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Gabriela Pavlendová; Peter Šín

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The Influence of Concrete Additives on the Thermophysical Properties Change after Freeze-Thaw Cycle

Gabriela Pavlendová[1, a)] and Peter Šín[1, b)]

[1]Faculty of Civil Engineering, Slovak University of Technology, Radlinského 11, 810 05 Bratislava, SK

[a)] Corresponding author: qpavlendova@stuba.sk
[b)] peter.sin@stuba.sk

Abstract. In recent years we can see a rise in synthetic materials, mainly fibers, used for producing building materials. Concrete as one of the most widely used building material is brittle and has also poor energy absorption. These might be well improved using steel or fibers. Synthetic fibers are manufactured from polypropylene nylon or polyvinyl alcohol, which is expensive and damaging to the environment. Hence great attention is given to the usage of recycled plastics instead of the manufactured one. Natural fibers reinforcement is found as the solution for low-cost building material in developing countries where they are locally available and cheap to acquire. The use of natural fibers in developed countries has not been accepted as an alternative to synthetic fibers despite the increased pressure on achieving sustainable construction, although their usage has a long history. Let us only mention the Egyptians using straw fibers to reinforce mud blocks for building walls. In this paper, we compare the thermophysical properties of cement-based materials with synthetic fibers and horse manure fibers. We measured these properties before and after the freeze-thaw cycles. The minimal change of thermophysical properties after freeze-thaw cycles was observed for the sample with 10% horse manure fibers.

INTRODUCTION

The reason for our interest in cement-based materials was also explained in our previous papers [1, 2, 3]. Cement-based materials have a dominant position in the construction material's market. Various kinds of plastics in different size, shape, and percentage are added to cement-based materials and their effect on mechanical and thermophysical properties is investigated mainly because of the environmental concerns. The countries face the most difficulties in plastics packaging waste recycling since no country has yet reached the 50% level of recycling [4]. Plastics have a different affinity to water and entrap air molecules and hence change the porosity [5]. In praxis plastics waste in lightweight concrete is commonly accepted because of better thermophysical properties, reduction of CO_2 emission in the process of concrete production as the amount of mineral aggregate decreased. Concrete structures are constantly exposed to the changes in temperature, relative humidity (RH), which are the reasons for the deterioration processes. In our previous works, we tested the influence of artificial ageing on the thermophysical properties and tested some mechanical ones.

In this paper, we give the results of the freeze-thaw cycle influence on thermophysical properties. We also compare water sorption-desorption isotherms (in a limited range) for cement-based materials with plastic and natural fibers.

MATERIALS AND METHODS

Concrete samples composed of 350 cm^3 of cement, 1050 cm^3 of sand, 350 cm^3 of water + additive. The list of samples and their composition is depicted in Tab. 1.

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TABLE 1. Samples and their composition.

Sample	Additive (cm^3)	Additive (kind)
Pure concrete	0	None
C. with 5 % PP	70	Fibers
C. with 10 % PP	140	Fibers
C. with 12.5 % PP	175	Fibers
C. with 5 % HM	70	Manure
C. with 10 % HM	140	Manure
C. with 15 % HM	210	Manure

C. – concrete, PP – polypropylene, HM – horse manure

Plastic fibers (PP) with the length 12-18 mm, diameter 0.02 mm were made by Adfill Co., Hull, Great Britain. Horse manure was taken from the horse training center Carpathia, Bratislava, Slovakia, dried, with fiber length 10-15 mm, diameter 0.1-0.3 mm. We used Cement Ladce, Slovakia (Portland-composite cement) CEMII / B-M (S-L) 32.5R, and the finest fraction sand, Trnava, Slovakia with the diameter <0.064 mm, 99 % SiO_2.

The samples were mixed with a paddle mixer, dried in covered plastic forms for 30 days, and afterward put into the oven at the temperature 90 °C for 7 days. Samples have the base 100 × 100 mm and thickness ranging from 14 to 15 mm according to the conditions of used measuring method. All samples were polished to achieve smooth surfaces.

Thermophysical properties were measured by pulse transient method at the temperatures: –30 °C, –15 °C, 0 °C, 15 °C and 30 °C using the thermophysical transient tester RT 1.02.

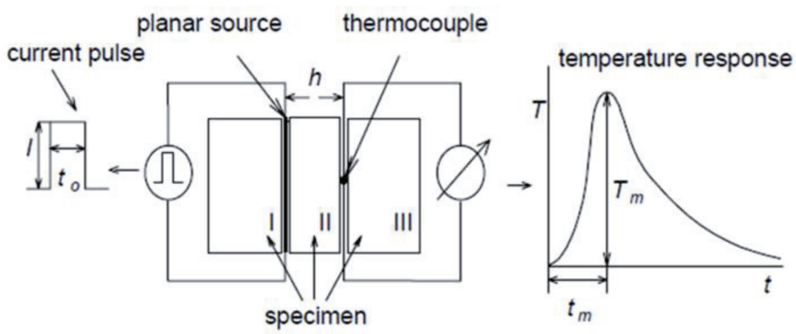


FIGURE 1. Principle of the pulse transient method where T = temperature and t = time.

The resulting values of the quantities were determined by the arithmetic average of ten measurements. The reproducibility for thermal conductivity measurement is 3% of reading + 0.001 W/m.K and for specific heat 3% of reading + 1 J/kg.K. Expected uncertainty for each of the properties is 6% depending on pore size distribution. [6].

Investigated thermophysical properties were measured in dry state before and after artificial freezing in apparatus Slab-Freeze-Thaw Tester No. 82.995.455.3 after 50 temperature cycles of 6 hours, or 12.5 days in total. Before artificial freeze-thaw cycles, the samples were soaked into the water for 24 hours.

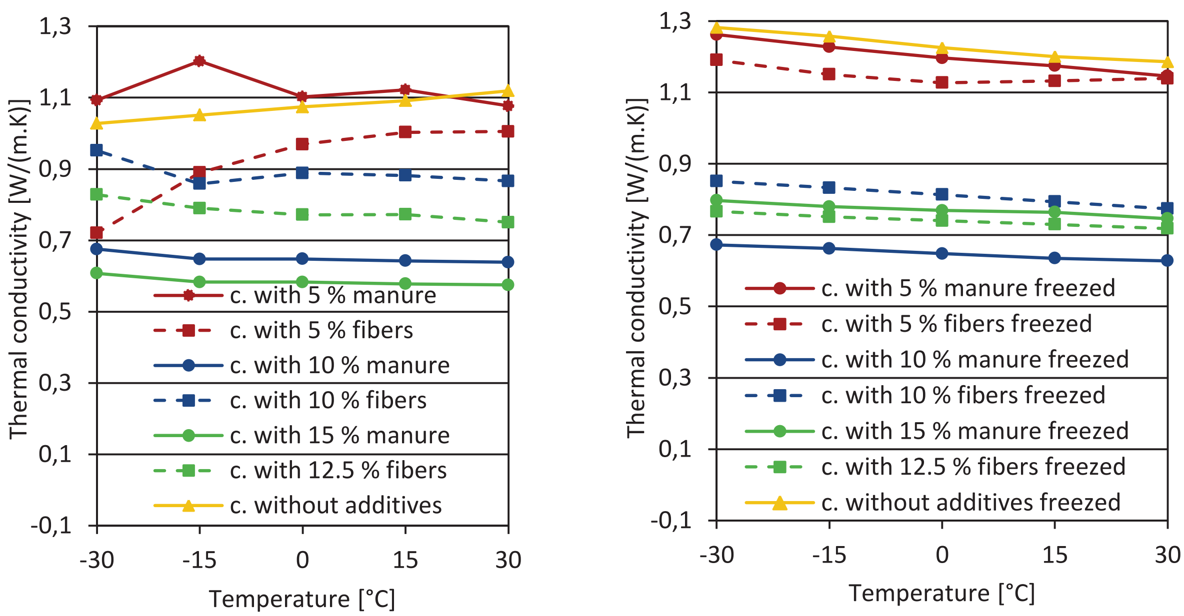
Sorption and desorption curve was carried out after artificial wetting in the climatic chamber BINDER MKF (E3). The measurement started from sorption at relative humidity: 20 %, 50 %, 80 %, 95 %, followed by desorption at relative humidity 80 %, 50 %, 20 %. The temperature was held at 20 °C. Every 6 weeks the humidity was changed to the next step and every 2 weeks the samples were weighted until constant mass (after 6 weeks) was achieved. The total sorption experimental study lasted one year.

RESULTS AND DISCUSSION

When water freezes, it expands about 9 percent. As the water in moist concrete freezes, it produces pressure in the pores of the concrete. Eventually, if the developed pressure exceeds the tensile strength of the concrete, the cavity would dilate and rupture. The accumulative effect of successive freeze-thaw cycles can eventually cause irreversible changes in the quality of cement-based materials.

In our previous experiments, thermophysical properties of concrete with the addition of natural fibers (horse manure) and synthetic ones were tested. The minimal change of thermophysical properties was measured for the sample with horse manure fibers.

The values of thermophysical properties before and after freeze-thaw cycles are in the following figures.



(a) (b)

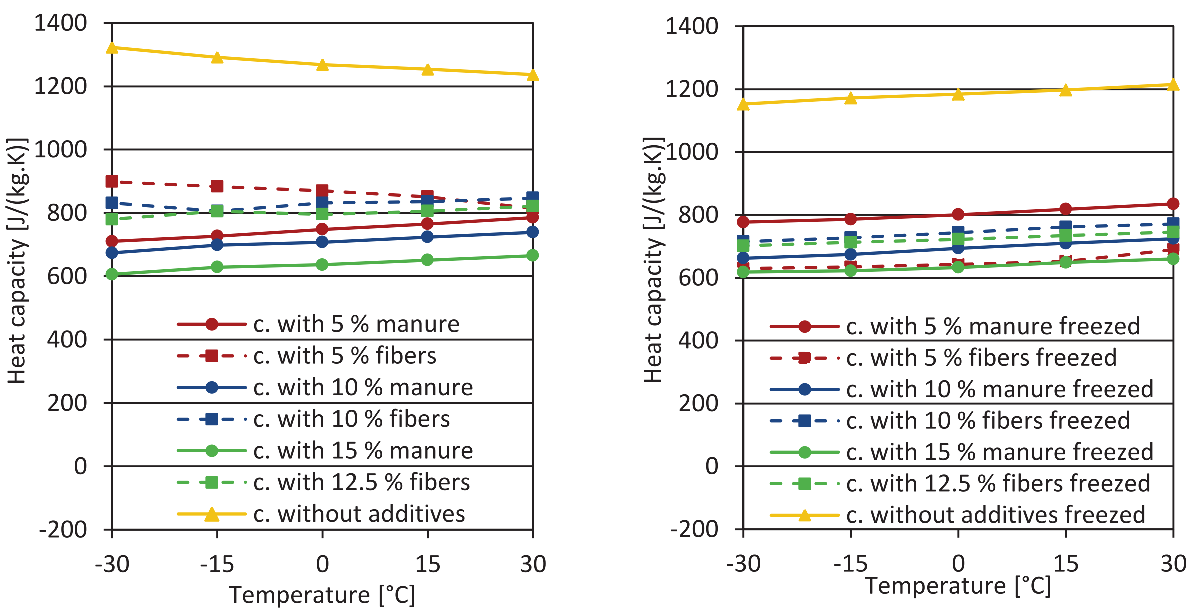
FIGURE 2. Thermal conductivity of samples with different additives versus temperature before (a) and after (b) freezing

For all tested samples, thermal conductivity values after freeze-thaw cycles decrease with increasing temperature. We, therefore, compare percentual changes in the boundary temperature values before and after freeze-thaw cycles for all thermophysical properties. The results for thermal conductivity changes are in Table 2.

TABLE 2. Thermal conductivity changes before and after freeze-thaw cycles.

Sample	Thermal conductivity at -30 °C	Thermal conductivity at +30 °C
c. with 5 % manure	15 % increase	9 % increase
c. with 5 % fibers	25 % increase	13 % increase
c. with 10 % manure	change is within statistical error	change is within statistical error
c. with 10 % fibers	change is within statistical error	11 % increase
c. with 15 % manure	31 % increase	30 % increase
c. with 12.5 % fibers	change is within statistical error	change is within statistical error
c. without additives	25 % increase	5 % increase

Thermal conductivity change for the samples with 10% of manure and 12.5% of fibers was within the statistical error (less than 5%). The irregular courses for samples with 5% horse manure and 5 % fibers before freezing were most probably due to the not evenly distributed additives. After freeze-thaw cycles, the course of all samples had the same tendency.



(a) (b)

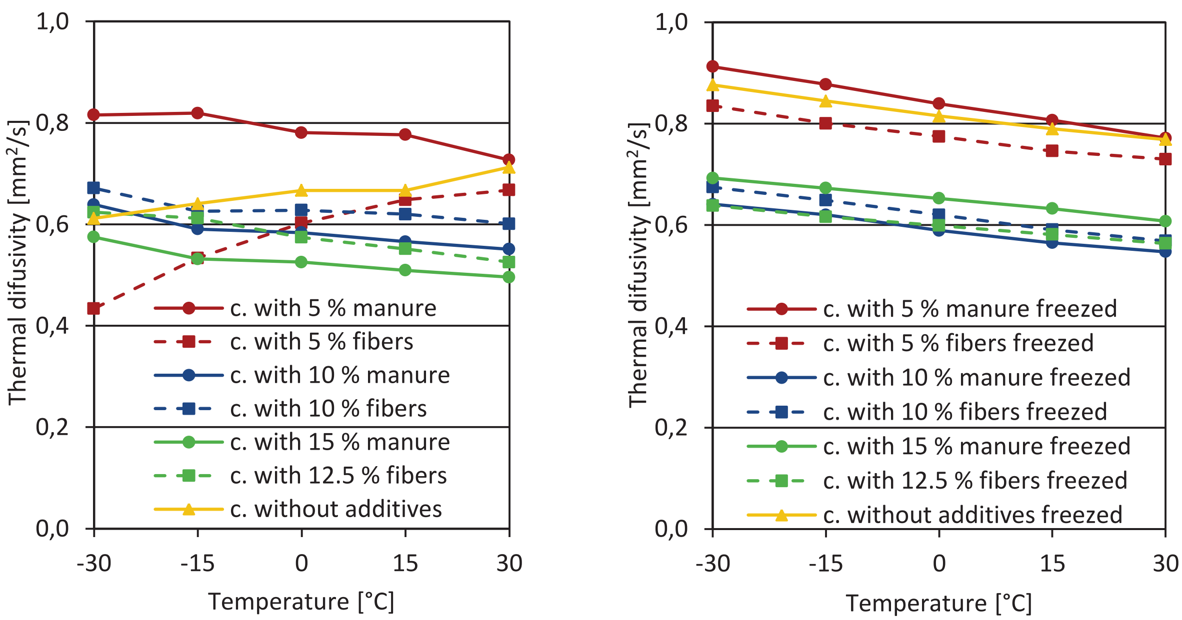
FIGURE 3. Heat capacity of samples with different additives versus temperature before (a) and after (b) freezing

For all tested samples heat capacity values after freeze-thaw cycles increase with increasing temperature. We, therefore, compare percentual changes in the boundary temperature values before and after freeze-thaw cycles. The results for heat capacity changes are in Table 3.

TABLE 3. Heat capacity changes before and after freeze-thaw cycles.

Sample	Heat capacity at -30 °C	Heat capacity at +30 °C
c. with 5 % manure	9 % increase	6 % increase
c. with 5 % fibers	30 % decrease	23 % decrease
c. with 10 % manure	change is within statistical error	change is within statistical error
c. with 10 % fibers	14 % decrease	9 % decrease
c. with 15 % manure	change is within statistical error	change is within statistical error
c. with 12.5 % fibers	10 % decrease	10 % decrease
c. without additives	13 % decrease	change is within statistical error

Heat capacity change after freeze-thaw cycles within the statistical error (less than 5%) was only for concrete with 10% and 15% of horse manure.



(a) (b)

FIGURE 4. Thermal diffusivity of samples with different additives versus temperature before (a) and after (b) freezing

For all tested samples, thermal diffusivity values after freeze-thaw cycles decrease with increasing temperature. We, therefore, compare percentual changes in the boundary temperature values before and after freeze-thaw cycles. The irregular courses for samples with 5% horse manure and 5 % fibers before freezing were most probably due to the not evenly distributed additives. After freeze-thaw cycles, the course of all samples had the same tendency.

The results for thermal diffusivity changes are in Table 4.

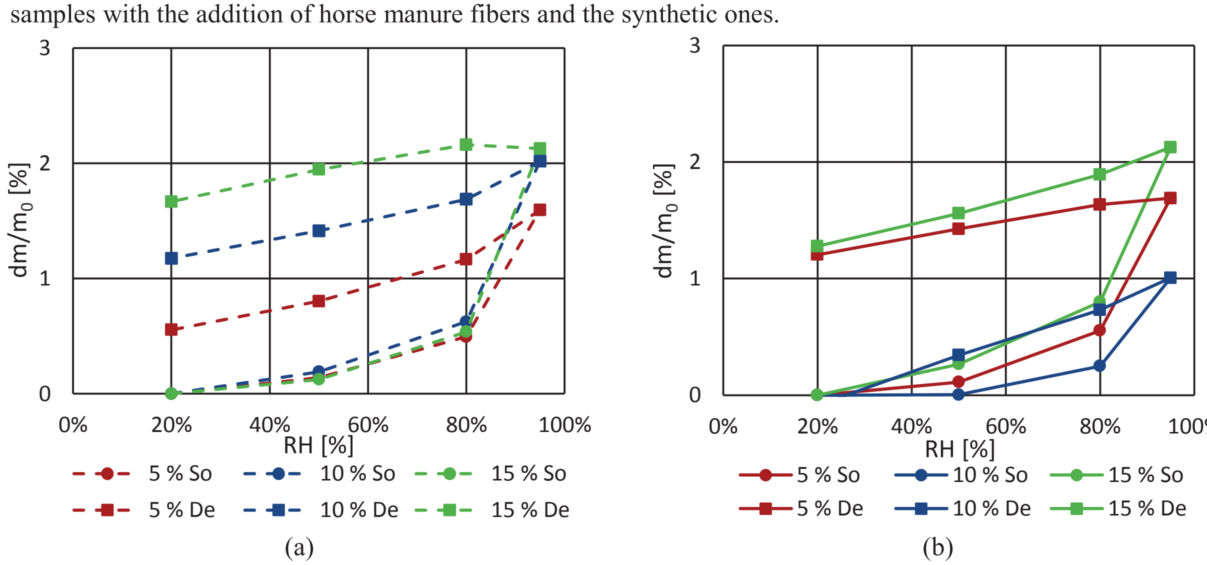
TABLE 4. Thermal diffusivity changes before after freeze-thaw cycles.

Sample	Thermal diffusivity at -30 °C	Thermal diffusivity at +30 °C
c. with 5 % manure	12 % increase	7 % increase
c. with 5 % fibers	92 % increase	9 % increase
c. with 10 % manure	change is within statistical error	change is within statistical error
c. with 10 % fibers	change is within statistical error	6 % decrease
c. with 15 % manure	20 % increase	22 % increase
c. with 12.5 % fibers	change is within statistical error	7 % increase
c. without additives	43 % increase	7 % increase

Comparing the results we observed the highest resistance to temperature changes for the samples with 10% horse manure and the samples with 10% and 12.5 % fibers.

All physiochemical processes that are responsible for durability issues in concrete, such as carbonation, chlorination, freeze-thaw cycles are moisture dependent. To predict or to prevent undesirable processes we need to understand moisture distribution in cement-based materials. Hence sorption-desorption data are essential. The equilibrium moisture content at a certain RH is higher for materials when desorbing than for the same material absorbing moisture (at the same RH) [7]. The carbonation process requires water and RH from about 50% to 70% is ideal for these reactions to occur. At relative humidity lower than 40% there is not enough water to dissolve carbon dioxide. When relative humidity exceeds 90%, when pores are filled with water, carbonic acid cannot penetrate the saturated pores and diffuse throughout the concrete.

The following figure displays the sorption and desorption isotherms (in a limited range) of tested concrete samples with the addition of horse manure fibers and the synthetic ones.



(a) (b)

FIGURE 5. Sorption (So) and desorption (De) isotherms of samples with different amounts of fibers (a) and horse manure (b) versus relative humidity (in a limited range).

Sorption and desorption isotherms (in a limited range) of tested samples have a similar appearance. The samples with fibers have a higher moisture content than the horse manure samples with the same w/b-ratio; means that the samples with fibers have a greater amount of gel pores and a lower amount of capillary pores. At low RH-s, all samples have similar desorption curves. The least hysteresis can be seen for the sample with 10% horse manure.

CONCLUSION

Minimal thermophysical properties changes after freeze-thaw test were for horse manure as a natural fiber additive to concrete. The sample with 10 % horse manure showed the highest resistance to freeze-thaw test. Changes in all tested thermophysical properties were within the statistical error (less than 5%).

The irregular course of measured thermal conductivity and thermal diffusivity for samples with 5% horse manure and 5 % fibers before freezing were most probably due to the not evenly distributed additives. After freeze-thaw cycles, the course of all samples for all thermophysical properties had the same tendency.

Comparing the sorption-desorption isotherms the sample with 10 % horse manure showed the least hysteresis.

It has been reported in the literature that changes in the pore structure can be expected during desorption measurement [8]. Therefore in the next step, we would like to repeat the measurement of sorption desorption isotherms (also at different temperatures) together with porosity measurement of the samples.

ACKNOWLEDGMENTS

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