INFRARED DRYING OF MINERAL WOOL PRODUCTS

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The laboratory drying of mineral-wool-products with a silicate-glass binding is described. Crust formation and the heat conditions during drying are discussed. The results of an investigation of the thermophysical and physicochemical characteristics of the obtained specimens are given.

The fabrication of new heat-insulating materials is a very urgent problem for many branches of industry. One attempt to solve this problem was the fabrication of materials based on mineral wool with various substances, such as phenolic resins, as binders [1].

However, the combination of the cheap raw material (mineral wool) and the expensive binder (resin), as well as the low thermal stability of the products due to the organic additives burn-up temperature ~623° K), did not provide a satisfactory answer to the problem.

The authors have carried out investigations on materials made of mineral wool with a water-glass binder.

Mineral wool consists of a mass of fibers obtained from a melt of metalloid and metal oxides. We used long-fibered mineral wool, produced in the Glass-Fiber Scientific Research Institute, with the following average characteristics: acidity modulus 2.04, bulk density 116 kg/m^3, beads more than 0.5 mm 3.4-6.0%. fiber diameter 4.6–6.3 μ, thermal conductivity at 318°K, 0.041 kcal/m^2 · deg · hr, breaking strain of 6μ fiber 116 kg/m^2, chemical composition (%): SiO_2, 51.04; Al_2O_3, 11.90; Fe_2O_3, 5.21; CaO, 22.65; MgO, 8.25; K_2O, 0.95; SO_3, traces; H_2O, 0.62 [2].

The binder was standard water glass of the following composition: $R_2O \cdot nSiO_2$, where R denotes Na or K. According to technical stipulations commercial water glass must not contain more than 1.5–2% Fe_2O_3 and Al_2O_3, more than 0.3–0.5% CaO and MgO, and its density must be 1.50–1.52 g/cm^3.

The experimental apparatus (Fig. 1) consisted of a MP-2M electric muffle furnace with a working space of 100 × 263 × 175 mm, a heater power consumption of 2.6 kW, maximum temperature 1273° K, with a thermoregulator 2, which kept the temperature in the furnace constant to within ±6°.

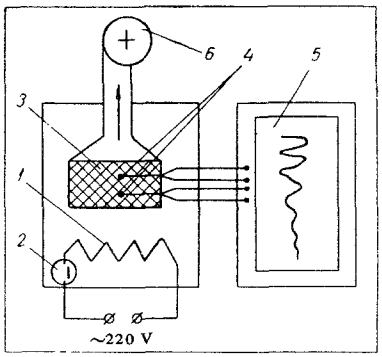

Fig. 1. Block diagram of experimental apparatus.

The specimen 3 is placed either on a supporting grid or in a metal box in the furnace. The temperature in the furnace and inside the specimens was measured by means of chromel-alumel thermocouples 4 connected to an EPP-09 recorder 5. Besides this, in certain experiments we used an air blower 6 to extract air from the furnace or draw it through the specimen.

The specimens were fabricated in the following way. Several layers of mineral wool were made into a stack 20–30 cm high. The stack was compressed from above by a mold plate and the sides were trimmed. The blank was weighed on a technical balance and was then steeped in a water-glass solution of fixed concentration and after impregnation was compressed on glass to a moisture content of 200%.

The obtained wet sample in the form of a brick 10 × 20 cm of varying thickness was again weighed on the balance and then installed in the furnace. After

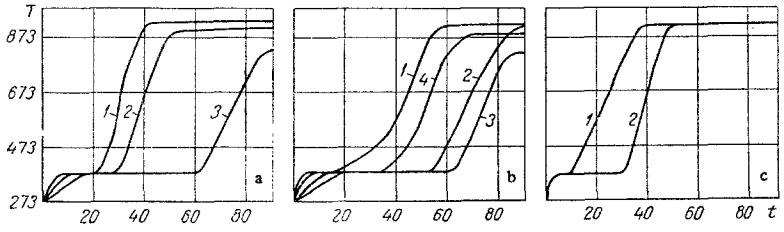

Fig. 2. Temperature T (°K) in: a) center of specimens 34 (1), 40 (2), and 85 (3) mm thick; b) in different layers of a specimen 85 mm thick lying on the floor of the furnace, with thermocouples located at a distance of 3 (1), 21 (2), 42 (3), and 80 (4) mm from the lower surface; c) the same for similar specimens with air drawn through them at a rate of ~50 dm^3/min (1) and without air drawn through (2). Time t in min.

the heat treatment the dry product was weighed. During the drying the temperatures at different depths in the specimen were recorded.

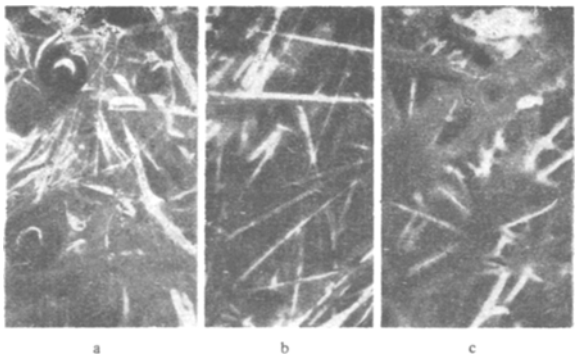

Fig. 3. Photomicrographs of structure of: a) wet specimen before heat treatment (solution, white streaks, is mainly distributed along the fibers, forming blobs at points where they cross); b) the same sample after heat treatment (the fibers are appreciably thicker, and there are local thickenings at the points where they cross, 50 ×); c) specimen after heating in closed furnace at 1123° K for 2.5 hr (melting of the fibers gives rise to a peculiar "dendritic" structure, 100 ×).

The drying temperature varied from 583° to 1023° K. With increase in temperature the total duration of the heat treatment was reduced and, in the range up to 923° K, the quality of the products was improved. Heating at 973° K or more led to a gradual disintegration of the mineral-wool fibers. They became soft and melted. This led to shrinkage of the specimens and to an increase in their density and thermal conductivity.

The finished specimens (surfaces, fractures, cut surfaces) were examined visually and photographed under low magnification ("Zenit" camera with attachment rings); their microstructure was investigated by photography under an MIM-8m microscope. In addition, we used conventional methods to determine the mechanical properties, thermal conductivity (steady heat-flow method), thermal stability, resistance to water, and other characteristics.

By measuring the density and from microscopic observations we determined semiquantitatively the distribution of the binding additive within the specimen.

As an examination of typical drying thermograms (Fig. 2) shows, the drying process can be divided into stages: heating to 373° K, evaporation of moisture at constant temperature, and heating until temperature equilibrium is attained.

The total duration of the heat treatment did not depend greatly on the moisture content of the specimen and was almost directly proportional to the thickness (Fig. 2a).

The drawing of air through the specimen, as was to be expected, greatly reduced the duration of the second stage (Fig. 2c). Weighing of the samples in different stages of the heat treatment showed that in the third stage there was a reduction of weight, presumably due to the removal of water of crystallization. The greatest loss of weight occurred at the second stage and was due to mass transfer, mainly in the liquid phase. The result is that dissolved binding chemical substances migrate along with the moisture. Hence, if the concentration of the solution is sufficiently high (above 10%) there is an increased amount of water glass in the 1- to 3-mm thick surface layer and on drying it forms a solid crust. The formation of a crust leads to a reduction in the rate of heat and mass transfer in the deep layers of the specimens, to a prolongation of the third stage of heat treatment, and also to nonuniform distribution of the binding material in the specimen. However, when solutions of low concentration (<5%) are used, crust formation is insignificant and, as Fig. 2b shows, the rate of heating at different depths is constant.

The theoretical description of the process is made difficult by the fact that, in addition to moisture transfer, there is transfer of the binding additive, which interacts chemically with the mineral wool, and the thermal conductivity and porosity of the surface layers are greatly altered. As a first approximation, at low concentrations of binding solution the existing theory of heat and mass transfer can be used [3].

The experimental investigations led to the obtaining of hard products in the form of bricks with the structure illustrated on the photomicrographs (Fig. 3).

The water glass, which is distributed along the fibers and at the points where they cross, binds them together and creates a rigid structure. Since mineral wool is an amorphous substance, heating to more than 973° K leads to melting of the fibers and the formation of a "dendritic" structure of greater strength (up to 50% greater) and to shrinkage of the specimen. Heating of one side to a temperature of 1123° K leads to shrinkage of only a thin layer (2–3 mm) on the heated surface without destruction or alteration of the properties of the specimen as a whole.

From our preliminary experiments we selected the best heat-treatment procedure, uniform infrared drying at 923° K, and the best concentration of binding solution to avoid crust formation and ensure sufficient mechanical strength, 5% by volume of water glass in water.

An investigation of specimens made with a solution containing 10% or more liquid glass showed a considerable difference in the thermal conductivity and mechanical properties of the outer and inner layers.

The series of specimens was subjected to mechanical and physicochemical tests, the results of which are given in the table.

The obtained products retain the most valuable property of mineral wool, low thermal conductivity; they differ slightly in leachability and possess good mechanical properties. They are sufficiently hard and have a low bulk density (~0.2 ton/m^3), which facilitates the assembly of heat insulation.

We also conducted tests on the water resistance of these products. The specimens were steeped in water until they had absorbed all they could and were then

Results of Mechanical and Physicochemical Tests of Specimens

Characteristic	No. of specimen				
	0 (mineral wool)	2B	3*	3B	4B
Water glass content, % by vol.	0	5	5*	5	5
Bulk density, T/m^3	0.1—0.2	0.208	0.207*	0.190	0.190
Tensile strength, kg/cm^2	—	0.128	0.113*	0.110	0.110
Bending strength	—	—	1.78	—	0.40
Water absorption, %	500	490	—	492	—
Leaching, %	3.0—3.5	3.9	—	3.6	—
Thermal conductivity, kcal/m^2 · deg · hr	—	0.04	0.047*	—	0.039

Characteristic	No. of specimen				
	6B	7*	8B	23B	1P
Water glass content, % by vol.	5	5*	5	10	20
Bulk density, T/m^3	—	0 218	0.190	0.232	0.28
Tensile strength, kg/cm^2	—	—	0.140	1.0	1.12
Bending strength	—	0.58*	0.76	1.5	—
Water absorption, %	—	475*	—	—	—
Leaching, %	4.4	4.6*	—	—	—
Thermal conductivity, kcal/m^2 · deg · hr	0.060	—	0.042	0.11**	—

*Data obtained in Laboratory of Physicochemical Measurements and Mechanical Tests of "Teploproekt" Trust.

**Average value for specimen 32 mm thick.

dried at room temperature. Performance of this procedure three times had no significant effect on their properties. This is due to the fact that heat treatment of liquid glass in contact with mineral wool leads to an irreversible change and the water glass becomes insoluble.

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