THERMAL PROPERTIES OF CARBON- AND GLASS FIBER REINFORCED CEMENT COMPOSITES IN HIGH TEMPERATURE RANGE IN A COMPARISON WITH MORTAR AND CONCRETE

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Abstract

High temperature thermal diffusivity and linear thermal expansion coefficient of several carbon- and glass fiber reinforced cement composites are determined in the temperature range up to 1000^0C and compared with several types of cement based composites without any reinforcement, namely cement mortar and two types of high performance concretes for nuclear safety related structures. The changes in thermal parameters are discussed from the point of view of changes of structure and chemical composition due to the high temperature exposure and taking into account the role of fiber reinforcement.

Key words: carbon- and glass fiber reinforced composites, thermal diffusivity, linear thermal expansion coefficient, high temperatures

1 Introduction

Carbon-fiber and glass-fiber reinforced cement composites are produced by incorporating a small amount of fibers (in the case of glass fibers these have to be alkali-resistant) in cement mortar to overcome the traditional weakness of inorganic cements, namely poor tensile strength and brittleness. The length and content of the fiber reinforcement can be chosen to meet the strength and toughness requirements of the product. Also, the type of aggregates can be varied in order to control thermal properties.

In the current research practice, the mechanical properties of fiber reinforced cement composites (FRCC) are in the center of interest of most researchers working on those materials. This is quite logical taking into account why they were developed, i.e. to improve the tensile and flexural strength of cement based composites. However, there are numerous applications of fiber reinforced composites that require a good knowledge of thermal parameters. For instance, lightweight FRCC can be used as thermal insulation materials, other FRCC can be employed as fire protection materials, etc.

Therefore, the knowledge of thermal properties of FRCC particularly in high temperature range is very important.

In this paper, high temperature thermal diffusivity and linear thermal expansion of several carbon and glass fiber reinforced cement composites are determined. Additional experiments are performed with several common cement based composites as well in order to show the effect of fiber reinforcement on the high temperature thermal parameters.

2 Experimental methods

2.1 High-temperature thermal diffusivity

The measurements were done in the temperature range up to 1000 ^{0}C using the double integration method, which is based on the results of experimental measurements of temperature fields in the sample at one-sided heating and the subsequent solution of the inverse heat conduction problem (see [1] for details).

The basic idea of the method is as follows. We have the one-dimensional heat conduction equation in the form

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(a \frac{\partial T}{\partial x} \right), \tag{1}$$

where a is the thermal diffusivity. We suppose T (t) and T (x) to be monotonous functions and choose a constant value of temperature, $\tau = T(x,t)$. Then, there must exist one-to-one parametrizations $x = x_o(\tau, t)$, $t = t_o(\tau, x)$, where x_o and t_o are monotonous functions. Considering this fact, an integration of heat conduction equation (1) by x and t can be done,

$$\int_{t_1}^{t_2} \int_{0}^{x_0(\tau,t)} \frac{\partial T}{\partial t}(x,t)\,dx\,dt = a(\tau)\int_{t1}^{t2} \frac{\partial T}{\partial x}(x_0(\tau,t),t)\,dt + \int_{t_1}^{t_2} \frac{q(0,t)}{\rho(\tau)c(\tau)}dt\,. \tag{2}$$

After some algebraic modifications we arrive at the relation for calculating the thermal diffusivity $a(\tau)$ in the form:

$$a(\tau) = \frac{1}{\int_{t_1}^{t_2} \frac{\partial T}{\partial x}(x_0(\tau,t))dt}\left(\int_{0}^{x_0(\tau,t_2)} T(x,t_2)dx - \int_{0}^{x_0(\tau,t_1)} T(x,t_1)dx \right.$$

$$\left. - \tau[x_0(\tau,t_2) - x_0(\tau,t_1)] - \int_{0}^{l} [T(x,t_2) - T(x,t_1)]dx \right). \tag{3}$$

2.2 High-temperature linear thermal expansion

The measurements of linear thermal expansion were performed in the temperature range up to 1000 ^{0}C by the method of Toman et al. [2]. The measuring device is based on the application of a comparative technique. Therefore, the measurement is performed simultaneously on a sample of a standard material (such as special steels where the $\alpha(T)$ functions are known) and the studied material.

The length change of the measured sample is calculated from the following formula:

$$\Delta l(T_i) = \Delta l_m(T_i) - \Delta l_s(T_i) + l_{o,s}\int_{T_o}^{Ti} \alpha_s(T)dT\,, \tag{4}$$

where Δl_m, Δl_s are the final readings of total length changes of the studied material and of the standard including the length changes of the ceramic rods (part of measuring device), respectively, $l_{o,s}$ is the initial length of the standard, and α_s is the known linear thermal expansion coefficient of the standard. The corresponding value of strain can be expressed in the form:

$$\varepsilon(T_i) = \frac{\Delta l(T_i)}{l_{o,m}}\,, \tag{5}$$

where $l_{o,m}$ is the initial length of the measured sample.

The measurements are then repeated with other chosen values of furnace temperatures T_i, and the calculation of $\alpha(T)$ function of the measured material is performed.

3 Materials and samples

The experiments were done with several different types of cement-based materials, cement mortar, two types of high-performance concrete, three types of glass fiber reinforced composites and a carbon fiber reinforced composite material.

The samples of cement mortar had the following composition (i.e. the mixture for one charge): Portland cement ENV 197 - 1 CEM I 42.5 R (Králův Dvůr, CZ) – 450 g, natural quartz sand with continuous granulometry I, II, III (the total screen residue on 1.6 mm 2%, on 1.0 mm 35%, on 0.50 mm 66%, on 0.16 mm 85%, on 0.08 mm 99.3%) - 1350 g, water – 225 g.

Penly concrete was used for a concrete containment building in a nuclear power plant in France and consisted of the following components: Cement CPA HP Le Havre (290 kg/m^3), sand 0/5 size fraction (831 kg/m^3), gravel sand 5/12.5 size fraction (287 kg/m^3), gravel sand 12.5/25 size fraction (752 kg/m^3), calcareous filler PIKETTY (105 kg/m^3), silica fume (30 kg/m^3), water (131 kg/m^3), retarder CHRYTARD 1.7, super-plasticizer Resine GT 10.62.

The Temelin concrete used for the concrete containment building of the Temelin nuclear power plant in the Czech Republic. The composition was as follows: Cement 42.5 R Mokrá (499 kg/m^3), sand 0/4 size fraction (705 kg/m^3), gravel sand 8/16 size fraction (460 kg/m^3), gravel sand 16/22 size fraction (527 kg/m^3), water (215 kg/m^3), plasticizer 4.5 l/m^3.

The samples of glass fiber reinforced cement composites denoted as GC I, GC II, GC III were plate materials with Portland cement matrix (cement CEM I 52.5 Mokrá), which was reinforced by alkali-resistant glass fibers (CEM-FIL 2 250/5B Tex 2450 30 mm for

GC I, CEM-FIL 70/30 6 mm for GC II and GC III), the materials SC II and III contained vermiculite and wollastonite. The basic composition of GC I, II, III is shown in Table 1 (the percentage is calculated among the dry substances only, water corresponding to the water to cement ratio of 0.3 is to be added to the mixture).

Table 1 Composition of glass fiber reinforced cement composites in %.

	Cement	Sand	Plasticizer	Glass fiber	Wollastonite	Vermiculite	Microsilica
GC I	47.99	47.99	0.62	3.40			
GC II	47.60		0.45	3.84	38.50	9.61	
GC III	56.88		0.92	7.66	8.68	21.51	4.35

The carbon fiber reinforced cement composite specimens (denoted as CC) had the following composition (calculated among the dry substances only): Portland cement CEM I 52.5 Mokrá 39.71%, microdorsilite 16.5%, wollastonite 39.6%, microsilica 1.96%, methylcellulose 0.11%, superplasticizer 0.98%, carbon fiber (pitch based 10 mm) 0.98%, defoamer 0.16%. Water in the amount corresponding to the w/c ratio of 0.8 was added to the mixture.

The dimensions of the specimens were as follows: for measurements of high-temperature thermal diffusivity 71x71x71 mm, for determination of high-temperature linear thermal expansion 40x40x120 mm.

4 Experimental results and discussion

Fig. 1 shows the results of high-temperature thermal diffusivity measurements. The highest values of thermal diffusivity were achieved in the whole temperature range by the two high-performance concretes, which is an expected result because they have the highest bulk density. The lighter fiber reinforced composites had significantly lower thermal diffusivity, to about one half of the values of HPCs. The thermal diffusivity of cement mortar was somewhere between these two limits. The character of thermal diffusivity dependence of fiber reinforced composites was different than for the concretes and mortar without any reinforcement. While the thermal diffusivity of fiber reinforced composites increased in the whole range of temperatures, the thermal diffusivity of concretes and mortar first decreased and from 400^0C it began to increase. The slower increase of thermal diffusivity of fiber reinforced composites in the range of highest temperatures compared to the cement based materials without any reinforcement can clearly be attributed to the positive effect of the fiber reinforcement that was in certain range able to prevent from opening wide cracks magnifying the convective mode of heat transfer. It should also be noted that the thermal diffusivity of GC I was only slightly higher than of other fiber reinforced cement composites (a higher difference was in the range of lower temperatures up to 400^0C) although its density was significantly higher. So, the effect of fiber reinforcement was in the highest temperature range similar for both heavier and lighter fiber reinforced composites. This may be related to the worse mechanical properties of the cement matrix of lighter composites.

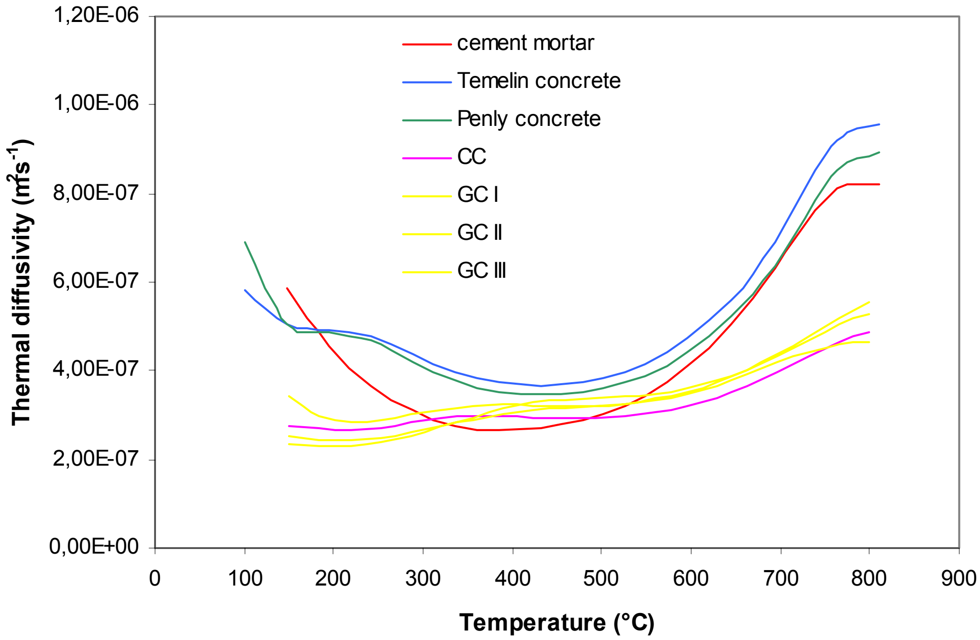

Fig. 1 Thermal diffusivity of cement based composites

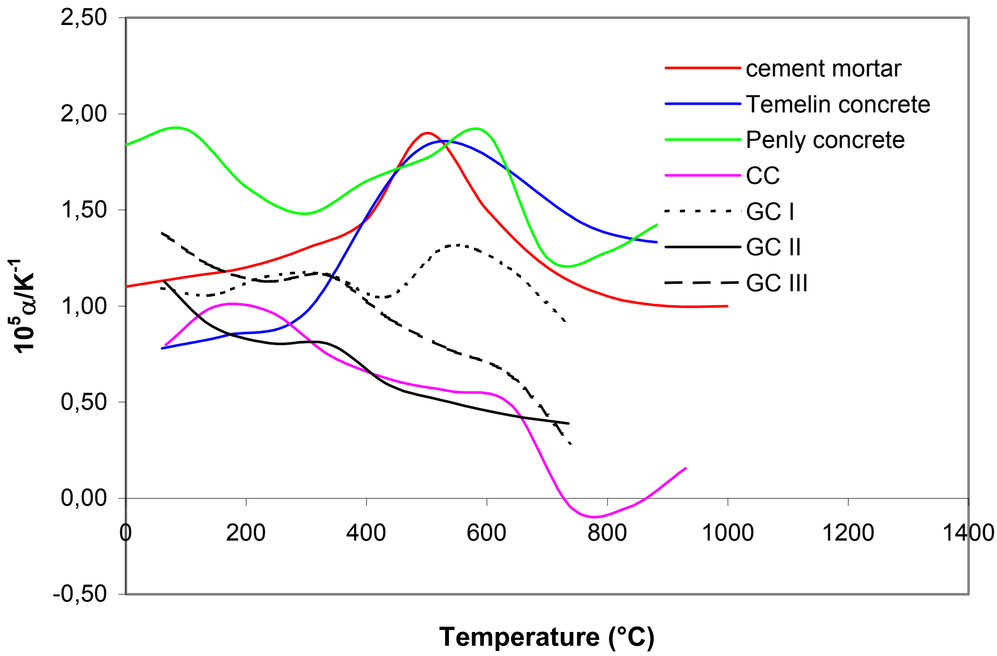

Fig. 2 Linear thermal expansion coefficient of cement based composites

The results of measurements of the linear thermal expansion coefficient in the high temperature range exhibit the positive effect of fiber reinforcement. The linear thermal expansion coefficient of mortar and concretes was significantly higher compared to the fiber reinforced composites and markedly increased with temperature up to about 500-

600^0C. For GC II, GC III and CC the linear thermal expansion coefficient even decreased with temperature in almost whole the temperature range studied. Apparently, the fibers were for these composites able to prevent the matrix from an excessive volume increase due to their good adhesion – contrary to GC I where the linear thermal expansion coefficient was almost constant up to about 600^0C. The decrease of linear thermal expansion coefficients in the highest temperature range for most materials is clearly related to the decomposition processes in the cement matrix, where the main role play the decomposition of calcium hydroxide at 460^0C and of calcium silicate hydrates in the temperature range between 700-800^0C.

5 Conclusions

Both carbon fiber and glass fiber reinforced cement composites exhibited significantly better thermal properties compared to the cement composites without any reinforcement during the high temperature exposure. The positive effect of both glass fibers and carbon fibers consisted clearly in their good adhesion to the cement matrix so that the matrix was kept together even after serious damage due to the cement decomposition processes, and wide cracks did not appear as in the case of cement composites without any reinforcement. Therefore, it can be concluded that the studied fiber reinforced composites have a reasonably good thermal resistance and can be conveniently used for the high temperature protection of building structures.

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