HYBRID COMPOSITE FOR HIGH-DEMANDING APPLICATIONS

Florin TACHE[1], Tanase DOBRE[2], Alina Alexandra TACHE[3]

Lucrarea prezintă pe scurt rezultatele cercetării din ultimii ani privind un nou material compozit hibrid. Sunt prezentate mai multe etape din dezvoltarea acestui material, de la concepție până la efectuarea de teste asupra unor mostre de compozit. Numit CFRAl (Aluminiu Armat cu Fibre de Carbon), noul material are proprietăți unice deosebite, cu rezultate excelente previzibile în aplicații ce necesită un material rezistent, fiabil, uşor şi care să facă față cu succes unor şocuri termice puternice. Cele prezentate aici sunt parte a rezultatelor obținute în Laboratorul de Transfer de Masă din Universitatea Politehnica Bucureşti privind sinteza unor noi compozite cu aplicații speciale.

Present paper describes briefly the results of the last years research on a new hybrid composite material. Several phases of this material's development are presented, from conceptual design to tests performed on some composite samples. Named CFRAl (Carbon Fibers Reinforced Aluminum), the new composite has unique and promising properties, with foreseeable excellent results in applications requiring a reliable, yet light, reinforcement material that can also withstand powerful thermal shocks. The work depicted herein contains a part of results obtained at Mass Transfer Laboratory of Politehnica University of Bucharest, where the synthesis of new composites for special applications presents a major interest.

Keywords: carbon fibers, explosion, bullet-proof, hybrid composite

1. Introduction

In the last few decades, composite materials have been used more and more often wherever lightweight, yet strong structures are needed [1]. There are numerous types of composite materials, differing by type itself, production method, uses etc. [2]. Regardless of type, composites have induced a major change in the way parts are designed, mainly due to their heterogeneity and anisotropy [3].

[1] PhD student, Faculty of Applied Chemistry and Materials Science, University POLITEHNICA of Bucharest, Romania, e-mail: flotasoft@yahoo.com
[2] Prof., Faculty of Applied Chemistry and Materials Science, University POLITEHNICA of Bucharest, Romania, e-mail: tdobre@mt.pub.ro
[3] MSc graduate, Faculty of Applied Chemistry and Materials Science, University POLITEHNICA of Bucharest, Romania, e-mail: ada_chirilus@yahoo.com

The material being analyzed in this paper, namely *CFRAl* (Carbon Fibers Reinforced Aluminum), involves reinforcing an aluminum matrix with carbon fibers. In order to make the two constituents work properly with one another, a fundamental issue must be surpassed, which is the electro-chemical incompatibility between aluminum and carbon. A handy solution has been employed with respect to this matter. Even in early stages of a composite material development, its final destination must be considered. Aspects like what kind of loads will act on the composite structure, their order of magnitude etc. are taken into account and thoroughly examined. The material considered herein is supposed to withstand the impact of small-dimension high-velocity objects and to have a good behaviour in the event of an explosion in its vicinity. Practical examples regarding its application could be bulletproof plates and any kind of containers that would successfully endure the explosion of a bomb inside them. The material has been under development for the past few years, showing promising results from its very beginnings [4].

The study and selection of materials that form a composite material is of paramount importance. A careful mixture of matrix and reinforcing elements, according to the destination of the composite to be produced, can lead to a material which has its constituents in complete accordance with each other and thus displaying very good properties.

Another important aspect in the development of a composite material is the technique and methodology employed when producing it. It is well known that, in general, the assembly of several elements has properties better than the sum of its constituents' properties. A good and simple example is that in the case of a fiber reinforced composite subjected to tensile – compressive loads, the matrix basically carries the compressive forces, while fibers have an excellent response to the tensile loads. Taken separately, The matrix (namely epoxy resin) would not withstand tension and the fibers would easily be torn apart by compression.

Developing a composite material includes, besides theoretical estimates regarding its composition and properties, experimental tryouts. Consequently, this paper also presents several tests conducted on different composite samples, ranging from standard tensile tests to the material's behaviour when a speeding bullet tries to penetrate a CFRAl plate.

Composites are considered to be heterogeneous and anisotropic materials obtained by the macroscopic combination of two or more phases that have a separation interface or interphase and which sinergetically cooperate, leading to the final properties of the whole composite material [3].

This paper presents, in brief, aspects regarding CFRAl manufacturing and testing, from preliminary samples to enhanced specimens able to stop a 9mm calibre bullet, and focuses on describing in detail the latest improvements regarding CFRAl's properties.

2. CFRAl Development

The first CFRAl samples produced in the UPB laboratory were made of 5 layers of $\pm 45^o$ carbon fibers fabrics joined together by the epoxy resin covering the aluminum powder. The composite was produced using the hand lay-up method, which presents the advantage of allowing one to modify the continuous medium percentage within a single composite section and also to change it from one layer of the composite to another. The method is used to obtain parts having, for instance, soft core and tough outer skin, that would withstand corrosion and other hostile external actions [4].

Several samples of the material were prepared for testing in various conditions, thus undergoing not only standard tensile tests, but also high speed bullet impact tests. The tensile tests revealed an ultimate tensile strength of around *125 MPa*, while standard *7.65* and *9 mm* calibre bullets penetrated the 5-layer material when shot from a 10-metre distance (*Fig. 1*).

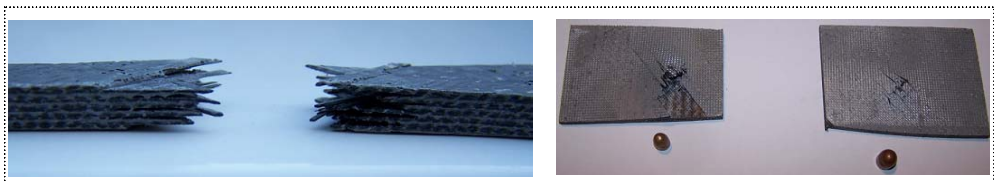

Fig. 1. Tensile and ballistic tests on early CFRAl specimens

The value for the tensile strength mentioned above is not high at all, but the main advantage of this new material is its *specific tensile strength*, namely the ratio between ultimate tensile strength and density, which is around $65.8\times10^3\ N\cdot m/kg$, a good starting point in the material development, showing that it has potential.

Analyzing the first samples proved beneficial as lessons were learned regarding the strong and weak points of this new material. Solutions are now being developed to enhance its manufacturing technology and properties.

A comprehensive theoretical approach is presented, as well as some new samples of CFRAl and the first experimental results regarding standard tensile, shock, thermal and ballistic tests performed on these specimens.

2.1. Theoretical Aspects

Having in mind the first tryouts regarding the production and testing of CFRAl, solutions have been sought out to enhance the material's properties. All aspects have been carefully analyzed, from selecting the materials to conducting the tests on the samples.

The “ingredients” have to be in close relation to the composite’s purpose, in this case to have a good behaviour in the event of an explosion inside a container made of CFRAl. An explosion is a gathering of several harsh effects that are not easy to investigate altogether, but can be well analysed separately. There are three main destructive factors that the material should account for in the event of an explosion:

- High thermal gradient – a sudden rise in temperature right after the moment of the explosion.
- High pressure gradient – considering a closed container, the pressure inside it increases to high values in a very short period of time.
- Impact with short fragments – small dimension and irregular form objects hit the material while travelling at very high speeds.

Each of these aspects is thoroughly analyzed on the next pages.

2.1.1. High Thermal Gradient

Carbon fibers are known to have a very good endurance to high temperatures, being able to withstand up to *2000 K* or even more. So the thermal concern with CFRAl relates to its matrix, namely the aluminum powder enveloped in epoxy resin. The resin is actually quite bad when it comes to thermal resistance, having a melting point of around *500 K*, while the aluminum powder can go up to *930 K*, depending on its purity. Overall, the thermal endurance of the composite is a combination of the three ingredients’ endurances, with the continuous medium having the role of only keeping stuck together the carbon fibers layers. Ultimately, this helps maintain the structural integrity of the material within acceptable parameters, so the overall structure that is made of CFRAl manages to keep its shape intact.

Even if the inner layers who are most affected by the temperature rise caused by the explosion would lose their integrity while the thermal wave penetrates the material, its intensity diminishes as the energy is consumed by the previously affected layers. So, in general, one can assume that the first 2÷3 layers of carbon fibers fabrics are completely destroyed by the thermal effect of the explosion, while the other ones remain intact and contain the explosion within the composite tank.

2.1.2. High Pressure Gradient

A spherical container made of CFRAl is considered, like the one shown in *Fig. 2*, with an explosion taking place in its center. Assuming a uniform distribution of the pressure on the wall, the sphere tends to increase its volume, so the composite layers that make up the container’s wall are being subjected to tension loads.

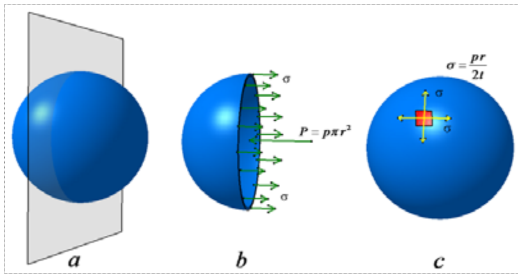

Fig. 2. Loads on the sphere wall

A detailed explanation of this analogy [5] leads to the formula for calculating the tension loads within the spherical container wall:

$$\sigma = \frac{p\,r}{2t} \quad (1)$$

Due to the symmetry of the spherical container, relation (1) is the same independent of the direction of the sectioning plane, as long as it passes through the sphere center. The concluding remark is therefore that the wall of a spherical pressurized tank is subjected to *tension loads σ* uniform in all directions (*Fig. 2 c*). These efforts, tangent to the curved surface of the sphere, are called *membranar loads*, as they are the only true loads acting on real membranes, such as soap bubbles or thin rubber layers.

Extrapolating and generalizing the model by considering a sphere with a very long radius, the spherical shape can be approximated with a planar surface. Consequently, a good indication of CFRAl's endurance to the pressure generated by an explosion is its tensile strength, much easier to evaluate and quantify by conducting standard tensile tests.

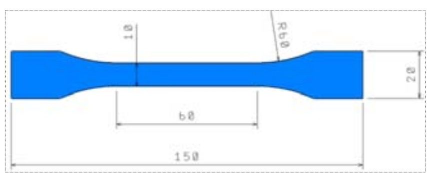

Fig. 3. Tensile test specimen according to SR EN ISO 527-1-2000 standard

The composite being made by overlapping several lamina groups, it can be considered, regarding the tensile strength, as a straight rectangular beam with non-homogeneous section and made of several elements with different properties, these elements being the lamina groups. Considering the classical theory of a beam under tension loads, one can say that the tensile strength of the laminate is the combination of the tensile strengths of the lamina groups that make up the composite [3].

2.1.3. Impact with Short Fragments

The effects of the short fragments resulted from an explosion on a CFRAl plate are analyzed by making an analogy with something far easier to quantify, test, measure etc., namely the resistance of this composite material when being impacted by speeding bullets.

Standard ballistic tests involve shooting a bullet from a 10-metre distance into a CFRAl plate fixed with a special substance, called *ballistic paste*, on a wooden surface. The paste keeps the sample stuck to the wooden surface where it is mounted even after the impact with the bullet.

Two widely-used bullet calibres have been used for these ballistic tests: *7.65 mm* and *9 mm*. A few parameters for these two bullets are listed in the following table.

Table 1

Test bullet parameters

Parameter / Bullet	Speed [m/s]	Mass [g]	Maximum range [m]	Effective range [m]
7.65	305	4.75	1500	50
9x18	315	6.10	1500	50

For each of the considered bullets, the energy to be dissipated at the moment of impact with a CFRAl plate is given by the formula

$$E_{bullet} = \frac{1}{2} \cdot m_{bullet} \cdot V_{bullet}^2 , \qquad (2)$$

where:

E_{bullet} – kinetic energy of speeding bullet, in *Joules*;

m_{bullet} – mass of bullet, in *kg*;

V_{bullet} – velocity of bullet, in *m/s*.

With the values in *Table 1*, the energy that needs to be dissipated by the composite plate is calculated to be around *220.9 J* for a *7.65 mm* calibre bullet and *302.6 J* for a *9 mm* calibre bullet.

The first CFRAl samples produced, made of 5 layers of carbon fibers fabrics, proved to be insufficient for stopping both types of bullets, as it can be seen in the right side image of *Fig. 1*.

For making new and improved CFRAl samples, two different types of carbon fibers fabrics have been used. They differentiate from one another by having different fiber orientations, $0/90^o$ and $\pm 45^o$, and by fabrics type, *plain weave* and *satin weave* [6]. By combining the two, a better resistance to an explosion is conferred to the composite material, with carbon fibers actually covering four different orientation directions.

The endurance of the composite material to bullet impact is mainly given by the carbon fibers layers. Therefore, the following paragraphs describe in detail some of the aspects related to this matter, with the resistance of the epoxy-aluminum matrix being minimized. It is not entirely neglected, as the continuous medium has the role of transmitting the loads from one composite layer to the next one and, at the same time, maintaining the general shape of the whole material by keeping the carbon fibers layers stuck to one another [7].

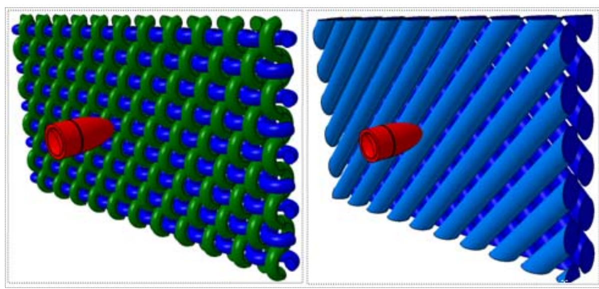

Fig. 4. Bullet impact on a carbon fibers fabric: a) *plain weave*; b) *satin weave*

Fig. 4a shows a *plain weave* carbon fibers fabric with the fibers being orientated in perpendicular directions to one another. The fibers in one direction are woven to those in the other direction. The representation in the image is intentionally exaggerated with respect to the thickness of the lamina for visualization purposes.

When hitting this fabric, the bullet tries to penetrate it by several means. One is the shearing force that appears in the exact section where the contact takes place between the edge of the bullet and the carbon fibers. It is well known that carbon fibers are very strong when subjected to tension, but very poor when it comes to shearing forces.

Another damaging factor is represented by the shock waves that are formed in the moment of impact and propagate along the first carbon fibers hit by the bullet. These waves arrive at the first weave point and, due to the bending radius of the fibers, they break the fibers in that location.

Last but not least, the bullet penetrates the fibers by simply displacing them from the point of impact around its diameter, making enough room in the fabric just to get through and arrive at the next layer, where the penetrating process starts again. But this time with less energy remained to be dissipated, as part of it was already consumed on penetrating the previous layer.

A similar process takes place in the case of a *satin weave* (*Fig. 4b*). Nevertheless, there are some important differences. The fibers are not woven to one another, but are kept together by being woven with a very thin glass fiber string. This string goes from a layer of carbon fibers orientated in one direction, practically a uni-directional carbon fibers layer, to an adjacent layer of carbon fibers orientated perpendicular to the direction of the other layer. There is no true carbon fibers fabric in this case, but a fabric of two layers of uni-directional fibers.

In this case, the shearing force is the same, as the bullet hits directly some of the fibers. But there is also the distinction that it first shears some fibers on the layer closest to the impact point side of one lamina, while the other layer is still intact and, by the time the bullet gets to it, some of its energy had already been spent cutting the first layer. Then the process repeats itself for the next lamina, practically shearing separately each uni-directional carbon fibers layer that makes the *satin weave*.

A big advantage of this kind of weave is the fact that the shock waves produced at the moment of impact can ride smoothly on each carbon fiber until they reach the edge of the material. There are no more bending radii to concentrate the efforts.

Penetration by just displacing the fibers around the bullet as it passes from one layer to the other is similar to the case of a *plain weave*, with the observation that the *satin weave* used in making CFRAl is much more dense than the *plain weave*.

3. CFRAl Properties Assessment and Experimental Tests

Considering the theoretical aspects already presented, new CFRAl samples have been produced in the UPB laboratory. These samples and their properties are described on the following pages.

3.1. Constructing Enhanced CFRAl Samples

As mentioned before, the first CFRAl samples were made by using the hand lay-up method. This meant that the carbon fibers fabrics were laid on a flat and smooth surface and the resin (Epifen RE 6513N-Epifen DE 7513 10/1, 0.1 kg Al/kg resin) was simply spread onto one fabric, then onto the next layer and so on. After all desired layers were arranged together, the material was just pressed and allowed to cure at room temperature.

This method is very easy to use and quite handy, but it has several major disadvantages, such as void spaces within the composite, due to the fact that each layer is laid after the previous one and there is no method to get rid of all air inherently caught inside. Another drawback is the curing at room temperature, which takes a long time and does not ensure a complete and correct reaction. This can lead to imperfect bonds between matrix and reinforcement and eventually to delamination.

The new CFRAl samples benefit not only from a more thorough theoretical approach, but also from a new manufacturing technique, that now guarantees a complete reaction and a smaller number of voids inside the composite mass. Two different types of carbon fibers have been used, a $0/90^o$ *plain weave* (*Fig. 5a*) and a $\pm 45^o$ *satin weave* (*Fig. 5b*). In the 3D computer representation, the scale is intentionally exaggerated in the thickness direction for visualization purposes.

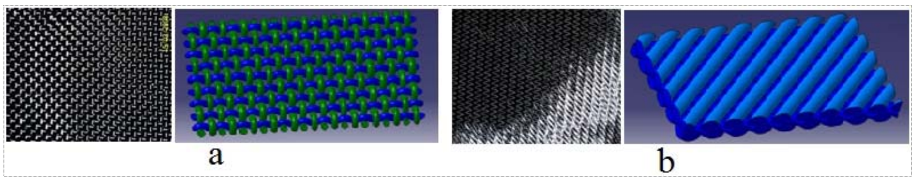

Fig. 5. Carbon fibers fabrics (real & symbolic representation)

CFRAl matrix has to endure high temperatures and keep the carbon fibers layers together, maintaining the general shape of the structure, until the energy of the explosion is dissipated. Therefore, a special system has been used as continuous medium, consisting of epoxy resin that envelops aluminum powders. Aluminum has a melting point of 660^oC and a density of $2700\ kg/m^3$, very low relative to other metals. The main characteristics of the matrix are:

- possibility of curing at room temperature;
- can be taken out of the mould at room temperature;
- very good thermal properties after a post-curing heat treatment;
- total absence of aromatic compounds.

Several samples have been produced, with 5, 10 and 14 layers, respectively, using both types of weaves or a single one, in order to show up the differences between their properties. In any case, the samples were pressed between the steel moulds and put in an oven for curing. A post-curing heat treatment has been applied to all samples, to ensure a complete reaction.

After curing, the raw CFRAl samples were cut into finite rectangular plates, getting rid of irregular edges. Standard specimens have been prepared for tensile tests and wider plates for conducting ballistic tests, thermal measurements and standard impact tests on a special laboratory machine.

Fig. 6. CFRAl samples (tensile and ballistic test specimens)

3.2. CFRAl Parameters

Some of the most important parameters of this composite material are its density and the fractions of the constituents within one composite, with respect to the entire mass and volume of the composite, respectively (mass fraction of matrix m_m and fibers m_f, volume fraction of matrix V_m and fibers V_f).

Table 2

CFRAl parameters

Composite \ Parameter	Density [kg/m^3]	m_m [%]	m_f [%]	V_m [%]	V_f [%]
CFRAl 5 x ±45^o	1839.02	75.51	24.49	74.98	25.02
CFRAl 5 x ±45^o	1739.17	75.97	24.03	76.78	23.22
CFRAl 5 x ±45^o + 5 x 0/90^o	1658.28	61.88	38.12	64.88	35.12
CFRAl 5 x ±45^o + 5 x 0/90^o	1654.82	63.50	36.50	66.45	33.55
CFRAl 10 x 0/90^o	1673.63	57.64	42.36	60.62	39.38
CFRAl 5 x ±45^o + 5 x 0/90^o	1751.53	73.27	26.73	73.99	26.01
CFRAl 5 x ±45^o + 5 x 0/90^o	1732.92	72.70	27.30	73.72	26.28
CFRAl 14 x ±45^o	1661.00	50.62	49.38	54.24	45.76
CFRAl 7 x ±45^o + 7 x 0/90^o	1633.01	44.44	55.56	46.82	53.18

CFRAl density has been improved especially in the last specimens produced (14-layer samples). It is important to notice the value of around *1.65 g/cm^3*, very close to the density of a classical carbon-epoxy composite material. Even though CFRAl has aluminum in its composition, the metal's density being very low with respect to other metals (*2.7 g/cm^3*) keeps the overall density of the hybrid composite close to the density of a composite with no metal inside.

An important aspect is also the fact that even if the density has been reduced from the first produced samples to the last ones, the resin completely envelops the carbon fibers, as it can be seen in *Fig. 7*, which presents a cross-section view of a CFRAl specimen (left image), magnified 200 times using a *BX 51 Olympus* microscope (right image).

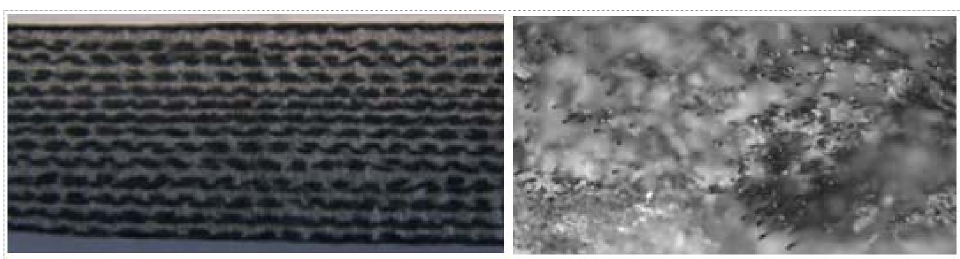

Fig. 7. CFRAl cross-section views (naked eye and 200x magnification rate)

3.3. Tensile Strength Assessment

The tensile strength of the first 5-layer samples was presented in the previous chapter as being around *125 MPa*. These samples also proved to be ineffective when impacted with a *7.65* and a *9x18 mm* calibre bullet.

The improved samples, with 10 and 14 carbon fibers layers and a new curing cycle to obtain a complete reaction have also been tested and the results differ very much from the first ones. Best tensile strength results were recorded for the 10-layer specimens and are detailed below, while 14-layer samples performed very good during ballistic tests.

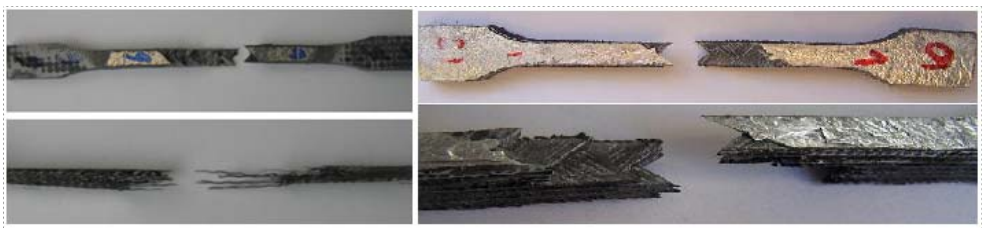

Fig. 8. Fractured CFRAl tensile test specimens (left – 10 layers; right – 14 layers)

The ultimate tensile strength of CFRAl (*Fig. 9*) is around *319 MPa* for specimens # *3 & 4* (10 layers of $0/90^o$ *plain weave*) and *276 MPa* for the other specimens (made of 5 layers of $0/90^o$ *plain weave* and 5 layers of $\pm 45^o$ *satin weave*). The Young's modulus is around *36 GPa* for specimens # 3 and 4 and *27 GPa* for the others.

Regarding the *specific tensile strength* of the new 10-layer samples, (ratio between their ultimate tensile strength and their density), the values are now $190.603 \times 10^3\ N \cdot m / kg$ for samples # *3 & 4*, and $158.621 \times 10^3\ N \cdot m / kg$ in the case of specimens # *1, 2, 5 & 6*.

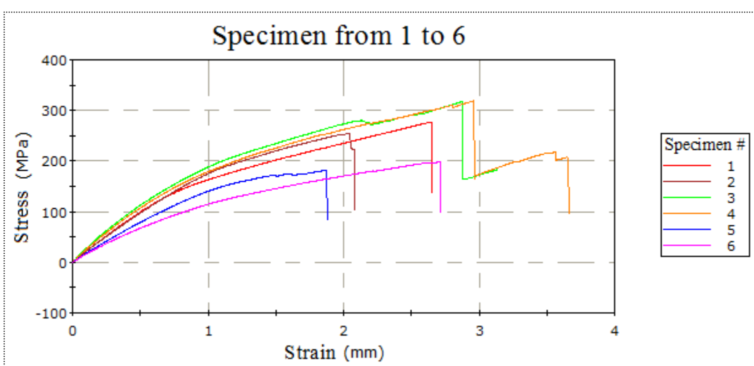

Fig. 9. Tensile test results on 10-layer CFRAl samples

It is important to note the enormous progress from the first samples, the specific tensile strength now being three times higher than that of the preliminary samples. These values were a little lower in the case of the 14-layer specimens (best tensile strength of *208 MPa* and specific tensile strength of $125.226 \times 10^3\ N \cdot m / kg$), but further tests are planned.

3.4. Ballistic Tests Results

The new and improved CFRAl samples proved much better than the first ones (shown in *Fig. 1*) also regarding bullet impact resistance. 10-layer samples managed to successfully stop a *7.65 mm* calibre bullet, and 14-layer CFRAl stopped a *9x18 mm* calibre bullet, both shots being fired from a standard 10-metre distance.

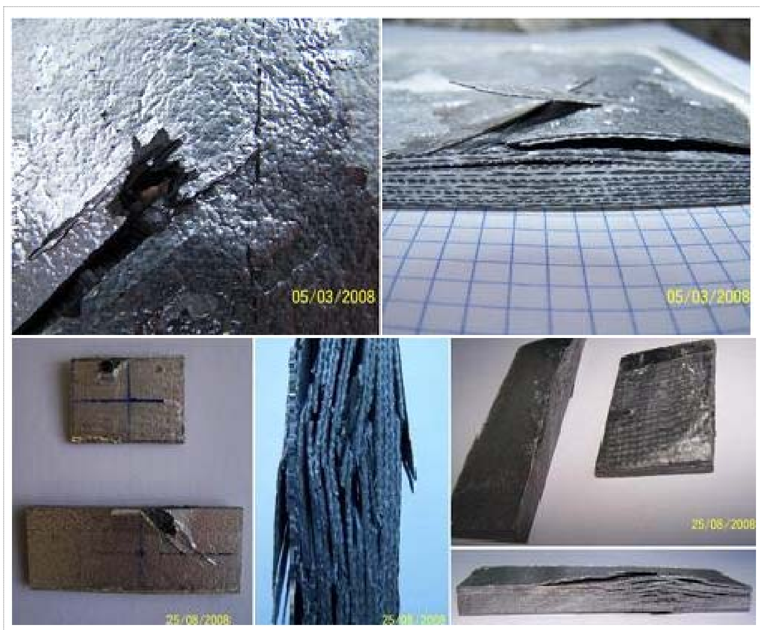

Fig. 10. Ballistic tests results on 10-layer and 14-layer CFRAl samples

Fig. 10 shows in the upper image (10-layer specimen) that the bullet only affects the first layers it encounters in its path and, as it penetrates them, it eventually breaks apart inside CFRAl, leaving the last layers on the other side of the plate intact, no delamination being detected. For the *9 mm* bullet impact test a CFRAl plates made of 14 carbon fibers layers were used, as the 10-layer setup proved insufficient.

The *9x18 mm* (*Makarov*) bullet produced more damage than the smaller bullet, but it was stopped by two different 14-layer CFRAl samples, separately.

One of the samples was made of only one type of carbon fibers fabrics, namely *satin weave*, where fibers in one direction do not bend over those in the other direction, ensuring a better dissipation of the impact energy, which goes straight towards the edges of the material, having no turns in its pathway.

The smaller sample in the lower image of *Fig. 10*, made of two different types of carbon fibers fabrics (*plain weave* and *satin weave*), also proved successful in stopping the *9x18 mm* bullet, but in this case the performance is credited to the high volume fraction of the fibers that compensated for the woven fibers bended over one another. In this sample, the volume fraction of the fibers in the composite is *53.18%*, higher than that in the 14-layer *satin weave* sample of only *45.76%*.

Consequently, with both types of samples successfully withstanding the impact of a bullet, four different orientation directions are accounted for in the case of a structure made of the two different types of carbon fibers fabrics, thus proving that CFRAl has a good potential to endure the effects of an explosion in the vicinity or inside a container made of this hybrid composite material [7].

3.5. Laboratory Impact Tests

One of the requirements for CFRAl is to withstand impacts. Besides ballistic tests presented above, standard laboratory experiments have been carried out on a 14-layer CFRAl plate *(±45^o satin weave*). Plate thickness was *11 mm* and length and width *120x100 mm* in order to fit properly on the testing machine.

Fig. 12. Laboratory impact tests performed on a 14-layer CFRAl plate

Though it has been impacted seven times (*Fig. 12*), the composite plate has a good endurance to mechanical shock, represented by a load of roughly *8.5 KN*, corresponding to an energy of *5.14 kg m* and a print of the hitting object on the composite plate with a diameter of *10.5 mm* and a depth of *1.7 mm* (graph in *Fig. 13* is for test # 7 – strongest hit).

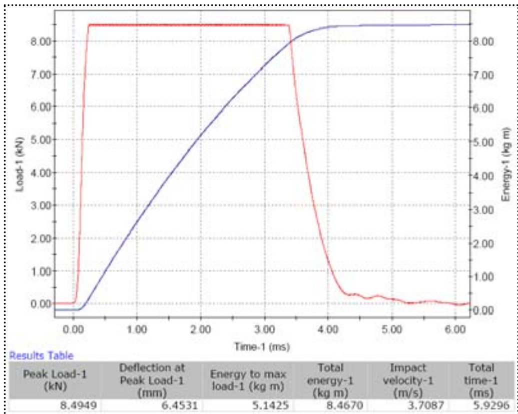

Fig. 13. Graph for impact test # 7 – strongest hit

The strain produced by each impact is very small and localized in impact areas. In a side view, the plate shows no warp on the face opposite to the impact area. The relatively long horizontal segment (about 3 milliseconds) present during each test can be explained by the fact that the material responds to the shock by distributing the impact energy in all its lamina layers. A major contribution is that of aluminum powders, which help in reducing vibrations right after impact.

3.6. Thermal Characteristics

Temperature values were recorded during heating and cooling of a 14-layer CFRAl plate. Several experimental rigs were used, with and without a heat sink, with two values for the electrical current powering a resistor acting as heater and placed at the end of an aluminum bar of square cross-section. This bar is at the other end in contact with the CFRAl plate, thus ensuring a uniform heat distribution in the contact area. Based on these measurements, a numerical code is being developed in an attempt to establish the thermal conductivity of the hybrid composite through the *dynamic method*. A few details are shown in *Fig. 14*.

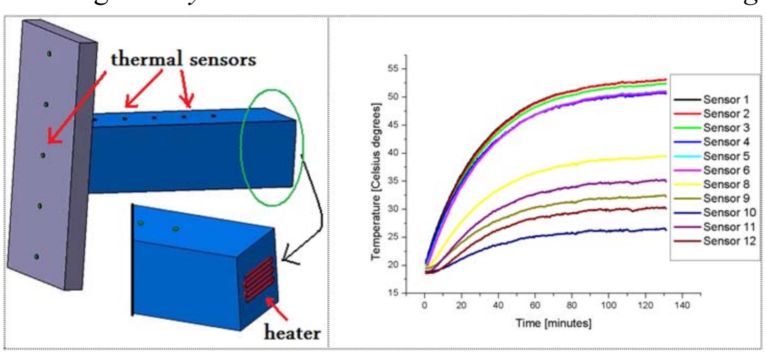

Fig. 14. Schematic of experimental rig and example of thermal measurements (heating cycle)

4. Financial Aspects

In the developing stage of a composite material, at least some aspects regarding its cost have to be considered, estimated and ways to diminish the costs for the material's production and maintenance sought out.

It is a long way from the raw constituents (resin and fibers) to finite test samples, employing resources which are not always easily assessed. Some of these resources are: materials for the moulds, screws and nuts for fastening the moulds, ceramic papers to ensure a smooth surface of the produced plates, tools for the lay-up process and preparation for curing in the oven, extra resin and fibers from the gross plates irregular margins, energy consumed by the oven for curing and after-curing heat treatment, cutting gross samples into standard test specimens, time etc.

With *Carbon Fibers Reinforced Aluminum* being still under development and the produced samples being actually prototypes, only raw materials costs are taken into account for now, when calculating the composite material's price. The costs of all other equipment used to fabricate CFRAl are neglected, considering that at least some of the aforementioned resources costs would be reduced in an eventual CFRAl large scale production.

The price of this material, is given in *Table 3*, for different lay-ups, in Euros per mass unit and per area unit, as CFRAl is now in the prototype phase. Even in this early stage of development, the prices are comparable to those of already produced bullet-proof vests and other similar ballistic protection materials. And they will indubitably go down in case of a large scale industrialized production of this material in the following years, considering also the fact that the price of currently produced composite materials worldwide has dropped significantly over the last decades.

Table 3

CFRAl price for different lay-ups

CFRAl type	Euro/kg	Euro/m^2
CFRAl 5 x ±45^o	30.85	289.83
CFRAl 5 x ±45^o + 5 x 0/90^o	52.22	536.84
CFRAl 10 x 0/90^o	43.32	452.80
CFRAl 5 x ±45^o + 5 x 0/90^o	36.09	494.82
CFRAl 14 x ±45^o	58.35	722.22
CFRAl 7 x ±45^o + 7 x 0/90^o	57.90	616.06

5. Conclusions

Carbon Fibers Reinforced Aluminum is a composite material that began to be developed in the Mass Transfer Laboratory of the Faculty of Applied Chemistry and Materials Science in cooperation with the Faculty of Aerospace Engineering from University "POLITEHNICA" of Bucharest, Romania, at the end of 2005, research being financed by the Romanian Space Agency [4]. The material is a hybrid composite, containing carbon fibers, epoxy resin and aluminum powder which, since the beginning of its development, has shown promising properties, with foreseeable excellent results in applications requiring a reliable, yet light, reinforcement material that can also withstand powerful thermal shocks. CFRAl development continued in the following years, supported by CNCSIS-TD CH450710 and CH450807 research grant for PhD students and is an integral part of the first author's PhD study [7]. The authors would also like to thank CNCSIS Romania for supplementary financial resources through the IDEI project code ID 1031.

Results obtained thus far and the material itself will continue to be analyzed in the future and the concluding remarks will help further improve CFRAl regarding its constituent elements and manufacturing technology. Additionally, ways to reduce costs will be sought out and solutions will be implemented in an eventual large scale production, with CFRAl having the potential of being used in domains varying from common goods and sports articles to bullet-proof vests, bomb-proof containers and space vehicles outer hulls.

R E F E R E N C E S

[1] *A. Beukers, Ed. van Hinte*, Flying Lightness, 010 Publishers, ISBN 90-6450-538-1, Rotterdam, 2005

[2] *A. Beukers*, Engineering with Composites, Lecture Notes, Delft University of Technology, Faculty of Aerospace Engineering, 2005

[3] *Gh. Zgură, V. Moga*, Bazele proiectării materialelor compozite (Basics of Composite Materials Design), Editura Bren, ISBN 973-9493-01-7, Bucuresti, 1999

[4] *F. Tache, V. Stanciu, T.G. Chiciudean, A.C. Toma, A. Stoica, T. Dobre*, Statistical Risks in High Performance Nano-Composites Technology for Space Structures (IAC-06-C2.8.04) paper presented in October 2006 at the 57th International Astronautical Congress in Valencia, Spain and published in the official IAC 2006 DVD proceedings, 2006

[5] *J. M. Gere*, Mechanics of Materials, 5th SI Edition, Nelson Thornes Ltd., ISBN 0-7487-6675-8, Cheltenham, UK, 2002

[6] *http://en.wikipedia.org/wiki/Plain_weave*, Plain weave – Wikipedia, the free encyclopedia, accessed 26-08-2008

[7] *F. Tache, T. Dobre, A. A. Chirilus*, Optimization and Modeling of CFRAl Properties and Manufacturing Technology (IAC-08-C2.I.5), paper presented in October 2008 at the *59th* International Astronautical Congress in Glasgow, Scotland and published in the official IAC 2008 DVD proceedings, 2008.