DEfcodoor
Development of an Eco-Friendly Final Consolidation Step Using Thermoplastic Fibre Placement for a Helicopter Door

**Background/ State of the art**
In terms of the environmental impact of manufacturing products for the aircraft industry, the aim is to reduce inputs (raw materials, energy, water, etc.), emissions and harmful environmental effects throughout the life cycle. The manufacturing technology currently used for helicopter doors is to manually lay down pre-impregnated sheets (prepregs) in the required fibre direction. The subsequent curing of the carbon fibre-reinforced thermosets is performed in an autoclave. This highly energy-intensive process and the noxious effects of curing thermosets require more eco-friendly solutions. If this procedure is replaced with Thermoplastic Fibre Placement (TFP) with a thermoforming step in between, the time- and energy-consuming autoclave process could be abandoned. In addition, faster cycle times can be achieved without the use of an autoclave.

With the use of thermoplastics, the potential for recyclability can be exploited in favour of a better environmental balance. The crucial benefit of TFP is the possibility of in-situ consolidation that eliminates the need for bonding, welding, riveting or other joining technologies. Consolidating in-situ involves a laser providing the required energy input for melting the thermoplastic matrix while a consolidation roller ensures that the different tape layers are consolidated at the same time.

**Objectives**
The main objective is to achieve cost and weight reduction by using economical as well as eco-friendly (“ecolonomic”) materials. Using laser-assisted TFP, customised laminates with improved mechanical properties can be produced in a single step by locally adding tapes according to the load paths. Thus, weight and scrap can be reduced as well as costs. The goal is to reduce scrap by 15%. By means of in-situ consolidation no extra weight is gained comparing to mechanical fasteners. Additionally, costs for bagging and consumables can be reduced if the autoclave process is eliminated by simultaneously guaranteeing a high quality of composite products.

**Description of work**
**Material selection**
A thermoplastic matrix material suitable for aircraft applications had to be selected. Therefore, a trade-off between performance, availability and costs was made. Polyethersulphone (PES) was selected; an amorphous high-performance thermoplastic. The chosen thermoplastic material is commonly reinforced with AS4 fibres and is available in the form of unidirectionally pre-impregnated tapes (AS4/PES).

**TFP process – relevant process parameters**
Using the selected material, the T-Peel test method was modified to enable fast manufacture and testing of a number of coupons with parameter variations. The process parameters ‘placement speed’ and ‘nip point temperature’ at the focal spot were found to be strongly influencing the laminate quality. ‘Tape tension’ and ‘consolidation pressure’ showed effects on the tape placement accuracy. Residual stresses could be decreased by heating the tool on which the coupons are placed.

**Material properties on coupon level**
After evaluation of the test results, an optimum parameter set was obtained and used for the determination of mechanical properties of AS4/PES tapes. In addition, the influence of post-consolidation steps in an autoclave as well as in a press was investigated. In reference to in-situ fibre-placed specimens an increase in shear properties of 22% in the case of an autoclave post-consolidation and 16% for specimens post-consolidated in a press were observed. The increase is explained by a decrease in thickness of post-consolidated specimens leading to an increase in fibre volume content. The high pressures applied during the post-consolidation steps were sufficient to remove any entrapped air within the tape material. No additional intralaminar voids were generated during fibre placement. It is expected that material properties of fibre-placed laminates will be enhanced once improved tape materials are available.

**Demonstrators**
The obtained tensile, compressive and shear properties served as input for the design of demonstrators. The demonstrators comprise an increasing level of complexity. The approach within the DEfcodoor project is shown in Figure 1.
**DEfcodoor process description**

The manufacture of all demonstrators consisting of stiffener and skin for helicopter applications follows the principle of the DEfcodoor process. Customised laminates are manufactured by using laser-assisted TFP and are then thermoformed into three-dimensional profiles. After insertion of a pre-cast core a skin laminate is joined in-situ to the thermoformed stiffener by TFP during the in-situ joining process. The soluble core is removed and an in-situ joined part is obtained. The manufacturing steps of the DEfcodoor process are shown in Figure 2.

By application of the optimum parameter set for the in-situ placement process, flat laminates were manufactured. These laminates were subsequently thermoformed in a press by using matched-metal tooling. The quality of the fibre-placed laminates was evaluated visually and by ultrasonic inspection. The quality was strongly dependent on the tape material used. The better the spool quality the more accurate the tape placement process was and the better the resulting laminate quality.

**Development of the in-situ joining process**

A procedure to manufacture cores matching the hollow of the thermoformed stiffener with high dimensional accuracy was developed. The core material used was Aquapour®, selected due to its high compressive strength and temperature stability as the core material needs to withstand the consolidation pressure and high processing temperatures during fibre placement.

**To enable fibre placement on top of the thermoformed stiffener, a tooling concept was developed and implemented as shown in Figure 3.**

**Figure 1. Approach within the project.**

**Figure 2. Principle of the DEfcodoor process.**

**Figure 3. Tooling concept for the demonstrator production using the DEfcodoor process.**

The concept consisted of an arrangement of aluminium profiles. The set-up was covered with an aluminium sheet with a recess area for the thermoformed stiffener to overcome the step formed by the thickness of the stiffener. During development of the in-situ joining process it was discovered that the process conditions for the in-situ placement differ from the ones for the in-situ joining. Normally, an infra-red camera, mounted to the TFP head, measures the temperature at the focal spot and adjusts the laser power and the angle of the laser optics. As the focal spot of rectangular dimensions was almost as large as the width of the demonstrators a correct temperature regulation is not enabled. Thus, the laser power and the optics angle were set to constant values. A test set-up was developed which enables the manufacturing of short beam shear test specimens close to reality. After evaluation of variations of laser power, optics angle and tooling temperature, an optimum parameter set was obtained and applied to the first demonstrator, the in-situ article. Several demonstrators could be joined successfully. After change of the empty spool, the application of the same process conditions led to different heat distribution on the incoming tape and the substrate. Process- and material-related reasons for the lack of reproducibility of the in-situ joining were investigated.

The combination of constant parameter settings and high variability in tape quality do not enable a reproducible process.

**Manufacture of the feasibility article**

The feasibility article was derived from the highest loaded area of the current helicopter door of EC 135. The complex, double-curved structure of the feasibility article required the development of fibre placement strategies in order to maintain the fibre orientations at each position of the curved demonstrator. Two laminate types were manufactured. The first type was commonly fibre-placed by employing 1 inch AS4/PES tapes for...
means of comparison. The second laminate type comprised steering of 0° plies along the curvature of the feasibility article by using ¼ inch tapes shown in Figure 4.

Figure 4. Commonly fibre-placed laminate (a.), steering of 0° plies (b.) along the curvature of the feasibility article during TFP.

After thermoforming of fibre-steered laminates less wrinkles and a better retention of the fibre orientation was detected in comparison to non-steered laminates. However, a significant influence on the formation of wrinkles can be attributed to the positioning of the pre-heated laminates in the press just before thermoforming. Figure 5 compares the results of thermoforming fibre-steered and non-steered laminates.

Figure 5. Feasibility article stiffeners after thermoforming laminates with steered 0° plies (a.)) and non-steered laminates (b.).

a) Results
The aim of the DEfcodoor project was to demonstrate the feasibility of the developed process for a helicopter door through the use of TFP and thermoforming. The first step was to manufacture the feasibility article - the fibre placement of laminates as well as the thermoforming of the fibre-placed laminates could be demonstrated well. However, the variability in the tape quality prohibited the development of a reproducible process for the joining of skin plies to the thermoformed stiffener by using AS4/PES tapes. The DEfcodoor consortium manufactured additional subcomponent demonstrators with another tape material, carbon fibre-reinforced polyphenylene sulphide (CF/PPS) tapes. In contrast to AS4/PES tapes, the demonstrators were joined in-situ in a stable and reproducible way by using CF/PPS tapes. Micrographs of the joint show no difference to the remaining laminate and indicate an excellent bond quality as shown in Figure 6.

b) Timeline & main milestones
The DEfcodoor consortium consists of Dutch Thermoplastic Components (DTC), Advanced Fibre Placement Technology (AFPT) as well as the Technische Universität München (TUM). The TUM, specifically the Institute for Carbon Composites (LCC), is the consortium’s leader. Airbus Helicopters Deutschland GmbH initiated the DEfcodoor project and represented the industrial partner of the consortium.

The DEfcodoor project started in September 2011 and ended in July 2013 after an extension of five months. The extension was necessary due to difficulties in delivery of the originally-preferred tape material as well as by the delay in installation of fibre placement equipment at the TUM. The project duration was 23 months.

There were three milestones in total. By the end of May 2012, the material properties on coupon level were gained and the design of the feasibility article was fixed. Due to issues with the tape material quality prohibiting a reproducible in-situ joining process, mechanical testing of the subcomponent was not feasible. During the production of the feasibility article, the input data for the life cycle assessment of the DEfcodoor process were collected. After the manufacture of the feasibility article visual and microscopic examination of the demonstrators were conducted in terms of validation.

c) Environmental benefits
The scrap rate could be decreased by 10% with respect to the current manufacturing process of the helicopter door by utilising thermoset prepggs. With increasing advancement in the fibre placement equipment further reductions in scrap should be possible.

The energy-intensive autoclave process can be eliminated once improved tape material is available enhancing the quality of fibre-placed laminates.

Using the DEfcodoor process, the demonstrators consist of one thermoplastic matrix material only and additional joining equipment (e.g. adhesive) is not required, the recyclability is considerably increased in relation to the current manufacturing process.
Project Summary

Acronym: DEfcodoor

Name of proposal: Development of an Eco-friendly final consolidation step using Thermoplastic Fibre Placement for a helicopter door

Technical domain: Thermoplastic Fibre Placement

Involved ITD
  Green Rotorcraft
  Eco-Design for Rotorcraft

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Starting date: September 2011

Ending date: July 2013

Duration: 23 months

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