Processability Analysis of Thick Braided Composites Manufactured with RTM Technology

S. Laurenzi[1*], M. Griccini[1], E. Lalia Morra[2], E. Anamateros[2], M. Marchetti[1]

[1] *Department of Aerospace and Astronautic Engineering, University of Rome "La Sapienza", Rome, Italy: s.laurenzi@aerorisc.diaa.uniroma1.it*

[2] *Agusta-Westland S.p.A, Aerospace Composites Center, Anagni, Italy: e.laliamorra@it.agusta.com*

SUMMARY: Thick braided carbon fiber/epoxy resin composites have recently become relevant structural materials in the field of aerospace and aeronautics. The aim of the present work is to investigate the effect of Resin Transfer Molding (RTM) process on braided composites for the fabrication of a helicopter transmission traditionally made with metallic materials. Several experiments have been conducted at different braided angles in order to study the relationship between braided angle, permeability and the flow transverse through thickness of the laminates and volume fraction.

KEYWORDS: Resin Transfer Molding, permeability, braided composites

INTRODUCTION

Metallic materials are traditionally used in the fabrication of transmissions, but they are susceptible to corrosion. Composite materials are known to have far better corrosion resistance and damage tolerance than metallic ones. In addition to the better overall performance, the composite top case weighs 40% less than the original cast metallic design. Braided structures are highly comfortable to conical structure. Braiding is a highly automated textile process. The carbon fibers are placed in the proper orientation in a precise and consistent manner using automation, which results in lower manufacturing costs and more repeatable processes. The advantages of braiding compared to standard tape and fabrics include strength in third dimension, improved fatigue resistance, more efficient distribution of mechanical stresses, conformability to complex shapes, reduced scrap and reduced labor costs. In combination with resin transfer molding process (RTM), it provides the capability of producing low-cost, high-quality components. The aim in RTM is to impregnate the reinforcement with resin as fast as possible, before the resin cures, while minimizing undesirable features such as voids and non-uniform wetting. In the case of helicopter transmissions, a dedicated tooling design analysis has to be performed in order to guarantee the completion of wetting process of the preform, because of the high thickness of the part and its non uniformity with abrupt increases. Furthermore, the pore space deforms as the preform is compressed, stretched, or folded inside a mold.

In this work, the resin flow front through the thick preform has been investigated for three types of braided materials, considering several experiments at different braided angles in

order to study the relationship between braided angle, permeability and thickness of the laminates for a specific volume fraction. It has been observed that for thickness more than 11 mm, the difference of flow front between the top and bottom of the preform starts to be consistent, meaning that the transverse flow through thickness cannot be considered negligible.
Furthermore, for cylindrical braids the tow spacing increases with reducing braid angle, resulting in the creation of flow channels that appear dominate the permeability.
This study is important to estimate the permeability profile of a braided preform, without which simulation models would not provide information useful for process design.

MATERIALS AND METHODS

Three types of 6K T300 carbon braided reinforcements have been used. In Table 1 material properties are shown for a 45 ° fibers orientation.

Table 1

Code	Weight (g/m)	Weight (g/m2)	Diameter (mm)
B-120-06	68	277	78
B-120-05	136	480	90
B-144-05	81	370	70

By changing the diameter of cylindrical braided, the braided angle is changed and a different weight for unit area is assumed. This aspect has been considered.
The resin used for tests has been the epoxy high temperature curing Hexcel RTM6. In fig 1 the resin viscosity profile is shown.

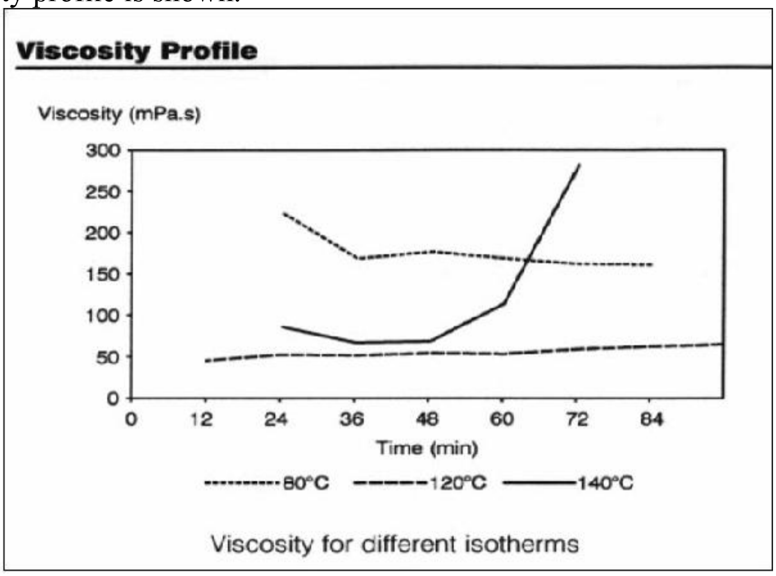

Fig. 1: Resin viscosity profile

Specimens Manufacture

Flat braided reinforcements were cut from cylindrical mandrels, with each layer retained using masking tape at edge as in Fig. 2.
The fiber volume fraction of the preform has been determined by the well known formula

$$v_{fr} = \frac{n A}{h \rho} \qquad (1)$$

where h is the thickness of the frame (8 mm, 11 mm, 15 mm), ρ is the average density of material (1.7 g/m³), n is the number of layers varying to keep constant the fiber volume fraction for several h, A is the weight for unit area. The fiber volume fraction was 0.67 for all experiments.

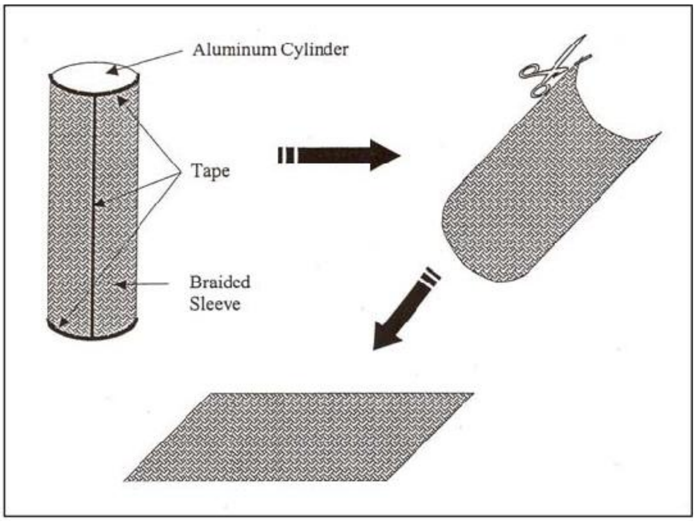

Fig. 2: Procedure to cut the braided layers

Samples have been produced at range of braided angles of 30°, 45°, 60°. Fig. 3 shows how a shape cell of a braided preform varies with the braded angle. So, several mandrels have been used, because of determined braided angle are obtained with specific diameter of cylindrical braided.

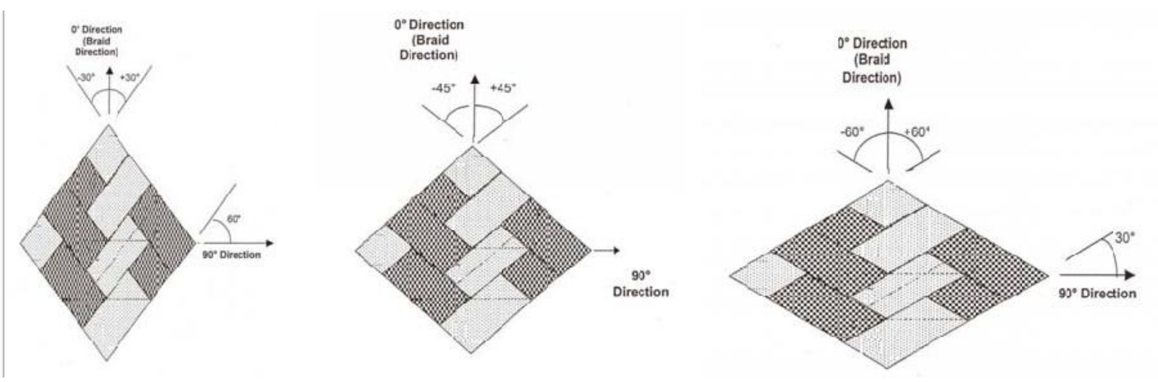

Fig. 3: Braided angles used for the experiments

Permeability Measurement

The permeability tests were performed in a rectangular RTM mold. The bottom and top mold is made of 5 cm thick glass so that the flow front progress can be observed visually. The thickness of the mold has been adjusted by using different frames. A grid had been drawn on the top and bottom glass to measure the fluid flow front position.
The permeability have been measured at different braided angles. All the permeability tests were carried out preheating the material at 80 °C and maintaining the mold at 120 °C. The fluid was injected into the mold under a predetermined constant air pressure (2 bar) and linear flow apparatus. During the test, a video camera recorded the fluid flow process at both sides of the mold. The flow front position at different times was obtained with the help of image grabbing system and some specifically developed software.
To establish the effect of the braid angles and thickness, a minimum of three permeability tests were carried out at each braid angle for a determined thickness and volume fraction. The permeability value has been determine with the classical Eqn. (2):

$$K_x = \frac{\mu \Phi \, slope\ of \left[x^2{}_f(t_f)\right]}{2\Delta P} \qquad (2)$$

where Φ is the porosity and μ is the viscosity of the resin. To study the effect of the thickness on the wetting preform, three frames have been used at specific volume fraction.

RESULTS

Following is the permeability as a function of braided angle for the different materials analyzed in the case of mold thickness equal to 8 mm. Each point is the average of three experimental data.

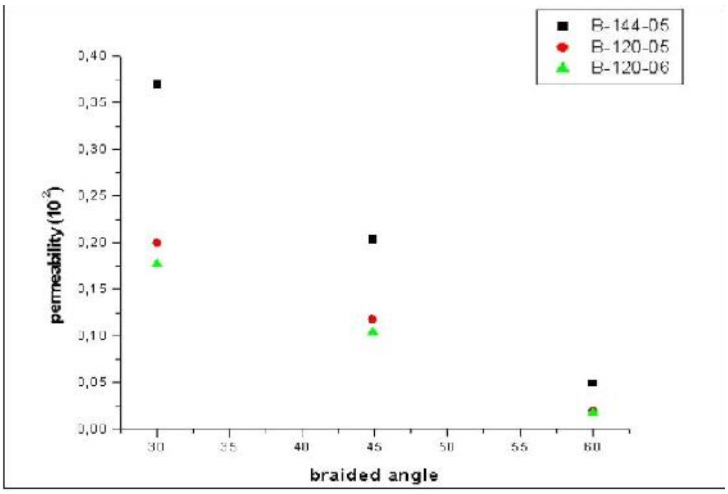

Fig. 4: Permeability parallel to mandrel axis with thickness equal to 8 mm

CONCLUSIONS

In RTM applications, resin flow induced defects, voids and dry spots are known as the largest source of quality and reproducibility problems. These defects are often caused by unbalanced resin flows, which are directly related to the fiber preform permeability variation. In our case, possible sources of this problem can be a local variation of braided angle during preform preparation and braided angle change for conical shape. In our experiments we studied the effects in variation of the braided angle on the permeability parallel to the mandrel axis. It is visible that, for all materials in exam, the permeability decreases with increasing of the braided angle. This appears to be due to the change in tow spacing with braided angle. The tows become non-linear with the flow direction, producing an additional resistance to flow of the resin. The permeability value is substantially the same with the changing of the thickness for a specific volume fraction, but the difference of the space run by the flow front between the top and bottom of the preform increases with thickness. These results imply that the transverse flow through thickness cannot be considered negligible. This phenomenon appears relevant for B-120-05, where the pore space between the tows is less than the other two materials studied, and will be taken in consideration for future simulation of the flow of entire conical structure for the process design.

REFERENCES

1. T. Kruckenberg and R. Paton, “Resin Transfer Molding for Aerospace Structure”, Kluwer Academic Publisher 1998.

2. D. Stover, “Resin-transfer molding for advanced composites”, *RTM,* Advanced Composites, pp. 60-80, 1990.

3. R. Davè, “A Unified Approach to Modeling Resin Flow During Composite Processing”, *Journal of Composite Materials*, Vol. 24, pp. 22-41, 1999.

4. J. Coulter and S. Guceri, “Resin Impregnation During the Manufacturing of Composite Materials Subject to Prescribed Injection Rate”, *Journal of Reinforced Plastics and Composite,* Vol. 7, pp. 200-213, 1988.

5 S. G. Advani and E. M. Sozer, “Process Modeling in Composite Manufacturing”, Marcel Dekker, Inc. New York-Basel.

6 Y. Luo, I. Verpoest et al., “Permeability measurement of textile reinforcement with several test fluids”, *Composites part A ,*Vol. 32, pp.1497-1504, 2001.

7 L. Ding, C. Shih, Z. Liang, C. Zhang, and B. Wang, “In situ measurement monitoring of whole-field permeability profile for liquid composite molding processes”, *Composites part A,* Vol. 34, pp. 779-789, 2003.

8 V. M. A. Calado, and S. G. Advani, “Effective average permeability of multi-layer preforms in resin transfer molding ”, *Composites science and technology,* Vol. 56, pp.519-531, 1996.