DEVELOPMENT OF THE DIRECT ROVING PLACEMENT TECHNOLOGY (DRP)

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Keywords: Automated Placement, Dry Fiber, Direct Roving Placement Technology, Online Binder Application

Abstract

The Direct Roving Placement (DRP) technology is in development at the Institute of Composite Structures and Adaptive Systems of the German Aerospace Center (DLR). A fully functional robotic unit that is able to produce dry glass or carbon fiber preforms has been set up at the Center for Lightweight Production Technology (ZLP) in Stade. All relevant process and material parameters that have an influence on the mechanical properties of parts being built with the DRP technology, are investigated. The main advantages of this new fiber placement technology are low material costs and high productivity.

The core of the technology, the end-effector, is able to process raw carbon fibers as well as glass fiber rovings. The biggest difference compared to other placement technologies is the integrated online binder application system. The binder system is used to keep the fiber rovings fixed in position, after they have been applied onto a three-dimensional tooling surface. In addition, the online application of a binder provides multiple options of individually tuning the mechanical properties of the preform or the final part.

1. Introduction

The Institute of Composite Structures and Adaptive System of the German Aerospace Center (DLR) investigates and develops a wide range of different automated fiber placement technologies. A relatively young technology is the Direct Roving Placement (DRP) method. The DRP technology is designed to reduce material costs by using raw fiber rovings instead of slit tapes, tow pregs or other pre-impregnated or preprocessed materials. Furthermore, it is designed to be a highly productive manufacturing technology, which is able to directly produce large three-dimensional preforms used for wind turbine rotor blades, boat hulls or other preforms with similar requirements.

Main focus and the initial trigger for the project was the need to develop an automated production technology for manufacturing wind energy rotor blade preforms. Along with the development of a robotic based roving placement end effector, numerous material tests were necessary to accomplish the objective.

Figure 1. Manufacturing area for wind turbine rotor blades at the ZLP with the DRP unit and a 45 m rotor blade tool.

2. State of the art

Productivity often is an important factor for preform manufacturing processes, especially when large parts are built. State of the art manufacturing processes for rotor blades or boat hulls comprise a large amount of manual work. However, large tools allow parallel manual layup of non-crimp fabrics (NCFs) by multiple workers at the same time. As a result, a quite high productivity of several hundreds or even thousands of kilograms of fibers per hour can be achieved. However, fiber alignment accuracy, reproducibility and overall manufacturing quality are reduced.

Several former and ongoing research projects on rotor blade manufacturing automatization have been focussed on automated fiber fabric layup and draping, for example the finished project mapretec of the Institute for Integrated Product Development in Bremen [1] or the ongoing project BladeMaker [2] as well as the research activities at the DLR Institute of Structures and Design in Augsburg with its multifunctional manufacturing cell [3].

Since 2013 the DLR in Stade is advancing the fiber placement technology with its GroFi® multi robot facility [4]. By working with up to eight coordinated layup units on one part (automated fiber placements units as well as automated tape layers) and by a significant reduction of secondary process times, the productivity of this facility will reach more than 100 kg/h. When producing high quality aircraft parts, this is a new benchmark. Compared to the target productivity for rotor blades of up to 2000 kg/h, the productivity of this facility will still be insufficient nonetheless.

Another important factor of a preform process are the costs. The costs for a large rotor blade or boat hull preform are mainly defined by the material costs. For rotor blades, the material costs can be up to 70 % [5]. Looking at the whole wind turbine, the rotor blades are even responsible for up to 20 % of the total costs [6]. A promising automation solution for the fiber deposition must therefore not only reduce manufacturing costs, but also material costs.

Recently, a new dry fiber placement unit was introduced by the German startup company Compositence [7]. Their end effector processes raw, untreated carbon fiber rovings. Originally developed for the automotive industry, this machine has a higher productivity than AFP units, though a lower layup accuracy. Their unit is designed to fix the fibers only on the edges of a tool, allowing a high speed point to point movement from one edge to another. This unit built the basic structure for further developments that have been done by the DLR and will be discussed in the following chapters.

3. Direct Roving Placement (DRP)

The Direct Roving Placement is an alternative fiber layup process to classic Automated Fiber Placement (AFP) or Automated Tape Laying (ATL) processes. The basic idea of this technology is to keep the manufacturing and material costs as low as possible, by processing the cheapest fiber products available. The material can either be raw untreated glass or carbon fiber rovings. The aim is, to engineer an automated placement technology for the production of low cost fiber preforms. Compared to a state of the art preform process where non-crimp fabrics are used, cost savings of up to 1 € per kilogram glass fibers can be achieved. When carbon fibers are used, the savings can be much higher, depending on the fibers and materials used. However, if compared with NCF processes, the DRP technology needs to be highly productive. Estimations show, that the productivity of a single end effector could easily reach 200 kg/h or even much more under optimal conditions. [8]

Untreated fiber rovings have no matrix or binder component to provide adhesive forces. Therefore, a suitable concept for the fixation of the fibers is needed. At the DLR in Stade a production unit is in development, which is equipped with an online binder application system (see figure 2).

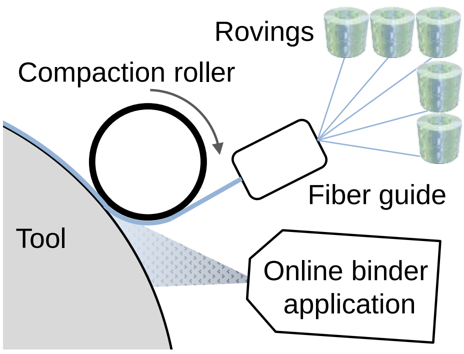

Figure 2. Concept of a Direct Roving Placement unit.

The binder system is a spraying unit that is able to apply thin films of adhesives to a surface of a three-dimensional tool. In order to apply a constant aerial weight of adhesives to the surface, the system is controlled by the speed of the tool center point of the fiber placement end effector. In addition to a precise control of the aerial weight, the equipment also allows the variation of the microstructure and the pattern of the adhesives, when being sprayed on (see figure 3).

Figure 3. Example of different textures when using different binder application parameters: drop or fiber like texture (left), web like texture (middle), fine silky coating (right)

Various parameters have an impact on the quality of the adhesive films. The most important parameter however is the binder itself. Different binders were tested and first results are discussed in the following chapter.
The online binder application offers some interesting advantages. Besides the usage of raw fibers with reduced material costs, also a nearly unlimited layup speed helps to reduce overall manufacturing costs. With no need to heat up pre-bindered material, there is no need to use high intensity heating modules, which often limit the overall layup speed. Another interesting option that comes along with online binder application is the possibility to produce different preform zones with individual mechanical properties. By adjusting the parameters of the binder application process, the mechanical properties of the laminate can be influenced directly.

Several material tests and testing of individual components and technologies have already been done. First glass fiber laminates have been produced with the end effector (see figure 4).

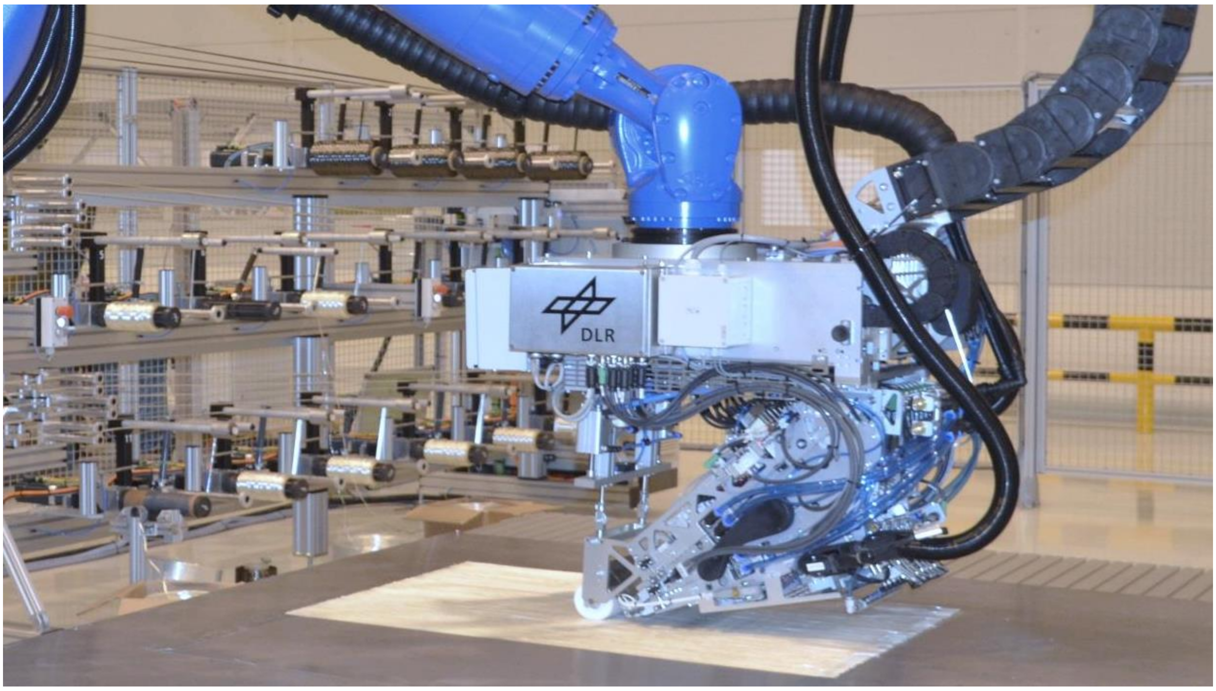

Figure 4. Picture of the DRP end effector and a fabricated glass fiber test laminate.

3.1. Binder investigations

At the beginning of the DRP technology development, one of the main goals was to find a binder with sufficient adhesion forces that can be processed without additional heating devices. Another important requirement is that the binder has no severe negative impact on the mechanical properties of the final fiber laminates. Since the project has been started in order to build an automated production technology for manufacturing wind energy rotor blades, test laminates were built with glass fiber non-crimp fabrics and a resin system that is certified by rotor blade manufacturers. As part of the material screening several binder systems with different chemical compositions were investigated [9]. Various parameters such as solubility of the binder system in the matrix with respect to washout effects, preforming properties and the mechanical performance of the final composite part were evaluated. The requirements to be sprayable as well as staying tacky long enough after application came along with the end effector concept. This finally led to a binder system based on an epoxy resin without hardener or accelerator components. By increasing the temperature of the binder and thus decreasing its viscosity, it can easily be processed with the spraying unit.

First, the binder's solubility within the matrix system was tested. If the binder has a critical solubility during the infusion, washout effects could occur. This may affect the permeability of a preform and local increase or decrease of the binder could have a negative effect on the properties of the laminate. Solubility tests of the selected binder, which are shown in figure 5, demonstrate that the binder remains as a separate phase when added to the matrix resin system at room temperature without mixing (a). When the mixture of binder and resin is stirred actively at room temperature, the binder is fully dissolved into the matrix system after two hours (b), which also can be seen in a magnified picture (c). Without active mixing at a curing temperature of 80° C, a partial solubility of the binder was observed (d).

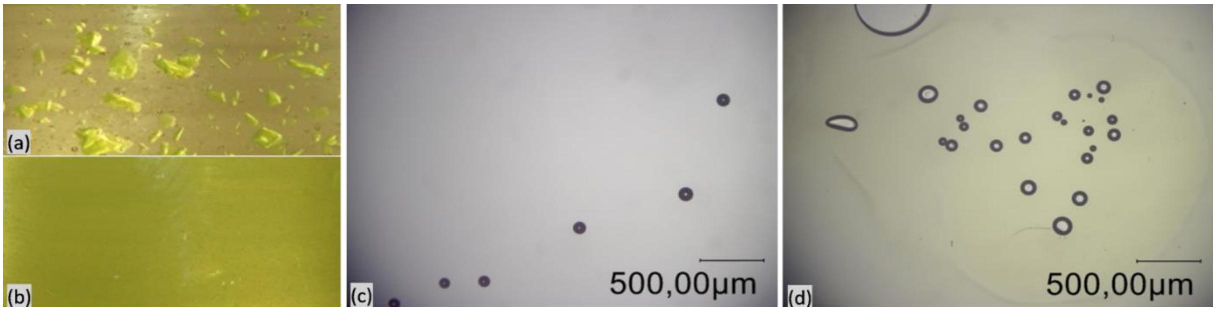

Figure 5. Picture of different binder solubility test setups: (a) no dissolving at room temperature, (b) dissolved when mixed, (c) magnification of mixed solution, (d) magnified picture of unmixed solution

Next, the binder was tested in combination with glass fiber NCFs. In order to investigate the mechanical properties, multiaxial and unidirectional NCFs were used and after being fixed with the binder, they were infused with the epoxy resin.
The results show, that the binder has only little impact on the properties of the laminate when tested in fiber direction (0° tensile and 0° compression tests). The matrix dominated characteristics however were improved by the binder system, which can be seen in figure 6. (The tests were made according to DIN EN 527-5, DIN EN 2850 and DIN EN ISO 14129)

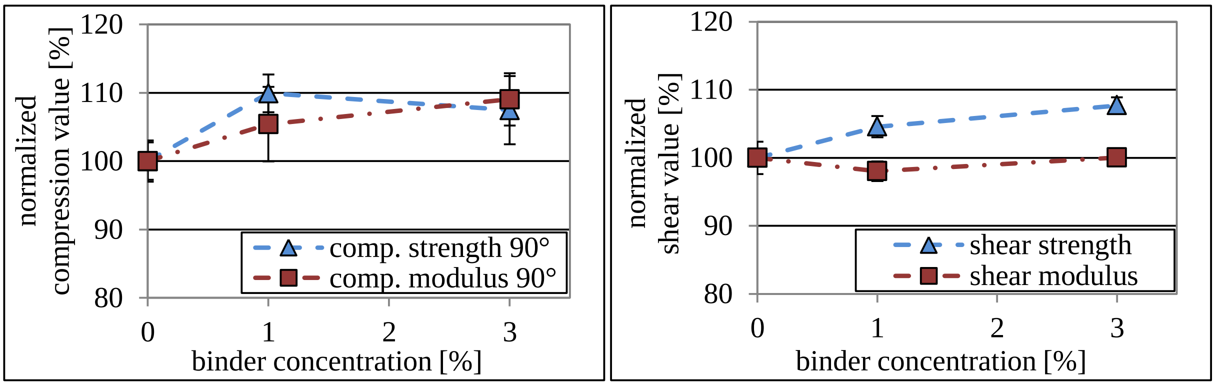

Figure 6. Compression characteristics (left) and shear characteristics (right).

The graphs in figure 6 show the compression strength and modulus (left) and the shear strength and modulus (right) for glass fiber laminates with binder concentrations of 1 wt. % and 3 wt. %, normalized to the non-bindered reference laminate.

3.2. Characterization of preform properties

The adhesive properties of the epoxy binder were evaluated measuring the peel strength. The interply adhesion was determined by a T-peel test in accordance with DIN EN ISO 11339. The tested samples consisted of two unidirectional glass NCFs, fixed together with the binder. Samples with two different binder concentrations were tested at three different ambient temperatures. The test setup can be seen in figure 7. From left to right the test bench, unbindered glass material at the beginning of the samples, bindered material after being peeled and the failure region, where fine binder strings occur, are shown.

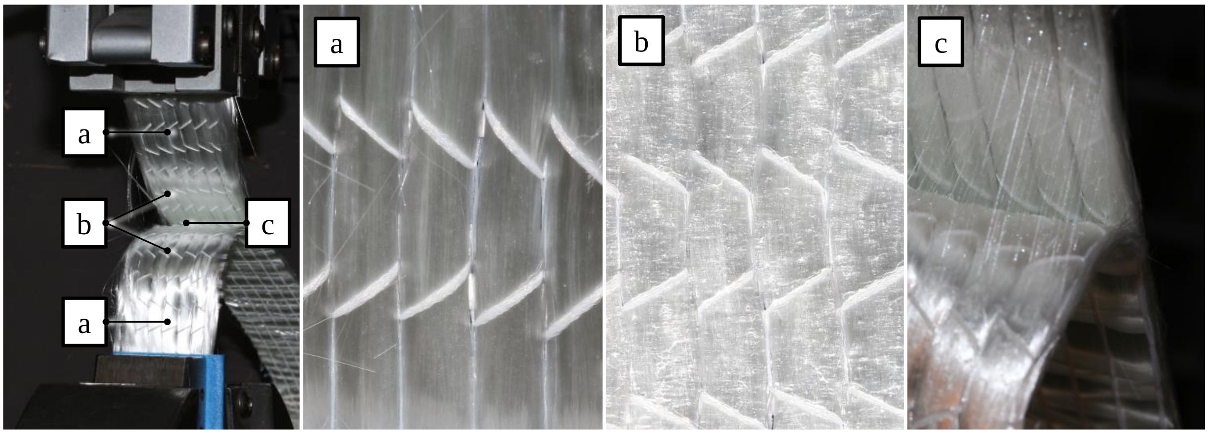

Figure 7. Test set-up with a T-peel sample and close-ups of the different sample zones.

The tests have shown, that the mean peel strength is strongly influenced by the binder concentration and temperature (see figure 8). With low binder concentrations (<10 wt. %) and room temperature (23° C), the conclusion can be drawn that increasing binder concentrations result in an almost linear rise of peel strength values. Thus, a three times higher binder concentration increases the peel strength from 0.7 to 3.1 N/cm. The assumption is that this effect is in direct correlation with the surface area coverage of the adhesive binder material. Since the preform surface with 6 wt. % binder is not totally covered, higher peel strength values can be expected when optimizing the binder application parameters. As expected due to the binder material characteristics, the peel strength decreases significantly at elevated ambient temperatures. At a temperature of 40 °C, the remaining peel strength of the 6 wt. % samples is already less than 10 % compared to the peel strength at 23° C.

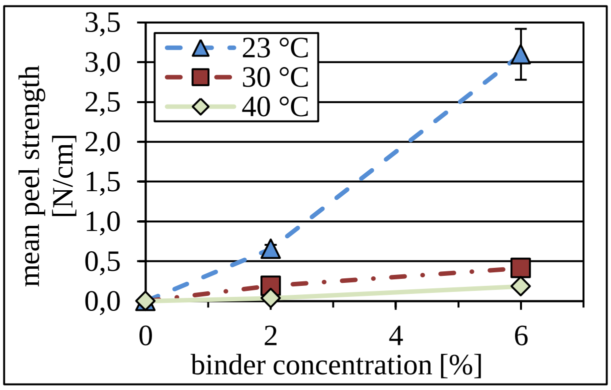

Figure 8. Mean peel strength in dependence of ambient temperature and binder concentration.

5. Conclusion and outlook

The first glass fiber laminates have been produced with the DRP technology and the reliability of the process is increased continuously. A suitable binder has been found and all material tests have shown promising results. Additional technical improvements are still in progress and further material tests will hopefully help to even improve the good results that have already been achieved. The next milestone will be the production of a 20 cm thick curved 3D preform.

In order to lift the technology to the maturity level necessary for real rotor blade production, a fully functional production plant concept is needed. For this purpose, the DLR is going the promising though challenging way of using mobile robot manufacturing units (see figure 9). The flexibility of a mobile Direct Roving Placement robot will enlarge the layup area and allow several units to work together on a single rotor blade tool. To improve the efficiency of multiple layup units working at the same tool, the DLR is already developing algorithms, currently used in the GroFi® project. The first mobile robot unit has already been delivered to the ZLP in Stade and will soon be equipped with an end effector.

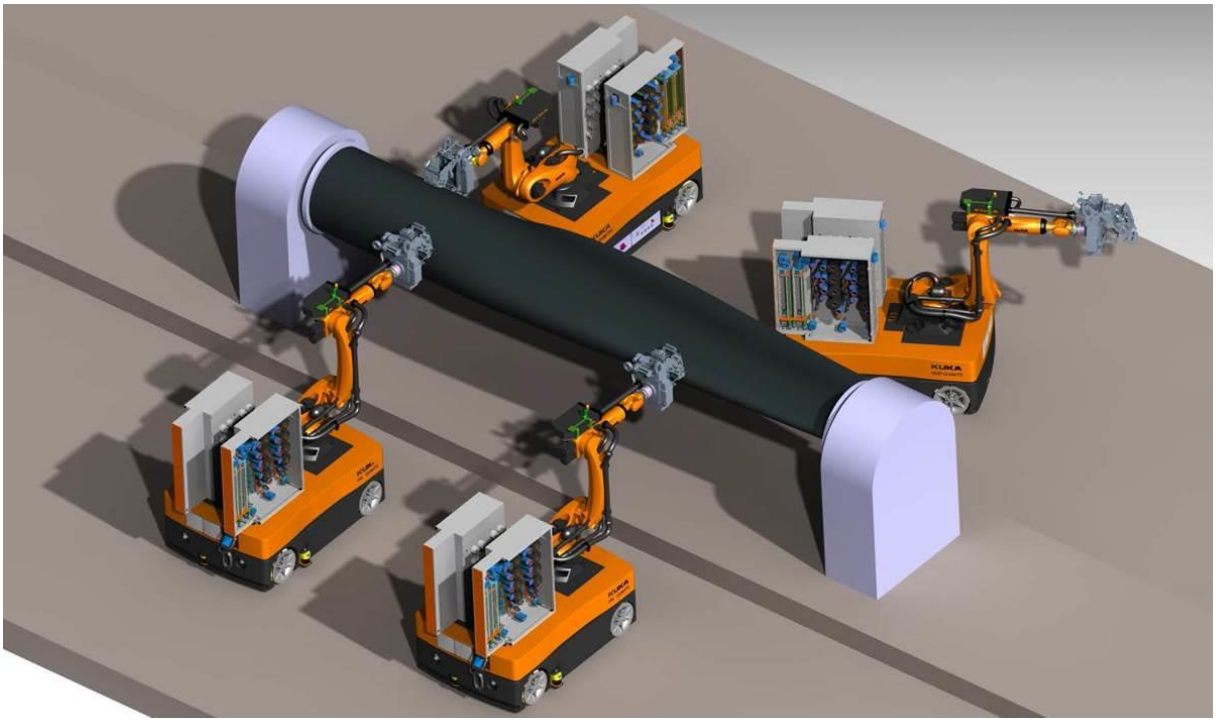

Figure 9. Mobile Direct Roving Placement units.

To reach a productivity of 2000 kg/h or more, multiple layup units as well as additional improvements of the end effector like an increased application width and the ability to apply thicker layers will be needed [10]. Once fully developed and taking future improvements like load path aligned fiber orientations into account, the DRP technology itself could allow improved preform designs, with less weight and therefore even less material costs.

With the ongoing follow up project SmartBlades II, nearly the whole process chain from design, preform manufacturing up to the final infusion of four 20 m rotor blades will be covered by the departments of the DLR FA Institute.

Acknowledgments

We thank the German Ministry of Economic Affairs and Energy for the funding of the SmartBlades project. Furthermore we thank the European Union for the funding of the MoDifaR project through the allocation of the EFRE fund.

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