FORMING OF A 0/90° HEMISPHERIC PART FROM A FLAT PREFORM MADE BY TAILORED FIBRE PLACEMENT

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Introduction

Reducing production costs and its environmental impact while maintaining or increasing the mechanical properties of engineered fibre-reinforced composite (FRC) parts is the challenge aeronautic, automotive or energy industries have to take up. Manufacturing 3D optimized FRC requires leveraging the potential of fibrous reinforcements by taking full advantage of the intrinsic anisotropy of fibres. Optimization of parts made from regular fabrics obtained by weaving, knitting or stitching often lead to quasi-isotropic parts due to the complexity of the loading path and the intrinsic limitation of unidirectional reinforcements' stacking. Fibre placement technologies like Automated Fibre Placement (AFP), Continuous Tow Shearing (CTS) or Tailored Fibre Placement (TFP) technologies are a class of additive manufacturing process that allow manufacturing nearly net-shape preforms with continuously varying orientations and thickness by depositing fibres only where necessary.

More precisely, flat TFP preforms are made of one continuous tow laid down on a backing material and following prescribed curvilinear paths. This tow remains in place thanks to a zigzag stitching. TFP offers a large choice of combinations for the backing material, fibre tows and stitching yarn. A single TFP preform can be made of several tow materials and the backing material can be a polymer film or woven or non-woven fabrics for example. Dry or commingled tow is used depending on the forming process involved. The stitching yarn material is usually polyester although higher performance materials are possible options. This technology allows a whole preform to be manufactured or can be used to locally reinforce a flat preform made of another fibrous reinforcements like woven fabrics or Non-Crimp Fabrics (NCF).

During forming, fibre motion inevitably occurs. Consequently, determining the flat TFP preform from the desired 3D optimized part, i.e. the flattening, is not straightforward. Since flattening cannot be investigated experimentally, the proposed work focused on modelling the forming of flat TFP preforms using the finite element method as a first step. To the knowledge of the authors, this is the first contribution to the numerical forming of flat TFP preforms. Some works [1, 2] investigated the experimental folding of flat TFP preforms or the influence of cuts in the backing material to avoid formability issues for complex varying orientations on doubly-curved shapes [3]. To validate the proposed modelling strategy, the forming of a dry TFP preform to obtain a 0/90° hemispheric part has been performed both experimentally and numerically.

Finite element model of a TFP preform

The TFP modelling strategy presented in this work uses the finite element method in an explicit time integration framework. It focuses on tracking the tow orientations during forming. Since continuously varying orientations can be achieved in a TFP preform, a semi-discrete approach has been chosen allowing representing tows explicitly. Two models are proposed that offer the option of retaining or removing the backing material before forming. Both, models are based on an embedded element formulation which assumes the stitching yarn to act as a perfect bond between the backing material and the tows or between layers. In the first model (Model I), the tows in each layer are considered to be fixed on the backing material. In the second model without backing material (Model II), a perfect bonding is assumed between adjacent layers at tows' intersections due to the stitching. In both models, tows are modelled using 2-node shear flexible beams. In Model I, the backing material is modelled using 2D elements.

Experimental and numerical forming of a 0/90° hemispheric part

To demonstrate the potential of TFP to manufacture FRC with complex orientations and large fibre orientation changes during forming, hemispherical forming of a dry flat 2-layer TFP preform has been performed both experimentally and numerically. The TFP preform have been manufactured using soluble PVA film as backing material, E-glass/PET tows and polyester stitching yarn. The 2D orientations allowing obtaining a 0/90° hemispheric part have been determined by analytical flattening assuming fibre inextensibility and no slip between the preform's components. Parallels of latitude and meridians of longitude were the targeted 3D orientations. Fig.1 shows the results of both experimental and numerical forming. The alignment with the targeted orientations is not fully achieved but shows good accuracy of the numerical model.

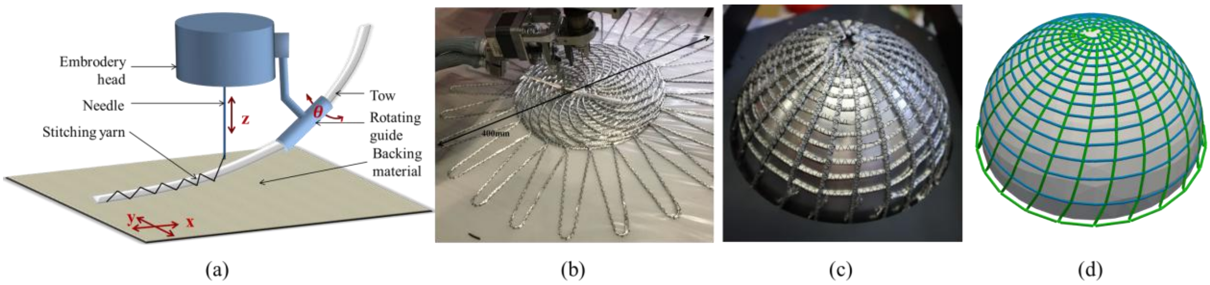

Fig. 1 – TFP principle (a), manufactured flat preform (b), experimental (c) and numerical (d) results of the forming of a 0/90° hemispheric part

Conclusions

The modelling of the forming of dry and thin TFP preform has been investigated. Two finite element models are proposed to take into account the possibility of retaining (Model I) or removing (Model II) the backing material of TFP preforms. Model II is validated by forming on a hemisphere a dry preform with 0/90° curvilinear orientations. The numerical and experimental results are in good agreement, demonstrating qualitatively the efficiency of Model II when the backing material has been removed from the TFP preform.

Finding a suitable backing material that allows for very large deformations and stitching is difficult. Therefore Model I was validated only numerically. In future works, Model I can be improved to take into account tow-to-backing material slippage, while conserving the embedded element formulation. Model I could be used to model the forming of TFP preforms where the backing material is another type of fibrous reinforcement such as woven fabrics or Non Crimp Fabrics. Interactions and slippage between tows should also been incorporated for a better modelling of the forming of TFP preforms.

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