

Radiation influence on micro-structural mechanics of an advanced hemp carbon hybrid composite

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The purpose of this paper is the development and analysis from the mechanical and micro-structural point of view a new biocomposite subjected to radiations, with applications in both nuclear industry and the accomplishment of parts in aerospace industry to reduce their weight and manufacturing costs. We refer to EMR that includes radio and microwave signals, infrared (radiant heat), visible light and ultraviolet, and x-rays and gamma rays. This new biocomposite improves the recycling degree meeting at the same time the structural and passive protection performances. A composite material may be subjected to radiations since is a part of a constituent material which operates in an environment with radiations or may be intended to be subjected to radiations to obtain material's superior properties. In this second sense, the challenge is to reach some increased static and dynamic structural properties carrying out composites with enhanced characteristics that put better in evidence the sandwich structure concept. Since the field of composites is an interdisciplinary one and more than a connection between stable disciplines such as chemistry, physics or engineering, the experience from these is essential to develop new materials with well-defined applications.

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1. Introduction

The idea of using composite materials do not lead only to replace metals or other composites but also using in a constructive way these materials, taking into account the outstanding properties and manufacturing possibilities to create innovative structures with new shapes that should be used for particular constructions. So, first, a material with increased strength, recyclable and easy to be manufactured is designed then is subjected to radiations seeking in this way the integration of this material in structures used in aerospace and especially in nuclear applications taking into account its properties. In general, there is a special fascination for natural fibers reinforced composites and even more in the production of cars, composites prove to be competitive in terms of costs and replacing possibilities of traditional materials (metals, ceramics, glass, etc.) [1-4].

Radiation is a process in which electromagnetic waves (EMR) travel through a vacuum or through matter-containing media. X and gamma rays are electromagnetic radiations being at the upper limit of the energy spectrum having the property to produce the phenomenon of ionization, through interaction with the atoms that travels the respective substance. X-rays with energy less than 100 keV are strongly absorbed by the substance while X-rays with energy greater than 200 keV and gamma rays may travel considerable thickness from the substance, their absorption being much lower [5-7].

Under the action of ionizing radiations, polymers are subjected to profound chemical and structural transformations, their chemical composition, structure and

all mechanical and physical-chemical properties are changing. Irradiation may affect the materials properties both in a negative way (case in which we are talking about damage by radiation) and in positive sense leading to an improvement of these properties. Physical properties of composite materials are significantly altered after irradiation due to the assigned energy of incident photons to elementary constituents of irradiated material. The assigned energy dissipates gradually in material, spreading spatially and being transferred from photons to electrons and from electrons to atoms, molecules and hence to the entire structure. This added energy leads to chemically active compounds and changes or failures in the crystalline zone, failures that become active centers for further transformations and lead to changes in the properties of these bodies.

2. Material and method

Irradiation of samples for testing has been conducted on IRASM irradiator (www.iras.ro) and absorbed dose has been measured with the ECB dosimeter. Irradiations have been performed in the 1-250 kGy range, covering the doses used in most applications of radiation technology, but very high doses also, in which the effects of degradation can be put into evidence with certainty. Thus, specimens made of composite materials based on thermosetting resin and hemp fibers have been irradiated some with a dose of 2 kGy and some with a dose of 56.7 kGy.

The new carbon-hemp fabric hybrid composite consists of four layers of thermosetting resin reinforced with carbon fibers having 40% fibers volume fraction and hemp fabric with the fibers volume fraction of 20%. This material is used due to the fact that it is a material find in the industry. The process for producing the carbon-hemp fabric hybrid composite material consists that to form layers, hand lay-up technology has been used which provides the use of a roller to impregnate with resin both carbon fibers and hemp fabric. The mechanical characteristics of the thermosetting resin with hardener are: tensile stress at break: 86 MPa; Youn's modulus: 3200 MPa; resistance to impact: 40 kJ/m² [8,9].

The layered composite panel is made of a carbon layer with a thickness of 1.5 mm alternating with a second layer of hemp fabric with a thickness of 0.5 mm, this operation repeats until a composite panel is carried out formed of four layers. Finally, the thickness of layered composite panel is 4 mm (Fig. 1). The obtained panel has been kept at room temperature for two weeks after which eight specimens denoted C-Cnp have been cut, having the corresponding shape for bending test [2].

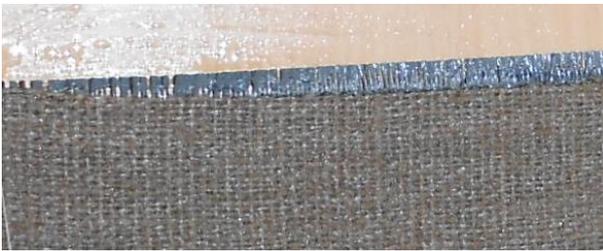


Fig. 1a. Hybrid carbon-hemp composite panel.

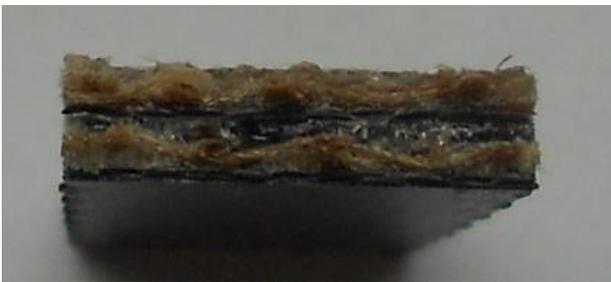


Fig. 1b. Cross-section through hybrid carbon-hemp composite panel.

The specimens cut from hybrid C-Cnp composite have been irradiated with a dose of 2 kGy respective 56.7 kGy after which they have been tested at bending on an LR5KPlus Lloyd Instruments material testing machine that provides a maximum force of 5 kN. The specimens have been subjected to three-point bending tests with a constant speed of 5 mm/min until break or until the stress (load) has reached a pre-determined value (Fig. 2).



Fig. 2a. Carbon-hemp specimen during three-point bending test.



Fig. 2b. Carbon-hemp specimens after bending tests.

During tests, load and deflection have been measured. The dimensions of each specimen, their width and cross-section area have been also accurately measured. These dimensions have been introduced as input data in computer connected to the testing machine having Nexygen software. This software takes the experimental data from testing machine and process them statistically [10-14].

3. Experimental results

In Table 1, the main mechanical characteristics of hybrid carbon-hemp composite are presented.

Table 1. Main mechanical properties of hybrid carbon-hemp composite.

Characteristics	Value
Stiffness (N/mm)	9465900
Stress at break (MPa)	157.12
Young's modulus of bending (MPa)	11832.0
Work to break (Nmm)	2203
Strain to break (-)	0.013697

After tests, a summary of experimental data have been carried out on non-irradiated and irradiated specimens with 2 kGy respective 56.7 kGy doses (Tables 2-3).

Table 2. Young's modulus of bending of non-irradiated and irradiated carbon-hemp composite specimens.

Specimen	Young's modulus of bending (MPa)		
	Non-irradiated specimens	2 kGy dosis irradiated specimens	56.7 kGy dosis irradiated specimens
1	3662.19	4701.09	3728.97
2	4455.91	3555.84	4323.13
3	4477.69	3852.03	3716.29
4	4160.15	4259.30	3817.76
5	4382.61	4185.66	2932.17
6	5036.92	5100.63	3707.38
7	2751.84	2387.86	3808.73
8	3272.22	3165.79	4625.06

Table 3. Tensile strength of non-irradiated and irradiated carbon-hemp composite specimens.

Specimen	Tensile strength (MPa)		
	Non-irradiated specimens	2 kGy dosis irradiated specimens	56.7 kGy dosis irradiated specimens
1	53645.50	68863.74	36415.78
2	65272.12	52087.59	42218.13
3	65591.25	56426.33	36291.92
4	60939.78	62392.17	37282.86
5	64198.43	61313.43	28634.49
6	73783.09	74716.28	36204.93
7	40310.17	34978.50	37194.67
8	47933.01	46373.98	45166.66

Flexural rigidity, Young's modulus of bending, work to break and load-deflection distributions are shown in Figs. 3 – 7.

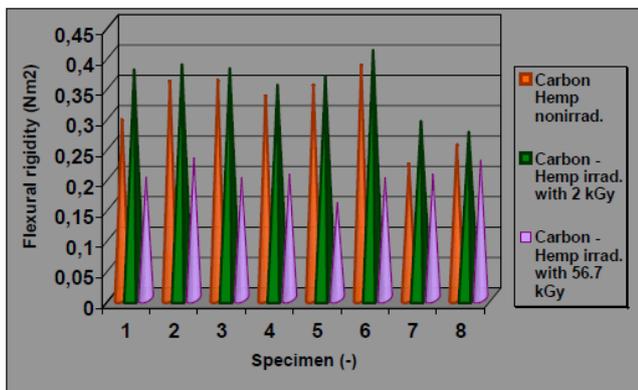


Fig. 3. Flexural rigidity distributions of non-irradiated and irradiated carbon-hemp composite specimens.

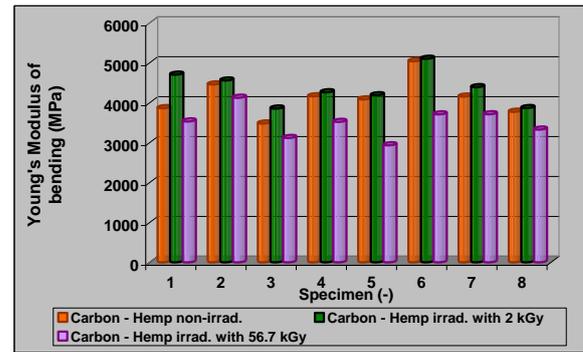


Fig. 4. Young's modulus of bending distributions of non-irradiated and irradiated carbon-hemp composite specimens.

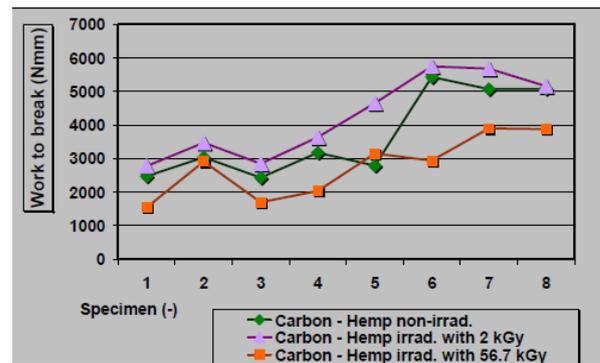


Fig. 5. Work to break distributions of non-irradiated and irradiated carbon-hemp composite specimens.

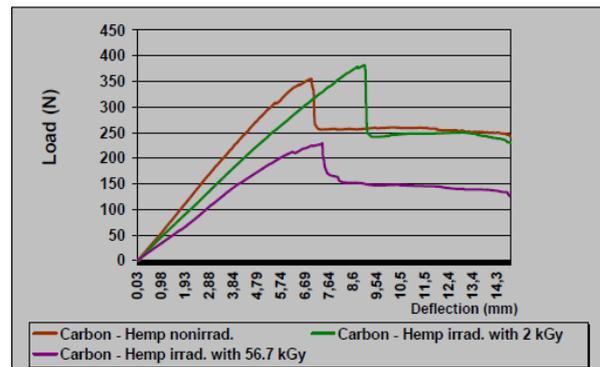


Fig. 6. Load-deflection distributions of specimen no. 4.

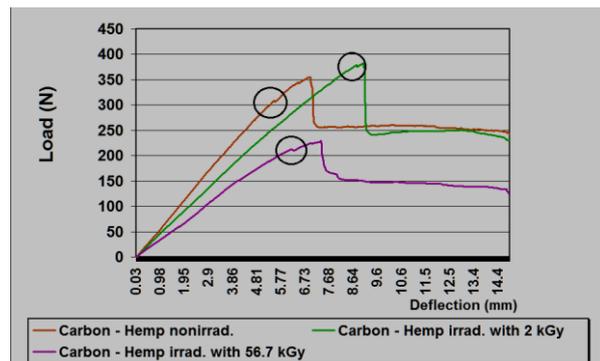


Fig. 7. Load-deflection distributions of specimen no. 4 with registration of first failure.

4. Discussion

From the graphical representation of the main mechanical properties shown in Figs. 3-5 it is obvious that this new hybrid carbon-hemp composite behaves much better if is irradiated with a lower dosis than a high dosis of irradiation.

Considering specimen no. 4 as a characteristic specimen from the group of three types of eight specimens (non-irradiated, irradiated with a dosis of 2 kGy and 56.7 kGy) we have represented in Fig. 6 the force-deflection distribution highlighting the first failure zone. This dosis was determine by the possibility to realize the experiment. It can be noticed that in case of non-irradiated specimen, the first failure occurs at a load of 308.72 N. In case in which the specimen is irradiated with 2 kGy dosis, the first failure appears at a load of 371.89 N and irradiated with 56.7 kGy dosis, the load value decreases at 213.61 N at which the first failure can be recorded. All these aspects reinforce the fact that the mechanical properties may be positive changed in case of a relatively small dosis of 2 kGy radiation but with the increase of radiation dosis, these properties decrease.

The macroscopic analysis highlights and determines failures stages of manufacturing technology. The view in detail has been carried out with a powerful microscope that can magnify the studied area by 500 to 2000 times and images have been accomplished as clear as possible and even into material's depth. The results obtained with microscope have been both 2D and 3D noting how the whole structure of this material has been changed. Thus, in fig. 8b, the cross-section of the new hybrid carbon-hemp composite structure is highlighted, i.e. carbon and hemp layers as well as the resin that in part has interfered with the hemp layer.

When the specimens have been irradiated with 2 kGy dosis (Fig. 9a), a "crystallization" of the resin layer occurs as well as an increase in the thickness of hemp and carbon fibers which led to an improvement of mechanical properties, as highlighted in Figs. 3-7. In contrast, increasing the irradiation dosis to 56.7 kGy a "crystallization" of both resin and carbon fibers occurs, the composite gaining a brittle appearance (Fig. 9b). This fact is reflected obviously in graphical representation of the main mechanical properties (Figs. 3-7) where it can be easily seen a rather significant decrease of these properties if compared with those obtained on initial non-irradiated composite but also on small dosis irradiated composite.

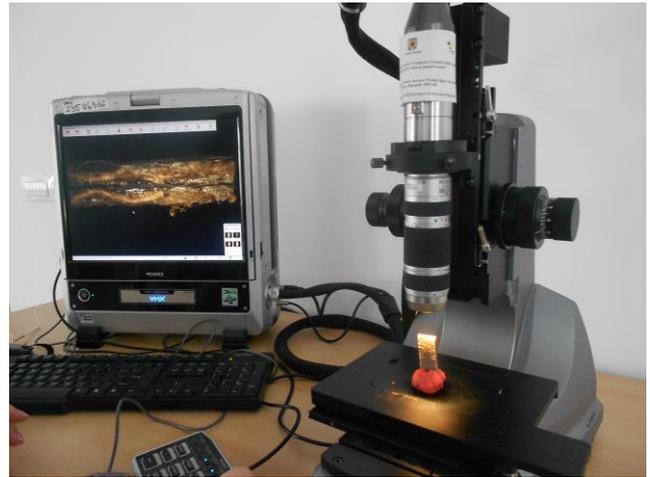


Fig. 8a. The VHX digital microscope.



Fig. 8b. Cross-section through the new non-irradiated carbon-hemp fabric based specimen (20X magnitude).

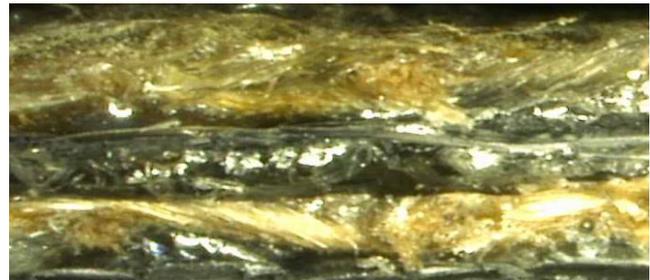


Fig. 9a. Cross-section through the new 2 kGy irradiated carbon-hemp fabric based specimen (20X magnitude).

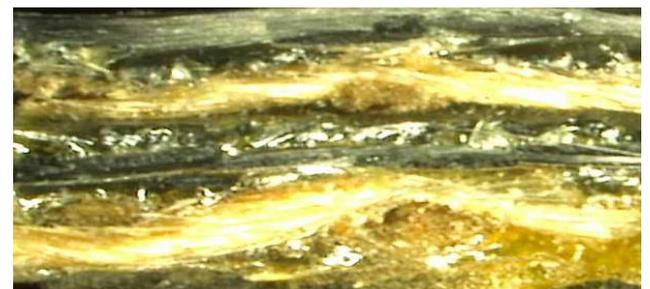


Fig. 9b. Cross-section through the new 56.7 kGy irradiated carbon-hemp fabric based specimen (20X magnitude).

Side and front views of macroscopic specimens' break area are visualized in Figs. 10-11.



Fig. 10. Side view of carbon-hemp fabric based specimens' break area.

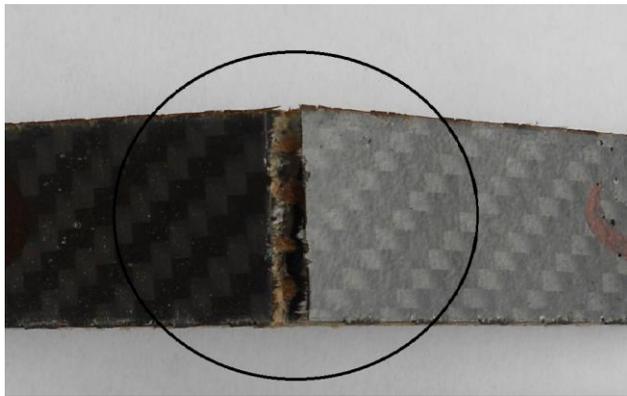


Fig. 11. Front view of carbon-hemp fabric based specimens' break area.

5. Conclusion

As general conclusions for metallographic analysis, we emphasize that macroscopic analysis has been carried out after a final control study performed on specially prepared surfaces. Conducting research on macroscopic composite specimens revealed also the layered and heterogeneous structure of the material. From the micrographs analysis conducted on studied specimens, the fibers distributions and orientation, the filler distributions as well as non-uniformities, material's failure, vacuoles and inclusions existing in resin matrix have been noticed.

The irradiation process revealed structural and morphological changes that affected the mechanical properties of new hybrid carbon-hemp composite however, the improvement of mechanical properties in case of a small 2 kGy irradiation dosis recommends this type of material for a wide range of applications in the automotive and aerospace industries.

References

- [1] H. Schürmann, *Konstruieren mit Faser-Kunststoff-Verbunden*, Springer (2005).
- [2] S. Vlase, H. Teodorescu-Draghicescu, M. R. Calin, L. Serbina, *Optoelectron. Adv. Mater. – Rapid Comm.* **5**(4), 424 (2011).
- [3] H. Teodorescu-Draghicescu, S. Vlase, *Computational Materials Science*, **50**(4), February (2011).
- [4] A. Modrea, S. Vlase, H. Teodorescu-Draghicescu, M. Mihalcica, M. R. Calin, C. Astalos, *Optoelectron. Adv. Mater. – Rapid Comm.* **7**(5-6), 452 (2013).
- [5] B. Mitrica, *Design Study of an Underground Detector for Measurements of the Differential Muon Flux Advances in High Energy Physics Volume*, Article ID 41584 (2013).
- [6] A. Sterian, *Mathematical Models of Dissipative Systems in Quantum Engineering, Mathematical Problems In Engineering*, Article 347674 DOI: 10.1155/2012/347674 (2012).
- [7] A. Sterian, P. Sterian, Book Editor(s): Gervasi, O; Gavrilova, ML, *International Conference on Computational Science and Its Applications (ICCSA 2007)*, Kuala Lumpur, (2007).
- [8] S. Vlase, R. Purcarea, H. Teodorescu-Draghicescu, M. R. Calin, I. Szava, M. Mihalcica, *Optoelectron. Adv. Mater. – Rapid Comm.* **7**(7-8), 569 (2013).
- [9] H. Teodorescu-Draghicescu, M. L. Scutaru, D. Rosu, M. R. Calin, P. Grigore, *J. Optoelectron. Adv. Mater.*, **15**(3-4), 199 (2013).
- [10] A. Modrea, S. Vlase, M. R. Călin, A. Peterlicean, J. *Optoelectron. Adv. Mater.* **15**(3-4), 278 (2013).
- [11] B. Gálfi, I. Száva, A. Kakucs, K. Harangus, *Ovidius University Annals of Mechanical, Industrial and Maritime Engineering* **10**, 187 (2012).
- [12] Komarnikova E., Sejnoha M., Szava I., *ș.a. –Selected chapters of mechanics of composite materials I*, Technical University of Kosice, 2011
- [13] M. L. Scutaru, C. Cofaru, H. Teodorescu-Drăghicescu, J., Timar, *Proceedings of the Int. Conf. Automotive and Transportation Systems (ICAT '13)*, Brasov, Romania, (2013).
- [14] S. Vlase, H. Teodorescu-Drăghicescu, M. R. Călin, M. L. Scutaru, *J. Optoelectron. Adv. Mater.*, **14**(7-8), 658 (2012).

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