»MULTI-MATERIAL-HEAD« ONE TOOL FOR 3 TECHNOLOGIES: LASER-ASSISTED THERMOPLAST-TAPE PLACEMENT, THERMOSET-PREPREG-PLACEMENT AND DRY-FIBER-PLACEMENT

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ABSTRACT

Automated laser-assisted tape and fiber placement systems allow the stacking of unidirectional and non crimped fiber-reinforced tapes in any fiber orientation to produce load optimized and weight minimized multi-layered structures. Automated and reproducible tape and fibre placement processes allows short cycle times, a high fiber volume content and reduced scrap rates.
So far fiber-placement systems were specialized for processing of a limited material spectrum.

In contrast, the all-in-one »Multi Material Head« developed by Fraunhofer IPT is a flexible and cost-effective fiber-placement system especially developed for SMEs and research institutes.
The novel tape- and fibre placement system is a laser-assisted thermoplastic tape, thermoset prepreg and dry-fiber placement unit and accomplishes three technologies (thermoplast tape placement and winding, thermoset prepreg placement and winding as well as dry fiber placement) with one tool only. Flexibility focuses different kinds of common fiber-reinforced raw materials as well as a modular assembly and software architecture to realize flexible production of FRP parts as well as scientific process investigation (e.g. using different measurement devices such as IR camera, pyrometers, multi-point radiometers). So SMEs can handle different kinds of common fiber-reinforced raw materials with low mechanical effort.
Advantages of a laser-assisted fiber placement process are precise and swift temperature control, high lay-up rates and high opto-electrical energy efficiency of diode laser sources.

1 INTRODUCTION

The main advantages that fibre-reinforced plastics (FRP) have over metals is their potential for tailored material properties (especially improved mechanical properties) such as better strength-to-weight ratio and improved chemical resistance (especially in highly aggressive environments) [1]. The anisotropy of unidirectional and non-crimp fibre-reinforced composites with adapted fibre orientations enable lightweight load optimized multi-layered structures. Overdesign, excess material usage, component weight, energy, waste and cycle time can thus all be avoided [2, 3]. Therefore, FRP is increasingly gaining importance to meet the growing economic and ecologic requirements, such as

low carbon footprint. With numerous new applications in transportation (aviation, automotive, marine), energy industry and consumer goods fibre composite technology is one of the ground-breaking global technologies for weight reduction. In any application where a mass has to be moved composite lightweight structures offer huge benefits in terms of higher energy efficiency and improved system performance. In the transportation industries lightweight design and structures enable significant fuel savings, a reduction of CO2 or other polluting emissions; in machine tool industries they offer greater stiffness, faster acceleration, higher speeds and better damping. The excellent impact behaviour of FRPs has enabled improved passive safety through the use of novel crash elements which improve passive safety and already save lives on a daily basis [4].
Optimal lightweight design can be realized when the orientation of the reinforcement fibers are adapted to the load cases of the component. The use of conventional thermoplastic composite sheets which have a constant wall thickness can lead to an over-sizing outside of the areas with maximum stress. This results in increased material consumption and component weight.
Automated manufacturing of load-optimized FRP components by laser-assisted tape and fiber placement systems is superior in terms of reproducibility, short cycle times and high fiber volume content (e.g. 60 to 65%, depending on raw material quality) [5, 6].

Traditionally fiber placement systems, processing thermoset prepregs, are used in aerospace for the automated and reproducible production of load-optimized structural parts, such as fuselage sections or wing segments [1, 7, 8]. Due to the short cycle times while processing thermoplastics on the one hand or spread dry-fiber-rovings covered with adhesive in combination with established infiltrations methods on the other hand, thermoplastics as well as load-optimized semi-finished textile products are interesting for automobile industry [9, 10].

Chapter 2 deals with the principle of tape- and fibre placement. Chapter 3 focusses on the tape- and -fibre-placement-system »Multi Material Head«. Finally possibilities for the combination of automated fibre placement with rapid prototyping technologies are described in chapter 4.

2 PRINCIPLE AND POTENTIALS OF THERMOPLASTIC TAPE-, THERMOSET PREPREG - AND DRY-FIBER-PLACEMENT PROCESS

Tape- and fiber-placement-systems in general consist of robot or gantry unit, material storage and feed, cut and guiding units, consolidation roller and heat source (figure 1).

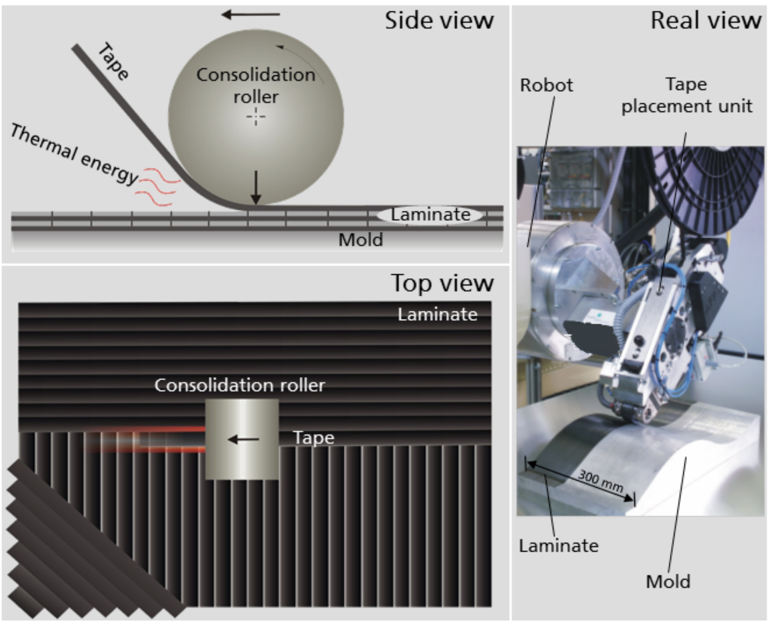

Figure 1: Principle of fiber placement

Based on the chosen semi-finished composite (thermoplastic tape, thermoset prepreg or spread dry-fiber-rovings covered with adhesive) the processing of composite parts is divided in prepreg- and infiltration route [11]. Dry-fiber rovings covered with adhesive (e.g. activated by thermal process energy), are not used for manufacturing components directly but for manufacturing of preforms instead (infiltration route). The preform has to be impregnated by using well-known impregnation processes, such as Resin Transfer Molding-processes (RTM) afterwards [12].

Unidirectional fiber reinforced tape, prepreg or spread roving covered with adhesive is uncoiled from a spool and fed next to a thermal heat source to the consolidation roller in the process zone. Thermal energy melts the surface of the thermoplastic tape, activates the adhesive of the spread dry-fiber-roving (in form of a binding material or powder) or increases tack and reduces viscosity of the thermoset matrix system. In addition to the incoming tape, prepreg or spread dry-fiber-roving the substrate is heated. Due the pressure of the consolidation roller, the incoming material is joined with the substrate. The moving of the tape and fiber placement system is added to a robot or gantry unit as an end effector.

Over the past decades laser-assisted tape-placement-processes proved to be the most energy-efficient and precise methods to applicate thermal process energy [13, 14]. The laser-assisted induction of heat allows a precise and swift temperature control without any heating of ambient components. Potentially, the precise and swift temperature control enables an in-situ-consolidation (out-of-autoclave process) while processing thermoplastic tapes [5, 6, 15, 16, 17].

Challenges that have to be met include the best choice of the laser source, the optics and the temperature control strategy.

The requirements of a tape- and fiber placement system base on the different material properties of thermoplastic tapes, thermoset prepregs and spread and bindered dry-fiber-rovings.

Thermoplastic tapes consist of unidirectional fibers impregnated and consolidated with a thermoplastic matrix system (e.g. PP, PA6, PA66, PA12, PES, PEEK). While processing thermoplastic tapes in an automated tape placement process thermal process energy melts thermoplastic matrix system of the incoming tape and the substrate. The incoming tape is joined with the substrate comparable to a welding process. During cool down of thermoplastic matrix system lower than its melting temperature molecular chains entangle [16]. In contrast to thermoset prepreg, a thermoplastic matrix system cures in an out-of-autoclave-process. Alternative processing of thermoplastic tapes in a tape- and fiber-placement-process in combination with an additional forming process is possible. Due to the separated consolidation process, semi-consolidated tapes can be processed [18]. While processing thermoplastic tapes or spread dry-fiber rovings covered with a thermoplastic adhesive in contrast to processing thermosets higher process temperature are necessary.

Thermoset prepregs consist of unidirectional fibers, which are pre-impregnated with a thermoset matrix system. Mostly epoxy, polyester, vinylester and phenol resin systems are used [19]. To prevent polymerization the pre-impregnated fibers need to be cooled during storage. Therefore guiding and cutting units of a prepreg-placement system have to be cooled and -in case of contamination- must allow an easy cleaning. The tack of the thermoset matrix system is increased by thermal process energy during the prepreg placement process.

From the point of view of material feed, dry-fiber-rovings covered with an adhesive need guiding units, which reduce fibre bending and transverse forces, because the fibers are stabilized only locally.

Figure 2 summarizes the most important differences between the three introduced fibre reinforced materials [20].

	Thermoplastic Tape	Thermoset Prepreg	Dry-Fiber-Roving (covered with adhesive)
	 Thermoplastic CFRP-Tape	 Thermoset CFRP-Prepreg	 Spread Dry-Fiber CFRP-Roving Binding material
Material properties	▪ Spread tows, which are impregnated with a thermoplastic matrix ▪ Unidirectional fiber direction ▪ At room temperature the fiber formation is stationary	▪ Spread tows, which are pre-impregnated with thermoset resin (prepreg) ▪ Unidirectional fiber direction ▪ Movable fiber formation and tacky matrix at room temperature ▪ Prepreg is covered with backing paper at least on one side	▪ Spread tows, which are covered with adhesive on one side ▪ Unidirectional fiber direction ▪ Filigree fiber formation at room temperature
Material storage	▪ No special requirements	▪ A cooled storage is necessary to keep the resin properties	▪ No special requirements
Thermal process properties	▪ Melting of the thermoplastic matrix at the surface ▪ Melting temperature depends on thermoplastic matrix material	▪ Reducing viscosity grade ▪ Increasing tack ▪ Viscosity grade and tack depend on temperature and thermoset resin	▪ Activating of the binding material, which covers fibers at the surface ▪ Activation temperature depends on binding material
Optical material properties	▪ Emission coefficient depends on temperature and angle	▪ Emission coefficient depends on angle	▪ Emission coefficient nearly constant
Consolidation/ Curing	▪ Consolidation depends on pressure and temperature during tape placement process ▪ With fully impregnated tapes an »in-situ-consolidation« is possible	▪ Activation of resin and increased tack during fiber-placement process ▪ Curing has to take place in a following autocalve process	▪ Dry-Fiber placement allows the production of preforms ▪ Preforms have to be impregnated e.g. in a RTM process

Figure 2: Properties of thermoplastic tape, thermoset prepreg and spread dry-fiber-rovings covered with adhesive

3 »MULTI-MATERIAL-HEAD« ONE TOOL FOR THREE TECHNOLOGIES

With respect of the different material properties Fraunhofer IPT developed a tape- and fiber-placement-system, which is able to process all of the mentioned materials: thermoplastic tapes, thermoset prepregs as well as dry-fiber-rovings covered with adhesive.

The Multi-Material-Head is one tool for automated laser-assisted thermoplastic tape placement and winding, thermoset prepreg placement and winding and automated preform-manufacturing (figure 3, [20]).

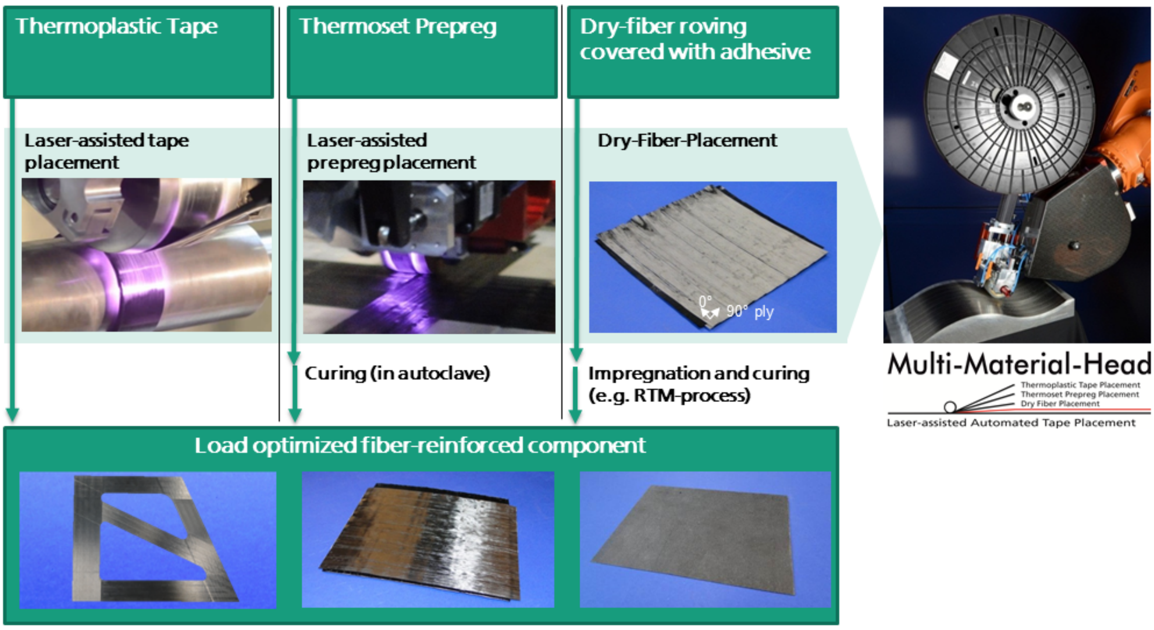

Figure 3: Manufacture of load-optimized fibre reinforced components using Multi-Material-Head tape- and fibre-placement system

The Multi-Material-Head-tape- and fiber-placement system has a modular assembly structure (figure 4), which allows the easy adaptation to the different material requirements, mentioned above. Figure 4 visualizes the material guiding, fed and cutting units, tape speed and tension controll, heat source (laser optic), IR-camera for measuring of process temperature and consolidation unit.
Instead of the integration of a laser optic also infrared emitter or hot gas torch can be installed. Instead of the IR-camera the integration of pyrometers is possible.
An additional element (not shown) removes the backing paper during processing of thermoset prepregs. All these components are assembled on a carrier structure from one side. Electrical components (e.g. for process control) are placed on the backside of the carrier structure. The fiber and tape placement system can be added as an end effector to industrial jointed-arm and linear gantry robots in variable manufacturing cells.

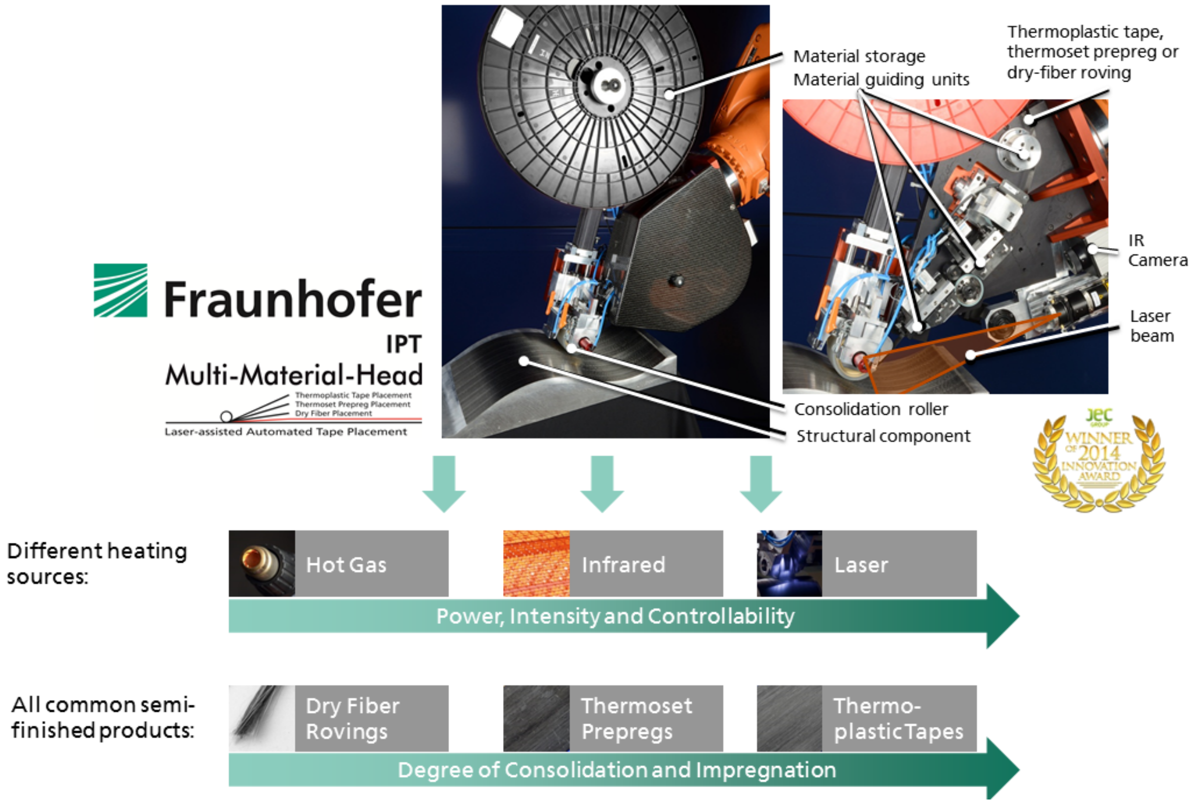

Figure 4: Multi-Material-Head developed by Fraunhofer IPT

Due to it’s modular assembly the Multi-Material-Head-tape- and fiber-placement-system reduces mechanically effort and increases flexibility. Flexibility focusses different kinds of common fiber-reinforced raw materials, a modular design as well as software architecture. A flexible production of FRP parts as well as scientific process investigation (e.g. using different methods and measurement devices (IR cameras, pyrometers, multi-point radiometers) is possible. So SMEs can handle different kinds of fiber-reinforced raw materials commonly used with lowest mechanical expenditure.
The Multi-Material-Head received the JEC Innovation Award in the category »Process« in Paris in 2014.

4 COMBINATION OF FIBER-PLACEMENT, THERMOFORMING AND RAPID PROTOTYPING

In addition to the development of tape- and fibre-placement-systems and -processes Fraunhofer IPT also focusses the connection of single technologies to complete industrial process chains.

An actual example is the combination of tape production, fiber-placement, thermoforming and rapid prototyping to realize a fast and cheap production of individualized products. In the BMBF-funded »LightFlex«-project (funding number 03XP0013E) a solution for the balancing act between geometric complexity on the one hand and mechanical product properties on the other hand will be developed (figure 5).

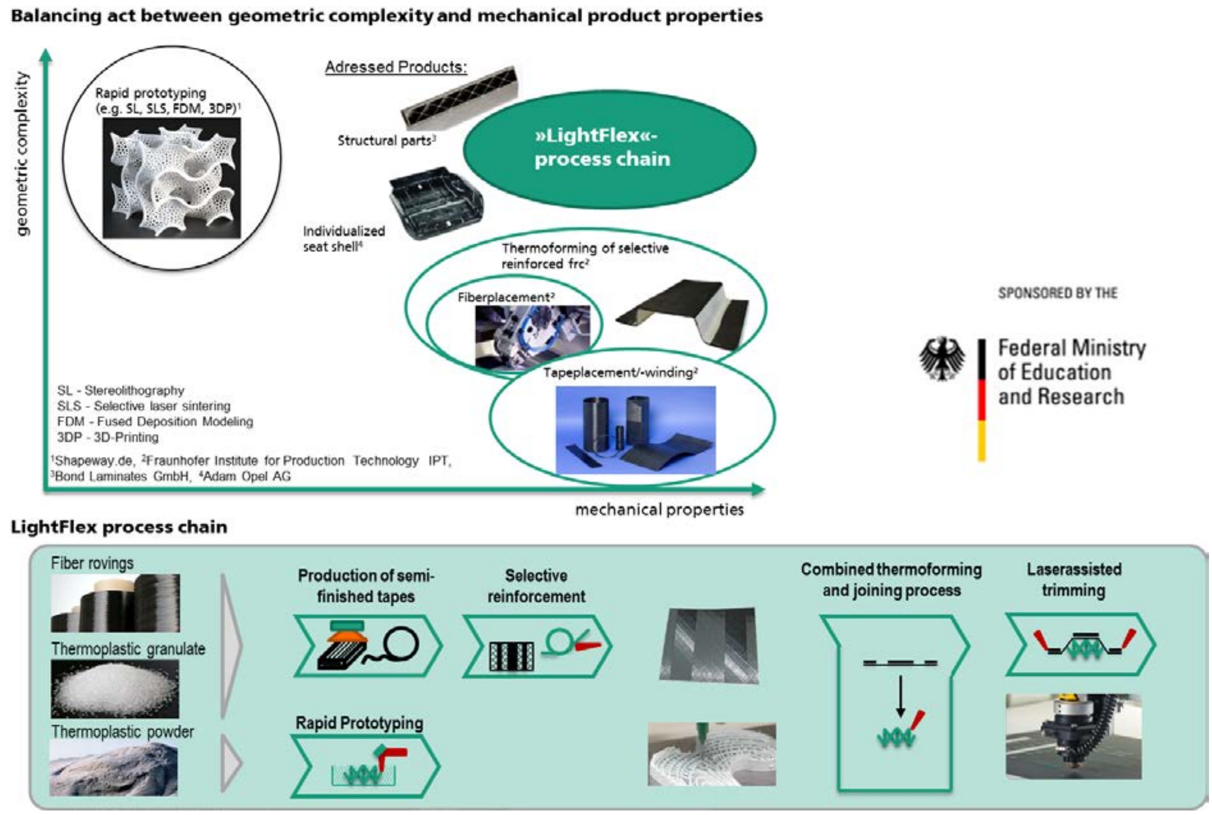

Figure 5: Balancing act between geometric complexity and mechanical product properties

Therefore in rapid prototyping manufactured components (e.g. reinforcement rips and other kind of stiffeners or assembly components) are joined in a thermoforming process with load-optimised composite blanks. The load-optimised composite blanks are selective reinforced by laser-assisted thermoplastic tape placement. Due to the combination of tape placement and thermoforming process material costs can be reduced by using semi-consolidated tapes (see also chapter 2). To shorten the process chain the tape extrusion (including quality assurance) will be integrated into the tape placement system during the project.
The »LightFlex«-project focusses on the individual prototype and small series production.

5 CONCLUSIONS

Automated manufacturing of fibre reinforced composites structures by using automated laser-assisted tape and fiber placement systems is highly desirable and advantageous with regard to reproducibility, cycle times and fiber volume content. Especially the stacking of unidirectional and non crimped fiber-reinforced tapes in any fiber orientation allows the production of load optimized and weight minimized multi-layered structures. The novel »Multi Material Head«-tape- and fiber-placement-system developed by Fraunhofer IPT, is a laser-assisted thermoplastic tape, thermoset prepreg and dry-fiber placement unit. So it combines three technologies within one tool: laser-assisted thermoplastic tape placement and winding, thermoset prepreg placement and winding as well as dry-fiber-placement for automated preform manufacturing. Especially SMEs can fulfill orders with changing materials without the need of investing in different placement units. Research and development institutes benefit of the modular construction and customizable software architecture.

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