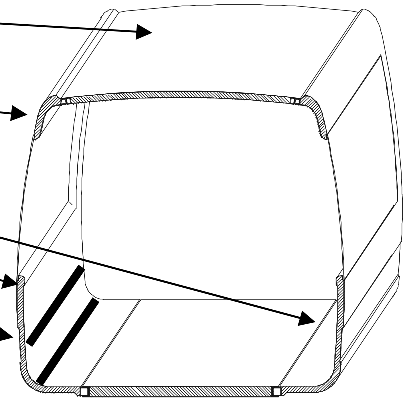
An all bonded bodyshell for public transport

Stork Fokker at Hoogeveen designed the bodyshell for a lightweight carbus. Within this design a large number of sandwich constructions and adhesive joints are present in order to optimise the stiffness and weight of the bodyshell.

1. Introduction

By the integrator and co-ordinator APTS (advanced public transport systems) a project was launched to design a carbus able to transport a vast number of people between the suburbs and the town centre at a regular pace. A bottleneck is the boarding time of the passengers. This issue was addressed with a large number of wide doors and a low floor having the same height as the busstop area. The articulated bus had to be equipped with a hybrid driveline consisting of a generator set and electric motors for each wheel. To be able to manoeuvre in the town centre, with limited space available, it was decided to steer all wheels. In this way it was no longer possible to use double mounted tires. While for a carbus with their typical stop and go traffic it is beneficial to have a low weight the single tires and the additional weight of the hybrid driveline made it even more apparent that weight of the carbus was an essential aspect.
Stork Fokker was asked to make a proposal.
A lightweight construction can be designed when all parts in this construction are load bearing and are loaded to the maximum. It is also advised to prevent local strengthening in areas where fasteners are distributing the load. The passengers causing the construction to bend present the main loading of the carbus. A construction capable of withstanding this kind of loading is the sandwich construction. Because the main stresses are located in the outer fibres away from the neutral axis it is possible to design the core to be of a weaker material and of course preferable light in weight. The highest stressed panels in the carbus proved to be some flat panels like the floor. It was decided to use aluminium skins for all flat panels. For constructing and bonding these panels we have the experience in house for over 30 years. Due to the freedom of forming all single and double curved panels are fabricated as a glass fibre reinforced plastic (GFRP) construction. Joining these different panels to form the bodyshell calls for a joining method that distributes the loads very evenly. Adhesive bonding proves to be a very good method for lightweight constructions.
To choose from all the different adhesives available a number of joints within the bodyshell are highlighted.

- Flat panels: floor and roof
- Sidewall module
- Sidewall module to floor
- Sidewall- to sidewall module
- Seatrail to sidewall module
- Front of the bodyshell.



2. Flat panels: floor and roof

Product requirements: Flat panels like floor and roof are constructed around a framework of aluminium extrusions filled with foam in the open areas. The aluminium skins then close this framework.
The roof in itself is not highly loaded and can therefore be manufactured with very thin skins. The skins form a large part of the construction and every kilogram is easily gained in this area. Now thin skins are prone to buckling while loaded in compression. The sandwich construction with its supporting core helps to prevent such a failure mode in this case up to 80 % yield of the aluminium skin. So the skins can be loaded almost to the maximum. The adhesives requirements are not very specific other than a shearvalue of 10 N/mm², which has to be maintained at the 90°C temperature over the generator room. Especially the floor has to carry the main bending moment. At the same time the floor may not deflect too much due to the required ground clearance. The requirements regarding the lowest natural frequency of 7Hz also called for the construction to be laid out with sufficient stiffness. The choice on the adhesive has an impact on this behaviour. The skins have to be joined to the aluminium extrusions rigid.

Solution: An epoxy adhesive is used with a high shear modulus capable of being applied to a thin film. To achieve this kind of application a roller machine is used to apply the adhesive evenly across the surface with the desired amount of adhesive. Then a heated platen press is used which enables the one-component adhesive to flow and to cure according to the supplier requirements. The maximum load distributed by this joint is relatively low in the order of 8 N/mm². The surface preparation of the aluminium consists of a chemical chromate conversion coating. This treatment being low cost still protects the bond against ingress of moisture and corrosion over a long period of time (experience in house show typical 20 years and more).
The carbus is articulated and this means that one bodyshell can swivel in relation to the other. The articulation system is only attached to the front of the floor of the second bodyshell. When this joint should yield then the loads are not transferred in a second loadpath. The consequences of such a failure could be life endangering and therefore a fair margin of safety should be applied. The one-component epoxy adhesive is capable of a maximum shear up to 30 N/mm² and we want the adhesive to adhere to the aluminium surface up to this very value. To achieve this the front of the framework of the floor is chromic acid pickled and anodised (CAA). Within 8 hours after the anodise process a thin layer of epoxy primer is being applied. The time schedule in which bonding should be performed is than far less stringent.
For reasons of logistics and to minimise the number of different adhesives, the floor and the roof as well as all the other flat panels are bonded with the same one-component epoxy adhesive.

3. Sidewall module.

Product requirements: The sidewall has a number of functions united. The main loads are the shear loads introduced by torsion of the entire bodyshell. Due to bending moments on the bodyshell shear loads as well as compression are applied. The sidewall should also act as a mounting surface for the seatrail. Upon impact, caused by a collision with another vehicle, the passenger ought to be protected from high acceleration forces and protected from injuries inflicted by protruding foreign objects.
The sidewall had to have an inner- and outer skin ready for painting.

Solution: The sidewall module is a construction element existing of a core surrounded by glass fibre reinforced polyester resin. By means of finite element method calculations the minimum thickness of the skin is calculated and the properties of the core verified. For reasons of weight optimising a high ratio of fibre-volume fraction is strived at but in this case it was decided not to do so. The costs involved with a high fibre-volume fraction process are much higher due to the production method and we still had to deal with the requirement regarding impact. This impact requirement was translated into a thickness of the laminate of 3mm and a fibre-volume fraction of 25% (40% by weight). The impact requirement was verified in a life true scale test whereby a car ran into the sidewall at 30 km/h. The small amount of damage and the absence of any protrusion was a clear go ahead for the laminate parameters.
In addition to the fact that the in- and outside had to have a smooth finish we stated that upon production no emission of styrene was allowed. This indicates that a closed mould process should be considered and eventually RTM (resin transfer moulding) was chosen. This process also offered the possibility of producing almost net leaving just a small rim of waste material along the perimeter. The chosen fibre-volume fraction was favourable in more than one aspect. It turned out that the pressure needed to transfer the resin in the mould did need to be that high. Since the core material has an ultimate allsided compression value of 2 bar the resin pressure is set lower. This in turn was beneficial to the mould itself since it deflects less under low pressure the shape of the product was more defined and the mould lasts longer. And still the low viscosity resin had time enough to fully wet the fibres within the geltime.
The sidewall module is postcured after demoulding to achieve a styrene level of 0.5%. This process gives the resin its final properties within a short time frame. It can therefore easily be sanded and handled but it also needed for areas where an adhesive joint is to survive for a long period of time. The low level assures that diffusion of styrene at a later stage in service shall not influence the adhesion of the adhesive.

4. Sidewall to floor

Product requirements: The lower part of the sidewall module forms a U-shape together with the floor. This form shows good stiffness properties only when the elements involved are connected as stiff as possible.

Solution: Due to the predicted shear stresses calculated from a running load and the foreseeable peel forces it was decided to use a modified roomtemperature curing two-component epoxy adhesive. This adhesive was favourable for its adhering properties on GFRP's and aluminium as well. Since the aluminium edge extrusion was already chromated the only process step left was to sand the sidewall module and solvent wipe the contacting areas.

Tolerances: The sidewall module is slid and rotated into the edge extrusion of the floor. The shape of the extrusion is carefully laid out so as not to slide away the adhesive or pressing it away from the joint. This would eventually lead to starvation of the joint and/or airbubbles in the adhesive film. The adhesive in this case is tixotropic and is capable of filling a gap of at least 1mm. Although it is advised to keep the gap as small as possible the properties of the GFRP sidewall with its stiffness and shearmodulus allow for a 1mm gap.

5. Sidewall- to sidewall module

Product requirements: The production method for the sidewall in a RTM process calls for a demoulding angle of at least 2 degrees. When two of these modules are mounted side by side the gap in between shall have a tapered shape as well. When a rigid adhesive is applied in this gap then upon loading the thinnest and most stiff area is taken the entire load. Since this area is limited the load applied may only be limited.

Solution: For this situation a highly flexible adhesive is preferred capable of spreading the load over a wide area. The low specific shear value of around 3 N/mm^2 presents no problem in this case since the area available is designed large enough. Because of the width of the joint (60mm) and of the thickness of the adhesive (3-5mm) allsided compression and tension is shown under loading. This leads to a much stiffer construction than accounted for by using just the material properties.

Tolerances: The front and aft flat panels are attached to the ends of the floor and are directly linked to the tolerances of the floor. The space in between is filled with the sidewall modules. Due to the number of gaps, differences in gapwidth can be levelled and the flexible adhesive allows for a considerable tolerance in gap. The stiffness of the construction and the loadpath is not affected by this tolerance difference.

6. Seatrail to sidewall module

Product requirements: The seats in the bodyshell are mounted to the wall only without any support to the floor. This allows for a simple cleaning operation in service because the floor surface is totally free from obstacles. Mounting the seatrail to the sidewall module brought along the following considerations:
The sidewall modules already defined as products made from GFRP skins have a lower shearmodulus than aluminium.
The seatrail is loaded perpendicular to the sidewall and due to the construction of the sidewall there are areas of significant difference in stiffness of the skin. Considering the pointloads introduced by the seats the construction of the seatrail itself led to an extrusion again made from aluminium. The attention is mainly focused on the joint of the seatrail to the sidewall.

Solution: First the extrusion was considered being attached to a weak surface. It can be observed that the weak surface bends under load causing high peelforces at the perimeter of the extrusion. (see figure 1) To withstand the peelforces a flexible sealant/adhesive was chosen. And because of the fact that the aluminium extrusion had to be designed from scratch the gap between the surfaces was made wider towards the outer perimeter of the extrusion. Than the joint was imagined lengthwise in the carbus having extreme differences in rigidity.
(see figure 2) If the seatrail were to be indefinitely stiff than the entire load would be transferred to the stiffest area and an even distribution of loads is not achieved. If in turn the seatrail would be indefinitely weak than the entire load would introduce a significant travel of the sidewall. The natural frequency would be too low leaving the passenger with a very unpleasant feeling while seated. The designed extrusion profile has a stiffness lengthwise equalising the flatwise-tensile forces in the adhesive to a level that the performance at fatigue is sound. The travel of the sidewall module has been set to a level known for the fatigue shearstress in the foam.

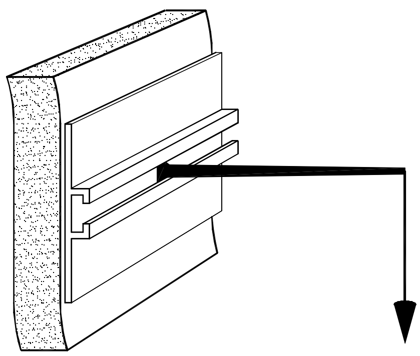


figure 1

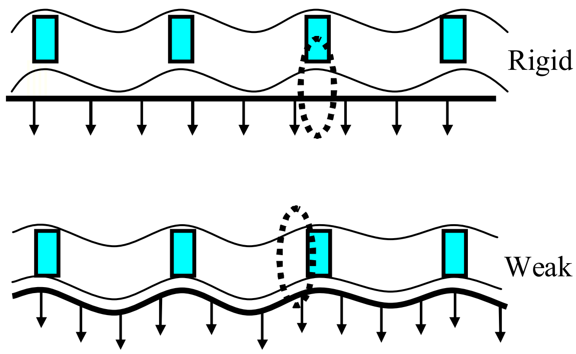


figure 2

Tolerances: The seatrail is mounted perpendicular to the sidewall causing the adhesive to be squeezed out until the prescribed bondline thickness is achieved. A variance in flatness of the inner surface of the sidewall has some influence on the thickness of the adhesive. The flatness of the surface lies within 0.6mm and therefore the thickness of the adhesive will vary between 3 and 3.6mm. This presents no difficulties for the adhesive.

Thermal expansion: The glassfibre material with random orientated fibres and the fibre-volume fraction together provide a thermal expansion of the GFRP to be almost similar to that of aluminium (24E-6). It is therefore possible to mount the long length of seatrail without too thick a film of adhesive. Nevertheless it should be considered that upon heating and cooling there still shall be temperature differences between the two elements. This is the reason why it is not permitted to use "rigid" methods of joining like rivets or screws combined with a flexible adhesive. During heating and cooling these hard elements will be forced to follow the seatrail and as a result the rivet and screw shall be pulled through the skin of the sidewall.

7. Front of the bodyshell

The front of the carbus bodyshell contains two so-called A-pillars where the front window meets the side window. Not far behind there is the position of the driver. For the protection of the driver it is not wise to form these A-pillars from GFRP or even CFRP (carbon fibre reinforced plastic). In the event of a collision the construction must have a buckling zone where energy can be absorbed. In case of a perpendicular load to the fibre direction, as with the A-pillar, the GFRP is capable of withstanding the load over a very short distance then it will break and snap. The momentum of the carbus still exists causing the load to travel on. For this reason a steel tube with inherent high degree of plastic deformation is mounted in place. For reasons of styling this A-pillar is shrouded with GFRP elements. To give the driver a maximum view these A-pillars have to have a minimal cross section and this indicates that the GFRP parts lie very close to the tube. The bondline thickness has to be minimised as well. A stainless steel tube was chosen for its thermal expansion coefficient of 17E-6 being close to the coefficient of GFRP. By placing additional Uni-Directional glass fibres in line with the tube direction the GFRP part with its random fibres is modified in order to overcome the difference still present. Due to the fact that the glass fibre in itself has a thermal expansion coefficient of 8E-6 the amount of UD-fibres in proportion to the random fibres can be chosen to equal the stainless steel properties on this aspect.

8. Testing

By weighing the requirements of product and adhesives accompanied by the knowledge of different application and production methods it is possible to make a good choice. However the necessity for testing still remains. It is of the essence to gain insight on the failure behaviour on the tested joints. Tests on item level have to be performed before the production starts. In this way the sidewall-to-sidewall joint was examined. Knowing that the adhesive would shrink the testitem was positioned in a way that the defined gap was maintained throughout the curing cycle. These testitems with PU-sealant and MS-polymer sealant were then exposed to temperature, moisture and saltspray. Flatwise tensile tests showed that due to the initially higher stiffness the MS-polymer was in favour for this application. The application method could be validated as well as performing a test to obtain a certificate of competence for the production personnel. Full-scale tests reveal whether all the steps taken in the development process and production process were successful. As of now the carbus conducted all the necessary laps on the testtrack fully laden as well as empty. Apart from minor deficiencies the tests were completed without comments on the bodyshell.

Ing L.C.Zwaneveld

Stork Fokker at Hoogeveen

E-mail: luit.zwaneveld@stork.com
Internet site: www.stork.com