INJECTION OF A COMPLEX PREFORM BY RTM PROCESS.

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ABSTRACT: This work concerns the manufacturing of a composite tube using RTM process. During the preforming stage, a woven braid is laid down and stacked on a mandrel so that reinforcement plies form conical shapes with a defined angle. An innovative experimental preforming procedure has been developed to respect the specific angle. The resin injection step has been studied both experimentally and numerically. The influence of processing parameters such as the injection pressure or the imposed flow rate on the position and the size of possible defects has been evaluated. A numerical study has been conducted to model the flow of resin within the different areas of the complex preform. Planar and through-the-thickness permeability studies were conducted experimentally as a function of the fibre volume fraction and the shear angle. Within the preform and especially along a radius of the part, variation of shear, fiber volume fraction, orientation of yarns and consequently variation of the permeability tensor must be taken into account for the simulation of the resin injection. Simulation results presenting the evolution of the flow front within the preform for different injection cases are discussed and correlated to the experimental study results previously mentioned.

KEYWORDS: Complex preform, RTM, Process parameters, Simulation, Braid permeability.

INTRODUCTION

This work concerns the manufacturing of a composite tube with 3D braided reinforcement by the RTM process. Specifically the influence of the preforming stage of the process on the resin injection is studied. Three-dimensional braided preforms have been used successfully used to manufacture composite materials in the aerospace and military industries over the last ten years [1]. Because braiding has the potential to produce complex shapes with fibre continuity at the edges and around holes and branches [2], braided structures are also used in several other applications, such as medical, automotive or sport equipment [3]. Classically, fibres are braided directly on a cylindrical mandrel with a conventional braiding machine. This process is an ancient technique, but as it could be automated, it is suitable for manufacturing reproducible preform for RTM process. The prediction of the fibre position along the mandrel as a function of the process parameters remains difficult. Consequently a lot of studies [4-6] concern the development of models which compute characteristics of braided preforms. These characteristics could be the braid angle, the yarn volume fraction, the covering factor and finally the influence of these parameters on the permeability of the braid [7-8].

In this work application, each ply of fibre must have a specific orientation with the axis mandrel. As a consequence, a conventional braiding machine cannot be used. From specific 3D carbon braided reinforcement, an innovative experimental preforming procedure has been developed. It is described in the first part of this paper. The analysis of the preforming stage at several scales (scale of the part, the ply or the unit woven cell) shows that the reinforcement is mainly submitted to in-plane shear deformation. Consequently the fiber volume fraction changes along the radius. The changes of the fibre orientation and local variations of fibre volume fraction have a significant impact on the permeability [9-10]. Consequently experimental permeability determination of the specific 3D reinforcement (planar and transverse) sheared and not-sheared has been conducted and will be presented with the characteristics of the reinforcement in the second part of the paper.

The outside flow front evolution has been measured along the transparent cylindrical closed mould and compared to a numerically study. A classical software, based on the finite element method, developed by the University of the Havre [11] is used. The pressure and the time required to fill the preform with resin can be estimated. The interest of the numerically approach is to see the influence of several parameters, such as the variation of fibre volume fraction, orientation of the fibre, on the computed time.

EXPERIMENTAL DEVELOPPMENTS OF THE PROCESS

Two main properties have to be respected on the final composite part. First, the angle between plies of braid reinforcement and the tube axis must be equal to a specific value. Secondly, the preform has to present an important fibre volume ratio with a homogeneous distribution along and in the part. From the 3D-braided reinforcement the experimental procedure consists in realizing one preform constituted by several plies [12]. Each ply must have a specific angle, (denoted α on figure 1.a) with the mandrel axis, and the preform must have a specific diameter given by the closed mould for the resin injection step. To realize this preform, a cylindrical mandrel with a conical base (figure1.a) is used. The braid length depending on the expected fibre volume fraction can be estimated and weighted. The braid is first slipped into the cylindrical mandrel and tied between two threads on a length which will define the ply. The first ply, with the expected orientation, is obtained by folding up the braid on the conical base of the mandrel. By using the same principle, the others plies can be superimposed on each other. A preform (figure1.b) contains approximately 120 plies, for 200g of carbon braided reinforcement.

In a second step the mould is closed and placed on the preform so that the resin can be injected (figure 1.c) under pressure or flow rate conditions, with a specific device developed at Orleans [13]. The outside flow front evolution can be measured as well as the time required to fill the mold.

After the preforming stage it's necessary to know the position of the reinforcement, the angle they form with the tube axis, the shear angle on plies, the local and global fibre volume fraction. A specific model, associated to the elementary braid scale [12] is defined to predict along a ply the evolution of the shear angle and consequently the local fibre volume fraction. Tomography (figure 2) is used to validate this model and obtain values of these parameters associated to the preform.

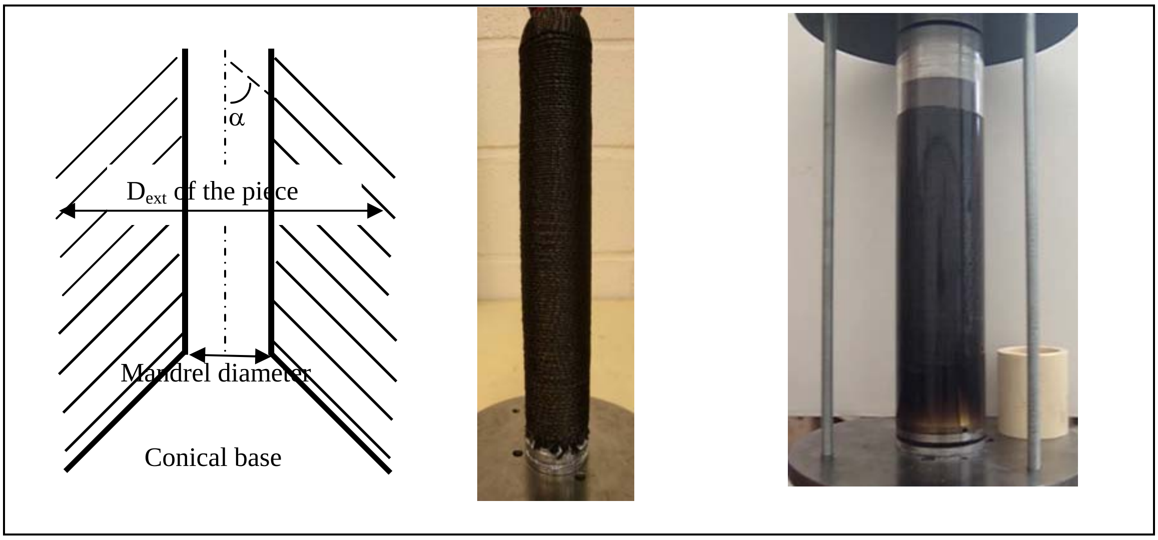

Fig. 1 (a) Scheme of the preform; (b) Final preform; (c) Resin evolution

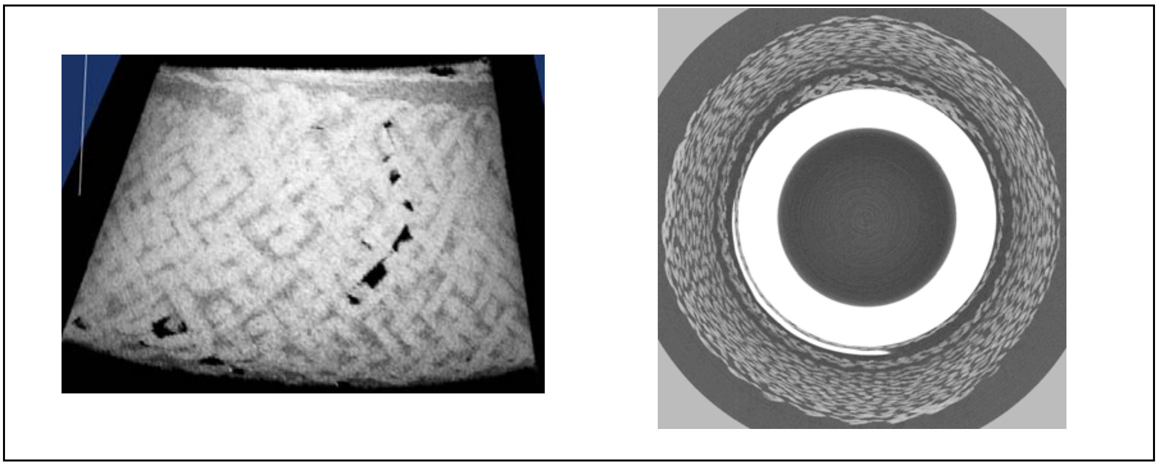

Fig. 2 (a) Position of yarns on a ply; (b) tomography to estimate the density

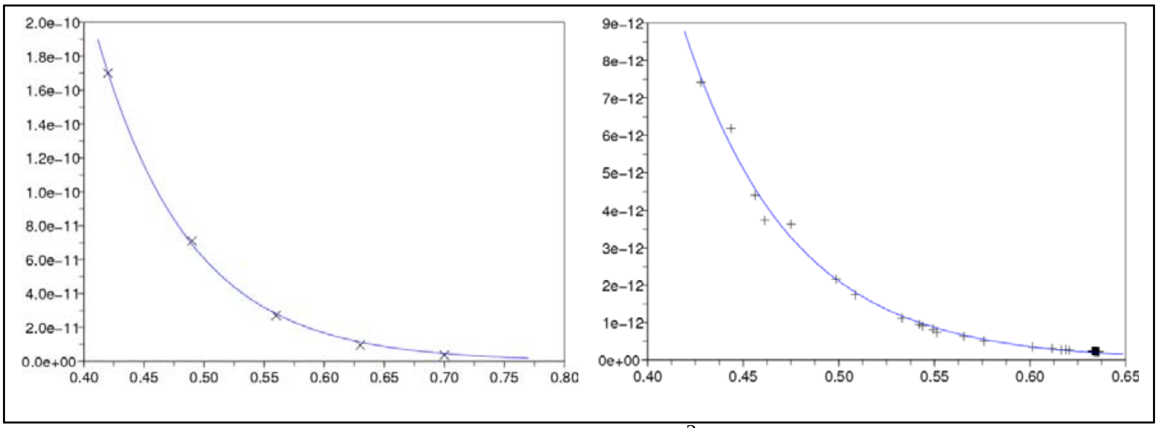

Fig. 3 (a) Planar and (b) transverse Permeability (m^2) as a function of the fibre volume fraction

CHARACTERISTICS OF BRAIDS AND SIMULATION OF RESIN INJECTION

Due to the specific angle between plies and the tube axis which is the direction of the flow during the injection step, the planar and through-the-thickness components of the permeability tensor are concerned. The determination of the longitudinal and through the thickness permeabilities was conducted experimentally, with specific devices at the University of the Havre [14]. Variations of the fibre volume fraction and shear angle between the yarns were taken into account following established methodologies. Figure 3 shows the evolution of the planar (3.b) and the through-the-thickness (3.c) permeabilities as a function of the fibre volume fraction.
Numerical simulations showing the filling of the part have been conducted. This modeling stage, at the scale of the part, has two objectives: first to analyze the influence of each characteristics of the complex preform on the flow of resin (in term of time required to fill the preform or applied pressure), and second to compare, these simulations to the experimental results. The mesh is realized by using the Abaqus software and the computing step is realized with the software developed at the University of the Havre [14]. Specific characteristics (fibre volume fraction, longitudinal and through the thickness permeabilities) are allocated to each element of the mesh. Figure 4.a shows an assembly of materials with specific fibre volume fractions, and specific permeabilities. On figures 4.b, 4.c, simulations of a quarter of a tube filling are presented. In Figure 4.b, the fibre fraction volume is constant (4.b) and in Figure 4.c, the fibre volume fraction is not constant along the radius. For the two tests, the flow front (left) and the time required for the filling (right) are presented. We can notice an influence on the orientation of the flow and consequently on the time required for filling the preform. In case of non-constant fibre volume fraction, the filling time is is about twice longer.

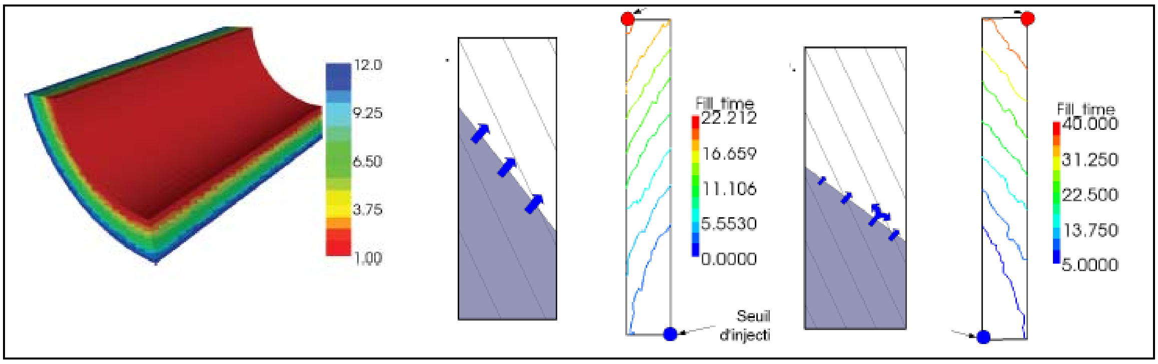

Fig. 4. Simulation. (a) Definition of material. (b) V_f constant .(c) V_f not constant.

CONCLUSIONS

Experimental and numerical works are developed in this study to understand the influence of the complex preform specificities on the resin flow. Particularly, the fibre volume fraction and orientation of the yarn within the preform are taken into account. The complexity of the preform in terms of reinforcement is analyzed by tomography and by analytical model (for the shear deformation). The first numerical results show an anisotropy of the macroscopic fluid flow. Significant variation either on the fibre volume fraction, or on the orientation of reinforcement, tends to increase the resistance of the fluid, and slow down the filling [15]. Future works are dedicated to compare numerical results with those obtained experimentally.

ACKNOWLEDGMENTS

The work reported has been carried out in the scope the project LCM3M (ANR, French National Research Agency) and has been supported by ROXEL company.

REFERENCES

[1] Chou TW, Ko FK. "Textile structural composites". Amsterdam, Netherlands: Elsevier Science Publishers B.V. 1989, 154–155.
[2] P. Potluri, A. Manan, M. Francke, R.J. Day. "Flexural and torsional behaviour of biaxial and triaxial braided composite structures". *Composite Structures*, Vol. 75 pp. 377–386, 2006
[3] A.P. Mouritz, M.K. Bannister, P.J. Falzon, K.H. Leong. "Review of applications for advanced three-dimensional fibre textile Composites". *Composites Part A*, Vol.30 pp. 1445–1461, 1999.
[4] L. Chen, X.M. Tao, C.L. Choy. "On the microstructure of three-dimensional braided preforms". *Composites Science and Technology*, Vol. 59, pp.391-404, 1999.
[5] P. Potluri, A. Rawal, M. Rivaldi, I. Porat. "Geometrical modelling and control of a triaxial braiding machine for producing 3D preforms ». *Composites Part A*, Vol. 34 pp. 481-492, 2003.
[6] G.W. Du, P. Popper. "Analysis of a circular braiding process for complex shapes". *Journal of Textile Institut*, Vol.85, n°3, pp.316-337, 1994.
[7] A.C. Long. "Process modelling for liquid moulding of braided preforms". *Composites Part A*, Vol. 32 pp. 941-953, 2001.
[8] X. Wu, J. Li, R.A. Shenoi."Measurement of braided preform permeability". *Composites Science and Technology*. Vol. 66, pp.3064–3069, 2006.
[9] S.B. Sharma, M.P.F. Sutcliffe, S.H. Chang. "Characterisation of material properties for draping of dry woven composite material". *Composites Part A*, Vol. 34, pp.1167–1175, 2003.
[10] E. Heardmann, C. Lekakou, M.G. Bader. "In-plane permeability of sheared fabrics". *Composites Part A*, Vol. 32, pp. 933-940, 2001.
[11] Ch.H. Park, A. Saouab, J. Breard, A. le Riche. "Simple models for mold filling stage in LCM and their applications to structure process coupled optimization". *Proceedings of FPCM8*, Douai, France.11 – 13 July 2006.
[12] A. Telmar, R. Agogue, D. Soulat, G. hivet, D. Zanelli. "Prediction of braid deformability during RTM Process". *Proceedings of 13th Esaform*, Brescia, Italy 7-9 April 2010.
[13] D. Soulat, A. Telmar, R. Agogué, D. Zanelli. « Étapes du procédé RTM pour pièces de protections thermiques ». *Comptes-rendus du 19ième Congrès Français de Mécanique*. Marseille 24-28 Août 2009. (in french)
[14] P. Ouagne, J. Bréard. "Continuous transverse permeability of fibrous media". *Composites Part A*, Vol. 41, Issue 1, pages 22-28 (2010).
[15] F. Loix, L. Orgeas, C. Geindreau, P. Badel, P. Boisse, J.F. Bloch. "Continuous transverse permeability of fibrous media". *Composites Part A*, Vol. 41, Issue 1, pp. 22-28, 2010.