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Measurement of the linear thermal expansion coefficient of concrete at high temperatures: A comparison of isothermal and non-isothermal method

Měření koeficientu lineární teplotní roztažnosti betonu při vysokých teplotách: Porovnaní isotermální a neisotermální metody

Summary

Two methods – the isothermal heating and linear heating – for the determination of the linear thermal expansion coefficient, $\alpha(T)$, are compared. The coefficient $\alpha(T)$ is in general evaluated as the temperature derivative of the thermal strain which is here measured by a push-rod dilatometer. We found that the pros and cons of the two methods were complementary. While in the isothermal heating method sample temperatures are well established, the linear heating method is much less time demanding and provides a large number of experimental data. The latter is important for a proper evaluation of $\alpha(T)$ as a derivative of the thermal strain as well as for the ability to observe processes that take place in samples as the temperature is changed. In order to obtain these results, a classical building material (a concrete containing ground ceramics as a partial replacement of Portland cement) was used for measurements in the temperature range of 20 – 800 °C.

Souhrn

Porovnáváme dvě metody pro určení koeficientu lineární teplotní roztažnosti, $\alpha(T)$, a sice, isotermální metoda a metoda lineárního ohřevu. Koeficient $\alpha(T)$ se obecně počítá jako derivace teplotní deformace, který je zde měřen pístovým dilatometrem podle teploty. Zjistili jsme, že výhody a nevýhody těchto dvou metod jsou komplementární. Zatímco při metodě isotermálního ohřevu jsou teploty vzorky dobře stanovené, metoda lineárního ohřevu je mnohem méně časově náročná a poskytuje rozsáhlý počet experimentálních údajů. To je důležité pro správné určení $\alpha(T)$ jako teplotní derivaci relativního prodloužení stejně jako pro schopnost sledovat procesy, které probíhají ve vzorku při změně teploty. Za účelem získaní těchto výsledků, byl v teplotním intervale 20 – 800 °C, na měření použitý klasický stavební materiál (beton s obsahem mleté keramiky).

Keywords

Concrete, Temperatures, Thermal Strain, Isothermal and linear heating

Klíčová slova

Beton, Teploty, Relativní prodloužení, Isotermální a lineární ohřev

Contents

1. Introduction

In general, materials change their volume, V, when their temperature, T, is changed. This thermal deformation is characterized by the material quantity [1]

$$\alpha_V(T) = \frac{1}{V_0}\left(\frac{\partial V}{\partial T}\right)_P \tag{1}$$

called the thermal expansion coefficient (V_0 is an initial volume). In the simple case when the volume varies with temperature only in one dimension, while the other two dimensions remain unchanged (or their change is negligible), α_V turns into the linear thermal expansion coefficient (LTEC) [2]

$$\alpha(T) = \frac{d\varepsilon(T)}{dT}\,, \tag{2}$$

where

$$\varepsilon(T) = \frac{l(T) - l(T_0)}{l(T_0)} \tag{3}$$

is called the thermal strain (T_0 is an initial/reference temperature). Within a narrow temperature interval, (T_0, T), the expansion coefficient α is approximately constant, yielding

$$\alpha(T) \approx \frac{\varepsilon(T)}{T - T_0}\,. \tag{4}$$

However, the latter relation is inappropriate in general, and one should evaluate α as the derivative given in Eq. (2). Otherwise, only the value of α at an unknown temperature lying somewhere between T_0 and T is obtained instead of its value at T (by the mean-value theorem of the integral calculus).

A correct determination of the expansion coefficient α by Eq. (2) requires an accurate measurement of the temperature and the corresponding thermal strain. For non-homogenous materials, such as building materials, samples of sufficiently large dimensions must be measured. This may cause problems especially for a correct measurement of the sample temperature. The temperature is usually measured by a thermocouple located close to the sample, so the temperature in the whole sample need not be known accurately. To avoid this, one may use an isothermal heating when the sample is kept at a given temperature for a sufficient time. This approach was applied for the measurement of α for building materials in [3-8], for example. Then the recorded thermal strain ε corresponds to a well-established temperature.

However, the isothermal heating usually does not allow one to observe physical and chemical processes that may take place in the sample during temperature changes. To this end, a non-isothermal heating, mostly a linear heating with a constant rate, may be conveniently used. The measurement of the expansion coefficient α for building materials by this method was carried out in [9-18], for example. The drawback of this method is the difficulty to associate a correct temperature with the measured values of ε.

This lecture is about the comparison of these two methods, the linear and the isothermal heating, for the measurements of the linear thermal expansion coefficient α and discussion about their advantages and disadvantages. As a non-homogeneous material, a classical building material was used, namely, a concrete containing ground ceramics as partial replacement of Portland cement. The measurements were performed for the temperatures between 20 and 800 °C.

2. Samples and measurement methods

The samples with a varying mass ratio of cement and ground ceramics were used. We labeled the samples as RC, RC10, RC20, RC40, and RC60 in the order of an increasing amount of ceramics. The composition of the samples is given in Table 1. The samples were prepared as follows. At first, a mixture of cement and ground ceramics was homogenized during 1 minute using a SPAR SP-200D mixer at speed level 2 and then siliceous aggregates were added. The mixing continued for 10 min under the same conditions. Then water was added into the mixture of solid components. The mixing proceeded for 1 min at a slower rotation speed level (speed level 1) and for the next 9 minutes at speed level 2. During the mixing process, the mixer was stopped several times and the material which was out of reach of the mixing paddles was placed back within their reach. A 100 mm × 100 mm × 400 mm mold lightly coated with paraffin oil was uniformly filled with the mixture. The sample was covered with a plastic film and stayed in laboratory conditions for 72 h. Then the mold was removed and the whole sample was covered with a plastic film. The plastic film protection of moisture evaporation was kept for 7 days. After a time period of 28 days after mixing, the samples were prepared for testing. Their dimensions were 16 mm × 16 mm × 160 mm.

Table 1 – Composition of studied materials

Composition	**Quantity [kg·m^{-3}]**				
	RC	***RC10***	***RC20***	***RC40***	***RC60***
cement CEM I 42,5 Mokrá	484.0	435.6	387.2	290.4	193.6
ground ceramics	0 (0%)	48.4 (10%)	96.8 (20%)	193.6 (40%)	290.4 (60%)
siliceous aggregates 0-4 mm	812	812	812	812	812
siliceous aggregates 8-16 mm	910	910	910	910	910
superplasticizer Mapei Dynamon SX	5.3	5.3	5.3	5.3	5.3
water	160	160	160	160	160

The experimental procedure for the determination of the dependence of α on T consisted of two steps:

(1) a direct measurement of the thermal strain $\varepsilon(T)$;

(2) a subsequent (numerical) evaluation of $\alpha(T)$.

The measurement of ε was carried out by the thermodilatometric analysis (TDA) which is a widely employed, well-known, and convenient method for the investigation of thermal changes in solid materials. In this research, a push-rod dilatometer with the resolution of 1 μm was used (see Fig. 1) [19].

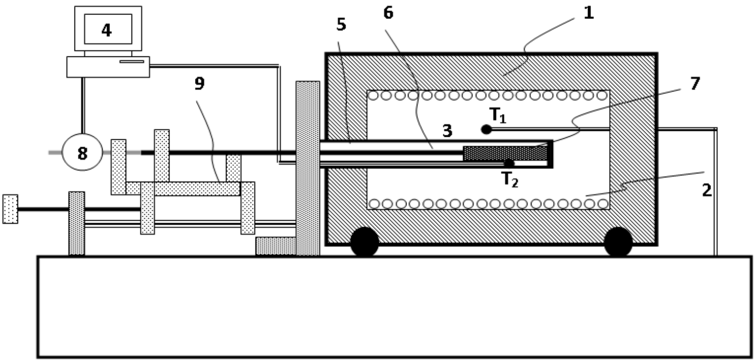

Fig. 1 – The scheme of a push-rod dilatometer: 1 – isolation cover, 2 – heating spiral, 3 – sample holder, 4 – computer, 5 – slot for thermally resistant ceramic contact rod (6), 7 – measuring sample, 8 – measuring sensor, 9 – static steel construction, T_1 *and* T_2 *– thermocouples*

We investigated samples, using two methods of measurement. In the first method, samples were studied during a linear heating from a room temperature T_0 up to 800 °C with the heating rate of 1 °C/min, and the thermal strain of the sample was measured continuously. More precisely, values ε_1, ε_2, … of the thermal strain were measured in short time intervals corresponding to temperatures τ_1, τ_2, … measured by a thermocouple placed near a sample. The series of points (ε_k, τ_k) provided a discrete representation of the true temperature dependence $\varepsilon(T)$ of the thermal strain. In the second method, the temperature in the dilatometer was increased linearly at the rate of 10 °C/min from T_0 up to the temperature of the isothermal heating (chosen as T_1 = 100 °C, T_2 = 200 °C, …, and T_8 = 800 °C) and kept at this temperature for 2 h. The corresponding thermal strain, ε_i, was measured at each T_i. Again, the points (ε_i,T_i) were a discrete representation of the function $\varepsilon(T)$.

Using the experimental data on the thermal strain, i.e., the points (ε_i,T_i) or (ε_k,τ_k), the linear thermal expansion coefficient $\alpha(T)$ was calculated according to Eq. (2) [4, 11]. As mentioned in the Introduction, the evaluation of $\alpha(T)$ according to Eq. (4) [3, 5, 9, 10] could be inappropriate and, thus, we shall not employ it here. The application of Eq. (2) in the case of linear heating is straightforward because of a large number of the experimental points (ε_k,τ_k) so that a smooth function, $\varepsilon_{\text{lin}}(T)$, interpolating these points can be readily found and the derivative of ε can be evaluated numerically with a good precision.

In the case of isothermal heating we first approximated the points (ε_i,T_i) by a smooth function, $\varepsilon_{\mathrm{iso}}(T)$, using a regression analysis, and then calculated $\alpha(T)$ as a derivative of this function. Since the α-β transformation of quartz is the dominant process in the studied samples, we chose the function $\varepsilon_{\mathrm{iso}}(T)$ as the hyperbolic tangent

$$\varepsilon_{\mathrm{iso}}(T)=\frac{\varepsilon_1(T)+\varepsilon_2(T)}{2}-\frac{\varepsilon_1(T)-\varepsilon_2(T)}{2}\tanh[a(T-T_{\alpha\beta})]. \qquad (5)$$

Here $\varepsilon_1(T)$ and $\varepsilon_2(T)$ are taken as polynomials that approximate the thermal strain in the interval from the room temperature to 500 °C and from 600 °C to 800 °C, respectively, a is a constant obtained by fitting Eq. (5) to the thermal strain in the interval from 500 °C to 650 °C, and $T_{\alpha\beta}$ = 573 °C is the α-β transformation temperature. The hyperbolic tangent form of the function $\varepsilon_{\mathrm{iso}}(T)$ from Eq. (5) follows from the statistical mechanical theory of first-order phase transitions applied to finite samples [20, 21].

3. Results and discussion

Since the concrete is a non-homogeneous material, for each of the five types RC, RC10, RC20, RC40, and RC60 we measured three samples and their average was plotted in the corresponding figure. For the sake of a reliable comparison, the samples had identical dimensions for both employed methods. Prior to the comparison of the two methods, we will discuss the processes that occur in the samples during heating up to 800 °C.

3.1 Processes

Figures 2, 4, 6, 8, and 10 show the temperature dependencies, $\varepsilon(T)$, of the thermal strain measured by both the isothermal and linear heating methods for all five types of the studied concrete materials. As is clear from the plots of ε vs. T, the thermal strain is a slowly increasing function of the temperature within the studied temperature interval, except in the range from 500 °C to 700 °C. In this range the increase of the thermal strain is rather abrupt. It is associated with the α-β transformation of quartz that takes place at 573 °C [22], as was also observed in [7, 16]. It is well known that if quartz grains are free and can change their dimensions without obstructions, their relative volume change is +0.68 % [23]. Moreover, the thermal expansion coefficient of α-quartz is 1.8×10^{-5} K^{-1}, while that of β-quartz is negligible [22, 24]. Above 700 °C the thermal strain again increases only slowly. The increase depends on the amount of the ground ceramics in the samples: the larger the amount of ceramics, the slower the increase. This is caused by the sintering of the ceramic part of the concrete.

Figures 3, 5, 7, 9 and 11 show the temperature dependencies $\alpha(T)$ of the linear thermal expansion coefficient measured by both the isothermal and linear heating methods for the five used concrete materials. From linear heating measurements we can easily observe processes occurring in the studied samples, such as the liberation of the physically bonded water (up to 150 °C) and the α-β transformation of quartz (at 573 °C). All obtained results on $\alpha(T)$ show that the samples were not dried (their initial moisture content was 2 % by mass) so that $\alpha(T)$ decreased up to 150 °C when the physically bonded water is completely liberated. Then $\alpha(T)$ slowly increases up to 500 °C.

Within the interval from 500 °C to 670 °C the coefficient $\alpha(T)$ exhibits a sharp peak corresponding to the α-β transformation of quartz in the samples. The peak has a maximum at a temperature slightly above the α-β transformation temperature 573 °C, as should be expected whenever the linear heating method is applied. Note that the observed peaks have the half-width about 100 °C and maximum about 5×10^{-5} K^{-1}.

The subsequent behavior of $\alpha(T)$ within the interval from 670 °C to 800 °C depends on the content of ceramics in the samples. For lower ceramic contents $\alpha(T)$ increases. When the ceramics content is 20 %, the value of $\alpha(T)$ is almost constant. Finally, when the ceramics content is above 20 %, $\alpha(T)$ decreases due to the sintering of ceramics.

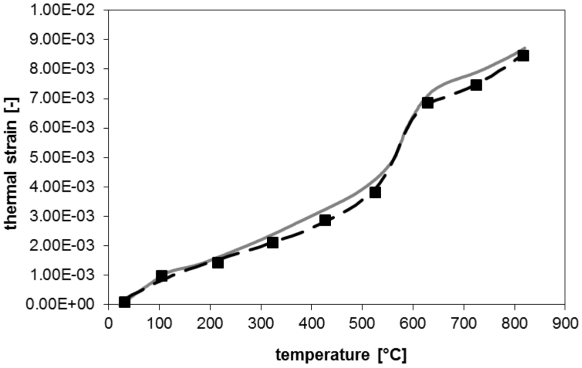

Fig. 2 – Thermal strain of RC sample during heating up to 800 °C for the linear and isothermal heating. The grey line corresponds to the linear heating, the black squares to the isothermal heating, and the black dashed line to an interpolation of the isothermal data.

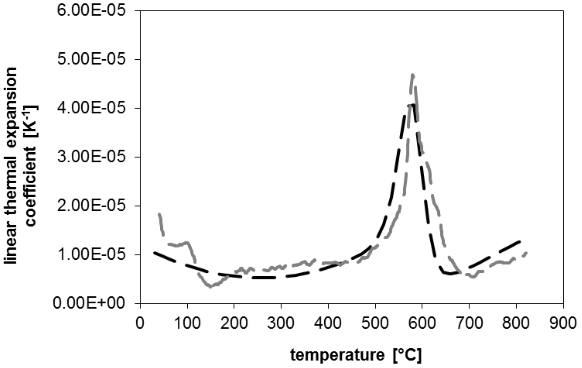

Fig. 3 – Linear thermal expansion coefficient of RC sample during heating up to 800 °C for the linear and isothermal heating. The grey line corresponds to the linear heating, the black squares to the isothermal heating, and the black dashed line to an interpolation of the isothermal data.

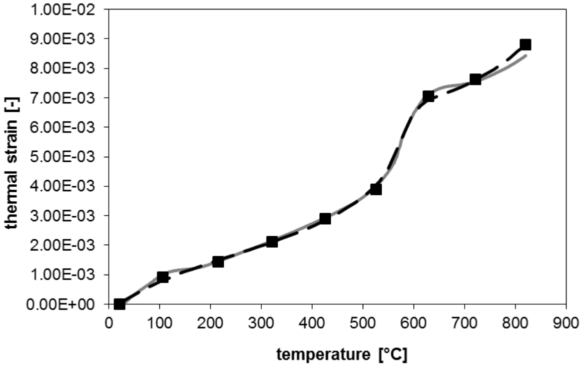

Fig. 4 – Thermal strain of RC10 sample during heating up to 800 °C for the linear and isothermal heating. The grey line corresponds to the linear heating, the black squares to the isothermal heating, and the black dashed line to an interpolation of the isothermal data.

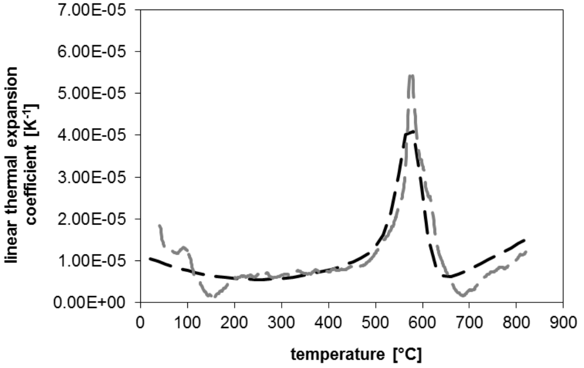

Fig. 5 – Linear thermal expansion coefficient of RC10 sample during heating up to 800 °C for the linear and isothermal heating. The grey line corresponds to the linear heating, the black squares to the isothermal heating, and the black dashed line to an interpolation of the isothermal data.

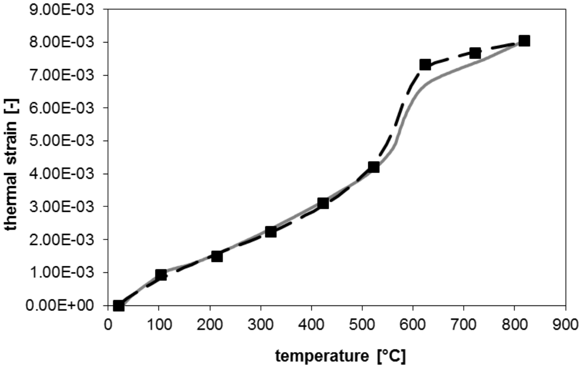

Fig. 6 – Thermal strain of RC20 sample during heating up to 1000 °C for the linear and isothermal heating. The grey line corresponds to the linear heating, the black squares to the isothermal heating, and the black dashed line to an interpolation of the isothermal data.

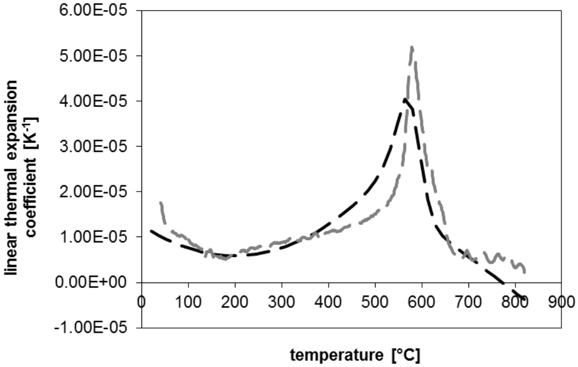

Fig. 7 – Linear thermal expansion coefficient of RC20 sample during heating up to 800 °C for the linear and isothermal heating. The grey line corresponds to the linear heating, the black squares to the isothermal heating, and the black dashed line to an interpolation of the isothermal data.

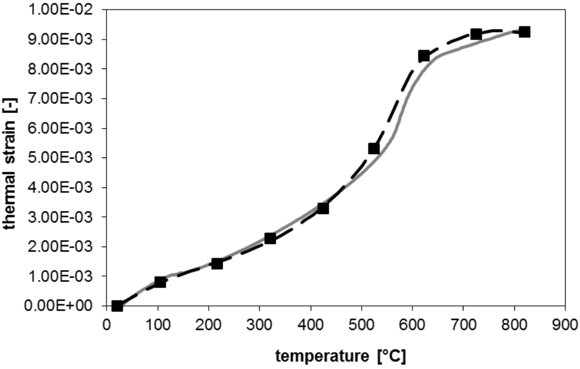

Fig. 8 – Thermal strain of RC40 sample during heating up to 800 °C for the linear and isothermal heating. The grey line corresponds to the linear heating, the black squares to the isothermal heating, and the black dashed line to an interpolation of the isothermal data.

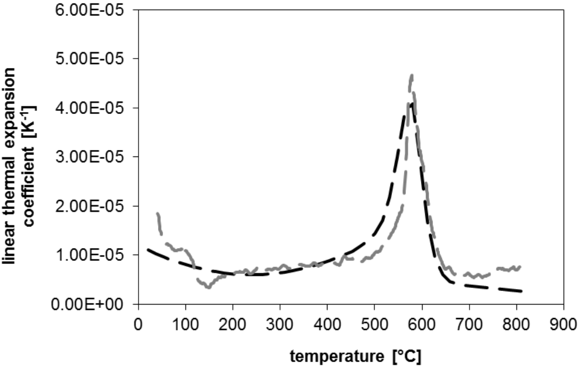

Fig. 9 – Linear thermal expansion coefficient of RC40 sample during heating up to 800 °C for the linear and isothermal heating. The grey line corresponds to the linear heating, the black squares to the isothermal heating, and the black dashed line to an interpolation of the isothermal data.

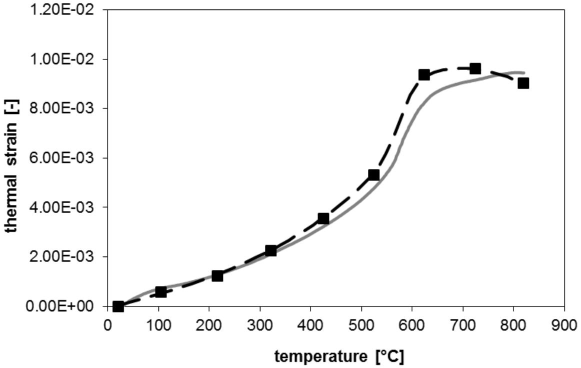

Fig. 10 – Thermal strain of RC60 sample during heating up to 800 °C for the linear and isothermal heating. The grey line corresponds to the linear heating, the black squares to the isothermal heating, and the black dashed line to an interpolation of the isothermal data.

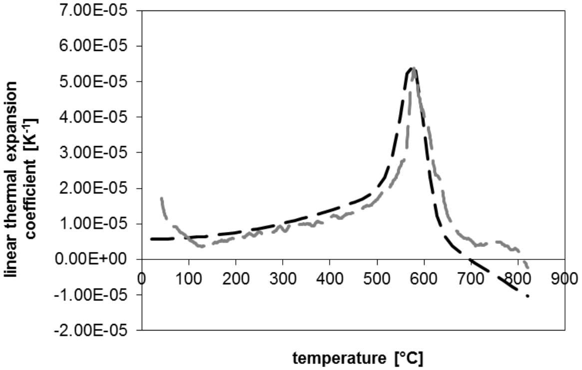

Fig. 11 – Linear thermal expansion coefficient of RC60 sample during heating up to 800 °C for the linear and isothermal heating. The grey line corresponds to the linear heating, the black squares to the isothermal heating, and the black dashed line to an interpolation of the isothermal data.

3.2 Comparison of the two methods

Comparing the results from Figs. 2 – 11 obtained by the linear and isothermal heating methods, it is obvious that the most significant differences take place in those temperature intervals where the physical and chemical processes occur in the samples. Indeed, a first difference is that the liberation of physically bonded water for the temperatures up to about 200 °C is not observed when the isothermal heating method is used. Then the values of the linear expansion coefficient $\alpha(T)$ are almost identical until another process (the α-β transformation of quartz) occurs between 500 and 650 °C. This process can be observed in both methods, but the values of $\alpha(T)$ in the isothermal heating method are smaller (by up to 37 %) than in the linear heating method. This is caused by an insufficient number of data obtained for the thermal strain in the former case, leading to a rather uncertain determination of the slope a in Eq. (5) and, thus, of $\alpha(T)$. Finally, in the temperature interval from about 650 °C to 800 °C the results yielded by both methods are again rather similar.

Since experimental data obtained by the isothermal and linear heating methods provide only discrete representations of the temperature dependence of the thermal strain $\varepsilon(T)$, one must find suitable functions, $\varepsilon_{\mathrm{iso}}(T)$ and $\varepsilon_{\mathrm{lin}}(T)$, that fit the corresponding data to a desired accuracy. Subsequently, the derivatives $\mathrm{d}\varepsilon_{\mathrm{iso}}/\mathrm{d}T$ and $\mathrm{d}\varepsilon_{\mathrm{lin}}/\mathrm{d}T$, respectively, are evaluated and identified with $\alpha(T)$. However, the isothermal as well as the linear heating method of determining $\alpha(T)$ has its advantages and disadvantages. Two aspects are particularly significant.

First, a sufficient number of the points (ε_i,T_i) or (ε_k,τ_k) must be collected from an experiment in order to get the fitting functions $\varepsilon_{\mathrm{iso}}(T)$ and $\varepsilon_{\mathrm{lin}}(T)$ that recover $\varepsilon(T)$ with a sufficient accuracy. This is especially essential when phase transformations (such as the α-β transformation in our case) or other processes occur in the studied material so that $\varepsilon(T)$ dramatically varies in some temperature range. If only a small number of the points are obtained, such dramatic changes cannot be described by the fitting functions accurately enough. As a result, the derivatives $\mathrm{d}\varepsilon_{\mathrm{iso}}/\mathrm{d}T$ and $\mathrm{d}\varepsilon_{\mathrm{lin}}/\mathrm{d}T$, which are very sensitive to changes in $\varepsilon_{\mathrm{iso}}(T)$ and $\varepsilon_{\mathrm{lin}}(T)$, respectively, may be rather different from the true linear thermal expansion coefficient $\alpha(T)$. From this viewpoint the linear heating measurements are very convenient because they provide a large number of the points (ε_k,τ_k). On the other hand, the isothermal measurements are rather time-consuming so that one usually collects only a limited number of the points (ε_i,T_i). Hence, the results on the LTEC evaluated from such isothermal measurements should be considered as less reliable, unless there is a sufficient number of data among the points (ε_i,T_i) that cover the temperature ranges where the thermal strain strongly varies.

Second, in order that the thermal strain ε is measured at a temperature T, the sample temperature should be equilibrated at T in the whole sample. Otherwise, the measured value coincides with the thermal strain at a temperature between minimal and maximal temperatures occurring in the sample at the time of the measurement. Therefore, in the linear heating measurements the value ε_k is not the thermal strain at $T = \tau_k$, but ε_k is equal to the thermal strain at the temperature T_k that is shifted with respect to τ_k, implying that the fitting curve $\varepsilon_{\mathrm{lin}}(T)$ is shifted with respect to the true curve $\varepsilon(T)$. The shift may not be constant within the whole range of investigated temperatures, but it generally varies with temperature. Hence, it may be intriguing to determine $\varepsilon(T)$ from $\varepsilon_{\mathrm{lin}}(T)$ because the curve $\varepsilon_{\mathrm{lin}}(T+\Delta T_0)$ shifted by a mere constant $\Delta T_0 > 0$ may not coincide with $\varepsilon(\tau)$. On the other hand, in the isothermal measurements the values ε_i can be rather safely identified with the thermal strain at $T = T_i$, and no problems with temperature shifts arise. From this viewpoint, the isothermal measurements are more reliable than the linear heating measurements.

4. Conclusion

The advantages and disadvantages of two experimental techniques, the linear and isothermal heating methods, for the determination of the linear thermal expansion coefficient were studied. For this comparison a non-homogeneous building material (a concrete containing ground ceramics as partial replacement of Portland cement) was used. The measurements were performed with a push-rod dilatometer for the temperatures from 20 to 800 °C. In the isothermal heating method samples are thermally equilibrated so that their temperature is well established. However, the method is rather time-consuming, usually generates a limited number of experimental data, and processes occurring in samples in various temperature intervals may not be observed. Obviously, a proper detection of sudden thermal length changes requires a large set of measurement data within the temperature interval where the changes take place. On the other hand, the linear heating method does not have these drawbacks. Its main disadvantage is that values of the thermal strain and, thus, of the linear thermal expansion coefficient correspond to temperatures slightly shifted with respect to the measured temperature. Nevertheless, the shift may be estimated, for example, if the dependence of thermal diffusivity coefficient on the temperature is known.

Using concrete samples of the same dimensions with various ceramics content, we demonstrated that the linear heating method for the measurement of the linear thermal expansion coefficient can be very convenient because it detects thermal changes of sample dimensions practically continually, thus allowing one to observe the associated thermal processes. Moreover, the obtained experimental results should be more precise than in the isothermal heating method because the latter usually employs only a limited number of measured data on the thermal strain and there is a strong dependence of the linear thermal expansion coefficient on a fitting function. Finally, the higher is the rate of the linear heating, the bigger is the difference between the measured temperature and the real temperature in the sample. Therefore, by decreasing the heating rate in the linear heating method the measured data approach the real values of linear thermal expansion coefficient.

5. Use of other thermal analyses in the civil engineering

For a study of processes occurring in the condensed state of materials and mutual reactions of the sample with the cleaning gas, the differential scanning calorimetry and thermogravimetry are very useful.

The differential scanning calorimetry (DSC) is a method in which one measures the difference in the power (heat flow) required to equally increase the temperature of a sample and a reference material as a function of temperature or time. Both the sample and reference material are exposed to the same controlled temperature program in a specific atmosphere. Thermal reactions, such as hydration and pozzolanic reaction in a concrete, decomposition of calcite, phase transformations, sublimation, reduction, desorption, absorption, and vaporization, can be measured by this method.

The thermogravimetry (TG) is a method where the mass change of a sample as a function of temperature or time is measured. Thermal reactions which are accompanying the mass change, such as the decomposition of portlandite or calcite, can be measured by thermogravimetry.

References

[1] H.B. Callen, Thermodynamics and an Introduction to Thermostatistics. Wiley; 2nd edition, 1985.

[2] A.M. Collieu, D.J. Powney, The mechanical and thermal properties of materials. Edward Arnold (Publishers) Ltd., London, United Kingdom, 1973.

[3] F. Vodák, R. Černý, J. Drchalová, Š. Hošková, O. Kapičková, O. Michalko, P. Semerák, J. Toman, Thermophysical properties of concrete for nuclear-safety related structures. Cement and Concrete Research 27, 415-426 (1997).

[4] L. Zuda, R. Černý, Measurement of linear thermal expansion coefficient of alkali-activated aluminosilicate composites up to 1000 °C. Cement & Concrete Composites 31, 263-267 (2009).

[5] Z. Shui, R. Zhang, W. Chen, D. Xuan, Effect of mineral admixtures on the thermal expansion properties of hardened cement paste. Construction and Building Materials 24, 1761-1767 (2010).

[6] D.L.Y. Kong, J.G. Sanjayan, Damage behavior of geopolymer composites exposed to elevated temperatures. Cement & Concrete Composites 30, 986-991, (2008).

[7] R. Černý, J. Maděra, J. Poděbradská, J. Toman, J. Drachalová, T. Klečka, K. Jurek, P. Rovnaníková, The effect of compressive stress on thermal and hygric properties of Portland cement mortar in wide temperature and moisture ranges. Cement and Concrete Research 30, 1267-1276, (2000).

[8] E. Vejmelkova, P. Konvalinka, P. Padevet, R. Cerny, Effect of high temperatures on mechanical and thermal properties of carbon-fiber reinforced cement composite. Cement Wapno Beton 13, 66 (2008).

[9] T. Uygunoğlu, İ. B. Topçu, Thermal expansion of self-consolidating normal and lightweight aggregate concrete at elevated temperature. Construction and Building Materials 23, 3063-3069 (2009).

[10] D.X. Xuan, Z.H. Shui, Temperature dependence of thermal induced mesocracks around limestone aggregate in normal concrete. Fire and Materials 34, 137-146 (2010).

[11] M. Zeng, D.H. Shields, Nonlinear thermal expansion and contraction of asphalt concrete. Canadian Journal of Civil Engineering 26, 26-34 (1999).

[12] V.K.R. Kodur, M.A. Sultan, Effect of temperature on thermal properties of high-strength concrete. Journal of Materials in Civil Engineering 15, 101-107 (2003).

[13] P.W. Chen, D.D.L. Chung, Effect of polymer addition on the thermal stability and thermal expansion of cement. Cement and Concrete Research 25, 465-469 (1995).

[14] M. Guerrieri, J. Sanjayan, F. Collins, Residual strength properties of sodium silicate alkali activated slag paste exposed to elevated temperatures. Materials and Structures 43, 765-773 (2010).

[15] M. Guerrieri, J. Sanjayan, F. Collins, Residual compressive behavior of alkali activated concrete exposed to elevated temperatures. Fire and Materials 33, 51-62 (2009).

[16] E. Kamseu, C. Leonelli, D. Boccaccini, Non-contact dilatometry of hard and soft porcelain compositions. Journal of Thermal Analysis and Calorimetry 88, 571-576 (2007).

[17] Y.F. Fu, Y.L.Wong, C.S. Poon, C.A. Tang, P. Lin, Experimental study of micro/macro crack development and stress-strain relations of cement-based composite materials at elevated temperatures. Cement and Concrete Research 34, 789-797 (2004).

[18] P. Childs, A.C. L. Wong, N. Gowripalan, G.D. Peng, Measurement of the coefficient of thermal expansion of ultra-high strength cementitious composites using fibre optic sensors. Cement and Concrete Research 37, 789-795 (2007).

[19] Utility model n.21752: An apparatus for the measurement of longitudinal changes of materials at high temperatures.

[20] C. Borgs, R. Kotecký, A rigorous theory of finite-size scaling at 1st-order phase-transitions. Journal of Statistical Physics 61, 79-119 (1990).

[21] C. Borgs, R. Kotecký, Surface-induced finite-sine effects for first-order phase-transitions. Journal of Statistical Physics, 79, 43-115 (1995).

[22] M.A. Carpenter, E.K.H. Salje, A. Graeme-Barber, B. Wruck, M.T. Dove, K.S. Knight, Calibration of excess thermodynamic properties and elastic constant variations associated with the α-β phase transition in quartz. American Mineralogist 8, 2-22 (1998).

[23] I. Štubňa, A. Trník, L. Vozár, Thermomechanical analysis of quartz porcelain in temperature cycles. Ceramics International 33, 1287-1291 (2007).

[24] D.L. Lakshtanov, S.V. Sinogeikin, J.D. Bass, High-temperature phase transitions and elasticity of silica polymorphs. Physics and Chemistry of Minerals 34, 11-22 (2007).

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Curriculum Vitae

Date of birth: January 30, 1978

Education

1998 – 2003 Faculty of Natural Sciences, Constantine the Philosopher University in Nitra, Slovakia, Field of study: Physics – Computer Sciences. Diploma thesis: Numerical Solution of Physical Problems with Graphical Interpretation.

2003 – 2006 Department of Physics, Faculty of Natural Sciences, Constantine the Philosopher University in Nitra, Slovakia, Field of study: Physics of Condensed Matters and Acoustics, Study program: Physics of Materials. PhD thesis: Termomechanical analysis of elektroceramics.

Employment history

April 2011 – present: Department of Physics, Faculty of Natural Sciences, Constantine the Philosopher University in Nitra, Slovakia.
Position: Assistant professor

March 2010 – present: Department of Material Engineering and Chemistry, Faculty of Civil Engineering, Czech Technical University in Prague, Czech Republic.
Position: Research fellow

January 2008 – March 2011: Department of Physics, Faculty of Natural Sciences, Constantine the Philosopher University in Nitra, Slovakia.
Position: Research fellow

April 2007 – December 2007: Department of Chemistry, Texas Christian University, Fort Worth, USA.
Position: Research fellow (Robert A. Welch postdoctoral fellow)

October 2006 – March 2007: ArcGEO :Ltd., Bratislava, Slovakia.
Position: Programmer – analyst

Research activities

Condensed matter physics and acoustics, thermophysical properties of materials.
My main research area focuses on experimental and theoretical study of thermophysical and mechanical properties of building and ceramic materials at room temperature and also during heating up to 1100 °C. The measurement methods which I deal with are dilatometry (TDA), thermomechanical analysis (mf-TMA), flash method of thermal diffusivity measurement, hot wire method, inverse method of thermal diffusivity measurement, differential thermal analysis (DTA), differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA).

Professional experience

Principal investigator of 1 scientific project from the Slovak Science Foundation (VEGA) and of 1 bilateral Czecho-Slovak project from the Slovak Research and Development Agency (APVV). Team member in 4 Slovak scientific projects under the VEGA, 2 bilateral projects under the APVV, and 2 European projects (Structural funds).
Member of the organizing committee of the conference Thermophysics 2010 and 2011.
Rector award in Constantine the Philosopher University (CPU) in Nitra in 2009 and dean award in the Faculty of Natural Sciences of CPU in 2012 (both for publication activities).

Publications

Author or co-author of 1 chapter in a foreign monograph, 28 papers in the WoS database, 15 paper in reviewed journals not covered by the WoS database, 7 papers in foreign conference proceedings, and 49 paper in proceedings of Czech and Slovak conferences.
Totally 10 citations in the WoS database and 20 other citations.

Selected publications:

CHMELÍK, František – TRNÍK, Anton – ŠTUBŇA, Igor – PEŠIČKA, Josef: Creation of microcracks in porcelain during firing. In: *Journal of the European Ceramic Society*. 2011, **31**, č. 13, s. 2205-2209, IF = 2.360

ŠTUBŇA, Igor – CHMELÍK, František – TRNÍK, Anton – ŠÍN, Peter: Acoustic emission study of quartz porcelain during heating up to 1150 °C. *Ceramics International*. 2012, **38**, n.8, p. 6919-6922. IF = 1.789

ONDRUŠKA, Ján – TRNÍK, Anton – MEDVEĎ, Igor: Estimation of mass transfer parameters during dehydroxylation in a large ceramic body by inverse methods. *Ceramics International*. 2011, **37**, č.8, s. 3299-3305. IF = 1.789

ŠTUBŇA, Igor – TRNÍK, Anton – VOZÁR, Libor: Thermomechanical and thermodilatometric analysis of green alumina porcelain. *Ceramics International*. 2009, **35,** č.3, s. 1181–1185. IF = 1.789

ŠTUBŇA, Igor – TRNÍK, Anton – VOZÁR, Libor: Thermomechanical analysis of quartz porcelain in temperature cycles. *Ceramics International*. 2007, **33**, č. 7, s. 1287-1291. IF = 1.789

ŠTUBŇA, Igor – TRNÍK, Anton – PODOBA, Rudolf – SOKOLÁŘ, Radomír –BAČÍK, Peter: Elastic properties of waste calcite – clay ceramics during firing. *Journal of the Ceramic Society of Japan*. 2012, **120**, n. 1405, p. 351-354. IF = 0.940

TRNÍK, Anton – ŠTUBŇA, Igor – VARGA, Gabriel – BAČÍK, Peter – PODOBA, Rudolf: Young’s modulus of heatproof tile ceramics Letovice during firing. *Journal of the Ceramic Society of Japan*. 2011, **119**, č. 8, s. 645-649, IF = 0.940

ŠTUBŇA, Igor – TRNÍK, Anton – VOZÁR, Libor: Determination of Young’s modulus of ceramics from flexural vibration at elevated temperatures. *Acta Acustica united with Acustica*. 2011, **97**, č. 1, s. 1-7, IF = 0.714

PAVLÍK, Zbyšek – TRNÍK, Anton – ONDRUŠKA, Ján – KEPPERT, Martin – PAVLÍKOVÁ, Milena – VOLFOVÁ, Petra – KAULICH, Viktor – ČERNÝ, Robert: Apparent thermal properties of phase-change materials: An analysis using differential scanning calorimetry and impulse method. *International Journal of Thermophysics*. 2013, **34**, n. 5, p. 851-864. IF = 0.568

ŠTUBŇA, Igor – TRNÍK, Anton: Young’s modulus of porcelain mixture after firing in the dehydroxylation region. *Ceramics – Silikáty*. 2007, **51**, č. 2, s. 102-105. IF = 0.418