LIQUID COMPOSITE MOULDING – ENABLER FOR THE AUTOMATED PRODUCTION OF CFRP AIRCRAFT COMPONENTS

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Abstract

Airbus' mission is to meet the needs of airlines and operators by producing the most modern 100+ passenger aircraft on the market. One well-proven approach for the realisation of high-performance light-weight structures is the application of carbon fibre-reinforced plastics (CFRP), offering the costumer the benefit of low energy consumption when operating the aircraft.
For the production of CFRP aircraft components Liquid Composite Moulding (LCM) processes are of major importance as an economic production of highly integrated and complex-shaped parts can be realised. One major challenge for the further development of LCM processes is the automation of the process steps.

1. Introduction

The latest Airbus Global Market Forecast for 2012-2031 offers a forward-looking view of the air transport sector's evolution, taking into account drivers and factors such as population growth, urbanisation, emerging markets, innovation and environmental impact. During this period, Airbus foresees the need for some 27.300 passenger aircrafts with seating capacities of 100 seats and above, along with nearly 900 new factory-built freighter aircrafts. The Global Market Forecast also anticipates more than a doubling of the world's overall passenger aircraft inventory, from 15.000 today to more than 32.500 by 2031. [1]

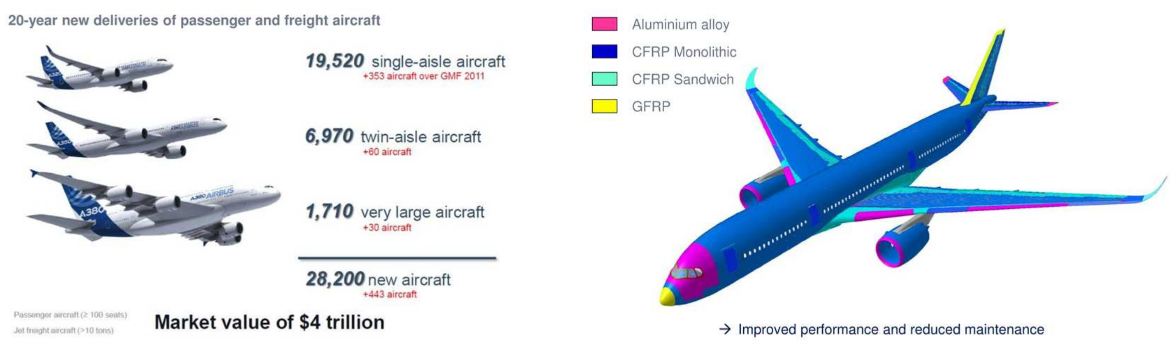

Figure 1. *Left*: 20-year demand for 28.200 new passenger and freight aircraft [2], *Right*: A350 XWB composite applications [3]

At the same time, it is expected that the world's leading aircraft manufacturers will face an increasing competition, e.g. due to new competitors entering the market. Taking these boundary conditions into account aircrafts need to be manufactured in the most economic way, offering the costumer an excellent price-performance ratio. Furthermore, the products need to fulfil the demands for the lowest possible fuel consumption and simultaneously for an increased seating capacity. Regarding the production of aircraft components, the realisation of light-weight approaches is required. Possible technical solutions are the development of alternative part designs or new material concepts or a clever synergy of both.

One proven approach is the application of fibre-reinforced plastics (composites), particularly the use of carbon fibre-reinforced plastics (CFRP). Parts made of fibre-reinforced plastics are characterised by excellent weight-specific mechanical properties. Furthermore, composites offer the freedom of design, the potential to produce highly integrated structures and very good resistance against environmental influences.

In modern civil aircrafts like the Airbus A350 XWB 53 % of the structural weight consists of components produced with composites [4] (Figure 1, right). Examples for major components realised with a significant content of CFRP are the fuselage, the wings as well as the vertical and the horizontal tail plane.

2. Liquid Composite Moulding

Today, the production of structural composite parts with thermoset matrices is realised by a great variety of manufacturing processes [5]. Composites with maximum mechanical properties which are required for aircraft components are often produced with prepreg materials out of epoxy matrices and carbon fibres. Commonly, these are placed and draped onto a mould and cured in an autoclave [6]. The applied prepreg materials ensure a high and constant fibre volume content as well as a good impregnation of the reinforcement fibres leading to a high part quality and thus to excellent mechanical properties.

For the production of structural components with a very complex design (e.g. multi-curved geometry, H-shapes, small radii, undercuts) Liquid Composite Moulding (LCM) processes offer a great potential for an efficient production.

In LCM processes dry fibre reinforcements are used as basic material. In a first step, the reinforcements are processed to near-net-shaped preforms according to the intended lay-up of the laminate. The geometry of the preform equals the final geometry of the part. In a second production step, the preform is placed into a mould and impregnated with a liquid resin system. For the realisation of very high mechanical properties epoxy resin systems are used. After the impregnation, the resin system is cured in the mould, usually by applying heat in order to accelerate the curing process.

LCM processes can be carried out in a very economical way as the basic materials used are significantly less expensive than prepreg materials. In most cases, no conditioned storage and processing of the reinforcement textiles are required. Due to the possibility of combining a large range of fibre reinforcements with different resin types a wide spectrum of part properties can be covered. Complex laminate lay-ups can be realised by modern preforming manufacturing technologies.

Generally, LCM processes are divided into two main process groups based on the principle of impregnating the fibre reinforcement with resin. These are designated as Resin Infusion (RI) and Resin Transfer Moulding (RTM) processes.

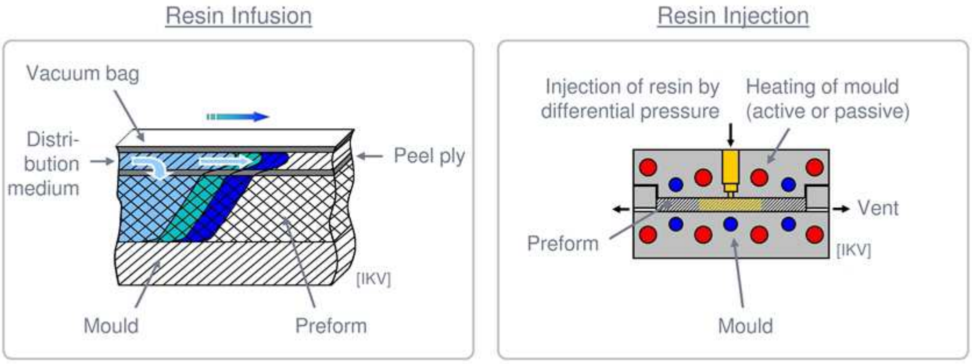

Figure 2. *Left*: Principle of Resin Infusion (RI), *Right*: Principle of Resin Transfer Moulding (RTM) [7]

Resin Infusion (RI) processes are characterised by an impregnation of the fibre reinforcement that is driven by the application of vacuum to the set-up. As a consequence the maximum differential pressure usable for the impregnation of the fibre reinforcement is 1 bar. Resin Infusion (RI) processes are commonly used to produce large parts with a thermoset matrix in a very economic way as only a one-sided rigid mould is used. Thus, the investment in tooling is comparatively little.

The textile preform is placed onto the mould, covered with a vacuum bag and sealed with tape. For the fast impregnation of the fibre reinforcement a distribution medium with a high permeability is used. Thereby, the resin is distributed very quickly within the medium and the impregnation of the reinforcement has to be realised only in thickness direction of the reinforcement. For an easy separation of the part from the vacuum bag and activation of the surface a peel ply is placed between fibre reinforcement and the other ancillary materials.

When using the *Resin Transfer Moulding* (RTM) process, the impregnation of the preform is realised by the application of pressure. Compared to the Resin Infusion process stiff moulds are used offering the possibility to apply a differential pressure > 1 bar. Thereby, the impregnation quality and thus the laminate quality can be improved.

For the RTM part manufacturing a prepared net-shape preform is inserted into the cavity of a rigid mould, similar to a mould which is used in injection moulding. By closing the cavity the preform is compressed to the final fibre volume content. For the impregnation of the preform, the resin is injected into the cavity through one or more injection gates. After the preform is completely impregnated, the part is cured at the required temperature and demoulded. The essential advantage of the RTM process with regard to the serial manufacturing of composite parts is that the process can be well automated.

3. CFRP components produced by LCM at Airbus

Within Airbus, high-performance CFRP parts are produced for more than 20 years, also applying LCM processes. Today, the production of aircraft components by LCM processes within Airbus is concentrated in three plants which are located in Getafe (Spain), Nantes (France) and Stade (Germany). Per year, significantly more than 10.000 parts are produced using LCM technology and the trend is increasing. The parts produced vary significantly in size, geometric complexity and laminate thickness. CFRP components for all civil aircraft programmes (Single Aisle, Long Range, Large Aircraft A380, A350 XWB) are produced by these production technologies. Subsequently, the process chains for the production of components by RI as well as for the production of components by RTM are discussed.

3.1. Resin Infusion (RI)

An example for the application of the Resin Infusion process is the production of angles for the keel beam of the A350 XWB. A part with a length of approx. 4,5 m is produced in a single infusion step.

Figure 3. Angles for A350 XWB keel beam, produced in Nantes [Source: Airbus]

The main process steps for the production of the part are cutting of plies, preforming, setup of vacuum bag, infusion of resin and curing. Subsequently, the part is demoulded, deburred and cleaned. Final process steps are the control of the part quality and trimming, if required.

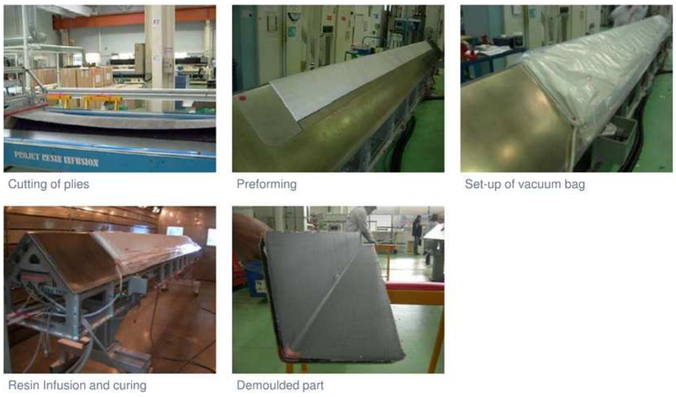

Figure 4. Process chain for the production of a CFRP part by Resin Infusion [Source: Airbus]

The main benefits of RI processes are:

- The production of parts with almost any size is possible, in particular the production of large-surface parts. There are only very low limitations in terms of geometric complexity and laminate thicknesses.
- Parts with a high level of integration can be produced which leads to a significant cost reduction in the subsequent assembly steps.
- The lead time of the infusion process is short as the impregnation of the preform is realised into thickness direction of the reinforcement.
- For the curing of the part no autoclave is required. By the use of ovens or self-heated tools high heating and/or cooling rates can be realised.

3.2. Resin Transfer Moulding (RTM)

Examples for the application of the Resin Transfer Moulding (RTM) process are the production of a door surround frame for the maintenance door in Section 19 of the A350 XWB with a length of about 3 m or of fittings for the A320 Vertical Tail Plane (VTP).

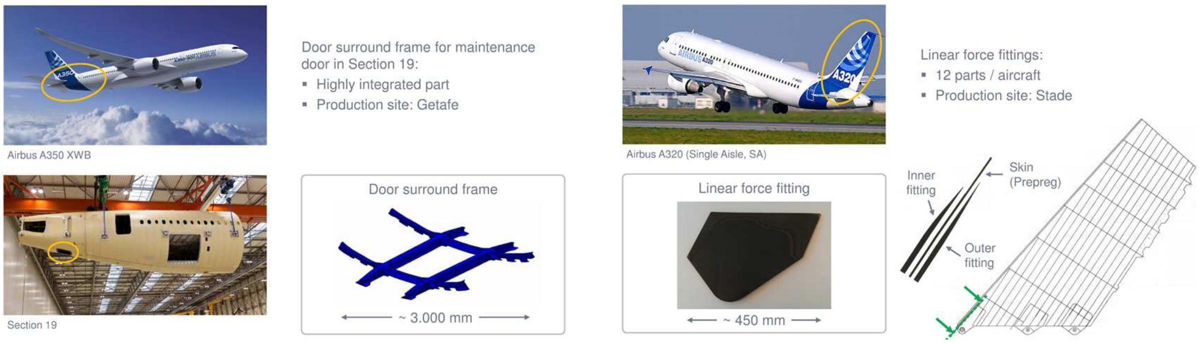

Figure 5. *Left*: Door surround frame for Section 19 of the A350 XWB, produced in Getafe [Source: Airbus], *Right*: VTP fittings, produced in Stade [Source: Airbus]

To illustrate the production of CFRP components by Resin Transfer Moulding (RTM) the process steps for the production of VTP fittings for the Single Aisle programme (Airbus A318-A321) is described in the following. The fittings are used for the connection of the Vertical Tail Plane (VTP) to the fuselage structure and thus are subject to very high mechanical loads during flight. The main process steps for the production of the fittings are cutting of plies, preforming, injection and curing. Subsequently, the part is demoulded, deburred and cleaned. Final process steps are the control of the part quality and trimming, if required.

One of the major advantages of the Resin Transfer Moulding (RTM) process is the feasibility to introduce a very high level of automation into the manufacturing process. In the case of the fitting production an automated RTM production cell was implemented (Figure 6).

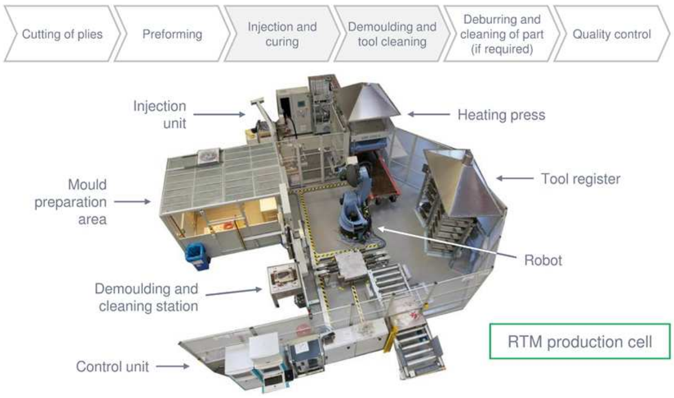

Figure 6. RTM production cell [Source: Airbus]

This automated production unit was developed together with the Composite Technology Center (CTC) GmbH Stade and finally integrated in a serial production environment in 2010. The production of the parts requires very little manual operations. Most of the process steps are performed automatically: First, a prepared preform is placed into the RTM mould. The industrial robot, responsible for all logistic tasks within this production cell, places the mould into the heating press. Afterwards, resin is injected into the RTM mould by an injection unit. The mould is heated to curing temperature and the liquid resin is cured. After completion of the curing cycle the robot moves the hot mould to a cooling station. Finally, the part can be demoulded and the tool is prepared for the next injection cycle.

Airbus produces structural parts in the RTM process due to the following main benefits:
- Parts can be produced with a reproducible laminate thickness. Thus, the fibre volume content is exactly defined, also for very thick parts (e.g. laminate thickness > 50 mm).
- The contour of the part is very accurate which leads to significant cost reductions in following assembly steps. Net-shape production is possible, thus, no further machining processes are required.
- Almost no ancillary materials are used.
- Parts can be produced with a high level of integration.
- The RTM process can be well automated, as shown in the example above.

4. Challenges

Considering the process chain for the production of structural CFRP parts by LCM technologies, one of the main challenges within aircraft industry is the delivery of components with excellent quality with reduced lead time. The benefit of a reduced lead time during production for the final costumer, the airline, is the accelerated availability of the ordered product. As the length of the planning horizon and the precision of the demand forecasts are codependent, shorter delivery times lead to higher prediction accuracy. Thus, the airlines can predict their demand for aircrafts with a higher accuracy leading to maximum capacity utilisation of the fleet.

Two general approaches are followed to fulfil the demand of a reduced lead time:
- Existent process steps are accelerated: This can be realised by the introduction of automation solutions. An optimum degree of automation has to be determined in dependence of the production rate, part complexity and labour costs. Furthermore, the processing time of the materials needs to be minimised. Today, the processing time is substantially defined by the curing time of the resin systems.
- Process steps are saved by the production of highly integrated parts: The workload for the production of highly integrated structures needs to be lower than the workload for the assembly of multiple parts with low integration level.

4.1. Automation of process steps

Considering the required process steps for the production of CFRP parts automation solutions are aiming at the acceleration of the preform production, the injection of the resin, the curing of the resin, the demoulding of the cured part, the cleaning of tools and the application of release agent (if required).

Besides numerous Research & Technology projects performed inside the Airbus Group several initiatives at other research institutions are observed aiming at improvements along the LCM process chain. Examples are documented in [8-12].

One very promising approach aiming at a fully automated, full-scale RTM production line is followed within the research project “EVo-RTM”, initiated and lead by the Center for Lightweight-Production-Technology (ZLP) of the German Aerospace Center (DLR) in Stade [13]. An intensive exchange between Airbus and DLR has been established to consider serial production demands from the beginning. The challenge to be solved by the DLR’s research activities is the development of production technology for complex, three-dimensional parts. Examples for such parts within an aircraft are stringers, frames and beams. Another challenge is to provide a process capable of the production of 100.000 parts per year.

The production of 100.000 parts per year leads to a production rate of about 20 parts per hour, assuming a three-shift production. State-of-the-art materials in aircraft industry used for RTM parts are hot-curing, single-component epoxy resins with curing cycles of 90 min and more. A reduced cycle time with existent materials requires an optimisation of heat treatment. A promising approach is the isothermal processing with a downstream curing by splitting cure time between the heated RTM mould and an oven.

For the needs of automation bi-component resin systems provide a better handling behaviour compared to single-component resins and is examined by DLR as well. The development of a mature process by controlling the process parameters is one of the project's scientific goals.

Technological innovations which are gained during Airbus' research and technology activities - often performed together with research partners - are continuously transferred into serial production. Thereby, Airbus is able to produce CFRP parts with cutting edge LCM technology considering highest quality requirements and economic demands at the same time.

4.2. Increase of integration level

Another approach for the reduction of the lead time during production of CFRP parts is the manufacturing of parts with a high level of integration. Thereby, subsequent process steps, mainly related to assembly of multiple parts with a low level of integration, can be reduced or even avoided. The benefits of highly integrated parts for the costumer are on the one hand the reduction of weight leading to lower energy consumption during flight and on the other hand reduced workload for the maintenance of the parts, e.g. for fastening elements or connectors.

One example for a highly integrated RTM part is the "Composite Multispar Flap" which is developed and tested in a Research & Technology project [14]. Figure 8 illustrates the main idea behind this development.

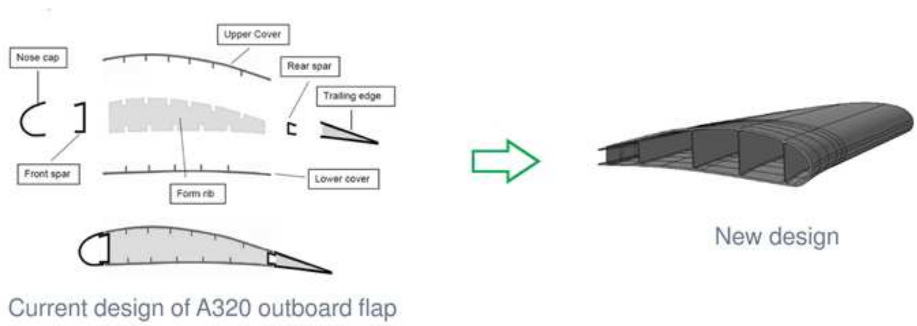

Figure 8. Composite Multispar Flap [Source: Airbus]

Today, the outboard flap of the Single Aisle aircraft A320 is designed as a differential CFRP flap. The large number of single parts leads to a high workload for assembly. Within the research project the outboard flap with a length of 7,4 m was designed and build as an integral box in one production step ("one-shot injection"). The spars are directly integrated into the closed structure. Thereby, the number of single parts is reduced by - 95 % [15]. The avoidance of subsequent assembly steps leads to a saving potential of 25 % in terms of recurring production costs [14]. This RTM part is a good example of how highly integrated parts contribute to an efficient production by the reduction of lead time.

5. Conclusions

Regarding the production of high-performance CFRP aircraft components, extensive operational experience and process know-how is available within Airbus. The application of CFRP offers a great opportunity to consequently realise light-weight approaches aiming at minimum energy consumption for operating the aircraft.

For the production of CFRP components LCM processes are of significant importance as the economic production of highly integrated and complex-shaped parts can be realised. One of the main challenges for the further development of these process technologies is the automation of process steps.

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