VOLUME-MASS PROPERTIES OF LAYERED UNWOVEN NEEDLE-PIERCED FIBROUS MATERIALS (VOLUME APPROACH)

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The volume-mass properties of unwoven fibrous needle-pierced materials in and outside of the zones created as a result of the action of needles were calculated. The properties were determined using a volume approach. Equations were derived for calculation of the masses, the volume and mass concentrations of all and type 1 fibers, and other properties in the regions mentioned. Both single and multiple needle piercings were considered. A program was developed to carry out the indicated calculations.

The problem of fiber distribution in an n-layer unwoven fibrous needle-pierced material was solved in [1, 2]. The cases of single [1] and multiple [2] needle piercing of the layers were considered. In solving these problems a volume approach was proposed, based on using the volume concentration of fibers in the zone of action of the needle. The authors obtained expressions for the mass, and mass and volume concentrations, of fibers in each layer of the fibrous material after stitching with single and multiple needle piercings. However, in many cases it is necessary to know the volume—mass properties of not only the entire material and each of its layers, but also of the zones formed as a result of penetration of the needle [3], as well as the same properties outside of these zones. The objective of this study was to determine these properties.

For convenience, the zone formed by action of the needle on the unwoven fibrous material is nominally designated as a "column." We use the same notation as in [1, 2]: D, W, T are the length, width, and thickness, respectively, of a piece of unwoven fibrous material; h_i is the thickness of the i-th layer, where T = \sum_{i=1}^{n} h_i; S_{1i}, l_{1i}, V_{1i}, \rho_{1i}, m_{1i} are the cross-section area, length, volume density, and mass, respectively, of a fiber of the first type in the i-th layer; S_{2i}, l_{2i}, V_{2i}, \rho_{2i}, m_{2i} are the cross-section area, length, volume, density, and mass of a fiber of the second type in the i-th layer; N_{1i} and N_{2i} are the numbers of fibers of the first and second types in the i-th layer; S_\Delta is the cross-section area of the blade of the needle; S_0 is the element of area on which only one needle acts; I = DW/S_0 is the number of needles acting on a piece of material with the dimensions DWT; \xi^0_1, \xi^0_{1i} are the volume concentrations of all fibers, and of fibers of the first type, in the i-th layer of the piece of fibrous material before piercing; h_{in+1}^i is the distance to which the fibers are drawn out of the i-th layer in the time of the t-th needle piercing; m^0_i is the mass of the i-th layer of the piece of fibrous material before piercing; \Pi^0_i is the mass concentration of fibers of the first type in the i-th layer before piercing (i = 1, n). Other notations are introduced as needed.

In order to determine the volume—mass properties of the investigated materials in the "columns" and outside of the "columns," the volume approach proposed in the aforementioned articles is used. We introduce the equations which were obtained for the case of a single needle piercing, the volume concentration of fibers in a "column" after a single needle piercing is given by the equation

\[
\frac{\xi_1^{1,1}}{S_{1a}} = \frac{1}{T} \sum_{i=1}^{n} \xi^0_{1i} \left( \frac{1}{\rho} \sum_{p=i+1}^{n} h_p + h_{in+1}^i \right),
\]
where

$$\xi^0_i = \frac{V_{1i}N_{1i} + V_{2i}N_{2i}}{D W h_i} \quad (i = 1, n).$$

The volume concentration of fibers of the first type in a "column" is

$$\xi^1_{i1\Delta} = \frac{1}{T} \sum_{i=1}^{n} \xi^0_i \left( \sum_{p=i+1}^{n} h_p + h^1_{in+1} \right),$$

(2)

where

$$\xi^0_i = \frac{V_{1i}N_{1i}}{D W h_i} \quad (i = 1, n).$$

We note that when $i = n (p = n + 1)$, then $h_{n+1} = 0$. The mass of all fibers in a "column" can be obtained from the equation

$$m^1_{\Delta} = S_\Delta \sum_{i=1}^{n} \rho_{hi\Delta} \left( \sum_{p=i+1}^{n} h_p + h^1_{in+1} \right),$$

(3)

and the mass and mass concentration of fibers of the first type from the equations

$$m^1_{1\Delta} = m^1_{\Delta} \cdot 100 \%,$$

(4)

$$\Pi^1_{1\Delta} = m^1_{1\Delta} / m^1_{\Delta} \cdot 100 \%.$$

The volume concentration of all fibers outside of the "columns" is given by

$$\xi^1 = \sum_{i=1}^{n} \left( V_{1i}N_{1i} + V_{2i}N_{2i} \right) - IS_\Delta \xi^0_i \left( \sum_{p=i+1}^{n} h_p + h^1_{in+1} \right) / \left( DW - IS_\Delta \right) / T,$$

(6)

and the volume concentration of fibers of the first type by

$$\xi^1_1 = \sum_{i=1}^{n} \left( V_{1i}N_{1i} - IS_\Delta \xi^0_i \left( \sum_{p=i+1}^{n} h_p + h^1_{in+1} \right) \right) / \left( DW - IS_\Delta \right) / T.$$

(7)

The mass of all fibers outside of the "columns" is

$$m^1 = \sum_{i=1}^{n} m^0_i - l m^1_{\Delta};$$

(8)

The mass of fibers of the first type is

$$m^1_1 = \sum_{i=1}^{n} m^0_i \Pi^0_{1i} - l m^1_{1\Delta};$$

(9)