Use of Composite Materials in Public Service Vehicles

P. Neves[1], A. A. Fernandes [1,2], A. Ferreira [1,2], A. T. Marques [1,2], N. Correia[1], B. Almada-Lobo[1,2]

[1] *Instituto de Engenharia Mecânica e Gestão Industrial, Porto, Portugal*

[2] *Faculdade de Engenharia da Universidade do Porto, Portugal*

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INTRODUCTION

Public service vehicles (PSV) play a major role in the transportation industry of both industrialized and developing countries. Although the share of passenger transportation in PSV is relatively small compared to private cars, environmental and energy conservation constraints will lead to an increased demand of PSV, mainly in cases with limited access (like city centers). Diesel powered PSV are more efficient than private cars (even with catalyst) as far as fuel consumption and environment pollution are concerned, when measured in terms of consumption and exhaust emissions per passenger per kilometer. The reduction of a PSV unladen weight is an objective, which is being pursued for a long time due to its effect on fuel consumption and functional performance.

The reduction of weight is particularly important in the light of legal requirements on axle loads, tire number and size and payload increase. By the significant reduction of structural weight it is expected to reduce further weight by reduced engine (same performance), reduced number of axes, and reduced gear, among others.

In railway applications space saving, reduction of direct operating costs and innovative production technologies seem to be the primary concern.

The transport industry is estimated to generate 22% of all carbon dioxide emissions and the car population is expected to grow by 45% by the year 2010. This led the European Commission and governments to set strict targets/commitments aiming at reducing 30% the emissions by 2010 compared to 1995. Reductions of this size need a change in technology.

The only way to reduce CO_2 emissions is to reduce fuel consumption by means of improved efficiency of engines and reduced weight of vehicles. The use of FRP sandwich design may provide such a radical change in technology, as demonstrated by the application of FRP sandwich design on marine and commercial ships, which led to a reduction of 50% of the hull weight compared to wood or steel structures. Other positive effects are: lower maintenance costs, good thermal insulation, shock resistance and other integrated functions, and no corrosion. Nevertheless, some aspects must be improved, such as fire properties, smoke emissions, joints, load introduction and transfer, and non destructive testing.

FEUP and INEGI are currently involved in three relevant projects in the field of land transportation, namely LiteBus, FEUPBus and CIVITAS-ELAN, where composite materials will be applied. An overview of these projects is given, by focusing on the main results already achieved and on the prospective to a near future. FEUP and INEGI mission and vision in the field of transportation is presented. FEUPBus (presented in ECCM12) is analysed in a wider perspective that includes LiteBus. The CIVITAS-ELAN is the recently launched project, which consortium includes some of the partners in FEUP-Bus.

LiteBus is an ongoing project that will be described within the contract restrictions, but covering the most relevant trends of development and investigation. The public information about the project is available at [1].

1 – OVERVIEW

Multimaterial technology (sandwich and/or hybrid materials) is becoming increasingly important in new vehicle design, since it offers significant opportunities for enhancement of product performance in terms of strength, stiffness and energy absorption, combined with weight reduction and space saving. Nevertheless, its use still lags far behind steel in the production of cars, buses, coaches and rail and marine applications.
The involvement in relevant projects in the field of land transportation also benefit from the experience and knowledge gained in other projects. The most relevant contribution in the frame of the presented projects is:

- Project management;
- Industrial engineering and management;
- Numerical modeling of structures;
- Experimental mechanics and structural integrity;
- Failure analyses and development of failure criteria specific to composite materials;
- Vibration/acoustic analyses/insulation/correction;
- Joint design and testing;
- Material and components testing;
- Process simulation;
- Cost modeling;
- Prototyping;
- Production launch and follow-up.

The most recent requirements to consider in the design of land transport vehicle structures include:

- Safety considering new forms of energy supply (e.g. natural gas, fuel cells);
- Passenger safety;
- Reduced harm to pedestrians in case of accident;
- Security/vandalism resistance, including impact resistance;
- Ease of repair, both integrated parts and exchange of components;
- Modern design with complex surfaces;
- Class A finished parts obtained by cost effective processes;
- Integrated structural functions allowing more efficient space usage;
- Ease and fast assembly and joining techniques for cost effective assembly and production;
- Corrosion free and geometrically accurate surfaces;
- Fire protection/Smoke and toxicity reduction and structural stiffness under fire;
- Cost.

2 - PROJECT: LiteBus

The project LITEBUS - MODULAR LIGHTWEIGHT SANDWICH BUS CONCEPT is focused on the development of a novel technology to manufacture bus/coach bodies using load carrying sandwich multimaterial panels that have to meet tough design requirements, such as: high static and dynamic performance, high flexural and torsional stiffness, adequate acoustics, crashworthiness, higher safety for passengers, reduced harm to pedestrians in case of accident, fire safety, corrosion resistance, easy repair characteristics and reduced assembly time.
The main overall objectives of the project are:

- Solving the problem of reducing weight and production costs of land transport vehicles through the development of a technology of modular bus/coach construction, using “all composite” multimaterial load carrying sandwich panels instead of a steel/aluminum spaceframe lined with sheets of different materials (metallic or non-metallic);

- Devise design methodologies that reduce production lead time through reduction of number of components, functional integration, and allowance for dismantling, easy repair and recycling;
- Developing high quality urban transport;
- Contribute to the shifting of balance between modes of transport;
- Contribute to improve road safety;
- Contribute to improve quality in the road transport sector;

The main goals of the project are the reduction of weight and production costs through:

- Development of a new concept “all composite sandwich material for the production of structurally resistant modular panels for the construction of “Body in White” structures, reinforced with fiber reinforced pultruded sections (FRP) sections;
- Development of a new radical concept vehicle architecture where “load carrying modular sandwich panels” are used instead of the traditional spaceframe structure (in steel or aluminum) lined with sheets of steel or aluminum. The use of sandwich construction and composite materials means that a higher functional integration will be achieved through the incorporation, in the structure, at manufacturing stage of several functions, allowing more efficient space usage and cost efficient manufacturing.

This project adopts an innovative holistic approach since:

- A new concept structural sandwich material with FRP reinforcements (pultruded sections and/or filament wound sections) and the technology to produce single large modular panels will be developed.
- New radical modular vehicle concept architecture, based on the use of structurally resistant composite sandwich panels to produce the structure (lateral, roof and floor panels), instead of the traditional spaceframe concept, either in aluminum alloy or steel hollow sections, lined with metallic or composite sheets.
- Design of a new product using principles of Extended Product Responsibility (EPR), which extends responsibility to a life cycle stage, taking into account environmental impacts of the product system and principles of Design for Manufacturing and Recycling (that takes into consideration the constraints imposed by the composite sandwich material);
- The new concept reinforced sandwich material and modular panel architecture and respective connections will be validated by numerical modeling simulation and a rollover test on a Bodywork Section;
- Design, implement, test and evaluate a new structural health monitoring concept relying on novel optical fiber sensing heads and readout equipment, based upon in-fiber gratings and micro-cavities for temperature and strain measurements in the body, for composite damage assessment.

The main scientific/technical objectives are thus:

- Reduction of 10-15 % of total unladen weight of a bus through a 60% reduction of "body in white” weight (which represents typically 20-25 % of the total bus weight), in comparison with current steel bodies. The stiffness of the bus structure will be equivalent to a steel body. Crashworthiness under rollover will be greater than bolted aluminum structure and better than steel structures;
- Manufacturing lead time should be reduced 30%, through the use of fewer components, easier and faster to assemble and join together and through integration of several functions in panel components;
- Tooling and jigging costs reduced 30%, since sandwich panels are considerably less expensive than stamping dies or jigs for welded construction;
- Reduction of 20% of noise and enhanced vibration properties;

- Greater corrosion resistance with adequate fire safety;
- Increased passive safety for passengers;
- Reduce harm to pedestrians in case of accident;
- Improved interior packaging and space (minimum of 10 %);
- Better aesthetics and aerodynamics of the body;
- Exterior and interior faces with better finishing ready to be painted;
- Servicing and repair of damaged structures easier to perform;
- Improved know-how in the use of FEM modeling of sandwich structures for bus and automotive applications;
- Validate software tools applicable to crashworthiness evaluation to the special case of sandwich structures;
- Develop fatigue design curves applicable to sandwich structures;
- Demonstrate the capability to remotely monitor 'structural health' of an 'in service' transport vehicle and validate the integration of event sensor systems;

The main technical achievements can be summarized as follows:

- Design, manufacture and validation of a sandwich material with high stiffness and energy absorption suitable for surface transport vehicle;
- Generation of new concept vehicle architecture, using systematic product development methodologies and Integrated Product Policy for a more environment friendly vehicle;
- Develop a new manufacturing technology for the production of large panels with functional integration. The materials, conceptual design methodologies, design philosophy and assembly methods can be applicable to other industry sectors in particular train rolling stock, ship/boats, and trucks and self-supported refrigerated containers.

2.1 – Main results already achieved

The concept design stage is complete and simulations have been done at three partners simultaneously, but using different approaches. The results have been continuously compared. Also, prototype production and experimental validation have been running.

The numerical analysis conducted at INEGI includes the following:

- Stiffness of individual components subjected to static loading. The results were used in the selection of foam core and skin materials.
- Crashworthiness of bus sections, according to UNECE R66, under rollover. Theses results must compare to steel construction benchmarks. Before experimental validation, the results concerning the envisaged material selection show that the external work until onset of intrusion (one pillar model) is close to 6.4KNm. This value is considered acceptable to start production of prototypes and test samples. If experimental validation results in the need to increase the flexural stiffness of the pillars, carbon fiber reinforced epoxy bands will be bonded or co-cured to the interior of the pillar skins. This solution makes it possible to maintain the approved geometry.
- Natural frequencies and natural modes of vibration.

3 - PROJECT: FEUPBus

FEUPBUS entails both research and technical development, and implementation and demonstration activities. The research phase started two years ago, mainly funded by FEUP and associated partners, and has already achieved significant results, such as:

- Exterior and interior manual sketches, renderings and 3D surface models.

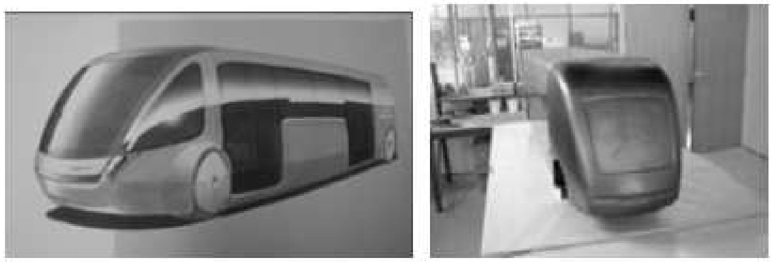

Figure 1 – Mock-up model

- Mock-up model of bus.
- Small-scale prototype, for preliminary studies in manufacturing processes and constructive solutions.
- Computational simulation models of rollover.

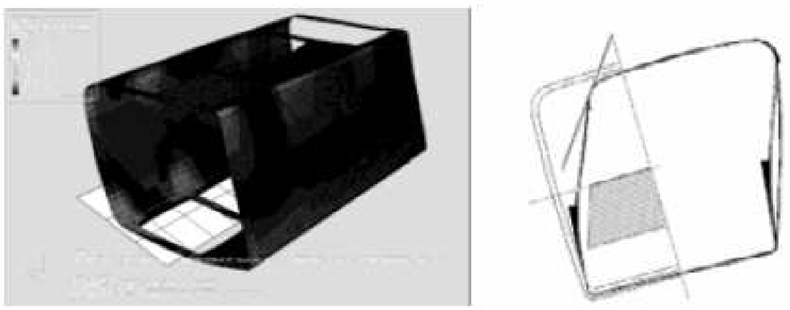

Figure 2 – Roll-over simulation

- Optimization of filament winding process through simulation.

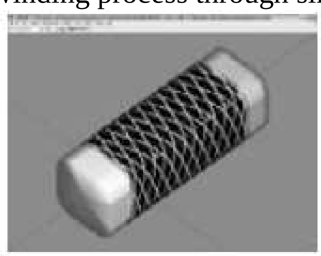

Figure 3 – Process simulation

The FEUPBus envisaged architecture, with only two helical wound skins, results in a structure containing a very weak pillar. This problem demanded a new constructive solution for the pillar.
Filament winding consists of the exact placement of fiber in the rotating component. The fiber rovings are fed continuously to the positioning head. The head describes the prescribed path of deposition, while keeping the tension in the rovings.
The dynamic simulations of the bus rollover have shown that the pillar would be the critical part. And so, it had to be analyzed much more intensively than any other part. A new section was proposed and sample pillar was built. The new section is shown in figure 4.

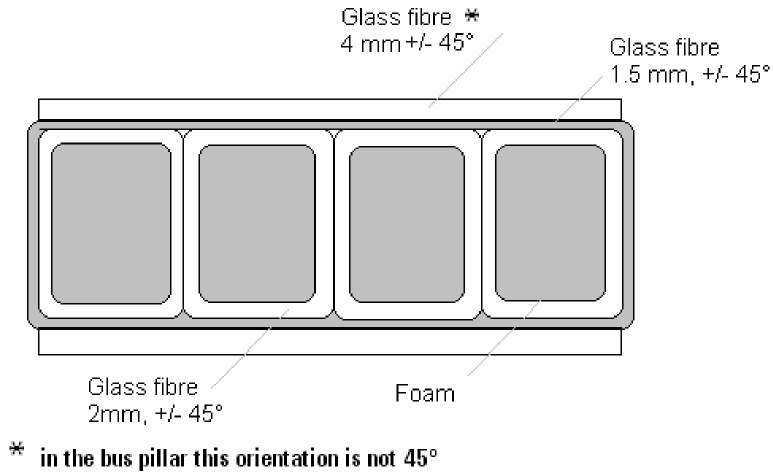

Fig. 4 – new pillar section

Because of machine schedule the pillar could not be actually built by filament winding. For this reason, the best expected mechanical properties were not achieved. It was built by manually wrapping glass unidirectional and +/-45º woven fabrics around the core sections and by vacuum infusing them. The result would be one first approach to the final solution.

The main objectives are to make the core stiffer, especially in the transverse direction and to avoid core damage. The easy separation of skin as observed in the first pillar has shown the need to close the borders of the pillar. The first pillar was the most elementary sandwich concept, reproducing the interior and exterior wound skins with no connection between them, except core. The envisaged pillar core is built separately and assembled together with the foam over the interior skin prior to exterior winding. Also, another drive is the need for increased strength and, specially, stiffness in the core. One possible solution is to subdivide the pillar in subsections along its width so as to form shear ties by winding (or, in our case, wrapping) fibers. The natural tendency to skin separation will now occur by delamination at the skin/core fiber interface, keeping the structural foam enclosed and so less prone to damage. The delamination is also expected to release a higher quantity of energy than the core damage. The core weight will increase but we are suppressing circumferential wound reinforcements and the balance is a global weight reduction. The overall idea is to build a component that can act as a spring in the range of loading expected in roll-over, since the major portion of energy release by damage should occur in the impact area in the roof and also because the pillar should be a damping element.

To consider this new section back in the bus body simulations, it was necessary to find the equivalent core properties and validate them through simulation and testing. So the sample pillar was tested in three points bending.

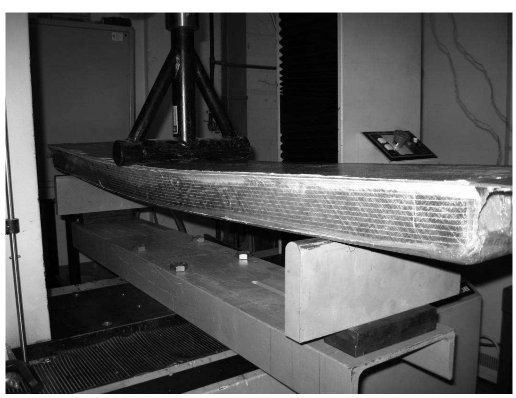

Fig. 8 – three points bending test

The maximum load was 64,14kN for a displacement of 44,1mm. The new core section significantly increases bending stiffness and allow safe energy absorption.

FE models – without cohesion elements – do not completely simulate the three points bending test. In practice, models simulate well until onset of delamination. This is not a very serious limitation; since the main objective is to have the pillar working with no delamination (spring) and failure onset can be predicted using ABAQUS progressive damage model. These results were taken in consideration in the analyses performed in LiteBus.

4 - PROJECT: CIVITAS-ELAN

The CIVITAS-ELAN Proposal [2] is the result of an intensive cooperation and exchange process during which the cities of Ljubljana, Gent, Zagreb (as leading cities), Brno and Porto (as learning cities) have developed a common work-plan for the CIVITAS Programme. Based on the cooperation agreement signed by the mayors of the five cities, a common mission statement for CIVITAS-ELAN has been agreed. The CIVITAS-ELAN mission is to “mobilize” our citizens by developing with their support clean mobility solutions for vital cities, ensuring health and access for all. Throughout the project this will be communicated with the citizens by using five characters, representing not only the five ELAN cities, but the citizens of Europe.

Within this project, FEUP will address the implementation of an innovative technology to manufacture bus bodies using lightweight fiber reinforced composite materials that meet tough requirements of high static and dynamic performance, powered by quiet and clean hybrid electric power trains, using wheel-mounted electric motors and diesel LPG or gas-driven combustion engines.

The main overall objectives of the measure are to:

- Establish a clean bus shuttle within one area of Porto city;
- Solve the problem of reducing weight and production costs of urban buses through the implementation of a technology of modular bus construction;
- Devise design methodologies that reduce production lead time through reduction of number of components, functional integration, and allowance for dismantling, easy repair and recycling;
- Develop high quality urban transport;
- Foster modal shift between transport modes;
- Improve road safety;
- Improve quality in the road transport sector, making it more attractive;
- Reduce CO_2 emissions

The project adopts a “fusion technology” innovation approach since it will integrate knowledge already available from different disciplines and industrial sectors, combining it into a new product not yet available in the market. The integration of knowledge and expertise, either from national or EU projects or from internal know-how of FEUP, namely from the ongoing FEUPBus project, and associated partners, will be validated in a prototype bus to be produced.

4.1 - Description of the work to be performed within CIVITAS

The activities are organized as follows:

- Research and Technical Development related activities
    - Study concepts of materials available in the market or produced in other EU-funded projects;
    - Compare their properties with requirements of stiffness, crashworthiness and manufacturability for bus;
    - Identify the advantages and drawbacks;

    - Study the possible processing methods and select the most applicable processes for large structural components (e.g. resin transfer molding, filament winding techniques);
    - Full material characterization from available databases including mechanical properties, strain rate dependency, fire resistance, and acoustic performance form, an essential input for the overall design;
    - Design of integrated load introduction functions in particular points of load transfer;
    - Provide a validated and safe design technology for joining composite materials and metallic inserts.
- Implementation & demonstration (incl. non-CIVITAS funded parts)
    - Identify a comprehensive set of product attributes/ user needs, in order to create a high quality information channel between the end user in the target markets and developers of technology/ product;
    - Develop new vehicle architecture, based on modularity guidelines;
    - Produce feasibility studies for function integration and exterior and interior sketches, perspectives, renderings and 3D surface models of the Bodywork of urban buses;
    - Develop industrial geometric drawings for prototype bodywork production;
    - Produce a prototype of a bus, incorporating the relevant concepts and technologies validated in the project;
    - Prove the feasibility of a competitive concept by incorporating the technologies, functionalities, and requirements, in accordance with the project objectives;
    - This bus is going to be used as a shuttle within a zone of Porto.
- Evaluation
    - Evaluation will be carried out by assessing the reduction achieved concerning the weight of the vehicle and its impact on reduction of CO_2 emissions;
    - In addition, this innovative bus will primarily contribute to a shift of balance of transport from individual cars to public transportation.
- Dissemination and training
    - Since the new bus will use a hybrid power train, there will be a need for training in mechanical aspects.
    - Additionally, training of drivers is need for two reasons: use of power trains and handling of the vehicle (which may be potentially less rigid than current buses).
- Partners and roles

FEUP will lead this task, and will collaborate closely with external partners, with clear complementary expertise, necessary for the integrated and holistic approach of the workpackage, namely:

    - Production capabilities composites materials parts/ components
    - Assembly and manufacturing capabilities
    - Concept design
    - Multimaterial, material development specialists;
    - Structural adhesive bonding;
    - Experimental capabilities both for small scale and full scale components and structures (static and fatigue tests);
    - Life cycle cost and other eco-design aspects.

4.2 - Verifiable results / How CIVITAS contributes to the result

Tangible outputs

- A prototype of a light weight hybrid bus
- A bus shuttle service within the selected area based on the light weight hybrid bus

Expected outcomes

Significant weight reduction without compromising customer and societal standards of vehicle performance:

- The use of composite material will lead to a reduction of the bus structure weight of 60% and overall unloaded weight between 10-15% for a 12 meters long bus (12 ton gross weight).
- Noise attenuation through better acoustic insulation with novel material sandwich;
- Higher passenger safety, through improved crashworthiness
- Reduced harm to pedestrians in case of accident
- Better aerodynamics
- 15 % of CO_2 reduction as compared to a ‘normal’ bus

Structural Design in a holistic multi-parameter approach

- A vehicle concept will be generated, using load carrying integral panels in composite materials for the fabrication of the vehicle body;
- Concept design and architecture will take into account principles of Design for manufacturing and design for Environment.

5 – CONCLUSIONS

FEUP and INEGI are involved in relevant projects in the field of transportation, involving partnership with relevant industry players and transport authorities.
The teams working in those projects have relevant experience in design, dimensioning, prototyping and experimental validation of bus structures and components (both metallic and composite).
A programme of experimental validation has been done to validate the numerical results.
Real scale prototype bus section roll over will be used to validate the proposed solutions.

REFERENCES

[1] www.litebus.com
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