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Intra-ply yarn sliding defect in hemisphere preforming of a woven preform

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ABSTRACT

Preforming is the first step to manufacture a complex composite part via Liquid Composite Moulding processes. The defects that may be encountered during this phase within the preform architecture may decrease the expected mechanical performances of the final part. The intra-ply yarn sliding is a defect frequently observed during preforming of a woven preform but its mechanism is far from being fully understood. The aim of this study is to analyse the mechanism of this defect arising when preforming of a carbon woven fabric into hemispheric shape. An experimental study followed by analytical analysis was performed to evaluate the effect of the process parameters, material properties and ply configuration conditions on the yarn tension and contact stresses. A significant effect of the yarn tension and the contact shear stresses on the defect occurrence was demonstrated. Based on this analysis, solutions were tested with success to prevent this defect.

1. Introduction

To manufacture complex composite parts, Liquid Composite Moulding (LCM) processes [1] offer a good compromise in terms of repeatability, production rates, low-energy consumption and low final cost [2]. The first step of these processes consists in draping a dry preform before the liquid resin is injected. Preforming is a difficult phase, and the physical mechanisms are complex because they depend on many parameters (shape of tools, characteristics of the preform, number and orientation of plies, loads applied, etc.). If the mechanical loadings (tension, shear, compression, bending, friction, etc.) to which the reinforcements are subjected during the preforming step have been well described in the literature [3–6], the generation and the control of defects are far from being entirely understood. At the macroscopic scale (preform scale) wrinkling is one of the defects that occurs most often. Boisse et al. [7] recently explained that the frequency of occurrence of the wrinkling defect was related to the weak textile bending stiffness due to possible slippage between fibres. Several numerical [8–10] and experimental [11–13] studies focused on the influence of blank holders or other systems to prevent wrinkles. These tools confer global tensile deformations at their vicinity and it was demonstrated that induced tensile forces in the fibre direction prevent wrinkling [14]. In the case of preforming tests on complex shapes of multilayer, which are the subjects of recent papers [2,14–16], Nezami et al. [17] underlined that, friction-based blank holders or other systems may reduce wrinkling, but induce other defects in the fabric, such as parallel fibre distortions without gaps, fibre distortions with small/large gaps, filament damage, broken or pulled out roving. Except for filament damage, these defects occur at the mesoscopic scale (tows, yarn). This is also the case of tow buckles. This defect is described in [17–20]. It can be reduced by the control of tensile deformation as shown in [21]. Another type of defects, less studied in the literature, can be defined as intra-ply slippage which occurs between the warp and the weft yarns of a woven reinforcement. In this case, the tow or yarn orientation cannot be controlled during the preforming step and the local pore spaces are thus modified. Large empty spaces can be observed between the yarn. Locally, the density of fibre may be reduced to very low values. As a consequence, the local permeability components for the injection steps [22], [23] are drastically modified, and one can expect to obtain resin rich zones within the composite part. This surely means that zones of weakness for the composite part are created. Allaoui et al. [13] have experimentally shown large yarn slippage on the vertical faces of a glass plain weave prismatic preform. Boisse et al. [7] described the numerical complexity to model this loss of cohesion of the woven network [24], and the need to use mesoscopic finite element models to allow the possible slippage between yarns. This slippage mechanism was also described during the bias-extension test [3,25], especially for large shear angles. During this test where the analytical kinematic [26,27] can predict theoretically the shear angle, the differences observed with measured angles can be explained by this slippage between yarns as the

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theoretical kinematic is based on non-slippage mechanisms. This slippage phenomenon is localised at the intersection of the three zones classically defined in this in-plane shear test. Concerning the in-plane shear behaviour identified by the bias-extension test of an unbalanced woven fabric, Barbagello et al. [28] noted the presence of measurable yarn slippages (up to a maximum that is around 10% of the total length of the yarns). In papers dedicated to the preforming of NCF fabrics [29–30] intra-ply slippage between fibres has been observed, without solutions to prevent or reduce this defect qualified as irreversible in [30]. Except in these studies, few articles of the literature deal with this type of defect. In this paper, experimental preforming tests were conducted on a carbon twill weave fabric. The slippage phenomenon occurred in zones with low shear angles, for specific ply orientation. Yarn tensions were analytically computed relatively to tools load to understand this slippage defect. The influence of the ply orientation and the ply dimension were experimentally studied to reduce tension in yarns and reduce this slippage. Finally, solutions based on the geometry of tools were proposed to prevent this type of defect.

2. Experimental conditions

2.1. Forming machine

Fig. 1 shows the experimental preforming machine developed at the GEMTEX laboratory [16,31]. The machine is composed of three basic parts: a punch and two square-shaped plates. In this study, a punch with hemisphere geometry (double curved surface) of a diameter of 100 mm was used. The punch movement is controlled by a pneumatic actuator with a constant mounting speed (45 mm/s).

Both upper and lower plates are a square shaped plate of 300 mm side length. The upper plate is made of Plexiglas and it has a thickness of 20 mm. Both plates have a circular hole in its centre. The hole diameter of the upper plate is 110.8 mm and its corner edge is machined from the fabric side. The lower plate is fixed into position whereas the upper one is mobile, parallel to the punch axis. This allows the arrangement of the fabric ply between the two plates in the desired orientation. The upper plate is subjected to a normal pressure applied by four pneumatic actuators placed on the plate corners. This normal pressure is controlled by the pressure of the compressed air supplied to the actuators. The experiments were conducted with two operating pressures 0.025 and 0.075 MPa that correspond to normal forces by each cylinder equals to 77.9 and 233.7 N respectively, according to the actuator specifications. These operating pressures were chosen after a first preliminary set of test and are related to the appearance of the intra-ply yarn sliding defect. When the minimum operating pressure (0.025 MPa) is applied, no sliding defect occurs. From an applied operating pressure of 0.075 MPa this defect takes place. The upper plate is considered as the blank-holder because it is the mobile plate and the normal force (P) is applied on its top surface, Fig. 1. The force (P) is called the holder force all over this paper. The lower plate is considered as the die since it is fixed into position in this machine configuration. For each experiment, the preforming force exerted by the punch is recorded as a function of the punch displacement. The force measurement is performed by means of a load cell mounted between the punch and the driving actuator. Also, the ply draw-in, border position and yarn arrangement after preforming are captured by a CCD camera. The camera is placed on the top side and its optical axis is aligned with the punch movement path.

2.2. Material properties and ply geometry

The commercial fabric “Hexcel HexForce 48,600 U 1250” was used in this study to perform the experimental work. It is classified as a 2D woven fabric made with a twill 2/2 weaving architecture and constructed of 3.7 warps/cm and 3.7 wefts/cm with a nominal area density of 600 g/m^2 and a nominal thickness of 0.62 mm. The constituent yarns, both warp and weft, are “AS4 C GP 12 K” high strength carbon fibres and they have a linear density of 0.8 g/m. Both yarns are not twisted and not powdered.

The forming tests were conducted using one ply of the woven fabric cut in a square shape with 260 mm side length. The fabric specimens were visually inspected and specifically chosen so that they are free of defect at the beginning of the forming test. The tests were performed using two initial orientations (0° and 45°) of the fabric on the die as presented in Fig. 2. The dashed lines sketched on the ply in Fig. 2 represent the warp and weft yarns passing through the punch main axis and aligned with the radius of the hole. These yarns are called radial yarn in the next sections. On the 0° orientation ply, the warp and weft yarns are parallel to the plate side edges, Fig. 2-a. For the 45° orientation, the warp and weft yarns are parallel to the plate diagonal and

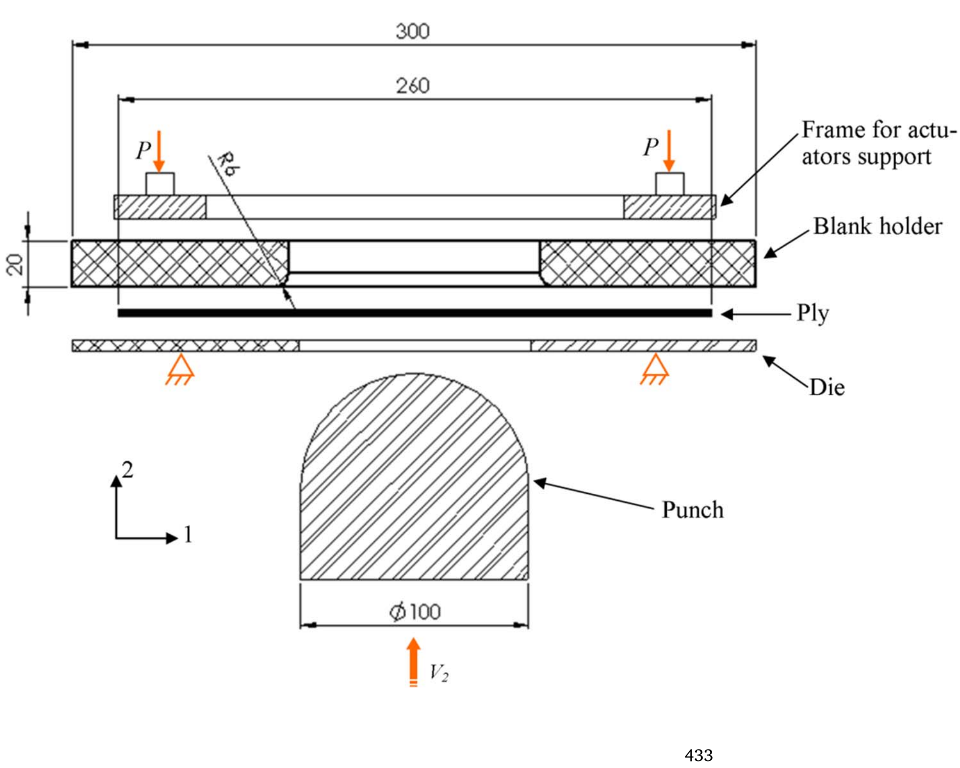

Fig. 1. Forming machine scheme with characteristic dimensions. All dimensions are in mm.

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