Summary

This report consist of a design study of a sidewall of a foldable container. Currently the sidewall consists of a steel frame with steel corrugation of 650kg, to be able to fold the container without a balancing mechanism, the goal to reach is to design a sidewall weighing only 100kg.

All requirements of the design are mentioned below:

1. Weight of maximal 100kg for the sidewall (including frame), excluding the bottom beam, levers and roof closures.
2. Meets the requirements considering the maximum loads and stiffness of the sidewall.
3. Meets the requirements of the internal dimensions as stated in ISO1496-1.
4. Walls must be interchangeable.
5. The costs of the design must be as low as possible, meeting the other requirements.

Reparation of the wall can be done simply and prevented as possible by taking the change of damage in account during the design stages.

To be able to reach the goal of 100kg, much lighter materials have to be used, but the strength of the sidewall must be at least the same. The highest loads can be found due to the stacking of the containers, which results in high compressive loads, and high tensile loads in the corners.

Thought can be of different low density materials, such as aluminium or composites. Due to the fact composites are lightweight, are currently going through large developments and can withstand high loads, composites are chosen.

Different use of composites is possible, for example can be thought of a single skin laminate. Such a wall will meet the requirements due to the tension loads, but due to the low thickness of a single laminate, the wall will lack stiffness, and not be able to cope with the compressive loads. To withstand the compressive loads additional stiffeners have to be placed, making such a construction very complex. Therefore sandwich structures are commonly used, made of two high strength faces separated by a low density core material.

The type of fibre can be determined with the different important requirements. To withstand the high tensile and compressive loads glass and aramid are not suitable to reach the goal of 100kg. So only carbon fibres are suitable to meet the requirements on strength.

Chosen is for woven fabrics instead of unidirectionals, due to the fact different loads are present in the design, both longitudinal as transverse. Also the low handling sensitivity is of importance to be able to guarantee the strength of the sidewall after fabrication.

Because of the strength requirements epoxies are chosen as the used resin, due to the fact polymers have less strength, but are cheaper. If we look at the epoxies available, a difference in curing

temperature can be distinguished. To be able to cure the sandwich as one piece, a curing temperature below 120°C is preferable. An epoxy is chosen on basis of the properties of the resin, which is self adhesive, cured at 120°C, has a glass transition temperature of 110°C and is suitable for use for large structural components.

Then the choice appears between prepregs (pre fabricated plies) or to make them self by hand layup. But to guarantee the strength of the plies and the required additional tools for hand layup prepregs are chosen. On the other hand prepregs are more expensive.

Because of the need of both strength in the in-plane direction and impact resistance in the out-of-plane direction, a combination of layer directions is chosen. With ±45 plies on the outside, both the shear and impact resistance is increased. The mid-plane plies have to withstand the in-plane loadings, requiring them positioned in the 0/90 direction.

With all face properties determined, the core can be chosen. Because the costs and weight are the two most important requirements, both honeycombs (costs) and balsa wood (weight) are not suitable in the design. The choice for foam causes some additional requirements to the core, because of the temperature the sandwich is cured at and the shear stresses which will be present during use. The Airex C70-foams will be chosen to be able to cure the total sandwich as one part.

To cure the sandwich an process has to be chosen, where hand layup, vacuum bagging and autoclave curing are suitable. For hand layup the equipment costs will be very low, but the sandwich will lack strength due to the process sensitivity. Vacuum bagging needs only a vacuum bag and oven to cure the sandwich. An autoclave will be very expensive, because of the large components to be cured, but will realize the highest strengths possible. Because of the requirements on both costs and strength, vacuum bagging is chosen.

The sandwich has to be fastened to the frame. Common types are the use of inserts or ramp down at the end of the sandwich, which can be mounted to the frame. Due to the preferred balanced load distribution into the sandwich, inserts are chosen.

To fasten the inserts to the frame the use of adhesives and bolts, or a combination, is suitable. Welding isn't possible due to the different metals involved and rivets won't be able to withstand the high tensile loads in the corners. On first hand adhesives are chosen, because of the fact bolts will be difficult to integrate along the whole length of the sidewall.

Also the locks and levers have to be integrated in the sidewall. Because of the core being 15/25mm, and the maximum thickness of 42mm, it is required to have locally a thinner core. Where ramp downs are commonly used to realize thickness variations. To be able to withstand loads, there are some requirements to a ramp down construction. If the corner theta is close to 90 degrees, it is very hard to get load up to the ramp and there is a danger of crushing the core from the edge during cure. If theta is close to zero it is possible to achieve load distribution of 60/40 among face sheets. There will be a large transition region causing low bending stiffness. And handling and cure problems with the core are present due to the core sharp edge.

With these advantages an angle of 18 degrees is optimal (1). But in practice often angels between 20 and 30 degrees are preferred. (2)

With the sandwich properties and mounting methods known the design is controlled if it can withstand the loads occurring from the load cases. From the Ansys modeling done by HCI it appears that only when payload is present, there are loads present in the sidewall. The stacking loadcase has the highest overall loads, together with the sidewall strength load case, these are the critical loadcases.

Within the stacking load case large forces can be found in the transverse-direction located in the hinges. These forces are caused by the bending of the frame to the inside, due to the mass of the containers on top. In the bottom corner hinges large tensile forces can be found. This due to the fact the side beams are assumed to transport the largest part of the loads, which causes tensile forces on the bottom corner hinges.

The sidewall strength load case consists of an applied internal loading is 0,6Pg uniformly distributed over the wall. Which means the load is assumed to rest for 60% to the sidewall, due to ship motions.

To get the exact mechanical properties for the laminate, the composite design software Kolibri (3) is used. This program needs properties of each individual ply to be able to calculate the modules and bending stiffnesses in the different directions. With the output of Kolibri it is possible to determine the bending stiffnesses of the total sandwich.

Summarized, three sandwich design principles are controlled:

1. Sandwich facings shall be at least thick enough to withstand chosen design stresses under design loads.
2. The core shall be thick enough and have sufficient shear rigidity and strength so that overall sandwich buckling, excessive deflection, and shear failure will not occur under design loads.
3. The core shall have high enough modules of elasticity, and the sandwich shall have great enough flat wise tensile and compressive strength so that wrinkling of either facing will not occur under design-loads.

The final weight is more than the desired 100kg. Where can be concluded large savings can't be found in the face sheet and core design, due to the fact they are taken as starting point of the design. To reduce the weight further, there can be thought of a modified top beam, which will reduce the weight further. On the other hand, the existing corrugation used weighs over 450kg, so a reduction over 80 percent is realized. Also can be thought of other designs of the frame, existing of the bottom beam and the top beam which are unchanged in the current new design. Possibly the top beam can be made less high, which also realizes a reduction of a few kilos.

Also the material costs can be determined, with a weight of 55kg for the faces and 20kg for the core, the price of the faces (including resin) is about 1100 euro and the price of the foam core is about 200 euro with a price of about 10 euro/m^2(4) with an area of 12m by 2m = 24m^2. The steel sidewall sheets consists of about 500kg of steel, which means a price of about 800 euro when made of standard steel. Also the price of the raising mechanism has to be taken into account in this comparison, which is assumed to be about 300 euro. If we compare the material costs of both designs, the material costs of the lightweight design will be about 1300 euro. And the costs of the steel version will be about 1100 euro.

The impact resistance of the sandwich will be important, due to the fact little damages will occur due to the load handling with forklifts. The impact resistance can be increased by more extensive or total replacement of the crushable core. A polyurethane core, or one made of a similar material capable of large elastic deformations at high strain rates appear to be suitable candidates. On the contrary a polyurethane core has a higher density and will be much more expensive, compared to the normally applied polymer foams.

Also moisture absorption will cause degradation of the sidewall. Some conclusions from other research are for example the fact well-satured epoxy/Kevlar laminates have 15-20% lower flexural properties. While epoxy/carbon fiber laminates show a tensile strength of approximately 20% lower, compared to dry samples. To protect the core from water ingress, the minimum thickness should be 0,5-0,6mm to keep moisture from seeping into the structure. Otherwise protective coating will be required.

Also Ultraviolet light plays a role, because epoxies are generally very sensitive to ultraviolet (UV) light and if exposed to UV rays for any significant period of time the resins will degrade to the point where they have little, if any, strength left to them. Vinyl esters are also very sensitive to UV and will degredate with time, although in general not as rapidly as an epoxy. Polyester, although being somewhat sensitive to UV degradation, is the least sensitive of the three to UV light. To prevent the laminates from degradation, gel coats can be used. In that case an UV screen is added to protect the resin, although for most gel coats the pigment itself serves as the UV protector.