3rd International Conference
″Advanced Composite Materials Engineering ″
COMAT 2010
27- 29 October 2010, Brasov, Romania

RESEARCH REGARDING THE INFLUENCE OF REINFORCEMENT ELEMENTS TO THE VIBRATION CHARACTERISTICS OF THE MINERAL COMPOSITE PRODUCTS

Alexandru PĂTRAŞCU[1], Constantin OPRAN[1], Vlad GHEORGHE[1]
[1] University POLITEHNICA of Bucharest, Production Engineering Department, Bucharest, Romania,
alexandru.patrascu@ltpc.pub.ro, constantin.opran@ltpc.pub.ro, vlad.gheorghe@ltpc.pub.ro

Abstract: *Mineral composite products have reached great achievement and high performances in civil industry, construction of prefabricated bridges, machine tool industry, transport industry and wind industry. Mineral composite with fiber reinforcements consist of two or more physically combined different natural solid minerals with fiber in order to create a new material whose properties are superior to those of the original material. Fiber reinforced elements are capable of improving mechanical strength, tensile strength, stiffness, hardness and dimensional stability of products using load transfer from matrix to the fiber and dissipation of forces in the composite structure. Technically, vibration characteristics are more important than ever, due to the more obvious trends: makingmachine-tools with superior performance, work speed with a high dynamic stability, the increasing precision of the machine. The objective of this research is to investigate the factors that influence vibration damping by the reinforcement elements in the fiber reinforced concrete composites. This paper presents a finite elements vibration analysis, simulation of the phenomena and concludes with our vision for future development in the field of mineral composite products.*
Keywords: *mineral composites, reinforcement elements, vibration characteristics, finite elements.*

1. INTRODUCTION

Mineral composite (M_iC_s) products have been created due to the continuous development of science, technology and the market demands for products with lower weight, high strength and high capacity for vibration damping.

An impact of the products made out of mineral composite materials was achieved in civil industry, where fiber reinforced mineral composite materials are used especially in the construction of mineral composite bridges. It also presents a good application in other industry sectors such as machine tool industry, transport industry, wind industry, etc. By using mineral composite materials theyare replacing conventional bridges with bridges made of fiber reinforced mineral composite materials, that have a lifespan of up to 2.5 times greater without a demanding maintenance.

A wide range of mineral composite materials is being tested, although only some of them are already being used. The most important are the following: polymer impregnated concrete (PIC), polymer concrete (PC), glass fiber reinforced concrete (GFRC), fiber-reinforced polymer concrete (FRPC) [5].

Technically, vibration study is more important than ever. If the system parameters describe a movement that varies alternatively in time around corresponding values of the reference state, the motion is called vibration. Vibratory movements may be periodic or not. Vibratory movements are called periodic motion when all parameters are repeating identically after a "T" minimum period, called “vibration period” or simply “time”. Often, the system performs moves of the material relative to the reference condition, movements that can be characterized by a limited number of parameters [9].

A vibration signal has several elements. Amplitude is always a valid measure for the severity of an anomaly. The frequency at which the vibration occurs indicates the source or type of anomaly causing the vibration.There are also systems to which the operation is to produce periodic disturbing forces, or machines that are based on the phenomenon of vibration. It can be concluded that there are cases where the vibrations are harmful and actions must be taken to remove or reduce them, but also cases in which vibrations are beneficial and steps are taken to use their leverage [9].

2. CHARACTERISTICS OF MINERAL COMPOSITE MATERIALS

2.1. Polymer impregnated concrete (PIC):

Polymer impregnated concrete is characterized by impregnating dry precast concrete with a liquid, monomer, and polymerizing the monomer by thermal, catalytic or radiation methods, improving structural and durability properties obtained with this composite system. The ability to vary the shape of the stress-strain curve presents some interesting possibilities intailoring desired properties of concrete for particular structural applications.The system becomes more complex when polymer is added to concrete. The high polymer fills the pores of the hardened cement paste phase, creating still another composite. The system may be considered as being a composite of coarse and fine aggregate in a matrix of impregnated cement (Figure 1) [5].

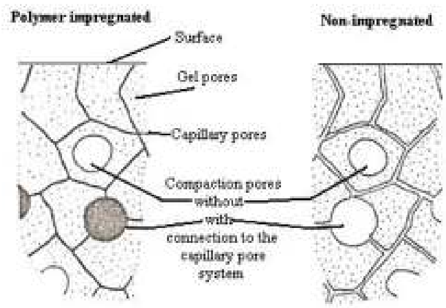

Figure 1: Scheme of pores in hardened cement paste [5]

The most important applications of polymer impregnated concrete are: bridge decking, tunnel support-lining systems, beams (ordinary reinforced beams and post-tensioned beams), underwater habitats, underwater oil storage vessels, ocean thermal energy plants, etc [5].

2.2. Polymer concrete (PC):

Polymer Concrete (PC) represent an aggregate filled with a polymeric matrix. The main technique for producing polymer concrete (PC) is minimizing the void volume in the aggregate mass so as to reduce the quantity of the relatively expensive polymer needed to bind the aggregate. A wide variety of monomers, prepolymers, and aggregates including epoxy polymer have been used to realize PC.

Flexural strengths, though much higher than for plain concrete, are limited by the aggregate-matrix bond strength and by disparities of the aggregate surfaces, which can introduce stress concentrations

PC's investigated cost more than conventional concretes for equal volumes of material, butalthough the density of PC is similar to that of the cement bonded material, the finished products is superioron a cost-to-strength basis [5].

2.3. Glass fiber reinforced concrete (GFRC):

Glass fiber reinforced concrete composites (GFRC) is an engineered material that contains high strength glass fibers surrounded by a cementitious medium. Its properties can change depending on the mix design, fiber content, and the techniques used in manufacturing. In this shape, both the fibers and the environment maintain their natural individual chemical characteristics, and the resulted concrete has improved final properties that cannot be obtained if either of the components is used individually. The glass fibers are the main elements that carry the load, while the enclosed matrix keeps the fibers in the preferred position and direction. The medium facilitates the transfer of the load on the fibers, and shields them from damage due to the environment [5].

2.4. Fiber-reinforced polymer concrete (FRPC):

Fiber-reinforced polymer concrete (FRPC) is characterized by a concrete matrix reinforced with fibers that have or not uniform distribution. Fibrous reinforcement is used to improve the strength and deformation properties of concrete. The concept of fiber reinforcement is to use the deformation of the matrix under stress to transfer load to the fiber. Substantial improvements in static and dynamic strength properties could then be achieved if the fibers were strong and stiff and loaded to fracture, provided there is, of course, a minimum fiber volume fraction.

The most important characteristics of the fibrous reinforcing agent are: fiber geometry, length and/or diameter ratio, fiber volume, fiber orientation, fabrication technique. All of these characteristics profoundly influence the properties and mode of failure of the fibrous composite.

The role of fibers is essentially to stop any advancing cracks by applying pinching forces at the crack tips, thus delaying their propagation across the matrix and creating a distinct slow crack propagation stage. The ultimate cracking strain of the composite is thus increased to many times greater than that of the unreinforced concrete [5].

3. REINFORCING FIBERS

The mechanical properties of most reinforcing fibers are considerably higher than those of unreinforced resin systems. The mechanical properties of fiber/resin composite are therefore dominated by the contribution of fiber to the composite [6].

The four main factors that govern the fiber's contribution are: the basic mechanical properties of the fiber itself, the surface interaction of fiber and resin (the interface), the amount of fiber in the composite (fiber volume fraction) and the orientation of the fibers in the composite [6].

Reinforcing fibers are used to improve the strength to weight and stiffness to weight ratios. Fibers are available in three basic forms: continuous (fibers are long, straight and generally layed-up to each other), there used chopped fiberchopped (fibers are short and generally randomly distributed), woven (fibers come in cloth form and provide multidirectional strength) as shown in Figure 2 [8].

Figure 2: Schematic Illustration of Fiber Types: a. Unidirectional; b. Chopped; c. Woven; [8]

4. VIBRATION CHARACTERISTICS IN MINERAL COMPOSITE PRODUCTS

Vibrations are often unwanted phenomena in the engineering field. When systems start vibrating at the wrong frequencies, the system might fail. Unwanted vibration causes two main problems: fatigue failure and failure due to excessive deformation. Fatigue failure occurs when a component is subjected to sustained cyclic loads. Excessive deformation may be caused if vibration occurs at a resonant frequency. To simplify this, the system is often modeled as a discrete system. Here the system is split up in parts, which are then evaluated separately [9].

Two types of vibrations can be distinguished, being free vibrations and forced vibrations. In free vibrations no energy is exchanged with the environment, while in forced vibrations there is energy exchange [9].

Vibration frequency representation, according to specialized literature [1]:

Law of motion for the vibration frequency modulation:

$$x = x_0 \sin[\omega_0 \cdot \omega(t) + \varphi] \quad \textbf{(1)}$$

t – generic time; x – position; ω– pulsation;φ – initial phase or phase difference;

Function ω (*t*) varies slowly in time and the amplitude remains constant x_0. If exciter force is not harmonic but periodic its expression can be developed as a Fourier series, like:

$$F_p(t) = \frac{a_0}{2} + a_1 \cos \omega t + a_2 \cos 2\omega t + a_3 \cos 3\omega t + \cdots + b_1 \cos \omega t + b_2 \cos 2\omega t + b_3 \cos 3\omega t \quad \textbf{(2)}$$

F_p – disruptive force; in which the coefficients a_0, a_k, b_k have expressions form:

$$a_0 = \frac{2}{T}\int_0^T F_p(t) \cdot dt\ ;\ a_k = \frac{2}{T}\int_0^T F_p(t) \cos(k\omega t) \cdot dt\ ;\ b_k = \frac{2}{T}\int_0^T F_p(t) \sin(k\omega t) \cdot dt\ ; \quad \textbf{(3)}$$

T – vibration period;

Expressing the equation of motion of a not-periodic vibration with the help of Fourier series and determining coefficients a_k, b_k is called Fourier analysis of vibration.

Exciter force can be develop also in form:

$$F_p(t) = F_0 \sum_{k=1}^{\infty} F_k \sin(k\omega t + \varphi_k) \quad \textbf{(4)}$$

5. MODELING AND SIMULATION OF THE PHENOMENA USING FINITE ELEMENTS ANALYSIS IN MINERAL COMPOSITE PRODUCTS

In order to make the modeling and simulation of the phenomena using finite elements analysis for mineral composite products we have used CATIA v5 r20 software, more exactly Generative Structural Analysis and Composites Design modules. The analysis was made on a plate of 200x600x20 mm dimensions plate made by mineral composites. As materials we used GFRC (glass fiber reinforced concrete) and a fiber reinforced concrete that we created in Composites Design module of CATIA v5 r20.

The stages needed to simulate the phenomena for the GFRC plate are similar with those we have made for the fiber reinforced concrete that we created in Composites Design module excepting the plate/composite creation. In Generative Structural Analysis model we opened the CATPart file, made in Part Design module, that we define in View Mode and assigned the materials options for GFRC in the Custom View Modes dialog box.

A New Analysis Case was opened to create a frequency analysis case by selecting in the dialog box Frequency Analysis Case option. To create a "*frequency analysis" case* means that you will analyze the dynamic boundary conditions of the CATAnalysis document. A standard structure of analysis specification tree is displayed. The Finite Element Model contains a Frequency Case, which contains empty restraints and masses object sets, along with an empty Frequency Case Solution 1.

To simply support the plate we've applied statically definite restraints as shown in Figure 5.1 (Clamp). On the upper surface of the plate we applied a distribute mass (Mass Surface Density) of 20kg/m^2 supports to create a Frequency Case.

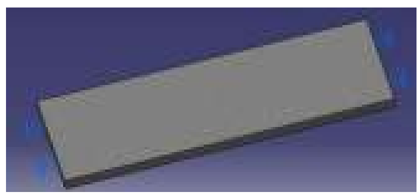

Figure 3: Statically definite restraints (Clamp)

To visualize vibration modes after computing the "*Frequency Analysis Case"* we generate a report. The deformation corresponding to the first vibration mode is displayed, and a deformed mesh image object appears in the specification tree under the "*Frequency Case Solution."* that contains the list of vibration modes with the corresponding frequency occurrences. After computing "*Frequency Analysis Case"* corresponding analysis results: Deformations (Create a deformed mesh image), Von Mises Stresses (Create a von Mises stress field image), Displacements (Create a displacement field image), Principal Stresses (Create a principal stresses image), Precisions (Create an error map image), Analysis report (results creating an analysis report).

The report results for the GFRC:

Table 1: GFRC – Mesh, Materials, Global Sensors and Minimum and maximum privot

Mesh:

Entity	Size
Nodes	238
Elements	564

Materials:

Material	GFRC
Young's modulus	7e+010N_m2
Poisson's ratio	0.23
Density	1980kg_m3
Yield strength	0N_m2
Coefficient of thermal expansion	1e-005_Kdeg

Global Sensors:

Mode number	Frequency Hz	Stability
1	6.9950e+002	5.7855e-016
2	1.6350e+003	2.4931e-011
3	1.8629e+003	5.6098e-011
4	1.8852e+003	7.4765e-010
5	3.4038e+003	3.6673e-007
6	3.5389e+003	1.8179e-007
7	3.9437e+003	3.0697e-006
8	4.0852e+003	1.1082e-005
9	5.4059e+003	1.0925e-004
10	5.6637e+003	1.1429e-004

Minimum and maximum pivot :

Value	Dof	Node	x (mm)	y (mm)	z (mm)
4.9754e+007	Tz	238	-1.1241e+002	-3.3658e+001	1.0000e+001
7.1594e+009	Tz	23	-5.6259e+002	-1.0000e+002	1.0000e+001

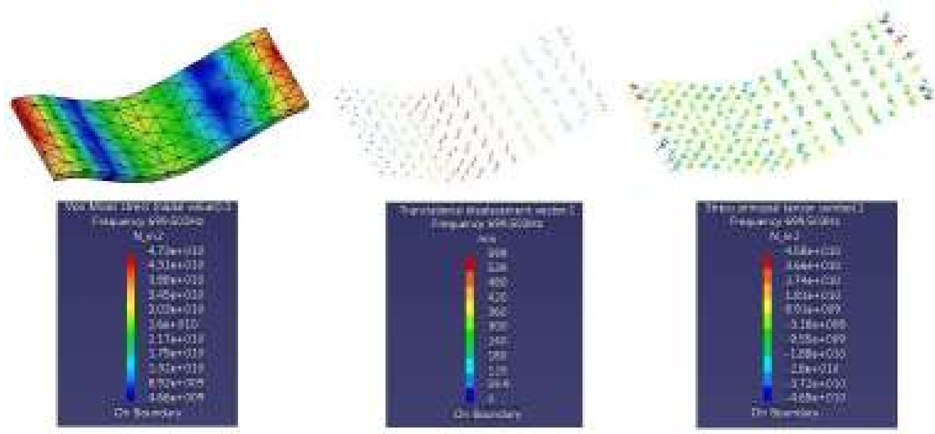

Figure 4: Extract from GFRC finite element analysis report results
Von Mises stress/Translational displacement/Stress principal tensor graph

Table 2: Fiber reinforced concrete – Glass fiber
Mesh, Modal Participation, Global Sensors and Minimum and maximum privot

Mesh

Entity	Size
Nodes	238
Elements	565

Minimum and maximum pivot

Value	Dof	Node	x (mm)	y (mm)	z (mm)
1.7518e+007	Tz	238	-1.1260e+002	-3.3658e+001	0.0000e+000
2.9182e+009	Tz	20	-4.5005e+002	-1.0000e+002	-3.5527e-015

Global Sensors

Mode number	Frequency Hz	Stability
1	3.9384e+002	3.0418e-016
2	9.1227e+002	4.6899e-011
3	1.0428e+003	1.1868e-010
4	1.0611e+003	5.2609e-010
5	1.9056e+003	1.5107e-007
6	1.9799e+003	2.9655e-007
7	2.1996e+003	6.7839e-006
8	2.3338e+003	2.7537e-006
9	3.0256e+003	1.8031e-004
10	3.1665e+003	1.6275e-004

Modal participation :

Mode	Frequency Hz	Tx (%)	Ty (%)	Tz (%)	Rx (%)	Ry (%)	Rz (%)
1	3.9384e+002	0.00	0.00	69.45	0.00	0.00	0.00
2	9.1227e+002	0.00	3.51	0.00	67.85	0.05	0.00
3	1.0428e+003	0.00	8.80	0.00	0.00	10.01	0.00
4	1.0611e+003	0.00	62.27	0.00	3.70	1.28	0.00
5	1.9056e+003	0.01	0.00	1.16	0.00	0.00	0.46
6	1.9799e+003	0.00	0.00	13.36	0.00	0.00	0.12
7	2.1996e+003	0.03	0.00	0.02	0.00	0.00	14.26
8	2.3338e+003	79.16	0.00	0.00	0.00	0.00	0.00
9	3.0256e+003	0.00	0.21	0.01	9.36	0.55	0.00
10	3.1665e+003	0.00	0.11	0.00	0.92	4.54	0.00
	Total	79.19	74.90	84.00	81.84	16.44	14.84

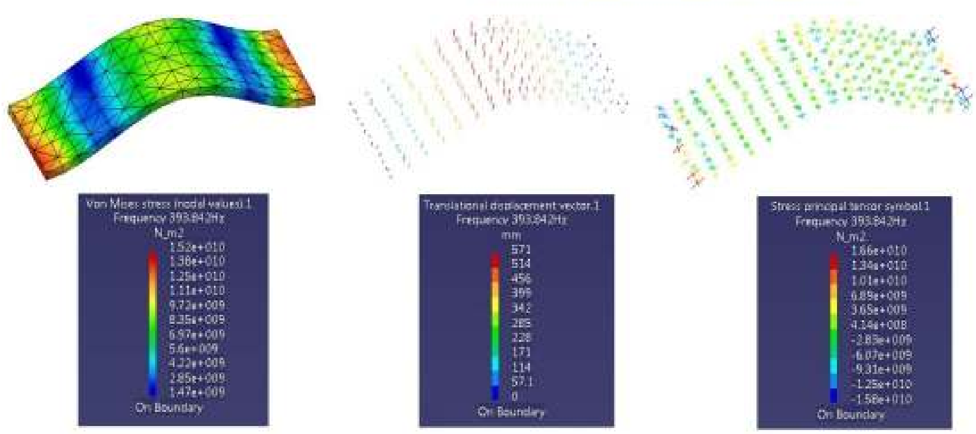

Figure 5: Extract from fiber reinforced concrete – Glass fiber finite element analysis report results
Von Mises stress/Translational displacement/Stress principal tensor graph

The finite element analysis for the fiber reinforced concrete was made in the same way, exception being made only for the plate that was created in Composites Design module. The fiber reinforced concrete plate that was made has a concrete matrix with eight parallel fiber glass layers, each one having a different orientation (0°, 45°,-45° and 90°).

Analyzing the extras tables (Table 1. and Table 2.) and figures (Figure 4 and Figure 5)from the report we are going to see that the difference of the deformation in *Translation displacement vector* is not a considerable one, but in *Von Mises stress* and *Stress principal symbol* the fiber reinforced concrete – Glass fiber is all most four times better than those obtained with the GFRC plate. The continuous fiber, that represent the reinforcement of our fiber reinforced concrete – Glass fiber, that have different directions (0°, 45°,-45° and 90°), represents the main factor of this result.

6. CONCLUSION

This paper studies the effect of reinforcement elements to the vibration characteristics of the mineral composite products. Using the analysis it results that:

a. finite element analysis is a valuable tool for evaluating the structural dynamic characteristics of structures during the design stage, even prior to prototyping. The method can be used to estimate operating stress levels and fatigue life of components and to estimate the natural frequencies, shapes for equipments and supporting structures. Modeling 3D using finite element techniques is an area of ongoing research activity;

b. the type of reinforcing fibers, the orientation of the fibers and the amount of reinforcing fibers significantly affects the response of our plate in the frequency analysis and represents the main factors that influence the vibration characteristics of the mineral composite products;

c. the results of this paper presents important data for the construction of mineral composite bridges that are the life cycle perspective in the infrastructure renewal.

7. ACKNOWLEDGEMENTS

The work has been funded by the Sectoral Operational Programme Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection through the Financial Agreement POSDRU/88/1.5/S/61178.

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