# GLASS FABRICS FUNCTIONALIZATION FOR THE DEVELOPMENT OF HIGH-PERFORMANCE SANDWICH STRUCTURES

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*The development of composite materials with high properties compared to traditional materials, was imposed by the fields of advanced technology: aerospace technology, medical construction technology of implants, but also in the automotive industry, in construction, especially naval industry, chemical, furniture industries and sports equipment industry. This article follows the behavior of various glass fiber fiberglass fabric specimens made from a mixture of different concentrations of EPOLAM 2001 resin and hardener to obtain information about the influence of the parameters studied: amount of resin, amount of hardener used, drying time and drying temperature on the final properties of the newly obtained material.*

**Keywords**: fiber glass, resin, hardener, composite materials, aerospace industry

## 1. Introduction

Composite materials have caused a real revolution in the industry, starting at the end of the last century and continues to develop with the same strength today because they have multiple advantages: they take on some useful properties in the design process of a machine or its component parts and eliminate some disadvantages that would occur when using a single element [1].

Other advantages of composites compared to traditional materials are: more resistant and lighter, easier to manufacture, with a greater positive impact on the environment [1].

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The emergence and development of new fields such as aeronautics, automobiles, and the development of military applications, imposed the development of this category of materials that can work in harsh conditions. For example, in the aeronautical industry the priority is the aerodynamic considerations of profile optimization and the realization of the conditions that are imposed due to temperature differences, fatigue resistance, stiffness, vibrations, etc. [2].

Therefore, traditional materials can no longer fully satisfy the ever-increasing and the complicated configuration of their structures it requires, from the point of view of the economic factor: i) the use of different traditional production technologies, which implies an expensive technique; ii) creating materials that are easier to obtain, which involved cheaper technology. Looking through the prism of the economic factor composite materials represent a new class of materials of great technological importance with increasing applicability in many fields, from civil engineering to aeronautical, naval or automotive industries. [3, 4, 5].

The main advantage of these materials is the high ratio between strength and volumetric weight (specific strength) and the low price of the complicated elements, in the case of large series production [6].

In most preliminary designs, including the aerospace industry, the first design configuration has an estimated accuracy of 10-20%. At this level, generic data are usually satisfactory because the greater uncertainty comes from the applied loading conditions. For example: many composites are used in situation of limit displacement or compressive failure by buckling prior to failure by compressive bending [7].

The flexibility of the design of the composite material has delayed the full integration of these materials due to the lack of specific characteristics equivalent to metal alloy specifications and associated databases [7].

The criteria that were considered when it was decided to replace certain parts of a structure, made from traditional metal/alloy materials, with parts produced from composite materials were: low strength-to-weight ratio, resistance to wear, corrosion, temperature, dielectric properties, the non-magnetic character and last but not least the lower-cost [8].

When it comes to the use of composite materials, there is no field, be it high-tech branches or traditional industries, where composite materials are not used. The main types of applications of these types of materials for the branches of industry, insisting on the areas where the environment leaves its mark on the state of tension and deformation [9].

Inherent damages, occurring during the composite production, are related to the defects of the constituent materials, but also to the manufacturing technology. These damages are produced by non-uniformities of the thickness of the layers, the lack of parallelism between the fibers, interruptions of the fibers, voids (air pockets) or other imperfections in the structure, delamination, but also due to inadequate or incorrectly used tools [10].

The priorities in the aeronautical industry are aerodynamic considerations, profile optimization and the achievement of special conditions imposed by temperature differences, fatigue resistance, rigidity, vibration, etc. Numerous studies have been performed to optimize the structure of these materials to improve the mechanical or thermal behavior, by increasing the fiber volume, short - range and long - range bending [11].

The aim of the work is to obtain advanced composite materials, which are current, innovative, and high-performance solutions for applications in cutting-edge fields such as aeronautics and modern transport. In this context, the main objective of the work is to develop advanced composites with high structural, thermo-mechanical and / or tribological performances, corresponding to ecological norms and international requirements, to replace the classical materials.

## 2. Materials and methods

All the materials used to manufacture of the samples were carefully handled, kept under special conditions (areas protected from moisture, at temperatures not exceeding 35°C, at a relative humidity lower than 65%):

-Fiberglass fabric 160 g/m$^2$, length 1000 mm, width 1000 mm, ECR 500 FABRIC consists of continuous threads of ECR glass fiber, bidirectional woven in a fabric with a specific weight of 500 g/m$^2$. ECR type glass fiber combines the mechanical and electrical properties of traditional E type glass fiber with high chemical corrosion resistance, superior thermal resistance, dielectric strength and better surface resistivity;

- EPOLAM 2001 Resin A (suitable for the production of tools, negatives, by casting concrete with resin or wet lay-up laminating);

- EPOLAM 2001 Hardener B (suitable for the production of composite structures by wet lay-up, infusion, vacuum, and low-pressure injection).

The sandwich structure of composite material was prepared by “Hand lay-up method followed by hydraulic press”. The Resin A was mixed with the Hardener B in the weight ratio of 3:1. After that was mixed with fiberglass fabric to make 15 mm thickness of sandwich structure with application of hydraulic press of 70 pSI ($4.83*10^5$ Pa) for 24 h. The mixture of Resin A and Hardener B was distributed evenly, without foreign bodies, ensuring the perfect alignment of the fibers, so as not to damage the appearance and performance. After this time the specimen was left to dry in the oven at a temperature of 65$^o$C and a humidity of 55% to ensure complete drying of the hardener for another 24 h.

The behavior of several fabric specimens made from a mixture of different concentrations of EPOLAM 2001 resin and hardener is followed to obtain information about the influence of the amount of resin and hardener used, drying time and temperature on the final properties of the newly obtained material [11].

The fiber volume test method determines the constituent content of the composite materials by immersion in oil for 24 hours. After this operation, the reinforcement remaining unaffected and allowing the calculation of reinforcement or matrix, as well as the percentage of void volume [12].

## 3. Test Parts

The samples were cut according to the shape of a suitable matrix for performing the tests. As the name suggests, the Short Beam Shear test subjects a beam to bending, just like the bending test methods, but the beam is very short relative to its thickness. For example, ASTM D 23441 specifies a support length to specimen thickness (s/t) ratio of only 4:1, as shown to scale in Fig. 1. The objective is to minimize the bending (tensile and compressive stresses) and to maximize the induced shear stress [13].

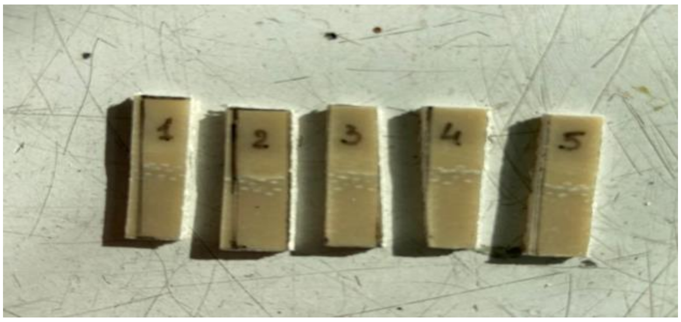


Fig. 1. Short-range bending specimens

The value of the flexural stress resistance for the composite beam or slab is known as the ultimate flexural strength. The maximum amount of stress and force that can be supported by a reinforced composite slab or beam is identified by the ultimate flexural strength. This is usually expressed as a bending moment value [14].

The maximum amount of stress experienced by the material under the yield moment condition is represented by the term ultimate bending strength [14]. The maximum value of stress in bending stress that can be sustained before the material fails is known as the bending strength. The composite material will fail under the maximum tensile bending stress before the maximum compressive bending [14].

Eleven specimens of varied sizes were obtained for which short-range bending tests, long-range bending tests were performed, and for one of them the fiber volume was calculated.

Long-range flex test tubes are 3.5 inches long and 0.5 inches wide. According to the data presented in the literature [13], the minimum value for the maximum long-range bending elongation is 65 KSI, with all 5 samples passing the test. It can be seen (Fig. 1) that the tested specimen has a uniform stretch, thus resulting in breaking strength.

Fig. 2 shows the samples for which they are tested long-range bending. A material with high flexural strength could resist deformation when force is applied in tension or compression; it inherently will withstand bending, stretching, twisting, and other types of stress. Products that are designed with low flexural strength materials may not survive long-term use in applications like sporting equipment.

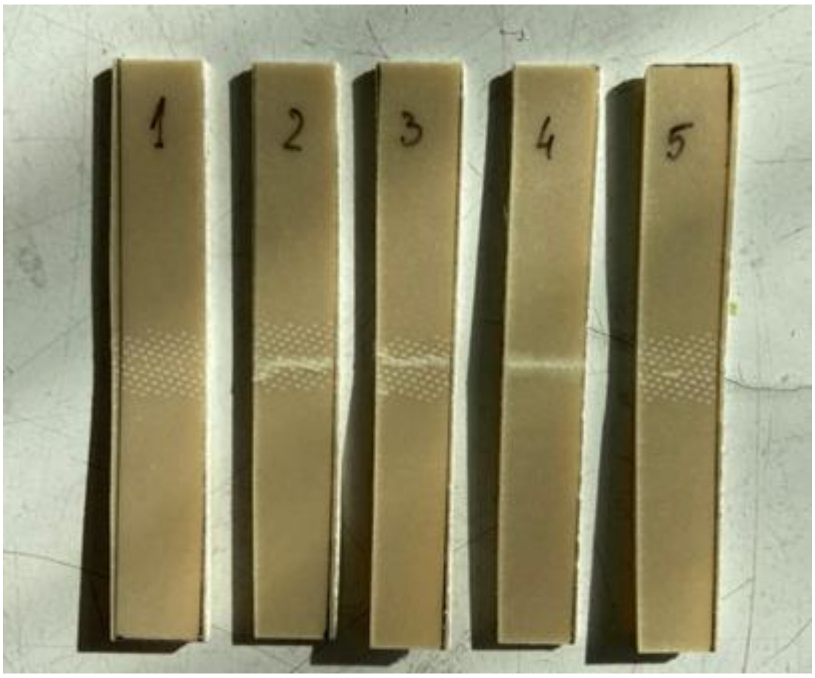


Fig. 2. Long-range bending specimens

Fiber volume ratio, or fiber volume fraction, is the percentage of fiber volume in the entire volume of a fiber-reinforced composite material (Fig. 3). When manufacturing polymer composites, fibers are impregnated with resin. The amount of resin to fiber ratio is calculated by the geometric organization of the fibers, which affects the amount of resin that can enter the composite. The impregnation around the fibers is highly dependent on the orientation of the fibers and the architecture of the fibers. The geometric analysis of the composite can be seen in the cross-section of the composite [14].

Fig. 3. Sample used to determine the fiber volume

## 4. Results and discussion

These test methods are used to determine the flexural properties of unreinforced and reinforced plastic materials, including high modulus composites and electrical insulating materials, by using a three-point loading system to apply a load to a simply supported beam (specimen). The method is applicable to both rigid and semi-rigid materials, but flexural strength cannot be determined for those materials that do not break or yield on the outer surface of the test specimen within the 5.0 % strain limit [14].

According to the literature, Fiber Reinforced Polymers are extensively used in Automotive (31%), constructions (26%), marine (12%), 10% electronic, consumer goods (8%) appliances (8%) but also in aerospace (1%), along with ~4% in miscellaneous applications. Also, Qureshi J recently reviewed the most important data in the field of FRP [15]. Moreover, glass fiber reinforced polymers (GFRP) are possible to be compatibilized with other materials and performant panels can be obtained [16].

Elongation at break, also known as fracture strain, is the ratio of the changed length to the initial length after breaking of the test specimen. Expresses the ability of the fiber to resist changes in shape without forming crack.

In Fig. 4 is presented the elongation at break for the long and short bending test. For the long-range bending elongation test, the size of the sink's is 80.9 KSI while the size is 1 inch long and inches wide.

Bending tests reveal the elastic modulus of bending, flexural stress, and flexural strain of a material. 3-Point bending involves placing the material across a span supported on either ends of the material and bringing down a point source to the center of the span and bending the material until failure while recording applied force and crosshead displacement (Fig. 4).

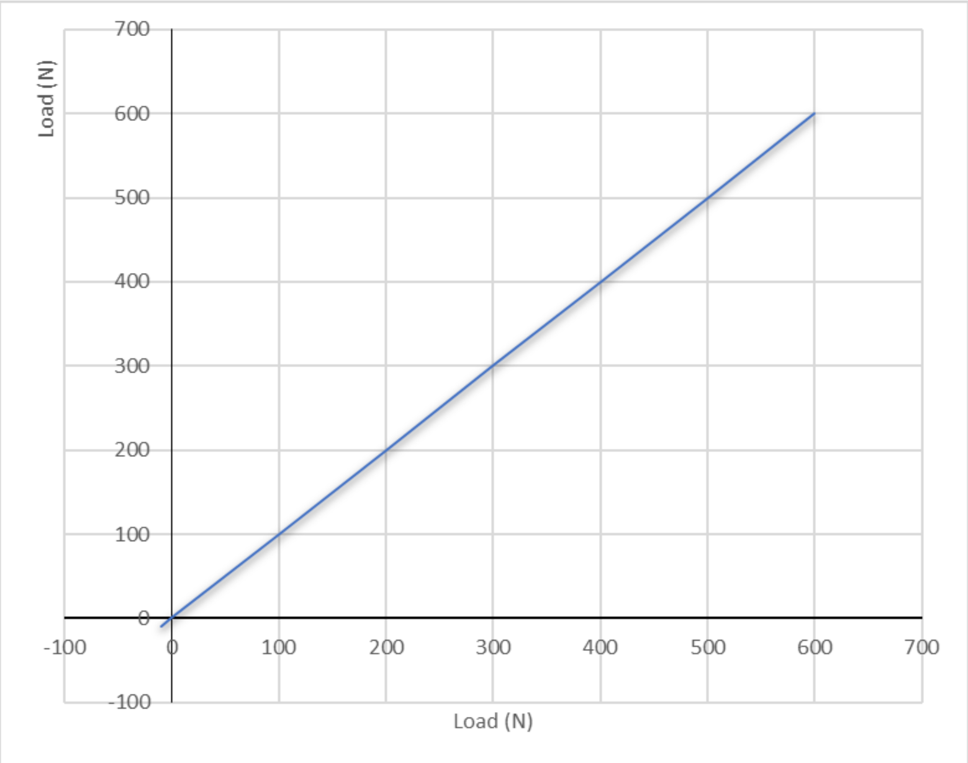


Fig. 4 - Elongation at break - Long and short bending test

For the short-range bending elongation test, the size of the sink's is about 1 inch long and 0.25 inches wide here and the value of the force is 8.4 KSI.

Test specimens of rectangular cross section are injection molded or cut from cast or extruded sheets or plates. Specimens must be solid and uniformly rectangular. The specimen rests on two supports and is loaded by means of a loading nose halfway between the supports [14].

In Table 1 the mechanical results for each sample that are presented. The device was used to test the samples is The INSTRON 6800 Series test system which is a more advanced and efficient option for users desiring increased repeatability and higher throughput, which relies on an extensometer and deflectometer to provide a more accurate reporting of strain.

*Table 1*

**Mechanical properties of the sample according to the long and short-range bending tests**

| Test part no. | Maximum elongation (Long range bending) [daN] | Maximum elongation (Short range bending) [daN] |
|---|---|---|
| 1 | 73.44 | 105 |
| 2 | 69.17 | 105 |
| 3 | 59.37 | 98 |
| 4 | 64.45 | 98 |
| 5 | 64.72 | 100 |

Materials that do not break at the maximum strain allowed by this test method may be more suitable for a 4-point bend test. The basic difference between the two test methods is in the location of the maximum bending moment and maximum axial fiber stresses. The maximum axial fiber stresses occur on a line below the load nose in 3-point bending and over the area between the load peaks in 4-point bending. A four-point loading system method can be found in Test Method D6272 [14]. Regarding the calculation method, the firing rate was 1mm / min for long-range bending and 1.27 mm / min for short-range bending. The force in the unit of measurement pounds per square inch (pSi)

$$S = 0.75 \cdot \frac{\boldsymbol{L}}{\boldsymbol{W * T}} (pSi) \qquad P = L \cdot \frac{3S}{2wT^2} (pSi) \qquad [17, 18]$$

Where:

S - shear strength, *pSi*
L - breaking load (breaking strength), *lbf*
W - width of specimen, *inch*
T - thickness of specimen, *inch*

P - flexural strength, *pSi*
L - load at failure, *lb*
S - support span, *inch*
W - width of specimen, *inch*
T - thickness of specimen, *inch*

The report of material tested shall include the following [17, 18]:

i) identification of the material tested;
ii) direction of cutting (warp or fill);
iii) support span length;
iii') support span to thickness ratio (as 16 times the thickness of the specimen, note as S);

iv) radius of supports and loading nose;
v) rate of crosshead motion;
vi) acceptance or rejection of the material;
vi' flexural strength.

Considering the two major properties of the glass fibers in GFRP, namely mechanical properties enhancement but also flame retardancy, these composite materials have great potential of use a wide range of applications [19].

In Tables 2 and 3 present all the results for long-range bending, respectively short-range bending necessary for calculation the pressure for both tests.

*Table 2.*

**Flexural strength by Long-range bending of tested specimens**

| Test part no. | W (inch) thickness | T(inch) thickness | L (lb) * force daN*2.20 | S(inch) 16*T | P(KSI) | AVERAGE |
|---|---|---|---|---|---|---|
| 1 | 0.52 | 0.079 | 161.5 | 1.26 | 95.4 | 77.9 KSI |
| 2 | 0.51 | 0.079 | 152.1 | 1.26 | 91.3 | |
| 3 | 0.49 | 0.079 | 130.6 | 1.26 | 80.9 | |
| 4 | 0.5 | 0.078 | 141.7 | 1.24 | 87.9 | |
| 5 | 0.5 | 0.078 | 142.3 | 1.24 | 88 | |

*Table 3.*

**Flexural strength by Short-range bending of tested specimens**

| Test part no. | W (inch) thickness | T(inch) thickness | L (lb) * force daN*2,20 | S(inch) 16*T | P(KSI) | AVERAGE |
|---|---|---|---|---|---|---|
| 1 | 0.25 | 0.08 | 231 | 0.32 | 8.6 | 8.9 KSI |
| 2 | 0.24 | 0.78 | 231 | 0.32 | 9.1 | |
| 3 | 0.26 | 0.78 | 242 | 0.32 | 9 | |
| 4 | 0.24 | 0.78 | 215.6 | 0.32 | 8.4 | |
| 5 | 0.24 | 0.79 | 242 | 0.32 | 9.4 | |

Both bending tests were compliant, resulting in an average 77.9 KSI for the long-range bending test and 8.9 KSI for the short-range bending test.

The sample obtained from 8 layers of weighed fiberglass fabric, weighing 0.1825 g, was immersed in oil for 24 hours, allowed to dry and then for another 24 hours, in an oven at a temperature of 70$^{o}$C and a humidity of 55%, had a mass of 0.1735 g.

The density of the fiberglass fabric is 0.8056 g/cm3 and the weight of a single thread is 0.0476 g. The density of the test piece was calculated, having the value of 2.55g / cm3.

*A_w=a/0,000645 g* [20]
$D=(a*d)/(atw-b) = 2.55g/cm^3$ [20]
*Vol.Fiber %=(Aw*B)/(Tp*D)*3.94*10^5*100= 46.4%* [20]

In these formulas Aw was used the total weight of the fiberglass, T average the average thickness of the laminate (0.078mm), B the number of fabrics in the composition, D the density of the fiberglass, $3.94 * 10^{-5}$ is a conversion factor to shade units [20], and 100 to be able to make a percentage [20]. Based on these values, the fiber volume can be determined.

Where:
n. fiber = 0.1825 (a)
n.thread = 0.0476 (b)
n.fiber.petrol = 0.1735 (w)
B = 8 (no. of fibre layers)
D = 0.8056 g/cm3

The calculated fiber volume is 46.40% left empty, in the literature [20] there are data confirming that it should be between 42-52%.

Taking into account high surface reactivity of the glass, surface modification can additionally improve the compatibility between the phases and thus the mechanical properties can be improved as reported for the polypropylene – glass fibres system [21].

The proposed composite in this paper is compared with other similar specimens from the literature date in Table 4.

*Table 4.*

**Mechanical characteristics of compozites**

| Sample | Flexural strength [MPa] | |
|---|---|---|
| | Long range bending | Short range bending |
| Proposed composite (this study) | 536.73 | 61.32 |
| | Average 299.03 | |
| PVC+Elium [22] | 243.75 | |
| PVC + Epoxy [22] | 206.25 | |
| PET + Epoxy [22] | 165 | |
| PET+Elium[22] | 159.4 | |

| | |
|---|---|
| EP/GF (HL) [23] | 300-400 |
| Nulite F [24] | 243.34 |
| Build it [24] | 331.09 |
| Z250 [24] | 500.09 |

## 5. Conclusions

The tested material met the necessary conditions to be used, having good mechanical properties, being within the limits imposed by the standards. Given that traditional materials cannot be used on a large scale, the introduction of new materials into the fiber structure (eg. recycled glass waste) could be tested to observe if the mechanical properties can meet the requirements for different applications, including aerospace application, but also if the fiber volume would increase.

The advantages of these fabrics are stability and reasonable porosity. Disadvantages include poor draping, high level of fiber creasing that causes relatively low values of mechanical properties compared to other fabrics. Composites are no longer just the privilege of the aerospace industry, defense and luxury products. They are quickly becoming a way to achieve high structural performance at low cost. They are found in most of the cars we drive, in all buses and trains, in boats and recreational and sports equipment such as skis or canoes.

Looking to the future the use of glass waste in the form of controlled granulation powder can bring major benefits by further addition along with glass fibers or fabrics. By reusing glass, the research includes two major interest areas: environmental protection and synthesis of new materials with special and high-performance properties using a sustainable approach.

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