A New Fiber Placement System for an Automated Production of Thermoplastic Composite Structures

Manfred Weck; Rainer vor dem Esche

1. Introduction

Technical progress in the area of mechanical and automobile engineering is always connected with progress in material development. Therefore importance and reasons of the material technologies for the development of components and systems are obvious. The aim of the employment of new materials are:

- enabling the manufacturing of new products,
- quality improvement of existing products and
- reducing costs.

Fiber reinforced plastics is a material group, which promises considerable progress in these aspects. These expectations are results from the successful employment of Fiber reinforced plastics in sophisticated areas like aviation, motor racing or competitive sports. Main arguments in all applications is the attempt to reduce weight or mass forces. High costs are of less importance in these applications. But for further application it is necessary to reduce production costs. Using long fiber reinforced plastics enables the reduction of production time up to 600%. There by this production cost are decreased /1/.

Therefore a Fiber Placement System was designed and installed at the Fraunhofer Institute of Production Technology. With this system it possible to manufacture components in Fiber Placement or Winding Technology with production speeds higher than 1 m/s.

2. Winding Strategy for Longfiber Reinforced Plastics

The winding technology is one of the oldest production methods for fiber reinforced plastics. First application can be found in 1948 at Hercules INC. for the fabrication of rocket nozzles /2/.A review of the last 20 years shows that the winding technology developed with an above average evolution. Simple machinery kinematics, high economic and technological efficiency, and an high degree of automation are the attributes of these technology.

Whereas thermosetting matrices use a hardening process following the production, thermoplastic materials offer the advantage of melting, compacting and cooling down in one process step. Increased efficiency can be achieved. *Figure 1* shows the principal procedure for winding thermoplastic materials. Coming from stock feed, the tape passes different rollers which measure the tape speed and generate the tape tension. Depending on the tape heating energy and efficiency in the nip point area '2' the tape can additionally be preheated from one or both sides in the area '1' or already heated up above melting temperature to reach good consolidation the mandrel should be tempered or preheated with radiators or heating elements. Pressure can be applied to the laydown point using rollers, tape tension or shoes.

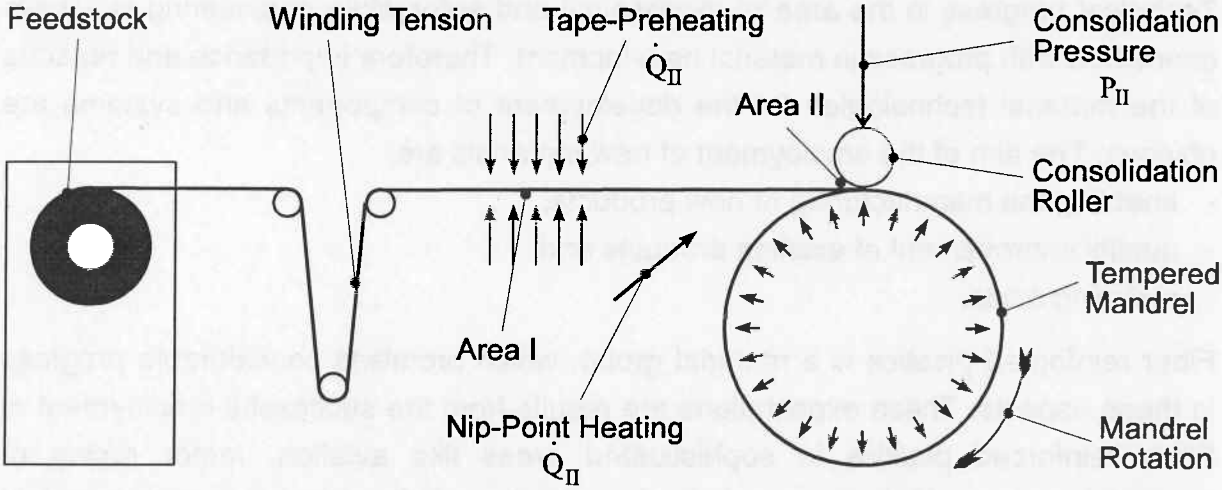


Fig. 1: Schematic graph of a thermoplastic winding process

The consolidation process can be subdivided into five essential steps:

- heating up the material above melting temperature,
- adjusting the joining surfaces by using cohesion and matrix flow,
- interdiffusion of macromolecules,
- compacting the material by using matrix flow and
- crystallisation of the matrix during cooling.

This clarifies, that process parameters like temperature, temperature distribution over tape cross section, pressure and cooling rate have significant influence on the consolidation quality. Compacting pressure, shown in figure 1 as P_{II}, is eliminating air bubbles. The pressure could be produced by using tape tension or cylinder rollers. For winding of non geodetic or concave structures a pressure roller is essential.

Different methods of energy input are used. Current methods are hot shoes, hotgas, open flame, IR-Radiator, CO_2- or Nd:YAG- Lasers. Advantages of non laser applications are low system and operating costs. The advantage of the laser power is the possibility to be controlled within milliseconds. A comparable amount of energy, focused in small local area within exactly defined intensity and time range cannot be reached by any other heat source. This is of almost importance for the production of non symmetric or concave structures, where constant tape speed and constant heating energy cannot be guaranteed. The polymer will be overheated or the temperature will not rise up to processing temperature.

Advantages of CO_2 lasers are better absorptance in polymers and therefore a higher degree of efficiency. Beam guiding of CO_2 light requires mirrors. This is the reason for difficulties in integration of this technology in machines with several axis. Nd:Yag laser light is guided by fibers and shows an advantage regarding freedom of motion and machine integration.

3. Fiber Placement Head for Manufacturing of Longfiber Reinforced Plastics.

Filament winding of thermoplastic composites involves placing a continuos filament onto a mandrel, heating the bond zone and applying pressure to consolidate multiple layers of fibers onto the mandrel. Typical winding machines employ a rotating mandrel while a fiber supply head is positioning the tape. The result is a typical winding structure with several cross sections uniformly distributed over the surface. Due to the high viscosity of molten thermoplastic, this might lead to trapping in voids within these areas. Influences on the material properties (*figure 2*) cannot be avoided. Better material characteristics can be achieved by placing tapes next to each other avoiding cross sections.

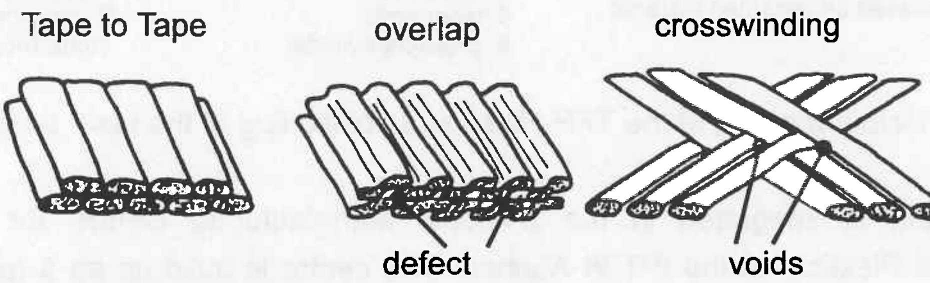


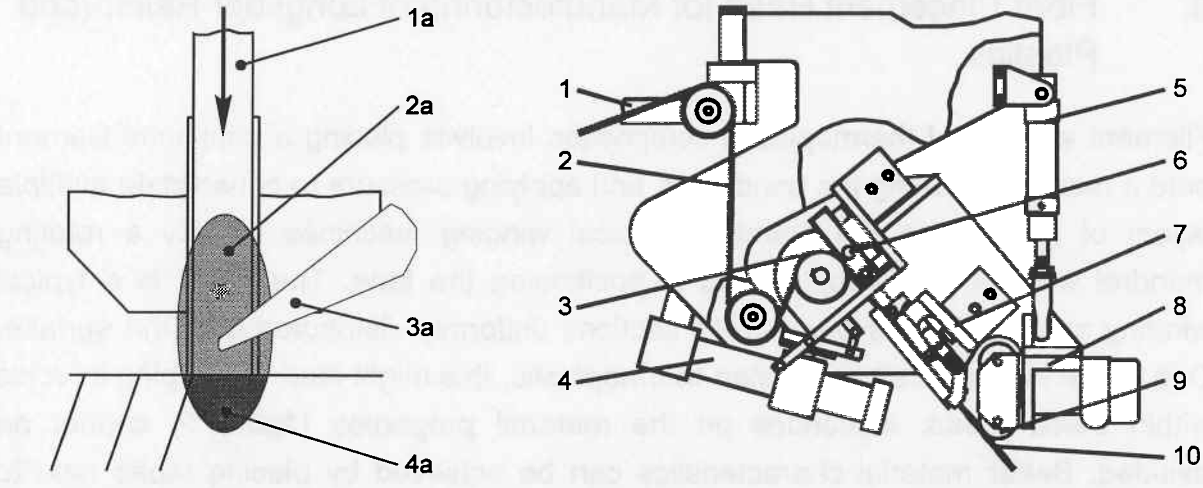
Fig. 2: laminate structures

An analysis of the tape laying process shows the following operations:

- A swivel arm has to guide the tape from feedstock to the processing head (TFP-Head),
- A twist distance has to compensate different orientations between feedstock and TFP-Head and guarantee proper tape handling,
- A driving roller feeds the material for starting a new path through the cutting unit to the consolidation roller,
- A cutting unit has to cut the incoming tape and supplementary guide and position it in the bonding zone,

- The tape heating takes place between the cutting device and the consolidation roller,
- The consolidation roller itself has to be adjusted to the mandrel surface. Therefore an automatic changing magazine is integrated to reduce non-productive time.

Figure 3 illustrates the orientation of the laser beam. The beam heats up the incoming material and the material on the mandrel. Both molten layers are compacting just in time by consolidation roller.



1a incoming material
2a energy focussed on incoming material
3a pyrometer beam
4a enery focussed on wounded material

1 swivel arm
2 distortion unit
3 feed unit
4 laser optic
5 pressure cylinder
6 speedometer
7 cutter
8 pivoted drive
9 pressure roller
10thermoplast prepreg

Fig. 3: principal drawing of the TFP-Head and positioning of the laser beam

The system is integrated in the „Flexible Manufacturing Centre for Longfiber Reinforced Plastics" at the IPT in Aachen. The centre is build up as a gantry robot system with two handling systems. Each of them has 4 linear and 4 rotational axis controlled by an Siemens RCM CNC. An 1.5 kW Nd:YAG laser is integrated. Manufacturing of complex components in winding or placement technology is possible.

4. Process Regulation and Controlling

Figure 4 shows, that the laser is direct by addressable by the CNC controller. Laser functions like „laser on" or „laser stand by" are switched and controlled by digital in- or outputs. The laser set value and the actual power value is set and controlled by an analogue interface.

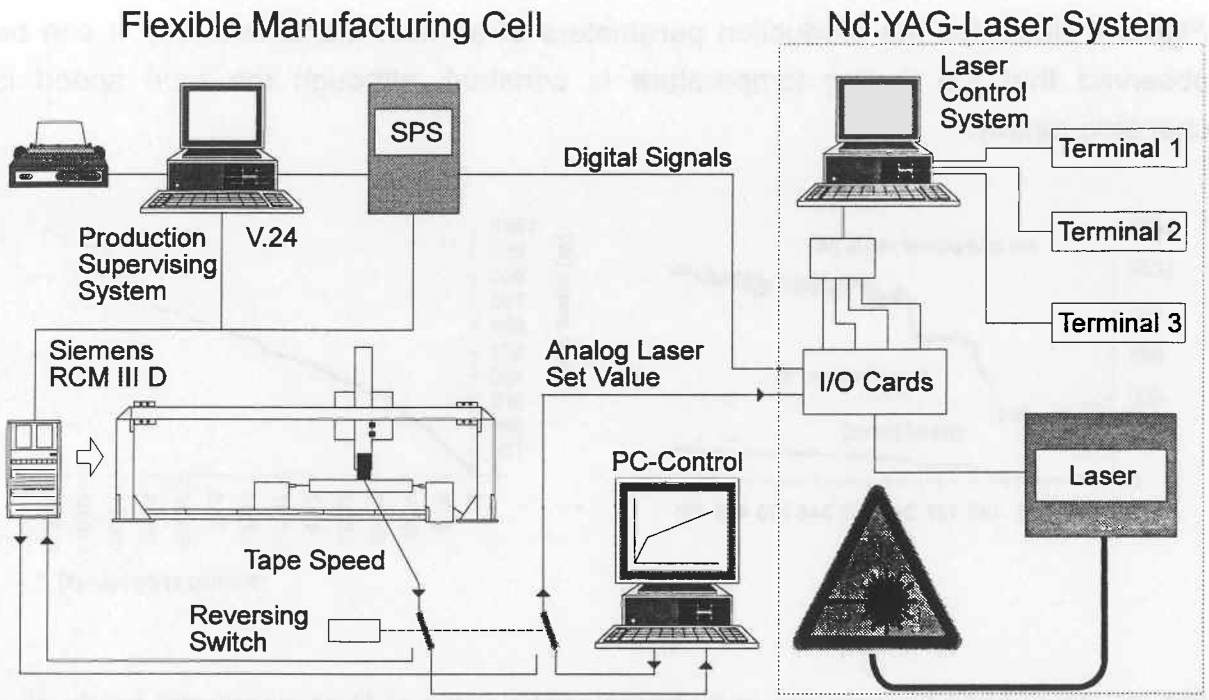


Fig. 4: Datalink between laser and manufacturing centre

The signal of the speedometer is analysed with an measuring rate of 2 ms. An experimental determined process function between tape speed and laser power is used for the set value.

Disadvantage of the system is, that there is no possibility to respond to changing environments, like changing material properties or soiled optic elements. Process control based on a modification of the process function is a solution for this. A pyrometer measures the fluxing temperature in the laser spot with a sampling rate of 12 ms. If the temperature leaves an defined set value range, the characteristic curve will be adapted in real time, illustrated in *figure 5*.

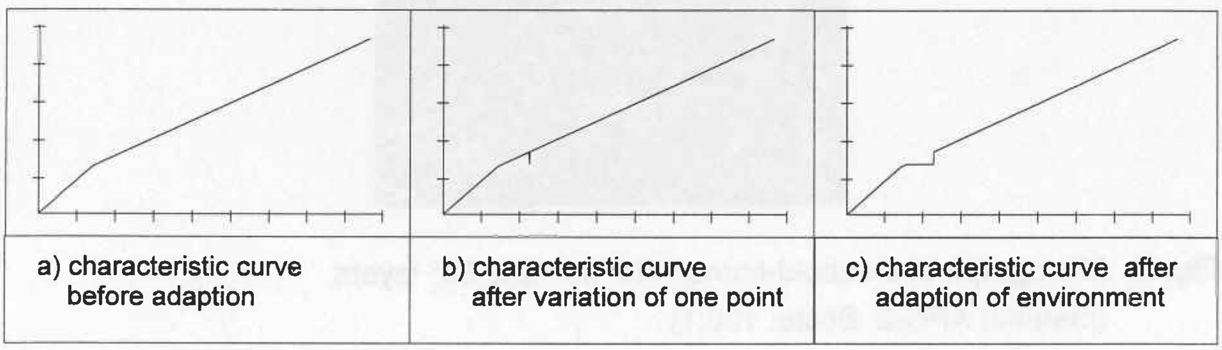
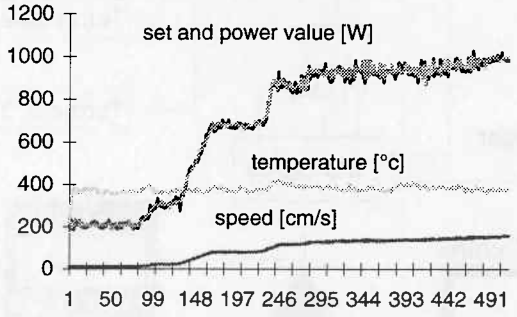


Fig. 5: principle drawing of an characteristic curve adaption

Figure 6 illustrates the production parameters of an fiber placement test. It can be observed that the fluxing temperature is constant, although the tape speed is changing rapidly.



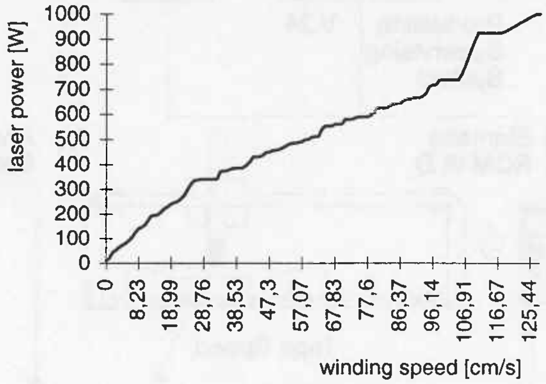


Fig. 6: production parameters and characteristic curve of fiber placement production with APC-2

Tests with PEEK/Carbon, natural and black coloured Glass/PP were successfully done. Round and square tubes were manufactured in winding and laying technologies with fiber orientations of 0°, 90°, ±45° and ±60°. The mandrels are heatable to modify the crystallisation behaviour. The material samples are analysed by DSC, ILS and micrographs. *Figure 7* shows an micrograph without voids and different fiber orientations. A boundary layer between single tapes can not be found. A sufficient consolidation was achieved.

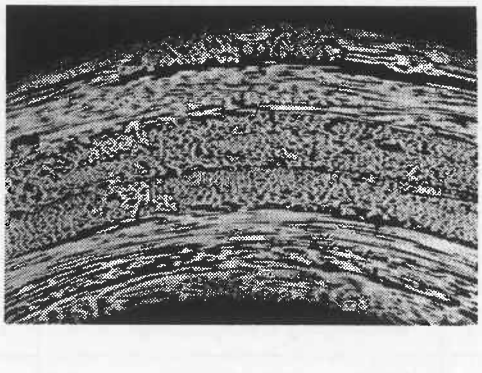


Fig. 7: Micrograph of a cuboid-corner with 90° and 60° layers (material APC-2, Scale: 130:1)

5. Conclusions

The tests carried out at IPT to produce components in fiber placement technology verified that an automated production with long fiber reinforced plastics is possible. *Figure 8* illustrates various demonstration tubes. Production speeds of 1.4 m/s producing APC-2 and Glass/PP materials with width of 6 mm show the high potential of this technology.

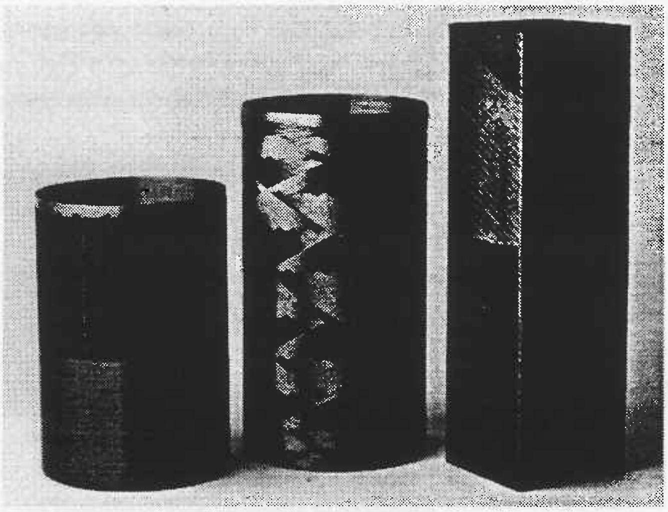


Fig. 8: Structures made from APC-2 tape (left to right: cylinder with true 0° reinforcement; wound structure with ±60° layer; cuboid with ±60° and 90° layers in fiber placement)

Hardening in an oven is not necessary because of the physical solidification process. Therefor it is possible to produce 600 % faster than conventional winding of thermoset materials. The process control based on modifications of a characteristic function guaranties high controllable production quality.

Latest examinations are employing following steps :

- production methods for manufacturing flat structures in tape laying technology
- processing materials with width up to 35 mm
- examination of different materials like Aramid/PA or Carbon/PVDF

The acceptance from laser assisted production technologies for long fiber reinforced plastics is joined with price levels of suitable laser systems in future. High power diode lasers have potential to combine high power with low investment and operating costs /8/. Such systems will give significant advantage in future. They combine high flexibility and power with good control properties.

6. References

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