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STUDY OF UNSATURATED PERMEABILITY OF AMAZON NATURAL FIBERS FABRICS

Jean da Silva Rodrigues
Instituto Federal de Educação, Ciência e Tecnologia do Pará – IFPA – Belém, Brazil

Roberto Tetsuo Fujiyama
Universidade Federal do Pará – UFPA – Belém, Brazil

José Antônio da Silva Souza
Universidade Federal do Pará – UFPA – Belém, Brazil

Maurício Maia Ribeiro
Instituto Federal de Educação, Ciência e Tecnologia do Pará – IFPA – Ananindeua, Brazil

Douglas Santos Silva
Instituto Militar de Engenharia – IME – Rio de Janeiro, Brazil

Pedro Henrique Poubel Mendonça da Silveira
Instituto Militar de Engenharia – IME – Rio de Janeiro, Brazil

Thuane Teixeira da Silva
Instituto Militar de Engenharia – IME – Rio de Janeiro, Brazil

Sergio Neves Monteiro
Instituto Militar de Engenharia – IME – Rio de Janeiro, Brazil

Abstract: In this work, the unsaturated permeability of natural fibers of curaua, jute and raffia, arranged in the form of aligned fibers and woven in a flat style, was determined through the process of rectilinear resin infusion using a polyester resin as the working fluid. Fiber compressibility tests were previously carried out in order to study the effects of the vacuum level inside the infusion chamber on fiber compaction and to predict the porosity of fiber arrays. The effects on the permeability of the surface treatment of curaua fibers with NaOH at different concentrations were also studied. The results showed that raising the vacuum level, by changing the state of compaction of the fibers, reduced the overall permeability of all fibers and arrangements tested. The alkaline treatment of the curaua fibers contributed to the increase in the global permeability of the fabrics by reducing the permeability inside the fiber bundles.
Keywords: Infusion, curaua, jute, raffia.

INTRODUCTION

Technological development related to consumer demands continues to increase demands on global resources, leading to major issues of material availability and environmental sustainability Faruk et al., (2012) [1]. In this scenario, several industrial sectors have sought alternatives in order to mitigate the environmental impacts arising from the production processes, as well as the use of manufactured products and their disposal.

In recent years, government regulations on carbon dioxide emissions and materials' recyclability have produced an increase in the use of natural fiber composite materials in both the automotive and construction industries. But one of the keys to its success is the possibility of using well-studied fiberglass composite processing techniques such as RTM, VARTM or infusion. It is therefore crucial to understand how key processing variables are affected when glass fibers are replaced with natural fibers, which have different structure, different fabric architecture and different chemical interactions with resins. One such variable is fabric permeability, which is the key parameter that regulates flow in the fiber bed, along with fluid viscosity. Tissue permeability is especially important in low-pressure injection techniques such as VARTM or vacuum infusion, where void formation and injection time can be dramatically increased when permeability decreases Francucci et al., (2010) [2].

Permeability indicates the relative ease with which the resin moves through the pore space in the porous medium and is a fundamental property used in the study of infusion. Permeability depends on reinforcement architecture, porosity, resin properties, processing conditions, mold design and part geometry. Resin properties that affect permeability are viscosity, surface tension and contact angle. Processing conditions such as injection pressure, flow rate and temperature affect permeability. Permeability can be unsaturated (transient) or saturated. When the flow condition is stabilized, the flow behavior would be independent of time and distance. Such a condition is considered as a steady state and the flow behavior is characterized using steady state or saturated permeability Naik et al., (2014) [3].

In the search for a better understanding of the effects on the permeability and volumetric fraction of the fibers of the compression of the reinforcing fabrics, compressibility tests were developed. The reinforcement compressibility test consists of preparing the preform in the stack to be analyzed and, by means of compression in a universal test equipment, obtain a graph of the compression pressure as a function of the thickness or volumetric fraction of the fibers Prado, (2009) [4].

In this work, the in-plane unsaturated permeability of natural fibers of curaua, jute and raffia arranged in the form of flat-style fabrics and aligned fibers/yarns was determined, using an unsaturated polyester resin as working fluid, through the use of the process resin infusion.

EXPERIMENTAL

MATERIALS

To determine the unsaturated permeability, *orthophthalic* polyester manufactured by Embrapol under the trade name ALPHA 190 with a viscosity of 0.48 Pa. was used. The natural fibers used were curaua fibers (*Ananas erectifolius*), jute (*Corchorus capsularis*) and raffia (*Raphia vinifera*).

The curaua fibers were supplied by EMBRAPA da Amazônia Oriental, Brazil, and were used in the form of aligned fibers and woven in flat style (screen), with an average weight of 0.035 g/cm^2. The jute fibers were acquired from the trade market in Belém, Brazil, in the form of woven fabrics in the flat style (screen), manufactured by "Companhia Têxtil de Castanhal", Brazil. To determine the permeability, the fibers were arranged in the form of unidirectional threads and flat fabric with an average weight of 0.0225 g/cm2. The raffia fibers were purchased in stores in the city of Belém, Brazil, in the form of woven fabrics in the flat style, with a grammage of 0.0237 g/cm^2.

METHODS

Determination of the Reinforcements Compressibility Curve

Reinforcement compressibility experiments were initially performed by stacking ten layers of fabric flat style in a circular shape with 100 mm in diameter, of each tested fiber, with previously determined masses. The tissue layers were then subjected to compression in an AROTEC universal testing machine with a 10 kN load cell and test speed of 1.0 mm/min. As the layers were being compressed, the volumetric fraction of the fibers was calculated from Eq. 1, obtaining the graph pressure versus volume fraction of the fibers. Tissues were tested in duplicate and compressed to the equipment load cell limit, 10 kN.

$$VF = \frac{m}{\rho}\frac{1}{eA} \qquad \text{Eq. 1}$$

where VF is the fiber volume fraction; m the mass of the 10 reinforcement layers (g); r the specific mass of the fiber being tested (g/cm^3); and the thickness of the layers being compressed (cm) and A the sample area (cm^2).

Determination of Permeability of Reinforcements

The permeability tests were developed as shown in Figure 1. Two layers of fabric were arranged in a flat style of the studied fibers on a flat glass mold. Release fabric and flow promoter (distributor medium) were placed over the fibers and the system was then sealed with a vacuum bag and sealing tape. After guaranteeing the tightness of the set, the unsaturated polyester resin was infused. A camera mounted on the assembly recorded the advance of the flow front, measuring the space covered and timing the impregnation time.

The unsaturated permeability in the plane was calculated using Eq. 2, derived from Marinucci, (2011) [5].

$$K = \frac{\mu\,.\varphi.l^2}{2\,t\,.\Delta P} \qquad \text{Eq. 2}$$

where K is the permeability in the plane (m^2); μ the viscosity of the fluid (Pa.s),φ the porosity of the reinforcement fabric (=1 – Vf, where Vf is the volumetric fraction of the fabric obtained in the compressibility test), l the length of the reinforcement fabric (m), t the time required for the flow front to travel through the preform (s) and ΔP the pressure

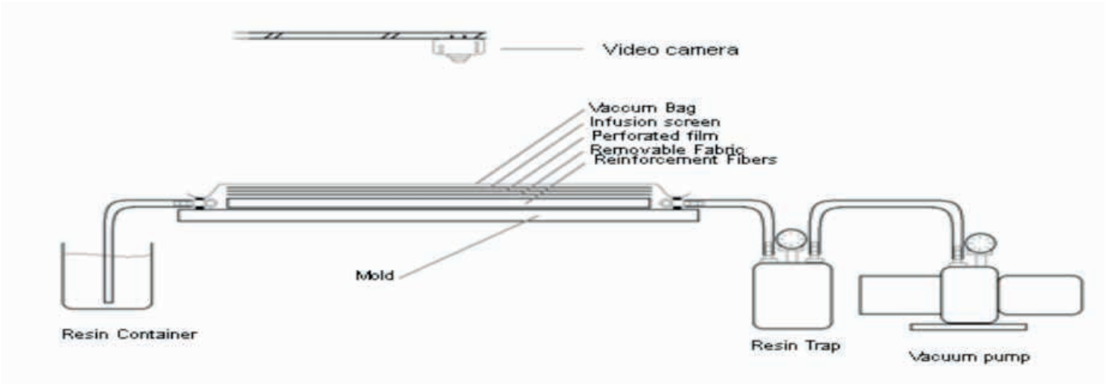

Figure 1: Schematic drawing of the apparatus used in the test for determination of unsaturated permeability in the plane.

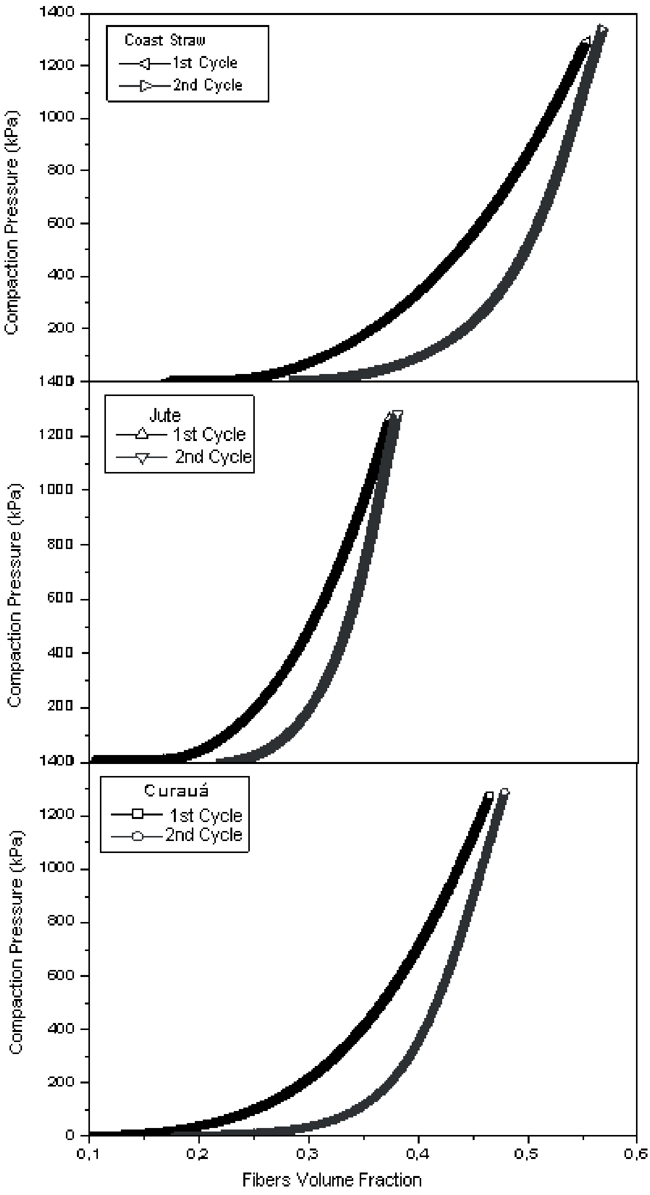

Figure 2: Compressibility test of curaua, jute and raffia fiber.

difference applied to the preform (Pa).

The porosity of the reinforcement fabric φ was calculated as $\varphi = 1 - VF$ *where VF is the volumetric fraction of the fibers calculated through the compressibility test, according to [4].*

RESULTS AND DISCUSSION

COMPRESSIBILITY CURVES OF REINFORCEMENTS

Analyzing the test results of curaua, jute and raffia fibers, it can be verified that they presented a behavior as reported by Chen et al., (2001) [6], with a linear initial region, a non-linear intermediate region and a final linear region. According the authors, the deformation of the non-linear region is a conjugate of the compression of the solid fibers and the deformation of the fiber arrangement filling the voids. The results show a significant difference in the behavior of the fabric under compression between the first and second test cycles, mainly in the non-linear phase, this is a result that is in agreement with what was observed by Madsen, (2004) [7]. Studying the compaction of yarns made of hemp vegetable fiber, arranged unidirectionally and randomly compressed in four cycles, the author observed that under high pressures, the volumetric fraction of the fiber tends to converge in the four curves, but in intermediate values, the compactability tends to increasing with the increase in the number of compaction cycles. This difference being greater between the first and second cycles and decreasing for subsequent cycles.

Figure 2 illustrates the result of the compressibility test for curaua, jute and raffia fibers. The data show that the maximum volumetric fraction reached by the curaua fiber in the first cycle was 46.5% and in the second cycle 47.9%. These values are very similar to those presented by Madsen, (2004) [7] testing unidirectional yarns of hemp fibers, for the same pressure level.

The maximum volume fraction achieved by jute was 37.3% and 38.04%, for the first and second cycles, respectively. This result, substantially lower than that achieved by the curaua fiber, was probably due to the arrangement of the jute fabric, in the form of threads with a considerable diameter in relation to the individual fiber, which makes it difficult for the fibers to accommodate when under compaction. Madsen, (2004) [7] tested randomly arranged jute fibers and obtained approximately 25% of volumetric fraction for the same pressure level.

The maximum volume fractions achieved by the raffia fiber were 55.4% and 56.8% for the first and second cycles. These values were on average 19% higher than the performance of the curaua fiber and 49% higher than those found for the jute fiber. This is probably due to the elongated character of the cross section of the fiber, which favors the arrangement in the form of a fabric, reducing the possible remaining channels during fiber compaction.

PERMEABILITY OF REINFORCEMENTS

Table 1 and Figures 3, 4 and 5 show the results of the in-plane unsaturated permeability test for curaua, jute and raffia fibers, respectively. The results indicate that as the vacuum level increases, permeability decreases, which was expected given that the greater the compaction force, the greater the volumetric fraction of the fibers and consequently the lower the porosity of the fabrics, making it difficult for the resin to pass through and closing the drainage channels. This behavior is analogous to that observed by Umer et al., (2011) [8], who determined the permeability of jute yarn blankets in different configurations, reaching decreases of approximately 85% in permeability by increasing the volumetric fraction of the fibers from 20 to 40%.

Figure 3 shows the results of the curaua fiber permeability test. The results reveal that the permeability of the curaua fabric was slightly lower than that of the aligned fibers, for the same compaction level. Significant impact on permeability was found for fibers treated with NaOH solution.

Fibers treated with 5%, 20% and 30% NaOH solution showed permeability 16%, 36% and 48%, respectively, higher than the permeability of in natura fibers. Authors such as Francucci et al., (2010) [2] and Naik et al., (2014) [3] have observed that the unsaturated permeability of natural fibers is lower than the saturated permeability, attributing this difference to the fact that natural fibers absorb a lot of resin, thus delaying the advance of the flow front during saturation. of the fibers. According to [9], the alkaline treatment promotes the removal of pectin and gum substances that involve the fibers, totally or partially solubilizing these substances, in order to allow the separation of the thick bundles of the raw fiber into fiber bundles that allow the production thin wires. Due to the removal of surface substances from the fiber and exposure of the microfibrils, it is expected that the region inside the fibers where the microflow occurs is more compacted, reducing local permeability. With the compression of the beams, the macroflow occurring between the beams can be increased. On the other hand, the possible partial solubilization of pectin substances can promote adhesion of fiber bundles, reducing flow resistance in the inter-beam region, contributing to the increase in global unsaturated permeability. A similar effect was observed by Francucci et al., (2010) [2], determining the saturated and unsaturated permeability of flat jute fabrics, in natura and treated with a solution of polyhydroxybutyrate dissolved at 2% in chloroform. As such, the unsaturated permeability of the treated fibers increased dramatically in relation to the fiber untreated.

The results of the permeability test of jute fiber in the form of aligned yarns and flat fabric are shown in Figure 4. As expected, permeability decreased with increasing compaction pressure of the fibers. The permeability of aligned fibers subjected to a vacuum of 53.3 kPa were 38% higher than those subjected to a vacuum of 101.3 kPa. For fabrics, the permeability of fibers submitted to a vacuum of 13.3 kPa (1.65 x 10-8 m^2), porosity of 0.82, was more than four times higher than that of fibers subjected to the highest vacuum level tested, of 101.3 kPa (3.88 x 10-9 m^2), with a porosity of 0.77. Francucci et al., (2010) [2] found for a flat jute fabric with a porosity of 0.775 being impregnated with a water/glycerin solution using the VARTM process, approximately 2.75 x 10-10 m^2 for the unsaturated permeability.

The results of the permeability test for the raffia fiber shown in Figure 5 confirm what was verified for the other fibers studied, the decrease in permeability with the increase in the vacuum level. It must be noted that the effect on permeability of raising the vacuum level from 53.3 kPa to 101.3 kPa was more pronounced for aligned fibers than for those arranged in the form of a flat fabric. This is probably due to the arrangement of fibers in the fabric, which is much more regular and flat, leaving fewer channels for macroflow than that of aligned fibers, in which the fibers, with a predominantly flat and elongated cross section, form spirals and shapes. This is a complex arrangement that overlap, favoring the macroflow for low levels of compaction, but with the increase in the vacuum level, these channels are substantially reduced, as can be seen in Figure 6.

CONCLUSIONS

The experimental investigations carried

Fiber	Vacuum Level (kPa)	Porosity Reinforcement	Fiber Arrangement	Permeability (m^2)
Curaua	101,3	0,75	Tissue	3,50E-09
	53,3	0,63	Aligned Fibers	4,79E-09
	101,3	0,61	Aligned Fibers	3,61E-09
	101,3	0,66	Aligned Fibers, 5% NaOH	4,19E-09
	101,3	0,69	Aligned Fibers, 20% NaOH	4,93E-09
	101,3	0,71	Aligned Fibers, 30% NaOH	5,35E-09
Jute	53,3	0,68	wires lined up	8,39E-09
	101,3	0,67	wires lined up	6,08E-09
	13,3	0,82	Tissue	1,65E-08
	53,3	0,79	Tissue	1,19E-08
	79,9	0,78	Tissue	4,46E-09
	101,3	0,77	Tissue	3,88E-09
Raffia	53,3	0,64	lined raffia	5,29E-09
	101,3	0,60	lined raffia	3,56E-09
	53,3	0,71	Tissue	3,92E-09
	101,3	0,68	Tissue	3,72E-09

Table 1: Results of the in-plane unsaturated permeability test.

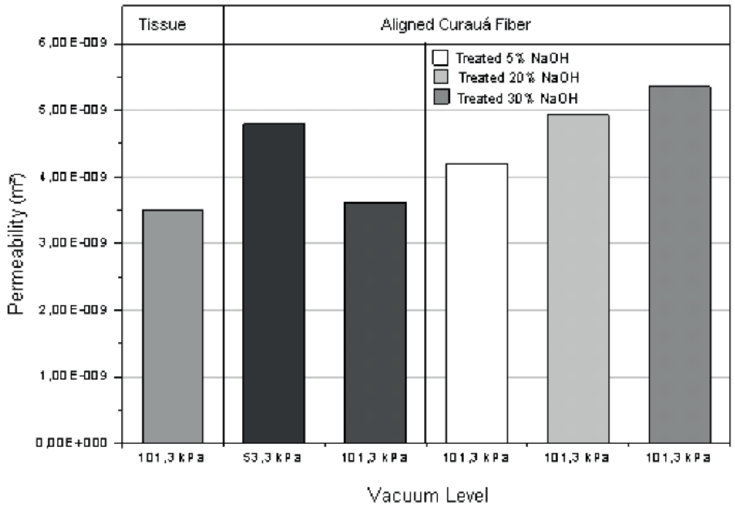

Figure 3: In-plane permeability of curaua fibers in the form of aligned threads and woven with in natura fibers treated with NaOH solution.

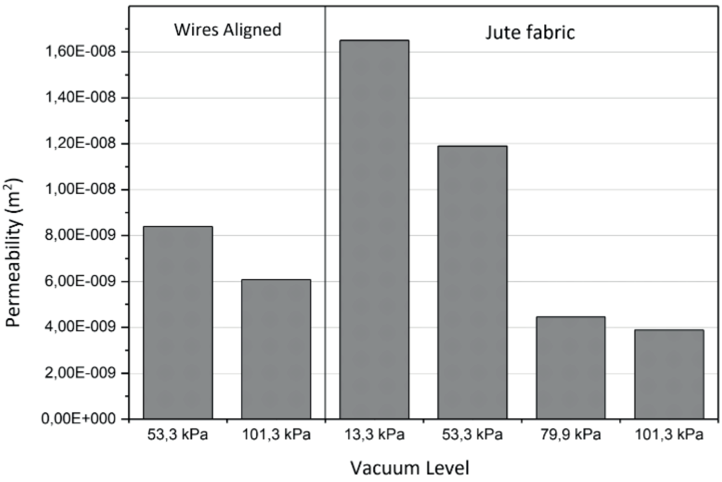

Figure 4: In-plane permeability of jute fiber in the form of threads and fabric.

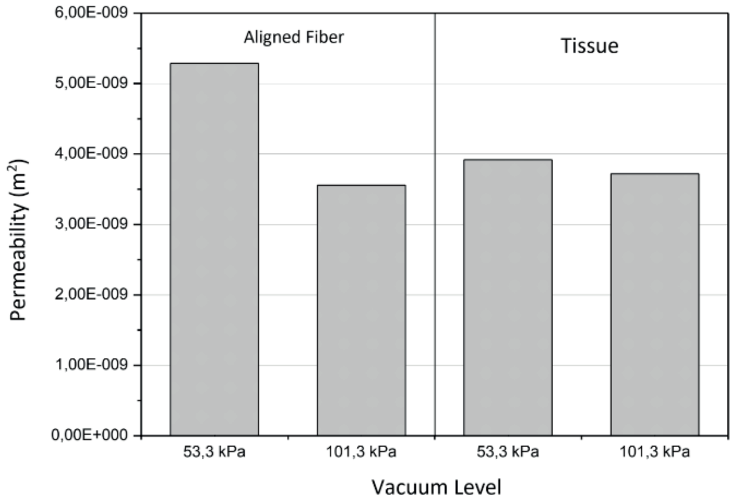

Figure 5: In-plane permeability of raffia fibers in the form of aligned yarns and fabric.

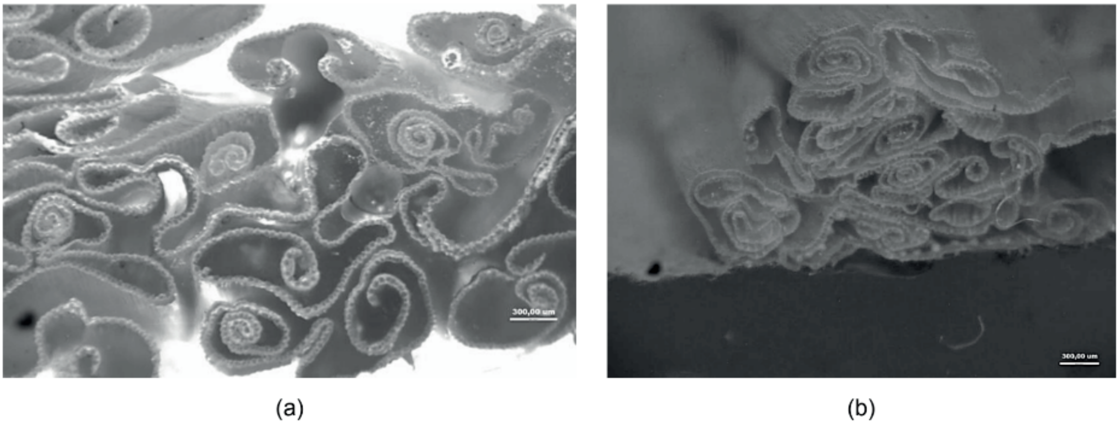

Figure 6: Cross-section of raffia-lined fiber-reinforced composites manufactured under different compaction conditions. (a) vacuum level of 53.3 kPa; (b) vacuum level of 101.3 kPa.

out in this work showed that the unsaturated permeability of curaua, jute and raffia fibers is significantly altered as a function of the arrangement of the fibers and mainly of the level of vacuum used, as a function of changes in the state of compaction of the fibers and consequently in the porosity of the fabrics and yarns.

The permeability of the curaua fabric was slightly lower than that of the aligned fibers, for the same compaction level. Curaua fibers treated with 5%, 20% and 30% NaOH solution showed permeability 16%, 36% and 48%, respectively, higher than the permeability of in-natura fibers.

The unsaturated permeability of the jute fiber in the form of aligned yarns and flat weave, as expected, decreased with increasing compaction pressure of the fibers. The permeability of aligned fibers subjected to a vacuum of 53.3 kPa were 38% higher than those subjected to a vacuum of 101.3 kPa. For fabrics, the permeability of fibers submitted to a vacuum of 13.3 kPa (1.65×10^{-8} m²), porosity of 0.82, was more than four times higher than that of fibers submitted to the highest vacuum level tested, of 101.3 kPa (3.88×10^{-9} m²), with a porosity of 0.77.

The results of the permeability test for the raffia fiber showed a decrease in permeability with the increase in the vacuum level, emphasizing that the effect on permeability of raising the vacuum level from 53.3 kPa to 101.3 kPa was more pronounced for aligned fibers than for those arranged in a flat fabric.

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