PROJECT MANAGEMENT APPLIED FOR COMPOSITE MATERIALS USED IN AERONAUTICS. CARBON FIBER AND NANO-ADDITIVES

Gina Florica STOICA[*], Irina-Carmen ANDREI[**], Nicoleta CRIŞAN[***], Delia PRISECARU[*], Adriana ŞTEFAN[**], Cristian STOICA[****], Anca GRECULESCU[*], Sylvain TACHEREAU[1], Dylan VEELERS[2], Katharzyna SZYMAŃSKA [3], Paul COZMA-IVAN[*]

[*]"POLITEHNICA" University of Bucharest, Faculty of Mechanical Engineering and Mechatronics, Machine Parts and Tribology Department, Romania (gina.stoica@upb.ro, delia.prisecaru@upb.ro, paul.cozma_ivan@yahoo.com)

[**]I.N.C.A.S. – National Institute for Aerospace Research "Elie Carafoli", Romania (andrei.irina@incas.ro, stefan.adriana@incas.ro)

[***]"POLITEHNICA" University of Bucharest, Faculty of Industrial Engineering and Robotics, Strength of Materials Department, Bucharest, Romania (nicoletacrisan@upb.ro)

[****] COMOTI – Romanian Research and Development Institute for Gas Turbines, Bucharest, Romania (cristian.stoica@comoti.ro)

[1]ENIT, l'École Nationale d'Ingénieurs de Tarbes, France (sylvain.taschereau@enit.fr)

[2]Saxion University of Applied Sciences, Enschede, the Netherlands (423895@student.saxion.nl)

[3]University of Technology, Lodz, Poland, (188520@p.lodz.pl)

DOI: 10.19062/2247-3173.2023.24.21

***Abstract**: This paper presents the results of theoretical and applied research related to composite materials, carbon fiber and nano-additives. The objective of this work is to investigate the properties and behavior of custom designed composite materials which are intended for applications in aerospace engineering. The holistic approach is expressed by the structure of this research project which consists of the technical part and the economic part, that is analyzed in terms of project management. The specificity of the work is given by the requirements of the European Project Semester EPS, where international teams of students actively experience a multidisciplinary and multicultural project for one semester in another university, which has developed research and industrial partnerships. For developing such project, the approach provided by INCAS as Research Partner is oriented towards Problem Based Learning and Project Organized Learning. The University as Organizer provides Project Related Courses and some complementary Project Organized Learning. The research was oriented towards the customized design and analyzing of composite materials samples for potential use in aerospace engineering, the development and validation of materials and methodologies. The benefits of the research project are related to the applications of composite materials and in the subsidiary to allow the students learn valuable professional lessons and experience from this research project.*

***Keywords**: Project Management, Composite Materials, Carbon Fiber, Nano-Additives, Aerospace Engineering, Applications*

1. INTRODUCTION

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part.

Composite materials have emerged as a major class of advanced elements and are either used as substitutions of metals/traditional materials in aerospace, automotive, civil, mechanical, and other industries. A unique feature of composites is that the characteristics of the finished product can be tailored to a specific engineering requirement by a careful selection of matrix and filler, [1]. Composite materials are commonly classified at following two distinct levels, with respect to the matrix and with respect to the reinforcement form - fiber reinforced:

1. The first level of classification is made with respect to the matrix constituent. The major composite classes include organic matrix composites, metal matrix composites and ceramic matrix composites. Types of composite matrices: a/ Polymer Matrix Composites (PMC), b/ Metal matrix Composites (MMC), c/ Ceramic Matrix Composites (CMC), d/ Carbon and Graphic Matrix Composites (CGMC).
2. The second level of classification is made with respect to the reinforcement form - fiber reinforced: Composites, laminar composites and particulate composites. Fiber reinforced composites can be further divided into those containing discontinuous or continuous fibers. Fiber reinforced composites are composed of fibers embedded in matrix material. Laminar composites are composed of layers of materials held together by matrix. Sandwich structures fall under this category. Particulate composites are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder form.

The advantages provided by the use of composites are many, including lighter weight, the ability to tailor the layup for optimum strength and stiffness, improved fatigue life, corrosion resistance, and, with good design practice, reduced assembly costs due to fewer detail parts and fasteners. Other pro's for composites use are: a/ long working life, b/ lower density with respect to steel alloys, c/ high strength to weight ratio, d/ low coefficient of thermal expansion, e/ five times stronger than steel.

On the other hand, the disadvantages of composites use refer to: a/ high raw material costs and usually high fabrication and assembly costs, b/ adverse effects of both temperature and moisture, c/ poor strength in the out of plane direction where the matrix carries the primary load, susceptibility to impact damage and delimitations or ply separations, d/ greater difficulty in repairing composite parts when compared to metallic structures.

The extensive use of carbon fiber composites in the construction of the modern airplane was one of the main reasons the team has decided to study and to research for potential improvements on the mechanical properties of a custom designed & made composite test samples.

2. STATE OF ART ON COMPOSITE MATERIALS USED IN AEROSPACE ENGINEERING

A wide range of load-bearing and non-load-bearing components are already in use in both fixed-wing and rotary wing aircraft. Many military and civil aircraft now contain substantial quantities of lightweight, high-strength carbon-, kevlar- and glass-fiber composites, as laminated panels and moldings, and as composite honeycomb structures with metallic or resin-impregnated paper honeycomb core materials.

Many modern light aircraft are being increasingly designed to contain as much lightweight composite material as possible. For elevated-temperature applications carbon-fiber-reinforced carbon is in use. Concorde's disk brakes use this material, rocket nozzles and re-entry shields have been fashioned from it, and there are other possibilities for its use as static components in jet engines. [3]

In modern aircraft, composite materials are used for the main parts like: 1/ fan, propellers, rotor system, 2/ aerostructure (fuselage, wings, empennage, flight control surfaces (i.e. flaps, elevator, ailerons), 3/ engine components, 4/ nacelle and pylon, 5/ systems.

For the reason of the compliance with the safety standards specifically stated in regulations for the commercial and military aircraft industry, the composite materials were gradually introduced in aircraft and space product constructions.

From the historical standpoint of the introduction and implementation of composite materials in aircraft industry, the evolution was done gradually, so that several phases could be recorded, depending on the damaged tolerance as assumed risk management and the compliance with the safety standards stated for the commercial and military aircraft industry. Phases of composites implementation in aircraft industry:

● The milestone which marks the beginning of using composites in aircraft industry can be associated with the Boeing 707 and DC-9 aircrafts, in the late 1950s.

● Phase #1: the composite materials implementation considered the parts such that the aircraft flying capabilities should not be damaged neither altered by their failure in operation, e.g. tertiary composite components, as: interior parts, sidewalks, bag racks and galleys.

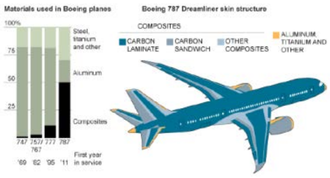
● Phase #2: implementation of the composite materials for secondary aircraft structures, as; spoilers, rudders, ailerons and flaps, after 1960s. After the 1970s, fiberglass was retained for many interior parts and fairings, while for the secondary aircraft structures (i.e. spoilers, rudders, ailerons and flaps) fiberglass was replaced by carbon fibers.

● Phase #3: implementation of the composite materials within aircraft primary structures, such as: stabilizers, wings and fuselage barrels. The design and use of carbon fibers and boron fibers initiated for military aircraft and expanded to commercial aircraft, for flight control surfaces (i.e. rudders, flaps) to stabilizers, wings and fuselage structures. The first high-performance composite materials implementation for primary structures was done in 1980s for the B 737 horizontal stabilizer, which was followed by thorough testing and in-flight evaluations.

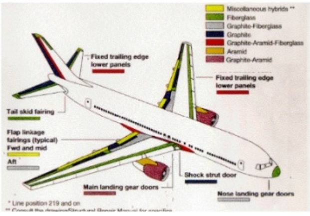
● Phase #4: is represented by the design, development and implementation into production of the composite materials for vertical and horizontal stabilizers, customized in purpose to achieving lightweight structures and improved aircraft performances.

● Phase #5: The completion phase consists in expanding the implementation of high-performance carbon fiber composite materials to the stabilizers, wings and fuselage. Another gained advantage is the significant decrease of the aircraft weight, since the stabilizers, wings and fuselage taken together represent about 50% of aircraft structural weight. A representative example of the new generation of commercial aircraft is the B 787 “Dreamliner” aircraft. The components of the B 787 “Dreamliner” which use composite structures, are: 1/ fuselage – almost full body, 2/ upper and lower wing skin, 3/ radome, 4/ flight control surfaces (i.e. wing flaps, elevators, ailerons), 5/ vertical fin, 6/ horizontal stabilizer. The development of composite materials implementation on Boeing aircrafts is detailed in Fig.1; composites implementation on Airbus A380 is presented in Fig.2.

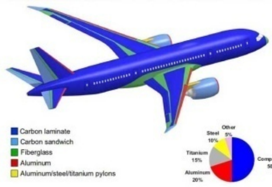
● Phase #6: The current phase corresponds to the increased use of composite materials on both military and commercial aircrafts. Composites use in commercial aerospace (exemplified by Boeing versus Airbus) is shown in Fig.3. Composites use in military aircraft detailed in Fig. 4.



(a) – Composite % usage in Boeing series B747, B757/B767, B777, B787



(b) – B757 Composite Components



(c) – B787 Composite Components

FIG. 1 Composite Materials Used in Boeing Aircraft Series [18-20]

The implementation of the use of composites in the aircraft industry has been gradually done, according to the validation of customed design composite parts, based on matching the capability to overcome loads and stresses with the compliance to the safety standards stated in the regulations of the military and commercial aviation.

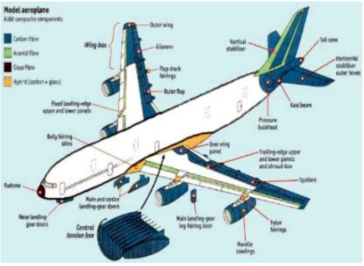


FIG. 2 A380 Composite Components, [21]

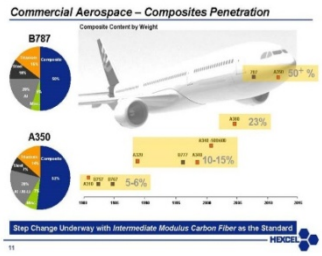


FIG. 3 Composites in Commercial Aerospace, Boeing vs. Airbus, [22]

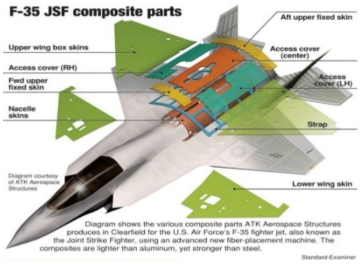


FIG. 4 Composites in Military Aircraft, [23]

The evolution of the use of composites in aerostructures has registered a % increase of composite materials, followed by steel and titanium alloys, compared to the decline in use of aluminum alloys and other metals; nevertheless, improvements of structural aluminum alloy continued to be developed.

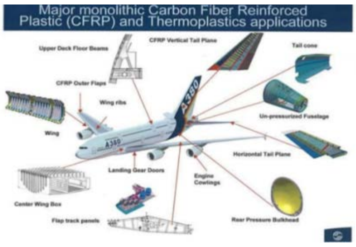


FIG. 5 Aircraft Composite Parts: Carbon Fiber Reinforced Plastic (CFRP) and Thermoplastics Components, [24]

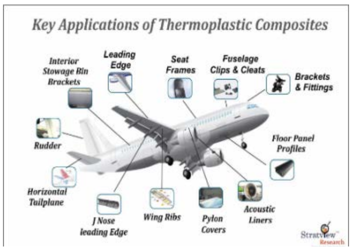


FIG. 6 Key Application of Thermoplastic Composites, [25]

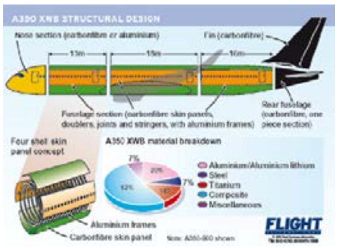
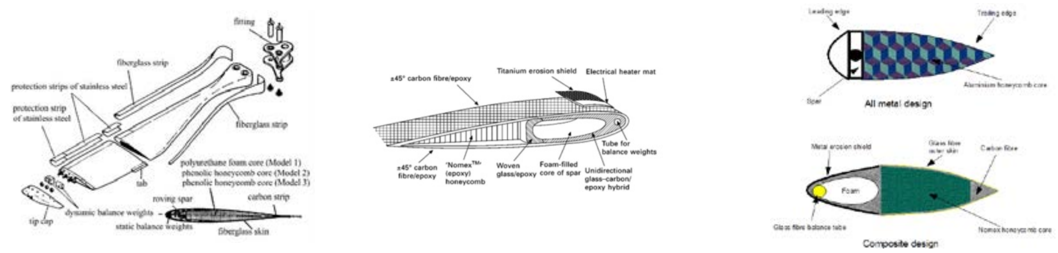


FIG. 7 A350 XWB Structural Design, Composite Parts, [26]

The combination of new construction design (e.g. nacelle and pylon, B 707 versus B 777, improved B 747-8 wing design) with the expanding the use of composites on aircraft (B 747 versus B 777) is the key element to provide improved product performances (higher specific strength and stiffness introduced by composites, which enabled lighter aircraft, powerful engine, and lower noise that declines the environmental impact).

The use of composites in helicopters follows the same objectives (i.e. higher specific strength and stiffness), for parts such as main rotor blades, tail rotor blades, composite weapons pylons. The Bell V-280 Valor helicopter is one of the first military aircraft flying with thermoplastic components, for the reason that thermoplastics can offer advantages in terms of weight, costs, production time and environmental impact. For manufacturing the Bell V-280 Valor helicopter, Bell Helicopter used two thermoplastic composites, induction welded ruddervators, and two compression-molded access panels manufactured from re-used thermoplastic waste material. Ruddervators are the control surfaces for an aircraft with a V-tail configuration; the two compression-moulded access panels were manufactured from recycled thermoplastic waste material from the two ruddervator. The light tactical S-97 RAIDER helicopter, which demonstrated in 2010 to achieve twice the average cruise speed of a conventional helicopter at more than 463 [km/h] (250 knots), integrates HexWeb honeycomb core composites and HexPly prepreg composite technologies, with the ultimate goal to provide the aircraft's structure and blades with light weight and extreme strength.



(a) Composite Rotor Blade, Blade Spanwise Details, [27]

(b) Composite Rotor Blade, Cross Section Details, [28]

(c) Rotor Blade Design, All Metal Design versus Composite Design, [29]

FIG. 8 Composite Materials Implementation for Helicopter Rotor Blades, [27-29]

For both the aircraft structure and the blades carbon-fiber-reinforced composite materials were successfully used. Taking into account the advantages provided by composites, as light weight and extreme strength, the future prospects of composites are to continuous expansion in use for aircraft industry, in large civil aircraft and military aircraft, joined with innovative concept design. New Concept Developments, such as X-48 B Flying Wing, Skyworks Vertijet VTOL, Transcend Air Vy 400 VTOL, represent successfully examples of embedding composite materials implementation.

Table 1- A summary of military, commercial and general aviation aircraft, incorporating composite materials [13]

Type/ Purpose	**Manufactured**	**Aircraft**
Fighter Aircraft	U. S., Europe, Russia	AV-8B, F16, F14, F18, YF23, F22, JSF, UCAV Harrier GR 7, Gripen, JAS 39, Mirage 2000, Raphale, Eurofighter, Lavi, EADS Mako MIG 29, Su Series
Bomber	U. S.	B2
Transport	U. S., Europe	KC135, C17, B777, B767, MD1-1, A320, A340, A380, Tu204, ATR42, Falcon 900, A300-600
General Aviation		Piaggio, Starship, Premier 1, Boeing 787
Rotary Aircraft		V22, Eurocopter, Comanche, RAH66, BA609, EH101, Super Lynx 300, S92
New Concept Developments		X-48 B Flying Wing, Skyworks Vertijet VTOL, Transcend Air Vy 400 VTOL

3. BASICS OF COMPOSITES: CARBON FIBER AND NANO-ADDITIVES

3.1 Carbon fiber

In carbon fiber materials the two constituents are reinforcement and a matrix. The main advantages of composite materials are their high strength and stiffness, combined with low density. In most cases, the reinforcement is harder, stronger, and stiffer than the matrix. The reinforcement is usually a fiber or a particulate. Particulate composites have dimensions that are approximately equal in all directions. Particulate composites tend to be much weaker and less stiff than continuous fiber composites, but they are usually much less expensive. [4]

Carbon fiber is defined as a fiber containing at least 92 wt % carbons, while the fiber containing a least 99 wt % carbon is usually called a graphite fiber. Carbon fibers generally have excellent tensile properties, low densities, and high thermal and chemical stabilities in the absence of oxidizing agents, good thermal and electrical conductivities, and excellent creep resistance. They have been extensively used in composites in the form of woven textiles, prepare continuous fibers, and chopped fibers. The composite parts can be produced through filament winding, tape winding, pultrusion, compression molding, vacuum bagging, liquid molding, and injection molding. The carbon fiber usually made up of raw material called precursor. It is combination of Polyacrylonitrile (pan) and Petroleum pitch (only 10% of the production).

3.2 Nano-Additives

The use of nano-additives, such as organo-modified layered silicates, carbon nanofibers or nanotubes and others, to reinforce epoxy resins has generated significant interest both academically and commercially in recent times. This interest is primarily a result of the concurrent improvements in mechanical properties such as toughness, strength and modulus. It has been well documented however, that, in order to achieve these property improvements, the nano-additive must be sufficiently dispersed and compatible with the epoxy resin. Depending upon the nano-additive in question, this brings a range of associated challenges unique to the material. [5]

3.3 Carbon nano-tubes

The discovery of carbon nanotubes (cnts) with their exceptional mechanical properties has led to novel approaches of using them as reinforcing nano fillers in composite materials. The results obtained so far promise a unique level of mechanical property enhancement through selective use of cnts and processing conditions. The nanometer scale reinforcing power of cnts in polymers offers an opportunity to develop new composite materials with superior mechanical and physical properties. A homogeneous and stable dispersion of cnts in different polymer matrices is found to be a major difficulty, which most of ten limits performance of the composite materials. Another important issue is the tuning of interfacial adhesion between the cnts and the particular polymer matrix, which also influences the mechanical performance of cnt reinforced polymer composites. An experimental determination of the interfacial strength is still a difficult procedure. Some progress has been made in this field, but to some extent it still relies on theoretical predictions. The stress-transfer from the matrix to the reinforcements is performed via the interface, which can be influenced by chemical functionalization of the surfaces of cnts. [6]

3.4 Organo-nanoclays

Nano clays are nanoparticles of layered mineral silicates which have attracted interest in recent years. Clays are used blended with composites to form nanocomposites which increase the strength, mechanical modulus and toughness of the composite while improving barrier and flame retardant properties.

However, cnt's can be a very good alternative, organo-nanoclays will be a better option. In this research a organo-nanoclay called cloisite-30b is used. The nano-composite powder cloisite 30b with a particle size was obtained from Southern Clay Products, inc. Cloisite 30b is a natural montmorillonite modified with a quaternary ammonium salt and it is designed to be used as an additive for plastics and rubbers to improve various physical properties such as reinforcement, synergistic flame retardant and barrier. Cloisite 30b consists of organically modified nano meter scale layered magnesium aluminium silicate platelets. The platelets are surface modified with an organic chemistry technique and it allows exhaustive dispersion into and provides miscibility with the thermoplastic systems for which they have been designed to improve. While enhancing the flexural and tensile modulus, the clte has lowered when the additives have been proved to reinforce thermoplastics. By incorporating the nano particles into the structure of the surface char formation and flame retardance of the thermoplastic systems have also been found to be improving.

Hydrogen-bonds are so called secondary bonds between two hydroxyl groups. The bond is basically an electrostatic attraction between two hydroxyl groups. A hydroxyl group is a covalent bond between oxygen and hydrogen. But because these atoms don't have the same charge, their electrons are not equally shared between them. The negatively charged electrons tend to spend most of their time around the oxygen atom which makes the atom slightly negatively charged. And the hydrogen atom positively charged. So, the hydroxyl group is very polar, and it will form easily the so-called hydrogen bonds between other polar hydroxyl groups.

The differences between the hardener and the nano clay are the types of bonds and the number of bonds. The hardener will form bonds between four epoxides and can create a 3d network of hardener and epoxides. The nanoparticles can only form bridges between two epoxides. So, this network will be less complex. The forming of the hydrogen bonds is an exothermic reaction. This means that it releases energy in the form of heat during the bonding process. Since its quite hard to mix the nano clay with the resin and takes about 20 minutes of time, the mixture product must be cooled down. If the resin is too hot when mixed with the hardener, it will get hard before it is used with the fibers.

3.5 Nano clay VS. cnt

The production process of nanotubes is very complicated and expensive. This makes the tubes also expensive. Furthermore, the nano clay is perfect for actively making crosslinks between the epoxy molecules. The purpose of both materials is the same, but they work very different from each other. The nanotubes for example are known to be very strong, thin and long. They can act as microfibers in the resin, where the nano clay forms at smaller scale little crosslinks. But there are a lot of different cnt's and they are tunable with different molecules. This is called functionalizing and can improve the solvability and can even form interactions between the epoxy as well, a common interaction for cnt's are the van der Waals attractions. The use of cnt's offers lots of opportunities, but they are very expensive. The nano clay is much cheaper and easier in use, like in the mixing process. As shown in table 10 both are good options, but for this purpose the nano clay is better.

Table 2 - differences between cnt's and cloisite-30b

Name	Costs	Solvability	Opportunities	Strength
Cnt's	--	-	++	++
Cloisite-30b	+	+/-	+	+

4. EXPERIMENTAL RESEARCH

Experimental research based on two test campaigns was conducted at INCAS, within the Materials and Tribology Unit.

The main target during the test campaign was to prove that cloisite 30b has a positive effect on the mechanical properties of carbon fiber composites while also learning the work ethic involved in manufacturing them. In order to produce valid results, instructed by the supervisors at INCAS, the tests were done under strict iso standards regulations. Two different samples were tested during the campaign, a reference material, carbon fiber composite (carbon fiber and epoxy resin) and a nano clay reinforced carbon fiber composite. Both samples were tested using the same input data, following the iso standard for flexure and tensile tests.

4.1 Test rig

In order to obtain conclusive result, the tests were done on a high precision INSTRON 5966 machine that could assure the same input data when testing each sample. [2]

Table 3 - technical data

Tensile strength	3.530 mpa
Tensile modulus	230 gpa
Strain	1.5 %
Density	1.76 g/cm^3
Filament diameter	7 µm

The 5960 dual column tabletop testing systems are universal, static testing systems that perform tensile and compression testing; and also perform shear, flexure, peel, tear, cyclic, and bend tests. For each test, there were used 8 layers of carbon fiber fabric (plain weave 200 gsm) manufactured by INCAS inhouse.

4.2. Epoxy resin l20 and eph 573 hardener

The resin used in the experiment is named l20. It is suitable for the manufacture of particularly high-performance components and structures reinforced with glass, aramid, and carbon fibers. Applications include the fields of satellite design, aerospace, automobile manufacture and ship-building, and the extremely exacting field of high-performance sports equipment as well as model construction. The resin is free of solvents and fillers, it has a low viscosity and has a high static and dynamic strength on its own. The second component, the hardener, is eph-573. This hardener is very suitable with the used resin and has like the resin a low viscosity. Eph 573 exhibits very good wetting properties with respect to glass, aramid, and carbon fibers as well is a superior adhesion to fibers. The combination of these components gives only 15 minutes of processing time.

4.3 TEST CAMPAIGN # 1

4.3.1. Preliminaries on Test Campaign # 1

The reference composite was made out of a simple epoxy matrix with a hardener and a carbon fiber reinforcement. 8 layers of woven carbon fiber were set and resin was added between each one with a brush.

After that, the composite was covered with aluminium sheets and placed under a mechanical press for 24 hours to harden it and avoid air bubbles. Finally, samples were obtained through cutting with the same side and plastic parts were glued on the extremity to avoid weakening the sample during the tightening process.

Moreover, samples were also obtained from pure resin to make a comparison and see how much the reinforcement improved the properties.

4.3.2. Reference carbon fiber composite

- 8 layers of woven carbon fiber (plain weave)

- 100 g of epoxy matrix
- 20 g of hardener
- In the first campaign there were conducted two tests:

1/ Tensile,
2/ Flexure.

- Two materials were tested:

1/ Reference carbon fiber epoxy composite,
2/ Reference hardened epoxy.

- Manufacturing the samples.

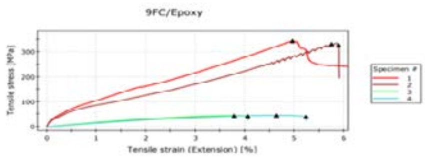
4.3.3. Tensile test / Test Campaign # 1

A tensile test, also known as a tension test, is one of the most fundamental and common types of mechanical testing. A tensile test applies tensile force to a material and measures the specimen's response to the stress. By doing this, tensile tests determine how strong a material is and how much it can elongate.

The tensile test was performed in compliance with the European standard iso 527-4:1997, it defines the conditions for the test to be normalized by the iso organism. [9]

The results of the test and dimensions of the samples are resumed in the upcoming figures.

In Fig. 9 are concluded the tests results of tensile test #1 conducted on reinforced samples (i.e. samples n°1 and n°2, which are reinforced with carbon fibers) versus unreinforced samples (i.e. samples n°3 and n°4, which are pure resin). A comparison of two identic samples indicates that the results are reliable.



	Load at Tensile strength [kN]	Tensile stress at Tensile strength [MPa]	Modulus (Automatic Young's) [GPa]	Modulus (Chord 0.3 % - 0.6 %) [GPa]
1	17.138	342.906	12.473	9.323
2	16.376	330.761	9.983	8.085
3	1.765	44.119	1.709	1.666
4	1.984	45.594	1.511	1.483
Mean	9.316	190.845	6.419	5.140
Standard deviation	8.599	168.647	5.646	4.148

	Tensile strain (Extension) at Tensile strength [%]	Thickness [mm]	Width [mm]	Length [mm]
1	4.960	1.680	29.750	97.000
2	5.746	1.680	29.470	92.200
3	3.785	4.000	10.000	82.000
4	4.636	4.300	10.120	64.430
Mean	4.782	2.915	19.835	83.928
Standard deviation	0.812	1.431	11.288	14.428

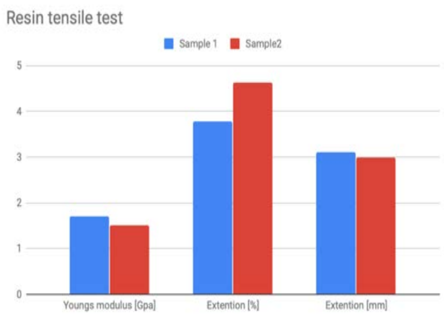


FIG. 9 Test #1 Results of Tensile Test Conducted on Reinforced Samples (n°1,2) versus Unreinforced Samples (n°3,4)

4.3.4. Tensile test in case of carbon fiber composite versus hardened epoxy resin

The results from the tensile test in case of carbon fiber composite were not valid, can conclude that it failed. The graphs show the point where the glue of the fixing tabs broke up, instead of the carbon fiber sample. The first tensile test campaign failed due to the wrong adhesive choice when attaching the tabs that would hold the sample in the grips of the testing machine.

The adhesive was not strong enough the tabs broke during the tensile test. Unfortunately, this occurred when testing both samples and this resulted in the team having to schedule another test campaign.

The results from the tensile test in case of hardened epoxy resin were a success. Both samples had similar values for Young Modulus and Extensions. Furthermore, the test validated the calibration of the testing rig.

The samples had very similar curves drawn in the graphs which clearly shows that having the same input data will result in very similar results.

Differences in the results came from the errors in manufacturing the samples and keeping them in the standard dimensions. From Fig. 10, a comparison of two identic samples indicates that the results are reliable.

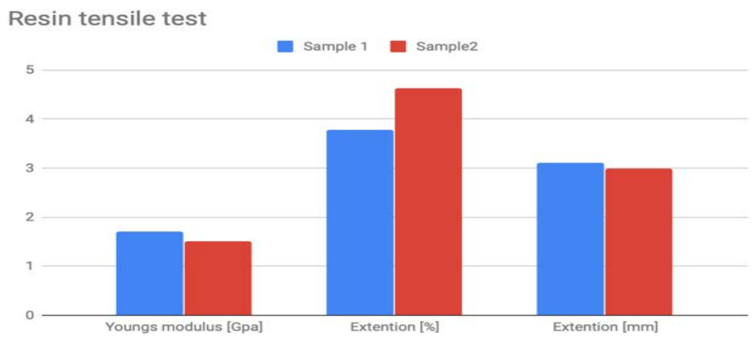


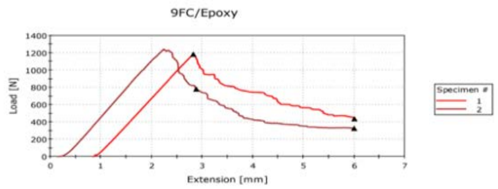
FIG. 10 Test #1 Results of Resin Tensile Test: Young Modulus and Extension

4.3.5. Flexure test / Test Campaign # 1

A flexure test does not measure fundamental material properties like in tensile or compression tests. When a specimen is placed under flexural loading all three fundamental stresses are present: tensile, compressive and shear and so the flexural properties of a specimen are the result of the combined effect of all three stresses as well as (though to a lesser extent) the geometry of the specimen and the rate the load is applied.

The flexure test implies placing a sample on two linear supports and then applying a force at equal distance to those supports. This test is ruled by the European standard Iso 178. [10]

The results obtained on the carbon fiber reinforced composite material are resumed on the first graph and table while the results of pure resin are resumed on the second part.



	Load at Tensile strength [N]	Modulus (Automatic Young's) [GPa]	Flexure stress at Tensile strength [MPa]	Flexure strain (Extension) at Tensile strength [%]
1	1,184.318	22.178	537.106	3.681
2	782.086	23.283	351.697	3.756

	Thickness [mm]	Width [mm]
1	1.800	29.400
2	1.800	29.650

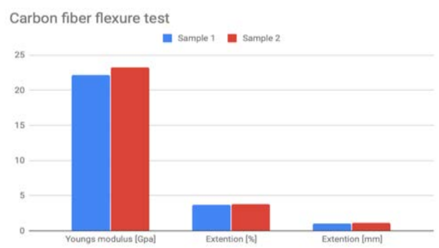
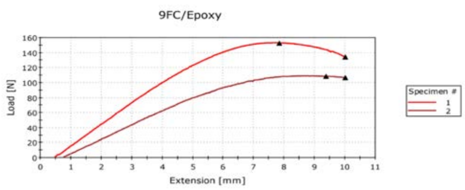


FIG. 11 Test #1 Results of Flexure Test of carbon fibers reinforced material, flexure test results graph and dimensions of carbon fibers reinforced material



	Load at Tensile strength [N]	Modulus (Automatic Young's) [GPa]	Flexure stress at Tensile strength [MPa]	Flexure strain (Extension) at Tensile strength [%]
1	152.625	2.354	80.662	5.073
2	108.599	2.152	70.394	5.486

	Thickness [mm]	Width [mm]
1	4.200	10.040
2	3.800	10.000

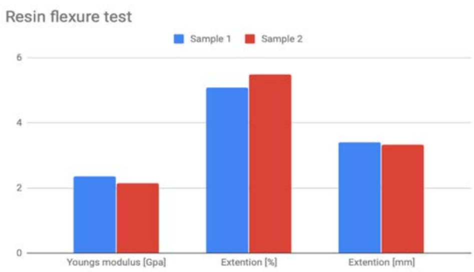


FIG. 12 Test #1 Results of Flexure Test of pure epoxy resin material, flexure test results graph and dimensions of pure epoxy resin material

As shown by the results, there are two differences: with the carbon fibers, samples can resist to a force almost 10 times higher, but they become less flexible. All in all, and after the tests completed, the carbon fibers have a real influence on the mechanical properties of the epoxy resin matrix.

4.4 TEST CAMPAIGN # 2

4.4.1. Preliminaries on Test Campaign # 2

During the second test, two different carbon fiber materials where made. One like the first test as a reference, and one reinforced with nano particles. As a result, from the first test the team has decided to conduct the test without the tabs for the tensile tests. The reference material was manufactured using the same steps as in the first conducted test campaign.

Cloisite-30b reinforced carbon fiber composite.

The used materials are:

- 20 g - hardener eph 573
- 100 g - epoxy resin l20
- 2 g - cloisite-30b

The reference material is the same materials as used in the first test. But this time it only consists 8 layers of carbon fiber instead of 9. The reinforced material took much more time to prepare because the nanoclay (cloisite-30b) has a poor solvability. This extra time is due to the mixing process. The nanoclay is added to the epoxy resin l20 in a concentration of 2% of the mass of the resin. First its roughly mixed with a glass rod, then it was placed in a sonic mixing machine. Because the nanoclay actively bonds to the resin in an exothermic process, the mixture will heat up. Therefore, it must be cooled with iced water around the glass mixing vessel. This process takes approximately 20 minutes.

After the mixing process, the hardener eph 573 was added at a ratio of 1:4 and slightly mixed with a glass rod. Now the resin is ready to be applied on the carbon fibers. After the 8th layer of carbon fiber, the resin cured to much because of the heat to add another layer. The composed material is prepared for the press to cure for 24 hours. First it was packed between two metals plates with a thin layer of mold release to get the surfaces flat, and then it was covered in Aluminium foil to protect the press from the resin. To avoid air trapped in the resin and to make it thin, the press was set at a pressure of 50n/cm².

4.4.2. Ultrasonic mixing machine

By ultrasonic mixing a good dispersion of the nanoclay into the resin can be obtained. This is needed because the nanoclay has a very poor solvability. And the nanomaterial will give negative results if it is not well dispersed. It is called ultrasonic when the frequency outranged the human hearing (>20khz).

4.4.3. Test results / Test Campaign # 2

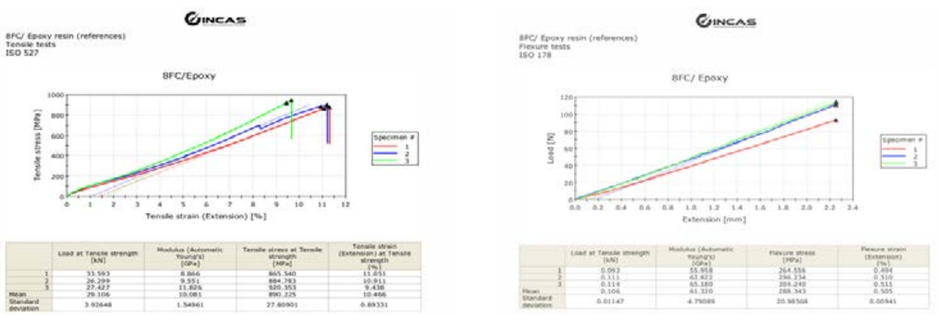


FIG. 13 Test #2 Results of Tensile Test (*left*), Results of Flexure Test (*right*) in case of the reference material

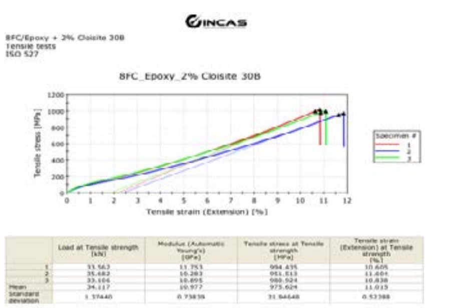
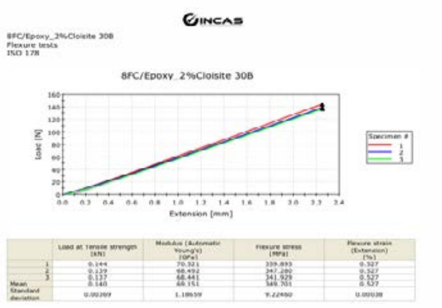



FIG. 14 Test #2 Results of Tensile Test (*left*), Results of Flexure Test (*right*) in case of the reinforced material

4.4.4. Analysis of Results and Statistics / Test Campaign # 2

To be sure the results from the test are valid, a statistic study was conducted. The benefit of the machine used to test the results is that it provides a mean and standard deviation. Since in this research two materials were compared, it's useful to know at which certainty conclusions can been made. To calculate this, the means and standard deviations of both test materials is needed. Where σ is the standard deviation. The total standard deviation in this test is 35,43 [mpa]. To make conclusions the interest is in the difference between the means of both materials. This difference is calculated by just subtracting the one from the other. This difference in mean $\Delta\underline{x}$ = 85,29 [mpa]. With these numbers the z-value can be calculated. This value is a number of standard deviations within a certain domain. In this case the difference between means. When the $\Delta\underline{x}$ Is divided by σ_{total} A z-value of 2,41 comes out. And following pre-calculated statistics tables this gives a certainty of 0.992024 of 1, so 99,2%. This concludes with a certainty of 99,2% that the cloisite-30b reinforced carbon fiber is stronger than non-reinforced carbon fiber in tensile tests. The same method is used for flexure strength and gave a certainty of 99,6%.

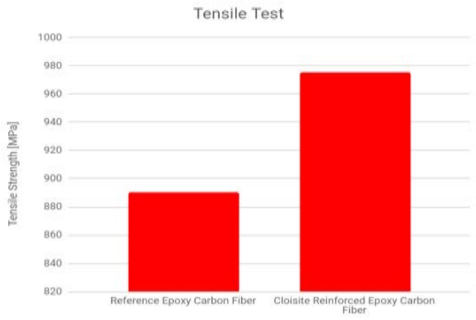
4.4.5. Tensile test results / Test Campaign # 2

Table 4 – tensile test results

Tensile test	Mean tensile strength [mpa]	Standard deviation [σ]
Reference epoxy carbon fiber	890,225	27,809
Cloisite reinforced epoxy carbon fiber	975,624	21,946
Mean difference	85,399	[mpa]
Total standard deviation	35,426	[mpa]
Z-value	2,411	
Certainty	0,992	99,2%

Table 5 - flexure test results

Flexure test	Mean flexure strength [mpa]	Standard deviation [σ]
Reference epoxy carbon fiber	288,343	20,986
Cloisite reinforced epoxy carbon fiber	349,701	9,225
Mean difference	61,358	[mpa]
Total standard deviation	22,924	[mpa]
Z-value	2,677	
Certainty	0,996	99,6%



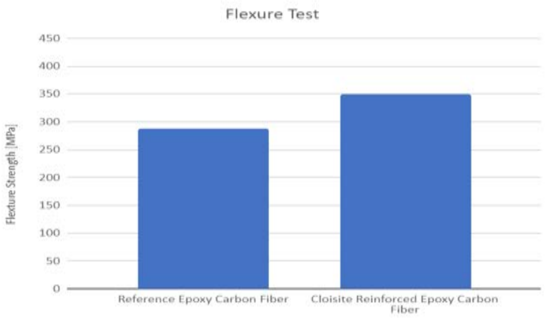


FIG. 15 Test #2 Tensile strength of reference material and cloisite reinforced cf (*left*), Flexure strength of reference material and cloisite reinforced cf (*right*)

5. CONCLUSIONS

5.1. Discussion. Lessons Learned

During the tests and the manufacturing processes of the materials we learned a lot. We noticed for example how important it was to prepare tests. Some of the tabs broke off during the tensile tests, thus some test results were not valid. We experienced that one test is not enough, you need more repeats to be sure the results are valid. Since the product is high-tech, it is hard to find a good marked for it at this moment.

5.2. Further Steps

It is possible to draw better conclusions after a more complex statistics study, like given a certainty that the reinforced material is at least 5% stronger, for example. This is a good subject for further research. Also, to find better ways to cool the mixture with the nano clay and to obtain better measurements, it is worth finding better ways to attach the gripper tabs.

5.3. Final Conclusions

According to the results of the tests, the role of carbon fibers in the epoxy resin-based material is really important in order to improve the mechanical properties (tensile, flexion etc.).

Since better efficiency of materials is always required, one of the most interesting ways to keep improving the mechanical properties of the composite is to find suitable nano-additives, to achieve better toughness, stiffness and even better thermal properties.

The improvements in strength comes with some disadvantages in manufacturing and this with the extra material costs will raise the total costs of the production of the material. For smaller parts its worth to consider using nano-additive reinforced carbon fiber for strength.

Concluding remarks:

- Cloisite 30b improves the mechanical properties of carbon fiber composite – (10 – 20 %)
- Mixing cloisite 30b with the epoxy resin is very time consuming
- Limited working time when using cloisite 30b resin mixture
- Cloisite 30b reinforced mixture is more suited for smaller parts
- The cost of cloisite 30b reinforced cfc is higher than the standard cfc
- Cloisite 30b could increase weight of larger parts compared to standard cfc

Table 6 - advantages and disadvantages of cloisite-30b reinforced material

Name	Costs	Manufacturability	Applications	Strength
Reference	++	++	++	+
Cloisite-30b	-	+/-	+	++

ACKNOWLEDGEMENT

This research was developed within the research partnership between [4]"POLITEHNICA" University of Bucharest, Faculty of Mechanical Engineering and Mechatronics and INCAS - National Institute for Aerospace Research "Elie Carafoli", through the European Project Semester (EPS) International Programme.

The team of Science Advisors and Coordinators: Adriana ŞTEFAN, Irina-Carmen ANDREI, Gina Florica STOICA, Nicoleta CRIŞAN, Delia PRISECARU, Cristian STOICA, Anca GRECULESCU.

The team of Tutors: Irina-Carmen ANDREI (INCAS Tutor), Nicoleta CRIŞAN (UPB Tutor).

This research is supported by INCAS - National Institute for Aerospace Research Elie Carafoli, as a beneficiary of the Project - Technological Development Platform for Green Technologies in Aviation and Ecological Manufacturing with Superior Added Value, TGA - TECHNOLOGIES FOR GREEN AVIATION, financed by the Competitiveness Operational Program 2014-2020 (POC), POC/448/1/1/Large R&D Infrastructures, SMIS CODE 127115, Contract of Financing no. 313 / 14.07.2020 funded by Romanian Ministry of Research, Innovation and Digitization.

REFERENCES

[1] L. Cademartiri et al, 2012. *Concepts of nanochemistry*. 2nd ed. Toronto: wiley-vch Https://www.instron.us/en-us/products/testing-systems/universal-testing-systems/ electromechanical/ 5900-series/5960-dual-column, 05/07/2019;

[2] D. Hull, 1981. A*n introduction to composite materials*. Cambridge University Press, www.academia.edu;

[3] Z. Sachin, Jadhav, 2015. *Composite carbon fiber materials*. Ijariie, www.academia.edu;

[4] K. Kar, 2017. *Composite materials: processing, application, characterization.* Springer, www.academia.edu;

[5] B. Harris, 1999. *Engineering composite materials*. The Institute of Materials, London;

[6] M.M. Shokrieh, 2013. *Reduction of thermal residual stresses of laminated polymer composites by addition of carbon nanotubes*. Elsevier, materials & Design, www.academia.edu;

[7] A. Godara, 2009. *Influence of carbon nanotube reinforcement on the processing and the mechanical behaviour of carbon fiber/epoxy composites*. Elsevier, Carbon;

[8] Iso 527 https://www.iso.org/standard/4595.html, 05/07/2019;

[9] Iso 178 https://www.iso.org/standard/70513.html, 05/07/2019;

[10] Insight 9, *Composite Materials Applications in Aerospace*, Aerospace Technology Institute, 2018;

[11] W. Roeseler, B. Sarh, M. Kismarthon, *Composite Structures: the first 100 years*, 16th International Conference on Composite Materials, The Boeing Company;

[12] ***, Materials Science and Engineering, Chapter 15 – Composites, 7th Edition, Cambridge University Press, 1996, Conference on Composite Materials, The Boeing Company;

[13] A. Quilter, *Composites in Aerospace Applications*, HIS, ESDU;

[14] R. Lofland (R. Lofland and Associates), C. Grant (Aerospace Composites Consulting), *Composites 101 Workshop*, AERODEF Manufacturing, AERODEFEVENT.com, Exibits, March 2017, Fort Worth, Texas, USA;

[15] Ulf Paul Breuer, Commercial Aircraft Composite Technology ;

[16] General Electric GE 90 Turbofan Engine;

[17] MIL-HDBK-17-3F, Department of Defense Handbook, Composite Materials Handbook, Volume 3 of 5, Polymer matrix Composites. Materials Usage, Design and Analysis, USA, 17 June 2002;

[18] https://www.keyshone.com/wp-content/uploads/2016/12/aircraft-composite-materials-of-boeing-767.png, 08/09/2020;
[19]https://duckduckgo.com/?t=ffab&q=composites+use+in+aircraft+b767&iax=images&iai= https%3A%2F%2Fwww.mdpi.com%2Fmaterials%2Fmaterials-13-01364%2Farticle_deploy%2Fhtml%2Fimages%2Fmaterials-13-01364-g001.png&ia=images , 08/09/2020;
[20]https://duckduckgo.com/?t=ffab&q=composites+use+in+aircraft+b767&iax=images&iai= https%3A%2F%2Fwww.1001crash.com%2Fdossier%2Fcomposite%2FB787_composite.jpg&ia=images , 08/09/2020;
[21]https://duckduckgo.com/?t=ffab&q=composites+use+in+aircraft+b767&iax=images&iai= https%3A%2F%2Fi.pinimg.com%2Foriginals%2Ff8%2F4c%2F37%2Ff84c3755d1118cf668a5251bcf193509.png&ia=images , 08/09/2020;
[22]https://duckduckgo.com/?t=ffab&q=composites+use+in+aircraft+b767&iax=images&iai= https%3A%2F%2Fwww.sec.gov%2FArchives%2Fedgar%2Fdata%2F717605%2F000110465908021748%2Fg97851bci012.jpg&ia=images , 08/09/2020;
[23] https://image.slidesharecdn.com/advancedcomposites-160127234721/95/advanced-composites-1-638.jpg?cb=1453938555 , 08/09/2020;
[24]https://duckduckgo.com/?t=ffab&q=composites+use+in+aircraft+b767&iax=images&iai= https%3A%2F%2Fd3i71xaburhd42.cloudfront.net%2F85416c75d82bdb253c296f6aea15b9b394b949f3%2F7-Figure5-1.png&ia=images , 08/09/2020;
[25]https://duckduckgo.com/?t=ffab&q=composites+use+in+aircraft+b767&iax=images&iai= https%3A%2F%2Fmiro.medium.com%2Fmax%2F2812%2F1*39VzaWjXx-tvzvJ6j1On1w.png&ia=images , 08/09/2020;
[26]https://duckduckgo.com/?t=ffab&q=composites+use+in+aircraft+b767&iax=images&iai= https%3A%2F%2Fd3i71xaburhd42.cloudfront.net%2F85416c75d82bdb253c296f6aea15b9b394b949f3%2F6-Figure3-1.png&ia=images , 08/09/2020;
[27]https://duckduckgo.com/?q=helicopter+rotor+blade+material&t=ffab&iar=images&iax=images&ia=images&iai=https%3A%2F%2Fwww.researchgate.net%2Fprofile%2FBosko_Rasuo%2Fpublication%2F265977369%2Ffigure%2Ffig2%2FAS%3A669457366126635%401536622482887%2FThe-helicopter-main-rotor-blade-made-of-composite-laminated-materials.png , 08/09/2020;
[28]https://duckduckgo.com/?q=helicopter+rotor+blade+material&t=ffab&iar=images&iax=images&ia=images&iai=https%3A%2F%2Fpilotteacher.com%2Fwp-content%2Fuploads %2F2020%2F05%2FComposite-Blade-Cross-Section.jpg , 08/09/2020;
[29]https://duckduckgo.com/?q=helicopter+rotor+blade+material&t=ffab&iar=images&iax=images&ia=images&iai=http%3A%2F%2Fwww.helistart.com%2FFigures%2FAirfoilConstructions.png, 8/09/2020.