# FLEXIBLE & AUTOMATED PRODUCTION OF COMPOSITE PARTS

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**Keywords:** tape placement, thermoforming

## Abstract

*The combination of laser-assisted tape placement and thermoforming enables the production of tailored components in various shapes and lot sizes by exploiting the synergies of efficient primary shaping and reshaping technologies. This was demonstrated by Fraunhofer IPT within the European large scale project »FibreChain«.*

## 1. Introduction

High performance components and their efficient production will form one of the most important key factors for the European industry. The project “Integrated Process Chain for Automated and Flexible Production of Fibre-Reinforced Plastic Products (FibreChain)” aims at the development of automated manufacturing systems and processes for fibre-reinforced thermoplastic composites components addressing intersectoral customers.

To achieve a flexible volume production, the synergies of efficient primary shaping technologies such as laser-assisted tape placement and reshaping technologies such as thermoforming are fully exploited. Tape placement enables with a single unit the automated production of large structural components (e.g. fuselages, wings), developable parts (e.g. pipes, tanks, shafts, tailbooms), tailored composite sheets as well as the local reinforcement of finished and semi-finished goods. Whereas tape placement is one of the most flexible processes available, thermoforming is one of the most productive. Thermoforming enables the reshaping of composite sheets and tubes (tailored, local reinforced or standard) into complex shapes (e.g. car body components, fuel lines) in cycle times of less than a minute.

Following the processes tape placement and thermoforming as well as some of the results achieved by Fraunhofer IPT will be presented.

## 2. Laser-assisted tape placement

Laser-assisted tape placement is an out-of-autoclave process which provides high lay-up rates at comparatively low investment costs. By using an energy-efficient laser system as the heating source, the required laminate bonding energy can be transferred with high accuracy to the nip point without wasting energy. The laser system only heats a defined area with a minimum amount of energy. Thanks to the fast reaction time of the laser system, the temperature can also be controlled very precisely. [1, 2] Due to the generative approach a lot of different part geometries can be realized. (Figure 1)

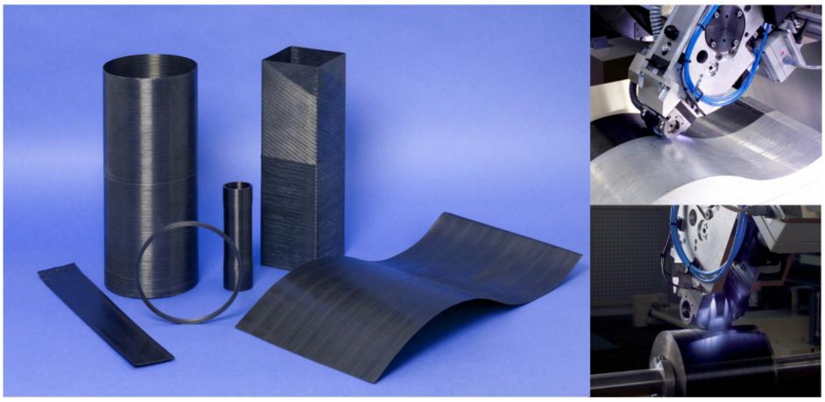

**Figure 1.** Process and shape diversity of laser-assisted tape placement

One of the possible applications is the substitution tape placement processes using thermosetting prepregs for the manufacture of structural components. Figure 2 shows a tape placed quasi-isotropic laminate meant as demonstrator panel for structural applications.

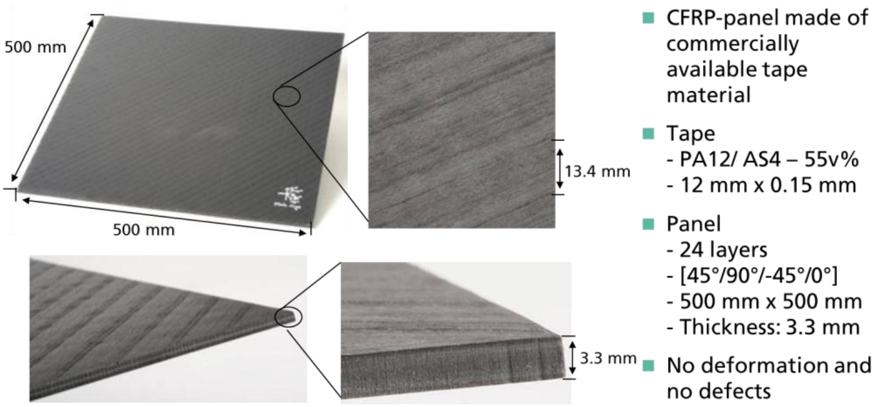


**Figure 2.** In-situ consolidated quasi-isotropic laminate made with laser-assisted tape placement

In a sensitivity analysis it could be demonstrated that varying that lay-up rate has no effect on the laminate bonding quality as long as a sufficient laser power is supplied. Important is the achievement of the optimal process temperature and that the consolidation system enables a sufficient consolidation length for a given lay-up rate.

Next for direct part production laser-assisted tape placement can also be used local reinforce components and semi-finished goods.

### *2.1. Local reinforcements*

It has been demonstrated that in laser-assisted tape placement, composite laminates combined with different types of fibers (e.g. carbon, glass), reinforcements (e.g. fabric, unidirectional), matrix systems (e.g. PA 6, PA 66, PA 12) and materials with strong varying colors or optical absorption properties can be processed using a diode laser system. The quality of the welding zone between the base composite laminates and the placed reinforcement tape have been evaluated with a 90° mandrel peel test. The reinforcements have been produced with a lay-up rate of 300 mm per second. The results are summarized in figure 3.

| Sheets / Tapes | PA12/carbon | PA 6/ carbon | PA66/carbon |
|---|---|---|---|
| PA 12/ carbon | ++ (could not be peeled, critical energy always > 8 N/mm) | - (max. 1,7 N/mm) | - (max. 1,6 N/mm) |
| PA12/glass | + (max. 4,4 N/mm) | - (max. 1,5 N/mm) | - (max. 1,7 N/mm) |
| PA 66/ carbon | - (max. 2,1 N/mm) | + (max. 7,3 N/mm) | ++ (could not be peeled, critical energy always > 8 N/mm) |
| PA 66/ glass | / (not tested, low critical energy below 2 N/mm expected) | - (max. 2 N/mm) | - (max. 1, 8 N/mm) |

sufficient laser power for tested lay-up rate (green frame) | insufficient laser power for tested lay-up rate (red frame)

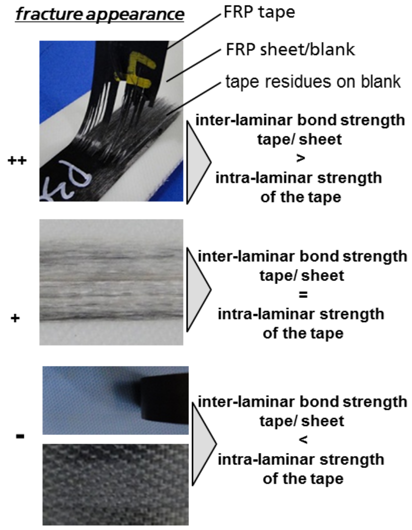


**Figure 2.** Overview of reinforcement trials with different material configurations at a lay-up rate of 300 mm/s

The mark "++" indicates a very good weld strength, that exceeded the intra-ply properties of the tape at the tested load case. The mark “+” indicates good adhesion between tape and blank. The inter-ply properties are similar to the intra-ply properties of the used tape at the tested load case. The mark "-" indicates a low joint strength. Furthermore, the critical energy needed to peel the tape is listed.

As expected, the combination of two identical materials did result in the highest weld strength, as similar chemical, thermal and optical properties of the joining partners are available. When joining different matrix materials it is important to ensure that the chosen process temperature fits to both joining partners. The more thermal stable material need to be fused without degrading the joining partner that is less thermal stable.

Using an optical heating the absorption properties of the used material in respect to the used wavelength of the used laser system is important. Different fiber-reinforcements can result in different optical absorption properties. The process can be adapted to joining two materials with different optical properties by adjusting the laser power distribution via the setting of the laser angle.

The fact that the PA66/GF blank could not be joint in the given test plan because of its low absorption degree in the near infrared spectrum, in conjunction with high welding temperature, high lay-up rate and limited available laser power. Welding a PA66/CF tape on PA66/CF blank at the same process conditions is been done with ease, since both joining partners absorb 85% to 90% of the used laser energy close to surface. [3, 4]

To combine the structural performance of UD-tapes and good price performance ratio of hybrid parts on complex shapes a subsequent forming process is required [5].

## 3. Thermoforming tape placed and reinforced components

Thermoforming is a well established manufacturing method to produce high performance parts, with complex shapes in high quantities. By using unidirectional reinforced panels as well as multi-material laminates for the process, the possibilities can be further enhanced. A lot of knowledge is given in the field of forming fabric reinforced composite sheets. Less work has been performed in the rather new approach of forming UD-reinforced and multi-material panels.

The new approach comes with new challenges as varying heating behavior and thermal expansions as well as a more complex draping process in order to avoid wrinkles. These challenges can be met, as figure 3 illustrates.

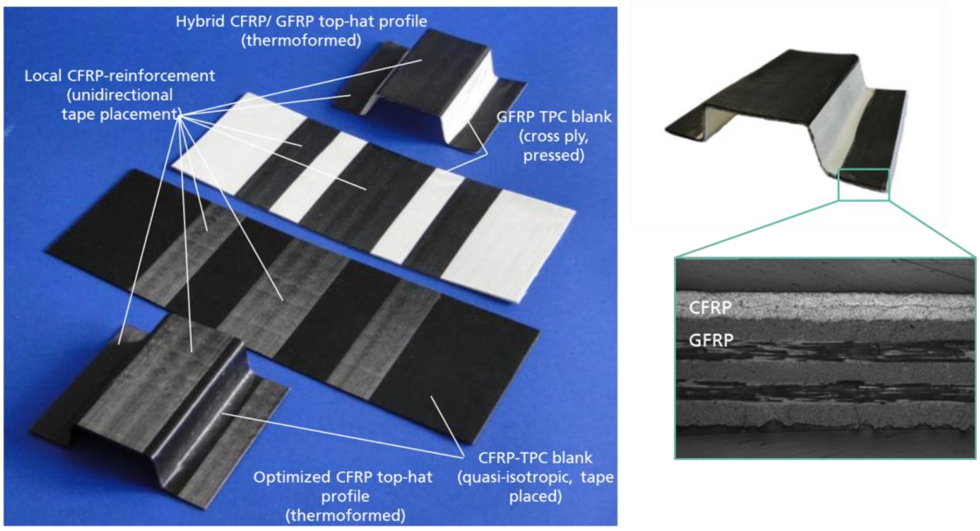


**Figure 3.** Locally reinforced and thermoformed parts

A novel approach is the thermoforming of pipes wound from thermoplastic UD-tapes. Winding bent pipes is a complex process in terms winding path creation, winding core manufacturing and de-moulding of the winding core. It also takes significant more time than winding straight pipes. Bent composite pipes as fluid supply systems however have a large industrial potential for example in the field of aerospace, chemical and power engineering. In addition such formable hollow frames have also potential application as lightweight frames structures in the field transportation, civil engineering as well as sport and leisure.

Fraunhofer IPT developed within FibreChain a new forming system that enables the homogeneous heating and forming of composite pipes. The forming process enables the manufacture of defined bending radii without compromising the diameter or mechanical performance of the original tube (figure 4). Important for the forming procedure was the development of suited forming moulds and stabilizing forming cores for the pipes. In addition knowledge of the relation between possible bending radius in respect to tube diameter and winding angles had to be established.

**Figure 4.** Straight tape-wound thermoplastic composite pipe, reformed to a bent pipe with thermoforming

## 3. Conclusion

It could be demonstrated that the combination of laser-assisted tape placement and thermoforming enables the production of tailored composites components with automated manufacturing methods. Components achievable by this approach combine high performance, sustainability, freedom of design and efficient producibility for low and medium lot sizes.

## 4. Acknowledgements

The authors would like to thank the European Community for funding the EU large scale project »FibreChain - Integrated Process Chain for Automated and Flexible Production of Fibre-Reinforced Plastic Products« at the European Community's Seventh Framework Programme under grant agreement no. 263385. Moreover we want to thank our industrial and academic partners.

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