Robert Černý – Michaela Totová – Jan Toman – Jaroslava Drchalová – Pavla Rovnaníková – Patrik Bayer *

ZMENY VLHKOSTNÝCH A TEPELNÝCH VLASTNOSTÍ CEMENTOVÝCH KOMPOZITOV VYSTUŽENÝCH SKLENENÝM VLÁKNOM V ZÁVISLOSTI OD TEPLOTNÉHO ZAŤAŽENIA

THERMAL LOAD INDUCED CHANGES OF HYGRIC AND THERMAL PROPERTIES OF GLASS FIBER REINFORCED CEMENT COMPOSITES

V príspevku je analyzovaný vplyv tepelného zaťaženia na základné teplotné a vlhkostné vlastnosti dvoch typov cementových kompozitov so sklenenými vláknami. Tepelná vodivosť, špecifické teplo a vlhkostná difuzivita sú určené po vystavení vysokej teplote od 600 do 800 °C. Zníženie tepelnej vodivosti o 50 % a zvýšenie vlhkostnej difuzivity v rozsahu jedného až dvoch rádov sú pozorované pri všetkých typoch testovaných materiálov po zahriatí na 800 °C. Na druhej strane špecifické teplo a hustota sú za tých istých podmienok znížené len o 10 %. Na analýzu príčin meraných rozdielov medzi vlhkostnými a tepelnými parametrami, spôsobenými teplotným zaťažením a nezaťažením vzoriek, sú použité výsledky meraného rozloženia pórov, snímania elektrónovým mikroskopom a teplotnou analýzou.

The effect of thermal load on the basic thermal and hygric properties of two types of glass fiber reinforced cement composites (GFRCC) is analyzed in the paper. Thermal conductivity, specific heat and moisture diffusivity are determined after high temperature exposure to 600 and 800 °C. A decrease of thermal conductivity as high as 50 % and an increase of moisture diffusivity in the range of one to two orders of magnitude are observed for all types of the studied materials after heating to 800 °C. On the other hand, specific heat and density in the same situation decrease by only about 10 %. In the analysis of the reasons for the measured differences between hygric and thermal parameters of thermally loaded and unloaded samples, pore distribution measurements, scanning electron microscopy and thermal analysis are employed.

1. Introduction

Glass-fiber reinforced cement composites (GFRCC) are produced by incorporating a small amount of alkali-resistant glass fiber in cement mortar to overcome the traditional weakness of inorganic cements, namely poor tensile strength and brittleness (see, e.g., [1]). The length and content of the glass 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 manage thermal properties. GFRCC are often employed in severe conditions. These might be exposed, for instance, to high temperatures and/or high mechanical loads. However, their thermal and hygric properties are mostly measured in laboratory conditions only, so that designers cannot take into account the changes in their material parameters after loading. In this paper, basic hygric and thermal properties of selected glass fiber reinforced cement composites are determined as functions of thermal load.

2. Methods for measuring thermal and hygric parameters

The measurements of thermal conductivity and specific heat were performed at room temperature using the microprocessor controlled portable device ISOMET 104 (Applied Precision). The measurement is based on an analysis of the temperature response of the analyzed material to heat flow impulses. The heat flow is excited by electrical heating of a resistive heater mounted into the probe having direct thermal contact with the samples. The temperature is sampled and as a function of time is on-line evaluated by means of polynomial regression. The coefficients of the evaluated regression polynomials are then used to calculate the measured quantities.

Moisture diffusivity κ was determined using a simple method based on the assumption that κ can be considered as piecewise constant with respect to the moisture content u (PCK method in

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* [1]**Prof. Ing. Robert Černý, DrSc.,** [1]**Ing. Michaela Totová,** [2]**Prof. Mgr. Ján Toman, DrSc.,** [2]**RNDr. Jaroslava Drchalová, CSc.,**
[3]**Doc. RNDr. Pavla Rovnaníková, Csc.,** [3]**Ing. Patrik Bayer**
[1]Czech Technical University, Faculty of Civil Engineering, Department of Structural Mechanics, Thákurova 7, 166 29 Praha 6, Czech Republic, E-mail: cernyr@fsv.cvut.cz;
[2]Czech Technical University, Faculty of Civil Engineering, Department of Physics, Thákurova 7, 166 29 Praha 6, Czech Republic
[3]Institute of Chemistry, Faculty of Civil Engineering, Technical University of Brno, Žižkova 17, 662 37 Brno, Czech Republic

what follows). Contrary to the most frequently used methods for κ determination, the PCK method is very fast even for materials with low κ, and, in addition, it exhibits a reasonable precision [2]. Therefore, its application for concrete is very suitable.

3. Material samples

The measurements were conducted on two types of glass fiber cement composites, denoted as SC I, II, in what follows. The samples were plate materials with a Portland cement matrix (CEM I 52.5), which was reinforced by alkali-proof glass fibers (CEMFIL, fiber length of 35 mm), the material SC II contained vermiculite and wollastonite. The basic composition of SC I, II 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).

The samples for the determination of thermal conductivity, specific heat and moisture diffusivity were exposed to the thermal load prior to the measurements. The chosen temperatures were 600 and 800 °C. For the sake of comparison, also the measurements with unloaded samples were done. The size of samples was for SC I 60 × 70 × 10 mm, for SC II 60 × 60 × 13 mm. The specimens were water and vapor-proof insulated on four edges by two-component epoxy resin ChS Epoxy 1200.

4. Experimental results

The measurements of room temperature values of thermal conductivity, specific heat and moisture diffusivity after thermal load are summarized in Tables 2-3. Always an average value from the measurements on five samples is given. Both thermal conductivity and specific heat are found to decrease with increasing the loading temperature, and the decrease of thermal conductivity is very remarkable, almost 50 % compared to the room temperature data. The moisture diffusivity exhibits an opposite behavior, a two order of magnitude increase for SC-I and one order of magnitude increase for SC-II are observed comparing the room temperature data with the data for high temperature exposure to 800 °C. It should be noted that the changes of thermal and hygric parameters are more remarkable between 25 °C and 600 °C than between 600 °C and 800 °C.

5. Discussion

In order to explain the observed differences in thermal and hygric parameters after the thermal load, mercury porosimetry, scanning electron microscopy have been done. The curves of DTA have been determined before thermal load of sample SC I and SC II, Fig. 1 and 2.

Pore volumes of samples, which have been heated at different temperatures are given in Figs. 3 and 4. Microstructure of samples at 20, 600 and 800 °C are given in Figs. 5 and 6. Fibers loaded at temperature 600 °C are not damaged, temperature 800 °C caused their collapse.

The fibers react at high temperature with cement paste and lose their round form and distort. The cement paste in sample SC I changes character of pores, see the graph in Fig. 3. The fibers of wollastonite are more stable at high temperature and they keep the

Composition of glass fiber reinforced cement composites in % Table 1

	Cement	Sand	Plasticizer	Alkali-proof fiber	Wollastonite	Vermiculite
SC I	47.99	47.99	0.62	3.40		
SC II	47.60		0.45	3.84	38.50	9.61

Thermal and hygric parameters of SC I Table 2

Temperature exposure [°C]	ρ_s [kg m^{-3}]	C [J kg^{-1} K^{-1}]	λ [W m^{-1} K^{-1}]	u_{max} [%]	κ [m^2 s^{-1}]
25	1960	920	1.124	10.6	$1.28.10^{-9}$
600	1865	920	0.706	15.6	$9.57.10^{-8}$
800	1820	900	0.666	16.2	$1.79.10^{-7}$

Thermal and hygric parameters of SC II Table 3

Temperature exposure [°C]	ρ_s [kg m^{-3}]	C [J kg^{-1} K^{-1}]	λ [W m^{-1} K^{-1}]	u_{max} [%]	κ [m^2 s^{-1}]
25	1090	1090	0.275	47.5	$2.52.10^{-8}$
600	1030	1050	0.198	56.8	$1.27.10^{-7}$
800	990	960	0.160	56.8	$3.18.10^{-7}$

structure of cement paste stronger than glass fibers. It is confirmed also by thermogravimetric analysis, see Figs. 1 and 2.

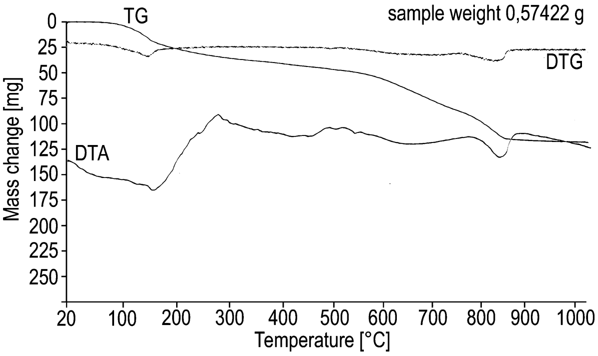

Fig. 1. Thermal analysis of sample SC I

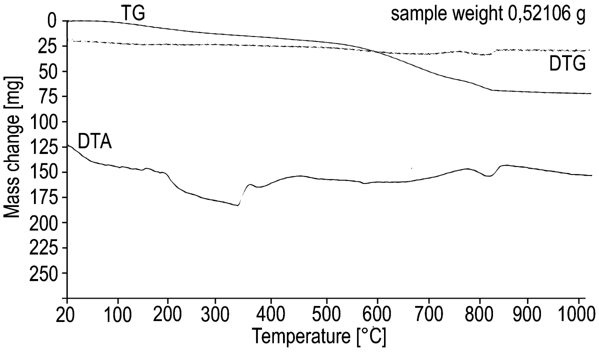

Fig. 2. Thermal analysis of sample SC II

Room temperature properties of the three analyzed types of glass fiber reinforced cement composites (GFRCC) are affected by the type of aggregates in the most significant way. Application of wollastonite and vermiculite instead of usual sand aggregates leads to a remarkable decrease of thermal conductivity. On the other hand, moisture diffusivity of GFRCC with wollastonite and vermiculite is higher compared to the sand aggregates, which is a clear consequence of a decrease of density to about one half. These are the logical consequences particularly of the character of vermiculite which has remarkably lower density compared to the sand.

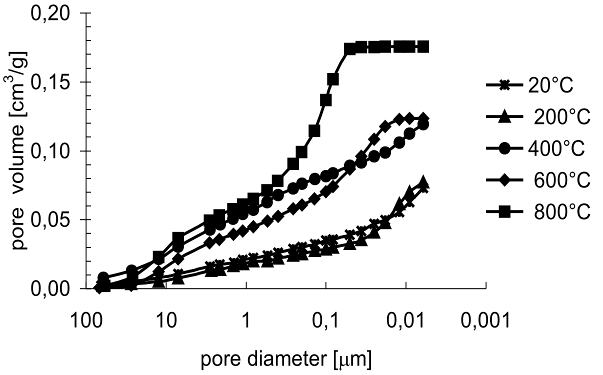

Fig. 3. Porosimetry of sample SC I

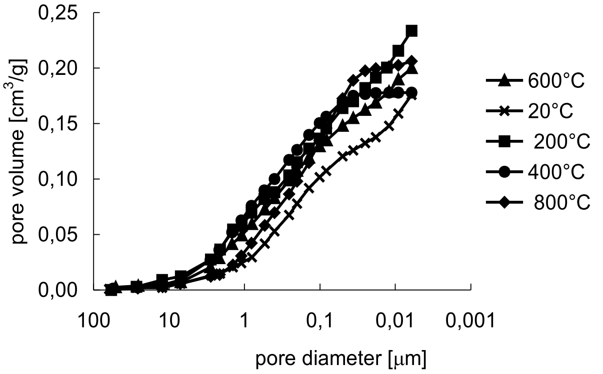

Fig. 4. Porosimetry of sample SC II

On the other hand, the behavior of GFRCC exposed to high temperatures is affected by the properties of the cement binder in the most significant way. The very fast increase of moisture diffusivity and a relatively fast decrease of thermal conductivity of all

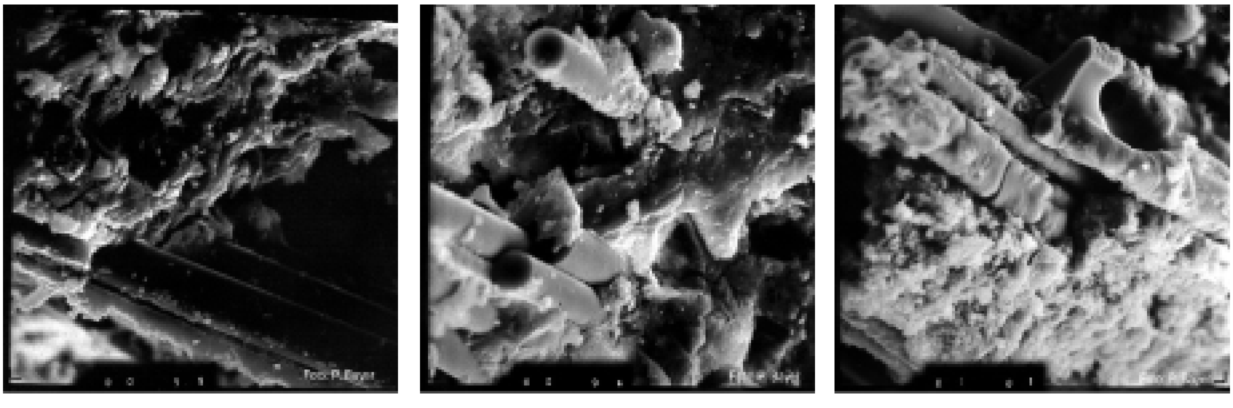

Fig. 5. Scanning micrographs of sample SC I

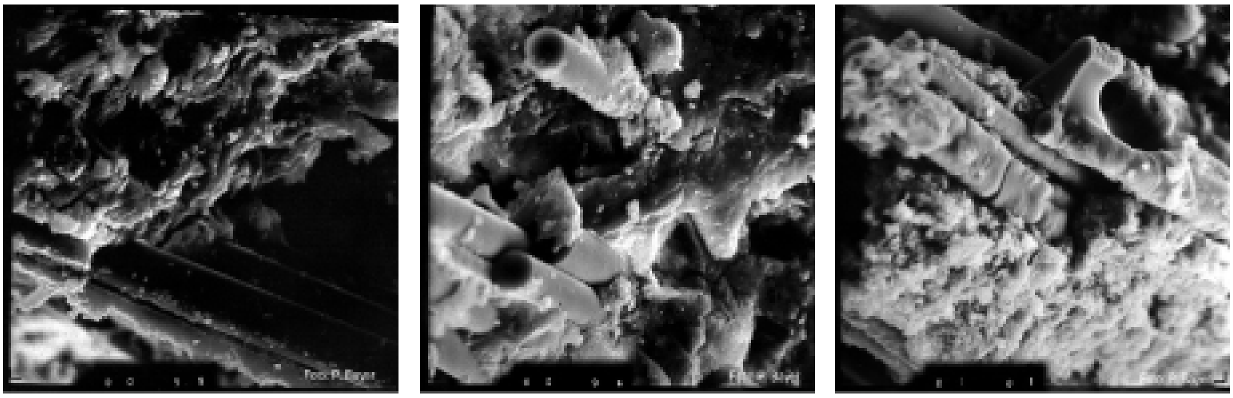

Fig. 6. Scanning micrographs of sample SC II

three materials with the heating temperature correspond well with the characterization experiments performed. From the point of view of structural changes in the cement gel, for the temperature range up to 1000 °C two processes are the most important, namely the decomposition of $Ca(OH)_2$ at about 490 °C and decomposition of calcium silicate hydrates at about 700 °C. During these processes, gaseous substances are released, water vapor in the first case, and carbon dioxide in the second. Therefore, the amount of bigger pores increases, which makes the liquid water transport easier and faster. In addition, due to the fast generation of a substantial amount of the mentioned gaseous substances, the local overpressure in some parts of the porous system may lead to crack appearance, and consequently to the opening of preferential paths for the pore water flow. The increasing amount of larger pores then logically leads to a decrease of thermal conductivity because of the increasing amount of the air in the material.

The much faster increase in moisture diffusivity of SC-I between 25 °C and 600 °C compared to SC-II was most probably a consequence of opening of wider preferential paths after the high temperature exposure because in normal conditions SC-I possesses lower moisture diffusivity than SC-II. A logical reason is the better function of glass fibers in SC-II, i.e. their better adhesion to the cement-aggregates matrix.

6. Conclusions

Two main factors were found to affect the properties of the studied GFRCC in the most significant way. For the room temperature parameters, the type of aggregates was found to be dominant, and an application of wollastonite and vermiculite instead of sand aggregates was identified to have a very positive effect because the thermal conductivity decreased in a significant way. Positive effect on the pore structure and mass loss has been also found. In the case of the high temperature exposure, the decomposition processes in the cement gel can be considered as the most important.

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