THERMAL CONDUCTIVITY OF GLASS WOOL FIBER

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Abstract

The article is dealing with study of thermal properties of fiber materials. For specific heat, thermal diffusivity and thermal conductivity determination the transient pulse method was used [1]. The results were correlated with the size of heating body and with the thickness of measured material. With the usage of electrical model the dissipations of thermal system were detected.

Key words: glass wool fiber, fractal structure, specific heat, thermal diffusivity, thermal conductivity and transient pulse method

1. Introduction

The fiber materials (e.g. glass wool fiber) are often used as thermal isolation in air and building industry. Therefore it is important to develop simply methods that will enable to determine its thermal properties (specific heat, thermal diffusivity and thermal conductivity) with suitable precision. The most often are these values measured in the stable state [1]. In this case it is necessary to provide defined thermal conditions (method of protected thermal table, method of indicator of thermal flow). The other methods are based on determination of thermal parameters from stepwise or pulse responses [2, 3]. The methods based on evaluation of responses to the periodical (harmonic) change of heat are developed nowadays [4].

In this article for determination of thermal properties of fiber materials the transient pulse method was used.

2. Experimental

For the responses to the pulse heat the Thermophysical Transient Tester 1.02 was used. It was developed at Institute of Physics, Slovak Academy of Science [5]. The block diagram of automated measurement workstation is presented in *fig. 1*. The measured sample, which was placed in the isothermal chamber, consisted of three parts of cylindrical shape. Between the first and the second part the heat source was placed (nickel folium 20 μm thick and radius $R_2 = 2$ cm). Between the second and third part one connection of differentially connected thermocouple (NiCr-Ni) was placed. The second connection was placed on heat exchanger where the constant temperature was kept with the help of thermostat. The temperature was measured by platinum resistance (Pt100Ω).

Heating-up of sample was provided by rectangular current pulse from the software directed source Mesit Z-YE-3T/x. The supplied heat was computed from the parameters of pulse (from the voltage U, current I and from the duration of impulse t)

$$Q = U I t . \quad (1)$$

The change of temperature between heat exchanger and sample was measured by nanovoltmeter Agilent HP4119A. The experiment control was carried by PC via GPIB bus and software equipment created by authors.

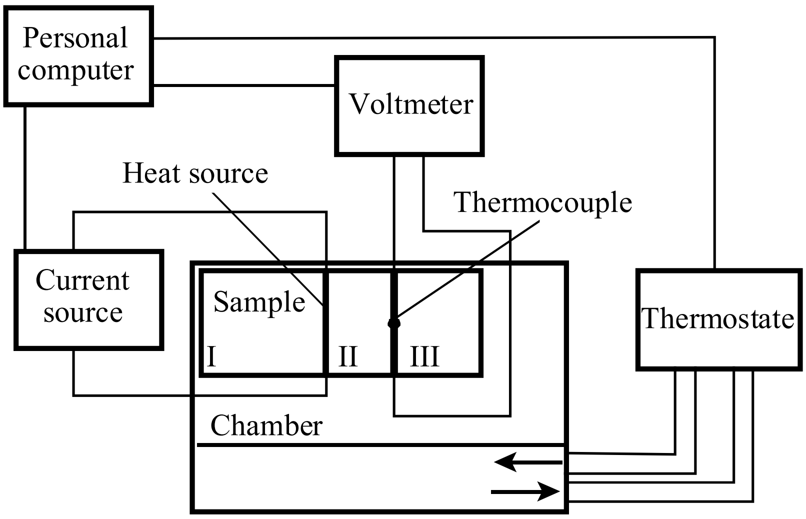

Fig. 1 The block scheme of measuring apparatus

3. Measured samples

Fiber glass wool is a lightweight, flexible, thermal and acoustical insulation material designed to provide the ultimate noise reduction. It is formed from resin-bounded borosilicate glass fibers. It is water and fire resistant, it has low density of combustion gas and low toxicity. It reduces transport of heat and sound. Its density in non-pressed state is 5 – 20 kg.m^{-3}, thermal conductivity is 0.03 – 0.04 W.m^{-2}.K^{-1} in 10°C [6].

Samples were round shaped with radius $R_1 = 3$ cm, their thickness was changed by pressing in the range of $h = (30 - 5)$ mm. The corresponding values of density together with values declared by manufacturer are presented in the *table I*. In this article there are discussed results of samples MJ-02 and MJ-05 that differ in the technology of fiber treatment.

Table I

sample	table values		not-pressed sample		pressed sample		ratio of pressing (densityies)
	thickness (mm)	density (kg.m^{-3})	thickness (mm)	density (kg.m^{-3})	thickness (mm)	density (kg.m^{-3})	
MJ–02	30	19.2	20	27.61	8	69.02	2.50
MJ–05	30	19.2	20	30.21	8	75.53	2.50

4 Heat loss from the sample surface

The heat Q transported from heat source to the measured material is dissipated because of finite size of sample. The magnitude of heat dissipation depends on ratio of size of heat source and thickness of sample and on properties of environment where sample is placed in (gas, air, vacuum). In [3] there are correction factors f_a and f_c introduced which is necessary to use when computing thermal parameters of material

– thermal diffusivity

$$a = h^2/(2\Delta t_m f_a) \tag{2}$$

– specific heat

$$c = \frac{Q}{\rho h \Delta T_m \sqrt{2\pi e}} f_c \tag{3}$$

– thermal conductivity

$$\lambda = ac\rho = \frac{Qh}{2\Delta T_m \Delta t_m \sqrt{2\pi e}} \frac{f_c}{f_a} \tag{4}$$

where h is sample thickness, ρ is density of material and ΔT_m is maximal temperature response for applicated thermal pulse; it will occurs in the time Δt_m after start of heating.

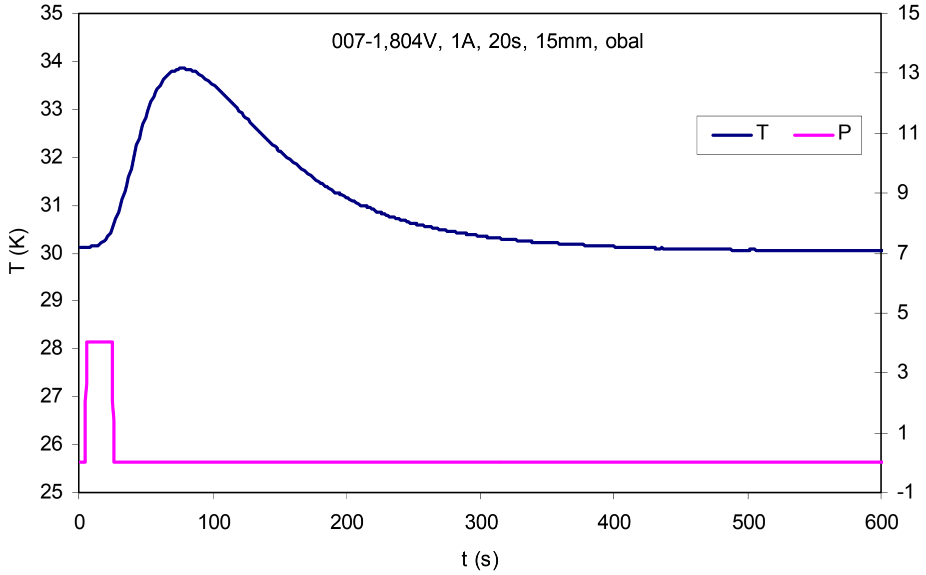

Fig. 2 Thermal response of MJ-02 sample for current pulse of 1.8W and duration 20s

On the *fig. 2* there is the typical response for MJ-02 sample together with the course of input that was used to power supply the heat source. For the current pulse P = 1.8 W input and duration t = 20 s and for different thickness of samples are these values presented in the *table II*

Table II

sample	h (mm)	Δt_m (s)	ΔT_m (K)	f_a [2]	f_c [2]	λ ($W.m^{-1}.K^{-1}$)	c ($J.kg^{-1}.K^{-1}$)	a ($m^2.s^{-1}$)
MJ–02	8	58.14	7.49	1.879	0.610	0.0413	4090	$2.93 \cdot 10^{-7}$
	20	74.14	2.54	2.683	0.345	0.0930	6701	$1.00 \cdot 10^{-6}$
MJ–05	8	62.34	6.48	1.879	0.610	0.0443	4291	$2.73 \cdot 10^{-7}$
	20	74.48	2.15	2.683	0.345	0.1102	7289	$1.00 \cdot 10^{-6}$
air						0.0250	1227	$1.58 \cdot 10^{-5}$

4. Dependencies of thickness

To verify the method (heat dissipation) the thermophysical quantities of glass wool fiber were measured while modifying the density of sample (by pressing it). Results of MJ-02 sample and MJ-05 are presented on *fig. 3*.

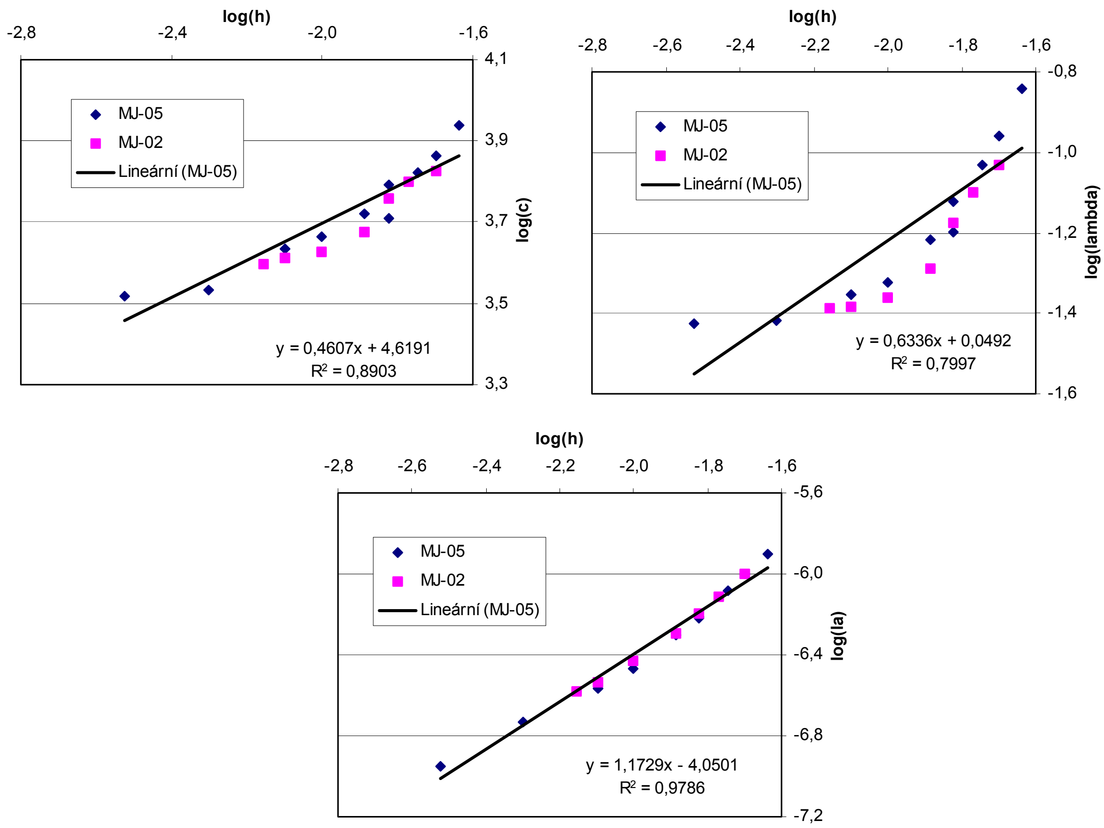

Fig. 3 The thickness depedencies of specific heat *c*, thermal conductivity λ and diffusivity *a* of samples MJ–02 a MJ–05

5. The model of transport of heat energy

From the stepwise (or unitary steps) thermal responses time constants of temperature increase (decrease) can be deducted. Because these dependencies are approximately exponential they can be interpreted easily. They can be approximated e.g. by responses of electrical model (presented on *fig. 4*) for the setting the switcher to on or off. Electrical quantities of this model correspond to these thermal quantities:

– electrical charge to the heat Q_T,
– voltage to the change of temperature ΔT,
– current to the flow of heat $I_s = \mathrm{d}Q_T/\mathrm{d}t$,
– electrical resistance corresponds to the thermal resistance $R_T = h/\lambda S$,
– electrical capacity to the specific heat $C_T = \mathrm{d}Q_T/\mathrm{d}T = mc = \rho S h c$.

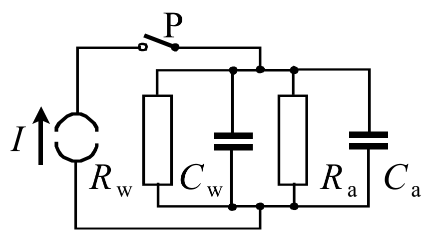

Fig. 4 The model of measured material

The time constant of thermal system is then:

$$\tau = R_T C_T = \frac{\rho c}{\lambda} h^2 = \frac{h^2}{a} \qquad (5)$$

The expected model of analyzed structure of fiber wool glass is presented at fig. 4. It starts with thermal conductivity and specific heat of the material of fibers (R_W and C_W) and the air among the fibers and in the surroundings respectively (R_a and C_a). To the source of heat corresponds the power source. The thermal pulse is realized by switching the switcher P on and off. Responses of voltage (which correspond to the changes of temperature) can be expressed by following equations:

–when switching on

$$U(t) = I_0 \cdot R_1 \cdot \left(1 - e^{-t/\tau_1}\right), \tag{6}$$

–when switching off

$$U(t) = I_0 \cdot R_2 \cdot e^{-t/\tau_2}, \tag{7}$$

where electrical resistance $R_{1,2} = R_a R_w/(R_a + R_w)$ corresponds to the thermal resistance, electrical capacity $C_{1,2} = C_a + C_w$ corresponds to the specific heat of system measured when heating or cooling the system. Time constants $\tau_1 = R_1C_2$ a $\tau_2 = R_2C_2$ characterize the course of temperature increase (decrease respectively) after the application of thermal pulse. These constants are different when measuring in the air atmosphere because of the different heat dissipation during cooling or heating sample up (constants R_a and C_a).

The *fig. 5* represents the typical dependencies of thermal responses of analyzed samples. Together with this functions there are presented courses of model responses when connecting and disconnecting the thermal pulse (6), (7). The time constants of ascending and descending edge are presented in *table III*. The values of diffusivity calculated using these time constants correspond with values calculated according equation (2). The results were corrected for the finite size of sample (a/f_a).

Table III

sample	h (mm)	ΔT (K)	a ($m^2.s^{-1}$)	τ_1(s)	a_1/f_a ($m^2.s^{-1}$)	τ_2(s)	a_2/f_a ($m^2.s^{-1}$)
MJ–02	8	13.76	$2.34 \cdot 10^{-7}$	38.5	$8.85 \cdot 10^{-7}$	83.3	$4.09 \cdot 10^{-7}$
	20	4.67	$1.96 \cdot 10^{-6}$	52.6	$2.83 \cdot 10^{-6}$	76.9	$1.94 \cdot 10^{-6}$
MJ–05	8	11.91	$2.19 \cdot 10^{-7}$	83.3	$4.09 \cdot 10^{-7}$	125.0	$2.72 \cdot 10^{-7}$
	20	3.94	$1.96 \cdot 10^{-6}$	66.7	$2.24 \cdot 10^{-6}$	55.6	$2.68 \cdot 10^{-6}$

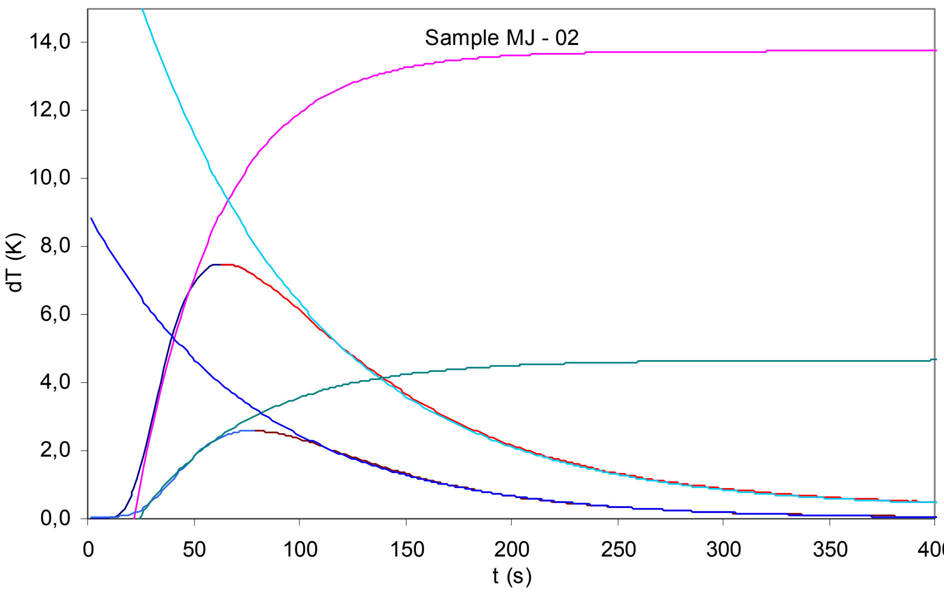

Fig. 5 The model characteristics of thermal responses of fiber wool glass for sample MJ–02 a) not pressed sample (h = 8 mm), b) pressed sample (h = 20 mm)

6. Conclusion

In this article there are presented results of measurements of thermal parameters (thermal conductivity, specific heat and thermal diffusivity) of glass wool fibers. It was found out that these parameters depend on thickness (compression, density) of material by power law. These changes are probably connected by the change of fractal structure when compressing the sample. Two concrete samples that differ by mode of production were analyzed in detail. The values of diffusivity are in a good agreement with results obtained from time constants of model that was used to interpolate responses. The values of thermal conductivity correspond with values declared by manufacturer.

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