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Analysis of the deformability of flax-fibre nonwoven fabrics during manufacturing

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ABSTRACT

The use of natural fibres for technical advanced products such as composites is widely increasing with the view to reduce the impact of the material throughout its life cycle on the environment. Some work has been performed on natural fibre based reinforcement textiles for composite materials. The mechanical and the formability behaviours of woven fabrics has particularly been characterised. However, few research work concerns the forming aptitude of nonwoven fabrics despite promising preliminary studies. In the present work, the mechanical characterizations of flax-fibre nonwoven reinforcements are carried out firstly. Then the forming tests of the nonwoven fabrics are performed to quantify their formability behaviour. The tensile and forming tests showed very different mechanical behaviours in comparison to the ones observed on woven fabrics due to the non-uniformity of nonwoven fabric. The high deformation potential of the nonwoven fabrics is established. The specific behaviour of the nonwoven fabrics is studied by analysing the local and global deformation mechanisms of the reinforcement during forming. Moreover, the manufacturing defects experienced in nonwoven fabric forming are demonstrated. The slippage/damage of network is a typical problem in the nonwoven fabric forming, which depends strongly on the fibre density (area density) of fabric and blank-holder pressure.

1. Introduction

According to INDA (the North American Association of the Nonwoven Fabrics Industry) “nonwoven fabrics are broadly defined as sheet or web structures bonded together by entangling fibre or filaments (and by perforating films) mechanically, thermally or chemically. They are not made by weaving or knitting and do not require converting the fibres to yarn [1]. Nonwoven fabrics are used in the automotive industry for a variety of applications due to their lightweight, sound efficiency, flexibility, versatility and easy tailored properties, low process and materials costs as well as an attractive cost/performance ratio [2,3]. They are playing a key role in the automotive market. They can be found in cabin air filters, in moulded seat coverings, headliners, trunk liners and carpeting [4]. They can also provide interesting properties as lining materials because of their ease of handling, their shape adaptability characterised by a high formability potential [5–9]. Such materials can be manufactured by bonding together fibres or bundles to create a nonwoven network.

Nonwoven fabrics are manufactured in one continuous process directly from the raw material to the finished fabric [10]. This is particularly interesting to minimise the production cost and the impact on the environment [11]. Because of the low mechanical properties of composites manufactured from random nonwoven mats, researchers in recent years have been looking for highly aligned, yarn-based natural fibre reinforcement structures for the manufacture of composite components in load-bearing applications [12]. Miao et al. [12] compared, in the case of natural fibre based materials, the mechanical properties of thermoplastic composites elaborated from un-oriented fibres to the ones from aligned fibre yarns. By using an Ashby method, Shah [13] recently proved that the absolute and specific tensile properties of PFRP (plant fibre reinforced plastics) manufactured using nonwoven fabrics are globally 2 to 20 times lower than unidirectional reinforcement based composites. However, the ones elaborated from nonwoven based fabrics outperform unidirectional and multiaxial PFRPs in terms of property per unit cost. If all these studies mainly deal with the tensile mechanical behaviour of composites manufactured from nonwoven reinforcements, the identification of the mechanical properties of dried nonwoven preform has not been widely studied

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[14]. Experimental analysis conducted by Farukh et al. [14,15] showed significant tensile strain abilities in the 50% range. They also showed that strong anisotropy in mechanical property could be observed because of the non-uniform orientation distribution of the fibres within the nonwoven structure. High deformability properties which are an advantage during manufacturing processes of composite materials may therefore be observed as a consequence of the large tensile strain abilities of the nonwoven fabric.

Resin Transfer Moulding (RTM) [16] is one of the main manufacturing process to produce composite parts for the transport industries [17,18]. A lot of experimental [19–26] and numerical [27–32] studies concerning the draping stage of dry reinforcement, the first step of RTM process, were carried out to analyse the deformability of different reinforcements on more and more complex shapes. Many studies have been conducted about the preforming of carbon, glass and also natural fibre textiles in woven fabrics [20,21,25,33,34], Non-Crimp- Fabrics [35–37], 3D interlock [38], weft-knitted fabric [39], and more recently braided reinforcements [40] were considered. However, the deformability of nonwoven reinforcements during the preforming step was not studied on the contrary to the resin flow characteristics (permeability) of natural fibre nonwoven during the injection step [41–43]. The behaviour of highly aligned reinforcements (woven, braided knitted, etc…) during the preforming step is characterised by complex coupled tensile, in-plane shear, bending but also and compaction deformations [28]. Criteria to define the feasibility to realize a particular shape are based on limits of these deformations, such as the locking angle [28,44,45] for the in-plane shear behaviour. Because of their manufacturing processes leading to a non-uniform orientation distribution of their fibres, the anisotropy and non-uniformity of nonwovens cannot be avoided. Consequently, the definition of criteria characterising the deformability during the preforming stage cannot be the same to the ones of highly aligned reinforcements. This study is dedicated to an experimental approach on the deformability of dried natural fibre nonwovens on a preforming device. A punch and die system was used to form hemispherical geometry and also a more complex square shape.

2. Materials and methods

Flax tows (Linum usitatissimum L. from the Normandy area of France) were used as reinforcement fibres in the nonwoven. The description of the fibres is presented in Table 1. The industrial flax-fibre nonwoven was manufactured according to the carding/overlapping/needle punching technology [4] by EcoTechnilin SAS in France under its commercial name Fibrimat. Two nonwoven reinforcements with the areal densities of 300 g/m2 (F300) and 450 g/m2 (F450) are considered in this work. F300 and F450 share the same manufacturing process. A dry process involving carding during which the fibres are bound together and parallelized in the machine direction to form a batt is used before undergoing bonding by the needling process. The main properties of the flax-fibre nonwoven preforms are given in Table 2. The areal density and the thickness of nonwoven were measured according to the standard methods ISO 3616 and ISO 9073 respectively. It can be noted that the standard deviation of the areal density is relatively high (10%) and is due to the non-homogeneity of both fabrics.

Table 1
Description of the flax fibres.

Reinforcing fibre	Flax
Origin	France
Average fibre length (mm)	80
Density (g/cm^3)	1.45
Colour	Natural

Table 2
The main properties of the flax-fibre reinforced nonwoven fabrics.

Nonwoven fabric	F300	F450
Manufacturer	EcoTechnilin (France)	
Production method	Carding/Needling	Carding/Needling
Area density (g/m^2)	300 (±30)	450 (±45)
Thickness (mm) (pressure 1 KPa)	2.50 (±0.02)	3.52 (±0.37)

The mechanical characterization of nonwoven fabric in both Machine and Cross directions (MD and CD) was performed in this work. During the tensile test, it was observed that the specimen did not deform homogenously. Large local area density variations can be observed during the test. Consequently associated to global mechanical responses, it is necessary to perform more local analysis. Ten local zones are defined to analyse the evolution of their surfaces during the tensile tests as shown in Fig. 1. Five symmetric up and below zones are defined on each test specimen. Each zone has the same initial surface area. Each test according to the ISO 13934-1 test method was repeated seven times. The crosshead speed used during the tensile test is 100 mm/min and the dimensions of the sample are 200 × 50 mm^2.

In order to investigate the formability behaviour of nonwoven fabrics during manufacturing, test specimens were prepared. The tested plies were cut in MD and CD (0/90° ply) and also in MD+45° and CD+45° directions (±45° ply). The surface dimensions of the specimens are 250 × 250 mm^2. A mark tracking technique was used to monitor the local deformations of the preform during the forming. The positions of the markers points are presented in Fig. 2. These markers are placed from the centre of the reinforcement to the edges every 15 mm. A video camera installed on the forming device is used to measure the evolution of the markers position.

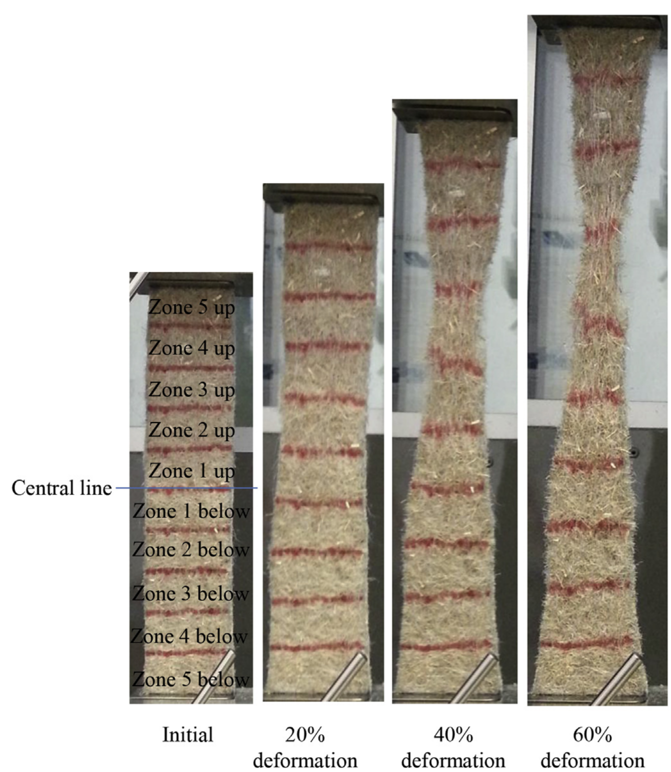

Fig. 1. Tensile specimen with ten zones (e.g. F300, in MD).