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EFFECT OF NEEDLE-PUNCHING DENSITY ON THE PERMEABILITY OF MATERIALS

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The needle punching density influence on material permeability in air filtration has been investigated. It has been found that the maximum permeability is gained under definite density of needle punching. The density of needle punching material is proposed to be estimated by the pore size and the pore tortuosity. The density influence of needle punching on characteristic variation has been demonstrated.

The properties of needle-punch materials are a function of the needle-punch density to a significant degree. The effect of the needle-punch density on the mechanical characteristics of the materials has been studied sufficiently completely [1, 2]. We investigated the less studied effect of the needle-punch density on the porosity and permeability of the materials in filtration of air.

The needle-punch materials with a surface density of 500-520 g/m^2 investigated in the study were made from polyester fibre with a linear density of 0.33 tex (TU 6-13-0204077-95-91) by the industrial method. The fibre webs were made by mechanical formation. The needle-punch density varied from 140 to 280 cm^{-2} with treatment of the cloth from both sides. The structural characteristics of the materials were established according to GOST 15902.2-79 and the air permeability (W, dm^3·m^{-2}·sec^{-1}) were determined according to GOST 12.088-77 *Textile Materials and Articles Made from Them. Methods of determination of Air Permeability"* on a FF-12/A instrument (Great Britain) using a working table with a 19.6 cm^2 opening and at fixed air pressure of 49 Pa.

The porosity of the materials was evaluated by the pore diameter (D_z, μm) and sinuosity. The pore size in materials with porosity coefficient ε_a (rel. units) and thickness d (m) were calculated from the Hagen—Poiseuille model [3] with the known air filtration rate w (m/sec) at pressure ΔP of 49 Pa and air viscosity μ equal to $1.84 \cdot 10^{-5}$ Pa·sec:

$$D_s = \left(\frac{32\mu d}{\Delta P \varepsilon}\right)^{0.5}. \tag{1}$$

Coefficient k_0 from the Kozeny—Karman model was used to evaluate the sinuosity of the pores of the material with the permeability coefficient K_{pr} (m^2) made rom fibre with diameter D_f [4]. In calculating k_0, we used $D_f = 25 \cdot 10^{-6}$ m:

$$K_{pr} = \frac{D_f^2 \varepsilon^3}{k_0 (1-\varepsilon)}. \tag{2}$$

The permeability coefficient of the materials was calculated from D'arcy's linear law [5]

$$w = \frac{k_{pr}}{d}\frac{\Delta P}{\mu}. \tag{3}$$

Coefficient k_{0*} reflects the dependence of the filtration rate of the medium on the shape of the pores in materials with the same porosity coefficients. This condition is satisfied in the study, and the porosity coefficient of the materials varied from 0.91 to 0.89 during needle-punching. As Eq. (2) suggests, for $k_0 = 1$, the filtration rate is only a function of the porosity of the material, which is attained in material with vertical fibres. Changing the position of the fibres decreased the permeability coefficient and as follows from Eq. (2), coefficient k_0 increases with a more complex trajectory of the air stream.

The dependence of the air permeability and bulk density (ρ, kg/m^3) of the materials on the needle-punch density (P, cm^{-2}) is shown in Fig. 1. The effect of the punch density on formation of porosity is shown in Fig. 2.

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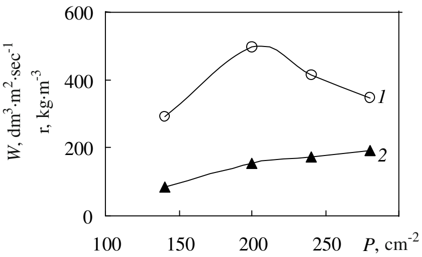

Fig. 1.

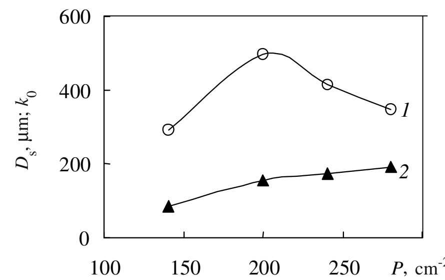

Fig. 2.

Fig. 1. Air permeability (1*) and bulk density (2) of material as a function of needle-punch density.

Fig. 2. Average pore diameter (*I*) and sinuosity (2) as a function of the needle-punch density of the material.

Judging by the data in Fig. 1, the maximum permeability of the materials is attained for a punch density of approximately 200 cm^{-2}. The permeability decreases with a lower or higher punch density. The extremal shape of the curve of the permeability of the materials as a function of the punch density was obtained with a continuous increase in the bulk density. The maximum permeability of the material was reached when the average pore diameter increased and the sinuosity decreased (Fig. 2). The almost two-fold increase in the permeability of the materials with an increase in the punch density from 140* to 20*0 $cm^{-2}$was obtained with a two-fold decrease in k_0 and an approximately 40% increase in D_a. This result indicates the dependence of the permeability of materials with these porosity coefficients basically on the sinuosity of the pores and to a lesser degree, on their size.

The mechanical method of forming fibre webs involves repeated building of the fibre layer taken from the combing machine. Insignificant reorientation of the fibres oriented in the plane of the web takes place at a low punch density and the structure of the fibre web is fixed when the layers approach each other.

The relatively low permeability of this material (Fig. 1) is probably due to the high mobility of the fibres and the change in their packing density during filtration of air. A change in the packing of the fibres will also cause them to be oriented in the plane of the web, which places significant air pressure on them. Formation of pores, which are the spaces between closely positioned fibres, is the consequence of close packing of oriented fibres. The air flow in deformed material is due to repeated alteration of its direction and separation into separate streams, manifested in the corresponding values of parameters D_a and k_0(Fig. 2). The large inertial losses of the air stream are the cause of the relatively low filtration rate.

Increasing the punch density alters the pore structure of the material due to reorientation of the fibres. For a certain ratio between the punch density and the cloth speed, pores delimited by compact bundles of fibres are formed. Local air flow over these pores increased the permeability of the material, and coefficient k_0 is minimum while D is maximum (Fig. 2). Higher permeability is also observed with low fibre mobility and preservation of the initial porosity during air flow.

A further increase in the punch density results in material with pores of complex shape, the consequence of filling of the pores with air. The change in the sinuosity of the pores and the complex trajectory of the air stream are the consequence of a decrease in the size of the fibre bundles captured by the needle barbs. We can hypothesize that the size of the captured fibre bundle will affect the pore size and filling of the pores with air. The decrease in the air flow rate is primarily reflected in an increase in coefficient k_0 with an insignificantly decrease in D_a (Fig. 2)*. It is very probable that the decrease in the permeability of the material is due to destruction of the fibres with an increase in the punch density. The fibre particles can be mixed by the air stream and affect the filtration rate.

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