OPPORTUNITIES OF ACHIEVING PERFORMANCE COMPOSITE PARTS WITH RECYCLED CARBON FIBRES

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Abstract
The recycling of carbon fibres by the technique of solvolysis in supercritical water, associated with the realignment of fibres finally allows the recycling of carbon fibres for structural applications in 2nd generation composite materials. A novel realignment technology, developed in Bordeaux's I2M allows for innovative semi- products made from second generation non-woven recycled carbon fibres. The use of these semi products, allows optimizing the weight/resistance ratio of the final composite in several directions unlike what can be done with conventional fabrics.
In the first part, we show the benefits of recycled and realigned carbon fibres over classic glass fibre fabrics by evaluating the specific flexural stiffness in both directions of a composite plate made with second generation fibres. We show that it is possible, on plates of constant thickness, to modify the stacking sequence in order to maximize the flexural stiffness without increasing the torsional stiffness simultaneously.
In a second part, we show, from the example of a product requiring different stiffnesses in two directions, that the use of recycled and realigned carbon fibres can improve the performance of a product at different levels: achievement of surf fins with 2nd generation carbon fibres shows that it is possible to obtain both a performance gain on this product and also an environmental gain. Furthermore, the implementation and the resulting appearance of these materials open new ways towards technological innovation that may promote the recycling of composite materials.

1. Introduction :

1.1. Carbon fibre recycling

To recycle composites containing carbon fibres, it is necessary to remove the matrix to recover the fibres. Several processes such as pyrolysis, pyrolysis in molten salt bath or solvolysis in supercritical fluids have demonstrated their effectiveness for separating carbon fibres and matrix without damaging the carbon. In order to maximize the properties of the recovered carbon fibre, it is necessary to keep the length of the fibres and realign it. Among the various methods for separating fibres and matrix, only solvolysis in supercritical fluid [1] does not require a fine grinding of the waste and does not require brewing inside the reactor which could entangle the fibres and prohibit their reuse. An industrial sector for recycling carbon fibre composites materials could be set up when clever uses of this particular fibre will have demonstrated their interest.

1.2. Recycled carbon fibre composite: a new material

The current lack of interest in recycled materials may be explained by the fact that they are often compared to their virgin counterparts. Since non-continuous carbon fibres recycled at I2M have specific characteristics (length between 50 and 150mm, zero misaligned fibres), we show here that the composite materials containing recycled carbon fibres will offer different properties from classical composite materials (with fibre glass or carbon). Thus, we believe that they must be regarded as new materials.

Following the solvolysis step for eliminating matrix of waste composite materials, the reuse of non-continuous carbon fibres is now possible thanks to the method developed at I2M and which has been the subject of patent: after the waste was rid of its resin , the fibres are separated and then realigned as UD tapes used to produce new "2 G" composite materials . Preliminary studies [2,] have highlighted the following points regarding the "2 G"composite
- Longitudinal stiffness equivalent to a composite UD if Lf> = 100 mm.
- The strength increases with the average length of the reinforcements.
- Large influence of the quality of the alignment and of the reinforcement rate in the strips.

The purpose of this work is to show that it is possible to exploit favourably the characteristics of the 2G Composites for producing parts with both technical and environmental gain. This work was carried out with the help of Notox, specialist in eco-designed surfboards.

2. Characterization of a 2G carbon-fibre composite material

2.1. studied materials

Composite materials have been performed with discontinuous realigned carbon fibres in order to modelize the recycled carbon fibres. The carbon fibres are Toray T700 virgin fibres realigned with the I2M process. the stripes of fibres (fig1a) are produced in order to realize composite plates containing 4 plies. The 280mm x 150 mm composite plates are achieved by impregnation with Araldite LY 5052 epoxy resin. The polymerization is realised under a pressure of 10 bar during 24 hours at room temperature. Several stacks [04], [904], and [±45] have been studied. The 25mm x 250mm samples are cut into the plates and the samples are provided with fiberglass stubs bonded to each end (fig1b).

Figure1a . Realigned carbon fibre stripes

Figure1b . 2°G composite samples

2.2. Measurement methods

The mechanical properties of the plies containing recycled carbon fibres are determined from tensile tests on 25mm x 250mm standard tensile samples.

Due to the spatial dispersion of properties, we use a "field" technique of measurement, which allows to measure mean values on large deformation zones. On each specimen a veil of white paint is applied and a black speckle pattern is painted. During the tensile test, a 25mm x 15mm area image of the specimen is taken every 5 seconds, then an image processing is performed using the CorelliQ4 software [3] to determine force / displacement curves.

3 samples by stacking are tested : [04], [904] and [± 45]
These results were used to identify the properties of the ply (Tab1)

	Mean value	Standard deviation
E_1 (MPa)	95395	1629,74
E_2 (MPa)	7734	1099,34
ν_{12}	0,85	0,61
G_{12} (MPa)	5296	348,00

Table 1. Mechanical properties of a 2°G T700 carbon fibre composite ply

The value of ν_{12} actually corresponds to a significant dispersion of the reinforcements' orientation (the standard deviation of fibre orientation is estimated to be 15 °).

2.3. Design of a composite material containing recycled carbon fibres with bending and torsion properties

Recycled materials are assumed to be of little interest because their properties are usually compared to equivalent virgin materials. However, it appears that in some cases the very high stiffness of the virgin carbon fibre composite material is disadvantageous (lack of flexibility of the product. vibrations), and therefore the use of recycled carbon fibres (eg semi-long) will be relevant in all cases where some complacency is required. The objective of this study is to design a structure using recycled carbon fibre (RCF) with bending stiffness equivalent to a glass fibre laminate 10.5 mm thick with a significant gain in mass.

The difficulty here resides i) in the fact that the carbon fibre is 3-4 times stiffer than glass fibre and ii) we want to work with constant dimensions (fig 2a) not to change other features of the product, it is therefore not possible to reduce the thickness. To avoid this problem, two solutions are proposed:
- sandwich structure with 8.5mm foam core and skins of 1mm thickness comply with imposed thickness. (fig 2b)
- The use of short carbon fibres (50 mm). Indeed, longer fibres lead to excessive stiffness [4].

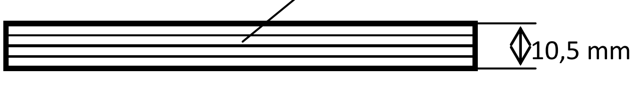

Figure2a . Glass fibre laminate

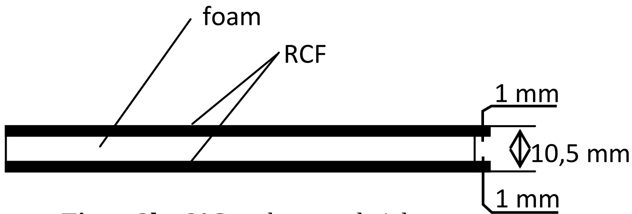

Figure2b . 2°G carbon sandwich

It should also be noted that the misalignment is greater when using short fibres, which will help to give flexibility in the longitudinal direction

We evaluate the properties of fiberglass laminate 10.5 mm thick using E glass properties + epoxy with the standard laws of mixture [5]. These properties will be assessed with different reinforcement rates, which correspond to values commonly encountered with this kind of processes of vacuum infusion or compression. Thereafter, we consider a stack of woven plies at 0 ° which is commonly used in this kind of parts. We have also reported the values obtained with a stack of plies at 45 °.

To obtain levels of stiffness equivalent to those of a 10.5 mm thick monolithic multilayer laminate, we performed a sandwich structure constituted of a polystyrene foam core of 8.5 mm thick covered with two-plies skins oriented at [±θ]. The value of θ should be determined in order to reduce the difference between the bending and the torsional stiffnesses of our material compared to the monolithic fiberglass composite.

The bending stiffness (D11) and the torsional stiffness (D33) of 10.5 mm thick glass fibre composite plates are shown in figure 3. These stiffnesses were calculated from the classical laminate theory [5].

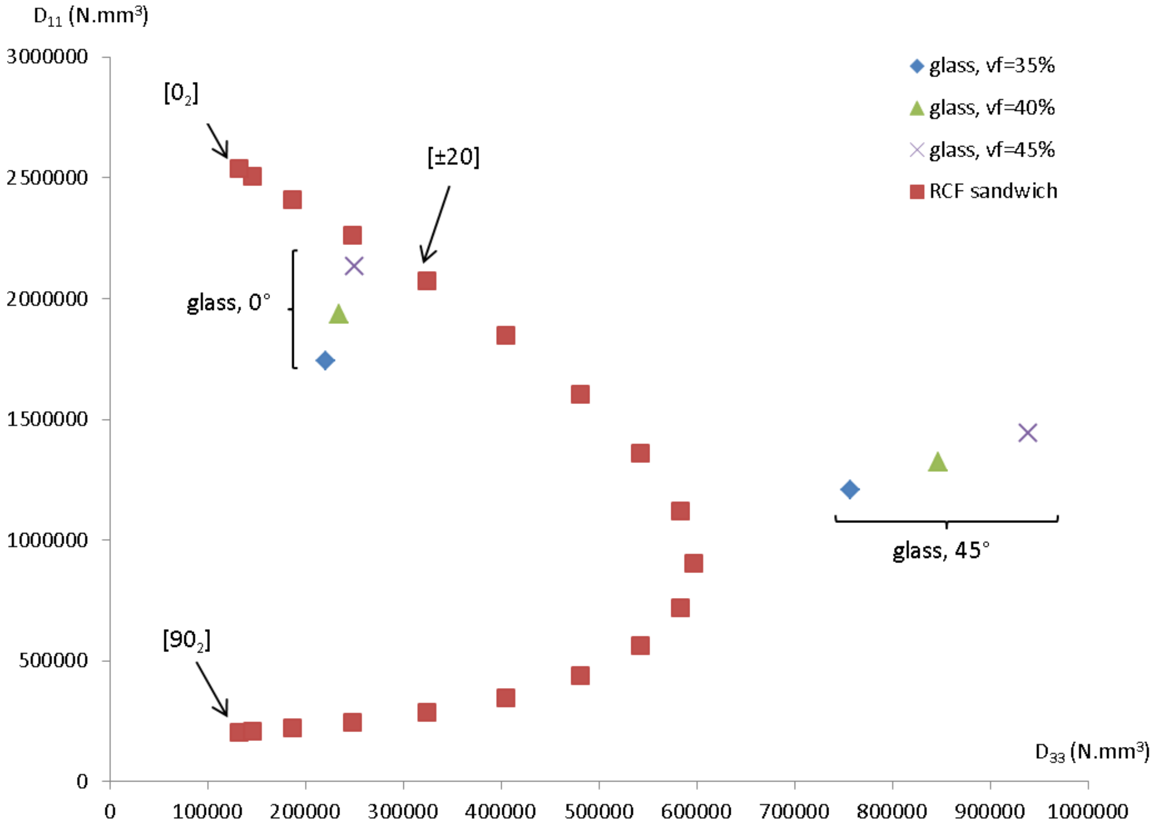

Figure 3. Diagram of bending stiffness (D11) vs torsional stiffness (D33) for the fiberglass composite materials and the staple carbon fibre (L50mm) sandwich composite material

It appears that we could choose a sequence [± 20] for RCF skins to get closer to the properties of the fiberglass composite. The stack [± 20] makes it possible to keep a torsional stiffness barely greater than the monolithic epoxy glass, while providing a flexural stiffness equivalent to that of glass fibre composite. The presence of a foam core guarantees the minimization of the quantity of material, which enables both to reduce weight and environmental impact.

3. Achieving a surf fin using recycled carbon fibres

The surfboards, like all high-performance products shall advance both technically and environmentally. Today, carbon fibre is very little used in these products because of its excessive mechanical properties that generate vibrations (resonance) over the navigation at high speed. The aim of reducing the environmental impact of these products rather leads to study the use of natural fibres but for now these materials do not provide sufficient mechanical properties. In contrast, the use of "semi-long" recycled carbon fibres could give, with equal performance (same design, same flexural stiffness), a significant weight decrease while reducing the environmental impact thanks to the use of recycled material.

3.1. Design of a surf fin

The main function of this part is to stabilize the surfboard. This piece must have some flexibility to be usable. The flexural and torsion stiffnesses influence the feelings of the user (handling, speed corner exit) and depend on the size of the surfer and wave conditions. Thus, a flexible longboard fin will forgive errors and gives a sensation of sliding curves to the user. This is why we wanted to make a carbon fibre fin which is lighter but not stiffer than the conventional fiberglass fin.

The chosen model (Figure 4) is a classic model of central fin for longboard "thruster" . Its dimensions are 200 x 200 mm ² to a thickness of 10.5 mm. It has a monolithic structure (stack of fiberglass plies, the details can not be disclosed for reasons of confidentiality).

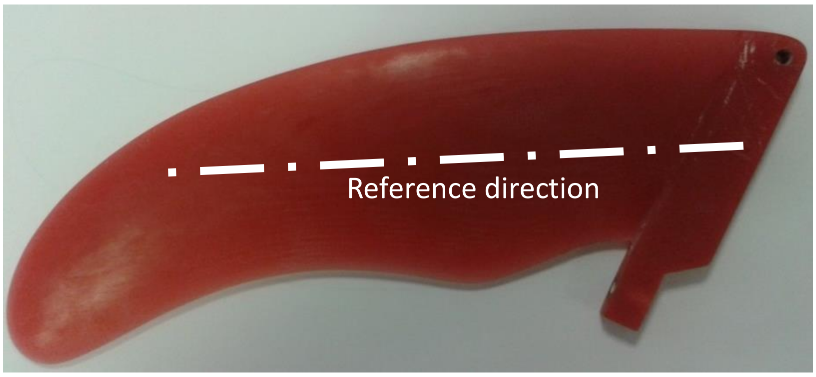

Figure 4. . Classic fiberglass surf fin for longboard « thruster »

The part consists of the fin: immersed portion that provides hydrodynamic function and of the base and which allows binding with the board. It is possible to identify a main direction of the fin (Fig. 4)

3.2. Realization of a staple carbon fibre surf fin

To achieve a surf fin that works the just as the original fiberglass fin, we chose the material defined in Section 2.3. The composite material thus consists of two skins of two plies of UD staple carbon fibres 50 mm long. Since the glass fibres of the original fin are oriented in the main direction of the fin, to maintain the same flexural stiffness, the UD staple carbon fibre skins are then oriented at ± 20 ° relative to the main direction of fin (Fig. 5). The skins of carbon fibres surround a core of 8.5 mm thick PS foam only in the useful part (immersed) of the fin. The base is monolithic, made of about 20 layers of semi-long carbon fibres (20mm <L <50mm).

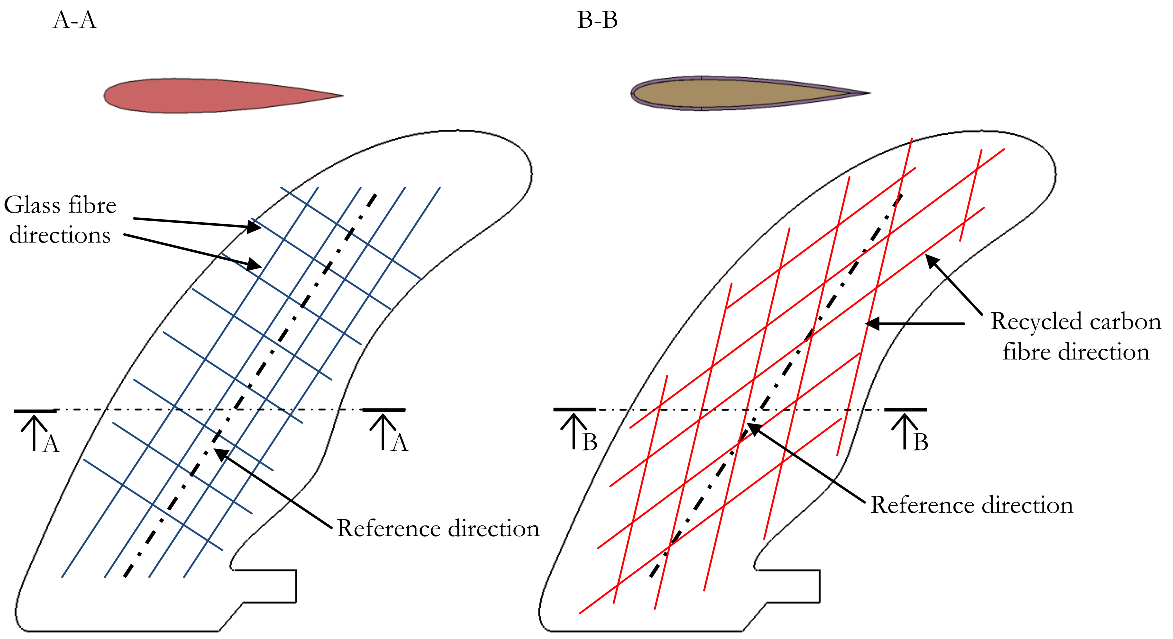

Figure 5 . Architectures of monolithic fiberglass composites and of the semi-long carbon fibres (skins)

The part is obtained by molding and wet impregnating of Araldite LY 5052 epoxy resin. Then the mold is maintained closed in an hydraulic press with a force of 15 kN for 24 hours. The polymerization takes place at room temperature.

3.3. Resulting product

After unmolding and deburring, we get a staple carbon fibre fin (Fig. 6) very light and lightly flexible, whose operation is very close to that of a conventional fin (which would have been impossible with virgin carbon fibres that would have led to vibrations).

Figure 6. *.Staple carbon fibres surf fin*

We may consider that the use of recycled carbon fibres in this product allows technology gains at several levels:

- The flexural stiffness is not changed but the torsional stiffness is slightly increased, which provides opportunities for tighter trajectories in maneuvers for experienced users
- The mass of the fin is reduced by 37% (120 g vs 190g originally), which is an advantage for a competition board since it facilitates the realization of more aerial maneuvers.

Moreover, recycled fibres enable environmental benefits since the use of a recycled material is usually less impactant than the use of virgin material, especially compared to a high energy content material such as fiberglass. It will be possible to quantify precisely the environmental gain only when a recycling network of carbon composites is in place.
We can add that the appearance of composite containing recycled fibres is quite interesting since it recalls the appearance of wood ; it shows by itself that the fin is composed of recycled fibres.

4. Conclusion :

There are many of high performance products for which some degree of flexibility is required. To improve performance (weight gain) these products must undergo a lighweighting and be composed of composite materials with a high specific stiffness. However, basic replacement of the glass fibre by virgin carbon fibres would have led to a too stiff part. Redesign of the architecture of the piece associated with use of staple fibers has allowed overcoming this difficulty. We have shown here that the features of recycled carbon fibres (staple fibre's length <100mm, available as strips partially realigned) to impart the composite materials unique properties. Thus the use of staple carbon fibers (recycled) allowed achieving a composite material having specific rigidity while maintaining flexibility. It should also be noted that the use of recycled carbon fibres can provide both technological and also environmental gains (when implemented in an energy efficient recycling network). Finally the appearance of composite with semi-long recycled fibres is very interesting and like the look of natural materials which further argues for the use of these materials in eco-designed products.

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