11th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2007, Hammamet, Tunisia, 05-09 September, 2007.

THE SPECIFIC HEAT OF RUBBER BLENDS MEASUREMENT

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ABSTRACT
Thermal properties play very important role in the process of production and application, as well as in the materials quality assurance. The numbers of various experimental methods of thermal parameters of solids measurement exists in recent times. However, the greater part of this methods requires a very sophisticated experimental equipment efficient provide for the strictly defined conditions of appropriate thermophysical experiments. The paper deals with an experimental measurement of specific heat of rubber blends for the automotive industry by using the first-order exponential model of cooling solid, because just this approach requires a minimum of restrictive conditions.
Keywords: rubber blends , exponential model, specific heat

1. INTRODUCTION
Generally, the thermal parameters investigation represents the thermal field analysis of the thermal disturbed specimen of examined material. From an experimental point of view it is concerned its registration by a suitably ordered equipment. From a theoretical side it represents the solution of sufficient partial differential equation which models the thermal transport inside the specimen on such border and initial conditions, that have to be respected by technical realisation of an adequate thermo-physical experiment. One of the simplest analytical models describing thermal transport inside solids is the first-order exponential model of the solid cooling in the fluid. The aim of described research is the effectual application of this model in the specific heat of rubber blends for the automotive industry experimental measurement.

2. FIRST-ORDER EXPONENTIAL MODEL
The simplest analytical model of a motionless cooling solid with density and specific heat at the constant presure c_p, without internal thermal sources and absorbents, may be formulated in the form of

(1)

which represents the conservation law of heat excurrents from body's volume V over its entire heat transfer surface S into the fluid environment. Variables T, t and q represent the spatially uniform but not constant thermal field, elapsed time and excurrents heat flux density, respectively, whereas n is an unit normal vector leading out of solid's volume. It is assumed that neither geometric dimensions, nor solid material properties or its thermo-physical parameters are not temperature dependent. At sufficiently low initial temperature of the solid T_0, as well as of ambient temperature T_{amb}, when the radiation heat transfer can be neglected, and provided the Biot number Bi << 1, thermal gradients inside solid will be negligible, such that neither temperature nor heat flux density will not be functions of spatial coordinates, hence they will be invariant towards desired integrations. Practically, if Bi < 0,1 it is possible the surface temperature consider the spatially uniform temperature of the solid. Subsequently, after a substitution of the vectors scalar product n . q by the Newton cooling law and after the relevant integrations and variables separation, the exact analytical solution of equation (1) is represented by the exponential thermal function

(2)

where

(3)

represents the time constant of the cooling solid dynamic thermal system, L = V/S is its characteristic dimension, h is an average coeficient of convective heat transfer from entire heat transfer surface and represents a thermal conductivity of the solid material. Right the thermal function (2) is usually termed as the first-order exponential model of cooling solid dynamic thermal system or as a lumped capacitance model [1].

3. SPECIFIC HEAT ESTIMATION

Provided all others specimen's parameters are known, equation (3) for the time constant τ makes it possible, after the detection of its value – e.g. by using some of the experimental data reduction methods [2] – compute the specific heat of its material. However, the convective heat transfer coefficient h largely represents the unknown quantity. At the same time, it is usually relatively very difficult to evaluate it experimentally. Nevertheless, the substitution of time constant in the thermal function (2) by relation (3) allows to determine the convective heat transfer coefficient from the experimental time history of the cooling solid surface temperature according to formula

(4)

It also allows to determine the specific heat from the same experimental thermal data series, namely via a process of its parametric fitting [3] by the exponential thermal function in the form of (4) using a appropriate chosen technique. The iterative Trust-Region algorithm of the nonlinear least squares fitting method [4] was used in our case. Number of unknown parameters, namely T_{amb}, $T_{max} = T_0 - T_{amb}$, c_p and h, invited construction of the recursive procedure of their identification [5].

4. EXPERIMENTAL PROCEDURE

The experimental thermal data set was colected from the surface of the vertically located specimen – with the geometry of semi-infinite 0,14 x 0.09 x 0.002 m slab mades of the investigate rubber blend for automotive industry, cooling in the air with constant temperature of 21,7 °C under the conditions of natural convection – by using the REYTEK THERMALERT MID infrared thermo sensor sensitive in the wavelength range of 3 – 8 μm. The thermal data registered with 64 Hz sampling frequency were transported to the collaborative 1,6 GHz / 1 GB RAM personal computer for a quantitative analysis realised in the Matlab® software package.

In the first step, the experimental data were smoothed by a robust smoothing procedure of a locally weighted linear regression using a least squares method with application of a quadratic polynomial regression model. The applied robust smoothing procedure with the span of 40 % of entire data set provided the resistant to utliers. The goodness of the smoothing process was checked by randomness of residuals distribution [6].

In the next parametric fitting of smoothed data set by thermal function (2), at first they were estimated all three unknown parameters T_{amb}, T_{max} and τ by using the first 400-steps iteration cycle of applied Trust-Region algorithm. Parameters were estimated in constrained intervals of their expected values. Subsequently, the identified value of T_{max} was substituted into the same thermal function (2) and smoothed data were fitted in the next iteration cycle in constrained intervals regarding the result of foregoing cycle. The new values of T_{amb} and τ were estimated in the next iteration cycle with the accordingly modified constrained intervals. This recursive procedure, hence fixing the value of one or more parameters identified in previous iteration cycle to identify the others in the next cycle, were repeted until confidence intervals all of three parameters reached their minimum, the randomness of residuals distribution reached the maximum and until the goodnes of fit statistics coefficients SSE, R - square, AdjR-square and RMSE were optimized [7].

Identified parameters T_{max} and T_{amb} of the exponential model in the form of thermal function (2) where then substituted into the thermal function (4). Subsequently, the unknown parameters c_p and h were estimated via the parametric fitting of smoothed experimental data set by this function in the same manner as thereinbefore.

5. RESULTS AND DISCUSSION

The raw experimental thermal data, smoothed data and result of their fitting process by exponential thermal function (4) are presented in the Figure 1.

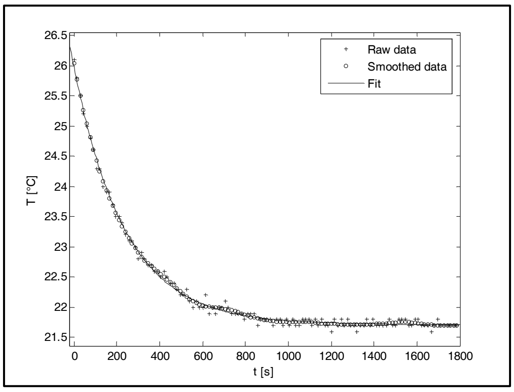

Figure 1. Raw experimental data, smoothed data and fitted curve.

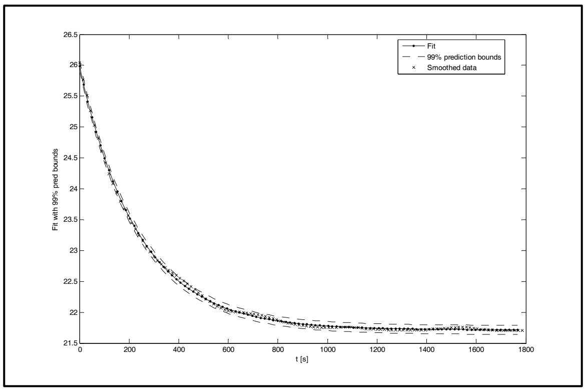

Figure 2. Prediction of the future experiment results with 99 % confidence bounds along with smoothed and fitted data ***set*** *.*

The estimated specific heat value along with its 95 % *confidence bounds, as well as with monitored goodness of fit statistics coefficients are presented in the Table 1.*

Table 1. The estimated specific heat value, 95 % confidence interval and monitored goodness of fit statistics coefficients values

c_p [J/kg/K]	95 % CI	SSE	R-square	Adj.R-square	RMSE
1394	1348 – 1440	0,0057	0,9979	0,9979	0,0218

Closeness of *SSE* and *RMSE* to zero value in conjunction with closeness of *R-square* and *AdjR-square* to the value of *1*, as well as a relatively narrow *95%* confidence interval confirm the equally high level of specific heat identification reliability via the described parameter estimation procedure. At the same time, attained results document also the high reliability of the first-order exponential model at the analytical description of the investigated rubber blend cooling process. Moreover, validity of the model is documented by prediction of future experiment results with the *99 %* confidence interval whose maximum range represents only *0,2°C* (Figure 2).

6. CONCLUSIONS

The described parametric fittig procedure provides to identify the specific heat of investigated rubber blend cooling in the fluid by using the first-order exponential model with high level of reliability.

7. REFERENCES

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