COST EFFECTIVE MANUFACTURING PROCESSES AND MATERIALS USED FOR THE CONSTRUCTION OF THE SUPERBUS

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SUMMARY

The Superbus, rendered in Figure 1, is a new concept for public transportation. It is sustainable, fast, economic, and appealing and transports passengers and goods from point to point and drives at high speed (250 km/h) on its dedicated and relatively cheap infrastructure.

In this paper the material used, the cost effective tooling and manufacturing processes for the construction of the Superbus are presented.

First, the materials used for the achievement of the structural design targets in combination with the lightweight requirements will be described in their application to the Superbus, which uses a composite chassis, IXIS thermoplastic bodywork and Lexan polycarbonate glazing. Then, the tooling and manufacturing processes utilized for the construction of the vehicle will be discussed in terms of the optimization between final good product and cost constrains.

Figure 1 Rendering of the Superbus.
1. INTRODUCTION

The Superbus [1] was introduced as one of the options for the Zuiderzeelijn, a fast connection between Amsterdam and Groningen and resulted to be the best option; the others being three different types of high speed train and the magnetic levitation train. In order evaluate the feasibility of its implementation, the Dutch Ministry of Transport and Water Management has decided to fund the realization of a demonstrator [2], which will be officially launched at the 2008 Beijing Olympic Games.

The Superbus is not only sustainable for that it does not produce CO2 emissions but for many other aspects. For example, it uses some recyclable materials, it is designed to increase the use of public transportation, thus limiting the ever growing private transportation, and it uses low power per passenger. The Superbus provides flexible transportation on request and therefore does not travel on a fixed schedule.

The Superbus is 15m long, 2.5 m wide and 1.6 m high and carries 23 passengers and a driver. The vehicle has 16 doors, 8 per side, due to the required comfort, privacy, and accessibility aspects. The overall vehicle weight is 9 tons, including the payload. The importance of the weight limitation of the vehicle has enforced the implementation of a new design and the use of lightweight materials. The structure of the vehicle is composed by a carbon fiber chassis. It uses IXIS for the central part of the bodywork, carbon fiber for the front and rear bodywork and Lexan for the glazing. The structural design of the chassis has proven significantly challenging for the presence of the 16 doors. In order to limit the weight, a crossbeam design has been implemented [3] so to enable the utilization of the entire vehicle cross section for torsion stiffness. The crossbeams design equates to a 40% weight reduction for the achievement of the target 30kNm/deg torsional stiffness, when compared to a more conventional design formed by horizontal beams.

The chassis is formed by a floor connected to 2 side frames united by 8 top beams, as showed in the assembled and exploded view of Figure 2.

![Figure 2: The assembled chassis and suspension system and the exploded view showing the components forming the central cabin](image)

The floor is made of two skins inside which there are six longitudinal beams and 16 transversal beams. Each transversal beam is divided in seven parts to intersect the longitudinal beams. The central part of the chassis is connected to the forward chassis
part, the driver house, and the rear chassis part, which envelopes the powertrain compartment.

2. MATERIALS

The structure is built almost completely from carbon-epoxy composites. This allows the weight of the bare structure to be kept to 1300 kilograms. The carbon fiber used throughout is Tencate Torayca T700. The complete load carrying structure is built using a 12K carbon fiber unidirectional tape and stitched tri-axial fabric of $0^\circ$ and $\pm45^\circ$ carbon fibers, which allows the lay-up to be more efficient compared to a standard lay-up of unidirectional tape and $45^\circ$ rotated fabric. The carbon fiber is used in combination with the latest development of epoxy resin developed for vacuum-assisted resin infusion molding by Dow Automotive. This epoxy resin has a very low viscosity and a long pot life, making it ideal for the main Superbus manufacturing process. For the floor skins and for the front and rear bodywork, Lantor Soric core material is used. This pressure stable polyester non-woven is ideal as core material for components that are in the area between monolithic parts and sandwich panels using foam or honeycomb.

A large part of the exterior bodywork is manufactured from SABIC’s latest development in automotive materials: IXIS, which is a thin sandwich consisting of skins of unidirectional glass fibers in a polypropylene matrix and a core of random glass fibers in a polypropylene matrix. The glazing of Superbus is made of polycarbonate Lexan, supplied by SABIC, in two material specifications. For the blue side windows glazing, 6mm and IR-absorbotion treated sheets are used. For the windshield, a clear 10mm clear polycarbonate Lexan is used.

3. TOOLINGS AND MANUFACTURING

The floor structure consists of two sandwich plates which are produced by vacuum infusion on a flat mould. The floor skins have been optimized in weight, height and stiffness through the utilization of a two millimeter thick type of Soric pressure stable polyester non-woven, used as core material. The bottom plate has been divided in three parts to allow access to the cabling and systems placed in the floor. Figure 3 shows the floor structure, the manufacturing of the top plate and the manufacturing of one of the three parts of the lower plate.

Figure 3: Floor assembly design (showing the top and lower plate, the 6 longitudinal beams and the 16 transversal beams) and the manufacturing of the top and bottom plates by vacuum infusion.
The whole floor is temporarily joined using mechanical fasteners to allow maximum flexibility during the assembly. The top plate is then bonded in the final assembly whereas the lower plate, which is divided in three parts, is bolted so to allow accessibility to the internal cabling and systems during testing of the vehicle.

The longitudinal beams (Figure 4) were manufactured by vacuum infusion in a simple U-shaped sheet metal mould. To ensure a proper mould filling, and to avoid fiber bridging in the negative mould radii, a patented pre-forming process is performed in a separate tool [4]. The transversal beams due to their large amount and relatively small dimensions were produced by hand lay-up. Each element presents a central hole to allow for installation of systems such as cables and air-conditioning in the floor structure, as shown in Figure 4.

![Figure 4: Manufacturing of one of the longitudinal beam by vacuum infusion, the tools for the parts composing the transversal beams and one of them manufactured.](image)

The roof connectors are made from moulds produced from CIBA tool material and the parts are manufactured by vacuum infusion, one of which is showed in Fig 5.

![Fig 5: Roof connectors mould and one of the 8 roof connectors manufactured](image)

The frame structure is made by hand lay up, using a left and a right mould of the whole central cabin to produce the various elements (Fig 6). The moulds were milled by a low-cost direct tooling route. The shape of the mould was milled with a 5 cm offset in polystyrene foam. A tooling paste was then applied over the complete surface which, after curing, was milled to the final contour. Finally, coating was applied to produce a smooth and surface. The doors are manufactured from the same mould by a first layer of hand lay up and the rest by vacuum infusion.
The doors exterior panels are made from a thermoplastic glass fiber reinforced sandwich laminate called IXIS, produced by SABIC. Such material is formed at high temperatures. Thus, the moulds used for manufacturing these parts are laminated with a high temperature resistant resin from positive moulds. This is done so to obtain high temperature resistant moulds at a relatively low cost. Figure 7 shows the positive mould and the realization of a sample of the exterior bodywork formed to the shape of the 5th door of the Superbus.
All glazing parts are formed from polycarbonate sheets. Due to the presence of double curved surfaces in the front windshield, the latter had to be produced in a number of parts due to optical requirements. To ensure wear and UV protection, a plasma coating was applied to the formed glazing in a subsequent step. Figure 8 shows a side window manufactured and coated.

![Fig 8: side window manufacture by Lexan polycarbonate glazing](image)

The body panels and glazing are adhesively bonded to the frame structure to comply with the required aerodynamic smooth surface. The assembled side panels are joined with the floor structure and roof beam elements to form the central part of the body work.

### 4. CONCLUSION

Designing and producing a totally new vehicle is challenging both in the process and because of the costs related. The usage of relatively low cost tooling and the utilization of vacuum infusion for the manufacturing of most of parts have significantly help the realization of the vehicle whilst remaining within the deducted budget. After the vehicle assembly, thorough testing will be performed to ensure and verify vehicle performances. The, the vehicle will be sent to Beijing for the official launch at the 2008 Olympic Games.

### 5. REFERENCES