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ScienceDirect

Procedia CIRP 66 (2017) 91 – 95

www.elsevier.com/locate/procedia

1st Cirp Conference on Composite Materials Parts Manufacturing, cirp-ccmpm2017

# Efficient production of tailored structural thermoplastic composite parts by combining tape placement and 3d printing

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**Abstract**

Thermoplastic composites, such as organosheets and unidirectional tapes, have become more and more popular in recent years. In certain high volume applications, they are often combined with non-reinforced plastics in overmolding processes. However, for product development or customized parts, more flexible process chains for the production of continuous fiber-reinforced thermoplastic parts are required. The automated placement of continuous fiber-reinforced thermoplastic tapes is an additive manufacturing technology which can be used to produce load-optimized tailored blanks. These blanks can be formed and joined with 3d printed structures to complex, function integrated, customized hybrid thermoplastic structures without the need of expensive molds.



*Keywords:* Thermoplastic tape placement, 3d printing, forming of thermoplastic composites, tailored composites

## 1. Introduction

Thermoplastic composites, such as organosheets and unidirectional tapes, have become more and more popular recently. While these types of materials have been used in high performance application such as aerospace industry for decades they are now emerging in more cost sensitive and high volume industries. Hence, efficient processing of these materials becomes more important.

Furthermore, for certain applications, e.g. consumer goods or automotive, thermoplastic composites are often combined with non-reinforced thermoplastics [1]. One possible production method of these hybrid thermoplastic parts is the overmolding process in which the thermoforming of thermoplastic composites is combined with an injection molding process.

However, for product development, customized parts or waste reduction, more flexible process chains for the production of continuous fiber-reinforced thermoplastic (CFRTP) parts are required. The automated placement of continuous fiber-reinforced thermoplastic tapes (ATP) is an additive manufacturing technology which can be used to produce load-optimized tailored blanks.

Several commercial solutions for the stacking of thermoplastic tapes with only local consolidation exist and increased production rates are recently achieved [2]. However, this process requires a time and energy consuming post-consolidation step, e.g. using expensive pressing equipment.

In contrast, the thermoplastic tape placement with in-situ consolidation is nowadays still mainly used for high performance applications or for winding of pipes and vessels. [3,4] In fact, such machines are mainly robot based and are more comparable to automated fibe-placement systems (AFP). Hence, they are not optimized for high volume manufacturing but for manufacturing more complex 3D shapes. Furthermore, expensive heating units such as diode lasers are used. [5] In this paper, a novel process and system which utilizes infrared for the in-situ tape placement of tailored thermoplastic blanks are presented. The influence of the production parameters on the resulting material properties is investigated.

Furthermore, a new approach of processing the resulting tailored thermoplastic composite blanks is investigated. These blanks can be formed and joined with 3d printed structures to complex, function integrated, customized hybrid thermoplastic parts without the need of expensive molds by using 3d printed structures. Finally, possibilities and methods to integrate these technologies into a connected process chain are presented.

**Nomenclature**

| | |
|---|---|
| AFP | Automated fibre placement |
| ATP | Automated tape placement |
| CFRTP | Continuous fibre reinforced thermoplastics |
| SLS | Selective laser sintering |
| b | thermal effusivity |
| $c_p$ | Specific heat capacity |
| $T_A$ | Temperature of joining component A |
| $T_B$ | Temperature of joining component B |
| $T_C$ | Contact temperature in joining zone between two components |
| $T_M$ | Melting Temperature |
| $T_3$ | Preheating temperature |
| $\lambda_\perp$ | Thermal conductivity perpendicular to the surface and fibre orientation |
| ρ | Density |

## 2. Manufacturing of tailored thermoplastic composite blanks

### 2.1. Tape placement with in-situ consolidation

In ATP of thermoplastic tapes, it has to be distinguished between two different processes. In several applications the thermoplastic tapes are just locally tacked [2] or not fully consolidated during the lay-up process [6]. Hence, a post-consolidation process in an autoclave or press is necessary.

Since several decades the AFP of thermoplastic tapes with in-situ consolidation is researched [7,8]. The main advantage of this process is, that the consolidation of the different tape layers takes place directly during the lay-up so that a time and energy consuming post-consolidation becomes redundant. Usually, the in-situ consolidation is achieved by heating up the feed tape above melting temperature before it reaches the nip-point between consolidation roller and laminate, see fig. 1 [3].

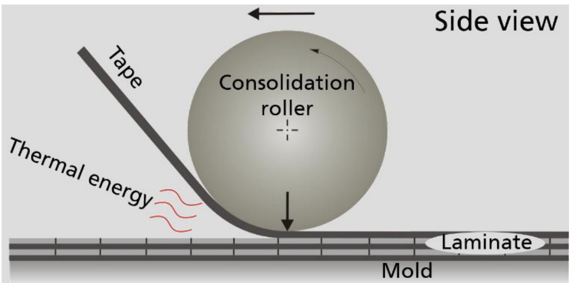


Fig. 1. In-situ tape placement process of thermoplastic tapes

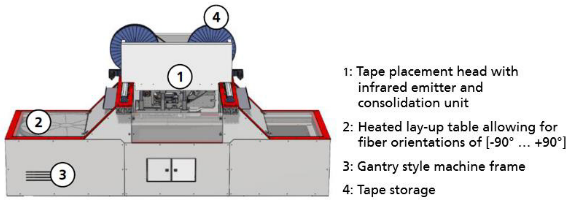


Fig. 2. Infrared based thermoplastic tape placement system

The thermal energy can be hot gas, infrared or laser radiation. The latter shows main advantages in terms of controllability and is hence often used for manufacturing of complex 3d structures [9].

### 2.2. Novel tape placement system

Fraunhofer IPT has developed a novel infrared based thermoplastic tape placement system, see figure 2. The ATP system consists of a gantry style machine frame in which an infrared based in-situ tape placement head is integrated.

Its unique consolidation unit, which consists of a synchronized steel belt, allows for cut and add on the fly. This means, that the thermoplastic tape can be laid up without starting and stopping of the process and is fully consolidated even close to the edge of the part. Both the tape placement head as well as the gantry system are controlled by the same Beckhoff NC system which allows a synchronization of all axis. Table 1 gives an overview of the technical data of the ATP system. Further information can be found in [10].

Table 1. Technical data of the standalone ATP system

| System properties | |
|---|---|
| Max. layup speed | 1 m/s |
| Diameter of table | 1.2 m |
| Max. power of infrared heater | 9600 W |
| Width of steel belt | 120 mm |
| Tape configuration | 3 x 25 mm tape width |

### 2.3. Results and material properties

The novel ATP system has been used to manufacture tailored thermoplastic composite blanks without post consolidation. Carbon fiber reinforced polyamide 6 tape, supplied by Celanese, has been used. The material properties are listed in table 2.

To investigate the optimal process parameters, several experiments have been performed. In preliminary studies, some optimal process parameters regarding layup speed, consolidation force, temperature of mold and temperature of consolidation unit have been found.

Table 2. Material data of thermoplastic tape

| Tape Material properties | Celstran CFT® PA6-CF60 |
|---|---|
| Polymer matrix | Polyamide 6 |