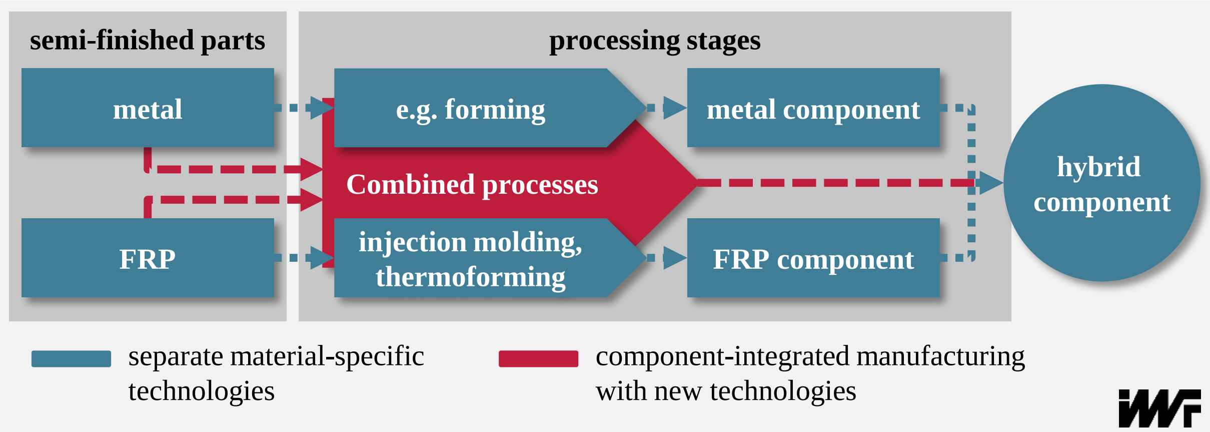


**Figure 1.** Two manufacturing routes of combining metals and FRP in one component [2]

The economic manufacturing of such hybrid components assumes a cost-efficient production to compensate for higher material costs. Existing material-specific orientated plant concepts are not suitable for volume production of multi-material components. Therefore, economic manufacturing of hybrid components involves production technologies that fit in existing plants and can be integrated into automated final shaping manufacturing processes, such as injection molding. In addition, these production technologies have to provide continuous process chains and therefore a high degree of automation. [3–6]

This research approach aims at developing an automated and integrated process chain (red track in Figure 1). In this setting continuous fiber-reinforced thermoplastics (TP-FRP), metal inserts and injection molding of short-fibred thermoplastics are used to create complex thin-walled hybrid components. Due to complicated processing conditions and properties of heated TP-FRP, a promising approach is to use a metal structure to improve handling properties and processability. Furthermore, the structure supports the achievement of mechanical properties and component functionality. The concept of an integrative approach in automated manufacturing of hybrid components using support structures to meet automation challenges has been introduced in [2]. Within the scope of this paper this concept is extended by investigations to the impact of mechanical interlocking effects towards increasing bond strength and dimensional stability.

## 2. Promising technologies and their challenges

Various manufacturing technologies and materials for lightweight design in automotive applications are still uneconomic because of long process cycle times. For example, resin transfer molding (RTM) technologies are technologically sophisticated for small scale production, but not yet economic for volume markets.

### 2.1. Integrated production technologies for thermoplastic-matrix FRP

By contrast, thermoplastics offer advantages in terms of recycling, higher ductility, impact resistance, processing and state of the art large scale production technologies [7]. Thermoplastic-matrix FRPs (TP-FRP) can be provided as organic sheet parts that are tailored, pre-impregnated and consolidated. Processing of TP-FRP gives the possibility of adapting series production technologies like injection molding [8]. A subsequent combined thermoforming and shaping process concludes the manufacturing process. This process combination enables the production of complex, function integrated and final shaped parts [8, 9].

New TP-FRP manufacturing technologies include automation solutions to connect the process stations

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material supply, placement in a mold, component manufacture and extraction [10]. However, these technologies are either limited to processing just a single material or a single semi-finished part in each cycle.

Current research focusses on processing multiple semi-finished parts in a single cycle to create complex components. Furthermore, these processes handle with parts of various material classes and properties. The aim is to develop a continuous process chain that integrates all manufacturing steps, beginning from material supply and ending with extracting a final shaped part. [11]

### 2.3. Identified challenges

Challenges of an integrative and continuous production technology result from differing processing properties of different materials. No suitable automation solution for volume production of hybrid components could be found so far to solve these challenges. The following three main challenges of processing hybrid TP-FRP components were identified.

First, preforming of composites in general differs considerably from those of conventional materials. This is caused by the change of their textile character molten to their solid character in consolidated and cold state within a small temperature range. In the molten state FRP have a low bending stiffness, which is simultaneously an advantage as well as a disadvantage for processing. On the one hand, this property enables shaping operations at comparatively low temperatures. On the other hand, this effects a limp and vulnerable behavior of the material.

Second, handling and transport of hybrid TP-FRP preforms and parts are challenging because of the differing material properties and low heat capacity of thermoplastics in small temperature ranges. The issue is the requirement of a molten matrix during further processing for shaping and consolidating. As long as TP-FRP are solid, processing does not distinguish from those of metal-sheets. In contrast, heated TP-FRP with viscous matrix need special handling equipment to avoid damages of the sensitive materials. In addition, their low heat capacity leads to a rapid cooling and small tight processing slots.

Third, positioning of complex hybrid components within a mold is difficult if dimensional stability is decreasing due to increasing temperature and decreasing bending stiffness. This is, however, necessary to guarantee close tolerances of the final product and processability with injection molding. The high temperature of the preform is necessary to enable a firm joint between the matrix and the molten plastics and to consolidate the TP-FRP.

The described three challenges focus on handling and automation problems arising from simultaneously processing different materials. Additional challenges occur, but are not discussed in this paper.

## 3. Research scope for an integrative approach

To find a solution for the above-mentioned challenges and to figure out processing possibilities is the scope of this research approach.

### 3.1. Integrative lightweight design

One important condition for an economic and technologically feasible approach is to explore the requirements for the production and the temporary properties of a component. Therefore, the design of a component and the material selection not only depends on the expected requirements during use but also on the requirements during production. Parts of different materials can assume different functions in the manufacturing process that favour an efficient production.

### 3.2. Process design using a metal supporting structure

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Based on a target component with a complex geometry that fulfils both a minimalized component weight and high demands on mechanical properties, a hybrid design of TP-FRP and metal sheets seems to be reasonable. In this case TP-FRP is used for surface construction and metal parts for high tension areas and to support the surface. Injection molding realizes functional elements and final shaping of the component. A suitable process design integrates all necessary steps to create the product out of semi-finished parts.

The preforming and pre-assembling for this application is similar to near-net shaping for RTM. The process has been designed by the authors. Cut-outs of TP-FRP become heated above melting temperature and pre-shaped at this temperature and also pre-assembled with metal sheets. Figure 2 shows exemplarily the preforming and pre-assembling process for hybrid components.

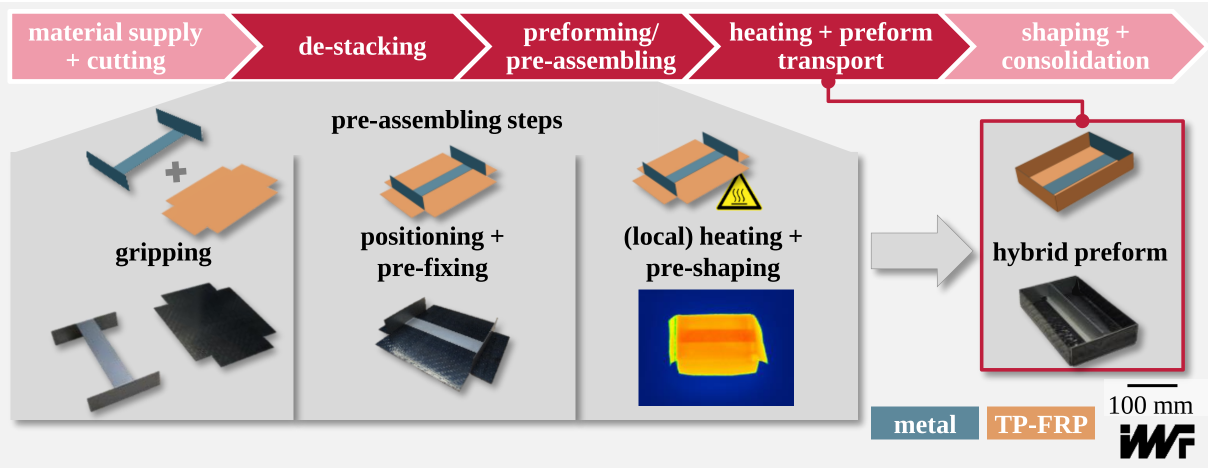


**Figure 2.** Pre-assembling process of TP-FRP pre-form with metallic structure [2]

The hybrid preform needs to be heated above the melting temperature for a consolidation of the TP-FRP. In addition, this temperature is required on the surface for an adhesive bonding with the injected plastics to assure maximum strength of the function elements. Because of melting the thermoplastic matrix, the material loses its previously given shape and dimensional stability. This complicates transporting and positioning operations in the injection mold.

Therefore, the approach is pursued to apply the metal sheet as a structure to support dimensional stability besides increasing mechanical properties. Such a structure allows to conserve a given shape of the preform. Close tolerances for placing and positioning the preform in the mold can be complied with this approach. In addition, the metal parts in such a preform enable to decrease requirements of handling and transport. Most conventional handling solutions become suitable.

### 3.3. Preliminary investigations of metal support structures

As described in [2] first investigations regarding the effect of metal supporting structures to component and processing properties have been made. In this study the manufacturing process and dimensional stability of different geometries have been explored and analyzed. The feasibility of manufacturing such a hybrid preform has been shown. The investigations of dimensional stability have been carried out by reheating the preform above melting temperatures after preshaping (Figure 3). The metal structure supported specimens show a highly increased dimensional stability in contrast to an only TP-FRP structure. The more a structure reinforces the edge areas of the component the higher is the realizable stability. The side panels, however, are not fixed to the structure and peel off with raising temperatures, because of the material's property to reestablish its initial state.

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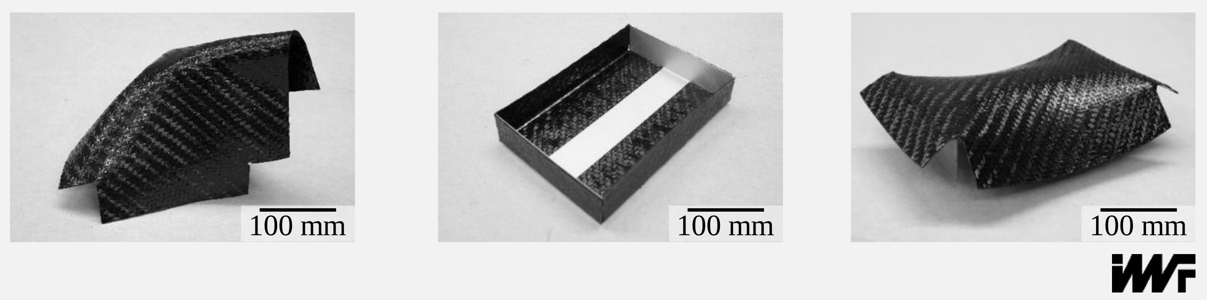


**Figure 3.** Results of preliminary study; (a) reheated preform without any support structure, (b) hybrid preform with support structure, (c) reheated hybrid preform with increased but insufficient stability

## 4. Proposal for an extension of this approach

The benefit of using a metal supporting structure has been shown successfully. Inadequacies in this approach still remain. This proposal aims at increasing dimensional stability and processability with an additional local form closure.

### 4.1. Form closure through interlocking effects

The proposal of this approach is to improve dimensional stability of the preform independent on its current temperature. To achieve this goal a mechanism has to be found that is able to maintain the geometric composition of the preform and its single parts. Positive fittings and friction-locked connections are not suitable for the application on a melted thermoplastic matrix. In contrast a form closure could be able to keep fibers in position even though the matrix becomes viscous.

### 4.2. Mechanical interlocking effect

A novel method to generate a form close between metal and FRP is based on mechanical undercuts. This mechanical undercuts are produced in a stamping forming process on the metal surface. Therefore, special tool geometries were developed which allow manufacturing of different forms of the clamping structures by variation of the process parameters. Figure 4 illustrates the structuring process schematically (a). Variation of structure orientation allows surface clamping and adaption to specific load paths in the component (b). By using continuous fiber-reinforced materials, a direct interlocking between metal and fibers can be realized (c). Finally this concept is applied to a component part [12, 13]

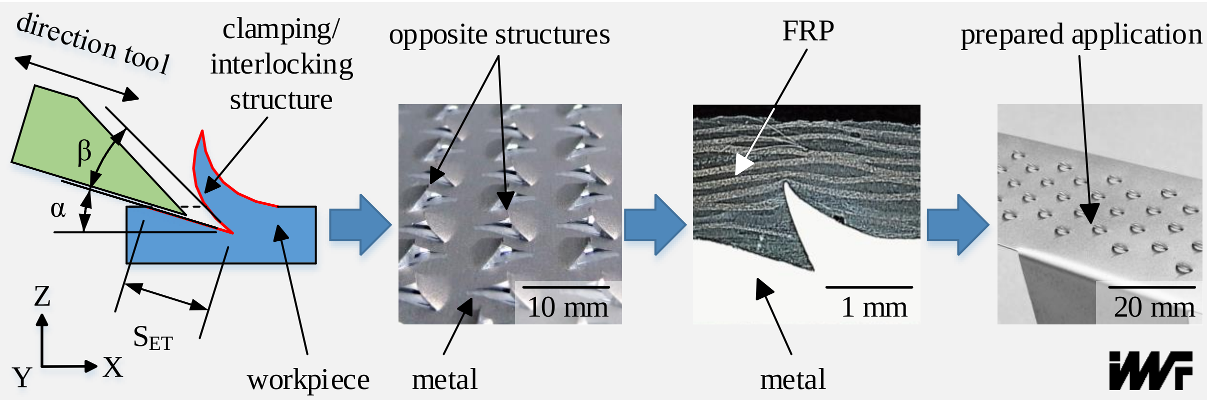


**Figure 4.** Interlocking structures; (a) structuring process, (b) metal surface of a coupon specimen, (c) micrograph, (d) prepared application for a component. Adapted from [12].

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## 5. Feasibility studies

To confirm the approach first feasibility tests have been carried out to characterize the producibility and adopted preforming process. Furthermore, the improvement of the dimensional stability depending on the temperature and impact on other preform properties are evaluated. The study is done on equal specimens as in the preliminary investigations. The preform with the geometry of a folded case is still manufactured manually. Its TP-FRP semi-finished parts have a thickness of 1 mm and 66 % woven continuous glass filaments impregnated with a polyamide matrix. Its basic dimensions are 210 mm x 150 mm x 40 mm. The metal supporting structure consists of a 0.5 mm metal (DC01) or a 1 mm aluminum sheet (EN AW 7075)

The producibility of the hybrid preform and interlocking effects have already been proven in the preliminary studies. The creation of the interlocking structures at the surface of the thin supporting metal sheets and the adopted preforming process have not been examined so far.

### 5.1. Producibility and adapted preforming process

The first part of this study is dedicated to the producibility of the interlocking effects at the surface of the supporting metal sheet. The used steel of the preliminary studies, could not be treated reliably to create these structures. Extensive parameter variations did not lead to reproducible results with existing materials and equipment. By change of the material to the aluminum this issue could be solved.

The known preforming process has to be adapted because of the interlocking elements as well. Hitherto the preforming comprised a manual placement and position in environmental conditions, a heating above the melting temperature and a preshaping of the TP-FRP around the support structure. In addition, the TP-FRP has to be grouted above the interlocking elements to create the form closure after the solidifying.

### 5.2. Reheatment studies

The major aim of this study is to improve the processability of heated hybrid preforms with a limp TP-FRP part. The interlocking of the TP-FRP with the support structure causes a fixation of fiber bundles and therefore a high dimensional stability even with melted matrix. To avoid that the TP-FRP lifts off from the supporting structure when the thermoplastic matrix is melted, the best orientation of interlocking the fiber bundles has to be found. Therefore, different orientations and sizes of the interlocking elements are applied on the surface. The orientation of the elements depends on the direction of the fibers in the TP-FRP. The different investigated orientations regarding the fiber orientation are shown in Figure 5. There are elements, that affect on the crosswise oriented fiber bundles (b and c) and elements, that affect on the lengthwise oriented one (d). These elements counteract to the reversal forces of the shaped fiber bundles.

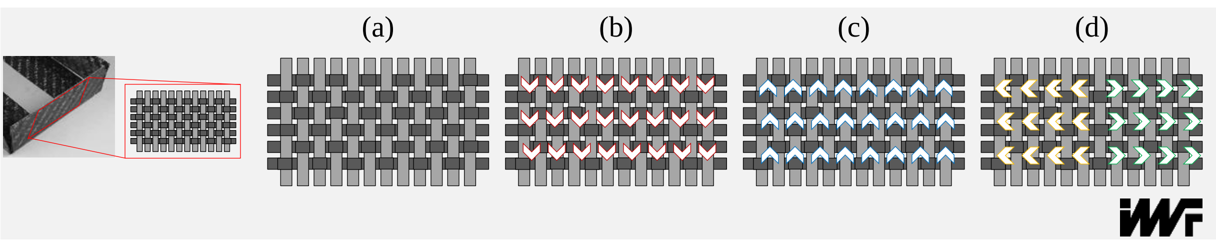


**Figure 5.** Schematic illustration of the effective fabrics, interlocking elements; (a) without, (b) down, (c) up, (d) left-right

The results of the reheatment studies are shown in Figure 6. On the one hand the results show the

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difficulties in manufacturing these preforms and on the other hand a rapidly increasing dimensional stability of the heated and limp hybrid preform. In some tests the TP-FRP still detaches locally from the interlocking support structure. This results from an insufficient contact pressure during the preform process. In general, the orientations against the straightening perform best, such orientations as (b) and (d). After several minutes of reheatment up to 270 °C the edge areas have not detached from the metal structure.

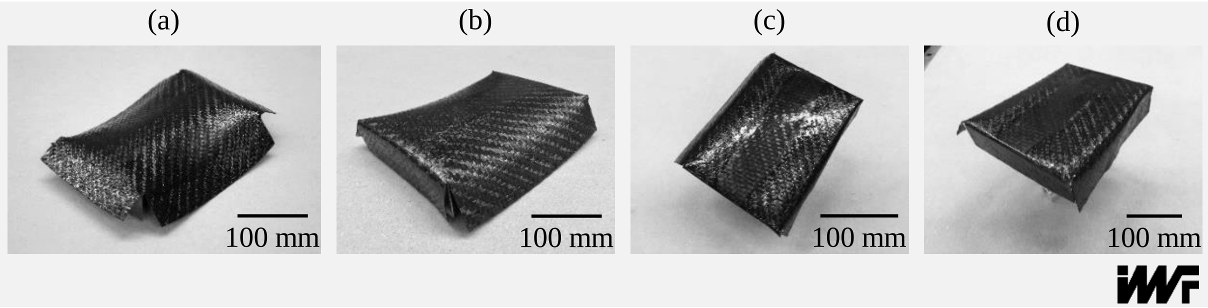


**Figure 6.** Schematic illustration of the effective fabrics, interlocking elements and the impact to dimensional stability; (a) without, (b) down, (c) up, (d) left-right

The remaining areas of attached TP-FRP, however, show the influence of the interlocking effect on the dimensional stability. Size and functional direction of the elements play an important role on the influence. The results of the reheating test of the specimens show the influence of varied element orientation and a specimen without interlocking elements. The interlocked TP-FRP does not detach from the metal structure and does not revert to its initial position. Figure 7 shows how the interlocking elements take effect in detail. After reheating the preform with orientation (b) some elements interlock fiber bundles and inhibit the detachment. Big elements of orientation (c) break through the TP-FRP and hold the preform in position. Elements of orientation (d) show best results because of interlocking those fiber bundles, that strive to restore their initial position, and of a variety of working interlocking elements.

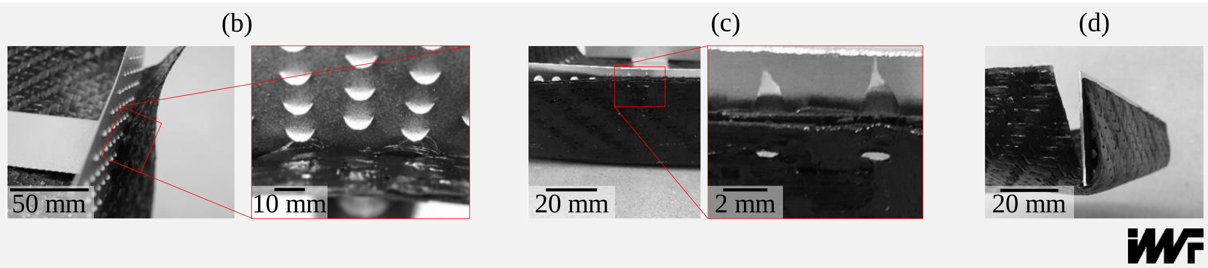


**Figure 7.** Local detail results showing the effectiveness of the interlocking elements; (b) down, (c) up, (d) left-right

## 6. Conclusion and Outlook

Today's demands for economic lightweight design require new production technologies and manufacturing chains. This paper described challenges and approaches of automated production of hybrid components using TP-FRP. A new method of considering the requirements of manufacturing in the component design have been presented. Preliminary studies showed the difficulties regarding dimensional stability at processing temperatures for downstream manufacturing steps. Therefore, it was hypothesized that the application of interlocking elements may increase at least the dimensional stability

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beyond all processing temperatures and may also effect the mechanical properties of the component. The feasibility study showed a benefit using such form closure effects for an increased dimensional stability.

Future work will have to develop molding tools to assure the application of the interlocking effect and furthermore a methodology for a functional and process integrated component design. Moreover, research will expand from preforming to connected molding processes.

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**References**

[1] Henning, F. and Moeller, Elvira, Handbuch Leichtbau: Methoden, Werkstoffe, Fertigung. München: Hanser, 2011.
[2] Dröder, K.; et al.; “An integrative approach towards improved processability and product properties in automated manufacturing of hybrid components” in Euro Hybrid Materials and Structures 2016, Kaiserslautern, Deutschland, 2016.
[3] Dröder, K.; et al.; “Symbiosis of plastics and metals: integrated manufacturing of functional lightweight structures in high-volume production” in Kunststoffe im Automobilbau, Düsseldorf, Germany: VDI-Verlag, 2014.
[4] Cherif, C, Textile Materials for Lightweight Constructions: Technologies - Methods - Materials – Properties. Heidelberg/Berlin, Deutschland: Springer, 2015.
[5] Ickert, L.; et al, Beitrag zum Fortschritt im Automobilleichtbau durch belastungsgerechte Gestaltung und innovative Lösungen für lokale Verstärkungen von Fahrzeugstrukturen in Mischbauweise, Berlin, Germany 2012. Berlin: VDA/FAT, 2012.
[6] Staiger, E.; et al.; “CFK-sheet metal hybrid composites” in 7th International Textile Conference, Dresden/Aachen, Deutschland, 2013.
[7] Mallick, P. K.; “Thermoplastics and thermoplastic–matrix composites for lightweight automotive structures” in Woodhead Publishing in materials, Materials, design and manufacturing for lightweight vehicles, P. K. Mallick, Ed, Boca Raton, Fla, Oxford: CRC Press; Woodhead, 2010, pp. 174–207.
[8] H.-P. Heim, Ed, Specialized injection molding techniques. Oxford, United Kingdom: William Andrew is an imprint of Elsevier, 2016.
[9] Reynolds, N. and Balan Ramamohan, Arun; “High-Volume Thermoplastic Composite Technology for Automotive Structures” in Automotive series, Advanced composite materials for automotive applications: Structural integrity and crashworthiness, A. Elmarakbi, Ed, Chichester, United Kingdom: John Wiley & Sons, 2014, pp. 29–50.
[10] Seidel, S, Anforderungsgerechte, thermoplastische Preforms für den Hochleistungsleichtbau. Hamburg: TuTech Verlag, 2015.
[11] Lippky, K.; et al.; “Integrierte Produktionstechnologien zur Herstellung hybrider Leichtbaustrukturen” in Lightweight Design: Springer Fachmedien Wiesbaden, 2016, pp. 59–63.
[12] Brand, M.; et al.; “Enhancing the tensile strength in hybrid metal-FRP materials through various interlocking structure patterns” in Euro Hybrid Materials and Structures 2016, Kaiserslautern, Deutschland, 2016.
[13] Müller, S.; et al.; “Increasing the Structural Integrity of Hybrid Plastics-Metal Parts by an Innovative Mechanical Interlocking Effect” in 20th Symposium on Composites, pp. 417–424.

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