PRE-ASSEMBLY AND HANDLING OF LIMP ENDLESS FIBRE-REINFORCED THERMOPLASTIC-METAL PREFORMS

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Abstract

A promising technology of producing hybrid components in high quantity is the manufacturing of thermoplastic-based fibre-reinforced components with metal inserts in a combined thermoforming and injection moulding process. The main challenge of feeding a forming tool with thermoplastic cut-outs is ensuring processing conditions such as temperature, due to low heat capacity, and position of the used materials, due to decreasing bending stiffness and tacky surface in molten condition.

This paper adresses these handling challenges and proposes a manufacturing concept, in which hybrid design not only affects the properties of the final component, but also the manufacturing itself, especially the automated handling process: In a pre-mould assembly process, several fibre-reinforced thermoplastic cut-outs and metallic components are stacked and fixed to build up a hybrid preform. In the subsequent process steps the assembled preform is heated, handled and processed as one unit.

This paper presents results of investigations on the mechanical and thermal behaviour of hybrid preforms during handling. The paper shows that the proposed concept has the potential to expand the selection of useable gripping principles and enlarges processing time slots due to higher local heat capacity. The results are validated in an demonstration process.

1. Introduction

The lightweight construction potential of metallic materials in automotive construction is slowly but surely reaching its technical and economic limits. Fibre-reinforced plastics (FRP) such as glass (GFRP) and carbon fibre-reinforced plastics (CFRP) have a much higher potential for lightweight construction due to their specific properties on the one hand, but due to their high material and manufacturing costs, they are no economic alternative for volume markets, on the other hand. [1]

Due to the current and future high costs of composite materials, the application of multi-material systems and hybrid constructions is aspired. Multi-material and hybrid systems follow the approach of using the right material at the right place for optimum function. [2, 3] In contrast to a complete substitution of metal by endless fibre-reinforced plastics, which does not make any economic sense, the advantages of different material classes should be combined in the material mix while minimising the respective disadvantages as far as possible. This enables an intelligent and flexible lightweight construction with different materials, which can cover different local requirements. [4]

In order to enable the economical production of integral and functionally integrated hybrid components and thus the use of this technology in competition with alternative lightweight construction, it is necessary to expand existing material-specific technologies and plant concepts. Only if a high degree of automation in continuous process chains is ensured, it is possible to use the full potential of the hybrid construction approach in large-scale quantity. [1, 5]

2. Automation Challenges in Handling of Heated Organo Sheets

High potential for industrialization lies in the processing of plate-shaped endless fibre-reinforced semi-finished thermoplastics (organo sheets) and metallic components in the thermoforming process as well as a process combination of forming and injection molding. In such a process, organo sheets are heated above their melting temperature and then formed and injected. These manufacturing processes are already used in large-scale applications in metal and plastic processing and achieve cycle times of 60-90 seconds. [6, 7]

In achieving large-scale production suitability of the abovementioned process combination for organo sheets, the mould and the handling system are of special importance. While the mould produces the final component at the end of the process chain, the handling systems upstream ensure reliable material preparation and feeding. Especially in the processing of organo sheets, automated handling plays a key role.

The difficulties that arise in the development of automated and continuous process chains mainly result from the properties and the resulting behaviour of the used organo sheets. The material properties differ from conventional processed materials in the automotive sector, such as metal. The material behaviour of fabrics with impregnated thermoplastic matrix is uncritical as long as the temperature is below the melting temperature of the matrix material. In this state, the organo sheets have a bending stiffness, which is sufficiently high to ensure a defined geometry and position during handling operations. Moreover, the surface of the material is solid and flat. Handling operations can be performed by using standard vacuum grippers without any special features. [8]

For processing the organo sheet in a moulding process, the matrix must be heated above its melting temperature. Due to fusing, the bending stiffness of the organo sheet loses the proportion of the matrix material and only the very low bending stiffness of the fabric remains. That results in a limp behaviour. This limp behaviour is advantageous for shaping, but there is the danger of damaging several fibers or losing their orientation. Furthermore, the limp behavior makes it difficult to ensure the geometry of the organo sheet during handling. Moreover, because of the molten matrix material, the surface of the sheet becomes tacky and uneven. In addition to the mechanical challenges, there is also a thermal challenge: the molten condition lasts only for a short time slot after stopping the heating process, due to the fast cooling of the thin-walled materials (0.5 – 2.0mm).

With partly complex handling equipment, special gripping principles and complex additional functions, attempts are made to master the demanding properties of semi-finished textile products during handling. Efficiency losses such as material waste due to damage to organo sheets during handling are accepted for almost all solution approaches. [9–12]

With the focus on the production of hybrid material components, this paper examines the question of whether a material combination of FRP and metal in one component can already be used advantageously during the manucaturing process by influencing the mechanical and thermal handling properties.

3. Pre-assembling of FRP-metall-hybrid Preforms and its Potentials

To meet the challenges described in handling heated organic sheets and against the background of component-integrated hybridization approaches, the authors propose a manufacturing process for FRP-metal-hybrid components (Figure 1). The process is divided into pre-assembly and the actual component production by forming and injection moulding.

In analogy to technologies such as preforming [7, 13, 14], in a pre-mold process step (pre-assembly), a load-path oriented hybrid preform is built up from the semi-finished products, which are required for the subsequent component. Organo sheet cut-outs (glass fibre-reinforced polyamide 6) and metallic parts are assembled and fixed by form fit, force fit or adhesive bond in order to ensure a sufficient handling resistance for joint transport and further processing as a unit.

When the hybrid preform is heated to process temperature, the thermoplastic matrix of the FRP components melts as usual, changes to the limp state and gets an adhesive surface. The properties of the metallic components of the preform hardly change in the range of the thermoplastic processing temperature compared to the properties at room temperature, as the melting temperature of the metal is far above the processing temperature of the polyamide 6 matrix (~290°C). Therefore, their stiffness does not decrease to any (handling) relevant extent, nor do the surface properties change with regard to their adhesion behaviour. Moreover, after removal from the heating unit, the surfaces of the metallic components cool more slowly than the FRP semi-finished products due to their higher thermal mass.

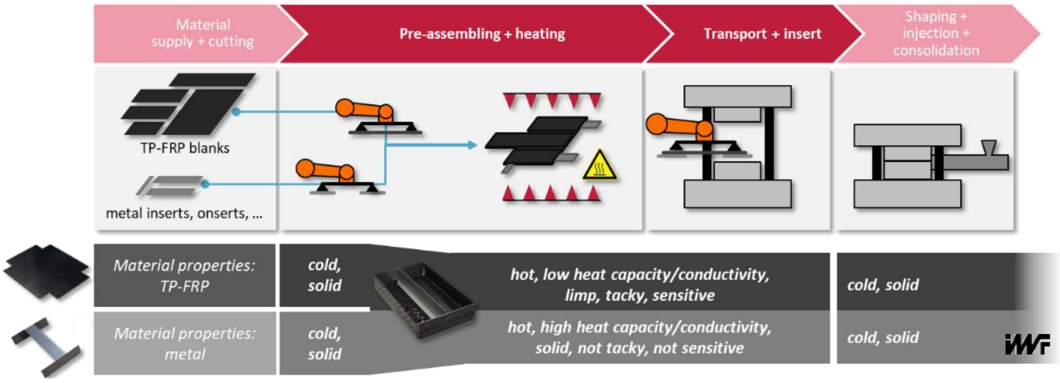


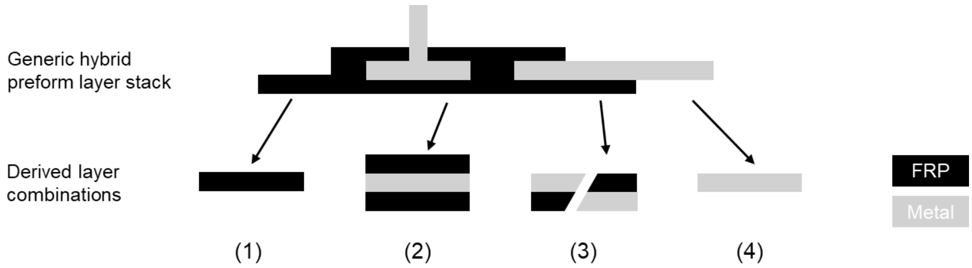
Figure 1. Opposite material properties during the manufacturing process of multi-material components [15]

The described manufacturing concept for a pre-mould assembly of hybrid preforms is characterised by the fact that in the production of plastic-intensive FRP-metal hybrid lightweight components in the thermoforming process, the different material properties do not only determine the properties and functions of the final component, but the material behaviour of the individual semi-finished parts is already used in advance during the production process.
The concept offers potential for automated handling on both the mechanical and thermal side: mechanical properties can be influenced locally by the use of stiffening elements such as sheet metals or force input elements in plastic-intensive preforms, which serve as support structures. This offers the potential to reduce the number of gripper-side support points. Moreover, stiffened areas in the preform allow for a wider selection of standard grippers to be used. While hot organic sheets are only handled in clamping frames or needle grippers, magnetic grippers or clamping grippers can also be used in combination with (stiff) metals.
From a thermal point of view, a targeted increase of the thermal mass in areas of gripping points has the advantage that the risk of local cooling due to heat conduction between preform and gripper is reduced. Ideally, the preform can be gripped in such a way that there is no direct contact between the FRP semi-finished product and the gripper system. This would also reduce wear of gripping components and damaging the preform because of the tacky matrix material.
The opposite material properties of FRP and metal in the heated state offer the opportunity to locally influence the bending stiffness, the adhesion behaviour and the heat capacity of the preform by a specific material combination. This results in the potential to meet the handling challenges already at material and design level and thus to reduce the material-related automation barriers.

4. Handling concepts for heated FRP-metal-hybrid preforms

Due to the aspired hybrid design of the preforms, areas with different mechanical and even thermal properties can be designed. Thus, both stiff and limp areas occur, which heat up at different speeds and vary during handling and cooling speed. In order to exploit the resulting potential for handling-friendly preform design and pre-assembly process of hybrid preforms, a corresponding understanding of the individual and combined material behaviour has been worked out.
The scope to be considered is determined on the basis of possible materials which are processed in the pre-assembly step, their combinations and interaction with system components (like grippers). On the

basis of the defined materials, a certain number of possible material combinations and layer build-ups results (Figure 2). Against the background of the presented pre-assembly process, four main layer combinations can be derived which are investigated in terms of their mechanical and thermal behaviour.



Gripper type				
Needle	- / +	- / -	- / -	- / -
Vacuum	+ / o	+ / -	+ / -	+ / +
Magnetic	- / -	+ / o	+ / +	+ / +
Clamping	+ / o	+ / +	+ / +	+ / +

Figure 2. Generic FRP-Metal-hybrid layer stack, its derived layer combinations and suitability of grippers for handling them in cold / heated state.

In the following, this paper focusses on general mechanical investigations regarding handling concepts. Based on the possible material combinations and layer build-ups, the suitability of four gripping principles (needle, vacuum, magnetic and clamping) for handling the various preform sections in cold and hot state was evaluated (Figure 2). An important requirement for handling technology is to grip multilayer structures made of various materials in cold and heated condition as a unit. The evaluation in the cold state was based on the assumption that the layers (2) and (3) are pre-fixed to each other. Without pre-fixing, the layers (2) and (3) can only be gripped using clamping grippers. Layer (3) can be gripped with a magnetic gripper without pre-fixing, if the metal layer is underneath. While a multi-layer structure of organic sheets can be handled by needle grippers in heated state, this gripping principle cannot be used, neither in cold state nor in combination with metallic components.

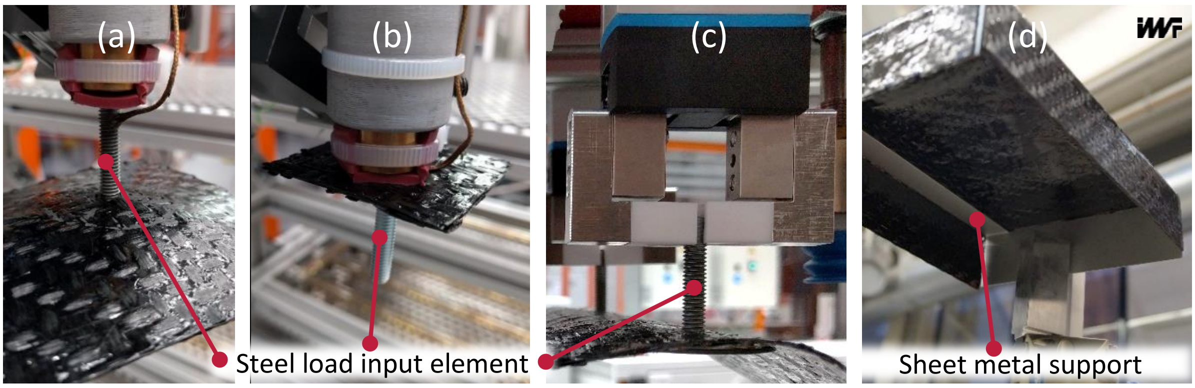


Figure 3. Gripping concepts for handling FRP-metal-hybrid preforms in heated state by magnetic (a, b) and clamping grippers (c, d).

By means of the evaluation of gripping principles, clamping grippers and magnetic grippers were selected for gripping the focused layers (2) and (3). Figure 3 shows the selected gripping principles using exemplary gripping scenarios: Magnetic grippers allow the direct gripping of metallic areas without contact to the FRP (a) or the gripping of a multi-layer structure of organic sheet and metallic component in combination with contact to the FRP (b). The FRP cut-out in (a) is hold by form fit, in (b) it is hold by force fit between the metallic component and the gripper. Clamping grippers are suitable for gripping metallic components (c) and for gripping metal and organic sheet as a unit (d). It is also feasible to grip the layer build-up without direct contact to the FRP (c).

Thermal investigations were made by the authors in [15]. There, the cooling behaviour of heated organo sheets (glass fibre-reinforced polyamide 6, thickness of 0.5, 1.0 and 2.0mm) at ambient air and in contact with various heat-resistant vacuum and needle grippers were carried out. Furthermore, the thermal potentials of handling hybrid preforms as shown in Figure 3 were demonstrated. While the handling of pure organo sheets by conduction leads to an accelerated cooling of the material locally, a similar cooling rate as in air could be achieved in metal reinforced areas. Thus, the critical time window during handling can be increased.

In summary, the feasibility studies of gripping principles for hybrid preforms show that the gripper range for hybrid preforms can be extended to include magnetic grippers and clamping grippers in addition to established needle grippers.

5. Demonstration Process

The following chapter concludes with an application of handling hybrid preforms in a demonstration process. A generic hybrid preform, consisting of an organo sheet (glass fibre-reinforced polyamide 6, thickness: 1mm) and four force input elements, is assembled. The process comprises the material supply, the pre-assembly, the joint heating and the transport from the oven to a tool. The schematic preform and the process are shown in Figure 4. For the handling processes, a handling tool with components of chapter 4 is used. The gripper is shown in Figure 4 and 5. It consists of four clamping grippers for gripping the force input elements and four vacuum grippers for gripping the cold organic sheet.

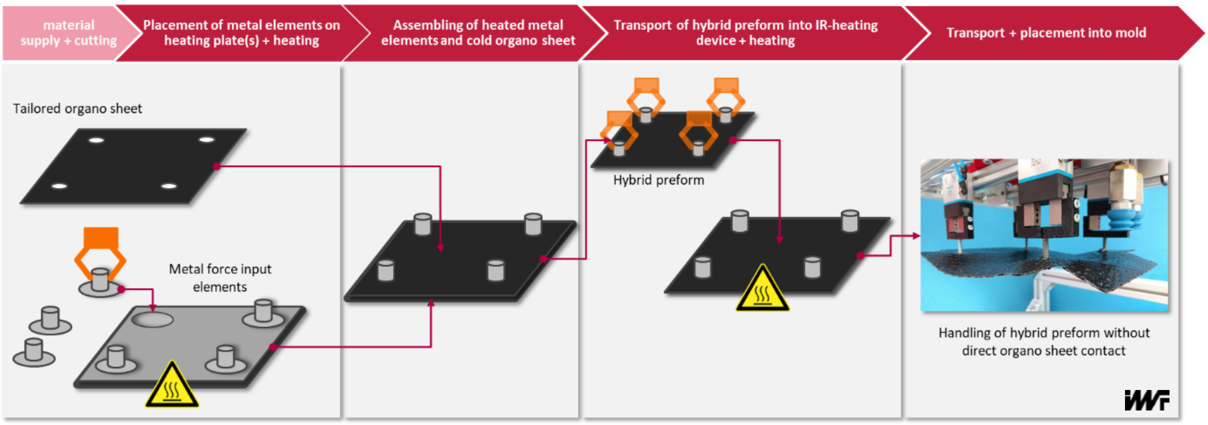


Figure 4. Exemplary pre-assembling and handling process with organic sheet and metallic force input elements by using clamping grippers

The process starts with the supply of a tailored and drilled organo sheet and four metal force input elements at room temperature. The force input elements are placed by the clamping grippers on a heating plate and are preheated to 200°C. The reason for this is that organic sheet and metal heat up at different rates in the IR field due to their different thermal mass and absorption coefficients. In combintion with occurring shading effects, they reach a different target temperature when heated at the same time. Shaded areas of the organo sheet may not melt. However, the aim is to achieve the lowest possible temperature differences. After reaching the preheating temperature, the force input elements are inserted into the holes of the organo sheet by handling the organo sheet cut-out with the vacuum grippers (Figure 5, 1). In the following step, the force input elements, which are form-fit connected to the organo sheet when lifted, serve as gripping points (Figure 5, 2). The pre-assembled unit is gripped by the clamping grippers and transferred into an IR-oven. To ensure positioning accuracy in the process, the four force input elements are placed and fixed on magnetic support points in the oven (Figure 5, 3). Then, the hybrid preform is heated. Once the target temperature (290°C) of the organic sheet has been reached, the preform is gripped again via the force input elements with the clamping grippers and transported from the oven to the mould (Figure 5, 4).

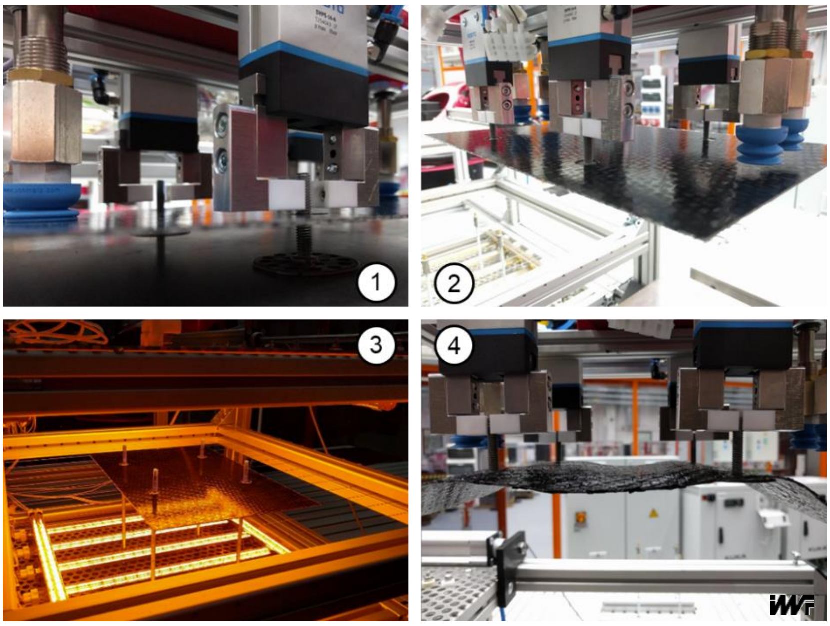


Figure 5. Demonstration process: (1) Pre-assembly, (2) transport of the cold hybrid preform, (3) heating and (4) handling of the heated and limp preform

On the basis of the demonstration process it is shown that the handling properties of a plastic-intensive hybrid preform can be specifically influenced by using different material properties. By gripping the metallic parts, no special grippers are necessary. Moreover, the organo sheet does not come into contact with gripper or tool. This prevents early local cooling through conduction. The available handling time is limited only by the cooling of the organic sheet in the ambient air.

6 Conclusion

This paper describes the automation challenges in handling heated organic sheets. Against the background of hybrid lightweight construction, a production concept is presented in which the combination of endless-fibre-reinforced thermoplastics and metallic inserts is already of benefit during the processing process. This is implemented in a pre-mould pre-assembly process. Focusing on the different mechanical properties of plastics and metals during the handling process, different gripping principles for the hybrid composite are evaluated. On the basis of a demonstration process, a pre-assembly scenario is presented. A hybrid preform is handled via its metallic components by means of clamping grippers. The chosen gripping principle allows handling without direct contact between the gripper and the organo sheet. This prevents early cooling.
Future work will continue to deal with the mechanical behavior of multi-material preforms. In addition,

further thermal properties during the handling procedures are examined. The research objective will be to provide support for efficient product and process design for automated manufacturing of multi-material components.

Acknowledgments

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