THERMOPHYSICAL PARAMETERS OF PERSPEX DETERMINED FROM THE TEMPERATURE RESPONSES MEASURED BY PULSE TRANSIENT METHOD

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Abstract:

The pulse transient method measures three thermophysical parameters (specific heat, thermal diffusivity, and thermal conductivity) in one single measurement. This paper discusses the thermophysical properties of perspex that is used as the standard reference material for thermal conductivity measurements in metrology. The evaluation of ascertained data is performed with the help of mathematical apparatus used for study of fractal structures properties [1, 2]. Data from this method are compared with table values.

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Keywords:

pulse transient method, perspex, PMMA, specific heat, thermal diffusivity, thermal conductivity

INTRODUCTION

Polymethyl methacrylate (PMMA) is the synthetic polymer of methyl methacrylate. This thermoplastic and transparent plastic is sold by the tradenames Plexiglas, Perspex, Plazcryl, Acrylite, Acrylplast, Altuglas, and Lucite and is commonly called acrylic glass or simply acrylic. The material was developed in 1928 in various laboratories and was brought to market in 1933 by the German Company Rohm and Haas (GmbH & Co. KG) **Chyba! Nenalezen zdroj odkazů.**.

Chemical analysis and materials testing are becoming ever more important as science, trade and society are getting more complex worldwide. The number and significance of decisions based on the results of chemical analysis and materials' testing is ever increasing in all spheres of life including science, economy, trade, health care, environmental and consumer protection, sports and jurisdiction. For this purpose results of analysis and testing have to be reliable and comparable as well as acceptable worldwide. The use of certified reference materials (CRMs) is an efficient and proper tool to achieve these goals **Chyba! Nenalezen zdroj odkazů.**.

Measurement of the thermophysical properties of PMMA shows that some effects influencing the measurement process have to be known when one want to use it as laboratory reference or standard reference material (SRM). This material should be used for validation of apparatuses upon well-known experimental conditions, to obtain reliable data **Chyba! Nenalezen zdroj odkazů.**.

We use the PMMA for the method calibration and comparing with the others methods. PMMA is presented in matrix of many composites.

The principle of the pulse transient method and the arrangement of the measured sample are shown in Figure 1. The heat pulse forms a dynamic temperature field of the sample.

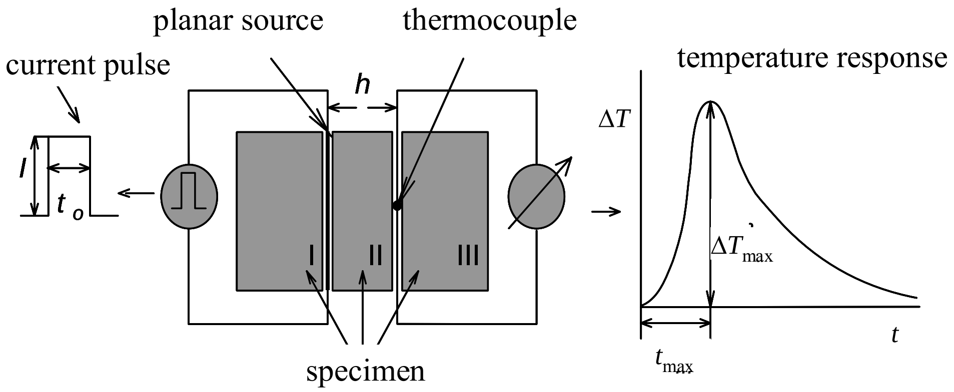

Figure 1 The principle of measurement of thermophysical parameters by the pulse transient method.

A sensor measures the time development of the temperature field (temperature response) in a point of the tested body. Then the temperature is characterized by a function **Chyba! Nenalezen zdroj odkazů.**

$$\Delta T = \frac{Q/S}{c_{\mathrm{p}}\rho(4\pi a t)^{(E-D)/2}} \cdot \exp\left(-\frac{h^2}{4at}\right). \tag{1}$$

The thermophysical parameters are calculated from the characteristic parameters of the temperature response (time and the maximum of temperature response to the heat pulse).

The thermal diffusivity is given by

$$a = \frac{h^2}{2t_{\max} f_{\mathrm{a}}} = \frac{h^2}{2(E-D)t_{\max}}, \tag{2}$$

the specific heat by

$$c_{\mathrm{p}} = \frac{Q}{\rho \Delta T_{\max} h} \cdot \frac{f_{\mathrm{c}}}{\sqrt{2\pi \exp(1)}} = \frac{Q/S}{\rho \Delta T_{\max} h^{E-D}} \cdot \left(\frac{E-D}{2\pi \exp(1)}\right)^{(E-D)/2} \tag{3}$$

and thermal conductivity by

$$\lambda = c_{\mathrm{p}}\rho a = \frac{Q/S}{2(E-D)\Delta T_{\max} t_{\max} h^{E-D-2}} \left(\frac{E-D}{2\pi \exp(1)}\right)^{(E-D)/2}. \tag{4}$$

The maximum temperature of the response for Dirac thermal pulse is obtained by introducing of the thermal diffusivity (2) in the term (1)

$$\Delta T_{\max} = \frac{Q/S}{c_{\mathrm{p}}\rho} \exp\left(\frac{D-E}{2}\right) \cdot \left(\frac{E-D}{2\pi h^2}\right)^{(E-D)/2}. \tag{5}$$

It is possible to definite the coefficient f_{a} (fractal dimension D respectively) for every point of the experimental dependence

$$f_{\mathrm{a}} = E - D = \frac{2\ln(\Delta T_{\max}/\Delta T)}{\ln(t/t_{\max}) + (t_{\max}/t - 1)}. \tag{6}$$

EXPERIMENT AND RESULTS

For measuring of the responses to the pulse heat the Thermophysical Transient Tester 1.02 was used. It was developed at the Institute of Physics, Slovak Academy of Science. The specimen of 30 mm in diameter and 6 mm thick was used for the pulse transient method. Its density is $\rho = 1184$ kg m^{-3}. Thermophysical properties of material were measured in atmosphere of air.

1. Comparison between experimental and recommended data of the thermophysical parameters of PMMA

All measurements were made at 25 °C. The pulse width of 4 – 40 s, the heat power of 0.18 up to 3.03 W was used and adequate the pulse heat energy of 3000 – 42000 J m^{-2} was obtained. The typical heat energy of pulse was about 13000 J m^{-2} that is low enough to avoid temperature damage of this material. The temperature response $\Delta T_{\max}$ in the range of 0.1 up to 1.4 °C was obtained. Analysis of these sets of data was carried out to find optimal experimental conditions.

The thermophysical parameters were calculated from the temperature response to the heat pulse using the Eq. (1).

The typical time responses of temperature for the rectangle (Dirac) pulse of different input power of heat with various pulse widths are presented in Figure 2. The heat power and width of pulse were changed for find the optimal measurement conditions and subsequently determine the reliable data of thermal diffusivity, specific heat and thermal conductivity of studied material. These results are summarized in Table 1.

Table 1 Thermophysical parameters of PMMA measured by the pulse transient method in optimum experimental conditions.

Q/S (J m^{-2})	P (W)	$\Delta T_{\max}$ (°C)	$t_{\max}$ (s)	a (m^2 s^{-1})	c_p (J kg^{-1} K^{-1})	λ (W m^{-1} K^{-1})
13 069	0.58	0.307	144	0.113	1425.0	0.190
13 149	0.67	0.307	139	0.119	1435.6	0.203
13 168	0.67	0.311	148	0.113	1416.5	0.190
17 325	0.67	0.398	146	0.110	1457.1	0.190
17 267	0.67	0.397	148	0.109	1456.9	0.188
15 065	0.76	0.359	146	0.115	1405.8	0.191
19 789	0.76	0.460	144	0.112	1440.5	0.190
17 990	0.92	0.424	148	0.113	1420.0	0.190
21 268	1.07	0.508	141	0.118	1402.6	0.195
26 252	1.07	0.622	144	0.113	1413.1	0.189
20 197	1.21	0.477	141	0.120	1419.1	0.202
23 753	1.75	0.563	139	0.124	1414.1	0.207
28 706	2.88	0.680	141	0.123	1415.2	0.207
40 081	2.88	0.955	148	0.115	1405.6	0.192
				(0.115 ± 0.005)	**(1423.4 ± 17.1)**	**(0.195 ± 0.007)**

The thermophysical parameters were calculated from the parameters of the temperature response to the heat pulse. Typical temperature increases for reliable data were between 0.3 °C and 1.0 °C that were equivalent to the heat powers of 0.58 W up to 2.88 W and to the heat energies of 13000 J m^{-2} up to 40000 J m^{-2}.

The pulse transient method gives data within the experimental error less than 4.35 % for thermal diffusivity, less than 1.20 % for specific heat and 3.59 % for thermal conductivity.

Table 2 Recommended values of thermophysical parameters of PMMA at 25 °C ***Chyba! Nenalezen zdroj odkazů.****.*

ρ (kg m^{-3})	a (m^2 s^{-1})	c_p (J kg^{-1} K^{-1})	λ (W m^{-1} K^{-1})
1188	0.112	1450.0	0.193

Average values of thermal diffusivity 0.115 m^2 s^{-1}, specific heat 1423.4 J kg^{-1} K^{-1} and thermal conductivity 0.195 W m^{-1} K^{-1} are in reasonable coincidence with recommended values, see Table 2.

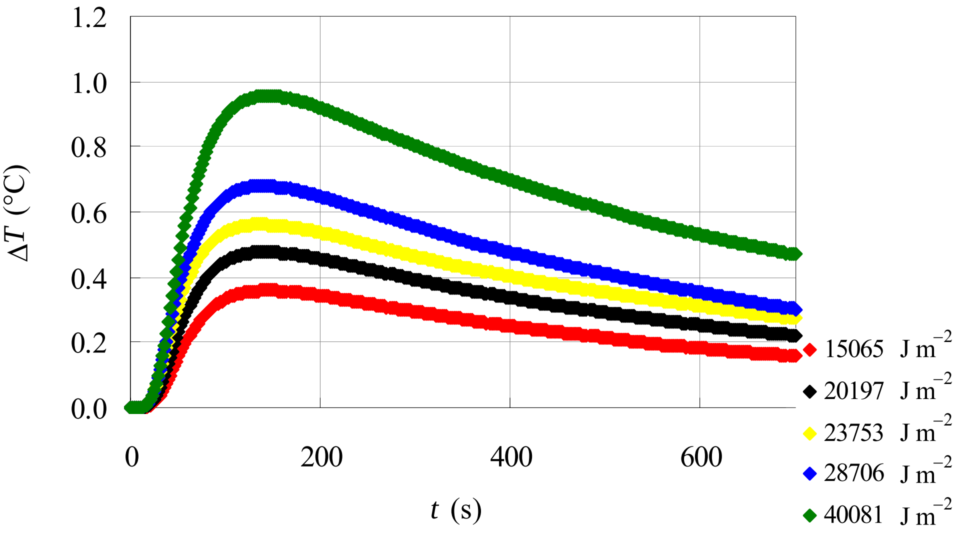

Figure 2 Temperature responses of the sample measured by the pulse transient method for different heat powers and various pulse widths; see Table 1.

The coefficient f_a (fractal dimension D respectively) of the fractal heat source for every point of the experimental dependence was calculated using the Eq. (6).

The fractal heat source characterizes the distribution of the temperature in the specimen in specific time. The character of these dependences differs for different thicknesses of measured sample. Dependencies of the fractal dimension on the time are plotted in Figure 3.

Generally we can say that all measured results were started from the value of the fractal dimension $D \approx 3$ and then they were saturated at the some constant value of the fractal dimension. This value of the fractal dimension depends on the losses during the transport of heat throw the sample.

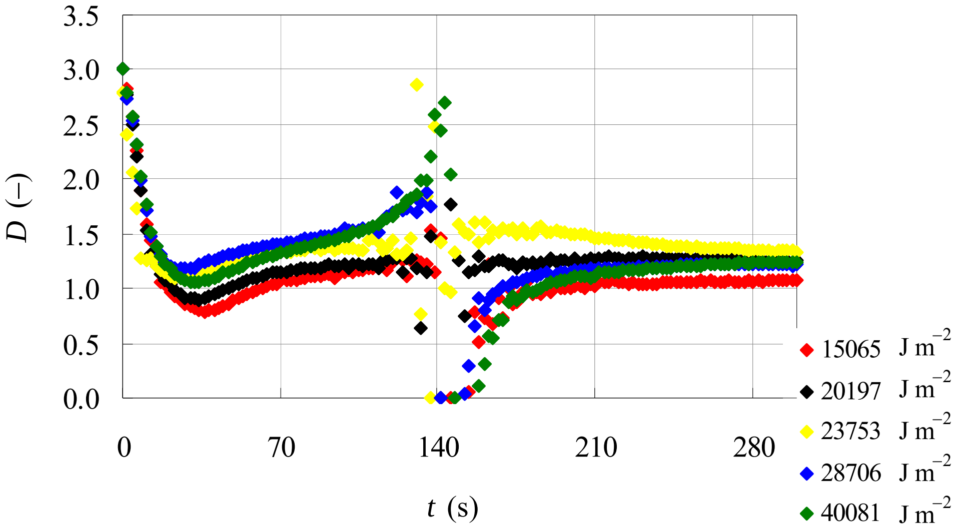

Figure 3 Fractal dimension of the heat distribution in the specimen determined from increased part of characteristics.

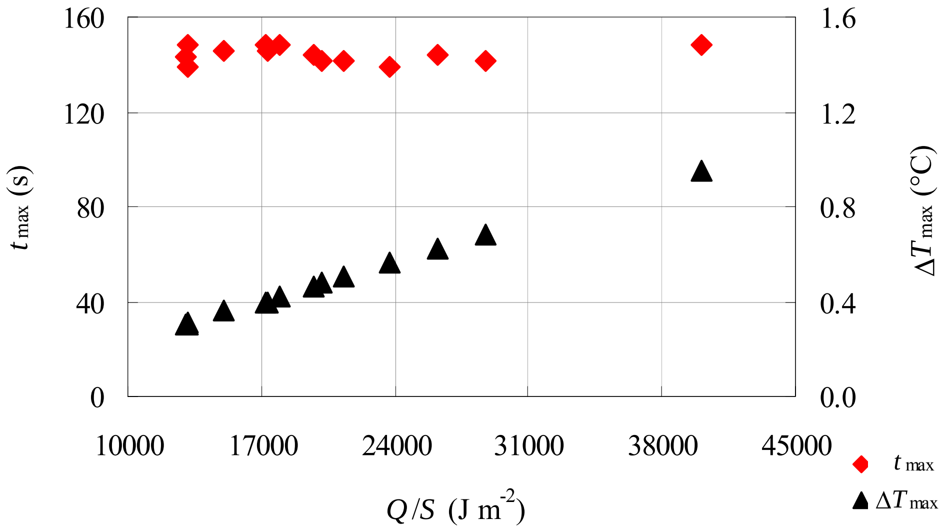

Figure 4 The dependencies of the position of maxima and adequate temperatures on the heat energy.

2. Study of thermophysical parameters of PMMA at 25 °C and 30 °C

The measurements were carried out with the sample temperature stabilized at 25 °C and 30 °C in atmosphere of air and in the same experimental conditions. The temperature response occurred in the range of 0.1 up to 1.4 °C. Experimental data was obtained for the pulse width of 4 – 40 s and the pulse heat energy of 6000 up to 36000 J m^{-2}.

Figure 5, 6, 7 and 8 illustrate the typical dependencies of the thermophysical parameters of PMMA on the heat energy for the heat power 1.75 W (the left side of these figures) and 2.50 W (the ride side of these figures).

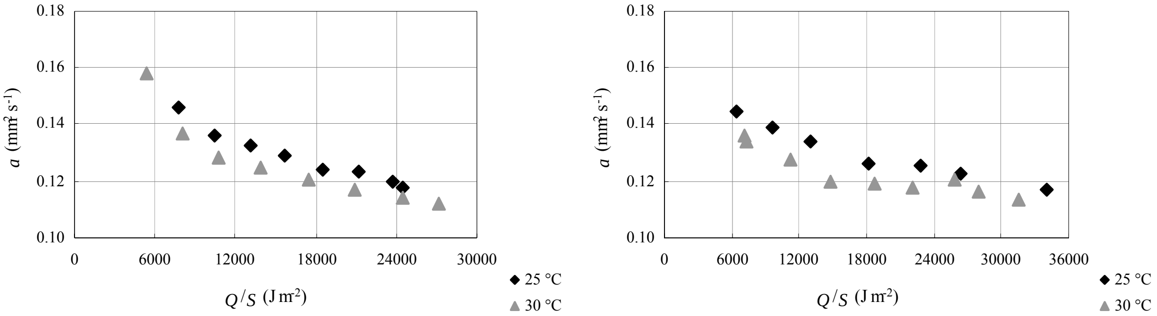

Figure 5 Thermal diffusivity of PMMA measured at 25 °C and 30 °C.
The heat power was 1.75 W – the left side of this figure and the heat power 2.50 W – the ride side.

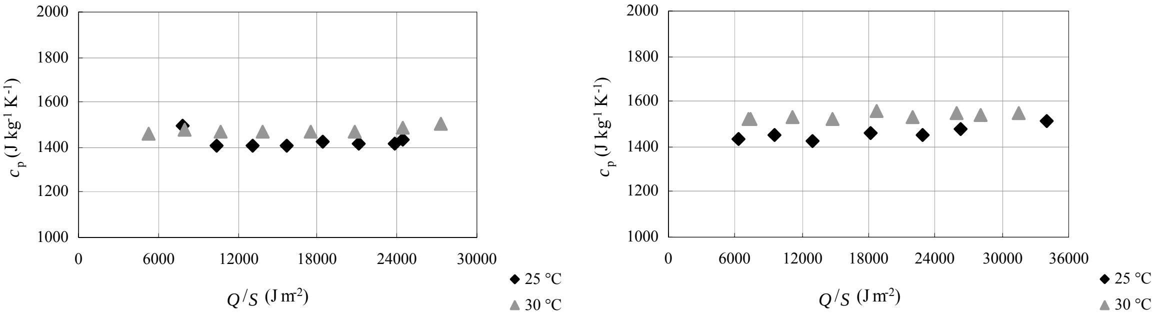

Figure 6 Values of specific heat of PMMA measured at 25 °C and 30 °C.

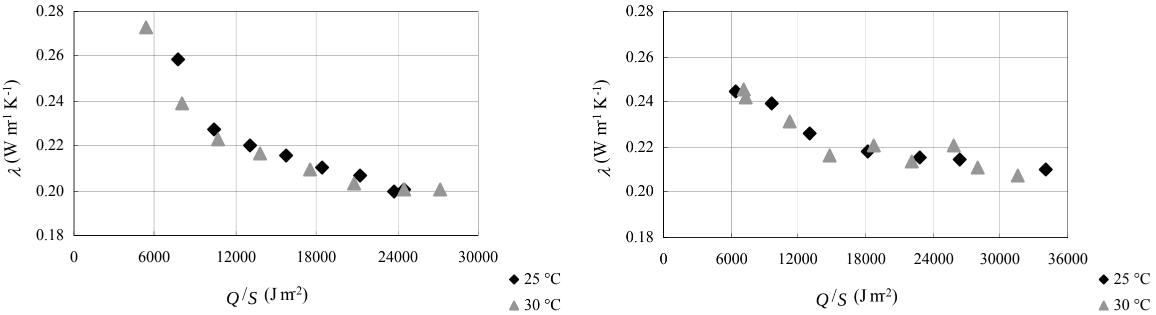

Figure 7 Thermal conductivity of PMMA measured at 25 °C and 30 °C.

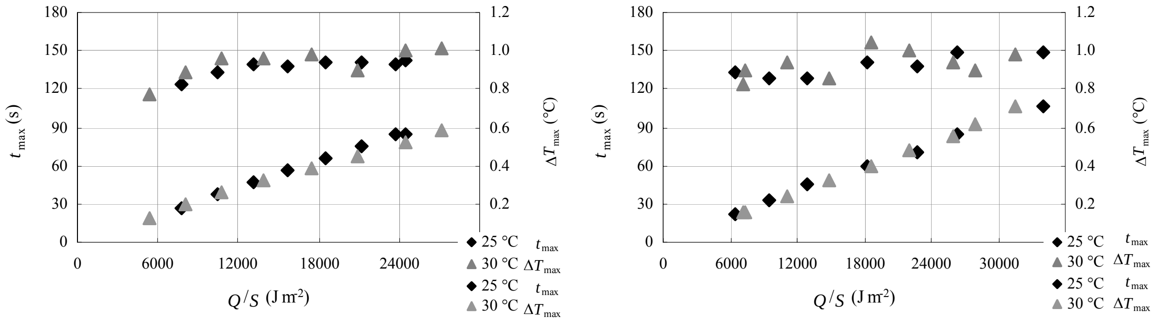

Figure 8 Dependencies of the positions of maxima and adequate temperatures of PMMA measured at 25 °C and 30 °C.

The figures mentioned above show that thermal diffusivity of PMMA slightly decreases with the increasing temperature as well as thermal conductivity. On the contrary, the specific heat increases with the increasing temperature of measured sample.

CONCLUSIONS

This paper presents the results of the measurements in optimal experimental conditions and of the study of the dependency of the thermophysical parameters on the temperature of studied specimen that were obtained on PMMA. The measurements were made in air. To interpret the outcomes, the simplified heat conductivity model is used [1, 2]. Results show the image of heat distribution in the specimen, in various time intervals after the heat supply from the source.

The analysis of experimental data measured by the pulse transient method for various heat power and pulse width of measurement was performed on polymethyl methacrylate (perspex). The optimization of the procedure of conditions metering was used to find the optimal range of measuring process at 25 °C where data stability interval exists, e.g. the values of thermophysical parameters are reliable. The value of thermal diffusivity calculated from the data stability interval was determined as $0.115\ \mathrm{m^2\,s^{-1}}$, $1423.4\ \mathrm{J\,kg^{-1}\,K^{-1}}$ for the specific heat and the value of thermal conductivity was calculated as $0.195\ \mathrm{W\,m^{-1}\,K^{-1}}$ and they are close to the recommended values; see Table 2. The pulse transient method gives data within the experimental error less than 4.35 % for thermal diffusivity, less than 1.20 % for specific heat and 3.59 % for thermal conductivity. These evaluations could be used for more accurate determination of the thermal parameters of studied (homogeneous and heterogeneous) matters.

Data measured on PMMA clearly show difference of thermophysical parameters measured in different temperatures for the same specimen and experimental conditions. Thermal diffusivity of PMMA slightly decreases with the increasing temperature as well as thermal conductivity. On the contrary, the specific heat increases with the increasing temperature.

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