INFLUENCE OF MICROSTRUCTURE MODIFICATION ON THE CAPILLARITY OF CEMENT MORTARS REINFORCED WITH 6 MM POLYPROPYLENE FIBRES

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Abstract

The paper presents results of capillarity and microstructure tests of four polypropylene-fibres-reinforced cement mortars. All composites were based on ordinary cement CEM I 42,5R and natural quartz sand. In the following recipes different ingredients (superplasticiser, silica fume, air-entraining agent) affecting the porosity structure of cement matrix were used. The capillary experiments consisted on measurements of changing mass of samples exposed to water. Tests were conducted for two months with reference to 12 samples of each composite. On the basis of linear dependence of mass gain on the square root of time, values of the water sorption coefficient were determined for each mortar. Microstructural tests were performed using mercury intrusion porosimetry (MIP).

The results of MIP tests indicated that due to application of chemical admixtures and silica fume, mortars of distinctly different porosity structures were obtained. Influence of microstructure modification was revealed in diverse course of capillary flow in tested composites. Different values of water sorption coefficient, describing the suction rate in the first hours of material exposure to water, were received. Another effect was different moisture content in mortars after 2-moths tests, caused by other absorption rate in a subsequent part of the experiment.

Keywords: cement mortar, capillarity, pore size distribution, polypropylene fibres, admixtures

1. Introduction

Durability of the cementitious matrix materials is closely linked to their possible water penetration. Moist composite is exposed to damages, not only related to the effect of freezing but also as a result of the chemical reactions with aggressive substances that are transported by water inside the material. Therefore, the factors which have a fundamental significance for the servicelife are the material moisture parameters.

The main mechanism responsible for liquid phase water transport is the occurrence of capillary water uptake. Its course is correlated with the pore structure of material. The

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microstructure of cementitious composites can be formed at the material level by the selection of mixture ingredients and their ratio.

One of the most important factors influencing the porosity is a value of water-cement ratio which can be restricted by using plasticising and superplasticising admixtures. The air entraining agents are used with an aim to improve the frost resistance of composites. As a consequence of their activity large diameter air-voids appear, which can still be penetrated through by water, but they also subsequently discontinue the capillaries [4]. Higher matrix tightness can be achieved by using cements with additives, or by introducing mineral additives (e.g. silica fume) directly into the mixture [2, 5]. Discontinuities in structures, e.g. microcracks that enable water to penetrate inside the material, can appear as a result of plastic shrinkage of cement paste, and their further propagation may proceed as a consequence of the mechanical or thermal loads or drying shrinkage. Limitation in number and width of the cracks can be achieved by an introduction of fibrous additives, e.g. polypropylene fibres [1, 7].

The work assessed the possibilities of modelling the course of capillary water transport in polypropylene fibre reinforced mortars by modifying their microstructure, achieved as a result of an application of the above mentioned modificators. Outcomes of the research on the influence of superplasticiser, air-entraining agent and silica fume on parameters of mortars without fibre-reinforcement were presented in [3].

2. Research programme

2.1 Materials

The research programme included microstructure and capillarity investigations of four cement mortars reinforced with polypropylene fibres, with length of 6 mm and diameter of 100 μm. Ordinary Portland cement CEM I 42.5R and natural quartz sand with granulation of 0/2 mm were used to produce the mixes. In the first composite (M1), which was set as a reference, water-cement ratio was kept as 0.55. Composition of mortars M2 and M3 was realigned by reducing water content by 20% and applying superplasticiser in amount of 1.1% of the cement mass. Additionally, to examine the influence of silica fume in mortar M3 5% of cement was replaced by this additive. Composition of mortar M4 corresponded with M1, however, air-entraining agent in amount of 0.3% of the cement mass was applied. From each mortar 12 cylindrical samples (Ø 8 cm × 16 cm) were prepared. Details of mix designs of investigated mortars are given in Tab.1.

2.2 Capillarity tests

First stage of the study was focused on capillary water absorption. In order to avoid an uncontrollable influence of water chemical bonding by an active binder during the experiment, the samples underwent the process of underwater conditioning for 12 months.

Taking into account that the starting moisture condition of the material significantly influences the speed and scale of the capillary transport process, all samples were being dried to a constant mass, thus ensuring the identical initial conditions. The process of drying was based on systematic and progressive increase of temperature to 105^{o}C, followed by cooling the samples. Once constant mass was obtained, all samples were being insulated on their sides with a polyethylene foil in order to enable one-way flow of moisture during the experiment.

Tab.1: Composition of tested mortars

Mortar	M1	M2	M3	M4
w/c or w/b ratio [-]	0.55	0.41	0.41	0.55
PP fibres [g/dm^3]	0.9	0.9	0.9	0.9
CEM I 42.5 R [g/dm^3]	490	525	499	490
Water (containing admixture) [g/dm^3]	270	216	216	270
Sand [g/dm^3]	1519	1629	1629	1519
Superplasticiser [g/dm^3]	-	5.78	5.78	-
Silica fume [g/dm^3]	-	-	26.25	-
Air-entraining agent [g/dm^3]	-	-	-	1.47

After establishing an initial mass, the prepared samples were located in trays filled with distilled water. The cylinder shape samples were located on stainless grates that served as supporting points, which enabled assumption that the water absorbing surface equals sample base surface (50cm^2). The cylinders were kept continuously submerged at 2÷3 mm during the entire experiment. For the period of two months systematic mass measurements were conducted in relation to four selected kinds of mortar (with 12 samples tested of each mortar). The frequency of measurements was correlated with the speed of water absorption. In the period of an intense mass gain the samples were weighed every 1, 2 and 4 hours, and when the process slowed down the measurements were taken every 2, 3 days.

2.3 Microstructural tests

During the next stage of the research structural tests were conducted, based on mercury intrusion porosimetry (MIP) method through the use of porosimeter AutoPore II 9220. Owing to its high and low pressure ports, the apparatus enabled measurement of pores within the range of 3 nm ÷ 360 μm.

For the purpose of conducting structural tests one representative sample of each mortar was taken from the core of relevant cylinder after testing its capillarity. The testing was based on increasing pressure in vacuum chamber with previously dried sample that was submerged in mercury and located inside.

3. Results

3.1 Microstructural test results

The results of the porosimetry tests were used to prepare graphs of pore size distribution (Fig. 1).

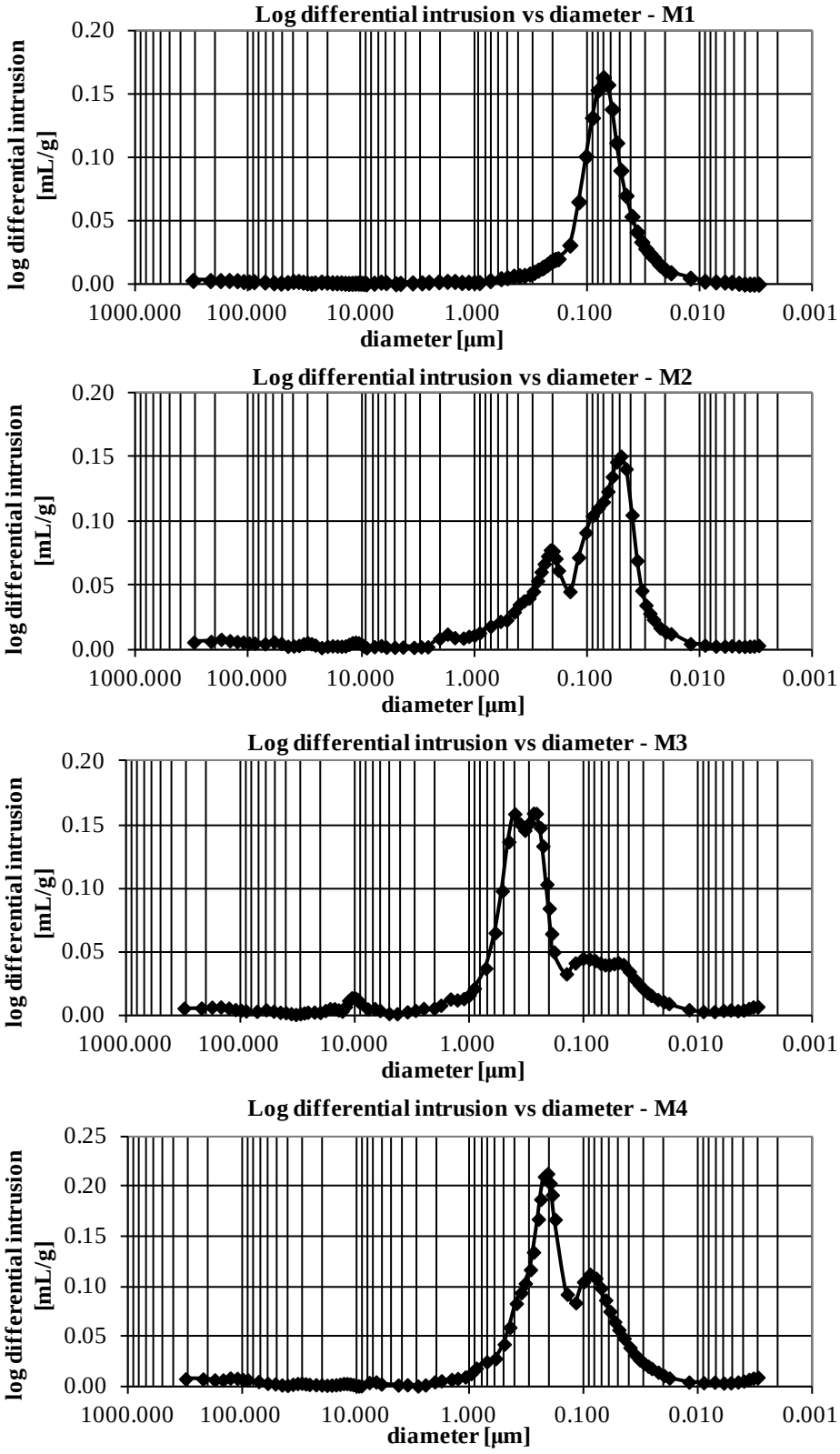

Fig. 1: Pore size distribution of tested mortars M1, M2, M3 and M4

Reference mortar M1, containing basic components and polypropylene fibres, showed unimodal pore size distribution with dominant group of 0.073 μm, which corresponds to the medium size capillary pores.

Reduction of w/c ratio and the use of superplasticiser (M2) plus silica fume (M3) changed characteristics of mortars porosity. In both cases the achieved structures showed wider range of the pores diameters and increased number of local extremes. In the case of mortar M2 noticeable was the shift in diameters of dominant pores towards the finer ones, and an appearance of the large capillary pores. Addition of silica fume had a significant effect on the increase of dominant pores diameters.

Characteristic feature of composite M4 (including air-entraining agent) was its bimodal distribution of the sizes of pores. A shift in pores diameter was noted in this case (0.19 μm). Similarly to mortar M1, second maximum was formed by pores of around 0.08 μm.

3.2 Capillarity test results

The carried out capillarity experiment allowed for the preparation of graphs, illustrating a dependence of cumulative mass of absorbed water per unit area on the square root of time of the experiment. Based on the slope of rectilinear segment of the above dependence, the value of water sorption coefficient was determined for each sample in accordance with the formula [6]:

$$A = \frac{\Delta m_t}{F \cdot \Delta\sqrt{t}} \tag{1}$$

where: A – water sorption coefficient [kg/(m^{2}h$^{1/2}$]; Δm_t – mass change of the sample during the time t [kg]; F – sample surface area exposed to water [m^2]; t – time [h].

Figure 2. shows a distribution of mass gain function for every individual sample in relation to the square root of time, whereas Fig. 3 illustrates the average courses of these dependencies for four tested mortars. Values of water absorption coefficients are presented in Tab. 2.

All microstructural changes which were caused by an application of chemical admixtures and silica fume were reflected by a varied course of the process of capillary transport of water.

The highest value of the sorption coefficient, which characterises water uptake rate during initial stage of contact between the material and water, was recorded for reference mortar M1. An introduction of air-entraining agent to the mixture resulted in a decrease of this parameter by 15%. Significantly better result was obtained for mortar of reduced w/c with superplasticiser (M2). The mortar had its value A at 2.001, which stood for 62% of A_{M1} value. The most considerable decrease in water sorption coefficient, by 55%, was recorded in the case of M3 composition, where 5% of cement mass was replaced with an additive of silica fume.

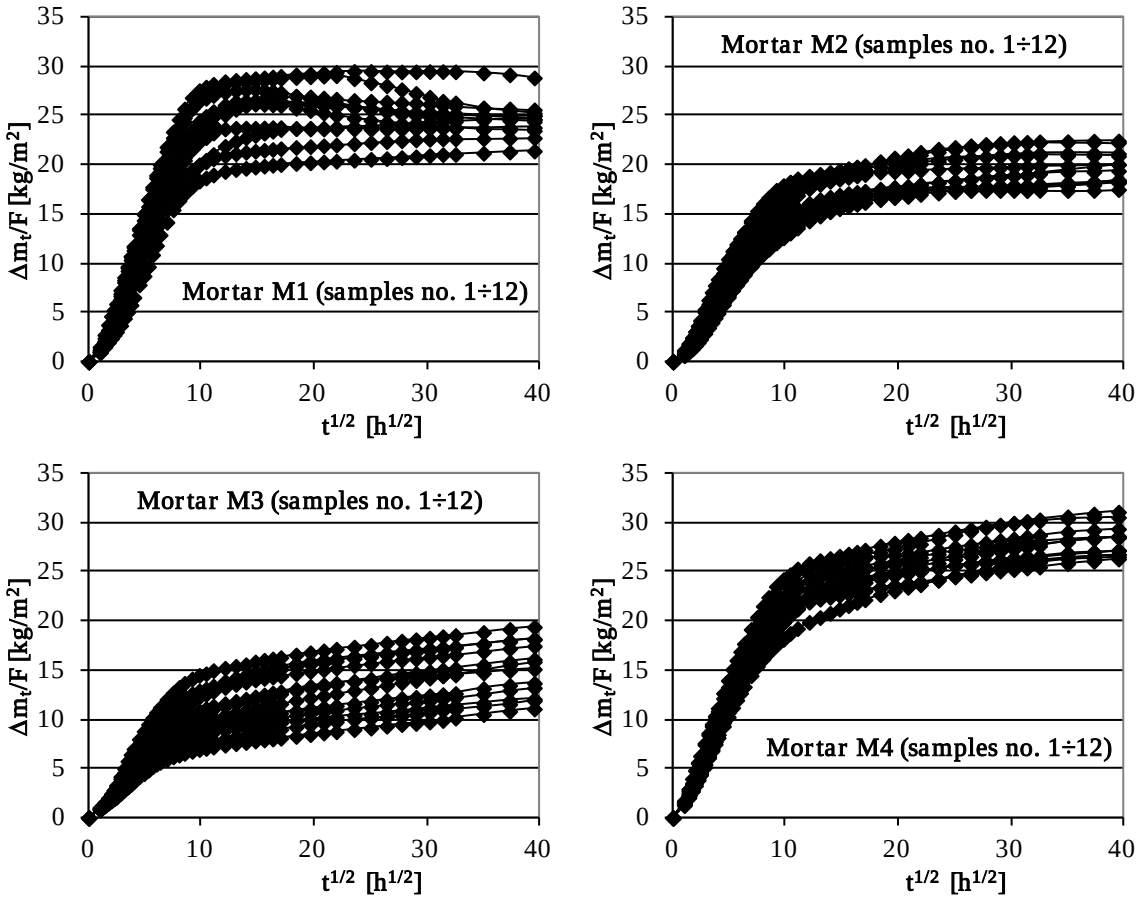

Fig. 2: The cumulative mass of absorbed water per unit area $\Delta m_t/F$ in relation to the square root of time $\sqrt{t}$ for samples of mortars M1, M2, M3 and M4

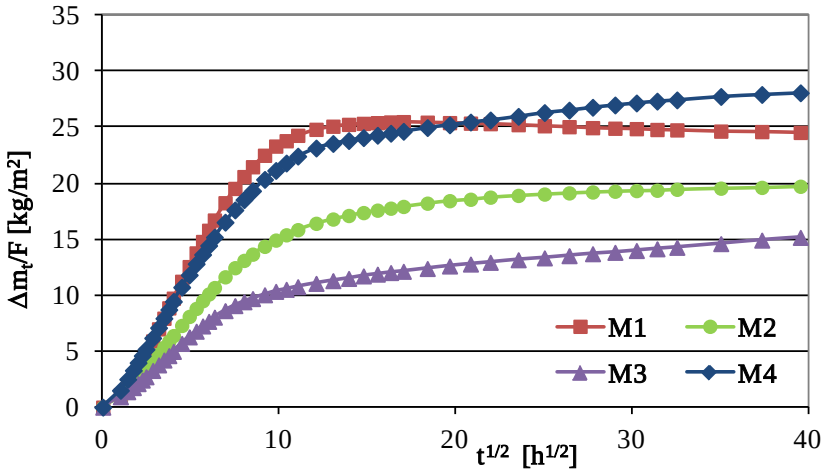

Fig. 3: Average cumulative mass of absorbed water per unit area $\Delta m_t/F$ in relation to the square root of time $\sqrt{t}$ for the tested mortars M1, M2, M3 and M4

It is worth noticing that the influence of microstructure modifications was not limited to changing the value of sorption coeffcient in tested materials. Moreover, a dissimilar course of water capillary transport in more advanced phase of the process was also noted.

The functional course of dependence of cumulative mass gain on the square root of time for mortar M1 meets the criteria of a model description, where two phases can be identified – phase of so-called intensive water absorption and equilibrium stage. After two months of performing continuous testing of this composite, the average final equilibrium moisture content was established at 7.45%.

After initial phase the modified composites were continuously showing noticable increases in mass, however the dynamics of changes was already much slower. As a result of significant slowdown in water absorption during the first phase of the experiement, in case of the two mortars M2 and M3 the obtained final average moisture of the samples came to 6.52% and 4.93% respectively. However, despite 15% decrease in parameter *A* value and as a result of continuous water absorption, mortar M4 attained moisture content of 9.61%, constituing almost 30% increase in relation to the reference mortar.

Tab.2: Values of water sorption coefficients *A* [kg/(m^{2}h$^{1/2}$]

Sample No.	**M1**	**M2**	**M3**	**M4**
1	3.241	2.406	1.559	2.510
2	4.059	1.963	2.358	2.182
3	3.396	2.177	1.545	2.541
4	3.072	2.132	1.087	2.845
5	3.809	2.679	0.870	2.517
6	3.084	1.633	1.067	2.525
7	2.762	1.813	1.011	3.113
8	3.715	1.652	1.411	2.907
9	2.400	1.967	1.605	2.850
10	2.771	2.065	1.963	3.090
11	2.889	1.598	1.282	3.083
12	3.338	1.923	1.509	2.721
Mean value	**3.211**	**2.001**	**1.439**	**2.740**
Standard deviation	0.463	0.308	0.405	0.278

4. Conclusions

Two-phase research programme analysis indicates that all chosen material factors (superplasticisers, air-entraining agent, silica fume) significantly influence the porous structure of mortars. As a result of variously modelled microstructures the capillary transport proceeded differently during both phases of the process – at the initial stage, which included first hours of material exposure to water, as well as at more advanced phase of the process. The most important effect of restricted water penetration inside the mortar was achieved as a result of modification with superplasticiser, which enabled reduction of w/c ratio with additional replacement of some part of cement with silica fume.

Concluding, the microstructure of cement composite can be modelled through correct choice of mixture composition and consequently the course of capillary water transport can be influenced which can improve its durability, freeze-thaw resistance or resistance to chemical aggression caused by e.g. penetrating groundwater.

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