

Preforming of a Fuselage C-Shaped Frame Manufactured by Resin Transfer Molding

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ABSTRACT

The need for efficient manufacturing approaches has emerged with the increasing usage of composites for structural components in commercial aviation. Resin Transfer Molding (RTM), a process where a fiber preform is injected with resin into a closed tool, can achieve high fiber content required for structural components as well as improved dimensional accuracy since all surfaces are controlled by a tool surface.

Moreover, RTM is well suited for parts that can be standardized throughout the aircraft, such as a fuselage frames and stringers. The objective of this investigation is to develop a preforming approach for a C-Shaped Fuselage frame. Two approaches are proposed: tri-axial braiding and hand lay-up of Non-Crimp Fabrics. The fiber architecture of the basic materials as well as the complete preforms is explained. The necessary preforming operations are detailed. The quality control measurement of fiber orientation and thickness are presented. A relation between the fabric lay-up angle, the fabric construction and the potential defects is drawn. The fiber architecture of the molded part is reported. The fiber volume content and void content of C-Shaped frames are measured using the acid digestion method. The outcome of this study can be applied to the fabrication of aircraft frames.

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INTRODUCTION

With the increasing number of aircraft structures made from composite materials arises the need for low cost manufacturing techniques that generate repeatable part quality. Resin Transfer Molding (RTM), a process where thermoset resin is injected through a fiber preform enclosed in rigid tooling, is a promising avenue for several reasons. The rigid tooling provides dimensional accuracy of the surfaces, thus limiting the shimming operations in subsequent assembly operations. Moreover, RTM does not require expensive autoclave that can occupy large factory floor space. RTM is used for a number of certified aircraft structures, such as the flaps installed on the Bombardier Aerospace regional jets [1], or the rudders on the Gulfstream G250 [2].

Even though the RTM process is well established, every part design requires a specific dedicated preforming strategy in order to achieve tailored mechanical properties. For example, advanced braiding techniques can be used to preform fuselage frames [3]. Even if conventional braiding offers a great potential for fiber lay-up automation, non-crimp

fabrics (NCFs) can be preferable since their reduced fiber waviness provides higher in plane mechanical properties.

The objective of this study was to develop a preforming method for the manufacturing of an aircraft fuselage C-shaped Frame. Triaxial braiding and hand-lay-up of non-crimp fabrics were the two preforming methods studied.

EXPERIMENTAL

As seen in [Figure 1](#), the manufacturing approach selected was to mold two mirror C-frames in one RTM injection, resulting in higher productivity.

The preform was first wrapped on a mandrel and inserted into a tool for resin injection. After curing of the resin, the mandrel was removed from the tool and the part was cut in two mirror C-frames. Residual trimmings can serve for process control testing.

The mandrel used in this study had a constant square section of 2.36 inches in height and 3 inches in width. With a radius of curvature of 44.5 inches and an arc length of 31 inches, the mandrel was designed to match a typical business jet fuselage curvature. The matched tool had a parting line

located along the mandrel straight centerline. The tool surfaces were machined to have a constant cavity thickness of 0.070 inches, all around the mandrel.

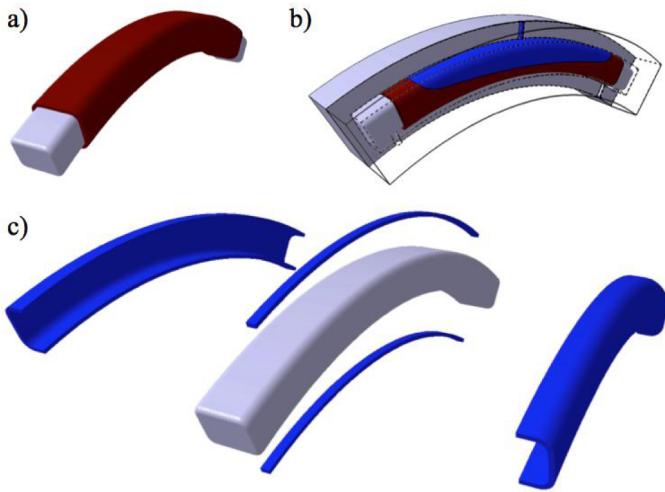


Figure 1. RTM fabrication of C-Frames: a) The preform is wrapped around a mandrel; b) The preformed mandrel is placed into the tool and the resin is injected; c) Two mirror C-Frames are cut from the cured part.

Since the C-frames manufactured in this study were not intended for an aircraft platform, only a few requirements were applied to the design of the preform. Firstly, the fiber orientations needed to be tailored to be as close as possible to a quasi-isotropic laminate, with an orientation deviation never exceeding $\pm 5^\circ$. Secondly, the targeted fiber volumetric content was 55-65%. Thirdly, since the tooling cavity was fixed to a thickness of 0.070 inch, the dry fiber preform thickness needed to be as close as possible to part dimension to insure ease of insertion into the tool.

Triaxial Braiding

The triaxial braid used in this study is made using 96 bias yarns and 48 axial yarns. The carbon yarns used for the triaxial braids are made of AMS 3892 certified HTS40 fibers (Toho Tenax). The bias yarns have 6K carbon filaments (400 tex) and the axial yarns have 12K carbon filaments (800 tex). The braid was manufactured using a robotized gantry system that guided the C-frame mandrel through the braiding ring. Table 1 shows the triaxial braided preform design.

Table 1. Description of the triaxial preforms.

Layer	Fabric	Fiber Orientation	Fiber Volume Content
1	Triax Braid	$\pm 60^\circ/0^\circ$	55%
2	Triax Braid	$\pm 60^\circ/0^\circ$	
3	Triax Braid	$\pm 60^\circ/0^\circ$	
4	Triax Braid	$\pm 60^\circ/0^\circ$	

The mandrel feed speed into the braiding ring was adjusted relatively to the braider speed in order to meet the $\pm 60^\circ$ orientation for the bias yarns and proper tensioning of the axial yarns. The braided preform comprised of 4 layers subsequently braided on each other in order to achieve 55% fiber volume content in the final part.

Two debulking operations were completed after braiding, for the second layer, and the fourth and final layer. A tackifier, an epoxy resin solvated in acetone, was first sprayed on the preform. Then, the preform was wrapped in perforated shrink tape. The taped mandrel was exposed to heat, in order to compress the layers under the shrinking action of the tape and evaporate the tackifier solvent. The solvent evaporated through the perforations in the shrink tape.

Non-Crimp Fabrics (NCFs)

The NCFs were all made using the IM65 fiber (Toho Tenax). Table 2 lists the different fabrics that were used in this study. The areal weights were taken from the manufacturer data sheets. The fabrics' nominal thickness was measured using a micrometer (103-177, Mitutoyo) while being sandwiched between 1 square inch caul plates.

Table 2. Description of the non-crimp fabrics.

Fabric	Component	Areal Weight (g/m ²)	Fabric Thickness (in)
UD NCF	Binder	19	0.015 $\pm$ 0.001
	Carbon Fiber	274	
	90° Supporting PES yarn	4	
	Tricot Stitch	4	
Triax NCF 1	Binder	19	0.037 $\pm$ 0.001
	Carbon 45°	274	
	Carbon 90°	270	
	Carbon -45°	274	
	Tricot Stitch	4	
Triax NCF 2	Binder	19	0.037 $\pm$ 0.001
	Carbon -45°	274	
	Carbon 90°	270	
	Carbon +45°	274	
	Tricot Stitch	4	

All NCF fabrics were covered using an epoxy-based binder that had a thermoplastic behavior. The binder was applied by lightly sprinkling the powdered form on the fabric and afterwards melting it onto the fabric by temporary heating the preform to temperatures above 100°C. The forming of the preform is reversible because of the thermoplastic character of the binder.

The first NCF used was made with unidirectional carbon fibers (UD) laid along the warp direction of the fabric. There are supporting polyester (PES) fibers running along the weft direction under the carbon yarns. The fabric is stabilized by a