Gripping Technology for Carbon Fibre Material

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Abstract
Nowadays, the realization of a series-ready production of continuous fiber-reinforced polymers can only be mapped with considerable effort. One of the main reasons for this can be found in the handling of semi-finished textile products that are dimensionally unstable and permeable to air, which poses great challenges. Supplying and feeding of semi-finished textile products is still carried out today mostly by manually performed steps. Having said that, this publication will deal first of all with the gripper requirements for an automated production. For identifying these requirements, the Resin Transfer Moulding (RTM) will be looked at as an exemplary process chain which, particularly in the automobile industry, is considered a production method that is suitable for large-scale production. After that, the available gripping principles are evaluated according to the criteria that have been deduced from the requirements and then the existing deficits will be derived. Based on this evaluation, this article presents adapted gripping systems for the automated manufacturing of fiber-reinforced polymers.

Keywords
Composite, Handling, Gripping

1 INTRODUCTION

In the light of new drive concepts and legislated general conditions regarding the reduction of CO2 emissions, the automotive industry will change radically in the years to come. Development and production of energy and resource efficient products will be of vital importance for the competitiveness of automotive companies in the future. Regardless of the selected drive concept, lightweight construction is one of the most important future technologies in automotive engineering in times of growing environmental awareness and dwindling resources.

The optimization of vehicle structures built in a conventional way is not achievable anymore in a cost-effective way by using metallic materials alone. Continuous fiber-reinforced polymers are superior to metallic materials in many ways as for instance in terms of weight-related stiffness and strength [6,10] and in terms of design freedom [2,6,10]. In sectors such as motor sports and aerospace, the use of continuous fiber-reinforced polymers is already technological standard by now. A transfer of this knowledge to the sector of series production vehicles is only possible to a limited extent due to economic and technological aspects. The established processes for producing these mainly carbon fiber or glass fiber reinforced lightweight products such as the Resin Transfer Molding (RTM) primarily require manual steps because of missing automation solutions and that makes it difficult to economically produce these components. Especially the handling of very flexible and air-permeable semi-finished textile products - as used in nearly all production processes - represents a big challenge for automated manufacturing. For this reason, the supply and feeding of semi-finished textile products is still predominantly characterized by manual steps today [3]. In order to reduce the production costs of composite parts, the overall automation level of production and especially the level of automated handling steps has to be increased.

But with the currently available gripper solutions on the market this objective can not be achieved. Hitherto, existing grippers show an insufficient process reliability and in addition, can not be optimally applied for all process steps. In the following paragraph, the RTM process is presented and the requirements concerning the grippers are deduced from it. And these requirements will be evaluated according to the defined criteria.

2 GRIPPING PRINCIPLES WITHIN THE RTM PROCESS CHAIN

The production of composite parts is always based on several process stages which are interconnected via process linking steps. The requirements concerning the gripper technology will be pointed out on the basis of the RTM. The RTM process is considered to be one of the suitable technologies for large-scale production of continuous fiber-reinforced structural components with a complex shape in the automotive industry [4].

2.1 Gripping Technology Requirements

In case of the conventional RTM process - as shown in figure 1 - the basic material for the fiber composites, the semi-finished products made of textile fibers, generally comes in rolls (1). The semi-finished textile products are mostly available as woven or non-woven fabrics. During the first process step the textiles are cut to size in multiple layers according to the later contour of the component (2). These flat cuttings are then sorted into piles and fed to a magazine (3). For creating the necessary layer structure, the required cuttings are taken separately from the corresponding magazines and piled up to form a stack (4) which is then processed to a preform (5). A textile preform means a near net shape, dry fiber formation with a load-bearing fiber structure. When the reinforcing fibers are positioned inside the molding tool, the two-piece mold is closed. Then the matrix will be injected and it hardens at high temperature (6). After that, the finished part can be taken out of the molding tool and can be further processed (7).

The following handling tasks result from the operational sequences of the RTM process:

a) Sorting of multi-layer semi-finished textile products
b) Separating from the stack and handling of single-layer semi-finished textile products
c) Picking up and handling of multi-layer semi-finished textile products
d) Handling of finished preforms
e) Handling of a hardened FPC component

When handling semi-finished textile products the main objectives are a nearly damage-free gripping and a high process reliability during the picking. These requirements have to be taken into consideration when selecting the gripping principle. Furthermore, the material properties relevant for the handling are changing throughout the process. The material properties of textile fabrics and nonwovens are divided into slip resistance, bending stiffness, permeability, area-related mass and fabric thickness [1]. For selecting the gripping principle especially the slip resistance and permeability are relevant properties. These two properties define the transmittable holding forces and the damage behavior of the textiles that can be caused during the interaction with the gripping system. During the process, the slip resistance increases whereas the permeability decreases. This means that during the process flow the requirements for the gripper decrease.

The preforming represents another limiting factor for the production of composite parts. There exist several approaches for producing these preforms. Gripping systems can systematically support individual processes here. The gripping systems can for instance preform the textiles according to their later contour or fix individual layers point by point to one another. But here, it has to be considered that, when a gripping element slips off the textile, it could cause undesired damages. By reducing the transmittable transverse forces of individual elements, this could be avoided.

In conclusion can be said that material and process specific requirements are arising for the deployed gripping systems. The highest requirement level for the grippers can be found in the handling steps a), b) and c) (see figure 1). These identified requirements will further on serve as evaluation criteria for the different gripping principles.

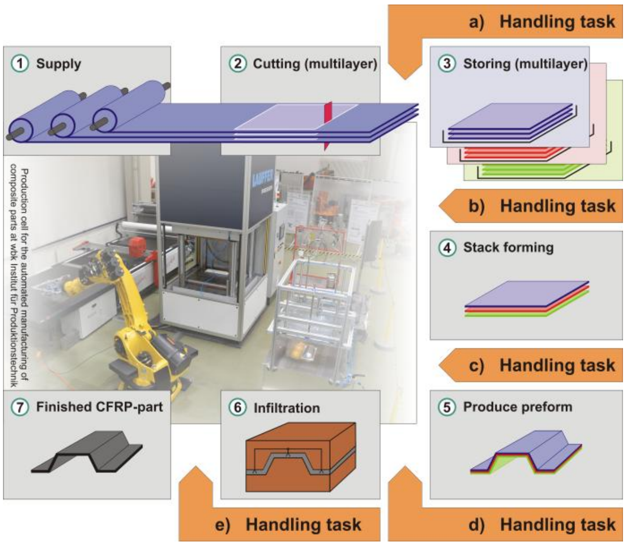

Figure 1 - RTM process and process chain steps.

2.2 State of Technology and Evaluation of Gripping Principles

Semi-finished textile products within the RTM process are mostly still supplied manually [3]. But there are grippers on the market that are basically suitable for the handling of these sensitive components [11]. An overview of common gripping principles [3,7,9,11,12] is given in figure 2.

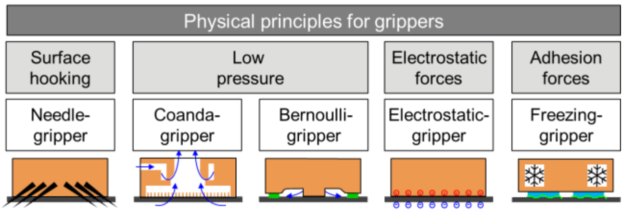

Figure 2 - Typical grippers for textile semi-finished products [8].

At present, needle grippers, Coanda grippers and Bernoulli grippers are used for handling semi-finished textile products. Electrostatic grippers [5] and grippers that work according to the principle of adhesion forces [12], like freezing grippers, are in contrast still a subject matter of current research activities. In the following, the gripping principles will be presented and evaluated with regard to the identified requirements for these specific materials and processes.

The most important criteria in selecting a gripping principle are the transmittable holding forces, divided into normal and lateral force, and a damage-free grip as far as possible. Furthermore, the handling tasks identified in the previous chapter have to be fulfilled. An evaluation of the gripping principles is shown in figure 3. The general feasibility was evaluated with the criteria “Separating” and “Multiple-layer gripping” which means sorting/taking a single semi-finished layer from a stack of textiles or picking several layers at once. The reliability of the gripper was also taken into account. The criterion “Energy efficiency” evaluates the efficiency of the gripping principle; in other words, the energy needed to pick up, transport and deposit the layer(s).

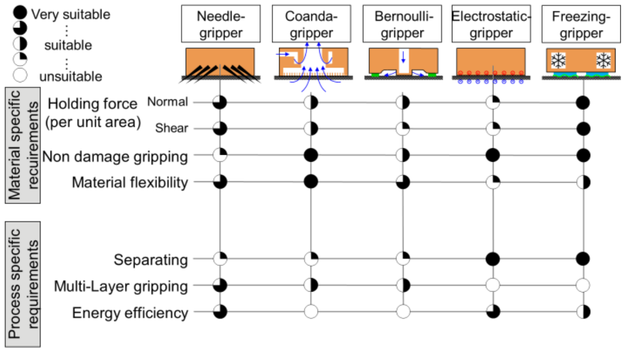

Figure 3 - Evaluation of gripper principles.

2.2.1 Evaluation of Grippers

Needle grippers belong to the group of form-fit grippers. The gripping principle is based on a pneumatically driven simultaneous extension of needles. These needles that are arranged in opposite directions penetrate the material and generate a form-fit connection between the gripping element and the component. With this principle a pick up of multiple layers is assured. In principle, the depth of penetration can be set with an adjustable needle stroke and thus, the amount of layers that need to be picked up. But depending on the stack, different gripping results are achieved and this has a negative impact on the process reliability. With this gripping principle, the textile has to be penetrated by the needles and this causes damages and displacements of the fibers or even fibre breakage [3,5,6].

A freeze (cryogenic) gripper creates an adhesive bonding with the textile material. This gripper is characterized in particular by high transmittable holding forces and a high process reliability. The freeze gripper shows also a high flexibility regarding the materials used [7]. Adhesion grippers always form only a bonding with the textile layer on the very top. They are very suitable for separating but there is no chance of picking up multiple layers. The use of water as a bonding medium shows a negative effect. Especially the materials used for the RTM technique show an incompatibility with water, even if applied only in small quantities [8], what makes the use of this principle impossible.

Electrostatic grippers as well as the Coanda grippers and Bernoulli grippers operating with negative pressure belong to the product group of force-fit grippers. The electrostatic gripper works with electrostatic fields that create a polarization on the upper side of the semi-finished product and in this way generate holding forces [5,12]. Electrostatic grippers are characterized by a high shape flexibility, a low moving mass and a good cost and energy efficiency [5]. But the very low holding forces are unfavorable for a use in automation [12]. Because this gripping principle, as well as the one previously described with the freeze gripper, involves only the semi-finished layer on the top, it is suitable for separating but not for handling multiple layers of semi-finished textiles on a stack.

Due to their mode of action, the very common Bernoulli grippers in the textile engineering can only transmit lateral forces to a limited extend and with additional tools like rubber elements. A negative impact also has the air flow coming out of the gripper (suction device). This air flow can cause frazzling and fiber displacements, especially along the edges of the semi-finished textile products and it can contaminate the fabric with oily particles coming from the supplied compressed air [5,8].

In comparison to the Bernoulli suction unit, grippers that operate according to the Coanda principle [9] feature advantages in the area of transmittable forces and material flexibility [8]. Furthermore, this gripper principle allows gentle, non-destructive and residue-free gripping with high gripping and positional accuracy [3]. Safe separating and multi-layer handling of semi-finished products from stack are only feasible to some extend with the Bernoulli suction unit as well as the Coanda gripper. New gripping parameters need to be determined by empirical experiments, for example experiments on the operating pressure, for every new handling task. Since the operation of these grippers only allows for deterministic control solutions and since the entire gripping process is subject to environmental influences, a high level of process reliability can not be achieved.

2.2.2 Conclusion

Presently, no gripper that may be used without adverse effects in an automated RTM process chain is available on the market. A particularly negative aspect is the low level of process reliability. So far, no pair of “gripper and semi-finished textile product” managed to exceed a maximum of 99,8% of gripper reliability [1]. Insufficient total process reliability is due to the fact that a handling system may consist of up to 1000 grippers and the fact that process reliabilities of the individual grippers are combined in multiple ways. Furthermore, so far only adhesive grippers may be used for a reliable separating process.

On the basis of the evaluation of section 2.2, the freeze gripper and the Coanda gripper are most likely to be used in automated RTM production. It was by modification, such as for example the use of other adhesives and the integration of sensors, that the disadvantages of the existing grippers were compensated against the advantages of the grippers at the wbk. The developed grippers and their additional functionalities will be presented in the following chapters.

3 MODIFIED ADHESIVE GRIPPERS

As explained in the previous chapter, adhesive systems show advantages regarding the holding power and the access without damage as well as in particular in the process of separating semi-finished products from stack. However, resin applied in RTM procedures is not compatible with low water volumes and thus excludes the use of freeze grippers.

Instead of water, it is appropriate to use compatible adhesives, matrix systems used in the infiltration process or common binder systems of the preforming process. Thus, a new adhesive gripper principle has been developed at the wbk which uses specifically introduced piezoelectrically generated vibration for dissolving the adhesive contact when removing the component. Here, the effect of mass inertia of adhesive objects is used for overcoming the adhesive forces. In the experiments, a 35 kHz ultrasonic resonance system was used for generating the speed necessary for dissolving the adhesive. The basic setup comprises a converter and a sonotrode as well as an optional booster for amplitude amplification.

The tasks and thus the requirements on the grippers are multiple. According to [13], the gripping process consists of three important sequences:

- Creating the contact between the object to be gripped and gripper
- Securing the gripped object during transportation
- Precisely laying down the object in the target position in the shortest amount of time

The requirements also apply to the ultrasonic assisted gripper system. This principle's gripping process may be divided into four phases as depicted as in figure 4.

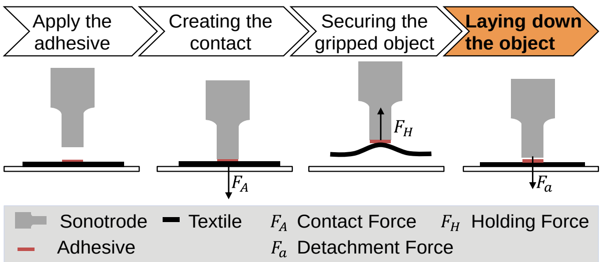

Figure 4 - Sequences of ultrasonic assisted gripping

During the first phase, the adhesive is put on the textile in case it is not already there. Subsequently, the contact between the sonotrode and the textile is established with defined contact force (phase 2). The connection is either made by curing (duroplastics) or hardening (thermoplastics) of the adhesive. The third phase describes the actual gripping, the securing of the textile in its position and its orientation during transportation. The necessary holding forces between the gripper and the textile stem from the adhesive and cohesive strength of the bonding agent. Since there a many different adhesives on the market, the adhesive power can be adjusted in many areas. The fourth phase is the most important one of oscillating gripping and is thus central to research in this field at the wbk. When it comes to adhesive gripping, the greatest challenge is to specifically remove the adhesive contact. It is in particular the generation of the forces needed to remove the adhesive that is of crucial importance. In [8], systems were closely examined and the repercussions on the removing power were discussed. Separating operations of semi-finished products from stack may very well be carried out according to the presented principle but multi-layer gripping however is not possible. By now, the gripping system has been further developed in order to realize a gripper element which absolutely lives up to its requirements. It was through the combination of a Coanda gripper and an oscillating system that a gripping element was created which absolutely combines the advantages of both systems. The prototype of this gripper is depicted in figure 5.

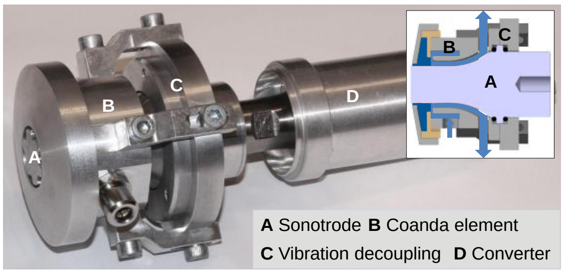

Figure 5 - Prototype and functional principle of the combined gripper.

Further advantages arise by combining these two operating principles. They can absolutely be used during the RTM procedure. The use of ultrasonic deactivates the lateral force of this system, without influencing the normal force, just as it is the case with contactfree handling with ultrasonic [14]. The results of measurement are depicted in figure 6. The transmitted normal force and lateral force were measured at the pressure of 6 bar, depending on the ultrasonic vibrations. A 35 kHz ultrasonic system was used in the tests. The amplitudes at the tip of the sonotrode measured around 20 µm.

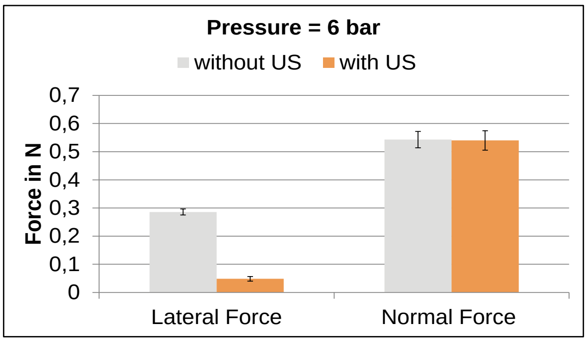

Figure 6 - Measured lateral and normal force depending on ultrasonic vibrations.

Thus, it is in particular in the area of preforming that targeted sliding of the gripper can be guaranteed without causing interactions with the textile. When it comes to conventional grippers, sliding can have repercussions on the quality of motion of the fiber or may cause other undesired damage of the textile. An ultrasonic welding system which also allows point by point fixing of the developed textile layers with ultrasound serves as the basis for the oscillating system.

4 SENSOR-BASED COANDA GRIPPER

The evaluation of the Coanda gripper shows that its benefits lie in the gentle handling and the flexibility of the semi-finished textile product to be gripped. However, the particularly poor energy efficiency as well as the insufficient process reliability only allow a limited use of an automated process chain.

Therefore, a new sensor system that is able to detect the different states of the gripping process has been developed at the wbk. The contact resistance spreading between the two electrodes of the suction surface of the gripper and the semi-finished textile product serves as the measurand (figure 7).

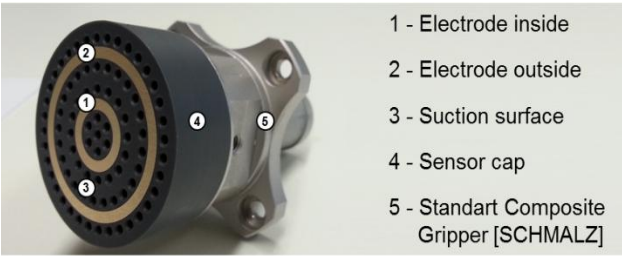

Figure 7 - Prototype of sensor-based Coanda gripper.

The generation of the grippers holding power, based on the so-called Coanda effect. By using this effect, a vacuum flow is generated by compressed air. This vacuum flow sucks the semi-finished textile product to the suction surface in which the two electrodes are integrated.

The contact resistance, which is measured between the two electrodes and the semi-finished textile product, depends on the holding power. Because of the relationship of proportionality between the operating pressure of the Coanda gripper and the generated holding power caused by it, the contact resistance is also a function of the operating pressure. This relationship is depicted in figure 8.

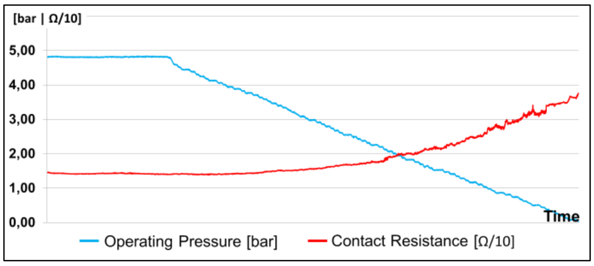

Figure 8 - Relationship between contact-resistance and the operating pressure.

The holding power also depends on the permeability of the entire multi-layered semi-finished product underneath the suction surface.

By sucking on additional layers of the semi-finished product, the permeability decreases and the suction power between the upper layers of the semi-finished product and the two electrodes consequently increases. This in turn directly affects the measured contact resistance. This connection is depicted in figure 9, using a constant operating pressure ($p_N = 5\ \mathrm{bar}$) for gripping one, two or no layers of a semi-finished product.

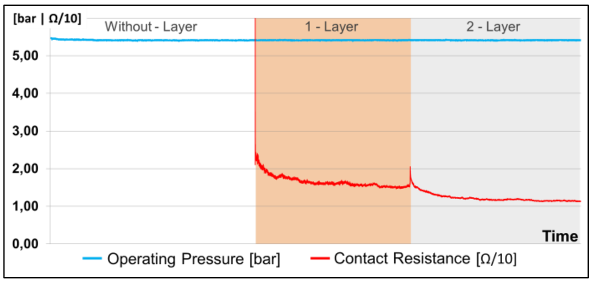

Figure 9 - Contact-resistance by gripping one, two and no layer of semi-finished textile.

By setting up a control circuit, comprising a sensor, control unit and regulating valve, the operating pressure is regulated in a way that the previously defined holding power is reached.

The air consumption of the gripper can be reduced to a minimum if regulated by a minimum holding power. This bottom value was determined experimentally and guarantees that the semi-finished product securely remains at the suction surface of the gripper. The setup prototype also allows compensating dynamically occurring process powers while maintaining minimal air consumption. This, for example, is needed for compensating robotic motion and the hereby caused acceleration. Such a control process is depicted in figure 10. This control system reduces energy consumption and at the same time minimizes interaction between gripper/textile as well as the hereby caused damage. The constant uncontrolled operation pressure, which is needed to compensate the given process force, is also shown in figure 10.

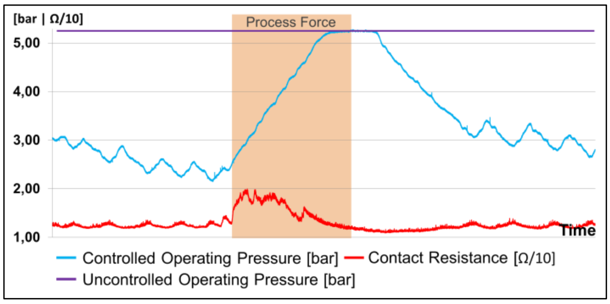

Figure 10 - Control process to compensate dynamic process forces.

In the field of composites, the use of the new sensor technology has created the opportunity to fundamentally increase the gripper's process reliability. This is in particular due to monitoring and its influence on the gripping process. A significant increase of energy efficiency was achieved by integrating the sensor into the loop. Compressed air savings of 80% volume flow rate were achieved in tests for static applications at an operating pressure of ($p_N = 5$ bar).

5 CONCLUSION AND OUTLOOK

The further development of existing gripping principles portrayed in this article has created new gripping elements which fulfill the requirements of the RTM process across several process steps.

Combining oscillating gripping and the Coanda effect facilitates reliable separating of textiles from stack, damage reduction during preforming as well as quick binder activation and fixation with ultrasound.

By implementing a new sensor technology, the gripping process may now be monitored continuously which in turn leads to an increase of process reliability. The use of a Coanda gripper together with these sensors reduces energy consumption significantly and thus fundamentally increases energy efficiency.

The set out solutions are continuously subject to further research. The next step aims at transferring the solutions to gripper systems consisting of various grippers set up in a different order. It is in particular in the field of performing, that these gripper systems could show great advantages compared to the present state of the art.

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