FORM-ADAPTIVE GRIPPING SYSTEM FOR LIGHT-WEIGHT PRODUCTIONS

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ABSTRACT

Today's systems for the production of fibre-reinforced plastics (FRP) realise cycle times under 3 minutes for injection and curing thanks to new materials (e.g. fast curing epoxy resins, high reactive polyurethane) and innovative process technologies (e.g. high-pressure-RTM, gap impregnation).
Such cycle times cannot be found in all steps of the thermoset RTM-process-chain. During the manufacturing of semi-finished non-impregnated textile preforms, reproducible processes for the separation, manipulation and draping of technical textiles are necessary. Especially small scale productions for load-optimized FRP-components require form-flexible and area-adaptive handling systems to handle individual blanks from CNC cutters.

The main requirements and challenges of an automated handling and draping system for technical textiles are full-areal gripping and the application of defined force patterns to ensure the handling of air-permeable and sensitive textiles without impairing the fibre-structure. Those requirements are met by the principle of electrostatic gripping whose applicability in the production of FRP-light-weight-components is being continuously developed at the Fraunhofer Institute for Production Technology IPT since 2007.

One of the main benefits of this handling-technology is the application-specific adaptation of the gripping-electrodes. Fraunhofer IPT is one of the worldwide leading developers of grippers with variable sizes and shapes and a flexible surface. Thus Fraunhofer IPT enables the electrostatic gripping systems for the handling in complex 3D-gripping and -draping scenarios for the composite-industry.

1 INTRODUCTION

Lightweight products made of fibre-reinforced plastics (FRP) are more and more commonly used in many industries like automotive, oil & gas, aerospace, energy and sports & leisure ([1], [2]). Especially their mechanical properties of lesser weight while simultaneously maintaining higher mechanical resilience make FRP an ideal material for high-performance applications as well as consumer applications.

Current systems for the production or FRP-components achieve cycle times under three minutes for injection and curing thanks to new materials (e.g. fast curing epoxy resins, high reactive polyurethane) and innovative process technologies (e.g. high-pressure-RTM, gap impregnation). Such cycle times cannot be found in all steps of the thermoset RTM-process-chain. Especially handling operations are often done manually and very time-consuming. Thus this paper presents the electrostatic gripping technology for the automated and adaptive handling of materials in the thermoset RTM-process-chain.

2 THEORY ON ELECTROSTATIC GRIPPING

An electrostatic gripper consists of a pattern of electrodes applied to a substrate material and covered with an insulating layer (Fig. 1). The electrodes can be of the same or opposing polarization. A static high voltage is applied to those electrodes in order to establish an electrostatic field, which enables the gripping effect. Electric dipole moments generate an areal adhesion between gripper and nearly each material (conductive or insulating). The areal application of force especially enables the automated handling of sensitive materials (e.g. mats, fleeces, rovings). Gripping forces with electrostatic adhesion can be modelled according to Coulomb’s law.

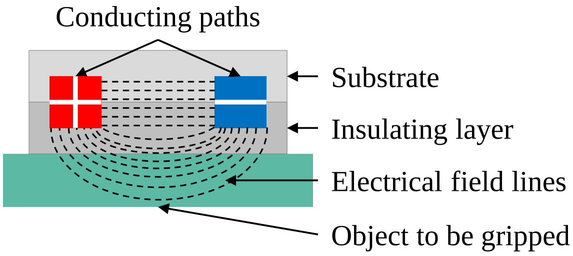


Figure 1: Exemplary structure of an electrostatic gripper (Fraunhofer IPT).

Electrostatic gripping is based on the effect of electrostatic induction (influence) or dielectric polarization ([3]) depending on the material to be handled (Fig. 2). If an electrically conductive material (e.g. carbon fibre) is to be handled, the effect of electrostatic induction (influence) applies. This means, that freely moveable electric charges in an object are redistributed upon the application of an electrostatic field generating the effect of electroadhesion. In case of an electrically insulating material (e.g. glass fibre) to be handled, dielectric polarization applies. Each atom in the material consists of a cloud of negative charges bound to a positive charge at its centre. As an electrically insulating material contains no freely moveable electrical charges, an electrostatic field does not induce any redistribution of charges. Instead, the centre of charge in the single atoms is distorted forming small electrical dipoles. Following the principle of superposition, those elemental dipoles generate the effect of electroadhesion.

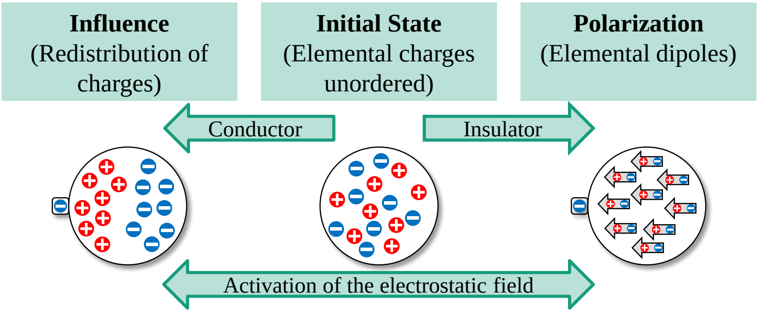


Figure 2: Effects of influence and polarization (Fraunhofer IPT).

The adhesive effect is based on coulomb’s law which states that inverse charges are attracted to each other.

2.1 Theoretical gripping forces of a simple electrostatic gripper

The simplest approach to an electrostatic gripper is a capacitor, where the opposite static potential of the electrostatic gripper is applied to the handling material ([4, 5, 7], Fig. 3).

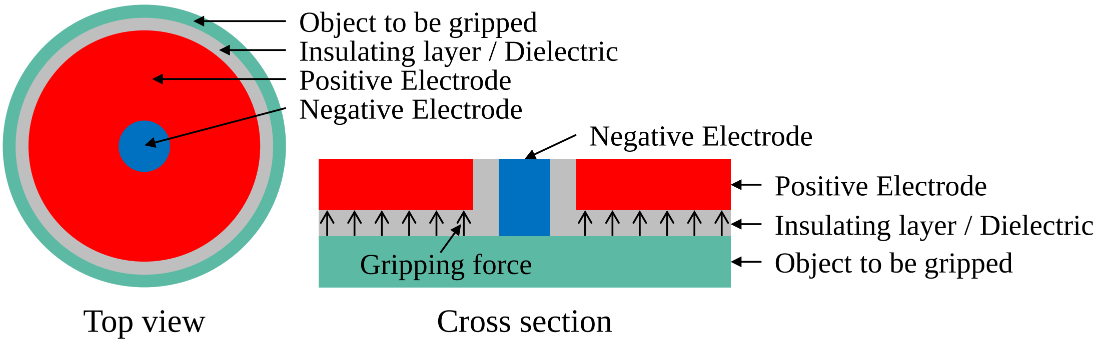


Figure 3: Structure of a simple electrostatic gripper (Fraunhofer IPT, [4, 5]).

The gripping force depends on the amount of electrical energy stored in the capacitor given by (1) where U is the static potential difference between both electrodes and C is the capacitance of the capacitor approximated by (2) where $\varepsilon = \varepsilon_0 * \varepsilon_r$ is the permittivity of the dielectric, A is the contact area of the gripper electrode and the material to be handled and d is the thickness of the dielectric.

$$W_e = \frac{1}{2} C U^2 \tag{1}$$

$$C = \varepsilon \frac{A}{d} \tag{2}$$

Substituting (1) with (2) and differentiating the outcome leads to equation (3) which denotes the electrostatic force between the two electrodes.

$$\frac{d}{dd} W_e = \frac{d}{dd}\left(\frac{1}{2}\varepsilon\frac{A}{d}U^2\right) \Rightarrow |F_e| = \frac{\varepsilon A U^2}{2d^2} \tag{3}$$

When plotting (3) as function of the voltage for typical voltages of up to 10 kV, Fig. 4 shows the qualitative characteristic of the force. It shows a quadratic progress based on the quadratic influence of the applied voltage. Fringing capacitances and electrical fields are not included in this approach.

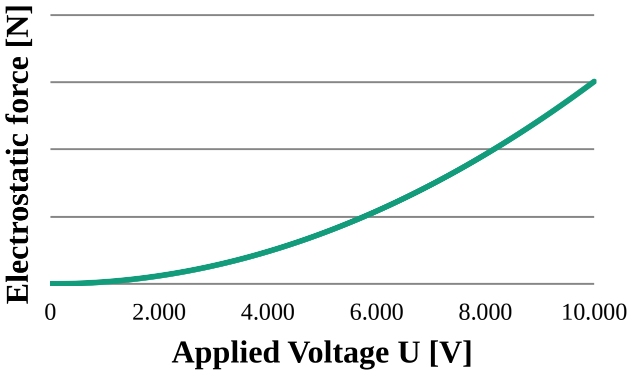


Figure 4: Qualitative characteristic of Equation 3 (Fraunhofer IPT).

As the gripping force is created by two opposite electrodes, a gripper schematic like shown in Fig. 3 only works with electrical conducting handling materials and is thus limited in its use and offers a high risk potential, as the high voltage is directly accessible.

2.2 Theoretical gripping forces of a comb electrode electrostatic gripper

A more practical and more user-safe approach to gripper design implies keeping high voltages within the electrically insulated gripper. This principle was already introduced in Fig. 1. In order to be able to simulate the force of the electric field, Koh et al. ([7]) developed a formula (Equation 4) based on empirical data ([8, 9, 10]) to simulate the arising forces between comb electrodes as depicted in Fig. 5. For the electrostatic gripping effect only the fields E_3 are of interest, as only those fields have an influence on the handling material. In simulations, the results are similar to the predicted electrostatic forces in 2.1.

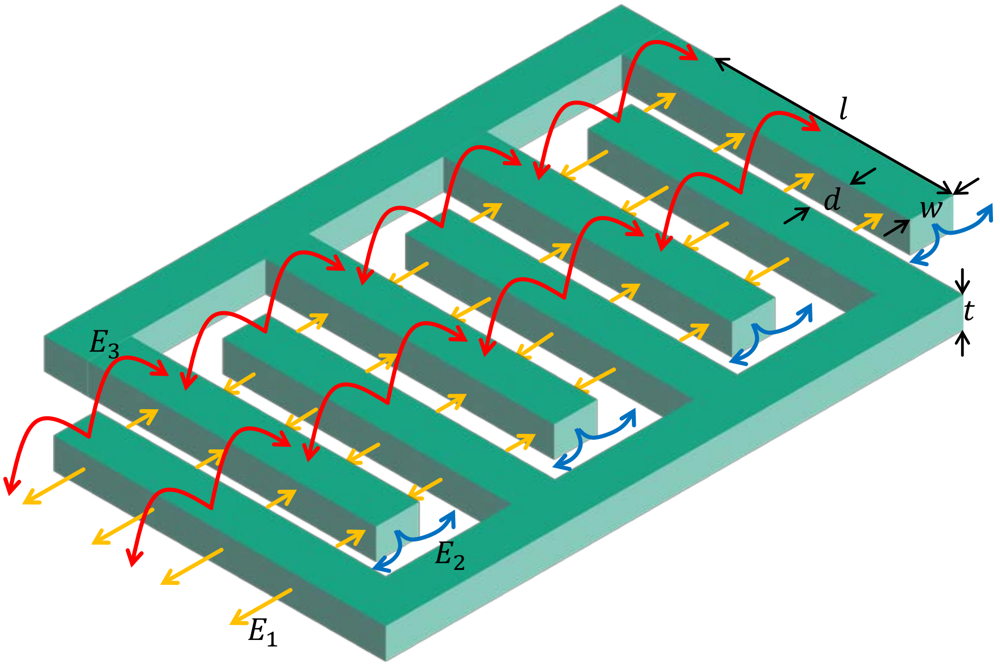


Figure 5: Important symbols and directions of electrical fields (Fraunhofer IPT, [7]).

$$F_{E_3} = \frac{\varepsilon w l U^2}{2d^2} + \frac{0.265\varepsilon w^{0.5} l U^2}{d^{1.5}} \tag{4}$$

The most interesting point from the examinations of Koh et al. ([7]) is how different parameters affect the maximum possible electrostatic gripping force. Those parameters include the electrical properties of the dielectric, width, length, thickness displacement of the electrodes, the static voltage applied and the electrical properties of the handling material. All these parameters have also been found to be important by Fraunhofer IPT during the work in research group 860 funded by the DFG ([11, 12, 13]).

3 PROPERTIES AND APPLICATIONS OF ELECTROSTATIC GRIPPING

Because of its properties, electrostatic gripping is especially suited for the handling of air-permeable (non- / semi-) rigid materials as used in the production of lightweight parts made out of (fibre-reinforced) composite materials.

3.1 Advantages of electrostatic gripping

One of the main benefits of the electrostatic gripping technology is the virtually independence of materials to be handled. It does not matter if the material is electrically conductive or insulating, non-rigid or rigid, air-permeable or airtight. The possible handling materials ranges from technical textiles (Glass, carbon, aramid etc.) over thin plastic films, stainless steel fabrics, glass-fibre-fleeces and paper/cardboard/board to micro-lenses.

The principle of electrostatic gripping effectively offers laminar gripping of the part surface. This secures warp-free and deformation-free gripping of parts and thus enables for handling of extremely sensitive materials.

Based on the gripper layout, defined pick & place actions are possible by area-selective gripping and separation from stack and defined draping even on curved surfaces, which especially enables further automation of RTM-processes by picking tailored-blanks from a CNC-cutter-table and draping them into a mould without needing manual actions (Fig. 6).

Another huge benefit of the electrostatic gripping technology is its energy-efficiency. The electrostatic field of the gripper builds up within milliseconds. Once the field is stable, the flow of current stops and no further energy is consumed. Depending on the material and the process, recharging pulses of current may be applied. Based on a theoretical calculation, a gripper the size of a DIN A4 paper only needs approximately 4.5 kWh of electrical energy for one million gripping operations which is far less than the energy consumption of a comparable vacuum gripper.

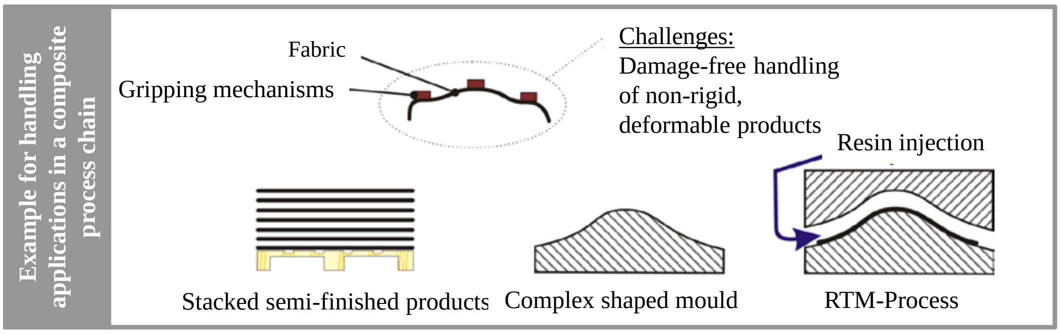


Figure 6: Automated draping of textiles into curved moulds (Fraunhofer IPT).

The electrostatic gripping technology also operates without noise making it very environmental friendly. Even though high voltages of several kV are used, the whole process is user-safe by design, active and passive measures. Passive measures involve proper insulation of the grippers against the environment. Active measures include measurements for leakage current and fault current circuit breakers for emergency cases. Safety by design includes, that the grippers are designed so that the energy they hold cannot exceed dangerous energy levels.

3.2 Multifunctional electrostatic grippers

By using transparent materials in the design of the electrostatic grippers, the integration of optical sensors directly into the gripper (e.g. for measurement of fibre-orientations, process quality etc.) is possible.

Besides the conducting paths for static electrical fields, conducting paths for alternating electrical fields can be integrated into the gripper layout. Those conducting paths could for example be used for induction heating in order to activate various materials during the handling operations, e.g. for tacking textiles wetted with heat-sensitive adhesive sprays.

One focus of research and development in the field of electrostatic gripping at Fraunhofer IPT lays especially on the multifunctional activation of electrostatic grippers.

3.3 Endeffector-kinematics for electrostatic grippers

Flexible endeffector kinematics are needed if using electrostatic grippers in an automated environment with focus on draping in curved moulds. An example for a flat, convex and concave adaptable kinematic is the “Octopus gripper” developed by Fraunhofer IPT ([11, 12, 13], Fig. 7). The octopus gripper features a cost-effective design made of stamped and bended segments. The primarily passive kinematic is self-adaptive and based on the biological model of a fish fin.

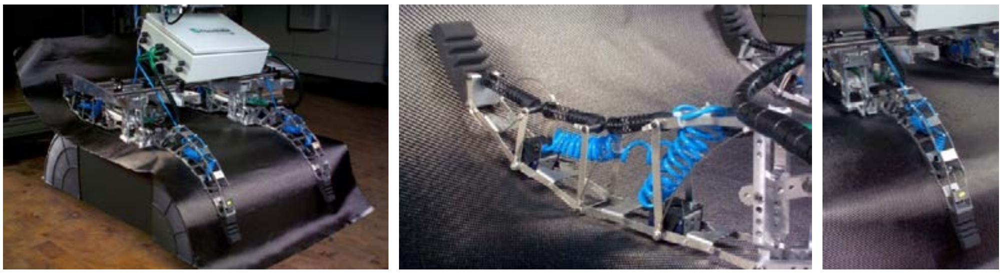


Figure 7: Octopus-Endeffector-Kinematics (Fraunhofer IPT).

4 RESEARCH AND DEVELOPMENT

Since 2007, the department “Fiber-Reinforced Plastics and Laser System Technology” at Fraunhofer IPT actively researches and develops electrostatic grippers and their applications. In the field of research, the focus lays on electroadhesive effects, gripper layouts, gripper materials, enhanced gripper functionality, process examination, material studies, concept studies and kinematics useable with electrostatic grippers. Fraunhofer IPT also develops and builds customized gripping solutions for the industry.

4.1 Gripper layouts and gripper materials

Electrostatic grippers can be divided into two groups: Rigid grippers and flexible grippers ([3, 14, 15], Fig. 8). As the electrostatic grippers (pads) are comparable to printed circuit boards, the same technologies as for printed-circuits are applicable.

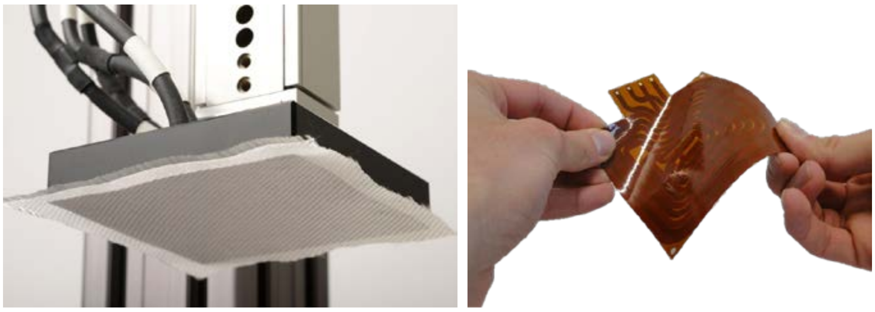


Figure 8: Rigid pad with glass fibre attached on the left, flexible pad on the right (Fraunhofer IPT).

Rigid pads consist of an electrically insulating base layer (e.g. FR-4 glass fibre epoxy), printed with electrical circuits and topped with a thin electrically insulating layer (e.g. Polyimide). In flexible pads, the base layer consists of a flexible material (e.g. Polyimide). The gripping surface can be coated to generate a sticky effect to enhance gripping forces ([15]).

As shown in Fig. 6 and in 3.3, flexible grippers are especially suited for automated handling and draping of textile materials. Figure 9 depicts a combination of the octopus gripper (Fig. 7) with a flexible pad adapting to a curved mold.

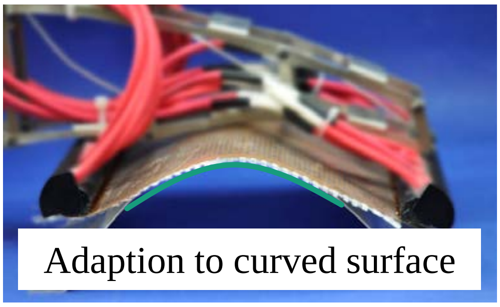


Figure 9: Combination of flexible pad and octopus gripper kinematic (Fraunhofer IPT).

The layout of the printed circuits on the pad is a very important part. Fraunhofer IPT found a comb electrode layout (Fig. 5) to be most effective. Especially the ratios between length, thickness and distance of the single fingers of the comb electrode are responsible for the strength of the electrostatic field to be generated. Figure 10 depicts different trials of possible geometries. It is visible, that the ratio has a high influence on the possible gripping forces varying by a factor of approximately 2.7.

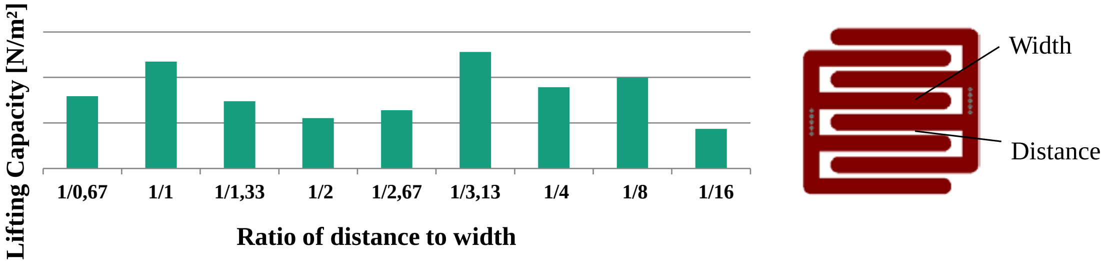
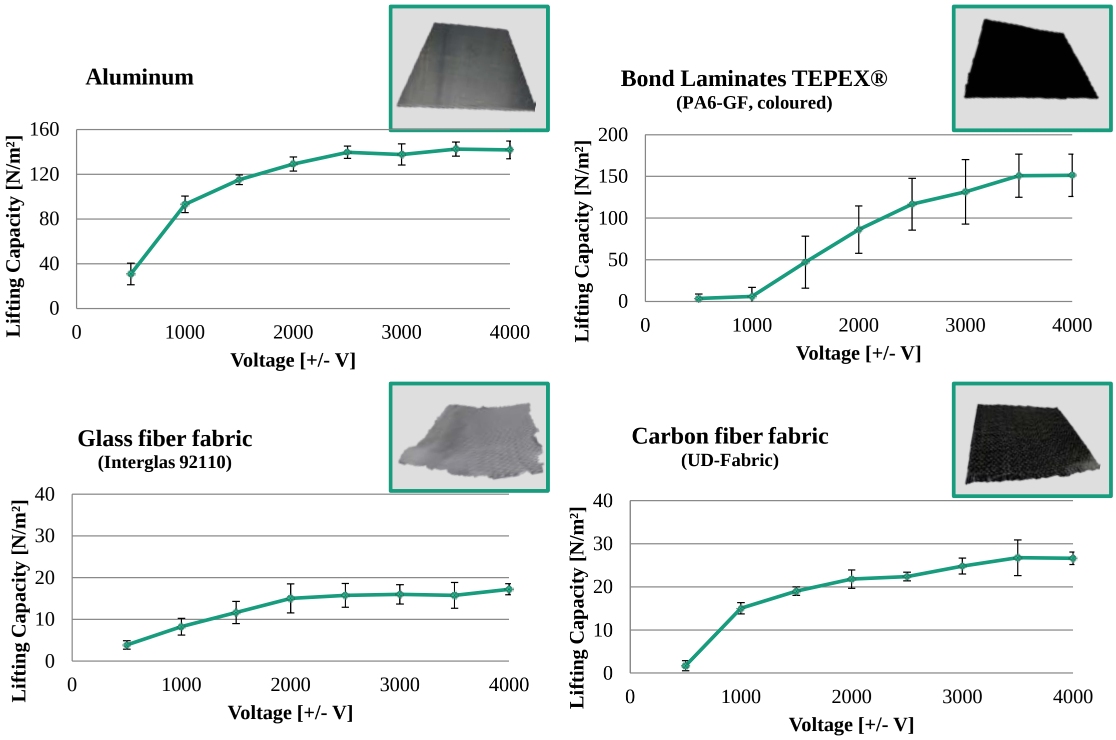


Figure 10: Influence of layout on lifting capacity (Fraunhofer IPT).

4.2 Material studies

As stated in 3.1, electrostatic grippers are suited for almost all materials. The specific weight of the material is the only limiting factor for the applicability of electrostatic gripping. Material specific gripping forces ranging from 2 N/m² up to 150 N/m² have been verified by experiments using static voltages of up to 10 kV, while maintaining a completely user-safe process (Fig. 11).


Aluminum

Bond Laminates TEPEX® (PA6-GF, coloured)

Glass fiber fabric (Interglas 92110)

Carbon fiber fabric (UD-Fabric)

Figure 11: Influence of layout on lifting capacity (Fraunhofer IPT).

Figure 11 shows the progress of the lifting capacity over the applied voltage for a selection of four different materials. The voltage applies to each of the electrodes in opposing polarisation. It is very interesting to see, that the curves show a degressive progress in contrast to the predicted progressive curve in 2.1 and 2.2. This change is most probably based on saturation effects and material properties.

4.3 Process studies

The repeated secure gripping and releasing different materials is part of process studies. The main challenge lies in the customization of the electrostatic gripping technology for every special use case. The determination of the right gripping voltages and the best gripper layout for a specific material can usually be done in a small case study by testing different parameters. Secure gripping of various materials can be achieved without too much effort.

The release of the materials is a bit more complicated. Once materials are exposed to an electrostatic field, the polarization of the material dissolves only slowly after the deactivation of the electrostatic field. Thus the material sticks to the gripper for an undefined time (up to 60 seconds). Depending on the application different release mechanisms can be applied to the gripper in order to secure the safe release of the handling materials.

One common method is to integrate air-holes into the pad through which air can be blown in order to push away the material. A new releasing-technology was developed by Fraunhofer IPT ([15], pat. pending) and works fully electrically by reversing the polarization of the material. This is achieved by repeatedly and exponentially decreasing reversion of the applied voltage, which enables for a secure release mechanism (Fig. 12).

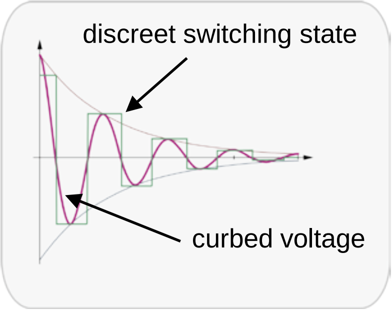


Figure 12: Reversion of the polarization state (Fraunhofer IPT).

When handling individual tailored preforms from a CNC-cutter table, it is important to have an adaptable area-selective gripping device that may adjust to every possible shape of tailored preforms. Fraunhofer IPT developed a method to directly control single separated areas in the same gripper to be able to pick up tailored blanks only in specified areas (Fig. 13).

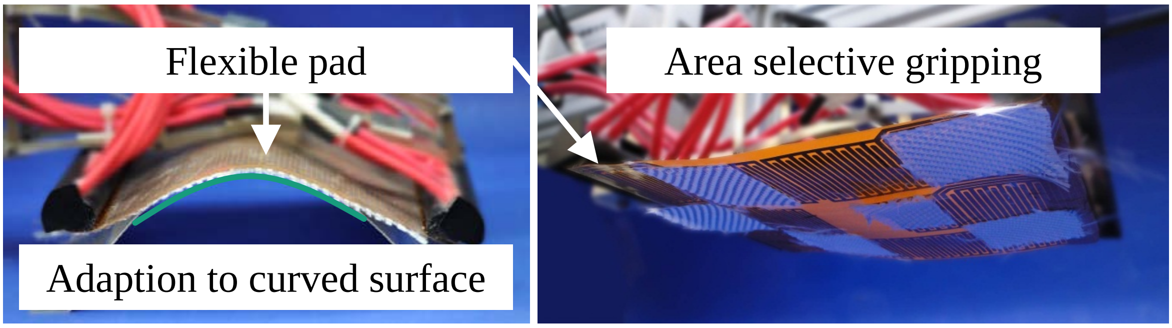


Figure 13: Area selective gripping of glass fibre mats (Fraunhofer IPT).

5 CONCLUSIONS

The electrostatic gripping technology matches the requirements of the automation of processes including the handling non-rigid, air-permeable sensitive materials like carbon or glass fibre textiles. This paper shows how the electrostatic gripping technology works, what their benefits are and where active research and development takes place. Fraunhofer IPT is one of the worldwide leading developers of grippers with variable sizes and shapes and a flexible surface. Thus Fraunhofer IPT enables the electrostatic gripping systems for the handling in complex 3D-gripping and -draping scenarios for the composite-industry.

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