STUDY OF THE FLAME RESISTANCE OF NEEDLE-PUNCH HEAT-INSULATING MATERIAL

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The flame resistance of needle-punch material made from a blend of thermostable fibres was investigated. The dependence of the flame resistance on the process parameters of the needle-punch heat-insulating material was established. The maximum value of the oxygen index of 39% was attained at a punch density of 150 l/cm² punching depth of 10 mm, and polyester fibre content of 10%. Addition of low-combustibility polyester fibre in the blend allows reducing the cost of the raw material and price of the material, with good flame resistance of the finished material.

The large number of plants operating in conditions of high temperatures, thermal radiation, convective heat, etc., in Russia is responsible for the demand for fire safety equipment and protective clothing. Humans are most frequently protected from hazardous factors by using nonwoven materials.

Materials made of relatively expensive special, thermostable fibres offer the greatest degree of protection, but the cost makes these materials inaccessible to many consumers. Fibres made of carbo- or heterocyclic polymers with high chemical bond energy are thermostable. The glass transition temperature of these fibres is greater than 250°C, they are unmelted and have high thermal and thermooxidative stability. The meta-aramid fibre Nomex from DuPont (USA) accounts for more than 90% of thermostable fibre production capacities. The predominant development of these fibres is due to the use of relatively inexpensive and available raw materials processed on a relatively large scale [1].

The outstanding resistance of Nomex to high temperatures and aggressive media is due to the structure of the meta-aramid polymer. The aromatic rings and conjugated amide bonds that join them have special strength and resistance to chemical attacks. They also ensure the high thermal stability of the skeleton of the polymer. For this reason, Nomex does not melt, is almost not carbonized, and is not pyrolyzed in long exposure to high temperatures. The high concentration of hydrogen, carbon, and nitrogen atoms in the structure of meta-aramid polymer and the dense electron cloud of the molecule itself ensure a high level of protection from penetrating electron radiation and consequently heating of objects protected by material made from Nomex fibre.

However, some foreign companies and companies in former Soviet republics have mastered production of more accessible fibres capable of preventing flame propagation. Substances called flame retardants or fireproofing compounds are used to reduce the combustibility of polymer materials. Inorganic and organic substances that contain such elements as halogens, phosphorus, nitrogen, boron, metals, etc., in their molecules are usually used as fireproofing compounds. All fireproofing compounds must be nontoxic and not release toxic products in burning, have sufficient light resistance, and be relatively readily available and cheap.

Of the existing kinds of fibre materials, the problem of fireproofing is most acute for polyester fibres, which occupy the leading position among all kinds of chemical and natural fibres. A polyester fibre that restricts flame propagation has been developed at Mogilevkhimvolokno Co. (Belarus’). This fibre is manufactured with a linear density of 0.17, 0.33, and 0.84 tex at a nominal length of 35, 38, 66, and 90 mm. Its basic strength and thermal properties are compared with the properties of Nomex fibre in Table 1.
Fig. 1. Dependence of oxygen index (%) on needle-punch density $X_1$, polyester fibre content $X_2$, and needle-punch depth $X_3$.

**TABLE 1. Characterization of the Properties of Nomex Fibres and Polyester Fibre with Reduced Combustibility**

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Strength, cN/tex</th>
<th>Elongation at break, %</th>
<th>Density, kg/m³</th>
<th>Oxygen index, %</th>
<th>Temperature of initial weight loss, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nomex</td>
<td>48</td>
<td>18-22</td>
<td>1380</td>
<td>29</td>
<td>400</td>
</tr>
<tr>
<td>Reduced-combustibility polyester</td>
<td>30-37</td>
<td>45-48</td>
<td>1380</td>
<td>31.7</td>
<td>275</td>
</tr>
</tbody>
</table>

We conducted an experiment in which blends of the fibres indicated above with 0.17 tex linear density were used to manufacture experimental samples of needle-punch nonwoven material. The experiment was conducted with the BOX-3 plan. The needle-punch parameters — density ($X_1$) and depth ($X_3$) — and polyester fibre content ($X_2$) — were selected as variable factors. The finished samples were tested to determine the oxygen index by the candle-burning method. The experimental data were processed on a computer with the well-known method. A regression equation characterizing the dependence of the oxygen index of the material on the variable parameters was obtained as a result:

$$Y = 29.75 - 0.39X_1 - 3.77X_2 + 0.96X_3 + 0.18X_1 X_2 - 0.49X_1X_3 - 1.83X_2X_3 - 1.63X_1^2 - 0.43X_2^2 + 3.15X_3^2.$$  

The plotted graphic dependence (Fig. 1) was used to analyze the effect of the variable factors on the oxygen index of the material. The flame resistance of the material increased with an increase in the needle-punch density to 150 l/cm², which was favored by intensive compacting of the fibres by the needle holder of the needle-punching machine. The pores that favor penetration of red-hot air in the structure of the material (convective flow) decreased as a result. A further increase in the needle-punch density decreased the oxygen index as a result of thinning of the structure of the material due to breaks in some fibres.

Increasing the needle-punch density to 10 mm compacted the material as a result of an increase in the number of burrs involved in formation of bonds between fibres.

The oxygen index decreased with an increase in the polyester fibre content, which indicated their lower resistance to heat. Using fibres of different length in the experiments was also a cause of this dependence. The length of Nomex fibre was 50 mm and the length of the polyester fibre was 35 mm. The shorter fibre formed a smaller number of bonds with the surrounding fibres, preventing compacting of the material. Using longer fibres would produce better results.

The maximum oxygen index of 39% was attained with the following parameters: 150 l/cm² needle-punch density, 10 mm needle-punch depth, 10% polyester fibre content.