ANALYSIS OF THERMOPHYSICAL PARAMETERS MEASUREMENTS OF STAINLESS STEEL BY STEP-WISE TECHNIQUE

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Abstract

The measurement of thermophysical parameters of Stainless Steel A310 by step-wise technique is presented. The method is based on generation of a dynamic temperature field by the heat that is produced in the form of a step-wise function inside the specimen. Theory of the method and its experimental arrangement are presented. Differences between ideal model and real experiment were found and discussed. Measured data are compared with recommended ones.

Keywords: transient method, thermophysical parameters, stainless steel

1 Introduction

The step-wise transient method[1] for measurement of specific heat, thermal diffusivity and thermal conductivity belongs to a class of the transient methods[2] with planar heat source and one-dimensional heat flow model. The method is based on production of a constant heat flow in planar heat source inside the specimen. The heat is produced by the passage of the electrical current through a planar electrical resistance. A thermometer placed apart from the heat source measures the temperature response during the production of heat, from which the thermophysical parameters are calculated.

Objective of the presented paper is an application of the step-wise transient technique for measurements of the thermophysical parameters, namely the thermal diffusivity, the specific heat and the thermal conductivity, with emphasis on reliability of the measured data. It's known that the deviations between the ideal model[1] and the real experiment due to incorrect experimental arrangement can induce both data scattering and data shift. According to used model one has to accept a compromise between the experimental possibilities and accuracy of experiment. The better are fulfiled the criteria of the ideal model the higher accuracy.

The measurements were caried out on stainless steel A310 as a typical material with a good thermal conductivity. In order to find deviations between the ideal model and the real experiment, the thermophysical parameters were measured for several thicknesses of specimen (distance between the heat source and the thermometer). Thermophysical transient tester model RT 1.01 (Intitute of Physic, Slovak Academy of Sciences) was used for measurements.

2 Theory

The principle of the pulse transient method is shown in Fig. 1. The method can be described as follows. The temperature of the specimen is stabilized and uniform. Then a small disturbance in the form of a heat flux is applied to the specimen. From the temperature response the termophysical parameters can be calculated according to the model used.

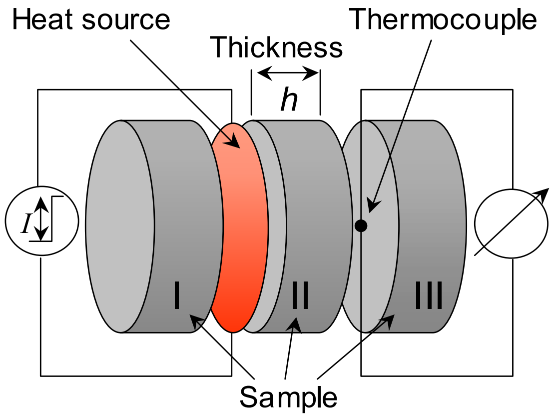

Fig 1 Experimental set up for step-wise transient method

The model of the method is characterized by the temperature function [1]

$$T(h,t) = \frac{q}{ac\rho}\left\{ \left(\frac{at}{\pi}\right)^{1/2} \times \exp\left(-\frac{h^2}{4at}\right) - \frac{h}{2} erfc\left(\frac{h}{\sqrt{4at}}\right) \right\}, \qquad (1)$$

where $q=RI^2$ is a heat flux supplied by heat source in the unit area, R is electrical resistance of heat source, I is supplied current, ρ is density and a, c are unknown thermophysical parameters (thermal diffusivity and specific heat). The temperature function (1) is the solution of the heat equation considering appropriate boundary and initial conditions.

Third termophysical parameter, λ - thermal conductivity, is defined by well-known data consistency relation

$$\lambda = ac\rho \,. \qquad (2)$$

The thermophysical parameters can be found by superimposing the temperature function (1) on the temperature response by an appropriate fitting technique. The sensitivity coefficients and their cross-correlation in Fig. 2 give us an overview on the time window in which the fitting technique should be used. There should be a balance between the sensitivity of measured parameters (better for longer time) and their cross-correlation (better for shorter time). The sensitivity coefficient β_p is given by [3]

$$\beta_p = p\frac{\partial T_i(t)}{\partial p}, \qquad (3)$$

where p is a parameter to be analysed and $T_i(t)$ is the temperature function (1). The cross-correlation of the sensitivity coefficients β_a and β_c of parameters: thermal diffusivity a and specific heat c, is simply defined as $\gamma(t) = \beta_a / \beta_c$.

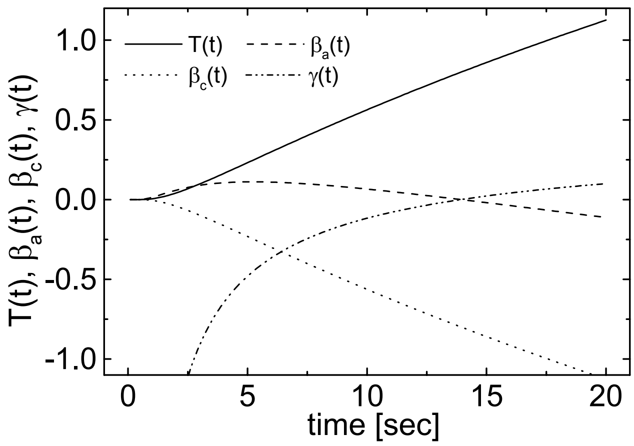

Fig 2 Ideal temperature function T(t), sensitivity coefficients $\beta_a(t)$ and $\beta_c(t)$ of parameters: thermal diffusivity and specific heat, and their cross-correlation $\gamma(t)$

3 Experimental set-up

The specimen, stainless steel A310, has the form of cylinder with diameter 20 mm and density ρ = 7902 kg.m^{-3}. The specimen is cut into three parts, where the second (middle) part of specimen (see Fig. 1) has the following thicknesses h = 2.9, 5.1, 6, 7.7 mm, that is four specimen sets. The outer parts of the specimen has thickness of 10 mm. The thin metal foil (Nickel) of thickness 20 μm in a form of meander is used as the heat source. Due to electrical conductivity of specimen the heat source is isolated with thin Kapton foil. The electrical resistance of the heat source is ≈ 2 Ω. A thermocouple, made of insulated Chromel and Alumel wires having the thickness of 50 μm, is placed apart of the heat source between second and third part of the specimen. A heat sink paste (fy Midland Silicones, Barry, Glamorgan) is used to improve the thermal contact between the individual parts of the specimen set.

The temperature of specimen is stabilized with heat exchanger, in contact with bottom face of specimen. Each temperature response is recorded in 300 points for all distances. All measurements are made at the temperature of 25 °C in air surroudings.

4 Ideal model versus real experiment

In order to get reliable data the experiment has to fulfil criteria[1,4] according to ideal model used. Unfortunately, a realization of experiments in the sense of ideal model is impossible in practice. Therefore analysis of differences between ideal model and real experiments has to be performed that enables to predict disturbing effects in the measuring process.

The ideal model supposes:

- geometrically non-limited specimen,
- infinitesimal thickness of the heat source with the same thermophysical properties as the specimen,
- ideal thermal contact between the heat source, thermometer and the specimen,
- negligible mass of thermometer.

On the contrary, the real experiment has the following:

- limited specimen,

- actual thickness of the heat source that induces its plumbless heat capacity,
- possible thermal contact resistance,
- negligible mass and heat capacity of thermometer.

Considering some differences stated above, the assumed effects that influence the measurements are:

- heat capacity and constriction[5] of the heat source,
- heat loss from the free specimen surface.

The effects are depicted in Fig. 3 as exemplary. The deviations between ideal function and real response are assigned to mentioned effects. One can notice the assumed ranges of effects in time.

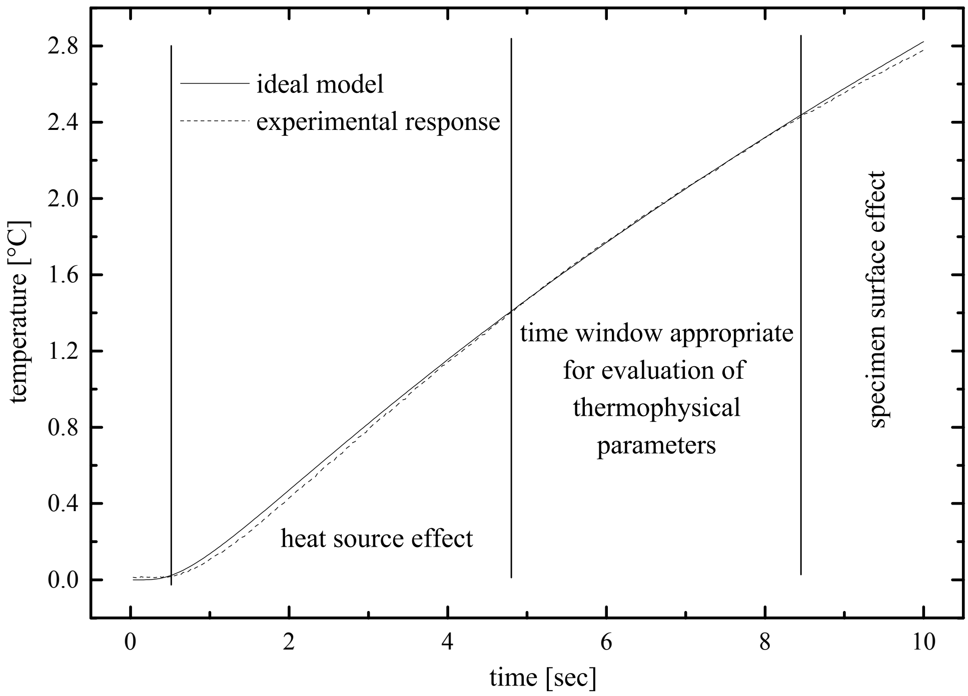

Fig 3 The effects influencing experimental response

5 Results and discussion

The measurements were performed for four various thickness of specimen. The corresponding temperature responses are depicted in Fig. 4. In each graph the measured temperature response is compared with ideal one. The thermophysical parameters arising in the ideal temperature function were obtained by fitting procedure from measured responses.

As we expected the effects of non-ideal experiment are notable in temperature response, in particular for smaller specimen thicknesses. We predicted the effect of heat source for shorter thickness and vice versa the effect of heat loss, for greater thickness of specimen. However, the graphs in Fig. 4 show the differences between ideal model and real experiment for smaller thicknesses of specimen, only. In addition, there is influence of both assumed effects for thickness h=2.9 mm. In this point of view, we suppose that heat loss from specimen surface was negligible during experiments, concernig higher thermal conductivity of specimen versus air surroudings. The heat source is continual producing the heat flux during measurement. Therefore the deviations in termperature responses in time we assign to the heat source effect only.

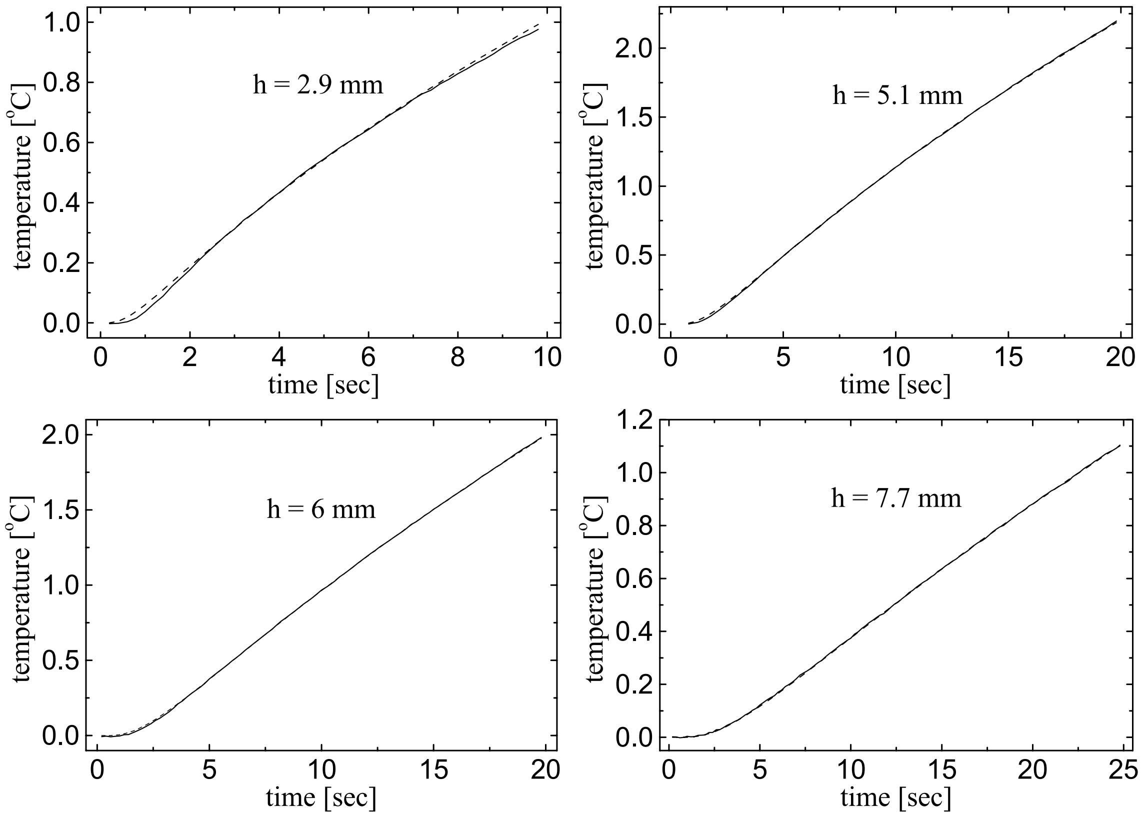

Fig 4 Measured (solid) and fitted theoretical (dash) temperature responses in various specimen thickness h

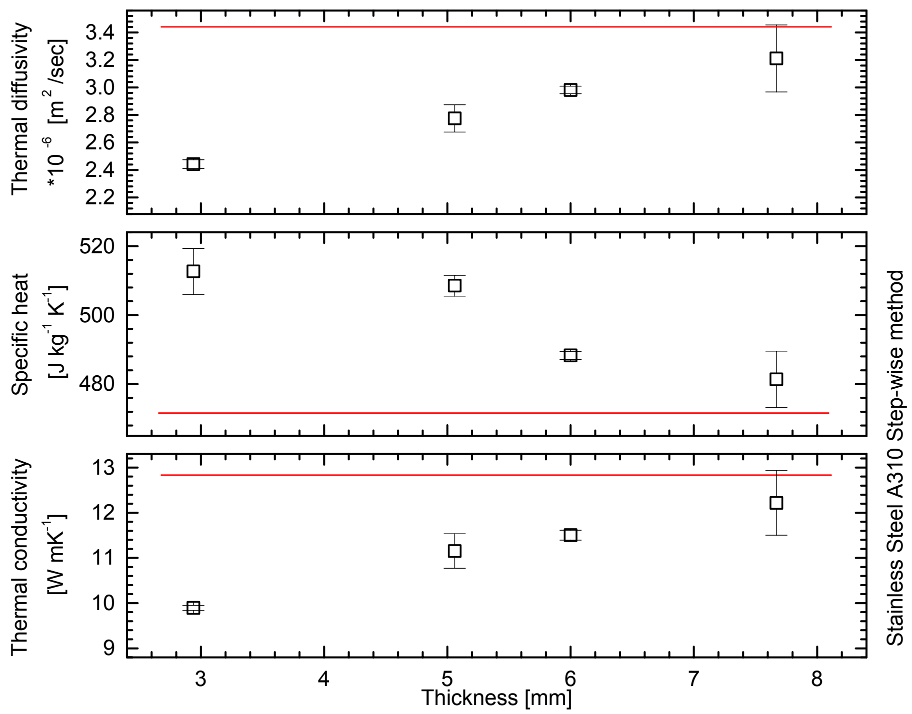

Fig 5 Thermophysical parameters of stainless steel A310 (line – recommended value)

In Fig 5. the thermophysical parameters of stainless steel A310 are shown as a function of specimen thickness. The measured values are compared with recommended ones[6] (solid line) for each parameter. Here, the strong relation is noticed between deviatons of temperature responses (Fig. 4) and deviations of evaluated parameters (Fig.5). For greater specimen thickness both the temperature responses and evaluated thermophysical parameters are more accurate. Basically, the fulfilment of the model conditions leads to reliable data.

Conclusions

Thermophysical parameters of Stainless steel A310 were obtained by use of step-wise transient method. Interval of reliable data seems to be above specimen thickness of 8 mm. Obtain more reliable data, additional measurements have to be performed on specimen thickness up to 15 mm. The effects of heat source, namely constriction of the heat source, its heat capacity and its dynamic properties, were found. The variation of heat source parameters should be used to reduce this effects.

Acknowledgement

This work was supported by the Slovak Science Grant Agency VEGA under Nr. 2/6066/01.

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