# INLINE CONTROL OF TAPE WIDTH DURING AUTOMATED TAPE PLACEMENT

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## Abstract

Automated tape placement offers to manufacture large scale structures with defined lay-up and locally varying fiber orientation. Both, thermoset and thermoplastic based tapes can be processed. Especially thermoplastic based tapes do offer possibilities to run the process with in situ consolidation, i.e. the final required consolidation level is reached during placement and no post consolidation is needed. Based on a good material knowledge, prediction of tape deformation during processing is possible. Since tape manufacturing processes do not deliver perfect tapes with regards to e.g. fiber-matrix-distribution, impregnation, tape surface roughness, tape cross section shape, tape dimensions, etc., predictability is only given if each individual tape batch is characterized carefully. An inline control of all required characteristics is hardly possible.
Consequently indirect characterization by inline detection of tape contour both, directly before and after passing the consolidation section, by means of light sectioning sensors is used. The aim is to identify the tape deformation and using phenomenological models to adapt processing parameters automatically. The development of the phenomenological models, their implementation in a targeting hardware, and its use as a cyber physical system in the process control unit of the placement system is described.

## 1. Introduction

Laminates having continuous fibers with a defined aligned orientation do offer most favorite lightweight properties. Formerly hand lay-up of prepreg was used when shell elements, whether small or large sized, were aimed. Increasing demand of such components, e.g. in the aerospace industry, resulted in development of automated placement techniques. Nowadays automated placement of thermoset based prepreg systems is state of the art and not only thermoset resin impregnated fibers, but also dry fibers or fully consolidated thermoplastic based tapes are processed. In the following “tape” is synonymously used for the whole variety of unidirectional fiber reinforced semi-finished materials. Whether one wide tape (Automated Tape Placement, ATP) or several small tapes (Automated Fiber Placement, AFP) are placed at the same time side by side, the challenge of varying tape width (Fig. 1) has to be taken into account to prevent gaps or overlaps during placement. The negative effect of such flaws on resulting mechanical component performance has been demonstrated [1,2]. Since the tape is placed by applying a compaction pressure, an additional deformation of the tape cross section is also given. This deformation will also challenge an accurate flaw-free placement, but also might be used to control gap or overlap formation. Controlling the compaction pressure will allow to control the resulting tape width.

Compaction pressure is one key parameter effecting the consolidation. For prepreg consolidation a good understanding has build-up and for example Belnoue proposed a modelling concept covering a wide range of processing conditions [3]. Also for the even more complex configuration involving fully consolidated thermoplastic tape materials, all relevant mechanisms acting under placement processing conditions have been analyzed intensively. Amongst others, Khan has published several papers dealing with:

- Effects of tape surface roughness and fiber-matrix viscosity [4],
- Transverse flow effects and according width change [5],
- Void dynamics [6], and
- Simulation based process optimization [7]

In his PhD-thesis [8] Khan summarized a good predictability of tape deformation based on literature available and partly adapted physical material models. It has been demonstrated one main assumption the models are based on, i.e. the Newtonian shear flow, is an oversimplification [9]. But nevertheless, an intensive material characterization ensures accurate simulation results.

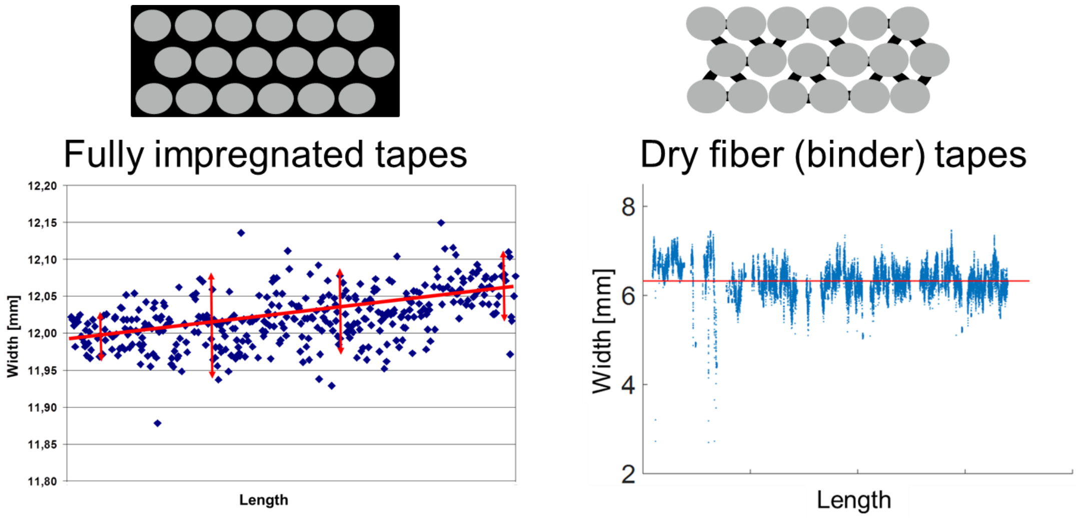


**Figure 1.** Typical width scatter for two different tape types estimated on samples having a length of more than 100 m.

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## 2. Inline detection of quality parameters

Having in mind the aimed process velocity, which should be at least in the range of 5 m/min, one of the most promising techniques is the use of light sectioning sensors. Not only the width, but also contour information is gained. Using such sensors the deformation behavior of the tape can be characterized inline. Therefore, the tape geometry is detected at defined positions directly before and after the nip point under the consolidation roller (Fig. 2). Since the detection at the second position directly behind the consolidation roller will also bring information about the relative position of the currently placed tape in relation to both, the previously placed adjacent tape and the layer below the just placed path. So, the build-up of the whole laminate is fully documented.

## 3. Model based process control

Complete required material data is hardly available. Instead of a physical, a simple phenomenological model is used. The phenomenological model is based on the tape deformation detected inline. Using this information, adaption of the machine control system is possible if real time generated input is available. This real time generation is done in a computing system directly connected to the physical elements of the manufacturing system, being able to handle big data, and collaborating with the machine control system. Typically such computing systems are called Cyber-Physical-Systems (CPS). The CPS is implemented in a targeting hardware being a component of the machine control system.

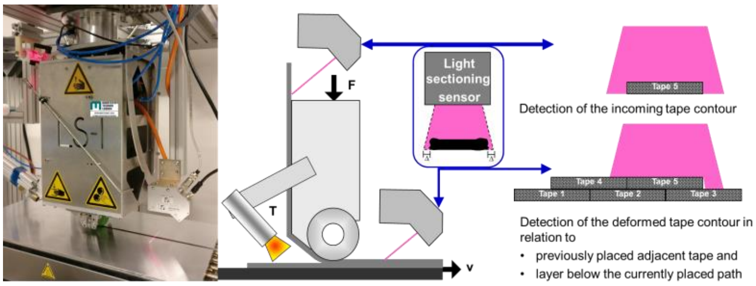


**Figure 2.** Inline measurement of tape contour (left) and gained information details (right).

Process parameters to affect the placement are:

- Process velocity
- Heating
- Compaction

For highest productivity the process velocity should be as high as possible and consequently it is not aimed to use this parameter extensively for process fine-tuning. Heating is, depending on what tape material is placed, more or less complex. In case of thermoplastic tape material several heating components are involved. At least a main heater, heating the incoming tape surface and the substrate surface, is necessary. Additionally substrate heating and incoming tape material pre-heating might be used. Furthermore, the consolidation roller might be temperature controlled. Whilst the main heater might be capable to change the energy input within very short reaction time, the other heating elements involved do have relatively long reaction time. So, concerning heating only a fast reacting main heater can be used for process fine-tuning. Latest in real component processing the finally acting compaction pressure will scatter significantly due to relative movement between head and tooling system. Since the effect of compaction on final consolidation quality is only minor, compaction pressure is a favorite candidate for inline tape width adaption. Modification of the test rig shown in Fig. 2 enables accurate control of the compaction pressure. In combination with the model based process control using the tape deformation data detected inline, intense study of resulting improvement of the placement process is possible. Beside resulting improvements reachable for different tape types a special future research focus will analyze more complex placement configurations, e.g. placement on ramps (Fig. 3).

## 3. Conclusions

Reliable production requires use of inline detected process information to enable optimized processing parameters. Beside the inline detectability of relevant parameters, handling of resulting big data is challenging. According strategies to generate useful input data, i.e. real time data processing, are needed, also. Finally, the process set-up must allow adjustment of quality guiding process parameters without any negative effect regarding process efficiency. In case of continuous placement processes, compaction pressure represents such an adjustable process parameter.

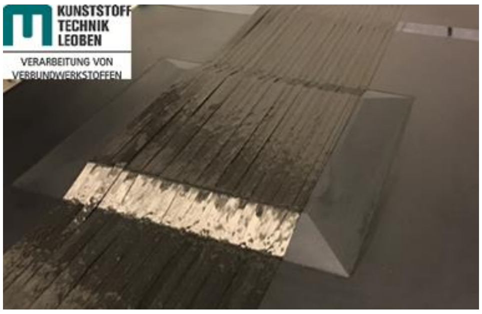


**Figure 3.** Placement on ramps.

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