Low Cost Aerospace Composites

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SUMMARY: A new low cost resin system has been used to produce a composite elevator. Vacuum infusion has been used as low cost, non-autoclave room temperature production process. The innovative design which is characterized by a high degree of integration helps reducing assembly cost. A top-down certification approach, in combination with a fully computerized process control helps to speed up the implementation of these new materials, processes and designs and bring down the certification costs. This is demonstrated by the design and production of a simplified elevator construction.

KEYWORDS: Vacuum infusion, vinylester, certification, top-down, building block

INTRODUCTION

Resin infusion in aerospace applications has traditionally been focused on pressure injection in stiff molds. This process is commonly referred to as Resin Transfer Molding or RTM. Several resin systems have been and are being used with the pressure injection process, like RTM6 and Cycom 890. A number of parts have been produced and certified for this pressure injection process. Although good product quality can be achieved, this process is very expensive and inflexible for design changes. Only limited part sizes are possible. Recent developments have focused on cost reduction by switching from pressure injection to vacuum infusion. This will greatly reduce the mold costs since only one mold halve is needed and the clamping system is obsolete. However, for aerospace applications, still the expensive resin systems are used which require infusion at elevated temperatures. This implies that the mold geometry needs to be compensated for thermal expansion mismatches and that some sort of heating equipment needs to be installed on or around the mold. Also the use of a one-sided tool has still limited the level of integration of parts. This research describes a new approach, were a room temperature processing and room temperature curing vinylester resin system is used. A free-standing post-cure can ensure a T_g up to 230^{o}C. New preforming methods and innovative tooling systems have allowed for a high level of integration. This is demonstrated by the production of a simplified elevator construction. The following chapter deals with some design aspects of the demonstrator product. The third chapter describes the production steps taken. In chapter four, some comments on certification issues are given. The paper ends with conclusions and recommendations.

DEMONSTRATOR DESIGN AND PRELIMINARY ANALYSIS

A composites redesign was made of an aluminium elevator of a business jet. Several concepts for a lighter and cheaper elevator were considered, where "design for manufacturing" was the leading requirement. This will consequently lead to concepts with a high potential for cost reduction. An evaluation was made among three materials: aluminium (original baseline design), Carbon T300-epoxy and Carbon IM7-vinylester, and two structural concepts: the stiffened skin and the sandwich concept.

Three load cases are analysed: maximum pressure distribution, balance weight loads and damage tolerance (one hinge failure). From this analysis, performed both by analytical and finite element methods, a optimal design evolved, together with a first estimate of laminate lay-ups and thickness'. This design is shown schematically in . The design consists of a fully integrated spar-rib center box, an upper and lower skin with integrated local sandwich stiffening elements and several leading edge and hinge close-out ribs. For repair ability considerations, it was decided not to integrate the trailing edge with the skins, but to use a detachable structure. The materials selected were IM7 plain weave fabric from Hexcel Schwebel (SGP203-CSDH-49) and Daron hybrid vinylester (Daron XP 45-A-2 + Daron XP 40-B-1). To overcome tolerance problems normally associated with vacuum infusion, a mold design is foreseen where all the assembly surfaces are defined by the stiff mold system. Due to the flexibility of the vacuum infusion process, any design changes like a (local) increase of laminate thickness, can be easily implemented without a major redesign of the mold system. The design of this structure has been based on mechanical properties resulting from a short screening program of the selected material combination. The new design showed a 30% weight reduction with respect to the baseline concept.

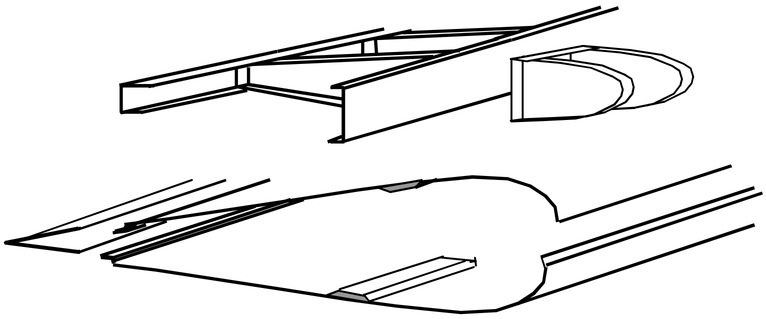


Figure 5: Schematic concept of elevator design

DEMONSTRATOR PRODUCTION

For demonstration purposes, it was decided not the produce a complete full scale elevator, but rather a simplified demonstrator with some critical features. A three rib structure was chosen with ribs at the minimum and maximum distances as they occurred in the elevator design. If it proves to be possible to infuse this part, the infusion of the complete elevator should also be possible with the proposed infusion strategy. A combination of flow simulations (Figure 6) and practical infusion experiments have led to an infusion strategy from an inlet channel along the lower side of the front spar to several outlet points located at the upper side of the rear spar in between the ribs. The production can be divided into two steps: vacuum infusion of composite parts and the assembly. The assembly of the demonstrator will be rather conventional and will include bonding and applying mechanical fasteners.

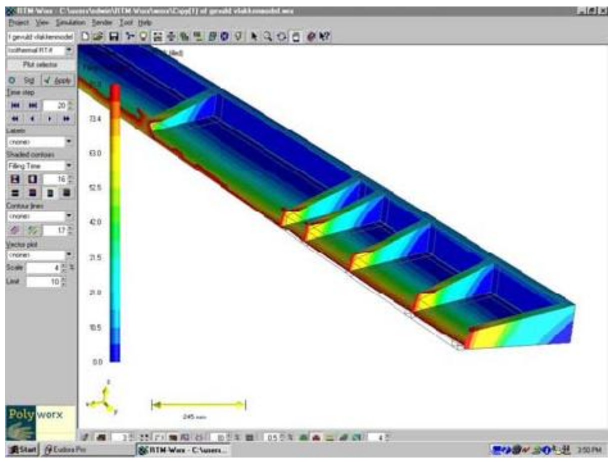


Figure 6: Flow simulation in RTMWorx (ref. 1)

The main focus of this paper will be on the vacuum infusion process. A mold system has been designed and constructed according to the proposed infusion strategy. The spar and rib laminates are preformed with a novel, patent pending preform method. Additional unidirectional tapes are interleaved in the flanges to increase the bending stiffness. To avoid tolerance problems during assembly, all bonding surfaces are defined by stiff mold surfaces. To ensure a reasonable surface quality on the vacuum bag side of the laminate, preshaped vacuum bags and nylon cowl plates are used.

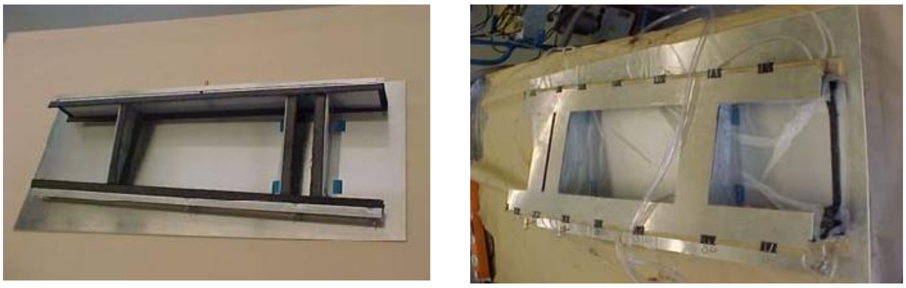
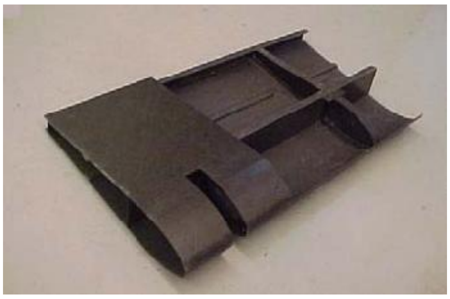


Figure 7: Mold with preforms (left) and mold sealed with preshaped bags and closing plate (right)

When the mold is completely sealed and the air tightness is checked, the resin is mixed according to the recipe in chapter 4. The resin is degassed for 5 minutes at 5mbar absolute pressure with a piece of Scotchbrite as bubble nucleator (ref. 2). The actual infusion is performed at 50mbars absolute pressure. After infusion, the pressure was increased to 200mbars absolute pressure before the resin inlet was closed. The whole procedure of checking air tightness of the mold, setting the pressures during infusion and curing and the opening or closing of resin inlets can all be computer controlled. After a 24hrs room temperature cure, the part is demolded. A freestanding post cure of 1hrs@120 ^{o}C, 1hrs@150 ^{o}C, 1hrs@180 ^{o}C and 1hrs@210^{o}C followed to achieve the 180^{o}C T_g-wet. For the other parts like the skins and the leading ribs, a similar procedure was performed. The resulting components are shown in Figure ***8***.

Figure 8: The integrated rib-spar structure (left), a skin (middle) and a leading edge rib (right)



For demonstration purposes, these components are only assembled by a bonding film. In the actual elevator, there will also be a need for rivets at critical locations. The resulting demonstrator is shown in Figure 9.

Figure 9: The demonstrator after assembly

CERTIFICATION CONSIDERATIONS

Aerospace is normally not associated with low costs. Especially when aerospace certified composites are involved, the costs can be enormous. The introduction of new low cost materials or new low cost production processes is hampered by the traditional *building-blocks* certification approach. For composites, testing on coupon scale will rarely give insight in the failure mechanisms of the complete composite structure. However, the traditional building block certification approach involves an enormous amount of tests on coupon scale. For a new material or process, all these tests have to be performed all over again. This has lead to the situation that, even for so-called innovative programs like the JSF development, which has been focused on affordability, very traditional and expensive production processes like prepreg autoclaving are still being used and only use is made of already certified materials. Therefore, to be able to make real progress, a different certification approach is proposed. Laminate analysis software like Kolibri (ref. 3) will be used to determine the required engineering constants. The input for this software follows from a small screening program on physical and mechanical properties. FEM calculations are been carried out to validate the structural design. A full scale test under the most extreme conditions will have to show the design meets the airworthiness requirements. Flight spectrum fatigues tests can also be replaced by single stage testing for composite structures since fatigue in composite structures is not a material issue but a design issue. Also the time and cost consuming product control step can be omitted if a proper process control system is implemented. The aim is to certify the minimal product quality which can be achieved within a prescribed process window. This certification approach of building and testing structures in combination with process control, rather than the traditional building block approach will drastically reduce the introduction time and cost of new materials and processes.

CONCLUSIONS AND RECOMMENDATIONS

It has been shown that it is possible to produce high quality composite parts with a high degree of integration. By using the most optimal process, material and design options for each situation, major weight and cost savings can be achieved. The process control system has also proven its value. Working with vacuum as driving force for the resin does imply the need of proper degassing of resin prior to infusion in order to achieve an aircraft worthy product quality. Preferably, a continuous degassing procedure should be developed, rather than the batch wise degassing applied in the laboratory. In an actual production environment, a large degree of automation and a flow oriented production set-up should be aimed for. The new, patent pending preforming processes allows for such a flow production and automation. The Center of Lightweight Structures has also been working on computer controlled process control for resin infusion processes.

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