CONTRIBUTION TO THE EXTENDED DYNAMIC PLANE SOURCE METHOD

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Abstract

The paper deals with measurement of the thermophysical properties (thermal conductivity and diffusivity) of PMMA (polymethylmatacrylate). The theory of the dynamic plane source method and modified experimental apparatus is described. Difference analysis is used for searching the time interval in which the measured data should be evaluated. Besides the influence of the heater and heat losses from the lateral sides of the sample also the influence of the noise is studied.

Key words: thermophysical properties, dynamic plane source method, difference analysis

1 Introduction

Transient methods represent a large group of techniques where measuring probes, ie heat source and thermometer, are placed inside the specimen. This experimental arrangement suppresses the sample surface influence on the measuring process. The temperature of the specimen is stabilised and uniform. Then the dynamic heat flow in the form of pulse or step-wise function is generated inside the specimen. From the temperature response to this small disturbance the thermophysical parameters of the specimen can be calculated.

Table 1. Basic characteristics of transient methods

Heat source	Heat generation	Heat flow	Heat source-thermometer	Measured parameters	Name of method
line	step-wise	radial	united	λ	Hot Wire
plane	pulse	1-dimensional	apart	a, λ	Pulse Transient
plane	step-wise	1-dimensional	apart	a, λ	Step-Wise Transient
plane	step-wise	1-dimensional	united	effusivity	Hot Plate Transient
disc	step-wise	3-dimensional	united	a, λ	Hot Disc Transient
circles	step-wise	3-dimensional	united	a, λ	Gustafsson Probe
plane	step-wise	1-dimensional	united	a, $\lambda > 2$W/mK	DPS
plane	step-wise	1-dimensional	united	a, $\lambda < 2$W/mK	Extended DPS

The summary of transient methods is given in Table 1 [1,2].

The dynamic plane source (DPS) method is arranged for a one-dimensional heat flow into a finite sample. On the rear side the sample is in contact with poor heat conducting material so that the temperature developed in the sample is close to adiabatic. This method appears to be useful for simultaneous determination of thermal diffusivity *a* and thermal conductivity λ of metals and good thermally conducting dielectrics.

The extended dynamic plane source (EDPS) method is the modification of DPS method for low thermally conducting materials. The insulating material on the rear surface of the sample has been exchanged with a very good heat conducting material (heat sink) which causes that the process after a short time approaches the steady-state condition.

2 Experimental

The arrangement of the experiment is shown in Fig. 1, where the plane source (PS) disc is placed between two identical samples having the same cross section as the disc. The rear side of the sample is in contact with heat sink, which is made of large Al blocks. The PS disc, which simultaneously serves as the heat source and thermometer, is made of a nickel film 20 μm thick covered from both sides with kapton layer. The diameter of the disc is 20 mm and the thickness of both specimens is about 3 mm.

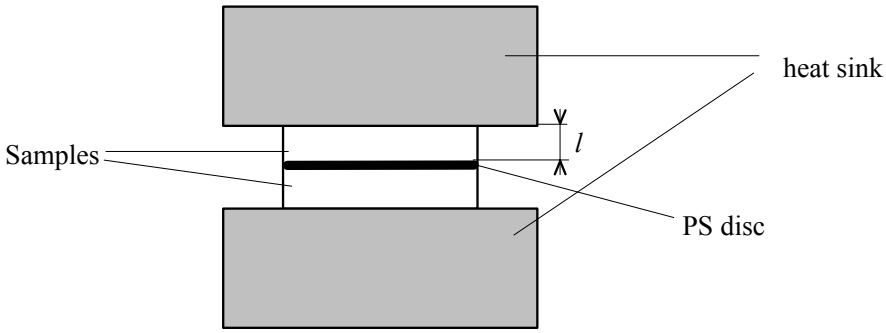


Fig 1 The setup of the experiment

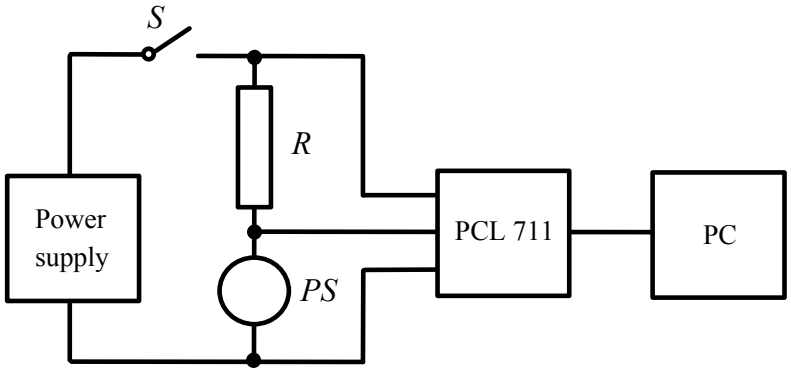


Fig 2 Experimental circuit design. *R* - constant resistor, *PS* - disc, *S* - switch

The heat flux, in the form of step-wise function, is generated by switching on the electrical current as shown in Fig. 2. Using the constant resistor, the electrical current and voltage across the PS disc are measured. Data acquisition is realised by means of a multichannel PC plug-in card PCL 711 (Advantech). So that the power as well as the instantaneous values of the disc resistance and temperature can easily be computed. Comparing with previous works [2, 3], in this experimental arrangement a cheap power supply is used. The advantage of this solution resides in the fact, that the measurement results are not influenced by a small instability of the set current.

3 Theory

Fig. 3 shows the theoretical temperature function which is a solution of the partial differential equation with boundary and initial conditions corresponding to the experimental arrangement. The temperature function is given by [2]

$$T(t) = \frac{ql}{\lambda}\sqrt{\frac{t}{\pi\,\Theta}}\left(1 + 2\sqrt{\pi}\sum_{n=1}^{\infty}\beta^{n}\,\mathrm{ierfc}\left(n\sqrt{\frac{\Theta}{t}}\right)\right), \tag{1}$$

where q is heat current density and λ thermal conductivity. Θ is the characteristic time of the sample and is given by

$$\Theta = \frac{l^2}{a}, \tag{2}$$

where l is thickness and a thermal diffusivity of the specimen. Parameter β describes the heat sink imperfection and ierfc is the error function integral [4]. The principle of the method resides in fitting of the theoretical temperature function given by (1) over the experimental points. In case of the best fit, both parameters λ and a can be determined. The method of fitting based on least-squares procedure was described in detail [2].

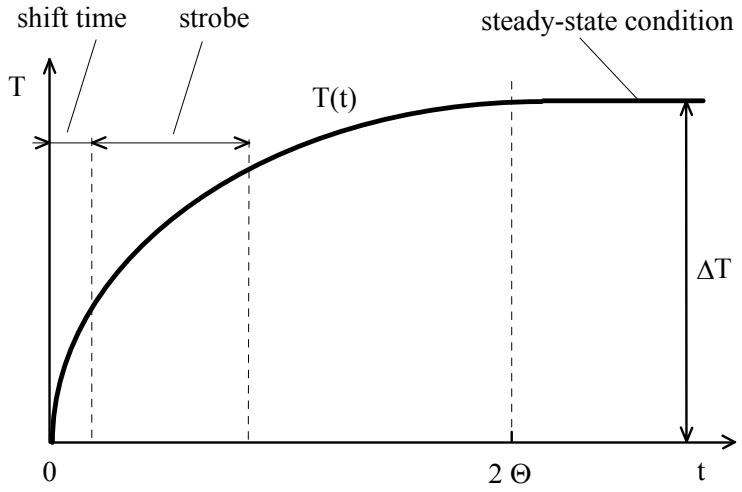


Fig 3 Temperature function - temperature increase as a function of time

4 Experimental data processing

In this section we will discuss some effects which can cause the deviation of the experimental conditions from the ideal one. We will show how some of these distortions can be eliminated by the proper evaluation technique. The first problem resides in the influence of the PS disc. The theory assumes an ideal PS disc - the homogeneous hot plane of negligible thickness and mass that is in perfect thermal contact with the sample. The imperfection of the disc will cause, that the beginning of the measured temperature function will be distorted. This time interval, described by the characteristic time of the disc Θ_D, is not suitable for computing of thermophysical parameters.

Heat losses from the lateral sides of the sample present the second problem. This can be eliminated by optimising of the specimen thickness described in [2]. But approaching the steady-state condition the heat losses are becoming more and more important. This time interval of the measured temperature function also can not be used. So we expect, that there exists a time interval in which the determination of thermophysical parameters will not be erroneous. This important time interval can be find using the procedure which was named difference analysis [1]. The procedure is based on fitting within the time interval (strobe) which is successively shifted in steps corresponding to the sample period. As in each fitting new values of parameters λ and a are computed, the shift time dependencies are obtained.

Fig. 4 shows the results of the difference analysis which was performed with theoretical points computed using equation (1). Quantization noise was added by rounding the points to 4 valid numbers. Fig. 4 and 5 shows the thermal conductivity λ, thermal diffusivity a and correlation coefficient r as the function of the shift time. The strobe was 25 s.

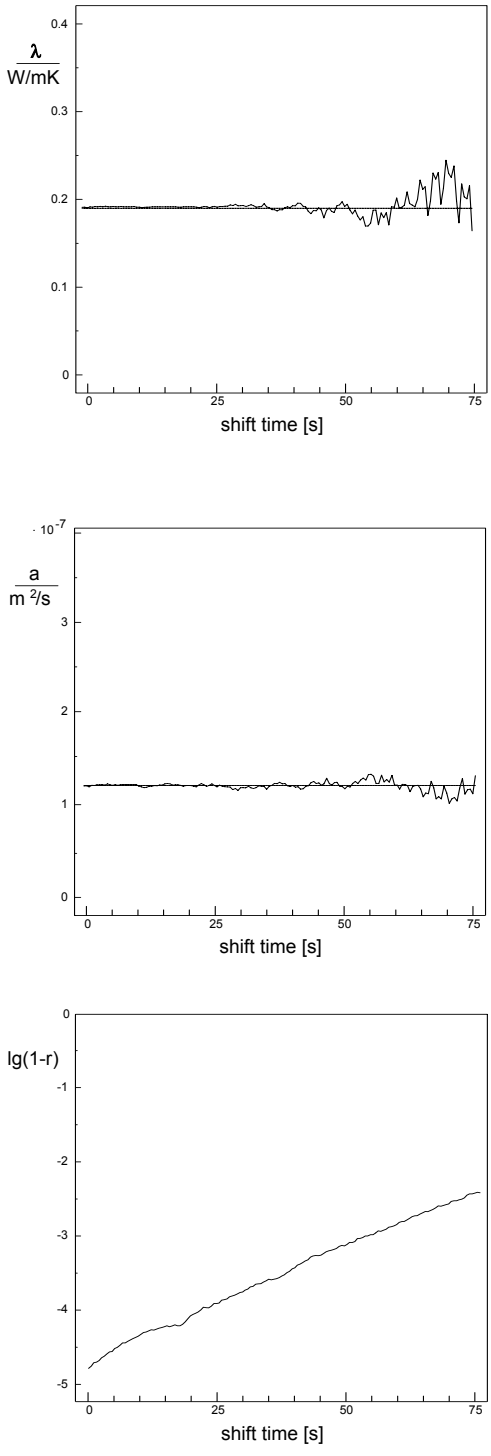
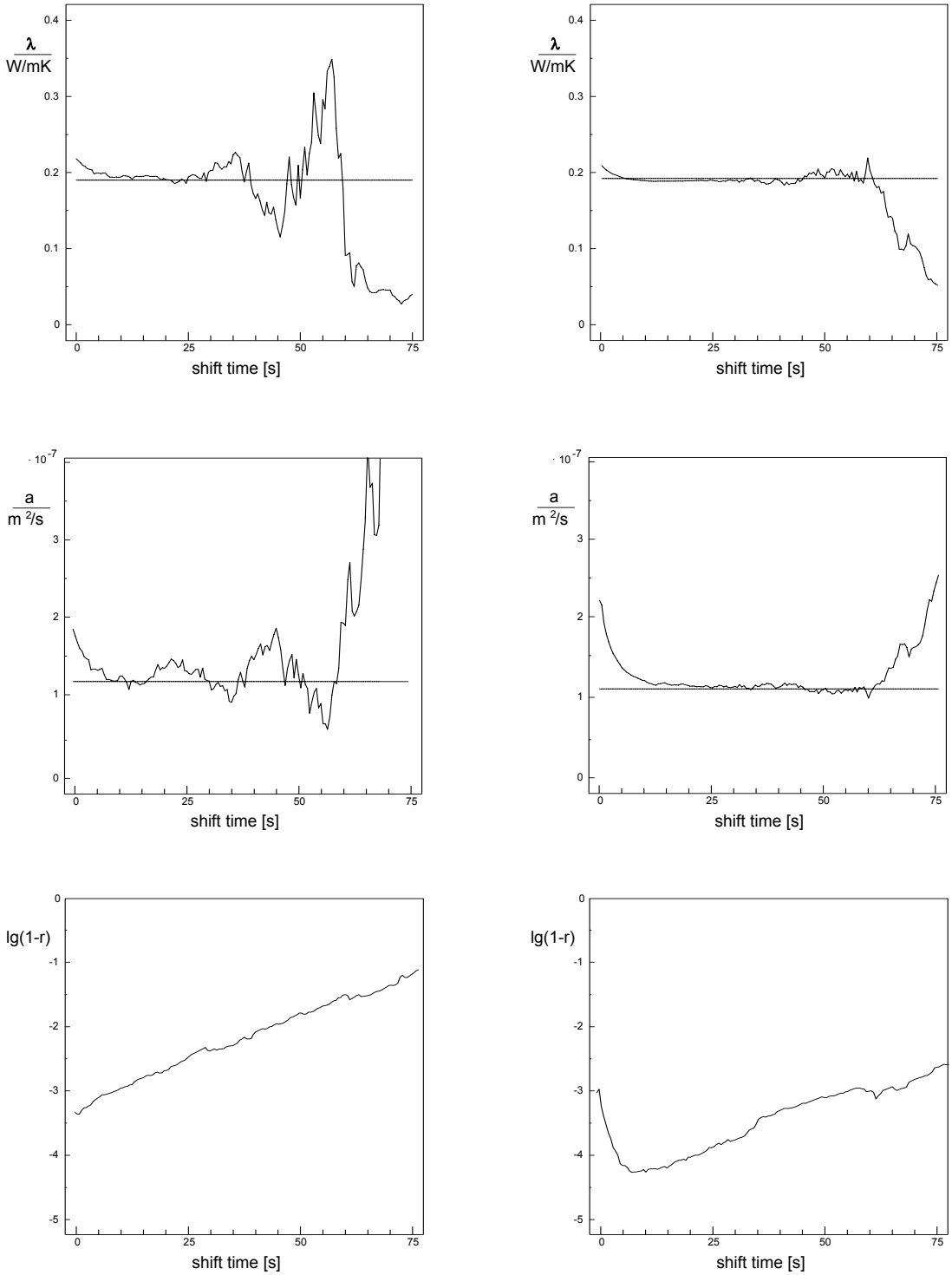


Fig 4 Results of the difference analysis - experiment modelling



a) I = 323 mA b) I = 663 mA

Fig 5 Results of the difference analysis - real measurements on PMMA
Thermal conductivity λ, thermal diffusivity *a* and correlation coefficient *r* as the function of the shift time

Fig. 5 shows the difference analysis of the real measurements on PMMA at 2 values of the heating current a) I = 323 mA and b) I = 663 mA corresponding to the total temperature rise at the steady-state condition ΔT = 1.9 °C and ΔT = 8.0 °C (Fig. 3), respectively. Fig. 4 and 5 show the dependencies of the correlation coefficient r which expresses fitting process perfection. In order to get an illustrative curve, the quantity lg(1-r) was plotted. The higher the scattering of experimental points, the larger value of this quantity.

5 Conclusions

Fig. 4 shows that for shift times less then 50 s the computed values of λ and a are nearly identical to the values put originally into the model and marked by horizontal lines. From the dependence of the correlation coefficient one can conclude, that the most accurate results will be attained at the shift time = 0, because the model does not contain the influence of the PS disc.

Fig. 5 a) shows that the sensitivity of the measuring device was not sufficient at the heating current I = 323 mA. The results are widely scattered and reasonable values can be obtained only for shift time = 10 - 15 s. The results in Fig. 5 b) are far more stabilised. The influence of the PS disc is clearly seen and characteristic time of the disc can be determined Θ_D = 5 - 10 s. It is remarkable that the dependencies of the correlation coefficient in model (Fig. 4) and experiment (Fig. 5 b) are very similar for shift times $> \Theta_D$. In spite of this the dependencies of λ and a in Fig. 5 b) show the influence of heat losses from the lateral sides of the sample for the shift times > 60 s. Therefore, the time window within which the fitting procedure can be applied is from 10 to 80 s.

The mean values of λ and a for PMMA material, measured at temperature of 20°C with heating current 663 mA, are 0.194 W/mK and 1.22 10^{-7} m^2/s, respectively, which are in good agreement with published values [1]. Data uncertainty is for thermal conductivity within 3% and for thermal diffusivity within 2%.

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