Recyclable composite materials for the nautical sector

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As part of our research project "Study on the recycling of glass fiber ships and on the performance of recyclable materials applied to the design of ships" in collaboration with Innovation maritime (IMAR), the Composite Development Center of Québec (CDCQ) compared different laminate constructions intended for use in the nautical sector. The aim of the exercise was to define a new construction that is more easily recyclable in order to replace a traditional construction made of glass/polyester composite materials. The original process of the boat covered by the study project being hand lay-up, a first configuration consisting of glass fibers and polyester resin was molded. Then, a second laminated was made by the infusion process with the same materials except for the last layer where an infusion mat was used to facilitate molding. Finally, a third construction, this one in acrylic resin and glass fibers was produced by infusion for comparison according to the same reinforcement sequence as the laminated #2. The details of the laminates made are presented in the table below while the laminates are illustrated in Figure 1. For the development project, monolithic constructions and sandwiches were produced. Note that only the properties of monolithic (coreless) laminates will be discussed in this article.

Table 1. Manufactured laminates

Laminate #1 – Hand lay-up polyester resin AOC R037-YQF-40	Laminate #2 - Infusion polyester resin AOC R037-YQF-40	Laminate #3 - Infusion acrylic resin Arkema Elium 188O
Gelcoat AOC Vibrin G315AC	Gelcoat AOC Vibrin G315AC	Gelcoat AOC Vibrin G315AC
Mat 1½ oz/pi² FiberLink M1-015-AB	Mat 1½ oz/pi² FiberLink M1-015-AB	Mat 1½ oz/pi² FiberLink M1-015-AB
Mat 1½ oz/pi² FiberLink M1-015-AB	Mat 1½ oz/pi² FiberLink M1-015-AB	Mat 1½ oz/pi² FiberLink M1-015-AB
Mat 1½ oz/pi² FiberLink M1-015-AB	Mat 1½ oz/pi² FiberLink M1-015-AB	Mat 1½ oz/pi² FiberLink M1-015-AB
WR 15 oz/vg² Georgian Bay Fabrics R15-A01	WR 15 oz/vg² Georgian Bay Fabrics R15-A01	WR 15 oz/vg² Georgian Bay Fabrics R15-A01
Mat 1½ oz/pi² FiberLink M1-015-AB	PP sandwich mat 2 layers 300 gsm FiberLink M3-20A-50M	PP sandwich mat 2 layers 300 gsm FiberLink M3-20A-50M

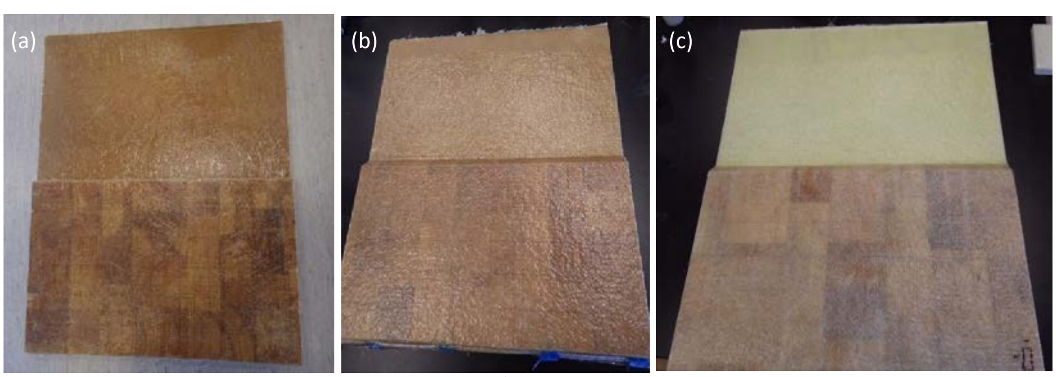

Figure 1. Laminates (a) standard glass/polyester made by hand lay-up, (b) glass/polyester made by infusion and (c) glass/acrylic made by infusion

The infusion molding was carried out using the following configuration:

- Inlet - resin: hose 3/8 inches in diameter with balance spring applied to the laminated.
- Output - vacuum: hose 1/4 inches in diameter with balance spring + brake in peel ply (Airtech Econostitch).
- Bagging with bag (Airtech RBG-125) and sealing tape (AT200Y).
- Vacuum infusion process at half-vacuum.

A 4-hour post-curing schedule at 65 ° C was done on all the laminates.

The use of infusion as an alternative to hand lay-up had several objectives : lighten the part while having higher properties (higher reinforcement rate), minimize porosity and limit volatile organic compounds or VOCs during the process (vacuum shaping). The figure below shows the mass per square meter of the laminates according to the different constructions studied. These data show that the infused laminates (polyester and acrylic) are about 22 to 28% lighter than the construction molded by hand lay-up.

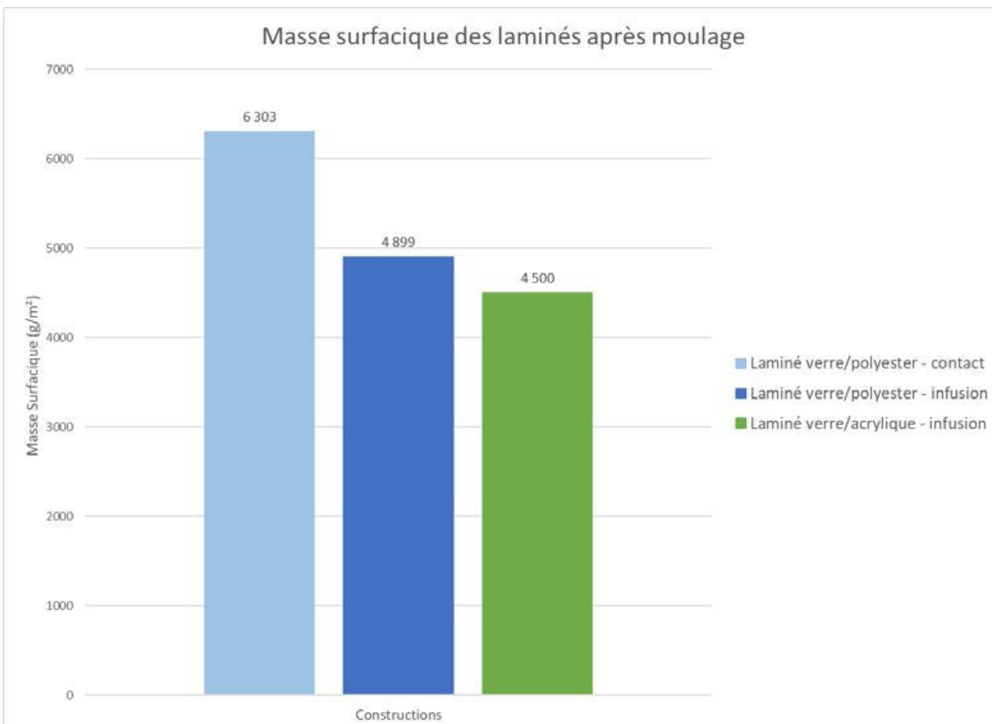

Figure 2. Surface mass comparison

Based on the theoretical surface masses of the reinforcements in the laminates and the surface masses of the rolled after moulding, the following reinforcement rates are estimated: :

Laminated #1 – Contact rolling glass/polyester	Laminated #2 - Infusion glass/polyester	Laminated #3 - Infusion glass/acrylic
37%	55%	59%

After moulding the laminates, the CDCQ characterized the different constructions in tension and bending in order to compare their properties. The tensile tests were performed according to ASTM D638 (Figure 3a) while ASTM D790 was used to determine the 3-point bending properties (Figure 3b).

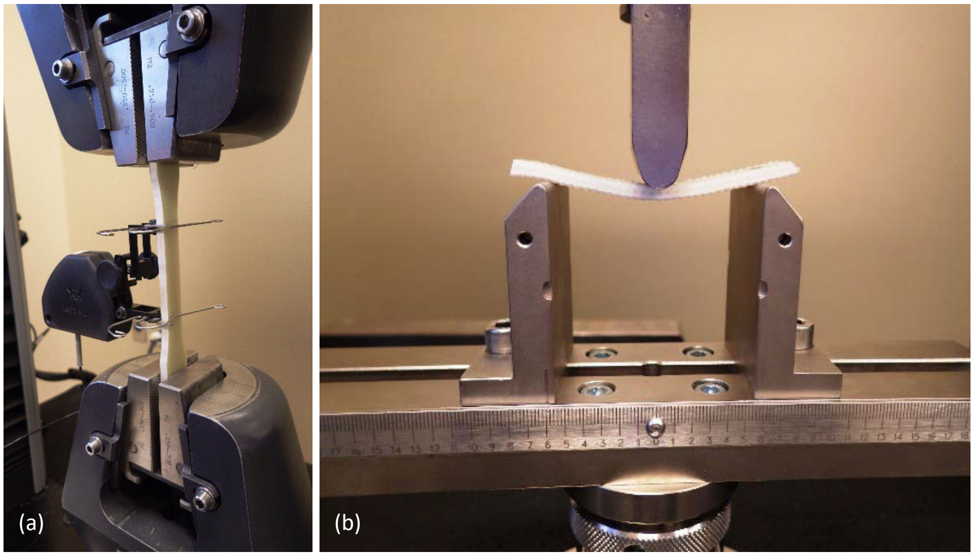

Figure 3. (a) tensile tests according to ASTM D638 and (b) bending tests according to ASTM D790

The following graphs present the results obtained during these characterization tests.

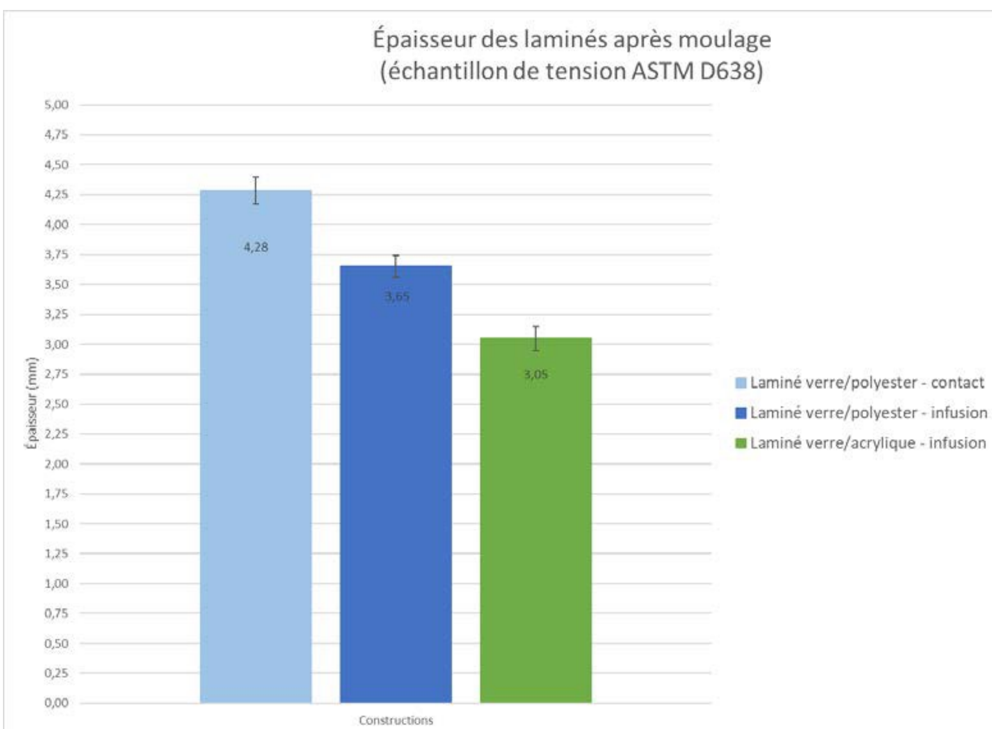

Figure 4. Comparison of laminate thicknesses for stress tests.

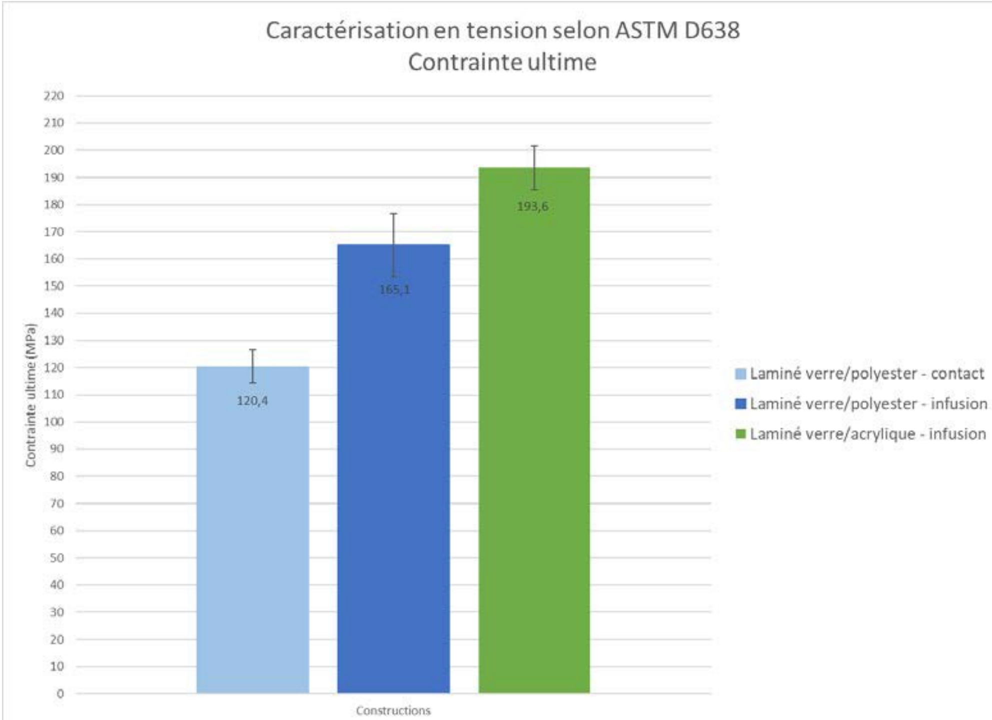

Figure 5. Comparison of the ultimate stresses in tension

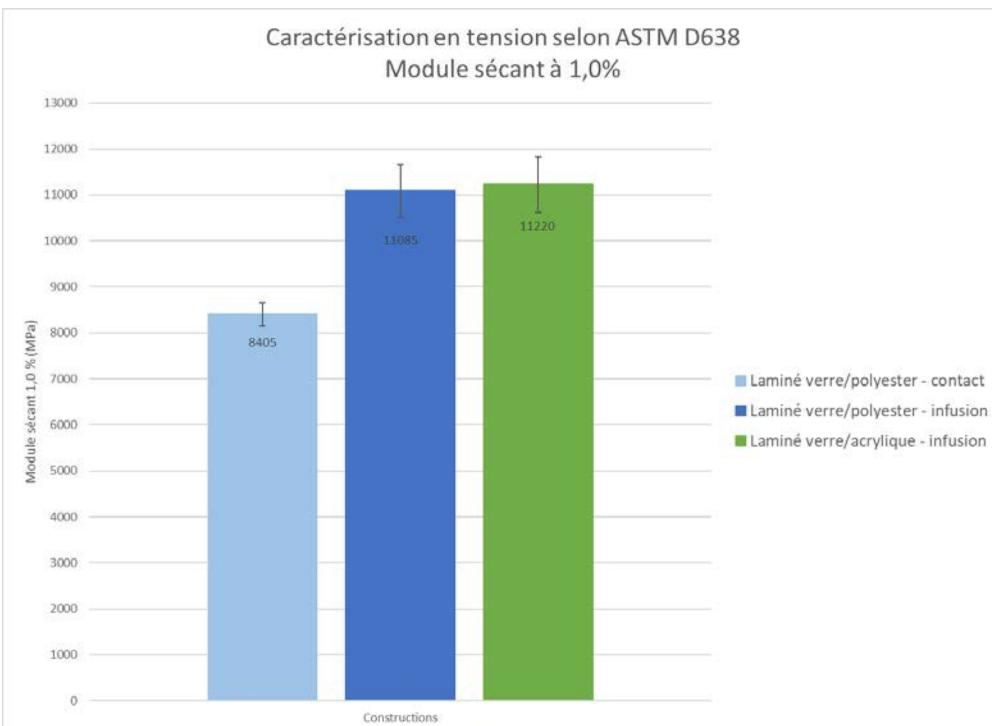

Figure 6. Comparison of voltage modules

The results of the stress tests show that the tensile strength properties are superior with the laminate produced with the acrylic resin versus those molded with the polyester resin. In addition, the tensile modulus is superior for infused laminates compared to that moulded by hand lay-up. It is also noted that the infused laminates are thinner than the #1 and that the reinforcement rate is therefore higher by the infusion process.

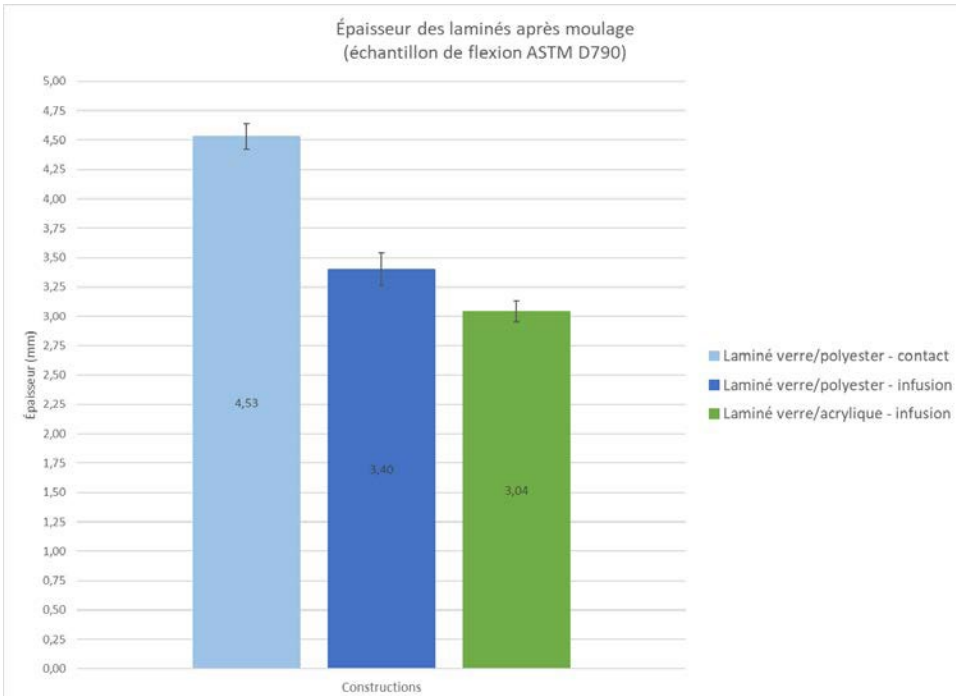

Figure 7. Comparison of laminate thicknesses for bending tests

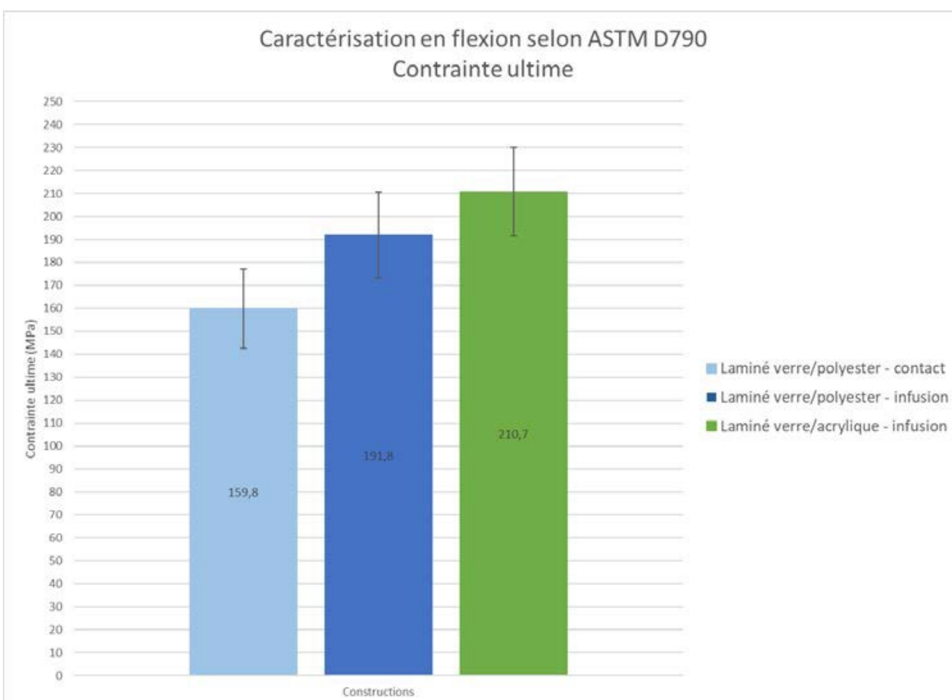

Figure 8. Comparison of ultimate bending stresses

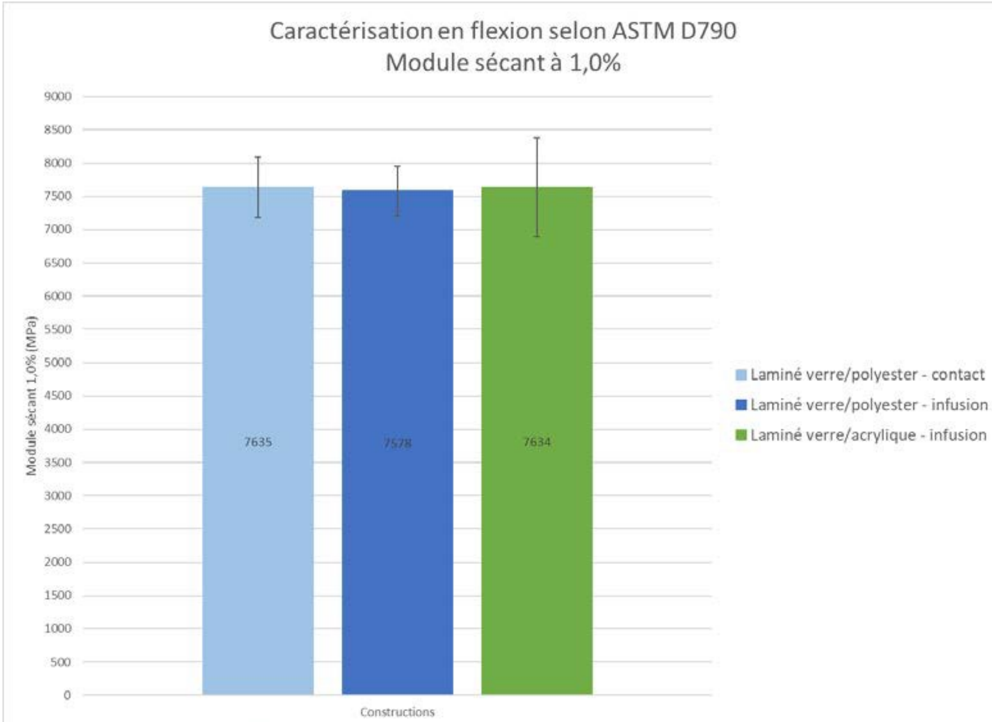

Figure 9. Comparison of bending modules

Bending tests allowed us to compare the characteristics of the constructions evaluated. First, the values show that the ultimate bending stress is higher for the laminated produced with the acrylic resin, followed by the laminated infused with the polyester resin. However, it is observed that the bending moduli are very similar from one construction to another. The thicknesses measured are still consistent with the molding processes and materials used.

The values obtained by characterization illustrate the intrinsic properties of the materials. However, in design, shape must also be considered when designing structures of equivalent stiffness. The rigidity of a structure is a function of its geometry. Thus, for a panel, the bending stiffness (the product of the modulus by the moment of inertia) is influenced by the thickness.

Although the properties of our glass/acrylic composite materials construction are advantageous in several respects, we encountered a challenge for our boat application. We seek to replace the current structure (glass/polyester) with an infused construction with equivalent or greater rigidity. In fact, the stiffness modules of the material, both in tension and in bending, meet this criterion. However, the #1 laminate has a higher flexural rigidity than other laminates thanks to its higher thickness. For example, in a simplified way, if we calculate the bending stiffness of our constructions, we obtain the following results:

Table 3. Flexional stiffness

Construction	Module (E) [N/mm²]	Width (b) [mm]	Thickness(h) [mm]	Moment of inertia (I) [mm⁴]	Flexional rigidity (EI) [N•mm²]
Laminated #1	7635	1000	4,53	7747	$5{,}91 \times 10^7$
Laminated #2	7578	1000	3,40	3275	$2{,}48 \times 10^7$
Laminated #3	7634	1000	3,04	2346	$1{,}79 \times 10^7$

Note: $I = bh^3/12$ for a rectangular section

In conclusion, the tests carried out made it possible to compare the different constructions studied. It has been shown that the manufacture of a composite material with an acrylic thermoplastic resin by the infusion process provides, compared to a traditional glass/polyester construction, superior mechanical properties in tension and bending, a higher reinforcement rate, lightening and generates a thinner laminate. In addition, the glass/acrylic material also considers the ecological aspect given its greater recyclability. In order to overcome the problem of thickness reduction harmful to nautical application, the project continued with the analysis of sandwich structures (laminated with core). At the end of this project, a prototype glass/acrylic composite boat will be manufactured and evaluated to demonstrate the performance of recyclable materials applied to ship design.

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