MECHANICAL BEHAVIOR OF A THIN LAYER GLASS FIBER STRENGHTENED OLD MASONRY

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Brick masonry structural system is commonly used in Romania and not only. This is due to its many advantages in terms of mechanical behavior based on increased capacity of stress redistribution. In case of seismic actions, many buildings have been partially damaged (in some cases more than 50%) leading to the investigation of appropriate strengthening solutions. In addition to traditional strengthening solutions, composite materials are an advantageous alternative due to the high strength versus weight ratio. This paper presents an experimental and numerical analysis on old brick masonry specimens made with weak lime mortar and limestone sand, subjected to uniaxial compression. The results were compared with finite element numerical analysis in order to show stress distribution between brickwork and strengthening layers applied. Several forms of strengthening application relative to masonry faces (interior and exterior) were considered in the numerical analysis. The beneficial effect on the mechanical behavior of strengthened masonry in terms of stress and strain distribution of both masonry and strengthening layers is shown to be dependent on the thickness of the strengthening layer.

Keywords: masonry strengthening, glass fiber mineral composites, mechanical behavior

INTRODUCTION

Masonry structures made with ceramic bricks were widely used in construction worldwide. Starting with Roman civilization these structural systems have progressed significantly due to the process of baking bricks in kilns. Mortar just as important as brick, is a key component of masonry and has also evolved. This technology has been taken up and used by many civilizations is spread all over the globe.

Depending on local resources, masonry have been adapted to the possibilities of the regions where they were applied. In Italy, lime, clay or volcanic ash are used as binder to make the mortar. Different combinations of mortar were identified in Romania as part of old masonry (Robertson, 1969; Mark and Hutchinson, 1986).

Research in the past years at the Faculty of Civil Engineering of Iasi focused on masonry systems made with local materials (Plesu *et al.*, 2012; Taranu *et al.*, 2013)

One of them is a sandy limestone called *pufar* mined near Iasi on Bucium hill (Pietraria village). Many churches and houses were made with masonry structure and mortar with *pufar* during the XVIIth - XVIIIth century. This mortar is characterized by reduced strength and large deformations capability. These masonry systems have a good behavior to multiple seismic actions that occurred during the life of the buildings analyzed. In this context the apparition and damage increasing to significant degradation require structurally efficient building solutions.

One of these solutions was identified by using a composite material with reinforced glass fiber mineral matrix (Taranu *et al.*, 2012; Baux, 2010; Thomas, 1972). The paper presents some experimental results and numerical analyses on unstrengthened masonry elements and strengthened with composite material.

MATERIALS

For the purpose of the experiments, 20 elements of masonry ceramic bricks with *pufar* mortar were made. The bricks were specially made by molding and baking clay, at 1:2 scale with dimensions of 117x60x36. The sand (*pufar*) was extracted from the hill near to Iasi and sieved with 2 mm sieve. Lime slurry was used as binder. Wet mortar has a good workability and adherence due to lime binder. Figure 1a presents a sample of simple masonry executed with same thickness of mortar joints.

In the second stage, for strengthening samples were used fiberglass mesh alkali resistant with 5x5mm network and mineral matrix. A strengthening layer of 1 cm thick, was applied by pouring fluid into a prismatic shape. The fluid mix is a combination of sand, Portland cement and calcium sulphate in β anhydride III' form manufactured from industrial wastes (Aranda, 2011; Toma, 2013). Figure 1 presents the stages of execution and pouring of masonry samples.

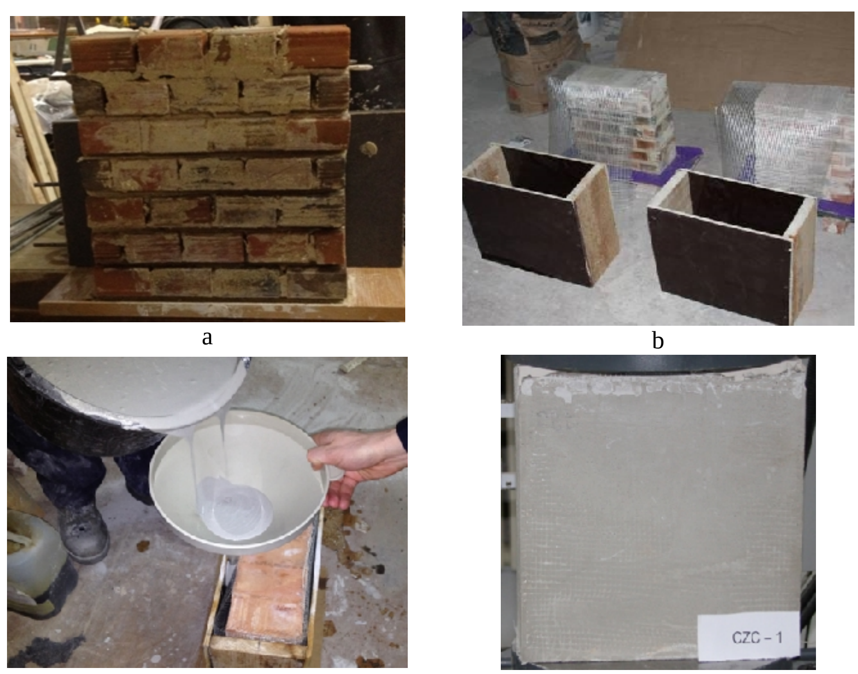
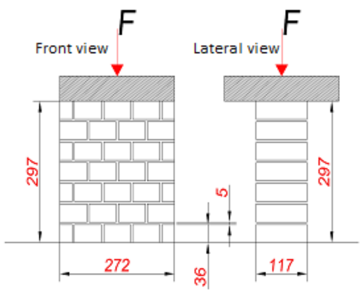


Figure 1. Preparation of masonry samples: a - simple unstrengthened masonry; b - glass fiber mesh reinforcement of masonry samples; c - pouring of the fluid mix; d - the final aspect of the strengthened masonry

All items were kept for 28 days under standardized conditions of temperature and humidity.

EXPERIMENTAL PROGRAM

Before testing the masonry samples, their component characteristics were determined. Masonry elements were tested in compression in a universal machine. Tests consisted of 5 samples of each type of masonry. The dimensions of the samples tested, as well as the loading schema are shown in Figure 2.



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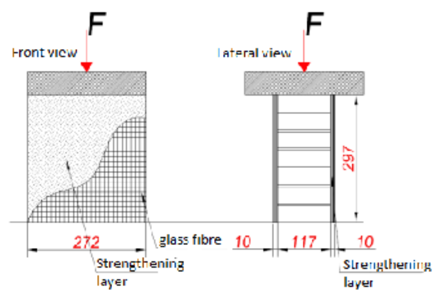

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Figure 2. Dimensions and loading schema: a - uniaxial compression on simple masonry, b - uniaxial compression on strengthened masonry

Testing was force controlled with a loading rate of 0.01 N/mm^2/s, until samples yielded completely. Displacements were measured with displacement transducer of the testing machine. Each of the 5 tests took about 25-30 min. The test was stopped when the failure of the samples occurred.

RESULTS AND DISCUSSIONS

The unstrengthened masonry samples tested in axial compression yielded by the appearance of vertical cracks parallel to the direction of force. They originally appeared in the layers of mortar after that in all the mass of bricks. The strengthened samples failure differs by taking in an early stage of deformation of thin strengthening layer. In these layers cracks were also propagated in the parallel direction to the loading of the sample. In Figures 3 and 4 the stress – strain curve and damaged samples are shown, respectively.

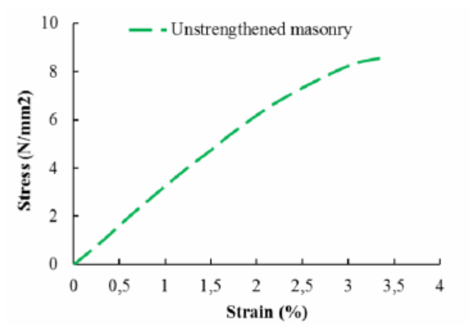


Figure 3. Stress strain curve for unstrengthened masonry

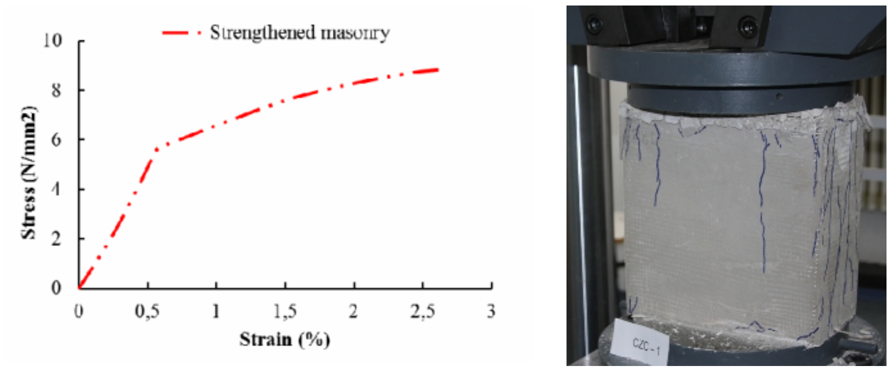


Figure 4. Stress strain curve for strengthened masonry

After completing the experimental tests values and mechanical characteristics were processed several numerical analyses were performed. FEM analyses assumptions were different depending on the composition of the samples. They were considered of distinct volumetric elements of strengthening layer, masonry, mortar or bricks. Figure 5 presents images of the models considered and their discretization.

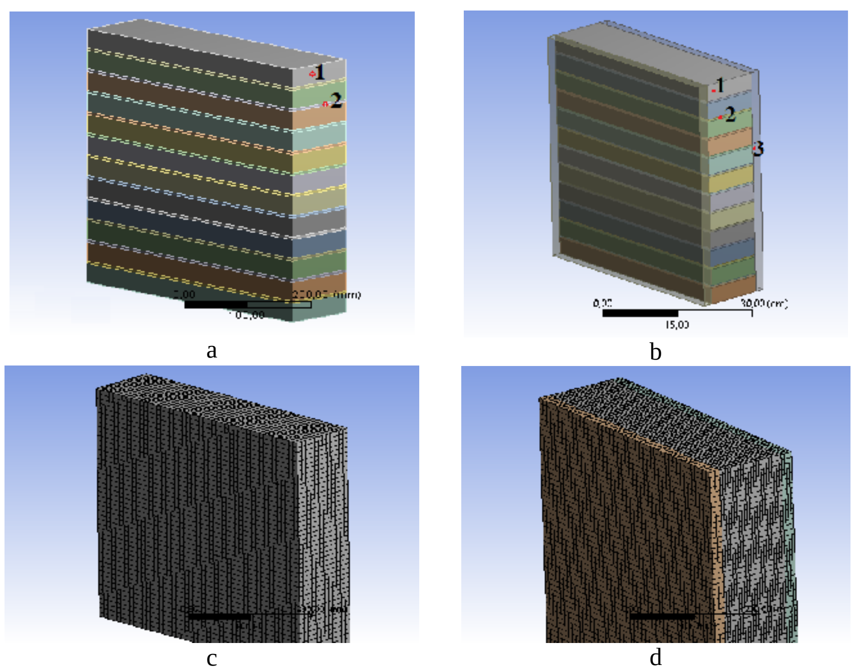


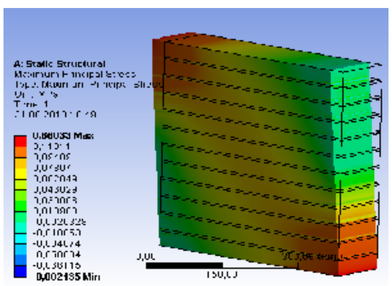
Figure 5. Numerical models analyzed: a - unstrengthened masonry (1 - brick, 2 - mortar); b - strengthened masonry (1 - brick, 2 - mortar, 3 - strengthening layer); c - homogenous simple masonry; d - strengthened masonry with 2 strengthening layers

For the numerical analyses performed on the samples the material characteristics presented in table 1 were used.

Table 1. Material characteristics

Material	Tensile strength (N/mm^2)	Compressive strength (N/mm^2)	Elastic modulus in compression (N/mm^2)
Mortar	0.29	2.30	208.95
Brick	2	14.72	426.23
Masonry	0.17	8.6	322.58
Mineral composite	11.78	26.84	9007

In the numerical model a horizontal load of 1000 N was applied in order to observe the distribution of the maximum and minimum principal stresses and strains. Figure 6 presents de image of map distribution of the maximum principal stresses in the case of the studied model.



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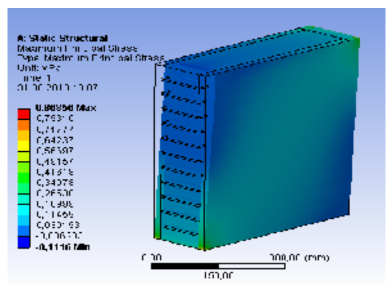

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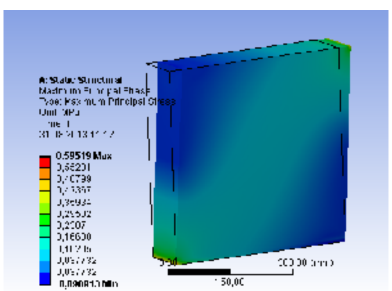

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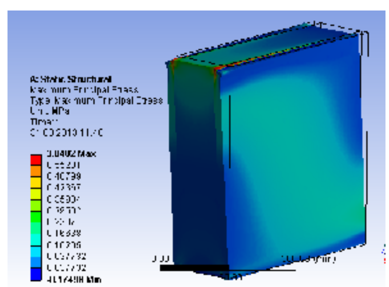

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Figure 6. Maximum principal stress: a - unstrengthened masonry composed model; b - strengthened masonry composed model; c - unstrengthened homogenous model; d - strengthened homogenous model

Comparing the results of numerical analysis and the experimental test the influence of weak mortar on masonry strength is visible. When strengthening layer is applied an increase of overall stiffness and resistance is present.

CONCLUSIONS

Masonry structures are numerous and spread all over the world. The use of local materials led to different behavior of these structures. Due to the age of many of these structures and damages that occurred during their existence, the study of these systems and finding suitable and compatible building solutions is required. In this paper some experimental results of uniaxial compression tests on elements of masonry with local mortar made of calcareous sand, called *pufar* which was used at a large scale in Iasi region were presented. In addition to verifying the material properties some strengthening solution based on glass fiber reinforcement mineral matrix composite were proposed and tested. The mineral composite consists in 50% of fine sand, 25% ordinary Portland cement and 25% of calcium sulfate in β anhydride III' form, manufactured from industrial wastes and fiberglass mesh reinforcement.

The results show a considerable improvement of the behavior of masonry by applying thin strengthening layer on both faces of masonry. The strengthening layer increases capacity and helps to redistribution of efforts in a more uniform manner across the mass of element. This solution can be applied successfully if it is possible to pour on both sides of the walls. Also it was noticed a good compatibility between materials associated (masonry and strengthening mineral composite) both experimental tests and the numerical analyses.

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