MANUFACTURING OF FILAMENT WOUND CYLINDERS LOCALLY REINFORCED BY TAILORED PATCHES

Cristiano B. Azevedo[1*], José Humberto S. Almeida Jr[2], Tales V. Lisbôa[3], Axel Spickenheuer[3], Leonardo G. Scherer[1], Sandro C. Amico[1]

1 – PPGE3M, Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, RS, Brazil
cristiano.baierle@ufrgs.br
2 – Department of Mechanical Engineering, Aalto University, Espoo, Finland
3 – Leibniz Institute of Polymer Research, Dresden, Germany

Abstract - Tailored fiber placement (TFP) is an embroidery technique capable to produce textile preforms with fibers oriented at arbitrary orientations, which makes them a suitable candidate to locally reinforce structures towards avoiding the addition of extra layers to meet design requirements. In parallel, filament winding (FW) process is a suitable technique to manufacture closed shells, but it has limited flexibility to generate local reinforcements. The aim of this work is to develop a hybrid process by synergistically combining patches made by TFP to reinforce filament wound cylinders. The feasibility and quality of the introduced process are herein evaluated. The patches are infiltrated through the vacuum assisted process (VAP). The produced locally-reinforced cylinders have low void content and good cross-sectional quality.
Keywords: *filament winding, tailored fiber placement, composite cylinders*

Introduction

Filament Winding (FW) is a suitable process for manufacturing axisymmetric structures, in which continuous fibers are deposited around a rotating mandrel [1]. It is commonly used to produce cylinders, pipes, shafts, pressure vessels, among others [2] and offers several advantages, such as high precision in fibers placement, high fibers volume fraction, and low void content [3, 4]. Nevertheless, since many structures have geometric discontinuities (e.g. holes, notches, groves), due to the continuity and kinematics of the process [5–7], it is unfeasible to place fibers locally to reinforce these areas. Generally, stress concentrations can be found in such regions.
An alternative way to reinforce such weak areas is by adding patches into/onto the structure. Tailored fiber placement (TFP) is a well-established textile manufacturing technique suitable to produce dry patches with extremely low curvature radii (minimum of 5 mm) [8], whose principles are illustrated in Fig 1 [9]: continuous fibers are placed in a 2D plane arbitrarily by rotating the roving pipe and movement of the base material in the plane. The fibers are fixed to the base material by a zigzag double lock stitch with upper and lower thread [10].
The aim of this work is to combine FW and TFP into a single hybrid process towards locally reinforce filament-wound structures, combining patches made by TFP to position fibers in order to reinforce cylinders manufactured by FW. Herein, it is presented some initial attempts on the feasibility of this new hybrid process.

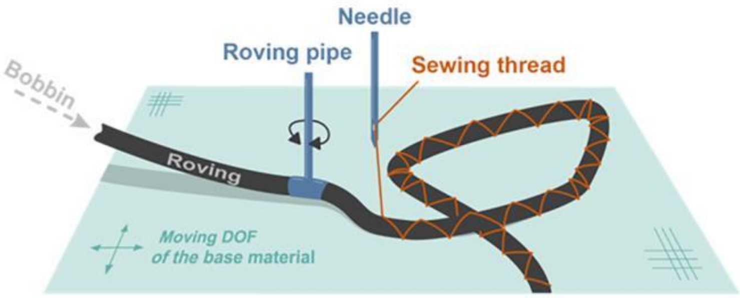

Figure 1 – Basic principle of TFP process [9].

Manufacturing

Considering that this is an initial attempt, simple patches and cylinders without geometric discontinuities are considered. In addition, an appropriate infiltration process for incorporating dry patches into the filament-wound structure must be developed as well as a proper curing procedure.

Filament winding: cylinders

Carbon/epoxy towpreg Sigrafil C T24-5.0/270-E100 from SGL Carbon are used to produce the cylinders by FW. The manufacturing code and simulation of the process is performed by CadWind V10 software. The winding is carried out in a Kuka KR 140 L100 robot with 7 degrees of freedom using a stainless-steel mandrel.

Tailored fiber placement: patches

The TFP patches are manufactured with carbon fiber HTS 5131 48K (3200 tex) from TENAX. The fibers are stitched onto glass woven fabric (areal density of 1.12 kg/m2), which represents the base material. The preform is designed through the EDOPath® software and manufactured in a TAJIMA embroidery machine. To evaluate the local thickness variation, three different patches are manufactured. They are all rectangular (1400 mm × 40 mm) with a sinusoidal thickness variation with a maximum of 1 mm, 3 mm, and 5 mm at center of the preform.

The hybrid FW-TFP process

First, a $[\pm 45]_{FW}$ layer is wound around a 50.8 mm mandrel. On top of this layer, impregnated TFP-based impregnated patches are place onto it. The impregnation of the patches is made with epoxy resin AR260 and AH260 hardener (100:26 g ratio) supplied by Barracuda through vacuum assisted process (VAP). A semi-permeable membrane that allows the passage of gases but does not the passage of the resin is used and vacuum is applied over the entire surface of the component. In this way, the trapped air and gases are removed from the system [11]. The vacuum is applied for 3 h. After impregnating the fibers from TFP, three patches are placed on the surface of the first filament wound layer along the longitudinal direction of the cylinder.
On top of the patches, another layer $[\pm 45]_{FW}$ is wound and the FW + TFP cylinder is cured in an oven with air circulation for 45 min at 140 ºC. The system is cooled down to room temperature and the cylinder is removed from the mandrel.

Testing

To assess the quality of resin impregnation, optical microscopies (Carl Zeiss microscope) from the cross-section around the patches areas are taken. The void content is measured using ImageJ software. In order to determine the degree of cure of the prepreg and the AR260 epoxy resin, differential scanning calorimetry (DSC) analyzes are performed in the uncured and cured conditions. A DSC Q20 TA Instruments equipment is used under nitrogen gas at 50 mL/min under heating ramp of 10 °C/min up to 220 °C.

Results

Manufacturing

Three cylinders were manufactured using the hybrid FW + TFP process with different patch thicknesses (1, 3 and 5 mm). The shape of the patches, with sinusoidal thickness variation, allowed an adequate positioning of the second FW layer, without voids and areas rich in resin in the transition between the FW and TFP layers. In addition, no visible defects were observed in the patch cross-section.

Testing

Optical microscopies were performed in the patch region, void contents of 0.82, 1.19 and 2.06% are found for the patches with 1, 3 and 5 mm, respectively. It is observed that the void content (Fig 2) increases with the thickness of the patch. This is because in the VAP process the resin impregnation occurs in the direction of the thickness, thus, the thickness is a critical factor of the process and thinner patches tend to have better infiltration quality.

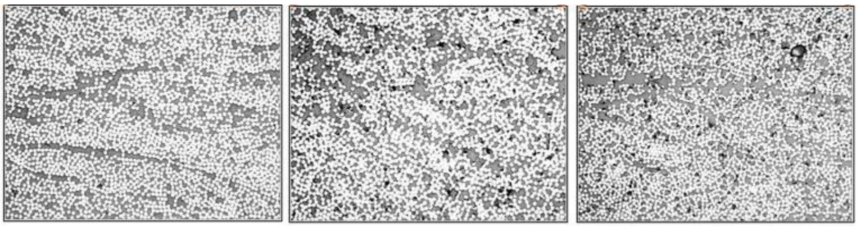

Figure 2 – Porosity measurement in the (a) 1 mm; (b) 3 mm; and (c) 5 mm patch region.

The DSC results for the prepreg samples are shown in Fig 3. It is observed that for the first heating cross-linking occurs, which is accompanied by the release of heat, thus generating a well-defined exothermic peak at ~152 °C. In the second heating, the exothermic peak disappears and the glass transition temperature (T_g) is of 119 °C. Samples of the AR-260 epoxy resin used to infiltrate the patches are also analyzed. During the first heating cycle, an exothermic peak of ~125 °C occurs and in the second heating cycle the exothermic peak disappears and the T_g is of 84 °C.

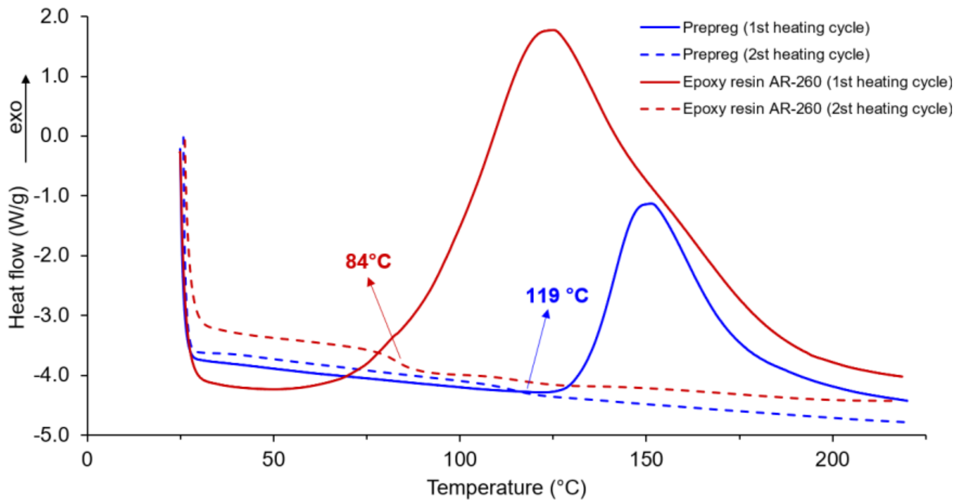

Figure 3 – DSC thermograms of both towpreg and AR-260 resin.

Thus, the curing temperature used in the oven is suitable for the simultaneous curing of both resin systems. The evaluation of the curing process is particularly important, because in the hybrid process, the prepreg resin may not be the same resin used in the infiltration of patches. For the hybrid process to be viable, it is necessary to define a curing time and temperature program that is capable of curing both resins.

Conclusions

This work presented the development of a new hybrid process combining TFP and FW towards locally-reinforce composite cylinders. The patches were positioned along the axial direction of the cylinder and the manufacturability of this new process was evaluated. Important insights into the hybrid process were obtained: the shape of the patches must have a smooth contour so the filament wound layer fully covers the patch, avoiding the formation of voids or resin rich area. The VAP infiltration process proved to be adequate, generating a low void content, although increasing the thickness of the patches increased the void content. The DSC tests allowed to define an adequate curing cycle of both towpreg and the resin used in the infiltration of the patches.

The FW+TFP process proved to be feasible, and the layout of the patches presented here demonstrated the possibility of positioning fibers along the longitudinal direction of the cylinder at an angle that is not possible via the FW process. Next steps of this research include the coupling of other patch shapes and also tailor patches around discontinuities onto the filament wound cylinder.

Acknowledgements

This work is supported by both FAPESP/FAPERGS (project number 19/2551 and 2019/15179-2) and CAPES/DAAD PROBRAL (project number 88881.198774/2018-01) grants.

References

1. T.V. Lisbôa; J.H.S. Almeida Jr; I.H. Dalibor; A. Spickenheuer; R.J. Marczak; S.C. Amico *Polym. Compos*, 2020, *41*, 2446.
2. I.H. Dalibor; T.V. Lisbôa; R.J. Marczak; S.C. Amico *Eur J Mech A Solids* 2020, *82*, 103994.
3. Q. Wang; T. Li; B. Wang; Q. Huang; M. Ren *Compos. Struct.* 2020, *346*, 112432.
4. J.H.S. Almeida Jr; M.L. Ribeiro; V. Tita; S.C. Amico *Mater. Des.* 2016, *96*, 431.
5. L. Zu; S. Koussios; A. Beukers. *Compos. Struct.* 2010, *92*, 339.
6. L. Zu; H. Xu; H. Wang; B. Zhang; B. Zin *Compos. Struct.* 2019, *207*, 41.
7. I.H. Dalibor; T.V. Lisbôa; R.J. Marczak; S.C. Amico *J BRAZ SOC MECH SCI*. 2019, *41*, 1.
8. K. Uhlig; L. Bittrich; A. Spickenheuer; J.H.S. Almeida Jr *Compos. Struct.* 2019, *222*, 110910.
9. L. Bittrich; A. Spickenheuer; J.H.S. Almeida Jr; S. Müller; L. Kroll; G. Heinrich *Math. Probl. Eng.* 2019, 2019.
10. A. Spickenheuer; M. Schulz; K. Gliesche; G. Heinrich *Plast. Rubber Compos.* 2008, *37*, 227.
11. S. van Oosterom; T. Allen; M. Battley; S. Bickerton *Compos. Part A Appl. Sci. Manuf.* 2019, *125*, 105528.