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LAMINATED COMPOSITE MATERIALS OBTAINED BY LAMINATION WITH CARBON FIBER

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ABSTRACT

Composite materials have had a rapid development in recent decades and have come to be used in various fields of industry, including civil engineering. The study of composite materials, but especially of those layered with fibers of different types, is based on improving the physical and mechanical properties and increasing the resistance of the resulting new materials. Through the experimental study, it is aimed to resolve some technological issues regarding the manufacture of samples from composite materials reinforced with carbon fiber and epoxy resins and to improve the mechanical resistance of the usual construction materials from the composition of resistance structures. Combining or reinforcing materials such as wood or concrete, with carbon fiber or glass laminated with epoxy resins or inserted directly into their composition as dispersed reinforcement, increases their properties. In this way, smaller dimensions of the elements can be obtained, leading to an increase in their load-bearing capacity. In this experimental work it is aimed to increase the mechanical and physical resistance behavior of certain materials with the help of carbon fiber laminated with epoxy resins. It has been chosen to use as raw material for samples: concrete, solid brick sandwich, wood, and extruded polystyrene. Depending on the utility of each, after lamination with carbon fibers, the samples are tested for bending moment, compression, fire resistance and shock resistance.

KEYWORDS: composite materials, carbon fibers, matrix, resistance

1. Introduction

Composite materials have appeared due to new demands in several technical fields determined by their rapid progress in the last century. Although this type of material has its origins since antiquity, we will go directly to the modern ones that came into use in the 1940s, reaching the form we know today, consisting of a polymer matrix reinforced with different types of fibres.

They were first used on a large scale in the aeronautical and naval industries. After the war they were also used in nuclear and space projects. As humanity approached the third millennium, composite materials began to be used in more and more fields, including the chemical, automotive, energy industry and, also in construction. Regardless of the technological area that uses these materials, they all follow the same mechanical, physical and chemical properties, which are difficult to achieve today. The aim of this paper is to highlight and analyse these special properties in the present experimental work.

2. Theoretical presentation

2.1. General aspects

2.1.1. Fibbers

fibres are one of the basic components of a composite material. It is a modern raw material, obtained through a complex technological process, hence its high price. Its properties are a determining factor in the behavior of the composite material because they act like a reinforcement, taking over the efforts to which the finished product is subjected.

The basic unit (Fig. 1) represented in the form of a cube that has an atom in each corner, and its sides represent the bonds between atoms [1-3].

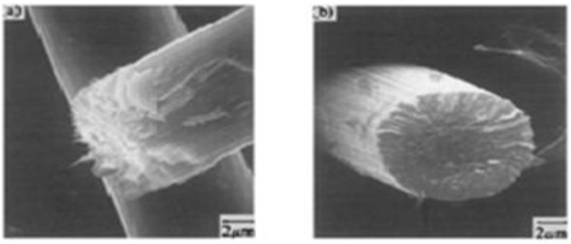

Fig. 1. *Basic unit*

This unit dictates the behavior of the fibres. Being an anisotropic material, its properties differ depending on the direction. The interatomic bonds in the composition of the fibres give it a very rigid and stress-resistant direction of stress, while all other directions are much weaker. This configuration gives properties dependence on the strong direction (ex.: thermal conductivity, electrical etc.) [4, 5].

The fibres are between 3-10 μm thick and the length depends on the type of fiber. In the first stage of processing, at the inter- atomically, the basic units, presented in the previous chapter, are randomly oriented (Fig. 2), offering an isotropic characteristic and resistances equal to those determined by the weakest directions. To obtain the finished product, the raw material is processed into fibres (by stretching), orienting the basic units in the direction of maximum strength and rigidity (Fig. 2). The fiber thus becomes an anisotropic material, clearly superior to the raw material in bulk and with strong resistances in the longitudinal direction [1, 4, 5].

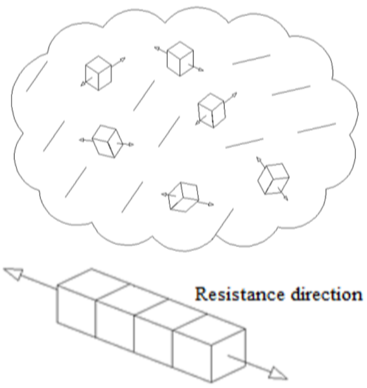

Fig. 2. *Resistance direction of fibers*

2.1.2. Carbon fibers

In nature, carbon is found in different forms, in organic and inorganic compounds. Carbon fiber was discovered in 1879 by Edison, but its industrial production began only in 1960, following a process developed by William Watt, for Royal Aircraft UK.

For a long time, their implementation was problematic, and the recipe for their production is constantly being improved. Carbon fibres appeared as a replacement for glass fiber, acting as reinforcement for a series of materials used in many fields and due to their properties: low density, chemical resistance, mechanical resistance, ease of being put into work and to be moulded in any form. The main disadvantage of fiberglass is their relatively high modulus of elasticity, which causes a fiberglass beam to buckle four times more than a similar steel beam. In restoration, carbon fibres are used in strengthening by plating some structural elements. Cladding with fiber fabrics consists in applying oriented structures characterized by the number of knots per square centimetre, the dimensions and the type of mesh on the surface of masonry, concrete, wood.

It should be mentioned that the fabrics are made of continuous fibres. These are structures with long lengths and small sections, which, due to the parallel ordering of molecules or crystalline domains, have a good mechanical resistance, as well as a high degree of impermeability. The binders used are various epoxy resins that adhere to the surface of the reinforced element and uniformly embed the carbon fabric. These resins must be strong and rigid enough to transfer the forces between the carbon fiber veneer and the protected element. The resulting material - CFRP (Carbon Fiber Reinforced Plastic) - has the following advantages: it is strong, resistant to the chemical attack of acids and bases, it is lighter than glass-based materials, non-magnetic, etc. Some carbon-based materials have strengths of over 3500 N/mm^2 – eight times that of steel bars and with a stiffness comparable to that of steel [1, 4, 5].

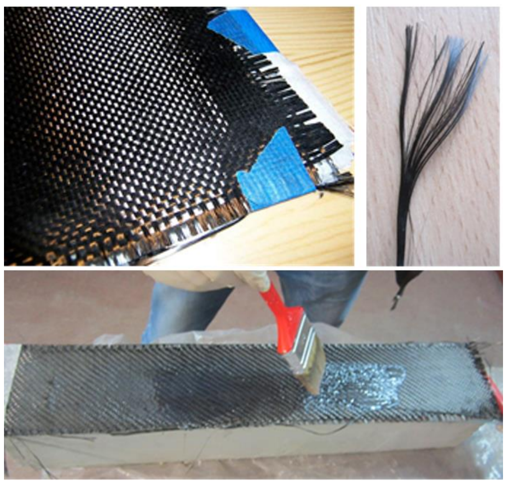

Fig. 3. *Carbon fibres*

There are also some disadvantages. Carbon, like steel, conducts electricity. The epoxy resins in the composition of the material lose their resistance at

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certain temperatures, even if they recover with the disappearance of the heat source. Therefore, carbon fiber reinforcement is an additional measure intended to ensure resistance to occasional loads such as earthquakes, in the event of a fire, the existing structures have the possibility to self-sustain for a time regulated by the function they shelter.

At present, CFRP materials are gaining wider acceptance as installation standards begin to emerge. The advantages of using carbon fiber-based materials in restoration and rehabilitation are numerous.

By consolidating with fibres, the structural elements will not have to be intervened except at the superficial level of the plaster, therefore it is not an invasive method and can be largely reversible. In general, it is not necessary to abandon the building by those who occupy it (only if the condition of the construction represents a danger), and the time required for the intervention is much shorter than in the case of other alternative procedures [1-3].

2.1.3. Matrix

To put the fibres mentioned in the previous chapter into operation, it is necessary to consider their arrangement in the appropriate direction, their fixation on the required element and the way of transmitting the efforts in the element to the fibres. These conditions are fulfilled by the matrix. The matrix is the second basic component of the composite material. The matrix is a plastic mass that encloses the fibres, after they have been placed in the correct position. Some types of fibres come in the form of "towels", which represent a strand of fibres, with the aim of facilitating installation.

The role of the matrix is to penetrate through this bundle of fibres until it reaches to include most of the fibres in its mass. Through this adhesion between the element, matrix and fibres, the transfer of efforts can be made, with the help of forces. They stress the fiber axially, introducing forces in the opposite direction (Fig. 4). These stresses are present along the entire length of the fibres, their intensity varies depending on the section in which they are analysed (for e.g.: at the ends, in the middle, etc.). In this way the fiber can absorb the stresses.

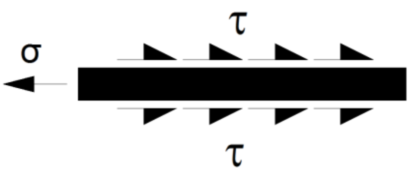

Fig. 4. *Axial stress on sample*

Other roles that the matrix fulfils: protecting the fibres during handling, putting into operation and performing the service, keeping them in positions that remove the risk of cracks, chemical compatibility between it and the fibres, improving the shock and fracture resistance of the composite.

The type of matrix used by us in this experimental work is an epoxy resin. This range of resins is predominantly used in the manufacture of high-performance composites. Considering the purpose and requirements of this experimental work, we need the special mechanical properties that this type of resins offer. In addition, they are resistant to corrosion and the effects of the environment, with good behavior at high temperatures, a fact that facilitates the installation in the structural elements of a construction. Before applying to the fibres, the resin is treated with hardeners according to a specific recipe, which determines the time and conditions in which the resin hardens. The chemical reaction can take place at room temperature or at high temperatures. A great advantage of these resins is the possibility to slow down the hardening process, by subjecting them to lower temperatures than necessary, giving the possibility to create pre-impregnated products, which can later be completed or put into operation. However, it presents disadvantages due to the high cost, the toxicity of the gases resulting from combustion, the high viscosity that complicates the lamination process.

3. Methods and results

In this experimental work we aim to increase the mechanical and physical resistance behavior of certain materials with the help of carbon fiber laminated with epoxy resins. We chose to use as raw material for samples: concrete, solid brick sandwich, wood, and extruded polystyrene. Depending on the utility of each, after lamination with carbon fibres, the samples are tested for bending moment, compression, fire resistance and shock resistance.

3.1. Preparation of samples

For all the samples we used the same technological process, carbon fiber lamination. Their surfaces were cleaned of dust, debris and other foreign bodies. We made sure that the wood is not treated with any kind of chemical substance and the extruded polystyrene was subjected to a test beforehand where we followed its behavior, from a chemical point of view, when it is in contact with the epoxy resin. In the next step, I prepared the resin by adding a specific amount of hardener, which would allow it to harden at ambient temperature. After applying the first layer of resin, on each of the samples, I laid a layer of carbon fiber fabric, cut to size, along with another layer of resin, to completely embed the fabric in the resin. For the next layer of carbon fiber, the process is repeated.

We obtained the following samples: extruded polystyrene prisms with the size 10 x 10 x 3 cm: - 1 x laminated with 1 layer of carbon fibres (1); - 1 x laminated with 2 layers of carbon fibres. Firewood samples with the size 1 x 4 x 55 cm: - 2 x laminated with 1 layer of carbon fibres (2); - 2 x laminated with 2 layers of carbon fibres. Solid brick samples, sandwich of 2 half bricks with M5 mortar, final size 12 x 12 x 17: 3 x laminated with 1 carbon fiber layer, (3). Concrete samples: cylinder h = 300 mm, d = 150 mm – 3 x side laminated with carbon fiber (4); - 3 x laminated with carbon fiber strips with a width of 5 cm (5). Prism with size 10 x 10 x 55 laminated with 2 layers of carbon fiber on one side (6). Standard samples are added to each sample category [1-3, 6, 7].

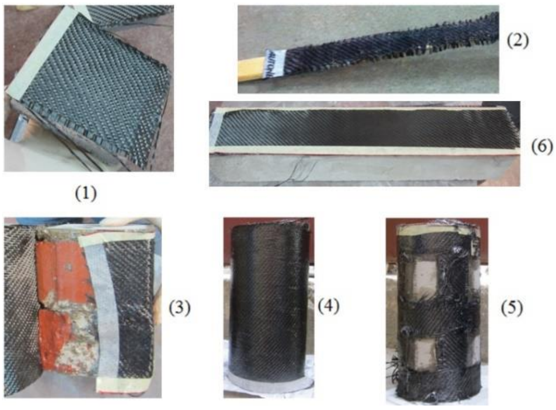

Fig. 5. *Preparation of samples*

3.2. Resistance to fire and shock

Laminated extruded polystyrene samples were tested with an open flame on the laminated side. The result was compared with the standard sample and a sample with glass fiber and special polystyrene adhesive, shown in the adjacent graph. It should be mentioned that in the case of the sample laminated with carbon fiber, burning occurs as in the case of the standard sample, while in the case of the sample covered with adhesive, it burns smoulderingly, without warning signs, which can represent a danger to you.

The shock resistance was determined by free-falling a 0.5 kg metal ball several times from a height of 1 m. No damage was recorded in the structure of the carbon fiber laminated sample.

The classic adhesive sample was destroyed in this test after only two drops of the ball.

Due to the shock resistance, the special appearance, and the fact that carbon fiber can be shaped into any shape, we recommend the use of polystyrene laminated with carbon fiber for special interiors: car showrooms, art galleries etc. [2, 3, 6].

Fig. 6. *Determination on fire resistance*

3.3. Compression resistance

For this test we used the brick samples and the concrete cylinders. After both tests, it was found that fiber lamination increased the strength of both samples. The samples failed when the carbon fiber broke. The standard brick sample yielded at an average value of 15.7 N/mm^2 compared to the fiber-reinforced sample at 17.98 N/mm^2. I calculated the recipe for C16/20 concrete, but the tests resulted in class C18/22.5. The reinforcement with carbon fiber strips increased the strength of the concrete with an average value of 0.80 N/mm^2 even though the reinforcement dosage was not optimal. The samples of reinforced concrete on the entire lateral surface with carbon fibres yielded at the average value of 25.07 N/mm^2. Limited by the small number of samples used, we cannot conclude the increase of the concrete class to C25/30, but all the results obtained fell within this class [2, 3].

3.4. Tensile bending strength

The wooden and concrete prisms were subjected to bending moment. A surprising result in the case of the concrete prism laminated with 2 layers of carbon fibres, where the resistance compared to the standard sample was significantly higher.

The standard prism yielded at 5.17 N/mm^2. The sample yielded at 9.12 N/mm^2 when the adhesion between the fibres and the sample suddenly weakened, a glass fiber resin being used. In the case of wooden prisms, the results are uncertain due to the incompatibility between the samples and the press and the poor adhesion between the resin and the wood. But an improvement in the resistances can be seen even from the approximate results [2, 3].

Fig. 7. *Determination on bending strength*

4. Conclusions

Following laboratory tests, it has been reached the following results:

- Polystyrene laminated with carbon fiber has a behavior, in an open flame, different from that covered with glass fiber and classic glue. The laminated one burns with a flame, a fact that will immediately indicate the possibility of a fire, while the one covered with classic adhesive burns smoulderingly and for a long time, behind the adhesive layer, without giving warning signs of fire. In both cases, the time required for the polystyrene to ignite increased significantly.

- The polystyrene laminated with carbon fiber has a significantly higher shock resistance than the one covered with fiberglass and classic adhesive, the latter sample being destroyed during the tests, while the one laminated with carbon fibres did not suffer structural or aesthetic damage.

- In the case of concrete cylinders laminated with carbon fiber, we recorded an increase in compression resistance of 4.03% in the case of those reinforced with carbon fiber strips and of 34.86% in the case of those completely laminated with carbon fiber. The layer of laminated carbon fibres acted as a fret, the samples yielding when it broke, providing no more support to the samples that were already cracked.

- The brick sandwich laminated with carbon fiber behaved similarly to the concrete cylinders, achieving an increase in compressive strength of 14.97%. The failure process is similar to that of cylinders.

- The flexural tension test of the wooden samples laminated with one or more layers of carbon fiber was compromised due to the incompatibility of the sample with the press used. The results obtained are uncertain, but we can state based on them that under favourable conditions the tensile strength by bending will increase significantly. In the laboratory we obtained an increase of 27.78 to 51.36% of the tensile strength by bending.

- The laminated concrete prism with two layers of carbon fiber on the stretched side, recorded a 73.49% increase in tensile strength by bending. It is a surprising result, considering that the sample failed when the adhesion between the laminated layer and the sample was broken. We are confident that when the carbon fiber lamination technology is applied under favourable conditions the samples can acquire better strengths, because if the adhesion is appropriate the samples will yield to the breaking of the carbon fibres, thus the strengths will increase.

In conclusion, the use of composite materials in construction increases the mechanical resistance of the materials. But the technological process of application and lamination must take place in favourable and specific conditions. The results of our tests confirm these two aspects, although we did not manage to reach the maximum potential of this technology.

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