Freeze-Thaw Durability of Fiber-Reinforced Lime-Based Mortars

M. Přinosil [1,a]

[1] *Institute of Theoretical and Applied Mechanics, Academy of Science, Prosecká 809 /76, 190 00 Praha 9, Czech Republic*

[a] *prinosil@itam.cas.cz*

Abstract: This paper presents results of experimental investigation focused on freeze-thaw durability of fiber-reinforced lime-based mortars. Evolution of structural deterioration and frost resistance were evaluated using non-destructive testing (resonance method). In this study, we consider two types of lime-based matrices (pure lime, lime-metakaolin) and two types of polyvinyl alcohol fibers in several volume fractions. The results showed that the resistance against the frost depends mainly on the matrix type and on the amount of fibers.

Keywords: Freeze-thaw durability; Lime-based mortar; Fiber composite; Fiber reinforcement.

1 Introduction

Lime mortars were widely used in the past for construction of buildings and monuments. Nowadays, lime-based materials are required for restoration of ancient structures due to compatibility with the original ones [1]. However, these materials can be often characterized by slow setting, high shrinkage, low strength and low deformation capacity [2]. Therefore, it is necessary to develop new materials, which overcome these drawbacks. For example, fiber reinforcement can improve behavior of a mortar under tensile loading, especially when the damage appears. Our intention is to systematically design the microstructure of high-performance fiber-reinforced lime-based mortar, so that imposed deformation does not localize into a single crack as in conventional mortars, but thanks to fiber reinforcement the mortar exhibits tensile strain-hardening behavior and cracking in the form of large amount of fine cracks (multiple cracking) [3]. Therefore, the mortar retains its macroscopic integrity under relatively high imposed deformations (for example due to volume changes, seismicity, etc.) and exhibits improved durability. The main objective of this work is to clarify freeze-thaw durability of developed mortars.

2 Materials and Specimens Preparation

The proposed mortars consisted of lime-based matrix and fiber reinforcement. Individual components were selected so as to meet criteria for multiple cracking and other desired mechanical properties [3, 4]. In order to ensure appropriate fiber-matrix interaction, fine grained filler represented by quartz sand with maximum particle size 0.3 mm was selected (manufactured by Sklopísek Střeleč, a.s.). The binder was represented by hydrated air lime powder Čerťák class CL 90 (made by Čertovy schody a.s.) and eventually by metakaolin Mephisto L05 (made by ČLUZ s.r.o.), which was employed especially for improvement of tensile strength of the matrix. Fiber reinforcement was represented by two types of polyvinyl alcohol fibers REC 15×12 and RSC 15×8 (both made by Kuraray Company, Ltd.) with different length (8 mm, 12 mm) and surface coating (REC fibers are coated by oil treatment leading to reduction fiber-matrix bond strength).

Ratios of individual components of the matrix were optimized with regard to the desired mechanical properties (tensile strength, fracture energy) as well as to workability of a fresh mixture [5]. Binder to aggregate mass ratio was equal to 1:3, mass ratio of lime and metakaolin to 3:1 (in lime-metakaolin mortars) and water ratio to 0.3 (calculated as ratio of weight of water and all dry ingredients).

With regard to the results of previous research [4, 6], this experiment was performed only on 4 configurations of the composition: pure lime mortar reinforced with 2.0% of RSC fibers (labeled as LS20), lime-metakaolin mortar reinforced with 2.0% of RSC fibers (LMS20) and lime-metakaolin mortar reinforced with REC fibers in volume fraction of 1.0% (LME10) and 2.0% (LME20). From each proposed mixture, a set of 6 prisms with dimensions 40×40×160 mm were prepared. Before testing, they were stored in laboratory conditions (i.e. temperature 20÷25°C and relative humidity 50÷60%) for approximately 2 years.

3 Methodology and Testing Set-Up

The investigation of frost resistance and structural deterioration of specimens was performed using adopted methodology defined in ČSN 72 2452 with non-destructive testing (resonance method) [7].

3.1 Resonance Method

This method can be used for determination of dynamic characteristics of tested materials. It is especially appropriate for homogeneous and isotropic materials, however, it can be used for heterogeneous materials like mortars and pastes as well [8]. The specimen is placed in horizontal position supported in the middle of its span. Excitation of vibrations is provided by impact hammer on one side of the specimens (in longitudinal direction), while the acceleration transducer is attached on the opposite side. The dynamic modulus of elasticity can be calculated for the specimen with a continuously distributed mass and free-free boundary conditions from the longitudinal vibration as:

$$E_{dyn} = \frac{4Lmf_I^2}{bh} \tag{1}$$

where L is the length of the specimen, m is the mass of the specimen, b and h are the cross-sectional dimensions. The first fundamental longitudinal resonant frequency f_I was evaluated by means of Bruel&Kjær device and PULSE Reflex software from signals of the applied force and the acceleration, which were transformed using Fast Fourier Transformation (FFT) to Frequency Response Function (FRF).

3.2 Investigation of Freeze-Thaw Durability

Before testing, specimens were saturated with water by immersion in bath for 24 hours. Each freeze-thaw cycle consisted of freezing at -20±3°C for 4 hours and free thawing at 20±3°C for 2 hours. All dimensions and weight of specimens were measured and dynamic modulus of elasticity E_{dyn} was evaluated using non-destructive testing before testing itself and after each 2 freeze-thaw cycles. Moreover, monitoring of visual aspect of specimens was performed. Testing was terminated when the value of E_{dyn} decreased below the 75% of initial value [7].

4 Results and Conclusions

Fig. 1 shows the evolution of dynamic modulus of tested mortars, while Fig. 2 shows the visual aspects of specimens at the end of testing.

In the case of pure lime mortar reinforced with 2.0% of RSC fibers, the dynamic modulus dropped below the limit value immediately after 2 freeze-thaw cycles. However, the specimens were compact without any visible damage (cracking, spalling of corners, etc.). After another several freeze-thaw cycles, some crack developed in specimens (Fig. 2a), but they were still compact thanks to the fiber reinforcement.

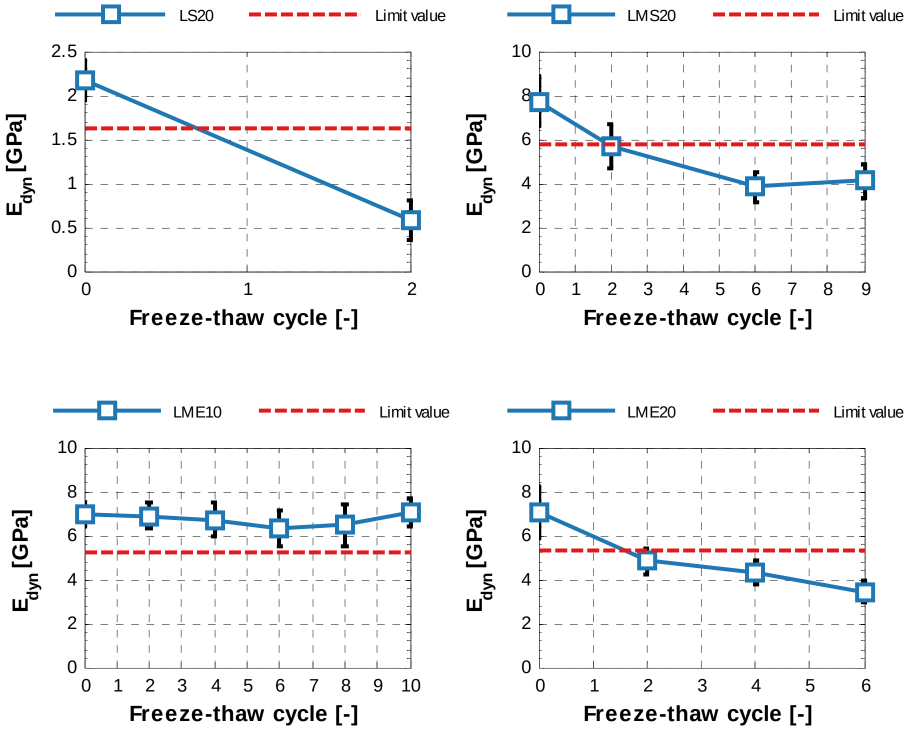

Fig. 1: Evolution of dynamic modulus of elasticity

The lime-metakaolin mortars exhibited higher initial value of the dynamic modulus than pure lime mortar, which confirms that these mortars are stiffer thanks to the addition of metakaolin. In the case of lime-metakaolin mortar reinforced with 2.0% of RSC fibers, the dynamic modulus was equal to the limit value after 2 freeze-thaw cycles and the specimens were compact without any visible damage. After 6 freeze-thaw cycles, the value dropped below the limit value, but the specimens were still compact without any visible

(a) LS20

(b) LMS20

(c) LME10

(d) LME20

Fig. 2: Visual aspect of tested specimens (at the end of the experiment)

damage. After 9 freeze-thaw cycles, the value of dynamic modulus was similar as previous value and the visual aspect did not change (Fig. 2b). In the case of lime-metakaolin mortar reinforced with 2.0% of REC fibers, the results were similar as the previous ones. The best results were achieved for the lime-metakaolin mortar reinforced with REC fibers in volume fraction of 1.0%. The value of dynamic modulus did not drop below the limit value during the testing in 10 cycles and the visual aspect was similar to the initial one (Fig. 2c).

5 Conclusions

The freeze-thaw durability of lime-based mortars reinforced with synthetic fibers in two volume fractions was experimentally investigated. The results revealed that the pure lime mortar suffered from temperature changes and after 2 cycles the value of dynamic modulus dropped below the limit value, however, the specimens were compact thanks to fiber reinforcement. In the case of lime-metakaolin mortar, the values of dynamic modulus of elasticity were generally higher. The results revealed that the evolution of the dynamic modulus of elasticity was similar for both types of polyvinyl alcohol fibers in the same volume fraction. Therefore, it can be concluded that the amount of fibers influenced the durability more than their type. The best results were not achieved for maximum considered volume fraction of 2.0%, but for the volume fraction of 1.0%. This conclusion is consistent with the results of mechanical tests [4, 6].

Acknowledgement

The presented research has been carried out with the financial support of the Czech Science Foundation under the project No. GB P105/12/G059 and institutional support RVO 68378297.

References

[1] J. Lanas, J.I. Alvarez, Masonry repair lime-based mortars: factors affecting the mechanical behavior, Cement and Concrete Research 33 (2003) 1867–1876, doi: 10.1016/S0008-8846(03)00210-2.

[2] A.L. Velosa, F. Rocha, and R. Veiga, Influence of chemical and mineralogical composition of metakaolin on mortar characteristics, Acta Geodynamica et Geomaterialia 6 (2009) 121–126.

[3] V. C. Li, C.K.Y. Leung, Steady-State and Multiple Cracking of Short Random Fiber Composites, Journal of Engineering Mechanics 118 (1992) 2246-2264, doi: 10.1061/(ASCE)0733-9399(1992)118:11(2246).

[4] M. Přinosil, P. Kabele, Mechanical Properties of Fiber Reinforced Lime-Based Mortars Evaluated from Four-Point Bending Test, Applied Mechanics and Materials 821 (2016) 526–531, doi: 10.4028/www.scientific.net/AMM.821.526.

[5] M. Přinosil, P. Kabele, Influence of composition on tensile and fracture properties of lime-based mortar, in proc.: Proceedings of the Conference Nano & Macro Mechanics 2013 (2013), eds. T. Plachý et al., Czech Technical University in Prague, Prague, 163–170.

[6] M. Přinosil, P. Kabele, Fracture Properties of Fiber Reinforced Lime-Based Mortar, in proc.: Proceedings of the 5th Conference Nano & Macro Mechanics (2014), eds. T. Plachý et al., Czech Technical University in Prague, Prague, 143–152.

[7] ČSN 72 2452 + Z1: Testing of frost resistance of mortar. Czech Office for Standards, Metrology and Testing, Prague, 2005.

[8] T. Plachý, P. Padevět, and M. Polák, Comparison of Two Experimental Techniques For Determination of Young’s Modulus of Concrete Specimens, in proc.: Proceedings of the 5th WSEAS International Conference on Applied and Theoretical Mechanics - Recent Advances In Applied And Theoretical Mechanics (2009), eds. C. A. Bulucea et al., WSEAS Press, Athens, 68–71.