New thermoplastic composite design concepts and their automated manufacture

Thermoplastic composites have inherent properties that make them ideally suited for low-weight, low-cost aerospace structures. These composites boast high toughness, reprocessability and excellent fire safety performance.

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Steps are currently being taken to move towards large primary structures, e.g. integrally-stiffened skin panels. New materials, innovative design concepts and aeronautics are key innovation factors.

Thermoplastic composites in aerospace to date

Thermoplastic composites are of growing interest in the aerospace sector because of their inherent properties. Their high toughness results in low-weight designs. The physical process only involves melting without a curing cycle, which results in fast and robust processing. Their excellent FST (fire, smoke and toxicity) properties and recyclability are also advantageous. Airbus recently teamed up with a Dutch cluster on the TAPAS project. An international research centre for thermoplastic composites, called TPRC, was also founded in the Netherlands in 2009.

Currently, a growing number of thermoplastic composite parts and assemblies can be found in state-of-the-art aircraft. Examples include multi-ribs concepts in many aircraft programmes and welded fixed wing leading edges for the A380 (Fig. 1) made from Ten Cate's glass/PPS.

Fig. 1:Welded fixed wing leading edge on an A380 wing (photo courtesy Airbus)

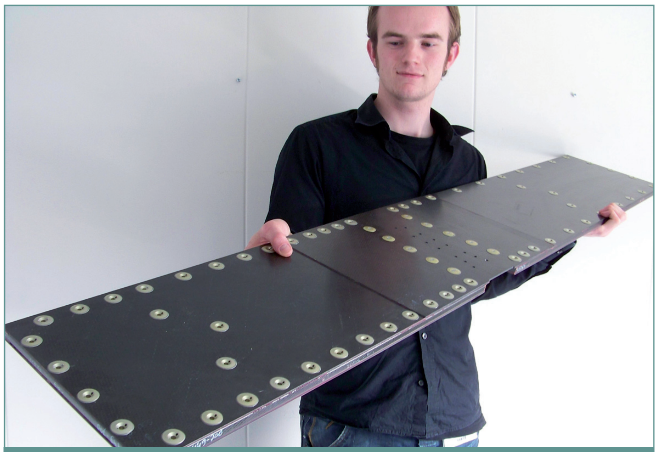

Fig. 2: Gulfstream G550 and G650 pressure bulkhead floor panel

Thermoplastic composite primary structures are an area where inroads have been made in the past. The pressure bulkhead floors of the Gulfstream 550 and G650 aircraft (Fig. 2) are a series of structurally-bonded carbon/PEI sandwich structures with press-formed stiffeners.

Airbus produces the cockpit floor of the A400M in thermoplastic composite.Recently, steps have been made to move towards welded primary control surfaces. The rudder and elevators of the new Gulfstream G650 business jet (JEC 2010 Innovation Award winner) are induction-welded multi-rib torsion box structures (Fig. 3).

Fig. 3: Welded Gulfstream G650 thermoplastic rudder

Induction welding, a technology researched by Dutch specialist KVE Composites Group, was industrialized by Fokker Aerostructures (Fig. 4).

Fig. 4: Induction welding of Gulfstream G650 rudder and elevators

The carbon/PPS (Ten Cate Advanced Composites) multi-rib design is 10% lighter and 20% cheaper than its carbon/epoxy sandwich design predecessor. Replacing adhesive bonding and bolts by welding is an important cost reduction factor, as are the press-forming of ribs and the ease of layup/consolidation for skins and spars.

Development of an integrally-stiffened thermoplastic skin concept

Fig. 5: Thermoplastic floor beam

In 2003, an airliner floor beam (Fig. 5) was developed in carbon/PEKK UD tape (Cytec). This high-build-rate product is suited for aeronautics, so that pick & place was chosen as the layup method for web and cap preforms. These are then melted together in a process called co-consolidation. During the development of the I-beam shaped component, a method was sought to simplify the manufacture of large numbers of stiffening ribs. The solution was to 'butt joint' a flat laminate by co-consolidating it with the basic I-beam (Fig. 6).

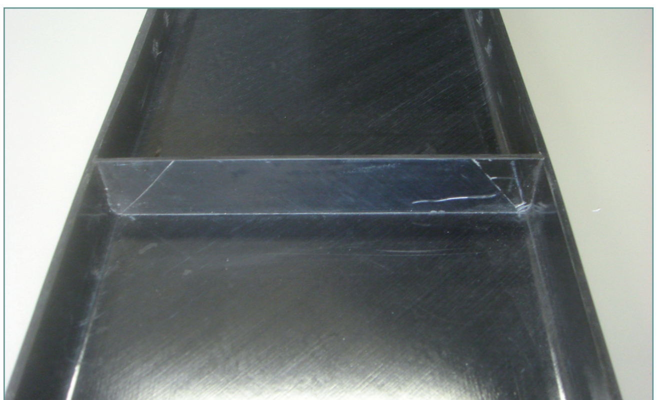

Fig. 6: Butt-jointed stiffening rib

This proved an effective solution, much simpler to manufacture than the initial design with press-formed stiffeners. The butt joint strength was subsequently optimized by adding a radius using an injection-moulded filler (Fig. 7).

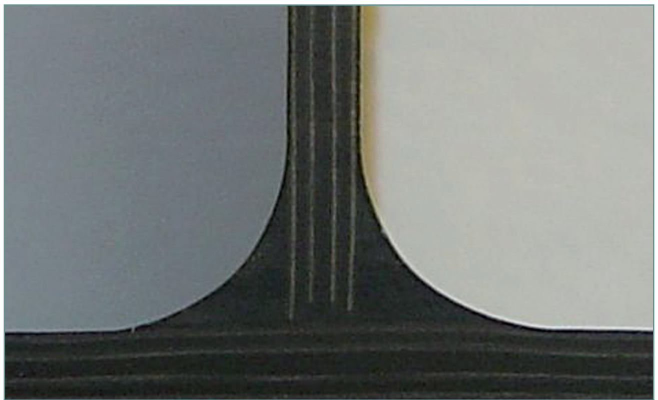

Fig. 7: Butt joint with radius filler

The development of the butt joint system opened a whole new range of opportunities for innovative design, such as a sine wave beam (Fig. 8), which normally is not easy to achieve in composites. Another design that sprung from the butt joint concept was an integrally-stiffened skin panel.

Fig. 8: Butt jointed sine wave beam

T-stiffeners are made from flat preforms and co-consolidated with a skin. The panel concept was developed and tested successfully in shear and compression together with the Dutch National Aerospace Laboratory in 2008 (Fig. 9).

Large thermoplastic primary structures

The Dutch industry, institutes and Airbus have been cooperating in the area of thermoplastics since 2005. This cooperation was intensified in 2009. Approached by Airbus, the Dutch Ministry of Economic Affairs initiated a cluster of Dutch companies and institutes. They joined forces with

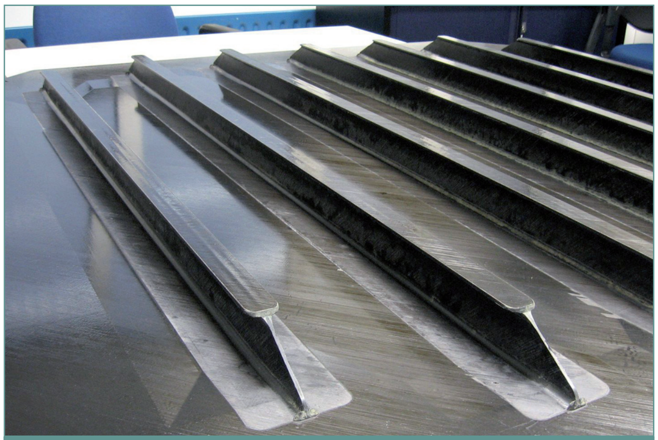

Fig. 9: Skin panel with integral butt joined T-stringers

Airbus and launched a 4-year project called TAPAS: Thermoplastic Affordable Primary Aircraft Structure.
The goal of the TAPAS project is to create the thermoplastic composite technology necessary to produce large primary structures for future aircraft programmes. Materials, manufacturing processes, design concepts and tools must be developed to a technology-readiness level (TRL) 6. Full-scale demonstrator products are being developed as part of this effort. The technological challenges include: development and qualification of suitable materials, the butt joint, and manufacturing technologies such as fibre welding, press forming and fibre placement.
Partners in the TAPAS project are Airbus, Fokker Aerostructures, Ten Cate Advanced Composites, Airborne Technology Center, KVE Composites Group, DTC, Technobis Fibre Technologies, Technical University Delft and the University of Twente. The Dutch National Aerospace Laboratory carries out related research projects and testing programmes in parallel.

Ultrasonic fibre placement

Fibre placement is the lay-up technology of choice for large surface area products with a double curvature. The currently available fibre placement equipment uses different heating systems, such as hot gas and laser. In 2008, Fokker Aerostructures started to look for suitable fibre placement equipment. Unfortunately, a chicken-and-egg situation arose in which serious investment was needed upfront whereas the production volume was still some time away for customers. In this context, ultrasonics appeared to be a good option for the heating source at a relatively low-cost.
Fokker Aerostructures has a long history of ultrasonic spot welding experience, such as welding injection moulded parts to thermoplastic plate components. Moreover, the layup of A380 fixed wing leading edge skins is done by ultrasonic spot welding (Fig. 10). Ultrasonic welding is a well-established, low-cost welding process.

Fig. 10: Ultrasonic welding, A380 J-nose skin

Although continuous ultrasonic welding of plates onto plates had proved difficult in the past, it seemed feasible to ultrasonically weld a thin carbon/UD tape onto a stack of UD tapes. To this end, ultrasonic welding units were integrated into a fibre placement head mounted on a robot (Fig. 11).

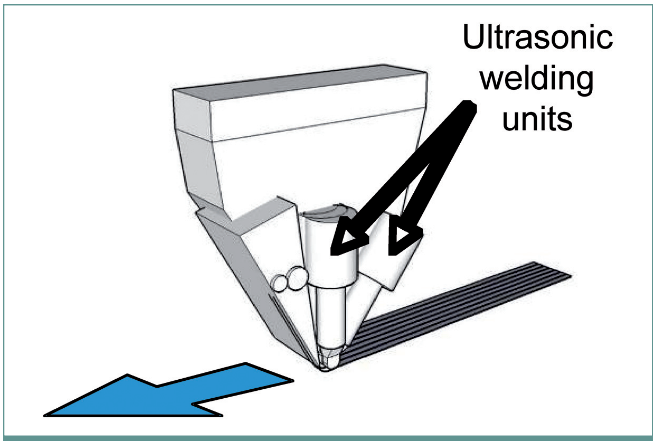

Fig. 11: Ultrasonic fibre placement head

The initial trials – welding 10-mm-wide carbon/PEKK UD strips by hand – were successful. The next step was to weld on a linear rail. By mid-2009, a 2x1x1 metre 3D R&D fibre

More information

Fokker Aerostructures designs, develops and produces lightweight aerostructures for the aerospace and defence industry. Customers include Airbus, Boeing, Lockheed Martin, Gulfstream, Dassault, Pratt & Whitney and Dutch Space. With their cost efficiency and environmental advantages, thermoplastic composites are a key technology for Fokker. The company's participation and co-operation in innovation networks together with customers, knowledge institutes and suppliers contributes to the continuous development of these materials.

Fig. 12: Butt jointed sine wave beam

placement cell with a single 10 mm-wide strip was built by Dutch aeronautics specialist Boikon. The UD strips were melted over a small portion of strip width, enough to affix the tape. With ultrasonic fibre placement, the challenge was to succeed in tacking a tape onto an underlying thick stack of plies at high speed, without slowing down the process and thus making it ineffective.

A new fixed wing leading edge concept was laid up with the fibre placement cell (Fig. 12).

The product development process, which started as an internal Fokker product improvement exercise, is now a part of a European Framework project called COALESCE (Cost Efficient Advanced Leading Edge Structure).

Fig. 13: Flat rib preforms

The new leading edge is a multi-rib thin skin design. The ribs are flat plate preforms (Fig. 13) which are butt joined to the skin during melting (co-consolidation) of the product.

The skin is fibre placed over a positive tool (Fig. 12). Two parts are manufactured simultaneously. The layup is covered by a caul plate, vacuum bagged and co-consolidated. One of the resulting parts is shown in Figure 14.

7-m torsion box demonstrator product

Fig. 14: Co-consolidated wing leading edge

A double-curved, 7-m-long torsion box demonstrator product is being developed as part of the TAPAS project. It will be built and tested in 2011. The product is a redesign of the central portion of the Gulfstream 650 horizontal tail (Fig. 15). Its skin will feature integrally butt joined T-stiffeners.

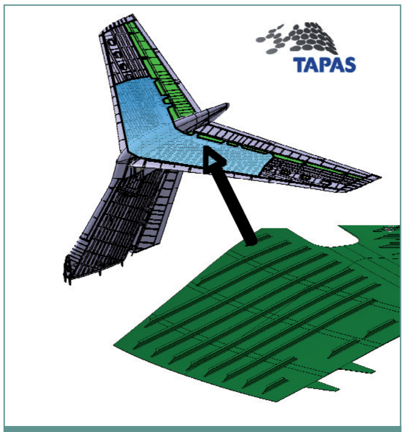

Fig. 15: TAPAS skin with integrated stiffeners drawn over full-size horizontal tail

Research is ongoing to determine if out-of-autoclave manufacturing is feasible.

Fibre placement is the preferred layup technology for minimizing material waste during the layup process.

A dedicated fibre placement cell will be used for skin layup. The cell will be programmed with CGTech's Vericut Composite Programming module, which links the CATIA design to the robot software. The cell can be expanded at modest investment for series production of 12-m full-span skin panels (Fig. 16).

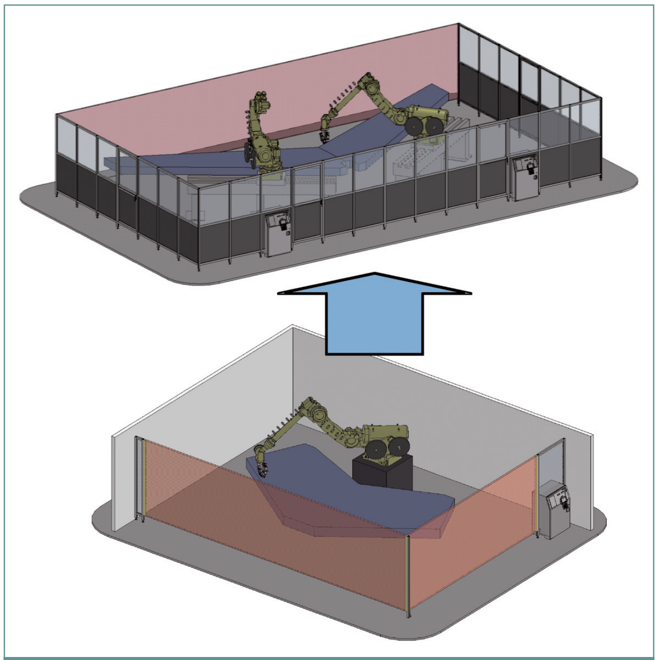

Fig. 16: Fibre placement R&D cell and production cell

This equipment approach is typical of the current trend towards part-centred aeronautics. A machine is tailored to the product concerned: size and shape, layup and build rate. The required material lay-down rates are achieved at minimum investment. Companies such as Accudyne Systems cater to this trend.

Other technologies being investigated in the TAPAS project are innovative press forming systems (by Dutch specialist DTC) for ribs and stiffeners, and the welding (KVE Composites Group) of stiffeners. Structural health monitoring with high sampling rate computerized analysis technology (Technobis Fiber Technologies) is also being developed and will be tested on the torsion box demonstrator.

In parallel, Airbus is incorporating these technologies in a fuselage structure demonstrator. The Technical Universities of Delft and Twente are conducting long-term research in the area of process modelling and design optimization.

Building the business case, growth potential

So far, applications have been created by a sound business case, combining a low-weight solution with affordable cost. The business case for large primary structures made of thermoplastics also needs to be proved. Cost and weight comparisons with other technologies, such as modern alloys and state-of-the-art thermoset solutions, are currently being made.

A weight reduction in comparison with thermoset composites is envisaged because of the toughness of thermoplastics. Excellent fire, smoke and toxicity properties also add to the equation. Recurring cost reductions are achieved through high-speed processing, simple design concepts such as the butt joint, and affordable materials.The growth potential with thermoplastics is large.

For example, if the advantages of high toughness, low processing cost and excellent fire safety make thermoplastic composites the material of choice for future airliner fuselage structures, the volume for thermoplastic composites will be huge. ■

More information:
www.fokkeraerostructures.com
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