EXPERIMENTAL TESTS AND FINITE ELEMENT MODELLING OF GLASS FIBER REINFORCED MINERAL MATRIX COMPOSITES

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The actuality of composite materials and the mechanical potential provided to the structural systems for new construction and strengthening solutions have led to many research studies conducted with great interest. Polymer composite materials have been studied for over 50 years and have been successfully applied in many technologies. In case of building constructions mineral matrix composites have the advantage of high compatibility between strengthened structural element and composite material used. Also these solutions can be used to create new structural elements meeting the same exacting structural requirements as traditional construction systems. This paper presents the results of experimental tests performed on one story structural model laterally loaded after in order to obtain the failure mechanism and maximum strength capacity. The experimental results are compared with FEM numerical analysis. The conclusions show the influence of glass fiber reinforcement and stress distribution in these composite systems, experimentally observed and compared with the numerical analysis results.

Keywords: glass fiber mineral composites, tensile strengthening, experimental tests

INTRODUCTION

The concept of fiber reinforced composite materials was developed in past decades and brittle cement-based paste was reinforced with asbestos fibers when in about 1900 the so-called Hatschek technology was invented for production of plates for roofing, pipes, etc. Glass fiber reinforced concrete (GFRC) was developed in the 1940s, but it was not used until the 1970s (Brandt, 2008). Extensive research carried out since the early 1960 has shown that a suitable composite material can be produced by reinforcing special cements such as gypsum-aluminous slag cement and high alumina cement with low alkali borosilicate glass fiber, commercially available all over the world (e.g. E glass) (Majumdar, 1971).

The ordinary E-glass fibers are not resistant and durable in highly alkaline Portland cement paste and the alkali-resistant (AR) glass fibers without addition of zircon oxide ZrO2 which were introduced by Majumdar and Ryder (Feldman, 1993; Nakagawa and Akihama, 2000; Singh and Garg, 1994).

Recent research work carried out at the Faculty of Civil Engineering of Iasi has shown that an efficient combination between glass fiber and a fluid cement paste can be used in such a manner as to obtain precast low weight panels for modular buildings and also for strengthening solutions of masonry walls (Taranu *et al.*, 2013; 2011). The basic ingredient for obtaining this mineral matrix is the ordinary Portland cement which is also the key ingredient for concrete. If an amount of calcium sulphate in the β anhydride III' form is added, the result is almost spectacular. This mixture needs just 20 % water of entire quantity and it is transformed to a fluid mix which can be cast in small spaces like a 5 mm layer between polystyrene sheets. Calcium sulphate in the β anhydride III' form was developed by French researchers starting with 2008 (Aranda *et al.*, 2011; Baux, 2010).

This article presents some results of the research based on the structural behavior of a prototype building entirely made of glass fiber reinforced mineral composite

(GFRMC). The structural model was tested to a maximum lateral load carrying capacity and numerical analyzed with FEM.

MATERIALS

The fluid mix necessary for an appropriate matrix is the calcium sulphate in the β anhydride III' form which is an ecological binder. This is obtained from phosphogypsum, lactogypsum or citrogypsum and can be used as partial replacement of the Portland cement in a mineral matrix. Adding water and sand with pre-established mix proportions, one can obtain a fluid mineral matrix with fast setting time and good mechanical characteristics in a very short period of time. The fluid mix can be poured in narrow spaces, having a width of at least 5 mm, embedding the glass fibre reinforcement that may be present. However, before using this high workability mineral matrix in structural elements, one needs to follow a two-step procedure. The first step would be the setting of the formwork in the desired shape of the structural element. This can be done by joining polystyrene sheets to one another. In this way, the formwork also plays the role of thermal insulation as in Figure 1. The second step of the procedure is the positioning of the glass fiber mesh as reinforcement before pouring the fluid composite mix into the formwork. The mechanical characteristics were determined in laboratory and the average values are presented in Table 1.

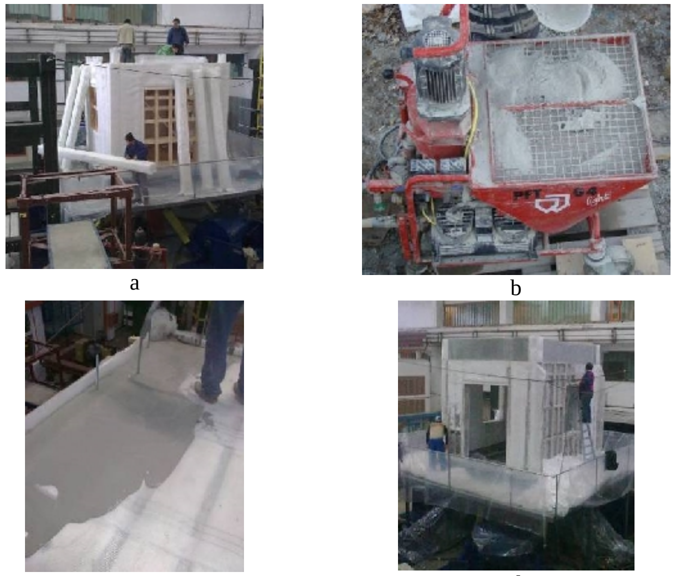
Table 1. Mechanical characteristics of the materials

Material	Compressive strength (N/mm^2)	Tensile strength (N/mm^2)	Compressive elastic modulus (N/mm^2)	Tensile elastic modulus (N/mm^2)
Glass fibre (alkali resistant without emollient obstructing yarn drifting - Mesh density (160 g/m^2)	-	2000	-	72413
Mineral matrix	31.29 [a] 25.72 [b]	7.28[c]	8840	9259
Composite (GFRMC)	28.78[a]	6.24[d]	9836	45595

[a] *Compressive strength on half-prisms;* [b] *Compressive strength on cylindrical samples;* [c] *Tensile strength from bending of the prismatic samples;* [d] *Uniaxial tensile strength on strips*

EXPERIMENTAL PROGRAM

The next step after performing the materials laboratory tests was the design and construction of a modular panel structure. Considering the laboratory facility and the testing machine capability, one story building model was designed with 3420 x 3420 mm in horizontal plan and a height of 3000 mm. Figure 1 shows the plan and the perspective view of the designed structure. The model was built directly on the shaking table platform. The base of the model made of a stiff steel frame was considered fixed and attached to the structure. After the mounting of the panels in their position the pouring and cast of the fluid mixture has started. This operation was done by an appropriate pump for mortars. The premixed binder in dry state form was mixed with the controlled amount of water in the pump. The setting time of the matrix was short and the entire structure was made in 4 hours.



a b c d

Figure 1. Stages of the building experimental model: a – mounting of the polystyrene panels; b – electro-mechanical pump; c – casting of the fluid mix; d – removing of the exterior polystyrene layer

The structural model was tested several times on the shaking table with different seismic actions. The performed tests had different levels of intensity from low with maximum acceleration of 0.1g to high with 0.4g. The maximum level showed that the model was stiff enough and that no damage was produced. After these tests, the model was positioned laterally to the shaking table and hinge connected to the shaking table. In this new position the structure was fixed at the base and laterally loaded by the shaking table with low frequency increasing load. The model was equipped at the same level of action with 2 LVDTs for the displacements measurement and a 200 kN force transducer. Figure 2 presents the equipped structural model before the experimental test.

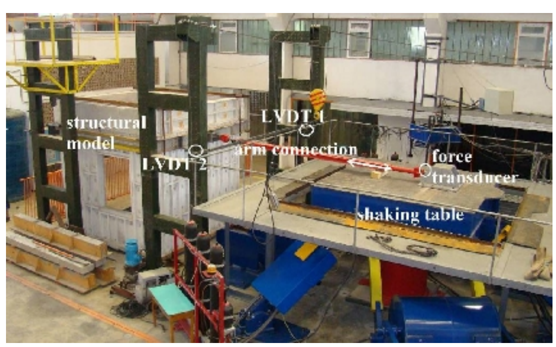


Figure 2. Structural model laterally connected to shaking table

In parallel with experimental test few FEM numerical analyses were performed. Figure 3 presents the loading schema of the side-wall of the structure which respect to the real environment of the test and was FEM analyzed.

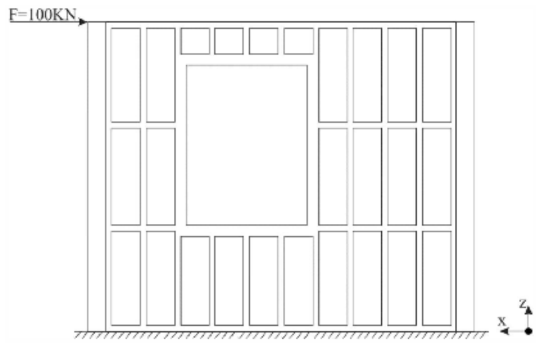
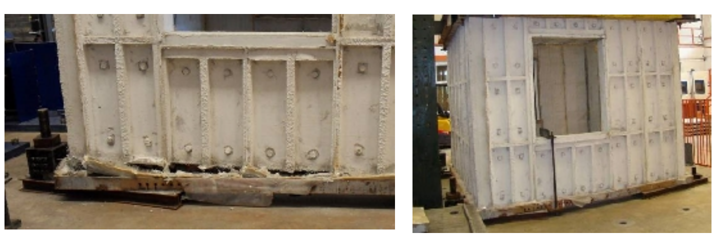


Figure 3. Loading schema of the GFRMC structural wall

RESULTS AND DISCUSSION

The first step of the experimental program was the selection of the loading vs. time action. Few cycle loading of the shaking table with a low frequency starting from 0.1 Hz and variable amplitude were imposed. The first test reveals that strength of the model at the base connection was very low and walls were detached of the base (Figure 4a). The entire model was still stable and stiff. This fact required additional connection of the structure to the base for an improved fitting (Figure 4b). Two additional tie rods were mounted around the window parapets. After this preparation the loading test was resumed.

The additional connections have proved to be effective meaning that the model was fully loaded with the laterally applied force. The last test consists in a push movement of the structure until this was totally damaged. The failure mechanism occurs in the window railings areas and in the corners of the windows. Figure 5 presents the load vs. time curve and the load vs. displacement curve recorded also.



a b

Figure 4. a) Failure of the base connection; b) additional connection of the structural model

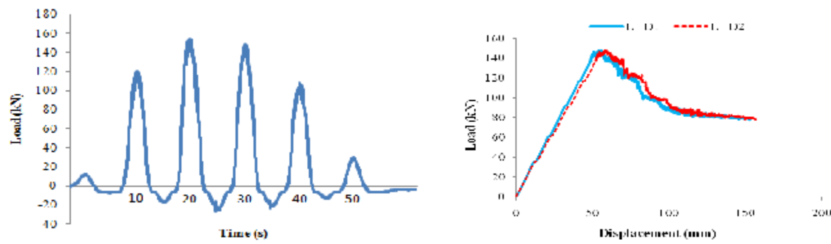


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Figure 5. a) Load vs. time applied on the model; b) load vs. displacements (left D1; right D2)

As was expected in the corners of the windows, the maximum tensile stresses appeared. The strength of the material was exceeded and local cracks developed. Some details with the failure mechanism are presented in Figure 6 and numerical results of the FEM analysis also.

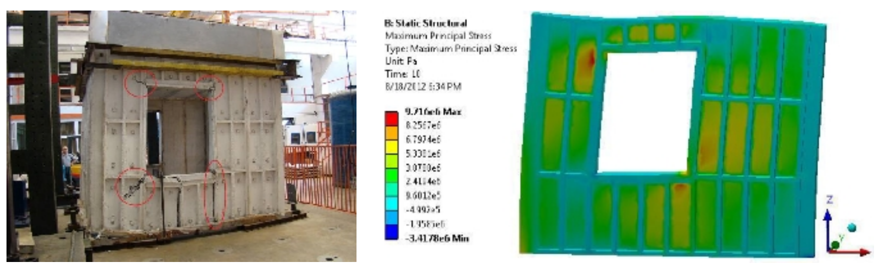

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Figure 6. a) Structural model damaged after the laterally loading test; b) maximum principal stress in FEM analysis

From the load displacement curve of the loading test it can be observed that the material has linear behavior until the cracks appear in the structure. The existence of multilayer of glass fiber reinforcements leads to a step by step failure which shows some ductility of the overall behavior. This means that even if the strength was exceeded large displacements are allowed. From the numerical results it can be observed the distribution of stress in the wall with stress concentration in the corners of the window with a maximum value of 9.7 N/mm^2.

CONCLUSIONS

Recent research showed that there is a possibility of using a green mineral matrix achieved by partial replacement of Portland cement with a binder from industrial waste in construction industry.

The intended use directions relate to the development of structural walls made of mineral matrix reinforced with fiberglass meshes. Another possibility for using this material is the utilization for structural rehabilitation of the load bearing elements from traditional building materials.

However the efficient use of these mineral matrix composites depends on a thorough knowledge of the strength and stiffness characteristics required for the design process; therefore a comprehensive experimental program has been designed and performed.

In this article some experimental and numerical results regarding the maximum laterally load carrying capacity of a composite structure made entirely of glass fiber reinforced mineral matrix has been presented. The built structural model has a total mass of 6 tones. The stiffness behavior and the low weight have proved a good seismic performance in several tests on a shaking table.

The main objective of laterally load carrying capacity experimental tests was the identification of the failure mechanism. The loading schema was numerical modelled with FEM and a map distribution of the stress and strain were analyzed. These results confirm the real behavior of the structural model. The failure mechanism was the result of high tensile stresses in the corners of the windows and high shear stresses occurred in the parapets under the window also.

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