Abstract

Sandwich structures have acquired an important position in current lightweight construction in recent years. They are mainly and successfully used in aerospace, vehicle construction, shipbuilding and other transport applications. Sandwich panels consist of a thick, lightweight core bonded to an upper and a lower thin and stiff face sheet. Sandwich structures are characterised by high bending strength and stiffness to weight ratio. The stiff and strong face sheets are used to carry the in-plane stresses while the core is used to carry the shear stresses produced by transverse loads. Therefore, a sandwich construction is especially suitable for applications subject to bending and in-plane compression loads. There are however common disadvantages to introducing forces or moments into sandwich structures, caused by a combination of the thin face sheets and the weak core material. The face sheets, as well as the core material, might break due to the complex three dimensional stress conditions in the area of the load introduction. In order to distribute these local forces, it is necessary to utilise special load introduction concepts, following specific design guidelines with regard to the mechanical, material and manufacturing requirements. There are already a couple of different load introduction concepts for sandwich structures. But all these conventional load introduction types are characterised by non-uniform loading of the different sandwich components so that the potential of a load introduction is limited by the weakest component.

At first a study of conventional load introductions according to the state of the art were carried out. As a result of this analysis it can be shown that the failure mode and mechanical behaviour of these load introductions can be quite different. Due to the non-uniform loading of the different sandwich components conventional load introductions fail because of local stability problems of the thin face sheets as a result of the weak core material, core failure due to high stress concentration in conjunction with low strength property, cohesive or adhesive failure of the bonding of the load introduction element, debonding between face sheet and core material as well as premature failure of one of both face sheets. Therefore, the current load introduction concepts are not optimal.

That is why, new kinds of „through-the-thickness“ reinforced load introductions, so called IDAK, as well as a suitable manufacturing process are developed in this thesis. A couple of especially suitable reinforced force transmission concepts have been

chosen from the great variety of available IDAK concepts for further investigation. For each of the selected reinforced concepts, a comparable conventional load introduction was manufactured, in order to perform a comparison of the mechanical properties to new IDAK concepts. Circular sandwich panels including a central load introduction are used as test specimens for the experimental study. The new IDAK concepts are characterised by insertion of „through-the-thickness“ reinforcements in the area of the centralised load introduction. Threads are used as reinforcements, which are inserted into the non-resin impregnated sandwich structure using a conventional sewing machine. The modified, double locked stitch with the loop in the lower face sheet is used as stitching type. The needle inserts the upper thread into the sandwich structure and creates a hole in the used polymer foam. During the stitching process, the upper thread makes a loop with the bobbin thread on the lower side of the sandwich panel. As a result of this the sandwich components and, if necessary, the used load introduction element itself, are joined.
As a part of this process, the double locked stitch sewing machine located at IVW was modified, suitable geometries of seams were developed and programmed into the machine, as well as an analysis of the multiple sewing machine parameters was carried out to achieve a good quality of the reinforcements. Furthermore a couple of parameter studies were carried out to determine the influences of different stitched and unstitched load introduction concepts, the geometry of the seam, the density of the reinforcements and the used thread material, with regard to the mechanical properties for each load introduction concept. On completion of the sewing process, the sandwich structure is impregnated with resin using a liquid composite moulding (LCM) process. After the curing process the impregnated threads can be seen as unidirectional fibre reinforced plastic bars within the core material, which increase not only the mechanical properties of the core material, but also of the complete sandwich structure and, especially, of the load introduction.
Quasi-static tension as well as a compression test facilities were developed to determine the mechanical properties perpendicular to the load introduction. Besides destructive and non-destructive tests (ultrasonic) were carried out to investigate the failure behaviour and mode of the load introduction. The results of the tensile and compression tests have proved that the compression and tensile strength, compression and tensile stiffness, the transverse shear strength, the peel resistance between

the face sheets and the core material, as well as the ability to absorb the fracture energy are all superior in the stitched load introductions in comparison to conventional ones. Furthermore, the IDAK concepts are characterised by a good fail-safe behaviour, as a result of the higher peel-strength and the „crack-stop-function” of the threads.

An analytical approach considering as example taken form of one special IDAK load introduction concept was developed to determine the pull-out force depending on the density of reinforcements.

In addition stitched and unstitched load introductions were analysed with the aid of the finite element method. Due to this analysis the experimental test results could be validated and the cause of the improved mechanical properties of the stitched load introduction was detected. The necessary material properties of the reinforcements, that would be necessary to perform a finite element analysis, were calculated with developed micro-mechanical models of approach.

Finally, the established results along the complete value-added chain of the new „through-the-thickness“ load introduction concepts were used to set up manufacturing and design guidelines.

The projected manufacturing process to reinforce load introductions of sandwich structures consisting of textile face sheet material and a polymer foam core can be integrated in existent preform-/LCM-processes easily.