

The Use of Hybrid Viscoelastic Sheets in the Shipbuilding of GFRP Planing Hull Vessels Externally Adhered to the Laminate

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Abstract. The use of viscoelastic sheets in the hull of vessels built from GFRP has been raised in previous works as an option to protect the vessel from the destructive damage of slamming. The present work proposes its use in boats previously built by adhering to the outside of the hulls of the ships. Its installation process is shown, and this new type of installation is compared. Through impact tests with GFRP panels, it is shown that the viscoelastic material maintains its property of absorbing slamming energy and protecting the interior of the laminate. Fatigue tests on the order of 5×10^4 cycles are carried out to evaluate the impact force, the accelerations that deform the laminate and the virtual energy work imposed on the panel. This option shows that designers have a new option to protect the hull of already built boats.

Introduction

Since the world set out to protect the environment, multiple ways to do so have developed. The maintenance of ships built in glass fiber reinforced plastic (GFRP) generates pollution which requires high investments so that they do not harm the surrounding environment. In the Galapagos Islands, there is a significant fleet of GFRP planing hull vessels. As these boats sail at high speeds, they must be light and cover long distances between islands to comply with tourist programs, this causes severe damage to the laminates of the hull in the bow due to the impact with the waves. Sailing at high speeds increases a phenomenon known as slamming [1]. This is a fatigue event on the material of the hull of the boat, which considerably reduces its useful life, making more frequent maintenance required within the nature reserve.

Vessels built with composite materials (with different combinations of reinforcing fibers and polymeric matrix) are more and more numerous, due to the good mechanical properties of these materials. Manufacturing with composite materials involves the placement of successive layers of reinforcing fibers (glass, carbon, polyaramid, etc.) that are impregnated with a resin that acts as a matrix, providing adhesion between the fibers, between the layers stacked in thickness and provides continuity to the laminated assembly. This means in practice that the hulls are built (together with other parts of the boat) by placing several layers, one on top of the other, until the total thickness of the laminate is obtained according to their structural stresses. The number of layers is associated with the structural resistance [2, 3] or with the other parts of the boat (decks, bulkheads, etc.). A boat made of composite materials will weigh less than a boat made of steel or aluminum. The use of GFRP partially sacrifices some aspects of its structural strength. The capacity to respond to impacts, fatigue events and internal stresses is diminished, which is directly reflected in the extension of its useful life, in service [4].

On the other hand, because they are multilayer materials, it is possible to introduce some type of energy dissipation mechanism into the lamination sequence. In such a way that a viscoelastic sheet that goes inside the laminate has been proven to protect it from low energy impacts. In no case against ballistic impacts, which involve very high deformation rates in the material.

Slamming is a phenomenon that occurs during navigation, usually above 20 km / h. The boat begins to rise or support itself on the surface of the water, and when the weight of the ship and the pressure of the water become unbalanced, it causes the ship to sink back to the initial position producing an impact on the surface of the hull. This impact supposes a sudden contribution of energy, which can be increased by the waves. This energy must be absorbed by the hull material, which after the impact returns part of the energy (compliance restoration) [5].

The insertion of viscoelastic sheets inside GFRP panels has been studied extensively in a numerical way and according to our own research on specimens tested in the laboratory, the modification proposal gives results and is ready to go to ships [6-7]. Even its adherence is applicable to the theory of hybrid bonds in the case of these materials, in which the stresses generated at the ends of the adhesive bond influence the adjacent layer of the bond [8].

This time, it is proposed to analyze by means of fatigue tests, the behavior of the viscoelastic layer superimposed on the laminate to obtain the energy data that the viscoelastic absorbs and the protection it offers. the solution to the premature aging of the planing hull vessels and the way they are used in boats already built, would represent a great option for the tourism fleet in the Galapagos Islands and the world.

Viscoelastic Layers as Energy Dissipators in the Construction of GFRP Laminates

In the Galapagos Islands, there is an important fleet of planing hull vessels between 12 and 15 meters in length. They sail 4 hours between Puerto Ayora and Puerto Baquerizo Moreno at 22 knots in some cases. They carry tourists seated on the main deck on cushions. In this area of the Pacific Ocean, the wind level and wave height have a Beaufort scale of degree 4 half the year, and the other half with the arrival of the cold current from Antarctica there are several months of degree 5. The Captains must be attentive to the waves during the entire navigation, because at that speed and in these sea conditions, the impacts with the bottom of the hull are very strong. The noise of the impact even becomes a nuisance to the human ear when reaching levels of 90 dB.

The slamming phenomenon has the following specific characteristics: its non-linear character in which the domain of time and not frequency predominates, and that it is completely random. The slamming pressures for the type of vessel considered, according to the Classification Societies of ships, especially the American Bureau of Shipping (ABS), consider that they range between the order of 2.25×10^3 [kN/m²] to 1.10×10^3 [kN/m²] depending on its longitudinal position at the bottom of the ship and by the curvature of the hull. Table 1 shows the characteristic data of the ship selected for experimentation.

Table 1 Characteristics of the ship at maximum load condition

Material	GFRP
L (length)	13500 [mm]
Δ (displacement)	9100 [kg]
B (breadth)	4300 [mm]
T (deadrise angle)	4,5 [°]
V (maximum speed)	22 [Kn]

The hull of these vessels corresponds to laminates by impregnation of type $[0^{MI}/(0^M/0^{WR})_4^0/0^{MO}]$ with mat type isophthalic fabrics, at Ortoftalic, Woveng Robing Ortoftalica. In the nomenclature, it is described as the first layer, the fabric that goes outside the hull of the ship and the weight of the resin. Due to the type of manual construction, there is a high percentage of porosity of up to (7%), which is reflected in the beginning of damage due to slamming impacts during navigation. The micropores line up forming microcracks, to later appear as fractures inside the ship. In most cases it produces water leaks. In Fig. 1, the interior connection of the hull with the fore bulkhead of the selected ship is observed. In it you can clearly see the breaking line that is propagating because of the tensile stresses that occur inside due to the deformation.



Fig. 1 Slamming damage observed inside the vessel

Previous research considered including viscoelastic sheets within the laminate, that is to say, placed under the second layer of rowing fabric protecting the rest of the layers. They are not used in the entire hull of the boat, but more critical where the phenomenon of slamming has the greatest incidence. The impact area occurs both to port and starboard, which directly affects the laminate of the hull, producing microcracks that change the flexural stiffness of the structure. To achieve this behavior, the protection layers are manufactured in very thin thicknesses with the viscoelastic polymer, encapsulating it in cells of another much more rigid polymer, constraining the deformation capacity of the viscoelastic polymer in its two main directions, in the plane of the sheet. In this way, the property of the viscoelastic material of having a Poisson's ratio close to 0.50 is taken advantage of, that is, the relationship between the deformations that the material experiences when it is compressed in the thickness direction with the deformations in the two perpendicular directions in the plane of the sheet. A material with a Poisson's ratio of 0.5 essentially keeps the volume constant when it is deformed in one direction.

When a viscoelastic is deformed by an impact without restricting its directions, it is compressed until it can no longer absorb any more energy and then expands dissipating all the elastic energy stored. On the contrary, if its deformation (expansion) is constricted in its two main directions in the plane of the viscoelastic layer, encapsulating the viscoelastic material in closed cells formed by a more rigid polymer, the material is given a great storage capacity of Energy. The more the pressures due to impact increase, the stiffer the viscoelastic material becomes and consequently, the more energy it absorbs. Through this viscoelastic cell design, when the protection layer is placed within the composite material laminate, the stiffness of the material grows exponentially as the impact energy attempts to deform the ship's hull. The response is non-linear and instantaneous, with a large amount of energy being stored in the viscoelastic layer, which, however, does not transfer it to the rest of the laminate, but rather slowly dissipates it. In this way, it is possible to reduce the damage generated in the laminate by the impact of slamming, slowing down its progression and, consequently, making it possible to extend the useful life of the boat.

The present work proposes the placement of the viscoelastic sheet on the surface of a boat hull already built and in use. Through laboratory tests with GFRP specimens, observe the energy behavior of the impact and if the laminate is effectively protected. This would allow the use of viscoelastic sheets to be extended and spread more widely to improve the useful life of vessels. Fig. 2 shows the difference in a section of a ship's hull. in a) the viscoelastic sheet is inserted into the laminate which corresponds to its initial conception. In b) the proposal to adhere it to the laminate so that it does not affect the hydrodynamics of the boat and protects from damage by slamming.

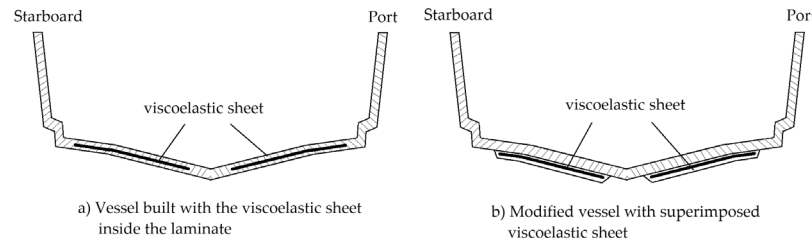


Fig. 2 Cross section of the planing hull vessel with a viscoelastic sheet a) built new b) modified not new

Experimental observation of the protection of the superimposed viscoelastic Layer

For the experimental observation of the behavior of the viscoelastic sheet superimposed on the hull of a ship, 3 panels were manufactured with the same characteristics of the selected boat, and the superimposed viscoelastic layer was added. The panels to be tested for fatigue, reproducing the slamming impact, were mounted on a base of a Shaker-type vibrating equipment to deform them. This equipment, its base, the panel and the superimposed viscoelastic sheet, can be seen in Fig 3.



Fig. 3 Impact vibrator with the test panel placed on the top.

Using a load cell on the top of the vibrator to compress with the panel, the force that deforms the panel is measured. As the vibrating equipment tries to maintain a deformation speed, it regulates the acceleration and therefore the load cell fulfills the function of registering the changes in force versus cycle. The equipment records the accelerations and the deformation velocity at the center of the impact. Strain gauges were also used to control the deformation of the panel at 4 [cm] of impact for control. In Table 2, the experimental values of the developed experiments are presented. The fatigue phenomenon was reduced on three panels at different force conditions, equal amplitude, and acceleration.

Table 2 Experimental values of the tests carried out

# panel	Frequency range [Hz]	Applied cycles [n]	Average strength [kJ]	Amplitude [G]
A	5-10	5×10^4	50	1
B	5-10	5×10^4	40	1
C	5-10	5×10^4	30	1

To evaluate the energy that the panel returns as mechanical work, the principle that a force F travels a distance x is applied. The work it does for the different frequencies ω over the angle between the force vector and the displacement vector Y , for each acceleration G at time t obtain the Eq. 1 which corresponds to the energy returned by the panel over the shaker.

$$E = Y \cdot \omega \int G(t) \cdot dt \quad (1)$$

When carrying out the tests, results were obtained such as those shown in Fig. 4. in a) it is observed that the acceleration imposed by the vibrating equipment on panel A, is rectified to maintain a regular profile curve. The peaks of highs and lows correspond to microdamage produced during deformation due to the laminate opposing bending. The acceleration curve corresponds to a test time of 60 [ms]. With this imposed acceleration, it is observed in a) that the panel impacted at 7×10^3 cycles presents microcracks around the areas of the viscoelastic in a minimal amount. in b) at 5×10^4 cycles of impacts made on average at 50 [KJ], microcracks have increased without detachment of the viscoelastic layer in the matrix.

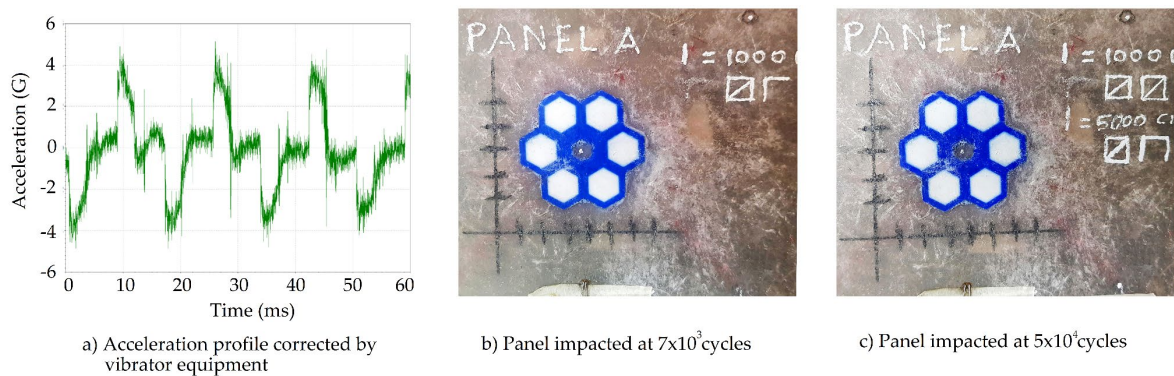


Fig. 4 Results of the tests carried out on panel A

Data were taken on the force exerted by the vibrator equipment in the impact versus cycles, and this is observed in Fig. 5. For panels A and C, there is a tendency to decrease, being greater that of panel A. On the other hand, the panel B showed a very complex dispersion to evaluate a trend. The results of panel B are not conclusive. During the tests it was found that the force tends to regulate with the acceleration, since the vibrating equipment stabilizes in the acceleration to deform in constant values over time. Force values are sampled because the type of load cell used does not allow a permanent record to be kept.

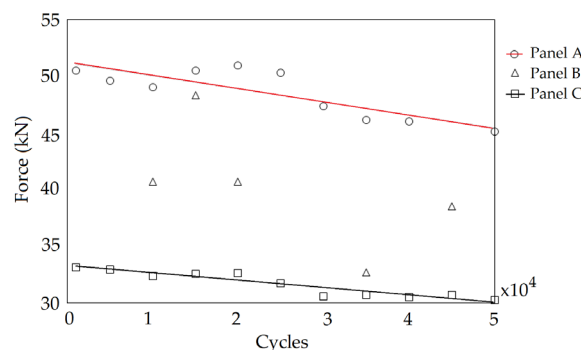


Fig. 5 Sampling of the applied force in the panels versus impact cycles

When these force values are transformed to returned energy, they draw the trend curves shown in Fig. 6. Panel A permanently loses its ability to return energy since the measured force that is regulated in the vibrator is still at damage levels. Panel B, product of force dispersion, does not show a trend curve. Panel C draws a trend curve that tends to stabilize, meaning that flexural stiffness has increased due to the level of damage reaching the threshold.

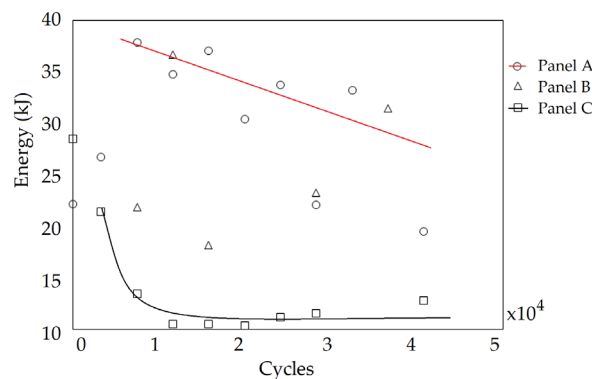


Fig. 6 Energy returned by the panels versus impact cycles

Conclusions

By superimposing the viscoelastic layer on the GFRP panels the impact damage can be effectively mitigated. Fig. 7 shows that the increase in flexural stiffness in a panel works in conjunction with the viscoelastic sheet stabilizing the damage. This trend curve, as it stabilizes, is the increase in useful life that we wanted to demonstrate. The generation and propagation of damage is controlled by improving the dissipation of the energy that remains in the form of damage in the GFRP. This approach opens up new perspectives in the design of the planing hull ship, since the superposition of the viscoelastic layers changes the way in which the stresses due to the phenomenon of slamming within the laminate are to be distributed and concentrated.

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