Composites: Part B 62 (2014) 29–36

Contents lists available at ScienceDirect

Composites: Part B

journal homepage: www.elsevier.com/locate/compositesb

Complex shape forming of flax woven fabrics: Design of specific blank-holder shapes to prevent defects

Emilie Capelle [a,c], Pierre Ouagne [a,*], Damien Soulat [b], Davy Duriatti [c]

[a] Univ. Orléans, PRISME EA4229, F-45072 Orléans, France
[b] GEMTEX, ENSAIT Roubaix 2 allée Louise et Victor Champier, 59056 Roubaix, France
[c] Groupe Depestele, BP 21, 14540 Bourguebus, France

ARTICLE INFO

Article history:
Received 14 November 2013
Received in revised form 15 January 2014
Accepted 4 February 2014
Available online 18 February 2014

Keywords:
A. Fabric/textile
A. Preform
A. Tow
E. Forming
Defect

ABSTRACT

This study concentrates on the possibility of forming a complex shape such as a tetrahedron using two untwisted commercial flax based fabric reinforcements using the sheet forming process. As some of the defects such as tow buckles or tow sliding cannot be predicted and therefore anticipated using simulation techniques, an experimental approach has been used to optimise the process parameters during forming. Specially designed blank holders were used to apply local adapted pressures to the fabric to reduce the pressure in excessively strained tows and to increase the strain in others. The defects previously encountered using a non-optimised blank holder set have been suppressed to a large extent suggesting that most of the commercial untwisted flax based fabrics that enable the best composite properties and best fibre volume fractions can be used to generate the most complex shapes.

1. Introduction

Due to their weight reduction capability, composite materials could be advantageously used in the automotive industry where large weight reductions are targeted and required by the regulation authorities [1,2]. In the present time, structural composite materials are mostly limited to high value products. It mainly concerns large panels such as bonnets. Some more weight reduction could be performed by manufacturing more complex structural or semi-structural parts. For many applications, natural fibre based composites could be used to manufacture these parts [2] because they are very light weight and show excellent properties that are generally comparable to the ones of glass fibre composites [3–5]. Moreover, the use of natural fibre composites could contribute to limit the impact of the part on the environment as renewable and recyclable (especially if thermoplastic matrix is used) resources are used [6,7]. Several review papers deal with the subject of natural fibres and demonstrate the high potential of these composites [8–15].

To manufacture such structural or semistructural parts, long aligned fibre reinforcement materials need to be used. For complex shape manufacturing, woven fabrics are generally considered as their in-plane shear ability allows the membrane to take up the complex geometries required [16,17]. Different woven fabrics can be considered. Because the natural fibres have a finite length, a first structure at the mesoscopic scale needs to be manufactured before the weaving stage. Numerous types of yarns or tows submitted to different surface treatments can be considered [18–22]. Dry spun yarns show high tensile properties. This is particularly interesting as these ones do not break during fabric manufacture, and high blank holder pressures can be applied during forming. However, their main drawbacks concern the fact that the spinning process consumes large amounts of energy, and also the fact that composites processed with spun yarn fabrics show lower properties than composites manufactured from tow based fabrics [23]. Moreover, larger spaces can be observed close to the crimp areas. The use of hopsack type reinforcement [24] could solve some of the previously mentioned problems, as the yarns are manufactured with aligned fibres held together by a helicoidal smaller yarn and the main yarns are woven with a plain weave style therefore limiting the spaces at the crimp areas. However, the manufacturing of such reinforcement requires a lot of different steps and operations and it can be expected that the energy consumption may be larger than for flat tow based woven fabric. Moreover, for flat tow fabrics, less space is left close to the crimp area and higher volume fractions can be expected and therefore higher mechanical properties.

Several processes can be used to manufacture such parts (manual technique, in situ weaving, etc.) but only resin transfer moulding (RTM) [25] or compression moulding with comingled

* Corresponding author. Tel.: +33 2 38 41 73 32.
E-mail address: pierre.ouagne@univ-orleans.fr (P. Ouagne).

http://dx.doi.org/10.1016/j.compositesb.2014.02.007
1359-8368/

fabrics [26–28] can be considered as these processes offer sufficient production rates for the automotive industry. The impregnation of the reinforcement by the fabric is mainly controlled by the compressibility and permeability parameters [29–31]. To give its shape to the part before or in the mean time of the impregnation phase, the sheet forming technique offers good production rate/cost ratio. However, previous studies have indicated that forming defects may appear. Particularly, wrinkles and vacancies have been encountered when dealing with the forming of spherical based shapes [32]. To avoid wrinkles, it is possible to increase the membrane tension by increasing the blank holder pressures [33]. This should be performed with care as sliding of tows leading to large vacancies could also appear [34]. Moreover, excessive membrane tension could lead to high tensions within the tows constituting the fabric. While this is not a problem with carbon or glass fabrics, high tensions should be avoided in natural fibre based fabrics manufactured with flat aligned fibre tows [35] as sliding of fibres within the tow can lead to local losses of fibre density. A compromise needs therefore to be found between the increase of the membrane tension to reduce the wrinkling defect and the need to keep low blank holder pressure to avoid sliding of tows and too high strains of the tows. Numerical methods can be used to predict the appearance of wrinkling defects [36] but it is not possible to predict defects arising in more complex shapes such as tow buckling, [37,38]. As a consequence, an experimental approach needs to be used. To prevent the appearance of this particular defect, specifically designed fabric architectures can be used and this has permitted a complex tetrahedron shape to be formed without any defect [39]. However, in the case of forming necessitating very high shear deformations, this reinforcement would probably not be suitable, and this is why it would be very interesting to investigate the possibility of forming complex shapes without any buckle appearance with commercially available woven fabrics, particularly with the ones showing good shear abilities. To reach this goal, it is important to study and optimise the process parameters. The design of the blank holders used in our previous studies was not optimised to minimise tow buckles [39] nor to avoid excessive strain in some of the tows [40]. The present study was therefore undertaken to optimise the process parameters controlling the sheet forming process during complex geometry forming of natural based fabrics to avoid the appearance of defects such as tow buckling and excessive tow tensile strains. To reach this goal an experimental approach had to be used as no simulation codes are able to detect these defects. The goal of the study was to locally apply the right blank holder pressure using a specifically designed blank holder set.

2. Experimental procedures

2.1. Sheet forming device for dry textile reinforcement

A sheet forming device presented in Fig. 1 was especially designed to analyse the possibility to form reinforcement fabrics. Particularly, the device was developed to examine the local deformations during the forming process [34,41]. The device is the assembly of mechanical part and an optical part consisting of video cameras associated to a marks tracking technique [42]. The mechanical part consists of a punch/open die system coupled with a classical blank-holder system. The punch used in this study (Fig. 1b) is a tetrahedron form with 265 mm sides. Its total height is 128 mm and the base height is 20 mm. A classical multi-part blank-holder system is used to prevent the appearance of wrinkling defects during the preforming tests by introducing tension on the fabric. It is composed of independent blank-holders actuated by pneumatic jacks that are able to impose and sense independently a variable pressure. The quality of the final preform is dependent on several process parameters such as the dimensions, positions, and the pressure applied by each of the blank-holders. These parameters can be easily changed to investigate their influence on the quality of the final preform [43].

2.2. Design of a new generation blank holder system

As mentioned in the Introduction part, several defects may appear during the sheet forming of complex shapes such as a tetrahedron. Both the tow buckles and the excessive tensile strain in tows are localised in zones close to the tows passing by the top of the tetrahedron as indicated in Fig. 2a by the black arrows [35]. In this

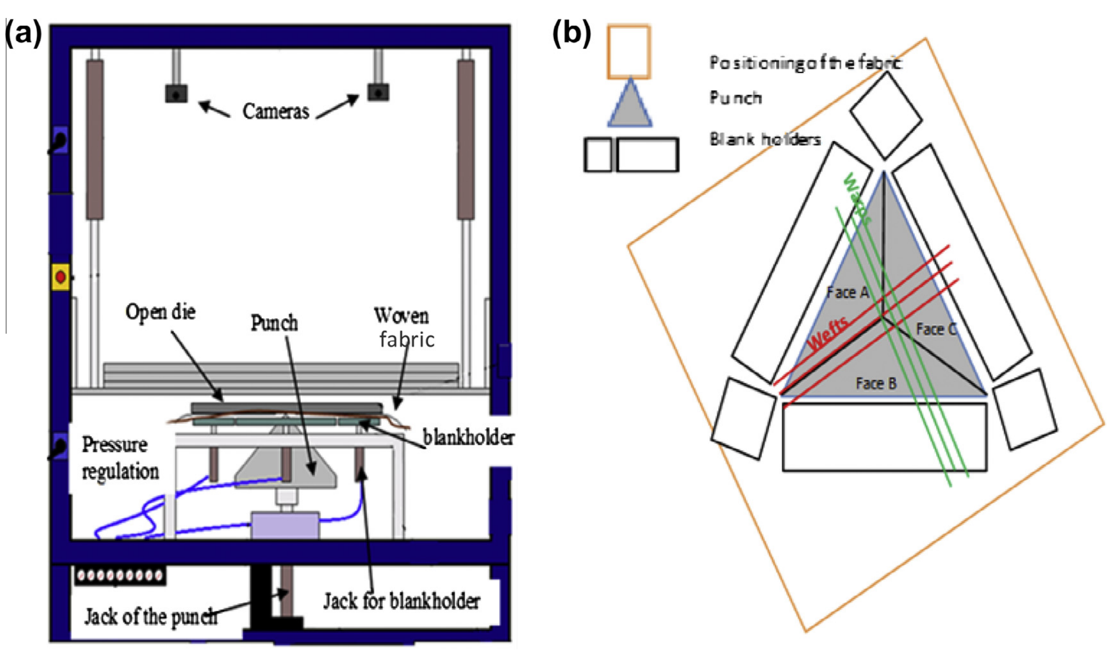

Fig. 1. (a) The sheet forming device. (b) Initial positioning of the fabric and first generation blank holder design.