

## Low-cost Automation for Prepreg Handling - Two Cases from the Aerospace Industry

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### ABSTRACT

With an increased use of composite materials within the aerospace industry follows a need for rational and cost-effective methods for composite manufacturing. Manual operations are still common for low to medium manufacturing volumes and complex products. Manual operations can for example be found in material handling, when picking prepreg plies from a cutter table and stacking them to form a plane laminate in preparation for a subsequent forming operation. Stacking operations of this kind often involves a great number of different ply geometries and removal of backing paper and other protecting materials like plastic. In this paper two different demonstrator cells for automated picking of prepreg plies and stacking of plane laminates are presented. One demonstrator is utilizing a standard industrial robot and an advanced end-effector to handle the ply variants. The other demonstrator is using a dual arm robot which allow for simpler end-effector design. In combination with a previously developed system for automated removal of backing papers both systems have shown to be capable of automatically picking prepreg plies from a plane surface and stack them to generate a flat multistack laminate. The dual arm approach has shown advantageous since it result in simpler end-effector design and a successive lay down sequence that result in good adhesion between the plies in the laminate.

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### INTRODUCTION

The combination of high strength and low weight that is achievable with composite materials like Carbon Fiber Reinforced Plastic (CFRP) has made these types of materials attractive to the aerospace sector. The use of CFRP in aircrafts has steadily increased and modern aircrafts can consist of around 50% (of structural weight) of CFRP and other composite materials [1]. This entails an increase in manufacturing volumes, making rational, cost-efficient manufacturing processes an important area for further research and development.

Unidirectional (UD) carbon fiber prepreg is a commonly used high performance material in aerospace applications. However, much of the current efforts in automated handling within composite manufacturing seem to be directed towards the handling of dry fiber fabrics for preform manufacturing. There are several examples of both research groups and companies developing solutions for dry fabric handling. Within the research community there are systems that have been developed for only handling two dimensional objects [2] as well as systems for three dimensional handling that also

include draping capabilities [3] [4]. As a commercial example Broetje Automation has developed a commercial system that uses vacuum technology for lifting permeable textiles [5].

When it comes to automated handling of prepreg Ward et al. [6] conclude that concepts for automated prepreg handling have been attempted but have so far made little impact in the composite manufacturing industry. Concepts have been developed in research projects, for example in the ARMATURE project [7], and are also promoted by commercial cutting equipment providers as reported by Black [8]. However, the implementation of these concepts in full scale manufacturing operations seems to be lacking. A key issue to address in order to design automated solutions for handling prepreg materials is to design the systems so that they can handle a great variety of geometrical shapes at the same time as the system remain as uncomplicated as possible [9].

Manufacturing using UD prepreg is mainly done by one of two approaches. The first approach is to place the prepreg onto a mold with the final product shape, thus forming/draping the prepreg layer by layer. Another is to stack several prepreg layers to form a

multilayer laminate (multistack) before giving the product its final shape in a separate forming process. The handling operation of pick-up, transport and laydown of cut prepreg plies from one surface to another is in this paper defined as pick-and-place. The technical development in this paper focuses in the pick-and-place process, with the aim of providing low-cost solution suitable for low-to-medium manufacturing volumes.

For composite manufacturing where prepreg is laid up directly on a mold tool manual operations are common for low production volumes and for complex parts. In manual layup the two major tasks, cutting and layup of prepreg plies, can account for around 40-60% of the manufacturing costs of a part [10]. For more complex shapes such as double curved surfaces or sharp corners it is difficult to lay down a ply correctly on the mold the first time without having to make small adjustments [12]. By using a manufacturing approach with a layup of a flat laminate, a multistack, followed by a forming operation the layup operation be simplified since it reduces the layup from a three dimensional case to a two dimensional case. A simplified layup case is especially advantageous when considering automated solutions since the end-effector does not have to conform to a curvature when placing a stack or a ply.

Automated Tape Laying (ATL) and Automated Fiber Placement (AFP) are absolutely dominant when it comes to automated layup of prepreg onto a mold [11]. However these two technologies have limitations in what parts can be manufactured cost efficiently. Geometrically complex parts with, for example short lay-down lengths and sharp corners and radii, can be difficult to manufacture using AFP or ATL resulting in a slow manufacturing process. There are cases, also when considering layup of flat multistacks, where ATL and AFP cannot be used due to required geometries and stacking sequences.

All in all, there is a need for automation targeting low to medium manufacturing volumes of complex prepreg based structures, where manual pick-and-place operations today induces a large part of the cost.

## PREPREG HANDLING AND GRIPPER TECHNOLOGIES

According to Buckingham and Newell [12] the two key material properties that affect the handling of prepreg are the rigidity and the tack. In composite manufacturing tack is usually defined as the ability of two prepreg plies to adhere to each other [13]. Unidirectional materials are sensitive to damages due to their highly anisotropic nature. The backing papers that are commonly used to protect prepreg also help to improve the rigidity of prepreg materials [12]. However, keeping the backing paper during handling operations to provide protection and improved rigidity requires a process to peel off the backing paper after handling. The peeling has been identified as a difficult process [12] but automated solutions have been developed and tested with promising results [14].

The tack of the material is related to the resin type, the fiber-to-resin ratio, the distribution of the resin and the temperature [12]. In probe tack tests Dubois et al. [15] show that the adhesion (debonding force)

between unidirectional prepreg and an aluminum probe is dependent on the contact time and force between the two surfaces. Longer contact times and higher contact forces result in a stronger bond. The probe tack test also shows that the resin viscosity is reduced with increased probe temperature, resulting in an increased prepreg tack with increased temperature. However the tack response to changes in temperature is dependent on the type of material. Findings reported by Crossley et al. [16] show that some prepreg materials experience increased tack with increased temperature while others show reduced tack when the temperature is increased.

The bonding behavior of a prepreg material, affected by for example contact time and pressure as well as tackiness, can affect the release of prepreg from a gripper or from the pickup surface as well as the adhesion between prepreg and backing paper. In handling unprotected prepreg with direct contact between the prepreg and the gripper, resin can be transferred risking contamination and resin buildup and subsequent gripper failure. All of these aspects (backing paper removal, tackiness, contamination risks, different handling properties in different fiber directions etc.) make prepreg challenging for handling operations using a pick-and-place approach.

Over the years a great number of gripping technologies have been developed, some for general purposes and other for very specific tasks. In reviewing gripping technologies it can be concluded that all technologies have their merits and suitable usages as well as drawbacks and it is important to find a gripping technology that best suits the particular handling task. Gripping technologies relevant for prepreg handling are shown in Figure 1 [14].

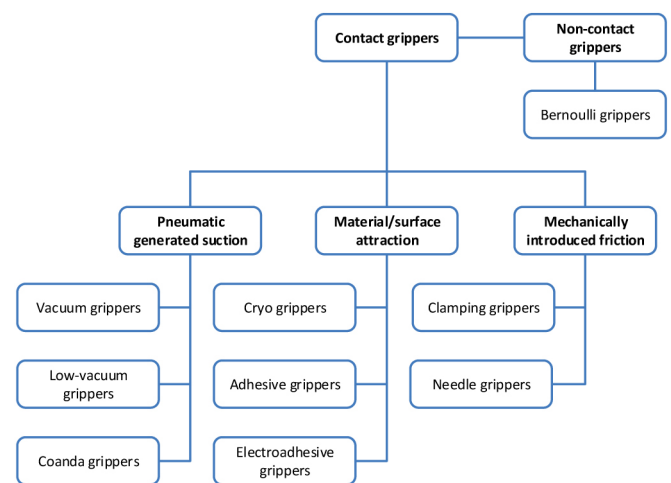


Figure 1. An overview of gripping technologies from [14].

Several of the gripping technologies introduce risks affecting the final quality, like cryo grippers that can introduce fluids [17], adhesive grippers that rely on attaching and detaching through adhesives and needle grippers that risk separating fibers. Some, like electrostatic grippers can drive system complexity [18] and others, like clamping grippers, generally require access from two sides. Coanda grippers, where the material floats under the gripper, seem to be an appealing alternative but the technology has shown problems in positional accuracy in handling operations [19]. The most common grippers in

handling operations are different types of vacuum based grippers where high vacuum grippers are used to handle permeable materials, for example dry fiber fabrics, an low vacuum grippers to handle more airtight materials like prepreg.

## PLY STACKING AND STAGGER

One of the more difficult aspects of automated systems for pick-and-place of prepreg is to handle the amount of different shapes that often is needed to stack a laminate, even in a flat two-dimensional case. In order to achieve desired strength and stiffness and to cancel any distortion, curvatures and avoid residual stresses of the cured product, each layer in a laminate is placed with a specific fiber angle. Also the prepreg material (or roll) often has a fixed width before cut. This means that in order to achieve the desired fiber angles for each layer, the prepreg sheet has to be cut into plies fitting the roll width, and the resulting plies assembled so that fibers run continuously in the desired angle, covering the desired stack form, see [Figure 2](#).

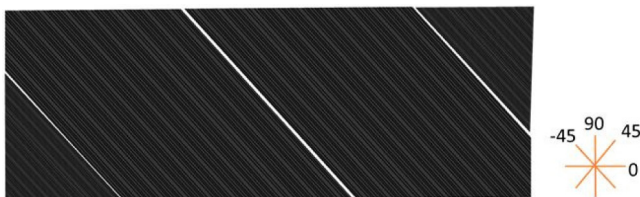


Figure 2. Example of an assembled layer out of -45 degree plies.

In order to maintain strength and stiffness properties throughout the laminate these “cut lines” cannot be repeated in the same place, thus a “stagger” is needed that shifts the cut lines, see [Figure 3](#). Staggerers increase the amount of geometrical shapes in a stack, making it a challenge for cost-effective and robust gripper design.



Figure 3. An example of a 40 layer stacked laminate with ply stagger. All lines of the full stack are indicated.

## TWO PICK-AND-PLACE DEMONSTRATORS

Automated handling of prepreg has been the focus of two separate research projects. Within each project physical demonstrators, have been built using two different approaches to the pick-and-place end-effector design. The purpose have been, experimentation and demonstration of different technical solutions. The two demonstrators are presented below and then compared as to draw conclusions in the following section.

### Single Manipulator Demonstrator

This demonstrator is a demonstrator cell for automated cutting, stacking and forming of multistacked prepreg. It was developed in the Triple Use project by Swerea SICOMP, SAAB Aerostructures and

KTH. The cell, shown in [Figure 4](#) consists of a handling robot, an ABB 6700-205 with a lifting capacity of 200 kg and a reach of 2.85 m. The handling robot cuts prepreg on a cutting table, picks and places the prepreg on the stack and removes the protective backing paper. The smaller robot, a KUKA KR10 R1100, with a handling capacity of 10 kg and a reach of 1.1 m then forms the multistack over a tool to produce a beam.

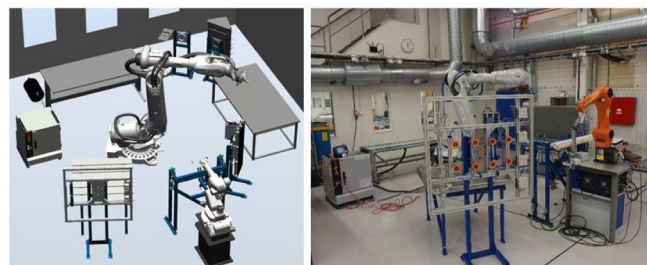


Figure 4. The demonstrator cell with a single manipulator solution. Left: the virtual cell in RobotStudio with the handling robot at the center of the cell. Right: The physical demonstrator cell.

The forming process, which has been developed by KTH as part of the project, is further described in [20]. After forming, the larger handling robot assembles the demonstrator product consisting of the formed beams and a skin. After this the product is bagged and cured making it an integrated composite structure. All manufacturing steps are described in [Figure 5](#) but for this paper, the focus will be on the pick-and-place aspects the demonstrator cell.

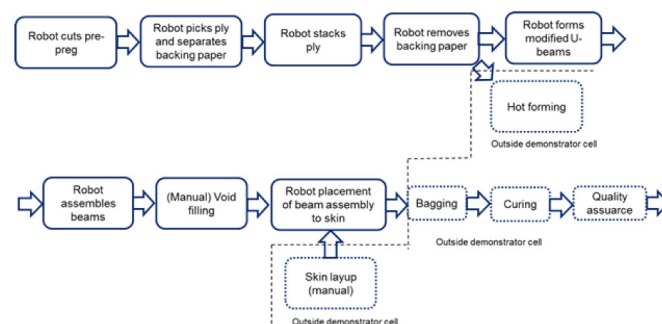


Figure 5. The manufacturing process in the demonstrator cell shown in [Figure 4](#).

The stack handled in the described cell is shown in [Figure 3](#) and the final gripper is shown in [Figure 6](#). The largest plies where approximately 1100×200 mm and the smallest around 80×80 mm. The gripper consisted of a V-shaped frame at 45-degree angle and individual zones that can be activated depending on ply geometry. The zones are by default extended but when triggered they are retracted using a pneumatic cylinder, as illustrated in [Figure 7](#). This feature is used to assemble gripping zones fitting a certain ply geometry to avoid disturbing adjacent plies during picking and placing. It also allows for the backing paper separation process to get access to the ply.