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SINGLE CRACK BEHAVIOR OF FIBER REINFORCED LIME-BASED MORTAR

M. Přinosil*, P. Kabele**

Abstract: *The behavior of a single crack in a fiber composite strongly influences its macroscopic tensile behavior after initiation of the cracking. It affects whether the damage locates in one macro-crack or is represented by large amount of fine cracks and the composite retains the ability to carry the tensile stress in hardening response. As part of the research of fiber-reinforced lime-based mortar, the model of a single fiber-bridged crack response was developed, which allows prediction of the cohesive response for experimentally identified micromechanical parameters of individual components of the composite. Subsequently, the direct tensile test was performed with notched specimens of fiber-reinforced mortar to evaluate cohesive relation and also to verify the model. The notch ensures formation and further development of just one crack. The experiment was carried out for several different amounts of fibers in the composite. The results show that the maximum bridging stress is not only affected by strength of the fiber reinforcement, but also by shear strength of the matrix, which reduces the load carrying capacity.*

Keywords: Single crack behavior, Fiber composite, Lime-based mortar.

1. Introduction

Fiber composites are one of the modern trends of material engineering. Fibers in the composite are important not only with regard to shrinkage, but also to carrying capacity after initiation of the cracking. By systematic design of the composition, we can achieve that the composite exhibits hardening response and damages in the form of large amount of fine dispersed cracks during high tensile deformations. In the past, several criteria have been defined in order to attain such behavior (Marshall and Cox, 1988; Li and Wu, 1992). These criteria are related to the behavior of a single crack (either to strength of fiber reinforcement or to energy associated with crack propagation).

In our research we are developing a fiber composite, which shows strain-hardening response and multiple cracking under tensile loading. It consists of lime-based matrix reinforced with short synthetic fibers. The use of this composite is intended for maintenance and repair works of historic building and monuments. One of the tasks during the mixture design is to determine the appropriate amount of fibers in the composite to satisfy the specified mechanical criteria. It is necessary to take into account the workability of fresh mixture as well. Therefore, the direct tensile test on specimens with notch from designed mixture composition was performed. The main purpose of this work is to experimentally evaluate cohesive law of a single fiber-bridged crack (relation between bridging stress and crack opening displacement - COD) and to verify the proposed micromechanical model.

2. Numerical Simulations

In our previous work we proposed the model of a fiber bridged crack, which was able to predict relation between bridging stress and crack opening displacement (Přinosil and Kabele, 2012). It is based on behavior of individual fiber, whose response can be described by analytical relation between applied load and pullout displacement of the fiber (Li and Leung, 1992). Cohesive stress in the model is then calculated as the sum of forces in all fibers bridging the crack divided by area of the crack.

* Ing. Michal Přinosil: Czech Technical University in Prague, Faculty of Civil Engineering, Department of Mechanics, Thákurova 7; 166 29, Prague; CZ, michal.prinosil@fsv.cvut.cz

** Prof. Ing. Petr Kabele, PhD.: Czech Technical University in Prague, Faculty of Civil Engineering, Department of Mechanics, Thákurova 7; 166 29, Prague; CZ, petr.kabele@fsv.cvut.cz

Micromechanical parameters used in these relations were experimentally evaluated (Přinosil and Kabele, 2012; Přinosil and Kabele, 2013). Since the fibers are randomly generated in a volume of the specimen, results show some variance. Fig. 1 shows the results for several considered amounts of polyvinyl alcohol fibers (type REC 15×8, produced by Kuraray Company) in lime-based matrix.

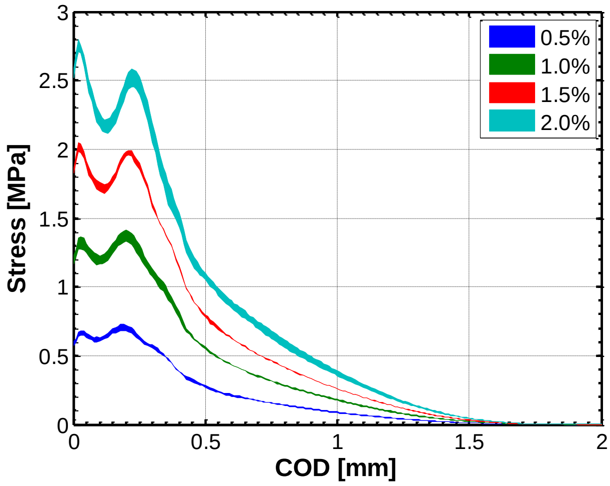

Fig. 1: Numerical tensile stress-crack opening displacement results.

3. Experimental Research

Experimental research was carried out in order to evaluate the single crack cohesive relation and also to validate the model. From fiber-reinforced lime mortar specimens with dimensions 16×55×80 mm were prepared with a thin notch around the whole cross-section at the middle of the specimen (Fig. 2, left). The notch was made in order to ensure formation and further opening of a single crack during tensile loading. Before the beginning of the test, the front surface of the specimen was covered by a contrasting color for the image analysis of displacements (Fig. 2, right).

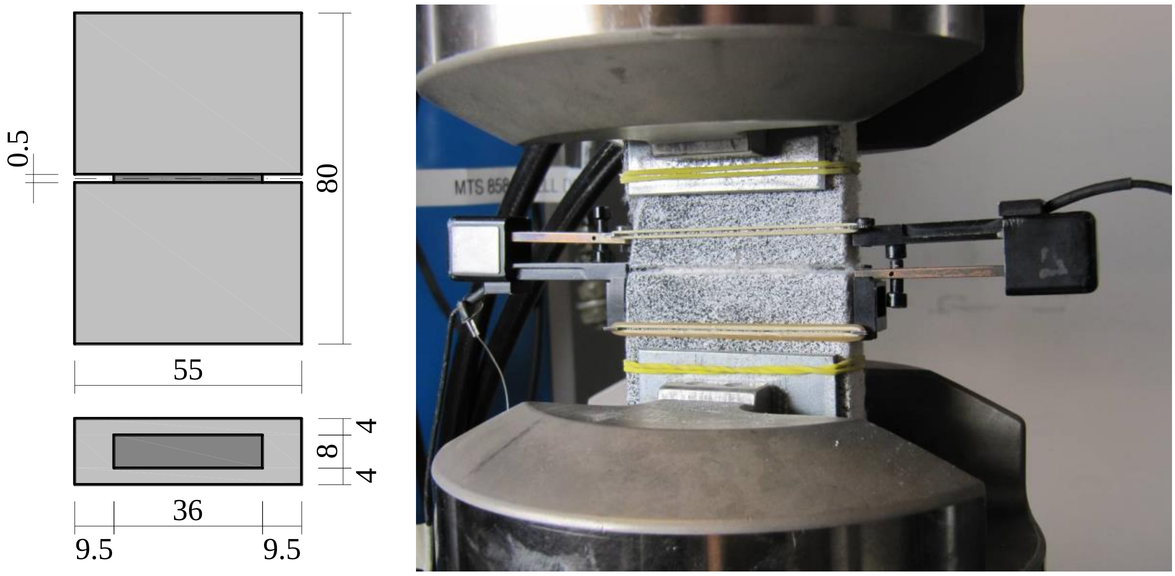

Fig. 2: Specimen geometry (left) and tensile test setup (right).

Direct tensile test was performed by means of the MTS 858 system with controlled crosshead displacement. During the experiment, the applied force in load-cell, crosshead displacement, deformation by two extensometers attached to the side surfaces were continuously recorded (Fig 2, right). Furthermore, the high resolution images of exposed part of the specimen were taken with frequency 1 Hz. Fig. 3 shows stress-crack opening displacement diagrams for mortar with four different fiber contents V_f (0.5%, 1.0%, 1.5%, 2.0%).

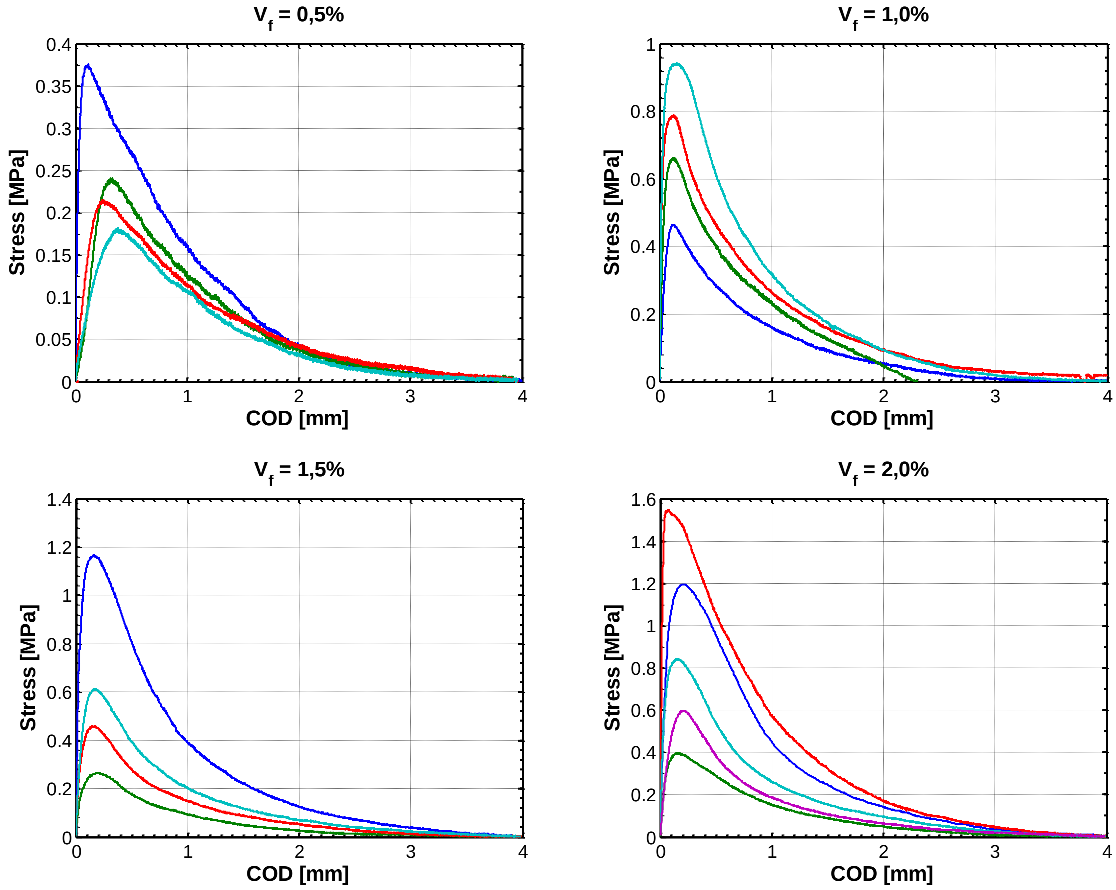

Fig. 3: Experimental tensile stress-crack opening displacement results.

4. Results and Discussion

In comparison with numerical simulations, experimental data show lower values of the maximum bridging stress and high variability. We consider that it is due to unusual mode of the failure. Instead of a typical flat crack, experimental specimens break in the shape of a shear cone (Fig. 4). For this failure mode it is expectable that the strength of fiber reinforcement is reduced because loading direction is not perpendicular to the crack surface. Thus the bridging fibers are more bent on crack surface and the concentration of the bending stress in a fiber reduces its load carrying capacity (Li and Leung, 1992). On the other hand, during breaking in this failure mode the frictional forces between both crack surfaces arises, but does not reach significant values. High scatter of the experimental results could be caused by variability of shear cone shape.

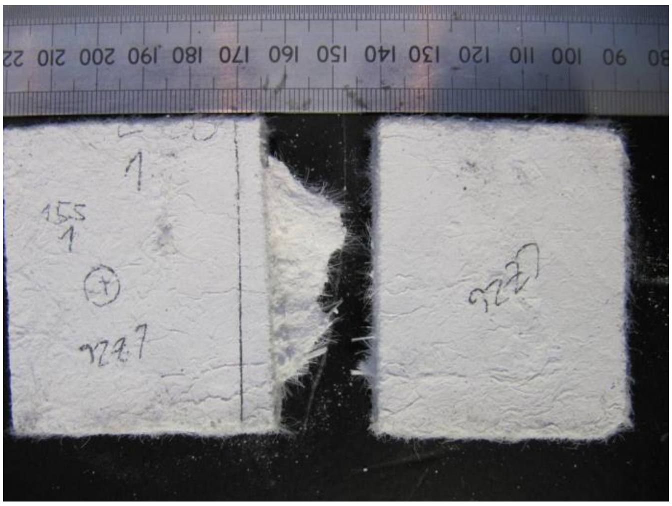

Fig. 4: Shear failure of the specimen.

5. Conclusions

The single crack response of fiber-reinforced lime based mortar has been investigated. Four sets of experimental specimens with different amounts of fibers were prepared and tested. Experimentally evaluated cohesive relations were compared with results of the proposed micromechanical model. In the case of experimental data, the value of maximum bridging stress was lower than the numerical results. It was caused by an unexpected mode of failure similar to a shear cone. This failure mode noticeably reduced the strength of the fiber reinforcement. Therefore, it is necessary to modify the proposed micromechanical model in the future work, so that it will be able to capture this phenomenon. Simultaneously it is necessary to perform detailed evaluation of results using image analysis.

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References

Li, V. C., Wu, H.-Ch. (1992) Conditions for pseudo strain-hardening in fiber reinforced brittle matrix composites. Journal of Applied Mechanics Review, 45, 8, pp. 390-398.

Li, V. C., Leung C. K. Y. (1992) Steady state and multiple cracking of short random fiber composites. Journal of Engineering Mechanics, 188, 11, pp. 2246-2264.

Li, V. C. (2003) On Engineered Cementitious Composites (ECC) – A review of the material and its applications. Journal of Advanced Concrete Technology, 1, 3, pp.215-230.

Marshall, D. B., Cox, B. N. (1988) A J-integral method for calculating steady-state matrix cracking stresses in composites. Mechanics of Materials. 7, 2, pp. 127-133.

Pereira, E. B., Fischer, G., Barros, J. A. O. (2012) Direct assessment of tensile stress-crack opening behavior of Strain Hardening Cementitious Composites (SHCC). Cement and Concrete Research, 42, 6, pp. 834-846.

Přinosil, M., Kabele, P. (2012) Prediction of the behavior of lime mortar reinforced with fibers based on their micromechanical parameters, In: Proc. International Conference on Structural Analysis of Historical Constructions, SAHC 2012 (Jasieńko, J. eds), Wroclaw University of Technology, Faculty of Civil Engineering, Institute of Building Engineering, Wroclaw, pp. 883-889.

Přinosil, M., Kabele, P. (2013) Influence of composition on tensile and fracture properties of lime-based mortar, In: Proc. 4th Conference Nano & Macro Mechanics 2013 (Padevět, P. eds), CTU in Prague, Faculty of Civil Engineering, Prague, pp. 163-170.