Composites: Part B 57 (2014) 47–55

Contents lists available at ScienceDirect

Composites: Part B

journal homepage: www.elsevier.com/locate/compositesb

Process simulation for a large composite aeronautic beam by resin transfer molding

S. Laurenzi [a,*], A. Grilli [a], M. Pinna [a], F. De Nicola [b], G. Cattaneo [c], M. Marchetti [a]

[a] Department of Astronautic Electrical and Energy Engineering, Sapienza Università di Roma, Italy
[b] Advanced Materials and Technologies Laboratory, Centro Italiano Ricerche Aerospaziali S.c.p.A., Italy
[c] Research & Innovation Technology, Alenia Aermacchi S.p.A, Italy

ARTICLE INFO

Article history:
Received 21 November 2012
Received in revised form 9 September 2013
Accepted 16 September 2013
Available online 26 September 2013

Keywords:
E. Resin transfer molding (RTM)
A. Polymer–matrix composites (PMCs)
Numerical analysis

ABSTRACT

This paper presents the numerical process analysis and the experimental investigation for the manufacturing of a reinforced carbon-fiber demonstrator of a large aeronautic beam by resin transfer molding (RTM). The component is a primary structure characterized by several thick sections with abrupt changes in shape that complicates the resin impregnation of the preform. Process simulations based on a finite element method-modified control volume (FEM-CV) were conducted to investigate the resin flow front patterns and find the injection scheme that guarantees both a good impregnation of the preform and a filling time compatible with the resin gel time. The beam component was successfully manufactured, and a good agreement between the numerical analysis and the fabrication process was demonstrated.

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1. Introduction

Aerospace industries always investigate new technology solutions responding to the market pressure and the technology demands. In order to comply with the environmental directions on CO_2 emissions, the next global objective is to reduce 50% of consumed fuel by 2020 and a further 20% by 2025. These objectives can be reached in several ways, the use of lightweight structures being the most cost effective from the industrial point of view. For these reasons, aerospace companies, which are traditionally based on the use of metal alloys, have turned to the research and development of composite polymeric materials. The main advantages of polymeric composites with respect to metals, such as resistance to corrosion and fatigue, and high performance/weight ratio, are a set of qualities for winning the current and future applications. In this context, resin transfer molding (RTM) is a cost-competitive process to manufacture composite structures for aeronautics [1–5]. Many parts manufactured using RTM in the aerospace field have been mostly related to non-critical structures, whereas the development of large critical structures by RTM still requires large research efforts. A good design for RTM leads to fabrication of three-dimensional near-net-shape parts, offering production of cost-effective structural parts in medium volume quantities [2,6].

Also, so far RTM process have been used for the manufacture of thin laminate structures and very little work on thick composites can be found in the literature. As a matter of fact, manufacturing a thick-sectioned structure by RTM is challenging and several important processing considerations have to be accounted for. The highly exothermic nature of thermoset resins and the limited temperature control make it difficult to avoid detrimental thermal and cure gradients within the composite [7]. Moreover, the resin transverse flow front, due to the preform permeability through the section, becomes relevant. The resin flow patterns are difficult to predict, making the gates and vents location analysis even more difficult to perform [6]. In the case of thick-section composites, therefore, the process features are a serious limitation for the manufacture of composite materials for critical structures. Process modeling can accelerate the path from conception to prototype, thus reducing industrial costs and time.

In this work, numerical and experimental studies were performed to manufacture an aeronautic beam demonstrator in composite material that is traditionally made by metal alloy. The component under investigation is a beam of a thrust reverser, which is a large primary structure with complex geometry (Fig. 1). The composite beam was redesigned from the metallic and thicknesses ranging from 3 mm to 33 mm. An inverse engineering approach was applied to determine the permeability values needed to perform the simulation process. Filling simulations based on finite element-modified control volume method were conducted in order to find the injection scheme that guarantees both a good impregnation of the preform and a filling time compatible with the resin gel time. The beam component was manufactured using a RTM mold designed according to the results of the process simulations.

* Corresponding author. Tel.: +39 06 49 919 756; fax: +39 06 49 919 757.
E-mail address: susanna.laurenzi@uniroma1.it (S. Laurenzi).

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http://dx.doi.org/10.1016/j.compositesb.2013.09.039

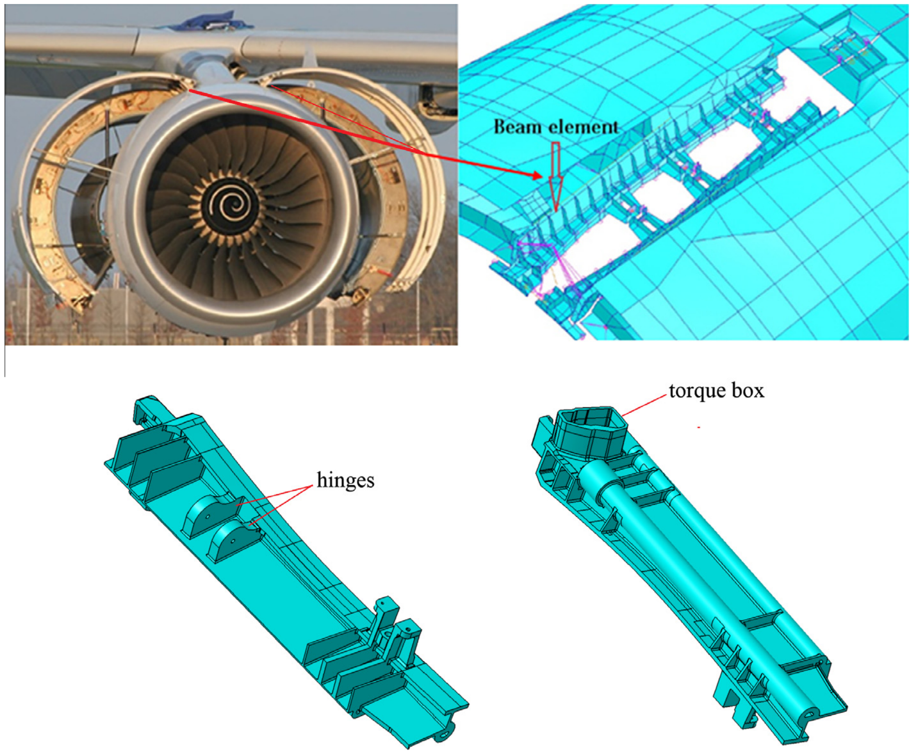

Fig. 1. Beam element of thrust reverser in nacelle (top); the beam is typically 1000 mm long and it has complex 3D shape with several thick sections as shown in CAD model (bottom).

2. Materials and methods

2.1. Materials

Hexcel G0926 carbon fiber reinforcements were used for the permeability experiments and for the component fabrication. The weave was a 5H Satin with areal weight of 360 g/m^2. The Henkel Epsilon 99900 binder was used for the preforming. The binder was dispersed at 10 wt% loading with respect to the fiber reinforcement, and the preform was maintained under vacuum at 120 °C for 1 h.

The resins used for the experimental tests were the epoxy Hexcel RTM6 and the benzoxazine Henkel Epsilon II 99110, whereas the beam demonstrator was manufactured using the benzoxazine system. This resin was selected because of its low exothermic behavior that guarantees a large processing window, thus avoiding premature resin gelling that can occur as a consequence of the large dimensions of the component. The two resin systems were used in according to the process cycles recommended by the producer. Table 1 summarizes the processing conditions adopted for the two resin systems during the experimental and numerical investigations.

2.2. Manufacturing

The resin selected to manufacture the beam requires that the entire apparatus (injection machine, dispensing resin and mold) is pre-heated to 80–90 °C before starting the impregnation phase. In our experiments, we used a commercial Hyperjet machine for mono-component polymers, which injects the resin at a constant pressure. The resin was loaded, degassed and heated inside the RTM equipment. When the set temperatures of both the resin and the mold were reached, the resin was pumped inside the mold until it came out from the vent. After the fiber preform was completely saturated with the resin, curing reactions were allowed to continue past the gel point to form a cross-linked polymeric structure.

Due to the complex geometry of the beam, several perform pieces were assembled to achieve the final part shape. Binder powder was applied to stabilize the layers. The lay-up of each part was designed using the commercial FiberSim software, in order to avoid fiber angle deviation and waste of material during the preform preparation, and for the reproducibility of the process. The plies were cut using an automatic machine and then placed in the mold. Finally the preform is consolidated under vacuum. Fig. 2 shows the process steps from the design to the perform fabrication. In particular, two consecutive ply creation steps are shown in Fig. 2a and b, where the green lines represent the boundary layers. Fig. 2c shows the layer after the automated cutting and the mold used to pre-shape the part, finally Fig. 2d shows a picture of the consolidation phase.

The beam was designed with quasi-isotropic laminations considering constant fiber volume fraction. The stacking sequence adopted for the characteristic thicknesses of the preform is

Table 1
Processing conditions adopted for experimental tests and numerical analysis. The demonstrator was fabricated with the process parameter of the system Epsilon II 99110 as reported in this table.

Resin	Density (g/cm^3)	Pre-heating T (°C)	Injection T (°C)	Viscosity at T_{inj} (mPa s)	Gel time (min)	Cure cycle
HexFlow RTM 6	1.12	80	80	180	240	75 min at 160 °C
Epsilon II 99110	1.22	110	110	100	240	90 min at 180 °C

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