DESIGN AND MANUFACTURE OF A COMPOSITE BUS

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Abstract

Within the project CIVITAS - Cleaner and Better Transport in Cities, a new concept of bodywork for a minibus has been developed.
Bearing in mind the financial resources available, it was decided to transform a Toyota Coaster, reusing the entire mechanical base (frame) and design a new body with composite materials.
In this paper, it will be presented the industrial design solution, related with structural concept, manufacture and assembly.
It will, also, be presented the structural simulation of the sandwich (sandwich Polyvinyl Chloride (PVC) core and COMBI skins) panels, using ABAQUS software and the estimated properties of the composite system were determined using ESACOMP software.
In parallel with the simulations, a manufacturing strategy was agreed with a shipyard (ENP-Estaleiros Navais de Peniche).
The technology applied was the Vacuum Infusion that uses the resin injection through vacuum, to impregnate and consolidate the laminate.
The final solution presents a weight reduction of 16% with respect to the original one. Moreover, with this manufacturing process, it has been possible to have big size parts with high quality finishing. The strategy used made a reduction in the number of parts as well as in the production time.

1 Introduction

The CIVITAS initiatives promote the sustainable development of the cities, improving the efficiency of transport systems and the use of less-polluting energies. The project's main objective is to reduce greenhouse gases (GHG) emissions.
In this context, it has been developed a lightweight body, using composite materials and innovative construction technologies (so far rarely used in this product segment).
Given the goals of this project and the available financial resource, it was decided to transform a Toyota Coaster, reusing its entire mechanical base (frame) and designing new bodywork totally with composite materials.

2 Design Concepts

The major objectives of the bodywork bus project were essentially to achieve:

- Superior specific strength and specific stiffness characteristics;
- Minimize production costs and maintenance costs;
- Reduce structural weight;
- Develop a concept for the production and assembly of bodywork;
- Define methodologies that reduce cycle time manufacturing.

2.1 Integral Structure of Composite Materials, Concept

The design concept reflects strongly the formal conceptual point of view and the traditional approach of reticulated structure covered with metal panels (usual manufacturing process, in this business), but with an integral composite structure, based on a truly monocoque structure in which the overall strength is mainly due to the behaviour of an unitary "shell".
The panels were considered as structural ones, reinforcing the local under the necessary openings (weakened sections), especially for the placement of "windows" with the dimensions imposed by existing regulations for this type of product.
In order to simplify the process of building the mould of the bodywork and reduce the associated costs, all faces were assumed as flat surfaces, joined by cylindrical matches of constant radius of curvature. The windshield was considered to be flat, but the rear glasses (polycarbonate) have become curved (though in one direction, for ease of production).

Then, the team decided to assume a high-floor bus, but placing at the bus stops elevated platforms, to allow for an easy and quick access inside/outside of the bus, for all users, and large internal and free areas, with only one double door to go in/out to the bus.

The final version of the bus concept can be seen in the figure 1.

Figure 1 – Views of final bus concept

3 Manufacturing Definitions

During these phase, despite to consider the Filamentary Winding as an interesting technology it was established, as final solution, to manufacture the body using the Vacuum Infusion technology.

3.1 Constructive Approach

3.1.1 Open Moulds

The vacuum infusion process requires moulds to produce the parts, which is the most expensive part of the budget. Nevertheless, as the moulds can be used several times, the cost can be depreciated significantly.

It was decided to build two open moulds, instead of just a closed one (single). These moulds, made of plywood for manual lamination, assured the critical dimensions of the project as well as the stiffness and the maneuverability of the model.
This choice allows the use of cold process of consolidation, which uses low pressure.
Given the considerable size of the pieces to be extracted, also enables a better control of the infusion process because it allows the access to all of the part points, as well as the detection and elimination of vacuum leaks, along with supervision of the flow of resin.
This choice has enabled lower cost once it requires cheaper materials and involves less constructive rigorousness (easy to execute) (Figure 2).

Figure 2 – Infusion of the parts using open moulds

3.1.2 Multi Parts Concept

The analysis led to a bodywork concept, based on two constituent parts bonded by structural adhesive (like a "welding"), namely the floor and bodywork (Figure 2). The external and internal flat geometries and constant bending radius made easier the lamination and the process of release parts from the mould.
Initially, it was considered a pure monocoque structure. However, to facilitate the construction and reduce the production time and costs, is decomposed into two parts, manufactured separately and fitted and bonded, with structural adhesive. The bumpers were manufactured separately too.
Several guide shapes were modeled in both parts to improve the fitting and consequently the bonding process.

3.1.3 Assembly

The floor part already includes the sills and also includes the metallic inserts to allow for its screwing on the supports of the frame (Figure 3).

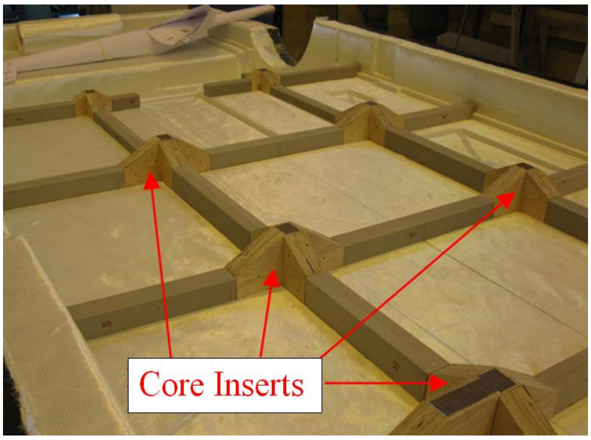

Figure 3 – Core inserts, predicted for the floor part, to allow screwing the bodywork on top of the chassis

3.1.4 Sandwich Type Structure

The material base for the core of the sandwich is PVC foam, with 80Kg/m3 of density (H80), and was involved by resin reinforced with fiber glass fabrics (GFRP), mixing 0º-90º plies with random plies, on fiber orientation.

3.1.5 Others Considerations ("Body" Part)

It was also discussed the possibility to build the bodywork by bonding 4 (four) different flat panels, made independently from each other to finally form the upper part ("Body" part). This process would not require the aforementioned mould. Panels would be made by Vacuum Infusion too, manually stratified, with average times of 40 minutes each. Thereafter the body would be mounted by bonding the panels assisted by vacuum.

4 Structural Design and Analysis

4.1 Validation of the Model

In order to validate the model, one sample of the column of the windows and two samples of the floor were manufactured.

A profile with 1 meter of length reproducing a pillar of the bus was developed by hand lay-up and consolidation with vacuum bag, with the dimensions shown in (Figure 4).

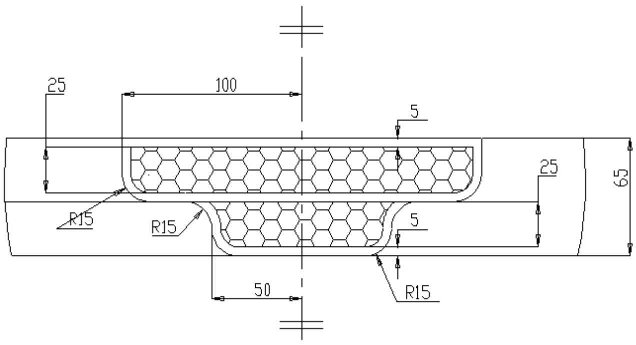

Figure 4 – Dimensions of the sample produced to be tested (section)

This is a sandwich structure with two cores, 25mm thick each in PVC foam, involved by laminated layers of random and blanket-crimp fabric (NCF).

The column was tested by bending, simply supported, applying a load in it middle point, until rupture (ranging from 800mm), to know its stiffness. A maximum displacement of 40mm was obtained, under elastic conditions, for a load of 25000N.

For the tests ENP shipyard also built two panels, 1:1 scale (1400mm x 1000mm) reproducing the floor. These panels also included metallic inserts to assembly the floor to the frame.

The floor plates have the following composition:

<u>Panels</u>

- Upper and lower skin (thickness 2.4 mm); PVC Core - 25mm

<u>Reinforcements</u>

- PVC Core - 50mm
- Skin strengthening - 3Combi (thickness 4.68 mm); outer skin - 2Combi (thickness 3.38 mm)

The samples were tested in bending until rupture according to their longitudinal and transverse directions, on Multi-axial Testing equipment "INSTRON".

A numerical model of a panel was developed with the specified lay-up.

The structural test was simulated by the finite element method, using the ABAQUS software. The properties for the materials considered were estimated by the ESACOMP software.
The loading has been applied in the normal direction to the panel. Two tests were performed on each of the two main panel directions, i.e., parallel and perpendicular to the floor rail.
Table 1 below lists the values of stiffness obtained in the experimental and theoretical simulations.

	K1 - Stiffness in direction 1 (kN/mm)	K2 - Stiffness in direction 2 (kN/mm)
Laboratory testing	2,892	5,189
Simulation	2,984	6,078
Error	3,18%	17,13%

Table 1 - Comparison of results obtained for the stiffness

4.2 Optimization of the Structure and Complementary Requirement Verification
Considering the results of previous simulations, ABAQUS software was used to create a finite element model of the bodywork and perform a structural simulation of the same. The mesh was built with elements of volume to the foam core and shell elements for the laminated (as in the simulation of the floor panels)
The bodywork has the following composition:
Panels

- Upper and lower skin (thickness 1.7 mm)
- PVC Core - 25mm

Reinforcements

- PVC Core - 25mm
- Skin strengthening - 3Combi (thickness 4.68 mm)

The bodywork model was supported just in the union areas with the floor and unsupported at the front sides. Despite the connection to the chassis in front sides being insufficient, it can ensure the necessary stiffness to prevent any large deformations. The applied loads on the roof were concentrated at points of the handrails used by passengers.
The following loads were considered in the simulation:

- dead weight;
- concentrated loads at points of support handrails (F1 =10kN, F2 = 3.35 kN; F3 = 3.35 kN);
- weight of Air Conditioning equipment placed on the roof (0.5 kN);
- doors weight (2 x 1, 5kN);
- load distributed uniformly on the floor (7kN / m²).

The maximum displacement obtained was 41mm in the center of the roof. The maximum displacement was 31mm in the floor. Maximum stresses occur in the central reinforcements of the roof, with a maximum value of 77 MPa.
The proposed solution expected a weight reduction around 30% in the bodywork.

5 Manufacture of the Bus Prototype

5.1 3D Models and Construction Drawings
The shape design (files of models (3D) and drawings (2D)) of the parts constituents of the bodywork and its assembly were prepared using SolidWorks software.

It was studied the fixings, to integrate several components on the bus, without compromising their function and safety. The composite nature of the body has imposed to placing plywood or metallic inserts (or the combination of the both) in the core of the sandwich, instead of the PVC foam. The anchorage areas into the floor part were built using metallic inserts combined with plywood, to ensure further consolidation and adjustment between the bodywork and the chassis.

5.2 Parts Infusion

5.2.1 "Floor"

The vacuum bag was placed, from above of the feedstock, and controlled the vacuum pressure, for an acceptable value for that kind of infusion, below 100mbar (Figure 5).

Figure 5 –Vacuum bag placement, pressure control and infusion (Floor)

5.2.2 "Body"

For the body part, the manufacturing process was equal as for the floor part and took 1h45m (part dimensions are 6220mm length x 2200mm width x 2300mm height).

5.3 Bonding

After demolding of the both parts, several adjustments were done to fit the parts and promote a correct bonding. The parts were bonded with structural adhesive.

The bodywork was considered ready to be transported to bus bodywork company facilities, to be mounted on the chassis and finished. The main structure weighted 1119Kg.

5.4 Bodywork Assembly

The bodywork was adjusted to be attached (some cuts were done to allow the placement). Using the metallic inserts (on the floor) like threaded nuts was possible screw it on top of the chassis.

5.5 Finishing Works

To conclude the bus it was necessary to paint it and mount all components. Some of the components had to be designed for us once the parts market, for this sector, did not have components compatibles with the features of this bus.

After painting inside and outside, the floor covering was applied and enabled to conclude the bus through clamping of the remaining components.

6 Results Obtained

The entire bus was weighed totalizing 3720Kg (Tare Weight). Therefore, the overall weight reduction was 380Kg (16%) (Figure 6).

Figure 6 – The weight reduction achieved on the Bus bodywork was 380kg (around 16%)

The manufacturing of the main structure by vacuum infusion, took 2h45m (Infusion process only).

7 Conclusions

This project aims at demonstrating the potential that the usage of composite technology has in the manufacture of high quality structural parts (Figure 7).

Figure 7 – Organic shape designed and perfectly reproduced by composite materials

The vacuum infusion manufacturing process has enabled parts of high surface quality with low roughness and significantly reduces the number of body parts and production time.
With the introduction of composite materials is possible to obtain parts of high strength and stiffness to the weight ratio structure, as well as low maintenance.
Using open moulds reduces manufacturing costs without compromising structural quality of the parts.