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EXPERIMENTAL ANALYSIS FOCUSED ON THE MATERIAL CHARACTERISTICS OF THE CEMENT-BASED POLYMER-MODIFIED MORTARS

Barbara Kucharczyková*, Hana Šimonová, Romana Halamová, Dalibor Kocáb, Martin Alexa

Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, 602 00 Brno, Czech Republic
* corresponding author: barbara.kucharczykova@vutbr.cz

Abstract. The article deals with the experimental analysis focused on the development of the physical and mechanical characteristics of the cement-based polymer-modified mortars (PCM) during ageing. Two different commercial products commonly used for similar in-situ applications were used for the experiment. The results of the shrinkage, elastic, fracture and strength parameters determined within the time interval from 3 days to 2 years of ageing are summarized and discussed in the article. The performed experimental analysis showed different behaviour of tested PCMs. The most significant differences were observed at the age of 90 days when one of the tested PCM showed a substantial decrease in most of investigated characteristics.

Keywords: Polymer-modified mortar, cement, shrinkage, fracture, modulus of elasticity, strength.

1. Introduction

Cementitious mortars modified by polymers, commonly known as polymer-cement mortars (PCM), find wide use in civil engineering especially in the rehabilitation and protection of both concrete and masonry structures [1, 2]. PCM have a monolithic matrix that uniformly combines the matrix of an organic polymer with the matrix of a cement gel [3]. Thanks to the homogenization of the cement matrix with the polymer, these mortars receive an improvement in some properties – e.g. workability, tensile strength, adhesion, or chemical corrosion resistance [4, 5]. Cementitious mortars can be modified by various polymers; e.g. latex, redispersible polymer powders, liquid resins, monomers, or acrylic and epoxy emulsions. Polymers and polymer-modified materials can nowadays be considered an important component of modern, sustainable civil engineering [6].

Applications where PCM are best used as well as how they are to be technologically implemented are regulated by documents and technical manuals supplied with each product; however, these instructions can often be rather vague. If PCM are wrongly applied, they may fail to perform and put the functionality of the entire rehabilitation system in danger [7]. Differences in the behaviour of PCM can also be expected with varying quality and type of substrate. They may behave differently in combination with e.g. high-quality concrete compared to non-fired bricks. It is also important to properly treat the surface of the substrate (removing dust, wetting and saturating with water) as well as curing the final PCM surface once exposed to the environment. In order to understand the behaviour of PCM and their use it is necessary to know the value of compressive and tensile strength at the age of 28 days as well as the progress of their other material properties, such as volume changes or crack propagation resistance over a long period of time.

2. Experimental part

The main aim of the performed measurements was to determine the development of the selected material characteristics of the PCMs during the ageing and show the specific behaviour which was observed during testing. To simulate inadequate curing conditions which can occur during in-situ applications, all tested specimens were not treated at all during the whole time of ageing and were stored in laboratory conditions with temperature of (21 ± 2) °C and relative humidity of (60 ± 10)%. For the first 72 hours they were stored in the moulds with uncovered upper surface. After demoulding all surfaces were left to dry freely. The results presented in this paper were partially presented in [7] and they are extended herein by the results of the tests performed at the specimens' age of approx. 2 years.

2.1. Materials

Two fine-grained polymer-modified mortars based on the Portland cement were prepared for the experiments. Because the commercial products were used, the trademarks and the composition of these products cannot be specified in the paper. Only general information taken from the technical sheets were used for the specification of the materials. Note, that both mortars are commonly used for similar in-situ applications. For the purpose of the results evaluation, the PCMs were designated as "V" and "VII" sets. The specimens of the "V" set were made of a two-component mixture where a liquid component was an

aqueous copolymer dispersion and a powder component contained a mixture of Portland cements and mineral fillers. The specimens of the "VII" set were made of a single-component powder mix, containing among others silica sand, Portland cement, microfibers including plasticisers and polymers, which was mixed with the prescribed dosage of water to prepare a fresh mortar [7]. Both PCMs were prepared using a hand-held mixer. The mixing process, including the mixing time, was proceeded in compliance with the technical sheet of each product.

Two types of the test specimens were manufactured for the purpose of experiment. The specimens with dimensions of $60 \times 100 \times 1000$ mm were used for the measurement of shrinkage process. Remaining characteristics were determined using the prismatic specimens with dimension of $40 \times 40 \times 160$ mm. All experimental results were evaluated for the specimens' ages of 3, 28, 90 and 730 days and were expressed by the mean value and sample standard deviation calculated from three and six independent measurements in the case of shrinkage and fracture tests respectively.

2.2. Testing techniques

2.2.1. Shrinkage

The shrinkage process was determined using the shrinkage drains with a movable head [8] which enabled to start the measurement of the relative length changes very early after the fresh-state material was placed into the measuring moulds. The inner surfaces of the shrinkage drains with the internal dimensions of 60×100 mm in cross-section and 1000 mm in length were coated with a 2 mm thick polyethylene foam mat to avoid a friction between the mould and test specimen during the measurement. In this way the relative length changes were measured along the central axis of the specimen using an inductive sensor leaning against the movable head of the mould during about 72 hours. Special markers were also embedded into the upper surface of the test specimens during their manufacturing to facilitate long-term measurement of relative length changes after the specimens were removed from the drains. The arrangement of the measurement is shown in Fig. 1. Refer to [9] for the test procedure details.

2.2.2. Dynamic modulus of elasticity

Each specimen was tested for the natural frequency of longitudinal vibration, see Fig. 2. The vibration was produced by a mechanical impulse generated by an impact hammer and the natural frequency was measured using an oscilloscope Handyscope HS4 with an acoustic emission sensor. The dynamic modulus of elasticity was then calculated from this measured natural frequency according to the standard [10] using the equation:

$$E_{dyn} = 4 \cdot L^2 \cdot f_L^2 \cdot D, \tag{1}$$

where E_{dyn} is the compressive dynamic modulus of elasticity in [MPa], L is the specimen length in [m], f_L is the natural frequency of longitudinal vibration measured in [kHz] and D is the material's bulk density in [kg/m^3].

2.2.3. Fracture test

The fracture characteristics were determined based on the results of the three-point bending test of prismatic specimens with dimensions of $40 \times 40 \times 160$ mm provided with an initial notch located in the middle of the specimens' length. The depth of the notch corresponded in all cases approximately to the 1/3 of the specimen's height. The span length was set to 120 mm. A mechanical testing machine FP10/1 was used for testing which enabled the displacement increment loading of the test specimens with a rate of 0.02 mm/min. The loading force (F) and deflection (d) measured in the middle of the span length were continuously recorded into the data logger during the test. Based on the $F - d$ diagrams the elastic modulus was calculated from the initial part of the diagram. The effective fracture toughness was determined using the Effective Crack Model and the work of fracture and the consequent specific fracture energy was calculated using work-of-fracture method [11, 12]. Because of the loss of stability, which occurred during the loading, the value of the work of fracture W_F^* was determined as an area under the proper part of $F - d$ diagrams before stability loss occurred. Refer to [13] for details about the determination of above mentioned characteristics. The informative value of compressive strength was determined on the specimens' fragments after the fracture tests were finished. Arrangement of the fracture and compressive test is shown in Fig. 2.

3. Results and discussion

The results of performed measurements represented by the average values (markers on the lines) and sample standard deviations (introduced in the table) for the specific age of specimens are shown in Fig. 3 – Fig. 5. The results displayed in Fig. 3 show development of the compressive strength (f_c) and dynamic modulus of elasticity (E_{dyn}). Different trend and also different absolute values of these characteristics were recorded for the set "V" and "VII". In general, the "VII" set shows higher values of f_c up to the age of 90 days in comparison with the set "V". On the other hand, a visible decrease in this characteristic was recorded at the age of 730 days, when the magnitude of the f_c is lower than the one at the age of 28 days and is very similar to the f_c value determined for "V" set at the same age. The curve of E_{dyn} values determined for "V" set shows gradual increase during monitored time-interval, whereas the "VII" set values started to decrease at the age of 28 days. In general, it can be stated that increase of E_{dyn} values was insignificant during the monitored time-interval. The results of

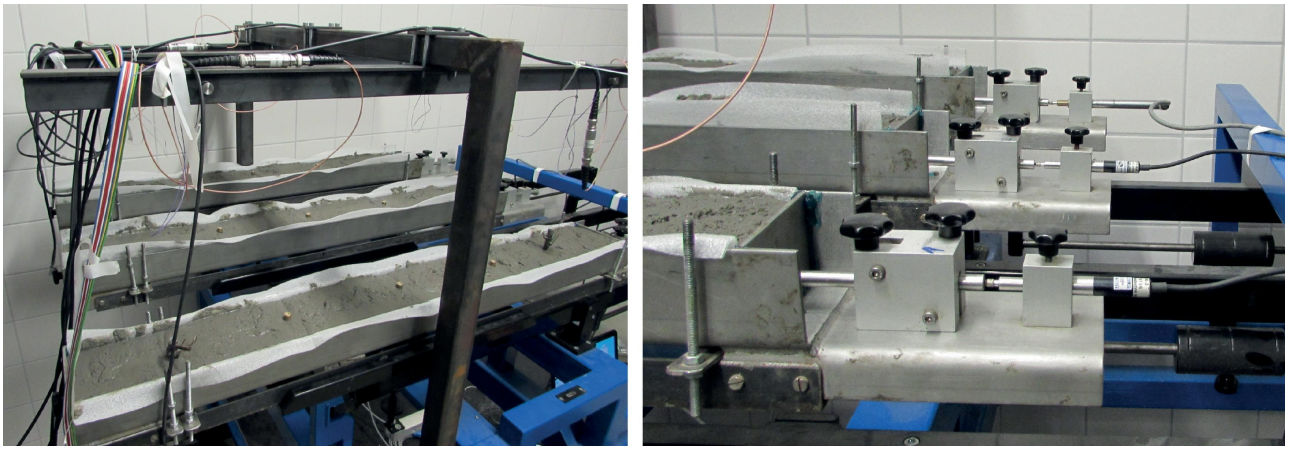

Figure 1. Arrangement of the relative length changes measurement.

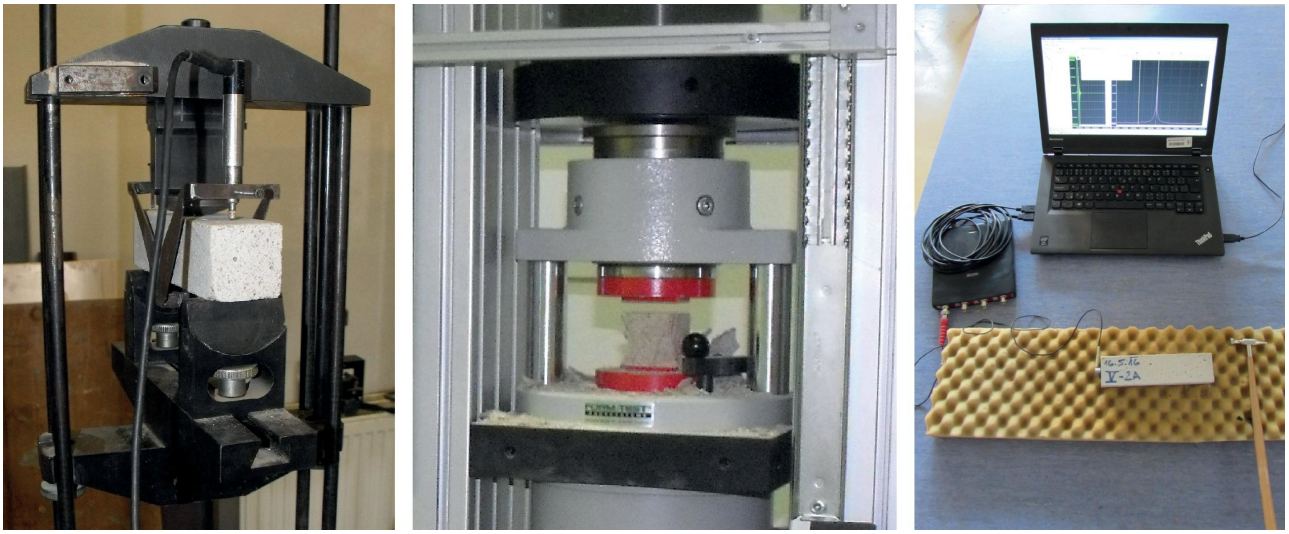

Figure 2. Arrangement of the fracture test (left), compressive strength test (middle) and resonance test (right).

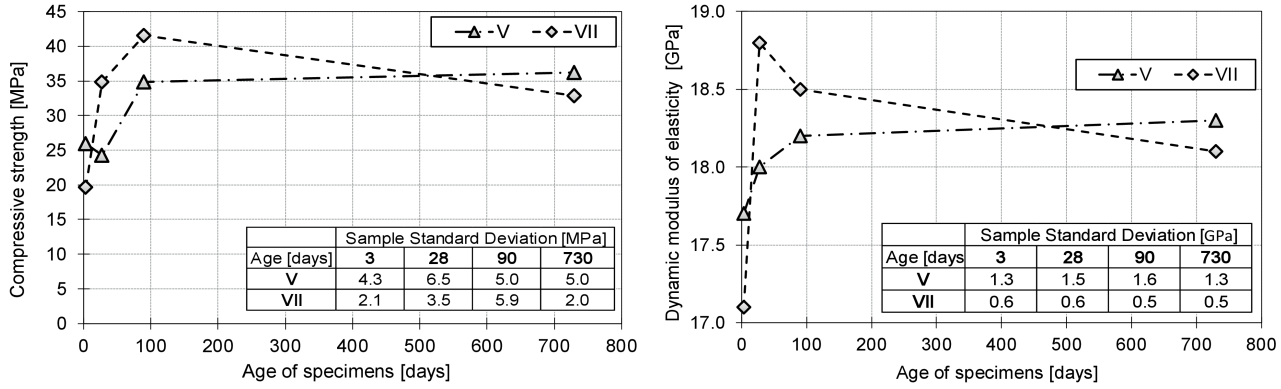

Figure 3. Development of the compressive strength (left) and the dynamic modulus of elasticity.

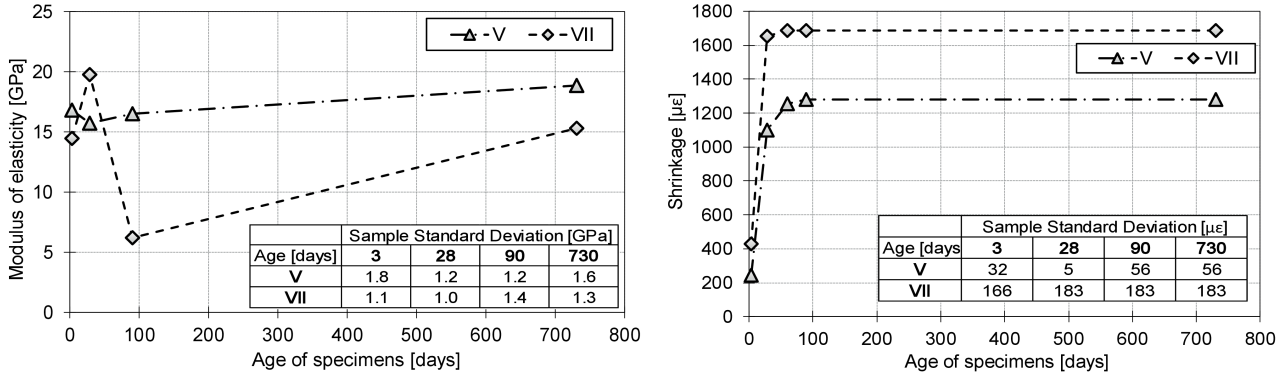

FIGURE 4. Development of the modulus of elasticity determined from $F - d$ diagrams (left) and the shrinkage process.

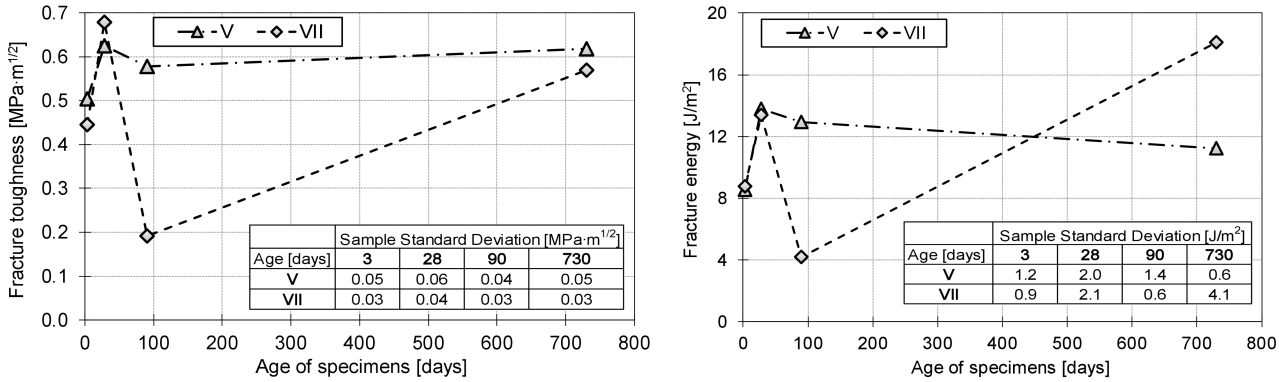

FIGURE 5. Development of the effective fracture toughness(left) and the specific fracture energy.

both characteristics are accompanied by relatively high variability.

In the case of the "VII" set, interesting trends are observed in the development of the characteristics obtained from the fracture tests (Fig. 4 – left and Fig. 5). A steep decrease in the values of elastic modulus (E_{fr}), effective fracture toughness (K_{Ice}) and specific fracture energy (G_F) occur after the age of 28 days. The values of E_{fr}, K_{Ice} and G_F decrease by about 70% within the age of 28 and 90 days. One of the explanation of this steep decrease can be found in the shrinkage curve (Fig. 4 – right) which shows a steep increase in the shrinkage values which reached almost the maximum within the 28 day of specimens' ageing. The results are also accompanied by a high variability. The tests performed at the age of 730 days show an increase in the values of all fracture characteristics within the 90 and 730 days. The values increased approx. 2.5 times, 3 times and more than 4 times in the case of E_{fr}, K_{Ice} and G_F respectively. This increase is supposedly associated with a self-healing ability of the material.

Results of fracture characteristics for "V" set do not show any dramatic decline of the fracture characteristics. The E_{fr} values slowly increase during whole time, values of remaining characteristics (K_{Ice}, G_F) increase up to the age of 28 days. After that both values decrease slightly. The G_F value shows a gradual decrease up to the age of 730 days. The shrinkage curve (Fig. 4 – right) of "V" set differs slightly from the curve of "VII" set. The shrinkage curve determined for "V" set is not so steep within the 3 and 90 days of ageing and the final shrinkage value is about 25% lower. The results show also much lower variability.

4. Conclusions

Despite the fact that both tested PCMs are used for similar in-situ applications, the performed experimental analysis, focused on the long-term development of the selected material characteristics, showed different behaviour of particular PCMs. The greatest differences were observed at the age of 90 days when, in the case of "VII" set, most of investigated characteristics significantly decreased in their values. On the other hand, the tests performed at the age of 730 days for "VII" set showed some self-healing ability of this material which led to the re-increasing of the fracture characteristics especially. The shrinkage curves, determined on the test specimens intentionally exposed to the free desiccation during whole monitored time-interval, showed a steep increase in the shrinkage values for both PCMs. This fact accentuates the necessity to use appropriate curing conditions during theirs in-situ applications. Important is also the fact that most results for both PCMs were accompanied with a high variability.

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