BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LVIII (LXII), Fasc. 1, 2012
Secţia
CONSTRUCŢII. ARHITECTURĂ

EVALUATION OF MECHANICAL PERFORMANCE OF A NEW GLASS FIBER REINFORCED MINERAL MATRIX COMPOSITE

BY

GEORGE ŢĂRANU *, IONUŢ-OVIDIU TOMA, RALUCA PLEŞU and MIHAI BUDESCU

"Gheorghe Asachi" Technical University of Iaşi
Faculty of Civil Engineering and Building Services

Received: February 2, 2012
Accepted for publication: March 28, 2012

Abstract. The use of fibers in different combinations with mineral matrices has started since Biblical times. Clay with different natural fibers like straw or horse hair where combined and obtained strengthened building materials. In the past decades synthetic fibers *e.g.* glass fibers, carbon fibers, were used with polymeric resins and cement matrices also. Finding an appropriate material and structural system made of fiber reinforced mineral matrix which has adequate mechanical performance, possibility of industrialization and a minimum price is a demand for researchers.

This paper presents the experimental investigations on the mechanical properties of a glass fiber reinforced mineral composite material. The strength characteristics were determined by means of uniaxial compression tests conducted on un-reinforced and glass fiber reinforced mineral matrix cylinders (100 × 50 mm) and uniaxial tensile tests conducted on flat specimens (400 × × 30 × 10 mm). The composite material is based on a mineral matrix made of sand – 50%, ordinary Portland cement – 35%, and calcium sulphate in β anhydrite III′ form – 15%. Age of testing was set to 7 and 21 days for compressive tests and 21 days for tensile tests.

*Corresponding author: *e-mail*: gtaranu@ce.tuiasi.ro

The obtained results concerning strengths, strains, elastic modulus are analysed and compared in order of using these values in future FEM analysis. The main objective of materials studied is evaluation of mechanical performance of mineral matrix composites to obtain structural elements or civil engineering structures, especially low cost houses with high structural and thermal efficiency.

Key words: mineral matrix composites; Portland cement; calcium sulphate; glass fiber; mechanical performance.

1. Introduction

Concrete, masonry, steel or wood remains principal materials for building systems. The reasons are multiple: there are almost everywhere in the world, are relatively inexpensive, their production maybe relatively simple, their applications covers many types of buildings and civil infrastructure works. All of these materials have their advantages but also disadvantages. If it can be found a new material with mechanical and physical performance like those well known then it should be researched (Andrzej, 1987, 2008; J.A.G.T., 1972; Majumdar & Laws, 1979).

The extensive research that took place during the past 30…40 years related to composite materials made it possible to better understand their behavior and applicability in the field of civil engineering. Glass fibers reinforced mineral matrix can be used to conceive different structural elements. The basic ingredient for obtaining an optimum mineral matrix with an increased workability and capable to be reinforced with glass fiber mesh is a mix between sand, ordinary Portland cement and calcium sulphate. High workability of the mix is given by the calcium sulphate in the β anhydride III′ form. The latter is obtained from phosphogypsum, lactogypsum or citrogypsum and can be used as partial or total replacement of the Portland cement (Baux, 2010; Aranda *et al.*, 2011).

First results of testing in the lab showed that the mineral matrix can be cast over a glass fiber reinforcement mesh and can lead to structural elements. The structural system can be made from modular panels, vertical and horizontal. Details of the composition and final aspect of the shear wall panels are presented in Figs. 1 and 2 (Ţăranu *et al.*, 2011; Toma *et al.*, 2011).

The fluid mix can be poured in narrow spaces, having a width of at least 5 mm, embedding the glass fiber reinforcement (GFR) that may be present. However, before using this high workability mineral matrix in structural elements, one needs to follow a two steps procedure. The first step would be the setting of the formwork in the desired shape of the structural element (Fig. 1). This can be done by joining polystyrene sheets to one another. In this way, the formwork also plays the role of thermal insulation. The second step of the procedure is the positioning of the glass fiber net as reinforcement before pouring the fluid composite mix into the formwork. After the fluid mix is cast in the formwork panels a structural element is obtained (Fig. 2).

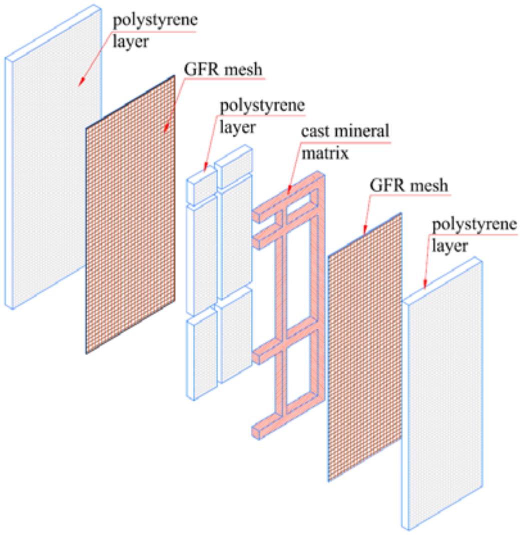

Fig. 1 – The composition of the shear wall panels made of GFR mineral matrix.

Fig. 2 – Prototype of the wall panels made of GFR mineral matrix.

The aim of this paper is to describe the mechanical results of the mineral composite material both for un-reinforced matrix and GFR matrix and to discuss main directions of their application in case of structural systems. The attention is concentrated on mechanical performance of the material and its components.

2. Materials

Cement-based matrices have been developed considerably during the last 40 years. The main components still are Portland cement and coarse and fine aggregate of different origin but there are several other components: super-plasticizers, admixtures and micro-fillers which can increase performance of these mixes. Also proportions between these components have changed. The materials used in this research are readily available on the market. The sand, which occupied 50% of the entire volume of the mineral matrix is rich in quartz and has a maximum grain size of 0.2 mm and was used in dry state.

The Portland cement used in this research was of type CEM II/A-S 32.5 R, with high early strength. The Portland cement was set to occupy 35% from the total volume of the mineral matrix. The third component of the composite mineral matrix, set to occupy 15% of the total volume, was the calcium sulphate in its β-anhydride III′ form, also known as Kerysten. This is a hydraulic sulphatic binder obtained from industrial by-products such as phosphogypsum, lactogypsum, citrogipsum, a.s.o. The product was derived from a hemihydrates ($CaSO_4$, $0.5H_2O$) and anhydride III $CaSO_4$. The combination of the two constitutive materials proved to be a very stable one.

The glass fiber reinforcement, shown in Fig. 3, is a mesh type made of glass fibers arranged along two orthogonal directions. The mesh was chemically treated with a thin alkali resistant layer. The glass fibers are equally spaced apart at 5 mm. The characteristics of the GFR, as given by the manufacturer, are shown in Table 1.

Table 1
Characteristics of the Materials Used

Material	Compressive strength MPa	Tensile strength MPa	Elastic modulus	
			at compression MPa	at tension MPa
Portland cement CEM II/A-S 32.5 R	32.5	3.5	27,500	–
Glass fiber alkali resistant	–	1,100	–	72,413

Fig. 3 – Glass fiber fabric used in matrix reinforcement.

2.1. Mix Proportions

The constitutive materials of the mineral matrix were weighted in their dry state, by means of a digital scale. The reference mix proportion was established as 50% sand, 35% Portland cement and 15% calcium sulphate. Mix proportions for all of the tested specimens are showed, in terms of percentages, in Table 2.

After dispensing of the components in dry state, these were placed in the mixer and mixed for 1 min. The water, representing 40% of the total volume of solid parts, was gradually added within 30 s during the second stage of mixing. Following the addition of water, the entire content was mixed for 30 s at a speed of 140 rpm and for another 90 s at a higher speed, of 285 rpm.

Table 2.
Mix Proportion of the Tested Materials

Spec. no.	Label	Sand %	Portland cement %	Calcium sulphate %	Water/total ratio	Glass fibre fabric %
1	NCK 50/35/15	50	35	15	0.40	0
2	NCK 1GF 50/35/15	50	35	15	0.40	1
3	NCK 2GF 50/35/15	50	35	15	0.40	2
4	NCK 5GF 50/35/15	50	35	15	0.40	5

2.2. Sample Preparation

The obtained fluid mixture was cast in cylinder moulds having the dimensions (height × diameter) 100 × 50 mm as well as flat specimens (prismatic) with dimensions (length × width × thickness) 400 × 30 × 10 mm.

The GFR specimens were cast following the same procedure. Figs. 3 and 4 *a* shows the casting stages of the specimens.

The glass fiber mesh represented in Fig. 3 was positioned with the weave in the longitudinal direction and the weft along the hoop of the cylinders and flat specimens. In case of cylinders the reinforcement ratio was of 5% from the cross-sectional area of the specimens. Details of the reinforced cylinders are shown in Fig. 4.

Fig. 4 – Aspects of the cylinders 50 × 100 mm.

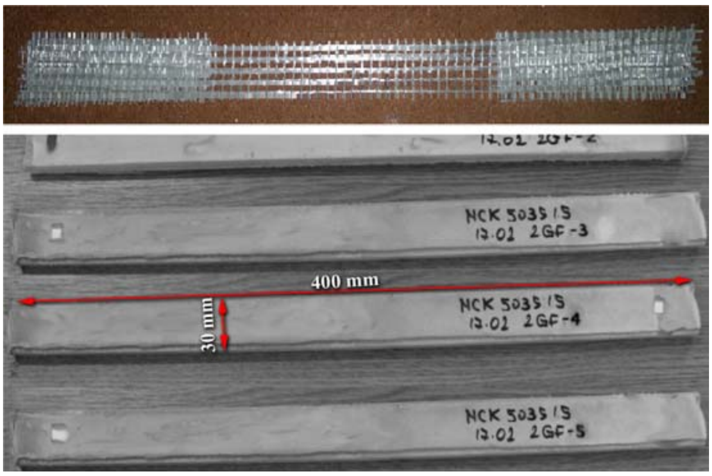

Fig. 5 – Aspects of the flat specimens 400 × 30 × 10 mm.

The flat specimens presented in Fig. 5 were obtained by pouring the fluid mix in 400 × 10 × 30 mm moulds. In case of reinforced samples, the reinforcing mesh was placed in the middle of the mould and the highly fluid mix was cast afterwards. Fig. 2 *b* presents the prismatic elements with their geometrical dimensions used in the uniaxial tensile test. The specimens were reinforced using 1, 2 and 5 layers of glass fiber mesh with the weft positioned along the longitudinal direction. The considered reinforcement ratios were 1%, 2% and 5%. The end sections of the prismatic bars were additionally reinforced using 5 layers of glass fiber mesh on both sides over a length of 100 mm. This was a measure to prevent local crushing of the specimen in the testing equipment. Five samples were made for each investigated case.

3. Experimental Set Up

The tensile strength of mineral matrix was measured by means of uniaxial tensile test conducted on flat specimens both for un-reinforced and GFR mineral matrix. The compressive strength was determined on cylinders specimens. The equipment was calibrated before any experiment could be conducted. The age of the specimens was of 7 and 21 days for the cylinders and of 21 days for the flat specimens. The longitudinal modulus of elasticity was determined both for un-reinforced and GFR specimens in compression and tension tests. The testing equipment is a Universal Materials Testing Machine ZWICK/ROELL model MTM SP 1000, force controlled. The loading rate was of 0.255 MPa/s in compression and 0.1 MPa/s in tension. The extensometer used meets the requirements of Accuracy Class 0.5 to EN ISO 9513 with long sensor arms. The accuracy of macro extensometer is from 20 μm and is given by the calibration report. The Elastic Modulus in compression was evaluated as secant for round specimens with relation

$$E_c = \frac{4L_0\left(X_H - X_L\right)}{\pi d^2\left(L_H - L_L\right)}, \tag{1}$$

and in tension with relation

$$E_t = \frac{L_0\left(X_H - X_L\right)}{ab\left(L_H - L_L\right)}, \tag{2}$$

where: E_c is the compression modulus, [N/mm² or Mpa]; E_t – tensile modulus, [N/mm² or Mpa]; L_0 = 50 mm – initial gage length; X_H – end of compression modulus determination, [N], (40% of maximum compressive strength); X_L – begin of compression modulus determination, [N] (at 0); d – diameter, [mm]; a – thickness of the flat specimen, [mm]; b – width of the flat specimen, [mm]; L_H – strain at X_H, [mm]; L_L – strain at X_L, [mm].

4. Results and Discussion

The cylinder and flat specimens, both unreinforced and reinforced, where tested and stress *vs*. strain curves where recorded. In Fig. 6 there are presented the comparative compressive stress *vs*. strain curves of the cylinders tested in compression. From the analysis of the graph shown in Fig. 6 it can be observed that at age of 7 days the strength in compression is of 13.8 MPa of the unreinforced matrix. At age of 21 days of the same material there is observed an increase of the strength with 39%.

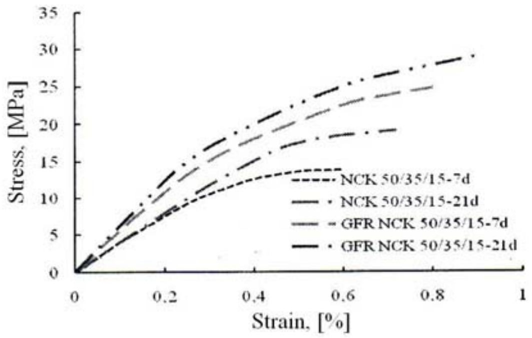

Fig. 6 – Comparative compressive stress *vs*. strain curves of the unreinforced and reinforced cylinders specimens at 7 and 21 days.

In the case of reinforced matrix at age of 7 days the compressive strength is of 24.8 MPa. At age of 21 days was observed an increase of the

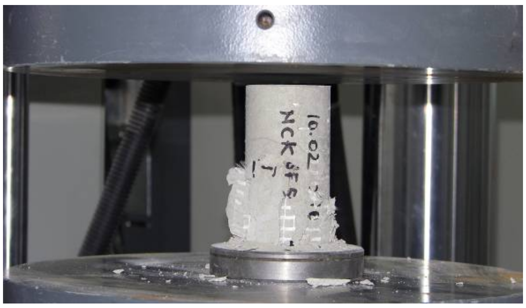

Fig. 7 – Failure of the reinforced cylinders in compression test.

compressive strength of the same material, of 16%. The difference between reinforced and unreinforced matrix it was observed in the failure behavior of the specimens. The unreinforced matrix was more fragile than the reinforced one. In Fig. 7 is presented the aspect of the tested glass fiber reinforced cylinder in compression.

Values of the elastic modulus in compression obtained from these results are presented in Table 3. It can be observed that there are some differences from the specimens which depend on the testing age and the presence of the glass fiber as reinforcement.

Table 3
Average Values of the Compressive Elastic Modulus

Specimen	Elastic modulus in compression N/mm^2	
	7 days cure period	21 days cure period
NCK 50/35/15	3,740	3,934
GFR NCK 50/35/15	5,280	5,500

In the case of flat specimens all of the tested specimens have a cure period of 21 days. The uniaxial tensile strength of the unreinforced specimen was determined to be of 1.4 MPa. There is a 82% increase in this value for the specimens reinforced with one layer of glass fiber mesh, reaching 2.6 MPa. Both strength and deformability exhibit a significant increase from the un-reinforced specimens to the reinforced ones. Adding an extra layer of reinforcement leads to an increase of 135% in the value of the tensile strength and the corresponding maximum longitudinal strain.

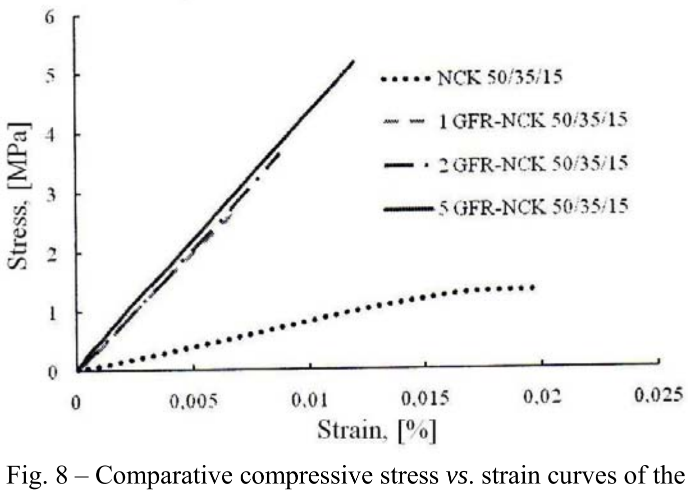

Fig. 8 – Comparative compressive stress *vs*. strain curves of the unreinforced and reinforced flat specimens at 21 days.

When 5 layers of glass fiber mesh reinforcement are used, the recorded tensile strength was of 5.2 MPa, almost a 371% times increase compared to the un-reinforced specimen. At the same time, the maximum corresponding strain decreased 1.65 times lower. Fig. 8 presents the comparative stress *vs*. strain curves of the tested specimens. Fig. 9 shows the aspect of the specimen tested where the glass fibers are broken.

Values of the tensile elastic modulus obtained from these results are presented in Table 4. The difference from unreinforced specimens and GFR ones are significant. There is an increase of 5 times of the elastic modulus in tension.

Table 4
Average Values of the Tensile Elastic Modulus

Specimen	Elastic modulus in tension N/mm^2
NCK 50/35/15	8,182
NCK 1GF 50/35/15	41,085
NCK 2GF 50/35/15	41,896
NCK 5GF 50/35/15	42,690

When the glass fiber percentage is greater, there is no significant increase of the elastic modulus (between 1% and 5% of reinforcement) but these values are smaller than the glass fiber tensile elastic modulus.

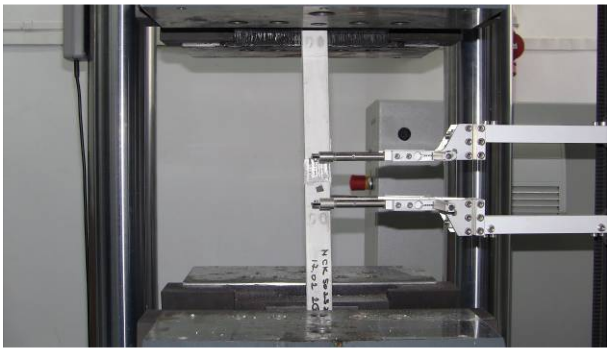

Fig. 9 – Failure of the reinforced flat specimen in tensile test.

5. Conclusions

Mechanical performance, behavior and the effectiveness of GFR mineral matrix composites have been studied in this work.

The results obtained and the observations made clearly revealed that the existence of GFR of maximum 5% not only increased the compressive and tensile capacity of mineral matrix composites but also significantly improved the ductility and Young's moduli of mineral matrix.

It can be concluded that, in the case of uniaxial tensile tests, the glass fiber mesh reinforcement is more effective than it was for the cylinders subjected to compression. Building low cost, light, durable and stiff structures may seem a difficult task. The extensive knowledge obtained from researching composite materials makes it possible to identify a material able to fulfill the durability, strength and economic requirements. Such a composite material is made of a mineral matrix reinforced with glass fiber mesh.

Successful use of various high performance materials based on cement matrix has a considerable positive influence on production of ordinary matrix. The addition of calcium sulphate in its β-anhydride III′ form, also known as Kerysten, obtained from industrial by-products such as phosphogypsum, lactogypsum, citrogypsum, makes possible to obtain an optimum mineral matrix with an increased workability which can be cast in small spaces. This capability leads to obtain structural elements made of mineral matrix composites with a low weight and enough load capacity for a structural monolithic system.

Various experimental and theoretical methods that are successfully applied will certainly be used in further research and development. The importance of determining the strength and the elastic modulus in compression and tension consist in use of these parameters in future FEM design of structural elements.

Acknowledgements. This paper was supported by the project "Develop and Support Multidisciplinary Postdoctoral Programs in Primordial Technical Areas of National Strategy of the Research - Development - Innovation" 4D-POSTDOC, contract nr. POSDRU/89/1.5/S/52603, project co-funded from European Social Fund through Sectorial Operational Program Human Resources 2007-2013.

REFERENCES

Andrzej M.B., *Fibre Reinforced Cement-Based (FRC) Composites after over 40 Years of Development in Building and Civil Engineering.* Comp. Struct., **86**, *1-3*, 3-9 (2008).

Andrzej M.B., *Present Trends in the Mechanics of Cement Based Fibre Reinforced Composites.* Constr. a. Build. Mater., **1**, *1*, 28-39 (1987).

Aranda B., Lanos C., Tessier C., Le Dret F., *Synthèse d'un liant vert capable de concurrencer le ciment Portland*. Journée des doctorants, Comunication orale, Université de Rennes, France, 2011.

Baux C., *Process for the Industrial Manufacture of Compositions Based on Anhydrous Calcium Sulphate*. In *The β-Anhydrite iii' Form, and Corresponding Compositions and Binders*. Patent: WO 2010/003827 A1, January 2010, K and CO (in French).

Toma I.-O. *et al.*, *Influence of Cement and Sand Type on the Strength Characteristics of Mortars with Various Contents of Green Binder*. Procedia Engng., **21**, 196-203 (2011).

Ţăranu G. *et al.*, *Evaluation of Mechanical Properties of Cement and Calcium Sulphate Mineral Matrix*. Bul. Inst. Politehnic, Iaşi, s. Constr., Archit., **LVII (LXI)**, *2*, 131-140 (2011).

Ţăranu G. *et al.*, *Experimental Evaluation of Elastic Modulus of Unreinforced and Glass Fibre Reinforced Mineral Matrix Composite*. (ICEUBI2011) Internat. Conf. on Engng., Universidade da Beira Interior, Covilhã, Portugal, 2011.

J.A.G, T., *Fibre Composites as Construction Materials.* Composites, **3**, *2*, 62-64 (1972).

Majumdar A.J., Laws V., *Fibre Cement Composites: Research at BRE.* Composites, **10**, *1*, 17-27 (1979).

* * * *Portland Cement*. Available from: http://www.lafarge.ro/c_uzual3.

* * * *Glass fiber*. Available from: http://www.fibreglassmesh.co.uk.

EVALUAREA PERFORMANŢELOR MECANICE ALE UNUI NOU COMPOZIT CU MATRICE MINERALĂ ARMATĂ CU FIBRE DE STICLĂ

(Rezumat)

Utilizarea fibrelor în diferite combinații cu matrice minerale a început încă din antichitate. Argila cu diferite tipuri de fibre naturale, ca paiele sau părul de cal, au fost combinate şi astfel s-au obținut materiale de construcții rezistente. În ultimele decenii fibre sintetice, ca fibra de sticlă, fibra de carbon, au fost utilizate cu răşini polimerice şi de asemenea cu matrici de ciment. Găsirea unui material adecvat şi a unui sistem structural realizat din matrice minerală armată cu fibre de sticlă care sa aibă performanțele mecanice corespunzătoare, posibilitatea industrializării şi un preț minim sunt tot atîtea cerințe pentru cercetători.

Se prezintă rezultatele unor cercetări experimentale asupra proprietăților unui material compozit mineral armat cu fibră de sticlă. Rezistențele caracteristice s-au determinat din teste la compresiune axială pe epruvete de tip cilindric (100 × 50 mm) din matrice minerală armată şi nearmată şi din întindere axială pe epruvete plate (400 × × 30 × 10 mm). Materialul compozit mineral este realizat dintr-o matrice minerală alcătuita din nisip – 50%, ciment Portland – 35% şi sulfat de calciu în formă β-anhidridă III' – 15%. Perioada la care au fost testate probele a fost de 7 şi 21 de zile pentru compresiune şi 21 de zile pentru întindere.

Rezultatele obținute, precum rezistențele, deformațiile, modulul de elasticitate, au fost analizate şi comparate în vederea utilizării viitoare a acestora în analize numerice cu metoda elementului finit. Principalul obiectiv al materialelor studiate este identificarea performanțelor mecanice a compozitelor cu matrice minerale pentru a obține elemente structurale sau structuri civile, în special locuințe cu buget redus cu eficiență structurală şi termică ridicată.