FEATURE

Adaptive, connected production of hybrid thermoplastic prototypes

Malena Schulz, Henning Janssen, Christian Brecher

Fraunhofer Institute for Production Technology IPT, Aachen, Germany

From a production engineering perspective, the freedom of design with composite materials offers an interesting possibility of product customization. The material varieties of each constituent, matrix and fiber, as well as the different fiber orientations and layups are some parameters which can be applied to the individual needs of the application. However, this high degree of freedom in design results in the need for more complex and novel production technologies. During the last decades, more and more machines were developed which enable cost efficient production of composites in shorter production times. These technologies mainly focus on mass production of a single optimized composite part in order to fulfill the high demands of industry. Thus, production machines do not utilize the full diversity of composite materials. In order to exploit this diversity, the production machines have to be flexible as well.

Having this in mind, the "LightFlex" project was initiated. Starting in 2015, a consortium of two German research institutes, the Institute of Plastics Processing (IKV) at RWTH Aachen University and the Fraunhofer Institute for Production Technology IPT, as well as several small-, medium- and large-sized enterprises created a flexible and automated process chain for manufacturing hybrid composite parts for efficient batch size one production. The project is funded by the German Federal Ministry of Education and Research. Motivated by the automotive industry, the aim of the project is to produce highly functionalized prototypes in order to reproduce comparable mechanical properties as parts need to have in serial production at a later stage. This is achieved by combining 3D printed parts with tailored composite blanks produced by tape placement of unidirectional thermoplastic tapes, shown in Figure 1.

The basic idea of the "LightFlex" process chain is to combine different manufacturing technologies each offering high flexibility. The main technologies used are rapid prototyping, tape production, tape placement and a combined joining and forming process as demonstrated in Figure 2. Rapid prototyping technologies provide freedom to create various shapes with complex geometrical features without the need of complex tools. The machine for producing unidirectional tape, which is developed by the IKV in this project, allows to combine a variety of materials with different qualities. Furthermore, it includes continuous quality assessment assuring the desired outcome of the product. The tape placement process developed at the Fraunhofer IPT creates tailored composite blanks out of unidirectional tape. By stacking tapes on top of each other individual structure-optimized layups with various fiber orientations are fabricated. Additionally, the use of unidirectional tapes with its favorable mechanical characteristics results in high performing composites. These technologies are finally combined in a simultaneous joining and forming process within a press: A part produced by rapid prototyping merges with a tailored composite blank out of unidirectional fiber-reinforced plastics. All these manufacturing technologies are connected to each other to accomplish a continuous production as demonstrated in Figure 3. Using photonic-based technologies, flexible handling strategies and quality assessment the process chain can be adjusted flexibly to the needs of the individual part. Hence, it offers an automated solution for prototype and low volume production of parts having superior mechanical characteristics.

The "LightFlex" process chain does not only provide a flexible production of lightweight prototypes, but also forms a complete production line from the manufacturing of the semi-finished product to the finishing of the final product. For this reason, the process chain allows to adjust a product's characteristic in

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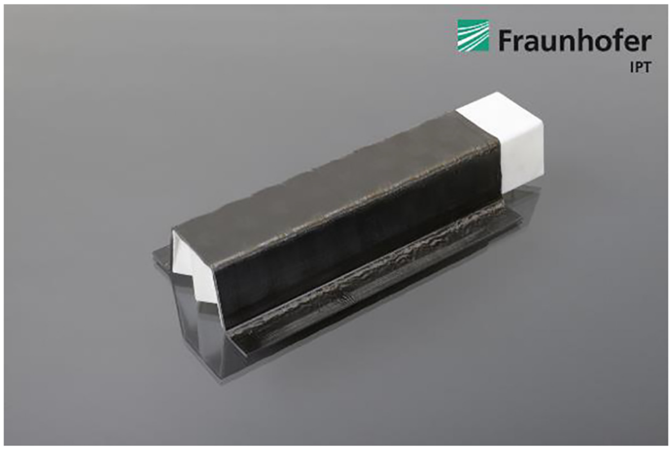

FIGURE 1

Hybrid thermoplastic prototype with 3D printed structure (PA12) and tailored composite blank (PA6/CF). [Guido Flüchter, Fraunhofer IPT].

order to meet the desired requirements. It also offers the possibility to apply a connected and intelligent production within the context of "Industrie 4.0". First trials for an intelligent production system are mainly adapted to conventional manufacturing technologies, such as the machining of metals. But until now, less research has been done with respect to the processing of composite materials. On the one hand, this can be explained by less mature process technologies for these materials in comparison to metal processing technologies. Composites are fairly new materials which is why process knowledge has not yet evolved compared to conventional materials. On the other hand, the anisotropy and heterogeneity of fiber-reinforced plastics

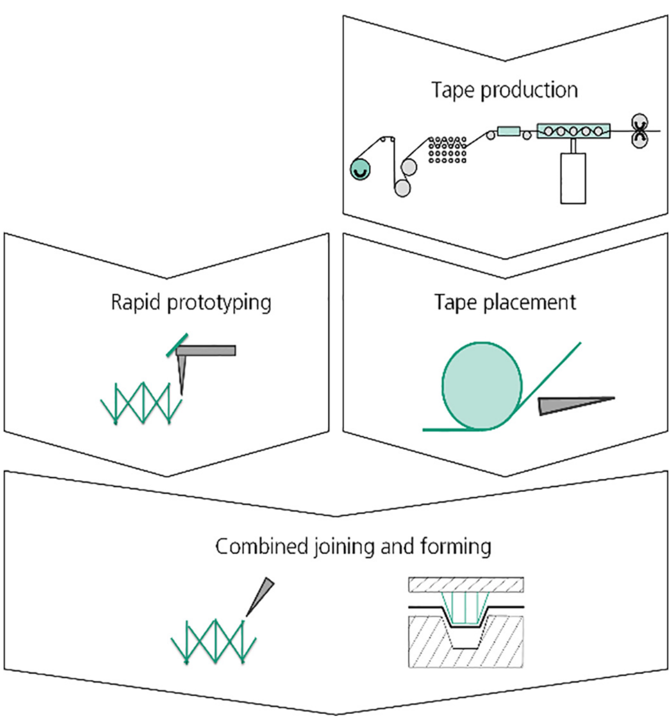

FIGURE 2

Flexible production technologies used in the "LightFlex process chain.

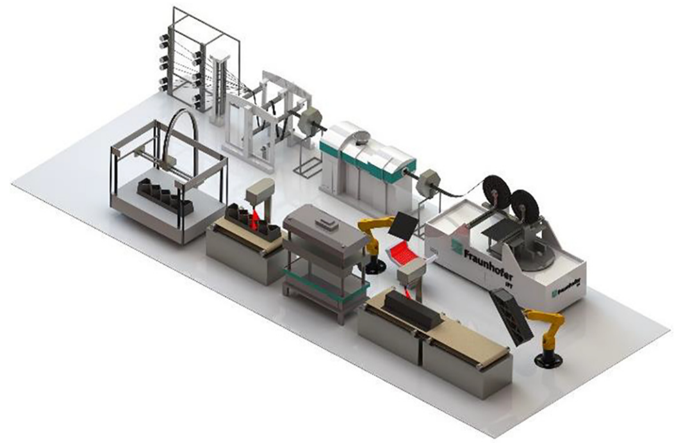

FIGURE 3

The "LightFlex process chain. [Fraunhofer IPT].

makes its process control more sophisticated. The great benefit of composites is that they offer a high variety of combinations giving an ideal platform for customization and smart manufacturing. Nevertheless, with the growing freedom of design the degree of complexity will increase, too, resulting in new challenges for production engineering.

Essential for the smart and flexible manufacturing of composites are the influences of process parameters on the subsequent steps. This requires profound material and process knowledge. In the case of tape placement, information about the type of tape and its material characteristics can have significant effects on the process parameters for the automated tape placement process. The homogeneity of fiber distribution, the degree of fiber impregnation as well as the tapes' roughness are further characteristics which can influence the tape placement process. Consolidation force, angle of incidence, absorbed energy and process velocity need to be adjusted in order to support contact and autohesion and, thus, the consolidation quality between each layer. Next to process parameters, the motion system of the tape placement process depends on geometrical tolerances of tape width and thickness. These can be caused by inaccuracies during the production of the tape and lead to imperfections during tape placement. Tape paths cannot be placed accurately next to each other resulting in geometrical inaccurate parts. Consequently, an exchange of detailed tape characteristics between tape manufacturing and tape processing as well as in-depth knowledge about the process are essential to enhance the quality of the finished part. Automated information exchange and a continuous feed of quality related tape data into the automated tape placement system is the desired destination of producing composite parts. It is a first step toward a smart production.

A potential of digitizing a process chain and interconnecting data is not only the adjustment of the tape placement process on the quality of the used material. It also ensures the traceability of relevant data of one specific product and creates a digital footprint. Process relevant data are collected, saved and can be uniquely assigned to a produced part. This can be done on a micro level concerning one production step or on a macro level including the whole process chain. It can also happen on a global level considering the interaction of various companies. Exchanging the digital footprint from one production step to the other or even between companies allows to trace back each quality related issue. This can be especially relevant for products, which are subjected to strict certifications, such as in the aerospace or medical industry.

In addition, capturing process data allows for an evaluation of the process itself. It is assumed that these data can be used as a closed-loop feedback system for optimizing the process as well as making it more intelligent. This can especially be helpful for processing composites. As indicated earlier, the robustness of composite manufacturing technologies suffers from the material's complexities. Creating a data lake based on individual digital footprints and analyzing the data can be a significant help in understanding the process. This empirical database can also be used for assessing the quality of the produced part within the process. Consequently, the optimization of production processes and the extensive knowledge about them are accelerated. This results in less costs and higher effectiveness. Especially, flexible manufacturing technologies, such as the automated tape placement, are a suitable environment for testing the feasibility and justifying its implementation. The above stated variety of process parameters of the automated tape placement system and its possibility of manufacturing diverse geometries allows the interaction of diverse settings for a flexible production.

The adaptive and connected production of composites still faces obstacles in its realization. First, the definition of suitable hardware and software is challenging due to either non-existing or non-suitable solutions. The increasing amount of system providers as well as their high costs, the uncertainty of a system's durability and the difficulty of backward compatibility, e.g. of controller components and hardware, are few examples of barriers hindering the willingness for implementation. For companies it is difficult to see the benefits from these investments. Second, data security has to be emphasized in order to enable secure data storage as well as information exchange and to withstand hacker attacks. Legal frameworks need to be created to face security failures and to ensure intellectual property rights.

When it comes to implementation, further barriers can emerge. The integration of the "LightFlex" process chain unveils such relevant and hampering issues for a successful implementation: On the one hand, there exist obvious barriers such as interconnecting machine hardware and controls based on standardized protocols. These obvious barriers can be addressed by accurate preparations of specialists in this field. On the other hand, there exist hidden barriers, which come up during implementation and are caused by the novelty of application. For instance, the results of "LightFlex" project show that transferring process and quality data from one process step to the other must be carefully considered as processes differ in their data acquisition methods. The discontinuous process of tape placement requires path-dependent data although the continuous process of tape production primarily provides time-dependent data. Especially, the discontinuous behavior of the automated tape placement is challenging as it implies repeated cutting of material, which makes it difficult to assign quality data to a specific layer or tape path. These barriers show that digitizing and connecting a process chain including data transfer from one step to another come across risks which are hard to quantify. Research in this area stimulates a connected and adaptive production of composite materials, which is necessary to reduce costs and make the material more attractive for future applications.

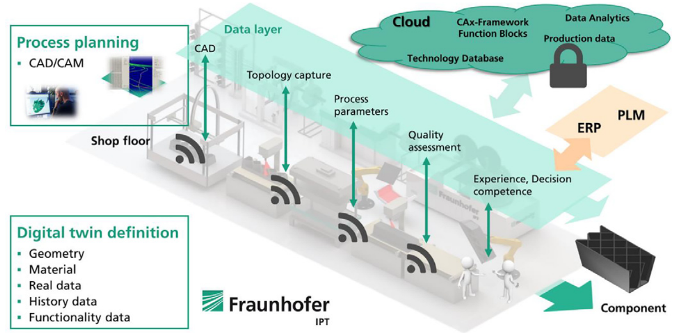

FIGURE 4

Connected, adaptive production for lightweight components. [Fraunhofer IPT].

In the coming year of "LightFlex" the Fraunhofer IPT will investigate methods to connect each step of the process chain, especially focusing on connecting tape production with tape placement. The aim is to connect the data recorded during tape production to the process parameters of the tape placement process. By capturing the data of each step, a digital footprint of the whole process chain can be assessed, evaluated and used as a feedback system. The findings of "LightFlex" can help companies to benefit from Industrie 4.0 and to get a roadmap for implementation.

The "LightFlex" project reflects the overall strategy of the Fraunhofer IPT on enforcing a networked, adaptive production. A holistic perspective is shown in Figure 4. The data layer represents the machines on the shop floor including their digital twins. An industrial cloud solution provides the data and application storage and offers flexible accessibility and adjustability. Existing enterprise resource planning (ERP), product lifecycle management (PLM) systems and more can also be connected. This perspective deals as a guideline for implementing the ideas of Industrie 4.0 in the context of lightweight production.

As a conclusion, the "LightFlex" project draws attention to the wide range of composite materials and shows how to connect flexible manufacturing technologies in order to exploit its versatility. This kind of a smart and flexible process chain opens up a chance for the automated and adaptive processing of lightweight components. The automated tape placement offers a suitable environment for testing different setups of intelligent processing as it is able to exploit the versatility of composite materials. The project does not only show how to produce composite parts flexibly, but also gives an insight into Industrie 4.0 for lightweight components. Further research in this field can open up new chances to stimulate the use of composite materials by decreasing expenses for production.

The project »LightFlex – Photonische Prozesskette zur flexiblen, generativen, automatisierten und wirtschaftlichen Herstellung individuell angepasster hybrider Leichtbauteile aus thermoplastischem Faserverbundkunststoff« (No. 03XP0013B) receives financial support from the German Federal Ministry of Education and Research (BMBF). We thank the BMBF and all academic and industrial partners of the consortium.