STUDY OF THE THERMAL CONDUCTIVITY OF TEXTILES FOR FIREFIGHTERS’ UNIFORMS

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Experimental data on determination of the thermal conductivity of textiles used for sewing clothing for firemen are reported. It was shown that nonstationary methods of measuring the thermal conductivity can lead to a large error in the results if the contact thermal resistances are not taken into account in the measuring instrument; a method for excluding them is proposed.

The dominant role in ensuring safe conditions in fighting fires belongs to special clothing whose heat-shielding properties are determined to a great degree by the thermal conductivity coefficient of the textiles used to make them. It is impossible to calculate the thermal conductivity with model concepts, and the experiment remains the basic source of information.

We measured the thermal conductivity of some materials used at the Bereg Association Plant (Pavlovo-Posad) for sewing firefighters’ uniforms. Samples of three types of fabrics were investigated: wet-spun union linen canvas (surface density of 460 g/m²), Silotex-97 made of synthetic high-modulus fibres with a polymer coating (210 g/m²), Nomex, made of aramid fibres (200 g/m²), and a nonwoven, batting (heat insulator). The thermal conductivity coefficient was considered to be some average or effective quantity that also takes into account the structural inhomogeneity of the fibre layer and the combined radiative and conductive heat transfer in it [1]. Two methods of measuring the thermal conductivity were used: the stationary flat-layer method and the nonstationary regular conditions method [2, 3].

The measurements with the stationary method were conducted in air at a temperature under 100°C and in a vacuum. The method is based on determining the heat flux (Q) passing through a flat sample of known area (F) and thickness (δ) and the temperature difference (ΔT) on its boundaries. The thermal conductivity coefficient, equal to

\[ \lambda = \frac{Q\delta}{F\Delta T}, \]

relates to the average sample temperature.

The working section for measuring the thermal conductivity was a multilayer structure with an electric heater in the center (area of 169 × 102 mm) made of Ural T-18 carbon fabric and insulated on both sides by a polyimide film 0.08 mm thick. The two fabric samples investigated, measuring 130 × 180 mm (in fluoroplastic film jackets to which the thermocouple sensors were attached). This system was attached on the outside to a package of glass 2 mm thick and tightened with elastic clamps which ensured a constant sample clamping force of ~20 cN/cm² during the experiments. Two copper—constantan thermocouples and one differential 10-junction thermopile (for measuring the temperature difference in the sample) were used for measuring the temperature; the diameter of the thermal electrodes was 0.07 mm. Digital millivoltmeters were used as secondary instruments.

In conducting experiments with a stabilized VSA-4 rectifier, the running current was established and after recording steady-state conditions, the heater power was measured (due to the symmetry, the heat flux through each sample was half of this quantity). The thermal conductivity coefficient was then found with Eq. (1). A correction was introduced for the heat flow at the ends of the working section (it did not exceed 1%).

In the measurements in the vacuum, the working section was placed in a chamber with a capacity of ~50 liters. The evacuation system, which included a VN-1MG forevacuum pump, provided a residual gas pressure of ~8·10⁻² mm Hg.
The thermal conductivity coefficients varied within the limits of 0.085-0.088 W/(m·°C) for canvas, 0.076-0.079 W/(m·°C) for Nomex fabric, and 0.035-0.036 W/(m·°C) for batting in the temperature range investigated in air. The temperature curves of the thermal conductivity are shown in Fig. 1.

As for the vacuum measurements, they produced thermal conductivity values one order of magnitude lower: in all materials investigated, it was 0.004-0.007 W/(m·°C) at ~30°C. The thermal conductivity of the samples decreased sharply during evacuation at a pressure of 20-10 mm Hg. This effect could have two causes: a decrease in the thermal conductivity of the filler gas and a simultaneous increase in the contact thermal resistances between fibres; as a result, the conductive heat flow through the sample decreased.

The thermal conductivity studies in regular conditions were conducted with a λ-calorimeter (LKT-1) in air at 20-25°C. The sample cooling rate in the measuring instrument \[ m = d[\ln \theta]/d\tau \] was found from the experimental curve of the excess temperature (\( \theta \)) as a function of time (\( \tau \)) [4, 5] and the thermal conductivity was calculated with the result:

\[
\frac{\lambda}{\delta} = \frac{1}{R_{\text{sam}}} = A m - k. \tag{2}
\]

where \( \delta \) is the fabric sample thickness; \( R_{\text{sam}} \) is the thermal resistance of the sample; \( A, k \) are the constants of the LKT-1 instrument; \( m \) is the cooling rate of the sample in this instrument.

The instrument constants \((A \text{ and } k)\) were determined during calibration experiments for a substance with a known thermal conductivity coefficient (air).

In the regular conditions method, the contact thermal resistances are a source of large systematic errors [6]. They appear in zones of contact of the samples with the smooth metal surface of the measuring instrument and are due to the fact that only small sections of the fabric — protrusions or ridges formed by the system of fibres — touch the surface of the metal. The effect of the contact resistances on the results of measuring the thermal conductivity of fabrics is especially pronounced, since relatively thin samples are usually used in the experiments, and these resistances are of the same order of magnitude as the thermal resistance of the object investigated.

To eliminate contact phenomena, the thermal conductivity was measured on samples with a different number of layers (from one to three). Since the thermal resistance is a linear function of the sample thickness (for the same clamping force), it can be represented as

\[ R_{\text{sam}} = R_c + (\delta/\lambda_c). \tag{3} \]

Resistance \( R_c \), which refers to the contacts of the fabric with the two smooth surfaces of the measuring instrument, can be determined by extrapolating the experimental curve of \( R_{\text{sam}} = f(\delta) \) to zero ply thickness. This curve, obtained for samples