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TEACHING POLYMERIC COMPOSITES IN CONSTRUCTION, A JOINT EFFORT OF EDUCATION, RESEARCH AND INDUSTRY[1]

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Fibre reinforced polymer (FRP) composites are currently finding a large use in many civil engineering areas. They are utilized in all composite structures with special electric and magnetic and corrosion resistance requirements, bridge decks, strengthening and rehabilitation of old structures of various destination and as reinforcement for concrete members. The authors present their experience with teaching of FRP composites as part of civil engineering *curricula*, some research associated projects and practical applications of these advanced materials. The teaching procedures, combined with national and international projects are presented and some demonstration projects implemented since 70s are discussed. Also the involvement of industry in teaching and understanding composites is underlined.

1. Why Composites in Civil Engineering?

The use of composites in all products beginning with automobiles, aeronautics, civil engineering, sporting goods, electricity and electronics, industrial engineering, shipbuilding, tools and medical equipment, railways, etc., is increasing.

Every day we see products made of monolithic materials, which means the individual components consisting of a single material (a non-reinforced plastic), or a combination of materials that are combined in such a way that the individual components are indistinguishable (a metal alloy).

Generally, composite materials consist of two or more materials combined in such a way that the individual materials are easily distinguishable. The engineering importance of a composite material is that two or more distinctly different materials combine together to form a composite material which possesses properties that are

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superior, or important in some other manner, to the properties of the individual components.

An example of composite is concrete or reinforced concrete. It consists of a binder (cement) and reinforcement (gravel), also three-phase composite made of concrete like a monolith and steel reinforcement.

The individual materials that form composites are called *constituents*. Usually composite materials have two constituent materials: a binder called matrix, and reinforcement (much stronger and stiffer than the matrix).

The main advantages of most composite materials are in the weight savings (lightweight – Fig. 1), mechanical and chemical resistance (Fig. 2), low maintenance, and easy design.

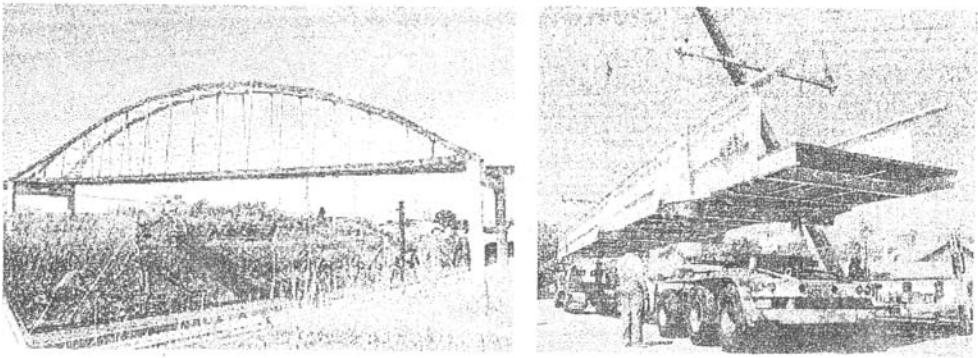

Fig. 1.– Lightweight bridges made of FRP pultruded shapes [1].

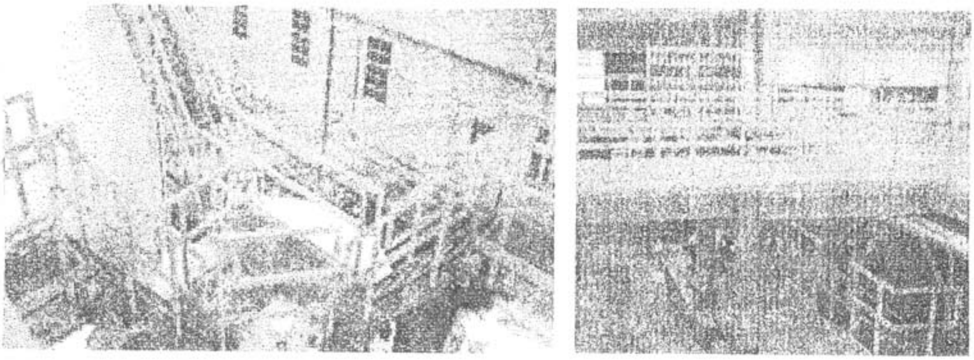

Fig. 2.– Composite stairways in chemical processing environments (*a*) and operating platform in corrosive environment (*b*) [2].

The properties that can be improved by forming a composite material include: strength, stiffness, corrosion resistance, fatigue life, thermal conductivity, and acoustical insulation [3]. Composites have good formability leading to efficient and aesthetically pleasant structures (Fig. 3). The designer can vary the material properties by changing the fibre orientation, fibre percentage, etc. An important role in the design of composites is taken by the right understanding of the fabrication process, material selection, mechanical behavior and structural analysis.

Fig. 3.– Umbrella structure made of GFRP (*a*) [4]; double curved roof elements (*b*).

Fig. 4 shows the phases of a composite system.

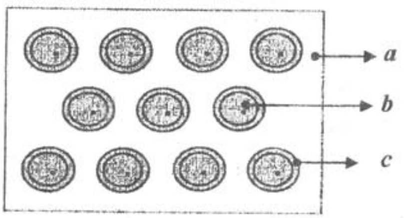

Fig. 4.– Phases of a composite system: *a* – continuous phase (matrix); *b* – disperse phase (fibres as reinforcements); *c* – interface.

The desirable functional requirements of the fibres in a composite are the followings: they should have a high elastic modulus for an efficient use of reinforcement; the fibres should have a high ultimate strength; the variation of strength between individual fibres should be low; the fibres must be stable and retain their strength during handling and fabrication; the diameter and surface of the fibres should be uniform. The polymeric matrix is required to fulfill the following main functions: bind the fibres together and protect their surfaces from damage during handling, fabrication and service life of the composite; disperse the fibres and separate them;

transfer stresses to the fibres; be chemically and thermally compatible with the fibres. The interface region is small but it has an important role in controlling the overall stress–strain behavior of the composites. It exhibits a gradation of properties and it is a dominant factor in the resistance of the composite to corrosive environments. It also has a decisive role in failure mechanisms and fracture toughness of polymeric composites.

2. Why Teaching Composite in Civil Engineering Faculties?

At the Technical University "Gh. Asachi" of Jassy, Faculty of Constructions and Architecture, fourth year students learn about composite materials, an introductory composites design course. They study fundamental aspects of composites design (*i.e.*, micro/macromechanics of composites) and practical aspects and applications. Highlights of the course are: Constituent materials and properties (resins and fibers); Manufacturing processes, Micro/macro-Mechanics of Composites, Design of composite properties (of manufactured panels or fabrics), Failure and Strength design, Sandwich elements, joining of composite material structures.

An important aspect represents the laboratory activities. Students, organized in teams, participate at: manufacturing of panels from basic constituents, testing of samples in tension, shear, testing of a sandwich panel, etc. The final week of the semester is reserved for students to visit (field trip) the Sandwich Panels Manufacturing S.C. OLTPAN S.A.

The objective and scope of the master courses, named "Structural Rehabilitation and Increasing of the Safety Level of the Constructions", provide design guidelines and methodologies for structural shapes and reinforcements for concrete (re-bar and externally bonded fabrics) and wood (bonded plates and fabrics).

The aim of all modules is:

a) To introduce the uniqueness and importance of composite materials for demanding and challenging applications.

b) To enable students to know the major fabrication techniques for the three types of composite materials: polymer matrix composites (PMCs), metal matrix composites (MMCs) and ceramic matrix composites (CMCs).

c) To teach commonly used reinforcing fibres and whiskers in composite materials, such as graphite, glass, Kevlar fibres and whiskers.

d) To highlight the critically important roles of interface in composite materials, types of interfacial bonding and how the interfacial strength may be measured and adjusted for improved performance.

e) To study various geometrical aspects in composite materials and let students know how to work out these basic geometrical relationships in laminae and laminates.

f) To explore the elastic and mechanical properties of composite materials, including unidirectional laminae, in-plane random fibre laminae, short fibre laminae, and laminates.

g) To analyse the stress and strain distributions at fibre ends, load transfer at the interface and the fibre end effects on mechanical properties in composite materials.

h) To use the laminate theory to formulate elastic and mechanical properties of laminae and laminates.

i) To examine the strength (tensile, compressive and shear), fracture energy and failure of various composite materials, including unidirectional laminae, cross-ply and angle-ply laminates, and short fibre composite materials.

j) To use software which help the students in solving and understanding the composite issues [2],...,[4].

Two major applications of composites in civil engineering structures are fibre reinforced polymer (FRP): highway bridge decks and added or embedded reinforcements to sustain overloads.

3. Teaching Methods and Procedures

The technological development in the last two decades requires a greater volume of scientific and technical knowledge. This knowledge can only be assimilated through complex general training. Education update to include the latest scientific achievements implies content restructuring:

a) The implementation of new subjects and chapters as a result of science diversification and integration and scientific information storage. The *Structure Made of Composite Materials* course complies with these content requirements by the educational materials students have at their disposal: collections of reviews like *Reinforced Plastics, Journal of Structural Engineering, Journal of Reinforced Plastics and Composites*, the lecture entitled *Structure Made of Composite Materials* [3], problems and practical applications of composite materials (video-tape and slides presentations, composites materials from laboratory stands), experimental tests to determine mechanical characteristics of composites, computer-assisted training of students using CADEC and Mathcad software.

b) The content of the *Structure Made of Composite Materials* course is oriented towards highlighting the relationships between various knowledge and related fields (strength of materials, theory of elasticity, etc.). It can be seen as a combinatory course which includes knowledge belonging to various scientific disciplines.

c) Information given in the *Structure Made of Composite Materials* course is organized and classified to avoid overloading.

d) Yearly course notes are optimized and are correlated with the latest discoveries in the field.

The educational strategy applied on the *Structure Made of Composite Materials* discipline follows three main directions:

a) The professor transmits the quantity of information involving students in its active and creative assimilation; in other words, the objective is to establish optimum relationships between teaching and learning.

b) The educational strategy acts in a field of factors and possibilities; its results include a certain degree of probability (any educational strategy has a stochastic or probabilistic nature – the balance and the role of the arbitrary factors are different from one strategy to another).

c) The educational strategy also requires a close relationship between the professor's activity and the student's activity.

The educational strategy used in the *Structure Made of Composite Materials* course contains a series of teaching methods and procedures: *lecture* (verbal presentation of the information specific to the technical subject by means of a logical chain of reasonings), *explanation* (the clarification of new concepts, relations and phenomena), *applications, work with the guide and technical publications, experimental tests*, etc.

Since the students studying the *Structure Made of Composite Materials* course have applications on computer as well, we may talk about the algorithmic educational strategy. This programmed training implements programming and algorithmic principles in the educational process. Students reach a special arrangement of the information transmitted by professor through steps and following the steps and logical sequences, they create small programs in MathCAD software. They also use the CADEC software to identify and check the mechanical characteristics of composite materials [6], [7].

Certain cognitive processes such as problem-solving and reasoning are particularly important in engineering tasks. Since most engineering methods involve some form of mathematics, physics, chemistry, this is a critical learning domain. In addition, engineering often involves innovation or invention; hence creativity is very important [8].

4. The Relationship Teaching – Research

Research pioneering in composite materials at the Faculty of Constructions and Architecture in Jassy started in 1968 with the first research projects on polymeric composites. The Composites in Construction Research Group (CCRG) began its activity in he same year.

In 1977 the *Design Guidelines for GRP Construction Elements* occurred and the efforts of the research team materialized in 1980 and 1987 at the *National Conferences on Composites in Construction* (in Romanian).

Between 1970 and 1992 the studies on *Structures Made of GRP* (*Design and Construction*) continued at the Faculty of Constructions and Architecture, culminating with the appearance of *Design Guidelines for Composite Sandwich Elements* in 1995. In 1996 the guide *Structures Made of Composite Materials* (English) was edited, followed by the book *Structures en Matériaux Composites* (French) in 1997.

In the last decade researches have continued with *Work on Structural Rehabilitation with FRP*, studies which have materialized with 9 PhD dissertations on polymeric composite structures and 5 MSc dissertations on polymeric composite structures.

The research groups for each major task consist of 1...2 senior researchers and

PhD and Master students, 5th year and 4th year students actively involved in all activities.

The latest national research grants included various approaches closely related to: material and system selection, testing methodology, evaluation of FRPs characteristics and application procedures. In addition, preliminary investigations on bond between FRP composites and conventional materials carried out to establish the compatibility between the components.

5. Joint Faculty – Industry Activities

The Department of Civil Engineering has close links with the Construction Industry. Members of the Civil Engineering Department and Structural Mechanics Department regularly undertake research and consultancy contracts sponsored by leading Civil Engineering Companies (recent examples Konti Steel Romania-Sandwich Pannels). Staff has an active role in the profession serving on national and regional committees of the Institution of Civil Engineers and the Institution of Structural Engineers, and other professional bodies. Undergraduate students benefit from these links in several ways: 1st year students have a Technical Tutor from a local construction company, who invites the student to visit and work in the Company offices and on construction sites, and introduces the student to the civil engineer profession; 2nd and 3rd year students have the opportunity to choose the place of practice (the construction company or manufacturing construction company).

From the literature survey envisages that the main market in construction industry of FRPs will be in conjunction with traditional materials in hybrid structures with improved performance and in-service properties.

6. Conclusions

After completing the *Structures Made of Composite Materials* course, the student should: appreciate that a unidirectional composite tends to fracture axially, transversely or in shear relative to the fibre direction, understand advantages of composite materials and fabrication processes, be able to apply the micromechanic of unidirectional fiber reinforced composites, understand the macromechanic of an orthotropic lamina, be able to use Maximum Stress or Tsai-Hill criteria to predict how a unidirectional composite will fail under multi-axial loading, implement the thermomechanical analysis of continuous fibre–reinforced composite lamina, understand the advantages and the disadvantages of bonded joints [9],...,[11].

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INSTRUIREA ÎN DOMENIUL COMPOZITELOR POLIMERICE ÎN CONSTRUCŢII, UN EFORT COMUN DE EDUCAŢIE-CERCETARE-INDUSTRIE

(Rezumat)

Compozitele polimerice armate cu fibre sunt utilizate frecvent în domeniul ingineriei civile. Aceste materiale sunt folosite în structuri compozite unde cerinţele electrice, magnetice şi de rezistenţă la coroziune trebuie satisfăcute, tabliere de poduri, reabilitarea şi consolidarea structurilor care au diverse destinaţii şi ca armături pentru elementele din beton armat.

Din experienţa lor în cercetare dar şi în predarea disciplinei *Materiale Compozite*, autorii evidenţiază legătura dintre educaţie, aplicaţii în cercetare şi parteneriat industrial. De asemeniea sunt dezbătute: istoricul materialelor compozite în cadrul facultăţii de Construcţii şi Arhitectură din Iaşi, începând cu anii '70, implicarea în contractele de cercetare naţionale şi internaţionale dar şi o serie de manifestări ştiinţifice cu caracter local şi internaţional.