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Nonwoven needle-punched fabrics with nano-sized polyurethane reinforcing sheaths for construction application

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ABSTRACT

Introduction. The purpose of the study is to investigate the influence of the impregnation degree of a non-woven needle-punched fabric with aqueous polyurethane dispersions of varying compositions on the formation of the porous structure of composite materials for construction applications. **Materials and methods.** The object of the study is a non-woven needle-punched fabric made of polyethylene terephthalate fibers (Technical Specifications TU 6-13-0204077-95-91) with a linear density of 0.33 tex (diameter 20-25 μm), impregnated with aqueous polyurethane dispersions of different compositions. The fibrous web was formed by mechanical means and strengthened with a primary needle-punching density of 180 cm^{-2}. The impregnation process employed aqueous dispersions of anionically stabilized polyurethane: the brand IMPRANIL DL 1380 (China), based on an aliphatic diisocyanate with a polymer concentration of 38±5%; and the brands Aquapol-11 and Aquapol-21, based on aromatic diisocyanates, produced by LLC "NPP 'Makromer' named after V.S. Lebedev", Vladimir, with a polyurethane concentration of 40±2%. **Results and discussion.** The influence of the aqueous polyurethane dispersions on their distribution pattern on the fibers during impregnation was determined. Materials with an optimal porous structure were obtained, which governs the heat and mass transfer processes while maintaining the required physic-mechanical properties. **Conclusion.** At an impregnation degree of less than 0.1 or a porosity coefficient of 0.8, fragmentary structures of the IMPRANIL DL 1380 polyurethane form on the fiber surfaces. This results in strong composite materials whose air permeability is practically the same as that of the original non-woven fabric. The development of such materials is of interest for thermal and sound insulation in building structures. When using Aquapol-11 and Aquapol-21 dispersions for impregnation, the polyurethane binder almost completely fills the space between the fibers. This leads to a decrease in the overall porosity of the composite, making it promising for use as a waterproofing material in road construction.

KEYWORDS: non-woven needle-punched fabric, aqueous polyurethane dispersion, impregnation, composite material, porous structure, nano-sized sheath

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Нетканые иглопробивные полотна с наноразмерными усиливающими оболочками из полиуретана для применения в строительстве

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АННОТАЦИЯ

Введение. Целью работы является исследование влияния степени пропитки нетканого иглопробивного полотна водными дисперсиями полиуретана различного состава на формирование пористой структуры композиционных материалов строительного назначения. **Материалы и методы исследования.** В качестве объекта исследования использовали нетканое иглопробивное полотно, изготовленное из полиэтилентерефталатных волокон (ТУ 6-13-0204077-95-91) линейной плотности 0,33 текс (диаметром 20–25 мкм), пропитанные водными дисперсиями полиуретанов различного состава. Волокнистый холст получали механическим способом формирования и упрочняли при плотности основного прокалывания 180 $см^{-2}$. Для пропитки использовали водные дисперсии анионно стабилизированного полиуретана марки IMPRANIL DL 1380 (КНР) на основе алифатического диизоцианата с концентрацией полимера 38±5% и анионно стабилизированных полиуретанов марок Аквапол-11 и Аквапол-21 на основе ароматических дииизоцианатов производства ООО «НПП «Макромер» им. В.С. Лебедева», г. Владимир, с концентрацией полиуретана 40±2%. **Результаты и их обсуждение.** Определено влияние водных дисперсий полиуретанов на характер их распределения на волокне в процессе пропитки. Получены материалы с оптимальной пористостой структурой, определяющей процессы тепло- и массопереноса при одновременном сохранении требуемых показателей физико-механических свойств. **Заключение.** При степени пропитки менее 0,1 или коэффициенте пористости 0,8 на поверхности волокон образуются фрагментарные структуры полиуретана марки IMPRANIL DL 1380, что приводит к получению прочных композиционных материалов, проницаемость которых по воздуху практически не отличается от проницаемости исходного нетканого полотна. Разработка таких материалов представляет интерес для теплоизоляции и звукоизоляции в строительных конструкциях. При использовании для пропитки дисперсий Аквапол-11 и Аквапол-21 полиуретановое связующее практически полностью заполняет пространство между волокнами, что приводит к снижению общей пористости композита и представляет интерес к его использованию в качестве гидроизоляции при дорожном строительстве.

КЛЮЧЕВЫЕ СЛОВА: нетканое иглопробивное полотно, водная дисперсия полиуретанов, пропитка, композиционный материал, пористая структура, наноразмерная оболочка.

ДЛЯ ЦИТИРОВАНИЯ:
Назаров В.Г., Дедов А.В., Бокова Е.С., Иванов Л.А. Нетканые иглопробивные полотна с наноразмерными усиливающими оболочками из полиуретана для применения в строительстве. *Нанотехнологии в строительстве.* 2026;18(1):32–41. https://doi.org/10.15828/2075-8545-2026-18-1-32-41. – EDN: WBWDXB.

INTRODUCTION

Porous non-woven needle-punched fabrics based on synthetic fibers [1, 2] are widely used in civil and industrial construction as thermal insulation [3–6] and sound insulation materials [3, 7–10], as well as in road and hydraulic engineering as geotextiles [11–13]. The primary requirement for construction-grade fabrics is the combination of high porosity for effective thermal and acoustic insulation with the mechanical property levels required for practical application, such as tensile and compressive strength.

To address this compromise, the technology of impregnating non-woven fabrics with polymer binders, particularly aqueous polyurethane dispersions, is employed [14, 15].

Non-woven needle-punched fabrics are predominantly manufactured by the mechanical method of forming fibrous webs, which results in pronounced anisotropy of their mechanical characteristics [19, 20]. To mitigate this, polymer binders ensuring a high degree of impregnation are used [21], leading to composite materials with low porosity.

The authors of this study have developed a method for thermomechanical treatment of non-woven fabrics. Its use allows for the production of fibrous webs with an adjustable balance between the porosity coefficient and mechanical properties [22–24]. The fabrics are processed in the gap between a heated metal roll with a diameter of 1 meter and a conveyor belt. Compared to processing on roll calenders [25, 26], this ensures gentler heating of the fabrics, as well as adjustable and layer-by-layer compaction of fibers across the fabric thickness. Collectively, this does not lead to a reduction in porosity but improves mechanical properties, ensures similar mechanical characteristics in the longitudinal and transverse directions [25, 26], and also influences the subsequent impregnation process, allowing for a reduction in the concentration and amount of polymer binder used.

In general, when using polymer dispersions for impregnation, several key technological factors determining the formation of the porous structure of composite materials can be identified.

This includes, first and foremost, the amount of polymer in the finished fabric, which reflects the degree of impregnation; the dependence of the structure formation character of the polymer binder in the non-woven fabric on the change in its volume during impregnation; as well as the nature of its distribution on the fiber and within the inter-fiber space [16–18].

The degree of fabric impregnation is a technological characteristic in the production of composite materials and is calculated by a known method based on the difference in material mass before and after impregnation. The method for monitoring changes in fabric volume during impregnation is described in detail in [18]. More complex is the analysis of polymer binder distribution within the structure of the non-woven fabric, as it is based on the visual assessment of photographs obtained by various microscopy methods or on determining indirect indicators characterizing the nature of porosity (air permeability, vapor permeability, etc.).

Controlling all the aforementioned factors allows for the production of composite materials with varying characteristics of heat and mass transfer, fluid permeability, and thermal and acoustic insulation properties.

The aim of this work is to investigate the process of porous structure formation in composite materials for construction and road applications depending on the degree of fabric impregnation with aqueous polyurethane dispersions of different brand compositions.

MATERIALS AND METHODS

The object of the study was a non-woven needle-punched fabric made from polyethylene terephthalate fibers (Technical Specifications TU 6-13-0204077-95-91) with a linear density of 0.33 tex (diameter 20–25 μm). The fibrous web was formed by a mechanical method and strengthened with a primary needle-punching density of 180 cm^{-2}. The thermomechanical treatment of the needle-punched fabric with an initial porosity coefficient of 0.94 was carried out on the aforementioned device at a temperature of 240 °C and a speed of 1.5 m/min. The porosity coefficient of the treated material was 0.88.

For impregnation, aqueous dispersions of anionically stabilized polyurethane were used: the brand IMPRANIL DL 1380 (China), based on an aliphatic diisocyanate, with a polyurethane concentration of 50±2%; and the aqueous polyurethane dispersion brands Aquapol-11 (AKV-11) and Aquapol-21 (AKV-21), based on aromatic diisocyanates, produced by LLC “NPP ‘Makromer’ named after V.S. Lebedev”, Vladimir, with a polyurethane concentration of 40±2%. The main properties of the AKV-11 and AKV-21 dispersions were investigated in the study [27].

Samples of the heat-treated fabric measuring 10×10 cm were immersed in a container filled with the aqueous polyurethane dispersion at room temperature and rolled with a roller for 3–5 minutes, which was sufficient for the dispersion to completely fill the fabric volume. The degree of fabric impregnation was controlled by diluting the initial dispersions with distilled water. After removal from the container, the samples were placed on a metal mesh until excess dispersion completely drained off, and then passed between squeeze rollers with a gap set to 1/4 of the fabric thickness, equal to 2.5 mm. The heat treatment of the impregnated fabric was performed at a temperature of 160 °C until the samples reached constant mass.

The degree of impregnation (C_M, relative units), characterizing the polyurethane content in the fabric, was calculated using the equation:

$$C_M = \frac{m_1 - m}{m}, \qquad (1)$$

where m_1 and m are the mass of the samples after and before impregnation, respectively, *kg*.

The mass of fabric and composite material samples was determined using electronic scales with a weighing accuracy of ±0.002 g. The thickness was measured according to GOST 12023-93 using a thickness gauge according to GOST 11358-70 with a scale division value of 0.01 mm. The relative error in mass determination did not exceed ±8%. The length and width of the samples were determined with a measurement accuracy of ±0.5 mm. The sample thickness, which primarily influenced the accuracy of composite material density determination, was measured at six uniformly spaced points on the surface of samples sized 10×10 cm. The maximum relative error in determining thickness and, consequently, the density of composite materials was ±9%.

The porosity coefficient (δ, relative units) of the composite materials, obtained by varying the degree of fabric impregnation, was calculated using the equation:

$$\delta = 1 - \frac{m_f / p_f + m_{PY} / p_{PY}}{V}, \qquad (2)$$

where m_f – mass of the fabric sample before impregnation with aqueous polyurethane dispersions, kg; ρ_f – density of polyethylene terephthalate fiber, kg/m³, equal to 1370 kg/m³; m_{PU} – mass of polyurethane in the sample, kg; ρ_{PU} – density of polyurethane, kg/m³, equal to 920 kg/m³; V – volume of the composite material samples, m³.

The determination of material air permeability was carried out in accordance with the requirements of GOST 12.088-77. Sample testing was performed on an FF-12/A instrument (Great Britain) at a constant air pressure of 49 Pa. To determine the air permeability of the heat-treated fabric and composite materials, the permeability coefficient was used, which was calculated from Darcy's linear law [28, 29]:

$$w = K\frac{\Delta P}{\eta d}, \qquad (3)$$

where: w is the air filtration velocity, m/s; K is the permeability coefficient, m²; ΔP is the air pressure drop, Pa; d is the thickness of the composite materials, m; η is the air viscosity, Pa·s, equal to 1.8×10^{-5} Pa·s.

The sorption capacity of the treated fabric and composite materials was determined on samples in the form of discs with an area of 100 cm². Five samples were simultaneously placed in a container with distilled water and removed after a 2-hour immersion. Each individual sample was then placed on a grid until the liquid completely drained off. The sorption capacity (Q, kg/kg) of the samples, expressed as the ratio of the absorbed water mass to the mass of the heat-treated fabric or composite material sample, was determined as the average of five measurements using the equation:

$$Q = \frac{m_2 - m}{m}, \qquad (4)$$

where m_2 is the mass of the sample after immersion and holding in distilled water for 2 hours, kg.

RESULTS AND DISCUSSION

To assess the change in fabric volume during impregnation, it has been proposed [16–18] to use a dimensionless ratio of the coefficients from equations describing the dependencies of composite material density (ρ, kg/m³) on the degree of impregnation (CM):

$$p = p_0\left(1 + \frac{k_p}{p_0}C_M\right), \qquad (5)$$

where ρ_0 is the density of the fabric used for impregnation, kg/m³;k_ϱ is an empirical coefficient with dimensions of kg/m³.

A constant volume of the treated fabric during impregnation with an aqueous polyurethane dispersion is characterized by the condition $k_\varrho/\rho_0 = 1$, which indicates a directly proportional relationship between the density of the composite materials and the change in polyurethane content determined by the degree of impregnation. A decrease in fabric volume during impregnation corresponds to the condition $k_\varrho/\rho_0 > 1$, reflecting a sharp increase in the density of the composite materials compared to the density achieved when impregnation preserves the fabric volume. An increase in fabric volume during impregnation is determined by the condition $k_\varrho/\rho_0 < 1$, which characterizes a lesser increase in the density of the composite materials compared to the density achieved when impregnation preserves the material volume.

The right-hand side of equation (5) contains two variables of equal dimension (kg/m³), namely the fabric density and the empirical dimensional coefficient k_ϱ. The following transformation of equation (5) leads to equation (6) with one dimensionless ratio of coefficients:

$$\frac{p}{p_0} - 1 = \frac{k_p}{p_0}C_M. \qquad (6)$$

For the original fabric (non-impregnated fabric) with IM = 0 and, accordingly, with $\rho_0 = \rho$, the condition $[(\rho/\rho_0) - 1] = 0$ hold. Both the right and left sides of equation (6) become equal to 0, indicating that the dependencies of $[(\rho/\rho_0) - 1]$ on IM originate from the coordinate origin.

The dependencies of $[(\rho/\rho_0) - 1]$ on IM for composite materials obtained by varying the degree of fabric impregnation with aqueous polyurethane dispersions of different brand compositions are presented in Fig. 1a. Additionally, the dependencies of δ on IM are shown in Fig. 1b.

When impregnating the heat-treated fabric with aqueous polyurethane dispersions of the brands AKV-11, AKV-21, and IMPRANIL, the values of the ratio k_ρ/ρ_0 are 1.68, 0.91, and 1.06, respectively. Based on the established values of the ratio k_ρ/ρ_0 it can be concluded that when using the AKV-11 polyurethane dispersion, the fabric volume decreases during impregnation, whereas when using the AKV-21 and IMPRANIL dispersions, the fabric volume remains unchanged.

During impregnation, the fabric volume can change both upon contact of the fabric with the aqueous dispersion in the impregnation bath and during the heat

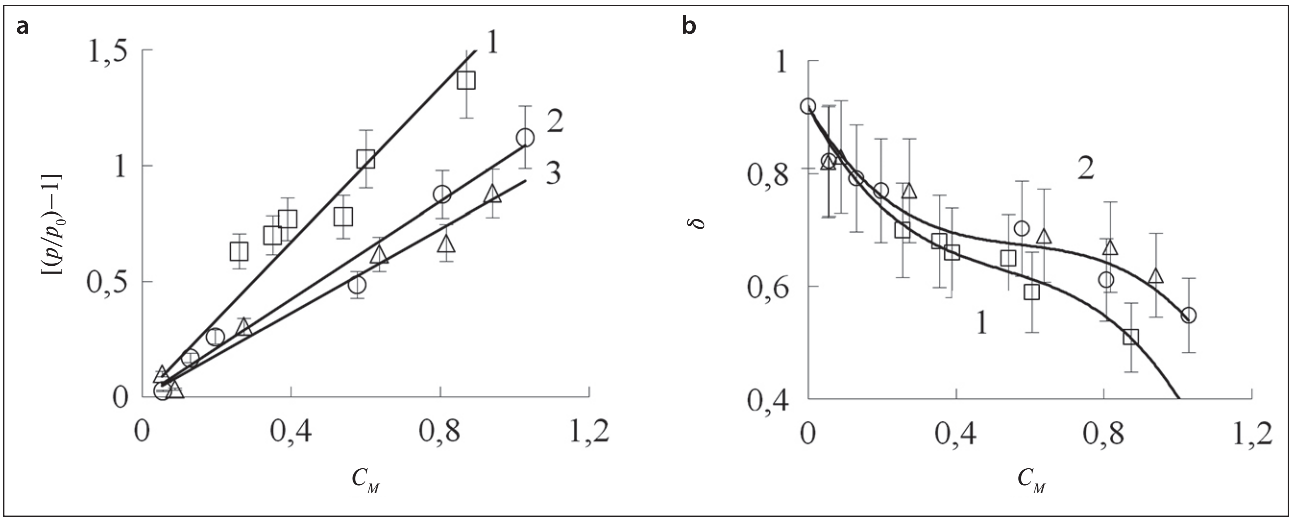

Fig. 1. Dependence of the ratio of composite material density to fabric density on the degree of impregnation with aqueous dispersions (a): AKV-11 (1), IMPRANIL (2), and AKV-21 (3); and dependence of the porosity coefficient (b) of fabric impregnated with aqueous dispersions AKV-11 (1), IMPRANIL (○), and AKV-21 (Δ) – general dependence 2

treatment of the impregnated fabric. Upon contact of the fabric with aqueous polymer dispersions, the volume increases, while during the heat treatment of the impregnated fabric, both a decrease and an increase in volume are possible.

The wetting of fibers by the aqueous polyurethane dispersion reduces friction between them, which leads to the disruption of frictional bonds formed between fibers during the needling process. A characteristic feature of needling is the reorientation of fibers in a direction perpendicular to the fabric surface. This reorientation is accompanied by the interlocking of fibers and a change in their configuration along the direction of needle movement. As a result of the disengagement of deformed fibers from each other, the fabric thickness increases upon removal from the impregnation bath, leading to a corresponding increase in volume.

The change in volume during the heat treatment of the impregnated fabric depends on the concentration of polyurethane in the dispersion used. To obtain composite materials with a relatively low degree of impregnation, diluted and low-viscosity dispersions are employed, which form nano-sized sheaths on the fiber surfaces (Fig. 2).

A consequence of the increased stiffness of fibers coated with polyurethane particle sheaths is a change in fiber configuration and their disengagement from each other, leading to an increase in fabric thickness and a decrease in density. It is evident that when polyurethane particles accumulate in the inter-fiber space without forming sheaths on the fiber surfaces, the fabric volume remains unchanged during impregnation.

As the concentration of polyurethanes in the aqueous dispersions increases and the viscosity of the dispersions rises, polyurethane particles form “bridges” that connect the fibers (Fig. 2). During the heat treatment of the impregnated fabric, water is removed, and the length of the bridges decreases. If the adhesive bond strength between the bridges and the fiber surfaces is sufficient, cooperative fiber movement occurs, leading to a reduction in fabric volume.

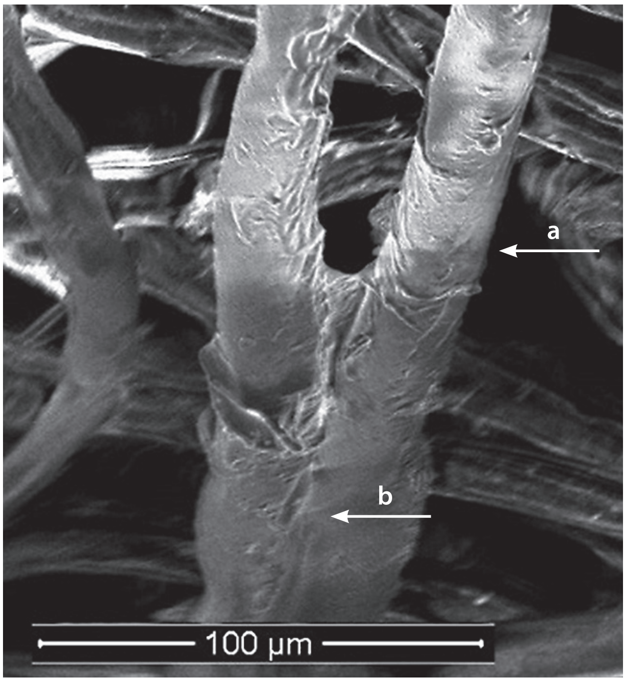

Fig. 2. Photograph of fiber sections showing the formation of polyurethane particle-based sheaths on their surfaces and bridges connecting the fibers (a – fiber section with a sheath of polyurethane particles; b – a “bridge” at the point of fiber fusion)

The preservation of fabric volume during heat treatment is a consequence of insufficient wettability of the fibers by the aqueous polyurethane dispersions. This results in relatively low adhesive bond strength between the "bridges" and the fiber surfaces, causing the bridges to detach from the fibers, which remain in the position achieved during the needle-punching process. The occurrence of these processes leads to the preservation of fabric volume during impregnation.

In contrast to the linear relationships between ρ and the degree of impregnation (C_M), the relationships between δ and C_M exhibit a complex pattern, indicating a non-uniform change in the porosity coefficient as the degree of impregnation increases. At $0 < C_M < 0.3$, the porosity coefficient decreases from 0.88 to 0.70. At $0.3 < C_M < 0.7$, it further decreases from 0.7 to 0.6, and with a continued increase in the degree of impregnation, a significant reduction in the porosity coefficient is observed.

The established relationship between δ and C_M is general for composite materials obtained using aqueous polyurethane dispersions of different brand compositions. For $C_M > 0.7$, compared to materials produced using AKV-21 and IMPRANIL dispersions, the porosity coefficient of materials made with the AKV-11 dispersion decreases to a greater extent with an equal increase in the degree of impregnation (Fig. 1b).

The decrease in the porosity coefficient at $0 < C_M < 0.3$ is a consequence of the formation of a fabric structure with non-uniform fiber packing density during the needle-punching process and the use of diluted dispersions. During needle-punching, from the side of needle action, compaction of the surface layer of the fabric occurs, leading to the formation of bundles with increased fiber packing density (Fig. 3).

When using diluted dispersions for impregnation, they are retained in the compacted surface layer of the fabric (Fig. 3), forming polyurethane particle "bridges" between the fibers. As a result of bridge shrinkage during heat treatment, the thickness of the surface layer decreases, leading to a significant reduction in the porosity coefficient. When using relatively concentrated dispersions, uniform impregnation throughout the fabric thickness is achieved. However, the lower fiber packing density in the bulk compared to the surface layer limits the reduction in distance between the fibers and determines the decrease in fabric volume during heat treatment solely due to changes in the surface layer. Under the condition $0.3 < C_M < 0.7$, this is characterized by an almost constant porosity coefficient (Fig. 1b).

The distribution of polyurethane particles on the fiber surfaces and in the inter-fiber space was determined based on the results of air permeability tests conducted on composite material samples. The dependencies of the air permeability coefficient of the composite materials on the degree of impregnation and the porosity coefficient are presented in Fig. 4.

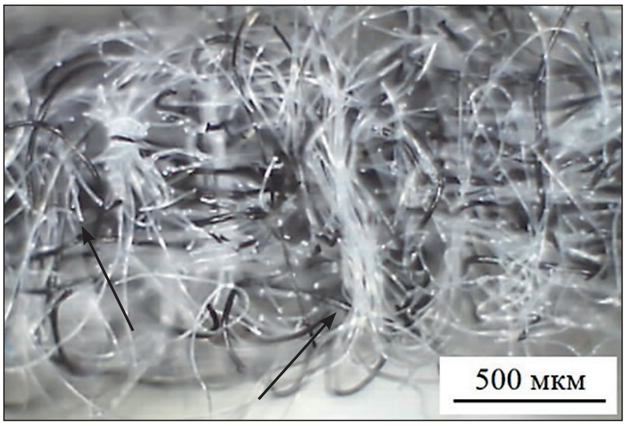

Fig. 3. Photograph of a cross-section of a needle-punched fabric (arrows indicate bundles of reoriented fibers with increased packing density; the compacted fabric layer is visible in the upper part of the micrograph)

For an equal degree of impregnation, the composite material obtained using the aqueous polyurethane dispersion AKV-11 exhibits the lowest permeability coefficient (Fig. 4a, dependence 1). Notably, according to the aforementioned \(k_\rho/\rho_0\) ratio values, the use of the AKV-11 dispersion leads to greater shrinkage of the treated fabric compared to other dispersions (Fig. 1a). The highest air permeability is observed in composite materials produced using the IMPRANIL dispersion, for which the relationship between the permeability coefficient and the degree of impregnation is represented by an almost linear dependence. This corresponds to a proportional relationship between the permeability coefficient and the change in pore volume.

The dependencies of K on IM for composite materials obtained by impregnating the fabric with AKV-11 and AKV-21 dispersions indicate that an increase in the degree of impregnation from 0 to 0.3 results in a relatively significant decrease in the permeability coefficient. Further increases in the degree of impregnation have an almost negligible effect on changes in the permeability coefficient for composite materials of varying compositions (Fig. 4a). These findings suggest that the volume of interconnected pores available for air transport is substantially reduced at relatively low impregnation levels ($C_M < 0.3$). This is associated with the concentration of the dispersion in the surface layer of the treated fabric (as described above), and further increases in the degree of impregnation have little effect on the volume of pores accessible for air transfer.

In contrast to the dependencies of K on IM, the dependencies of K on δ reflect a complex relationship between the reduction in pore volume and the permeability of composite materials. The influence of the porosity co-

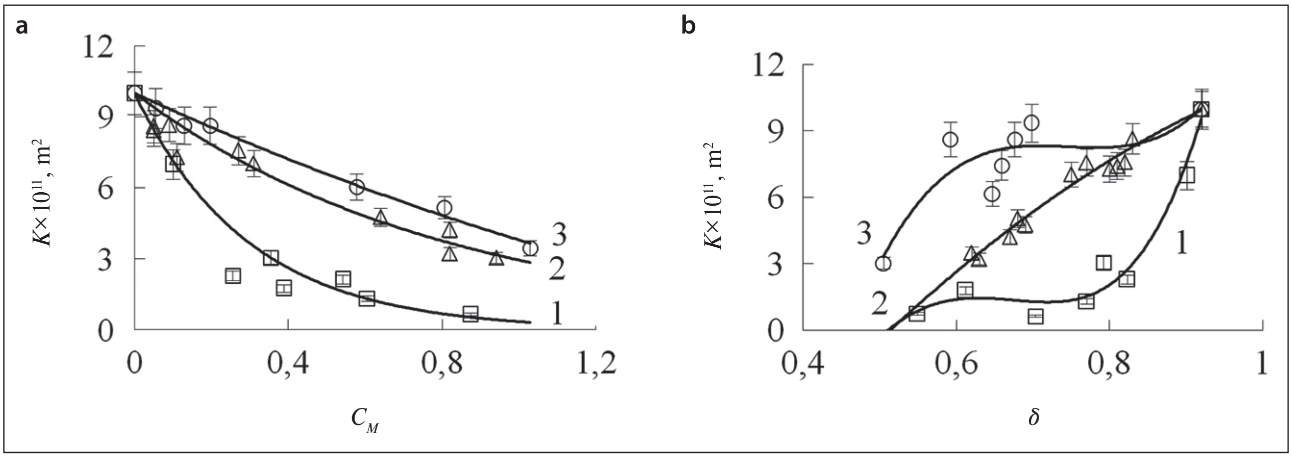

Fig. 4. Dependencies of the air permeability coefficient of composite materials on the degree of impregnation (a) and the porosity coefficient (b) when impregnating the treated fabric with polyurethane dispersions AKV-11 (1), AKV-21 (2), and IMPRANIL (3)

efficient on the permeability coefficient is determined by the composition of the aqueous polyurethane dispersion.

When using the IMPRANIL dispersion for impregnation, the permeability coefficient sharply decreases at a porosity coefficient below 0.60 (Fig. 4b, dependence 3).

At the same time, when using the AKV-11 dispersion, a relatively small decrease in the porosity coefficient from 0.88 to 0.80 leads to a substantial reduction in the permeability coefficient (Fig. 4b, dependence 1). For the AKV-21 dispersion, the relationship between the permeability coefficient and the porosity coefficient is described by an almost linear dependence, indicating a directly proportional decrease in the permeability coefficient as the porosity coefficient decreases (Fig. 4b, dependence 2).

The relatively small reduction in permeability coefficient associated with a decrease in porosity coefficient from 0.88 to 0.60 for composite materials produced using the IMPRANIL dispersion suggests that, when using diluted dispersions, polyurethane particles deposit on the fiber surfaces.

When using the AKV-11 dispersion, the significant decrease in permeability coefficient indicates that polyurethane particles primarily concentrate in the inter-fiber space. For the AKV-21 dispersion, both phenomena occur: particle deposition on fiber surfaces and particle filling of the inter-fiber space.

The dependencies of the sorption capacity of composite materials on the degree of impregnation and the porosity coefficient are presented in Fig. 5.

From the dependencies of *Q* on C_M, it follows that the sorption capacity of composite materials is determined by the brand composition of the polyurethane dispersions.

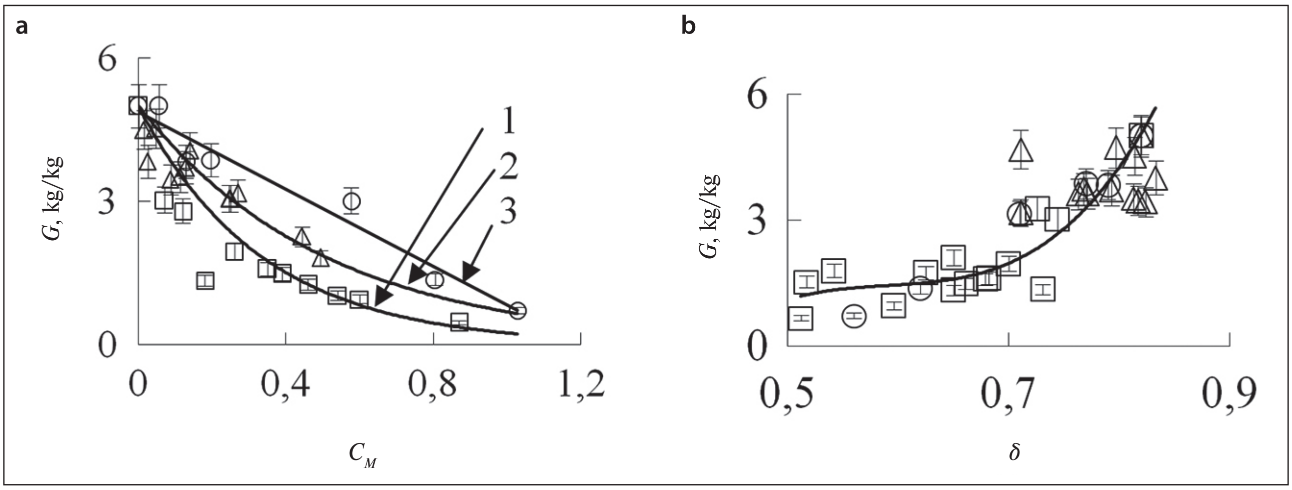

Fig. 5. Dependencies of the water sorption capacity of composite materials on the degree of impregnation (a) when using dispersions AKV-11 (1), AKV-21 (2), and IMPRANIL (3); and on the porosity coefficient (b) when impregnating the treated fabric with polyurethane dispersions AKV-11 (□), AKV-21 (Δ), and IMPRANIL (○)

For an equal degree of impregnation, composite materials produced using the IMPRANIL dispersion exhibit a higher sorption capacity. For these materials, the relationship between sorption capacity and the degree of impregnation is described by a linear dependence, indicating a proportional decrease in sorption capacity with a reduction in the porosity coefficient (Fig. 5a).

When using AKV-11 and AKV-21 dispersions for impregnation, an increase in the degree of impregnation from 0 to 0.4 leads to a relatively noticeable decrease in the sorption capacity of the composite materials. At $C_M > 0.4$, the sorption capacity shows little dependence on the degree of impregnation. This result indicates a non-uniform change in pore volume at different degrees of impregnation of the treated fabric (Fig. 5a).

The relationship between Q and δ for composite materials obtained using dispersions of different brands is described by a common dependence (Fig. 5b). This finding suggests that the sorption capacity is determined by the pore volume, which is formed by varying the degree of impregnation and changes in the fabric volume.

CONCLUSION

- When impregnating the treated fabric with the aqueous dispersion IMPRANIL, polyurethane particles deposit on the surface of the fibers at an impregnation degree below 0.4. When using the AKV-11 dispersion, polyurethane particles fill the space between the fibers. With the AKV-21 dispersion, polyurethane particles both deposit on the fiber surfaces, forming nano-sized sheaths, and fill the inter-fiber space.
- During heat treatment, the volume of fabric impregnated with the AKV-11 dispersion decreases, while with the other dispersions, the fabric volume remains unchanged.
- To determine the influence of impregnation on the air permeability and sorption capacity of composite materials, the most effective approach is to analyze the dependence of these characteristics on the porosity coefficient. At an equal degree of impregnation, this coefficient reflects the impact of polyurethane particle distribution within the fabric and the change in fabric volume during impregnation on porosity formation.
- It was established that for the construction of buildings and structures with the aim of ensuring their thermal and sound insulation, it is advisable to use composite materials based on non-woven fabrics impregnated with the polyurethane dispersion brand IMPRANIL DL 1380. Their structure ensures high air permeability while maintaining tensile and compressive strength. Composite materials obtained by impregnating non-woven fabrics with aqueous dispersions of the brands Aquapol-11 and Aquapol-21 are of interest for use as waterproofing materials in road construction.

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ADDITIONAL INFORMATION

The authors declare that neither generative artificial intelligence technologies nor artificial intelligence-based technologies were not used in the preparation of this article.

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Bokova E.S. – participation in the development of a scientific research program, revision of the text, conclusions of the article.

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