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Vacuum System for Reinforcing Fabric Handling

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The paper considers questions asotiated with automated systems to produce composite parts. Existing automated systems used in aerospace production are usually based on lay-up technologies. The main objective of the on-going development is to find an affordable production technology for composite parts that can be easily automated. The handling with dry reinforcing fabrics is objective of the paper: dry fabric is placed in a suitable mold where it is impregnated by selected type of a matrix and consolidated under vacuum bag afterwards. Based on experiments using standard gripping systems, it was found that local damage of reinforcing fibers occurs. For these reasons, a new vacuum suction-based gripper was developed. As a suction source industrial vacuum cleaner was used, whose performance can be regulated continuously. Functionality of the suction system was verified on six different types of reinforcing materials, using two different types of suction grid at three different levels of vacuum cleaner performance. Performed experiments verified suitability of the designed solution for manipulation with dry fabrics without the risk of their damage.

Keywords: Fibre reinforced plastic, Vacuum System, Automated Production, Gripper, Handling

1 Introduction

Composite manufacturing is one of the industries with a traditionally high proportion of manual labour. In recent years, this sector has also seen a gradual expansion of automated equipment, which enables manufacturers to ensure the high quality and repeatability of the production process that is required, particularly in advanced industries such as aerospace and medical applications. Historically, the oldest automated systems to produce composite components include winding systems to produce hollow rotationally symmetrical parts, as well as pultrusion lines to produce prismatic composite profiles. Together with the progressive increase of composite elements utilization, particularly in military aerospace, the necessity for an automated process capable of producing generic shaped elements with complex rein-forcement compositions has also occured. Automated tape laying (ATL) and automated fiber placement (AFP) systems, which emerged in the late 1980s in connection with the development programs of the F-117, B-2, and F-22 aircraft, are the answer to this requirement. These complex, sophisticated production systems can lay prepregs (fibres and strips of pre-pregnated matrices) directly onto the mould surface to create structurally and dimensiona-lly complex composite parts [1-5]. The main disadvantage of the above systems is their purchase price and necessity to work with expensive certified materials for which the system is designed [6].

In recent years, automated production of composite parts has also been increased intensively in the automotive industry. Due to the significantly higher price of composite products, compared to traditional metal body components, the highest increase in applications is noticeable in the premium brands of individual concerns. In this area, the HP-RTM technology, i.e. the rapid impregnation of reinforcement, enclosed in a heated metal mould, using a termo-mosaic or thermoplastic matrix that is injected into the mould under high pressure, is the most important [7-13]. The individual layers of reinforcement are cut on automated cutting plotters and then, using an automated system, folded into so-called pre-forms, and inserted into moulds subsequently placed in a heated press. Here they are saturated and cured. The cured parts are removed from the mould and moved on to the next stage of finishing. The advantage of this technology is the high speed of production, as production times can be achieved within minutes, unlike traditional methods, due to the elevated process temperature and the appropriate material system to ensure rapid curing of the composite product. The main disadvantage of this process is the high complexity and purchase price of metal moulds and production equip-ment, which makes this type of production process predestined for high volume production.

In both above disussed cases prevail single-purpose automated systems with a very high purchase price. Some examples of these state of the art robost and effectors for fabrics draping are shwn in refs. [14-17]. These systems are very expensive to aquire, which significantly limits the expansion of these systems into the area of small and medium-sized companies. The basic idea of the implemented research program is to develop a simple adaptable modular automated system, whose resulting price and economic return on investment will be acceptable for smaller companies in the Czech Republic. For these reasons, the proposed automated system is based on a simple, but reliable method of production of composite products, using contact lamination with vacuum bagging.

The actual process of composite parts manufacturing by the contact lamination method with vacuum bag laminating can be divided into several steps. These are: preparation of the dry reinforcement cut-outs, placing the dry reinfor-cement in the mould, preparation of the resin, saturation of the dry reinforcement with the resin using a roller or brush, insertion of the process layers into the mould, sealing using a vacuum sheet followed by vacuum pressing of the layers, curing, removal from the mould and finishing of the composite blank using standard machining techniques.

2 Verification of commercial accessible solutions

In this section, consideration to the process of transfer the cuttings from the cutting plotter to the moulds is discussed. For this purpose, an extensive search of existing gripping devices suitable for handling glass and carbon reinforcing was carried out. Due to the porous nature of these materials, it was not possible to use conventional vacuum systems as they are unable to maintain a sufficient level of vacuum necessary for successful gripping when handling porous fabrics. For these reasons, experiments were initiated using a needle-bead gripping system [18] (Fig. 1), a Bernoulli gripper [19] (Fig. 2.) and a gripping system consisting of a combination of the two mentioned above [20] (Fig. 3.). These three systems were tested in combination with several types of glass and carbon fabrics with different weave types, weights, and different numbers of superimposed reinforcement layers to verify the sensitivity and limits of each system.

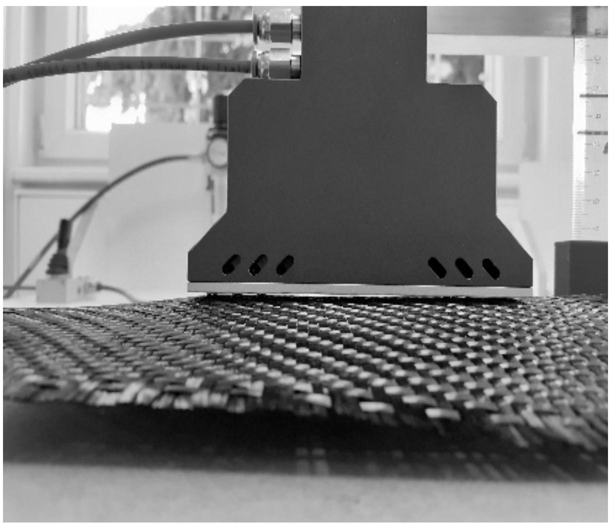


Fig. 1 *Needle gripping system*

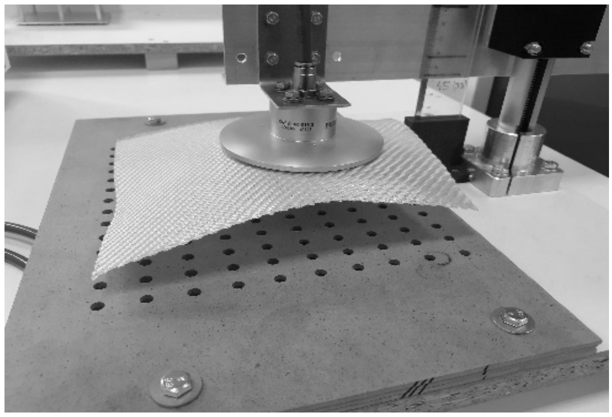


Fig. 2 *Bernoulli gripper*

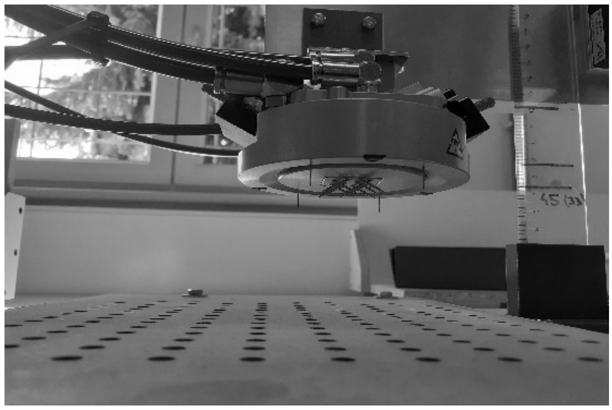


Fig. 3 *Combined gripper*

During experiments with needle gripping systems, it was found that it was difficult to individually grip the top layer of fabric from a bundle of multiple cuts. This is due to fact that to create a guaranteed grip, the needles must pene-trate the entire thickness of the fabric with a considerable overlap. Consequently, the needles are in contact with the lower layers of the fabric, which are also griped. The rows of needles are ejected from the manipulator at an angle of 45° regarding the base and individual rows of needles are slewed about 90° to each other so that the material was mechanically locked. However, the sequential needles ejecting at 45° angle causes tension and sliding of the yearns in contact with the needles. It causes local damage of all types of fabrics. Typical damage mode of fabrics is shown in Fig. 4.

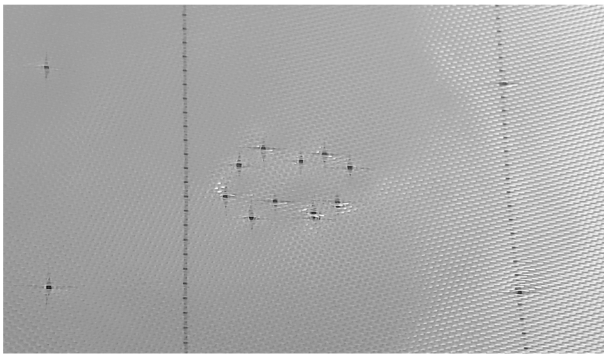


Fig. 4 *Typical damage mode of fabrics by needle gripper*

The experiments with Bernoulli gripper verified possibility of the fabric top layer independent gripping from a multi-layer bundle by using of a suitable adjustment of the inlet air pressure. Unfortunately, due to the non-contact gripping method, where the fabric floats on the generated air cushion, which is a secondary effect of the suction effect created by blowing compressed air through the slot, the system is very sensitive to the balance of the grip. If the cut-in was not gripped at its centre of mass, it would gradually slip from the gripper towards the more massive part of the cut-in.

3 Design of vacuum system

Due to the complications arising from the use of commercially available gripping systems, it was decided to develop a proprietary gripping system that would be capable of handling technical fabrics with low grammage and fine texture, including satin weave, without the risk of localised weave damage as in the case of mechanical gripping systems. Based on these requirements, a custom vacuum system was developed, consisting of a square grid with circular holes, a confuzor in which the air intake is accelerated and therefore the static pressure is reduced, a transition sleeve which serves to attach the vacuum attachment to the tent-dardized end of the suction hose of an industrial vacuum cleaner.

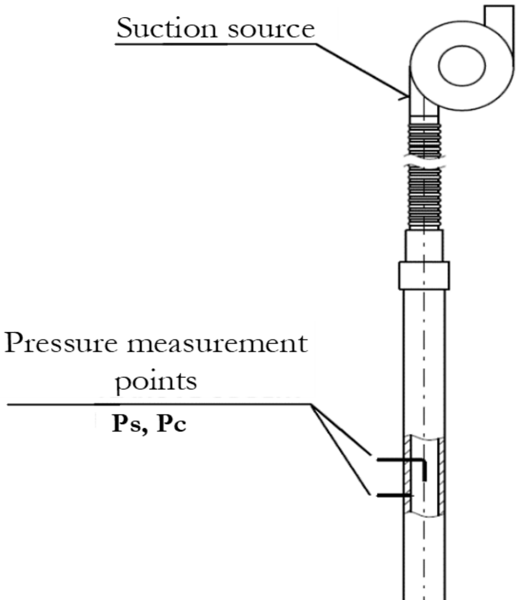


***Fig. 5** Concept of measuring installation*

This geometrical concept (Fig. 5.), extended by an intermediate piece inserted between the confuzor and the suction hose end, designed to measure the static and total pressure of the airflow, was mainly used to verify the sensitivity of the gripping process to the parameters tested, which were the power level of the industrial vacuum cleaner, the geometry of the suction grid, the fabric weight, the weave and the resulting porosity of the gripped fabric and the limiting distance at which the gripping of the fabric occurs. The suction source chosen was a Kärcher WD 6 P industrial vacuum cleaner with infinitely variable suction power control. To testing the limiting distance of the vacuum system, at which the cuttings are pressed against the suction grid, the vacuum system was mounted on a traversing fixture (Fig. 6), which allowed the suction grid to be continuously brought closer to the cuttings while guaranteeing their parallel position.

***Fig. 6** Measuring assembly*

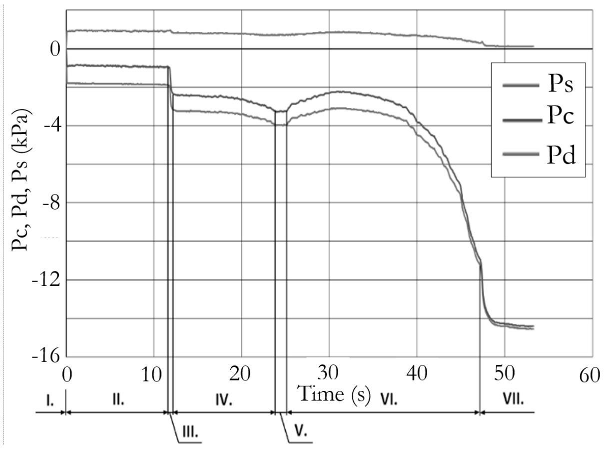
4 Verification of designed vacuum system

The measurement was carried out by placing the cut on the measuring fixture pad, setting the position of the suction grid with a distance of 50 mm from the pad, starting the vacuum cleaner at one of the three tested powers and using the traverser to bring the suction grid closer to the fabric until it was draped. Afterthat the suction grid was continuously move close into the pad together with suction pressure decreasing. The static and total pressure waveforms were measured using pressure gauges throughout this measurement cycle. This procedure was repeated at 3 different levels of vacuum cleaner suction power, with 2 suction grids with different diameters of suction holes and with 6 different types of fabrics (Tab. 1). The fabrics were draped either individually or in multiple layers stacked on top of each other.

Tab. 1 *Tested fabrics*

Type of Fabric	*Type of fibre*	*Fabric mass*	*Type weave*
Vectran Vct200	*Polyester*	*200 g/m^2*	*Twill 2/2*
S2-glass STYLE 6580	*S – glass*	*199 g/m^2*	*8H Satin*
Vertex	*E – glass*	*800 g/m^2*	*Canvas*
Style 450	*Carbon*	*200 g/m^2*	*Canvas*
UD CST 200	*Carbon*	*200 g/m^2*	*Unidirectional re-inforcing*
Style 404	*Carbon*	*600 g/m^2*	*Twill 2/2*

Graph 1 shows a typical development of the total pressure (pc) and the static pressure (ps), measured in the intermediate circular cross section and the calculated dynamic pressure (pd), in different phases of the measuring cycle.



Graph 1 *Typical measured pressures profile (Vectra 200 g/m2, grid hole diameter of 4.75 mm, one plies)*

The individual phases of the measurement cycle marked I. - VII. in the Graph 1 represent:

- I. - Suction source starting
- II - Phase of decreasing the distance between the suction grid and the fabric pad
- III - Phase of the fabric suction from the pad to the centre of the suction grid (relative distance 31 mm)
- IV - Phase of further reduction of the distance between the suction grid and the pad, the edges of the cut remain in conection with the pad by atmospheric pressure (Venturi effect)
- V - Phase of limiting approach to the pad, the edges of the injection are still in connection with the pad
- VI - Phase of separation from the pad, the edges of the injection are still attached to the substrate
- VII - Cut edges unstick from the pad, full adhesion of the tooling to the grid.

The individual phases described above are photo-documented in Fig. 7.

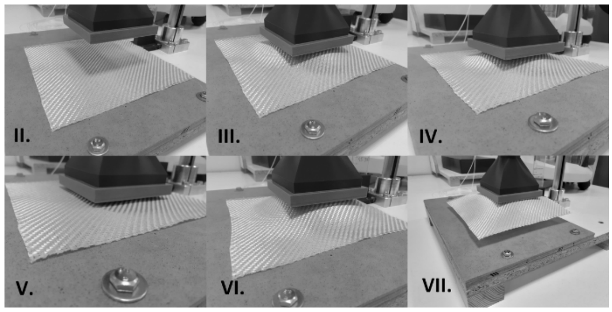
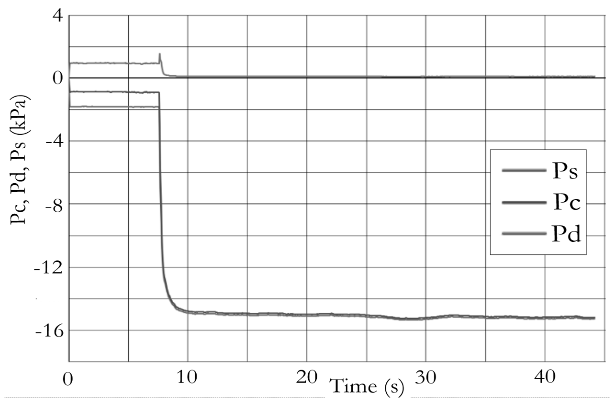


Fig. 7 *Individual phases of fabric fastening*

The fixation of the fabric edges to the pad, which caused unwanted pulling and deformation of the originally per-pendicular weft and warp weave was eliminated by inserting of a perforated pad. The perforated pad ensured necessary air supply under the gripped cut-in. Graph 2 shows the typical measured pressure waveform during this procedure. Unwanted side-effects were eliminated, and the cut-in was immediately draped to the full surface of the suction grid after the limiting distance was achieved. Therefore, no needles are used, no damage of fabrics was observed.



Graph 2 *Typical measured pressures profiles using of a perforated pad (Vectra 200 g/m2, grid hole diameter of 4.75 mm, one plies)*

5 Vacuum system load capacity measurement

Another measured parameter, important for the design of the final geometry of the gripping system, was the load capacity of the system induced by the vacuum depending on the power setting of the suction source. For this purpose, the test cut-in was mounted into an additional frame that allowed sequential loading of the draping cut-in by additional weights (see Fig. 8). The results of the suction system capacity measurements are shown in Graph 3.

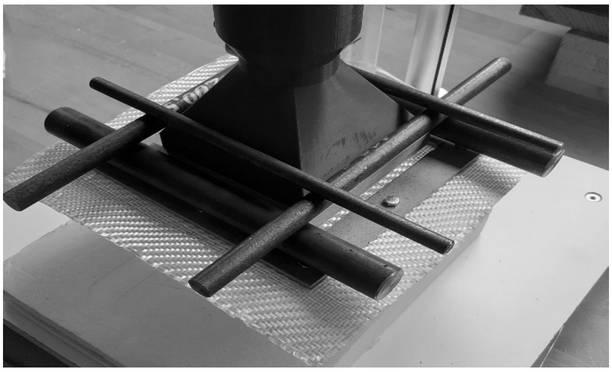
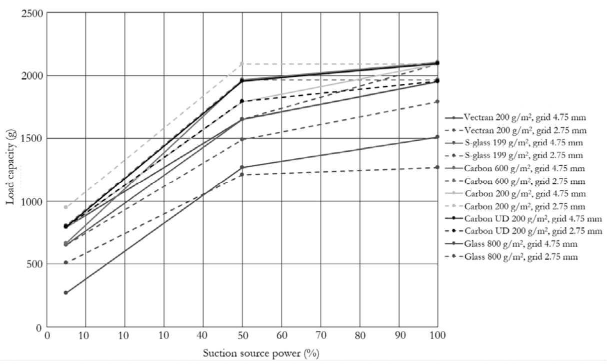


Fig. 8 *Tooling for measuring of system loading capacity*



Graph 3 *System loading capacity according to the level of suction source power and type of fabric*

As can be seen from the graph, contrary to expectations, the system capacity does not increase linearly with increa-sing degree of the suction power source setting. This phenomenon is related to the porosity of the clamping cut-in. In the case where the draping material is impermeable, the load capacity would be defined only by the product of the area of the suction grid and the magnitude of the vacuum. In our case, the suction capacity is a function of the vacuum magnitude, the volume flow capacity, and the permeability of the fabric to be draped. If we introduce an analogy with the fan power, which is defined by the product of the difference of the pressures in front of and behind the fan and the volumetric air flow (1) [21], and neglect the losses, the specific value of the suction power Q of Ps can be determined from the measured values of the static air pressure and the knowledge of the geometry of the measuring space according following equations.

$$\boldsymbol{P = \Delta p \cdot \dot{Q}\ [W]}, \tag{1}$$

$$\boldsymbol{P_S = \Delta p_S \cdot \dot{Q}\ [W]}, \tag{2}$$

$$\boldsymbol{\Delta p_s = p_s - p_a\ [Pa]}, \tag{3}$$

$$\boldsymbol{\dot{Q} = v \cdot S = \sqrt{\frac{2\cdot(p_c - p_s)}{\rho}} \cdot S\left[m^3 \cdot s^{-1}\right]}, \tag{4}$$

Where:

p_s…Measured value of static pressure [Pa],

p_c…Measured value of the total pressure [Pa],

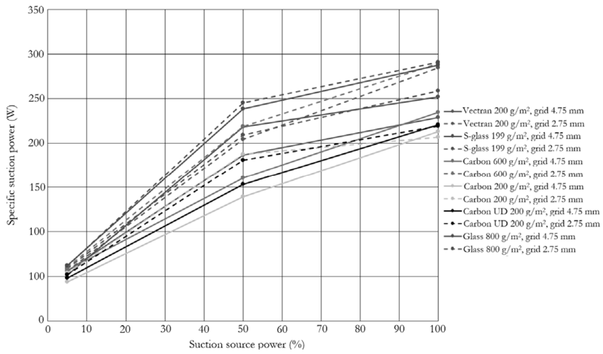
p_a…Ambient atmospheric air pressure at temperature of 20°C [Pa],

S…Pipe cross section at the point of pressure sampling [m²],

ν…Mean flow velocity at the point of pressure sampling [m.s^{-1}],

ρ…Air density at temperature of 20°C [kg.m^{-3}].

Graph 4 shows the values of the contracted suction power calculated from the measured values of total and static pres-sure, for all measured fabric and grid types.



Graph 4 *Specific value of suction power depending on the level of suction source power and fabric type*

6 Discussion

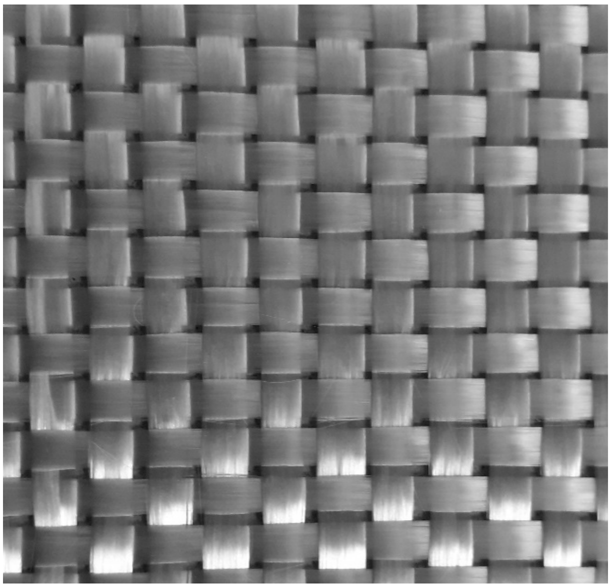


Fig. 9 *Glass fabrics „Vertex“*

When comparing the trends in specific suction power and the trends in load capacity shown in Graph 3, there is a similarity in the non-linearity of the specific suction power as a function of the suction power setting. At the same time, when comparing the Graph 3 and Graph 4, the influence of the permeability of the draping fabrics is evident. For example, the fabric type Glass 800 g/m^2 Vertex (see Fig. 9), which is characterised by a sparse weave, although the vacuum system achieves the highest specific suction power, the vacuum system at the same time achieves the lowest carrying capacity. When comparing this fabric with the 200 g/m^2 Carbon fabric (see Fig. 10), where the vacuum system achieved the highest contracting capacity, the difference in weave is evident.

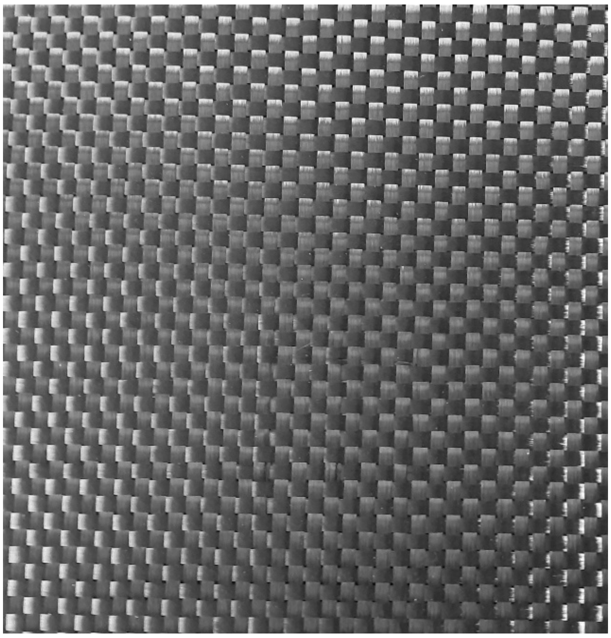


Fig. 10 *Carbon fabrics „Style 450"*

The glass fabric contains a larger free space ratio at the warp-weft crossing than carbon fabric, which allows to achieve a higher volume airflow compared with carbon fabric. It should also be noted that in the case of weave fabric is draped, a lower static pressure value is achieved in the vacuum system due to the higher permeability of this fabric. The resulting value of the load capacity of the vacuum system is a function of many interacting parameters and it is therefore necessary to verify this value experimentally for each type of fabric.

7 Conclusions

The experiments verified the suitability of the designed vacuum system to handle the cuttings of different types of dry fabrics with porous character. Due to the suitably selected grid and diameter of the holes in the suction grid, the vacuum drap system is characterized by sufficient load capacity and at the same time does not damage the draped cuttings. As the influence of the fabric permeability on the resulting load capacity of the system is not fully understood, further experiments should be carried out. These results would allow to predict the load capacity of the system only based on the measured value of the permeability of a particular fabric. The demonstrator, on which the functionality of the gripper has been verified, will also be further modified to draping of curved preforms and to accurately put in them in general shape moulds.

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