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Experimental and numerical analyses of manufacturing process of a composite square box part: Comparison between textile reinforcement forming and surface 3D weaving

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A B S T R A C T

Textile reinforcement forming is frequently used in aeronautic and automobile industries as a composite manufacturing process. The double-curved shape forming may be difficult to control and can lead to defects. Numerical simulation analysis can predict the suitable forming conditions and minimize the defects. Wrinkling as one of the most common flaws can be experienced easily during textile composite forming for certain specific shapes, for example the square box. In order to product a composite square box without wrinkles, a surface 3D weaving process has been developed to weave directly the shape of final part without the step of 2D preforming. In the surface 3D weaving the three directions are completely designed. The warp and weft yarns on all the surfaces of square box are absolutely under control and the final 3D ply has a homogeneous fibre volume fraction.

1. Introduction

Textile reinforcement forming is an important stage in Resin Transfer Moulding (RTM) process which has shown the potential to produce complex composite parts with double curvatures. Depending on the geometry of the final composite parts, on the fabric characteristics (weaving, properties of the fibres,…) and on manufacturing parameters (tool loads, blank-holder pressures,…), the double-curved shape forming may be difficult to control and can lead to defects, such as wrinkling, buckling, fibre fracture, slippage of network…, when the composite parts have high curvatures and large deformations. Forming stage will have a significant influence on the resin flow impregnation by the modification on the permeability [1–4] and on the characteristics of the final composite part [5–8]. In this case, numerical simulation analysis of dry textile reinforcements should be performed to predict the feasibility forming conditions, optimize the main forming parameters and minimize the manufacturing defects [9–18].

Wrinkling as one of the most common flaws can be experienced frequently in both dry textile reinforcement forming [9,13,19] and prepreg fabric forming [16,18]. The possible relative motion of fibres due to the internal composition of textile reinforcement leads to a very weak bending stiffness [7,20]. Boisse et al. [13] have underlined that wrinkling is a global phenomenon depending on all strains and stiffnesses and on boundary conditions of forming. Wrinkles modify strongly the local fibre volume fraction and have a negative influence on the performance of the final composite part. In the manufacturing of certain specific parts such as the square box (Fig. 1), wrinkles can be developed easily in the corners.

Many studies have been done about the textile composite forming of hemispherical [21–23], double-dome [10,24,25], and tetrahedral shapes [9,13,25], but few research work has deal with square box [26,27]. In order to product a composite square box replacing the aluminium part in some aeronautical applications, the present paper presents two possible manufacturing processes: textile composite forming and surface 3D weaving. The experimental and numerical studies about the textile forming with a square box punch show that it is easy to experience the winkling onsets. As one alternative to the forming process, a surface 3D weaving method is proposed. During the last decade the weaving technology has been well developed. In 2006, Kamiya et al. [28] have shown the advanced fabrication methods for 3D textile fabrics. Then Lou et al. [29] described the important parameters during weaving process and Chen et al. [30] demonstrated the fabrications of different 3D textile architectures. Bilisik et al. [31] continued the studies of weaving process and focused on the Multiaxis structure.

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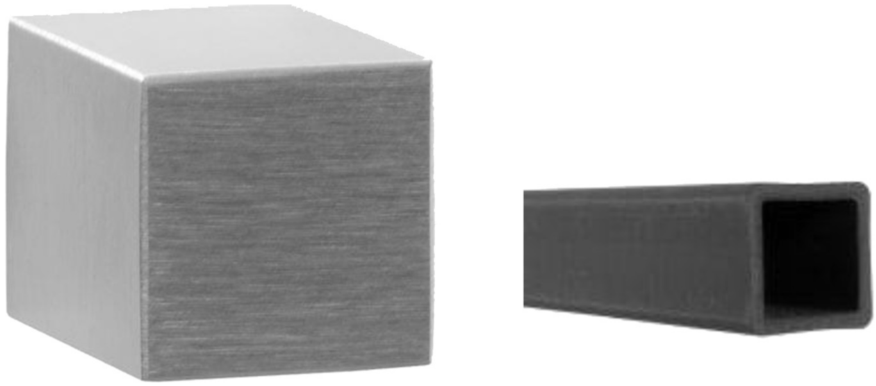

Fig. 1. The square box part.

Recently, a new numerical model has been developed by Vilfayeau et al. [32] to analyze the weaving process for 2D fabrics. Based on these contributions on weaving process, the surface 3D weaving can weave directly the shape of final part without the preforming stage on 2D fabrics as the three directions are completely designed. A comparison between the textile reinforcement forming and the surface 3D weaving will be carried out. Some quality criteria of deformed fabric will be analyzed, in particular the orientation of the yarns and possible manufacturing flaws. By using the surface 3D weaving technique, a square box without any wrinkles can be obtained. The final 3D preform has a homogenous fibre volume fraction due to the warp and weft yarns under well-controlled.

2. Textile reinforcement forming

2.1. Experimental forming with a square box punch

The experimental forming with a square box punch is performed on a specific preforming device shown in Fig. 2a [33]. This device permits to analyze the possibilities of the double-curved shape manufacturing with a given textile reinforcement in different forming conditions. The principle properties of the used textile fabric (Fig. 3) are noted in Table 1. The surface dimensions of the specimen are 300 mm × 300 mm. Four pneumatic jacks apply an adjustable pressure on blank-holder. In order to measure the important forming parameters by optical method such as material draw-in, intraply shearing, wrinkles…, the "open-die" forming system and a transparent blank-holder are used. Another pneumatic jack linked to the punch imposes a movement and control the stroke of punch. A load sensor acquires the punch force during the forming. Fig. 2b describes the diagram of the forming and the main dimensions of the tools.

Figs. 4 and 5 present the square box forming with 0°/90° and −45°/45° plies at a weak pressure of blank-holder (0.05 MPa). The pressure value is the one of the pneumatic jack and this pressure is applied homogenously on the blank-holder. The forming stage corresponds to a 85 mm displacement of punch. The in-plane shear angles on the upper surface and lateral surfaces of deformed 0°/90° ply inferior to 5° are measured due to the very weak intraply shearing effects (Fig. 4a). On the contrary, the strong shear effects corresponding to an in-plane shear angle superior to 60° are observed on the corners of the square box. Consequently, large wrinkles are developed (Fig. 4b).

In Fig. 5, the in-plane shear on the upper surface of deformed −45°/45° ply is negligible. However, the important in-plane shear effects corresponding to a 25°–35° shear angle can be noted at two triangular zones shown in Fig. 5a. As same as the forming of 0°/90° ply, the maximum in-plane shear angle can be observed on the corners (around 50°) and this strong in-plane shear effects leads to wrinkles (Fig. 5b). As the wrinkling depends on the fabric characteristics, the form and size of the wrinkles are different in the forming for 0°/90° and −45°/45° plies (Figs. 4b and 5b).

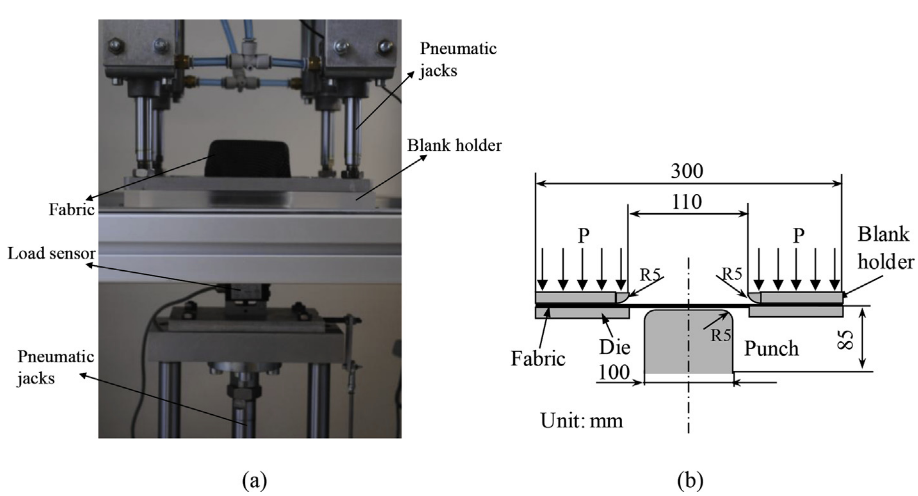

Fig. 2. Preforming with a square box punch.