

Propriétés thermomécaniques des préformes textiles obtenues par le procédé Tap-Laying

Thermo-mechanical properties of textile-structural preforms obtained through the Tap-Laying process

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Résumé

Dans cet article, les propriétés de déformation du lin/polyamide 12, un textile structurel composite obtenu par le procédé Tap-Laying sont étudiées expérimentalement. Lors de sa fabrication, le renfort ou le pré-imprégné doit être préformé à la forme souhaitée. Le comportement mécanique joue un rôle important dans ce processus. Cependant, ce processus de thermoformage est généralement réalisé à des températures élevées, et le comportement mécanique peut donc être altéré dans cet état. Dans cet article, les propriétés thermomécaniques des fils mélangés lin/polyamide 12 (PA12) et des pièces préfabriquées obtenues par le processus de Tap-laying ont été analysées au moyen d'essais de traction et de flexion dans le plan à différentes températures. Les résultats montrent que l'augmentation de la température en dessous du point de fusion du PA12 améliore la résistance du tissu. En outre, l'ajustement des différentes couches de ruban peut améliorer la résistance des composants pré-imprégnés. Cela suggère que la fluidité du PA12 a un effet significatif sur les propriétés de traction et de flexion.

Abstract

In this article, the deformation properties of Flax/polyamide 12, a textile structural composites obtained by the Tap-Laying process are studied experimentally. The reinforcement or prepreg must be performed to the desired shape during manufacture. Mechanical behavior plays an important role in this process. However, this thermoforming process is generally carried out at high temperatures, and the mechanical behavior can be altered in this state. In this paper, the thermomechanical properties of flax/polyamide 12 (PA12) blended yarns and prefabricated parts obtained by the Tap-laying process were analyzed through in-plane tensile and bending tests at different temperatures. The results show that increasing the temperature below the melting point of PA12 improves the strength of the fabric. In addition, adjusting the different layers of tape can enhance the strength of the prepreg components. This suggests that the fluidity of PA12 has a significant effect on the tensile and flexural properties.

Mots Clés : Composites textiles; Tape-laying; thermoplastique; comportement thermomécanique
Keywords : Textile composites; Tape-laying; thermoplastic; thermo-mechanical behavior

1. Introduction

Thermoformed prepreg that is widely used in smart sports equipment, automotive, and aerospace sectors, is a common method for manufacturing recyclable composite parts. A key step in this process

is transforming the initial flat reinforcement material into the desired three-dimensional shape. The deformability of the reinforcement material plays a crucial role in fiber orientation, which in turn influences the properties of the prefabricated body and ultimately determines the final mechanical quality of the composite component. Kayode et al. [1] studied the impact and flexural properties of flax fabrics based on their structure and the thickness of their outer plies. Furthermore, the preforming process is critical for the manufacturing of advanced structural composites and is closely linked to these mechanical properties. Deformability properties, based on mechanical behavior, have been extensively studied to characterize defects and various shapes [2–4].

For continuous fiber materials, most studies available in the literature focus on the deformability of two-dimensional woven synthetic fiber reinforcements (e.g., glass, carbon). Over the past decade, interest in eco-friendly composites has grown significantly. Numerous studies have been published on natural fibers, bio-based matrices, and their composites [5–8]. Natural fibers are particularly appealing due to their low cost (especially in developing countries), excellent specific mechanical properties, and effective acoustic or vibrational damping capabilities [9]. Despite the growing interest in natural fiber reinforcements within the composites industry, their deformation properties remain poorly understood and insufficiently studied. It is only recently that research on the mechanical properties and the formation of complex shapes of flax-based fabrics has been published [10].

2. Materials and methods

2.1 Flax/PA12

The material was a flax/PA12 blended yarn, with flax staple fibers carded to create a yarn over which PA12 yarn was wound and subsequently woven into a twill fabric on a loom (Fig. 1(a)). The flax and polyamide fibers had mass fractions of 64% and 36%.

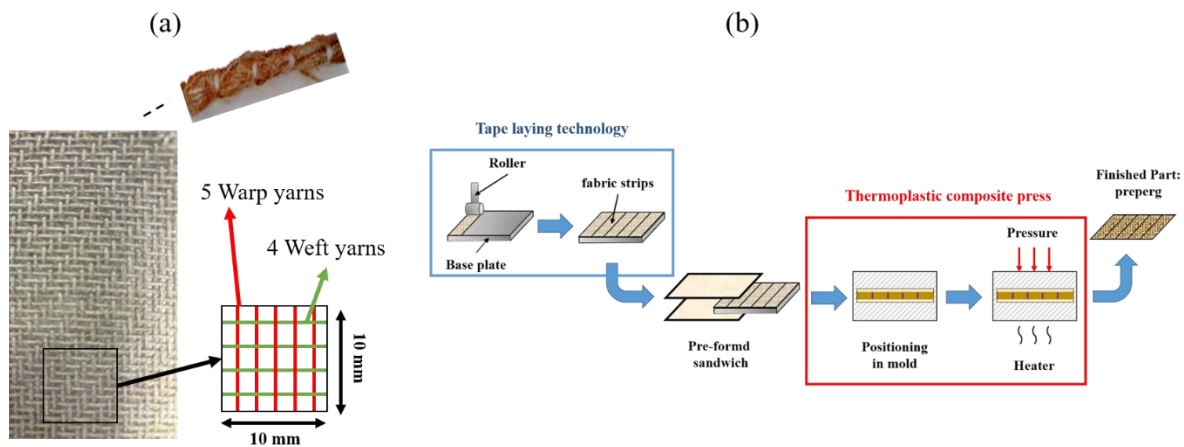


Figure 1. (a) Structure of linen/PA12 fabric, (b) Production process for pre-impregnated parts.

The properties of the fabrics are summarized in Table 1. A slight difference exists between the radial and weft directions of the fabrics, as the yarn density is higher in the radial direction. Fig. 1(b) illustrates the preparation process of preperg components.

Material	Parameter	
Twill Fabric 2-2 flax/PA12	Fabric construction	Schappe Techniques
	Fabric Type	Twill Fabric 2-2
	Masse par unit area (g/m ²) – ISO3616	395 ± 2
	Thickness (mm) – ISO9073	2.02

	Number of wires per unit area (m ²)	900 files
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Table 1. The main properties of woven linen/PA12 fabric.

2.2 Methods

Tensile and flexural tests were carried out at different temperatures to analyze the in-plane tensile and flexural properties of preperg components made from the above fabrics and tape lay-up processes further. In this context, the preperg that are not linked to the tape are defined as T-warp. The preperg done by the tape laying process is defined as Warp samples with Strips (such as WarpS-0°, WarpS-90°, WarpS-45°) according to the cutting direction.

Tensile Test

Tensile tests were conducted using a universal tensile testing machine equipped with a thermostatic chamber, as shown in Fig. 2. The flax/PA12 fabric was inserted and secured using the top removable fixture. A load cell on the top fixture measured the force in real-time during testing. The machine was configured with a 150 mm gauge length to ensure precise sample fixation [11]. Each test, conducted per the ISO 13934-1 standard and was repeated five times. The tensile tests used a crosshead speed of 30 mm/min, with a sample size of 200 × 50 mm², as shown in Fig. 2(a). Preliminary tests confirmed zero sample slips, ensuring accurate results.

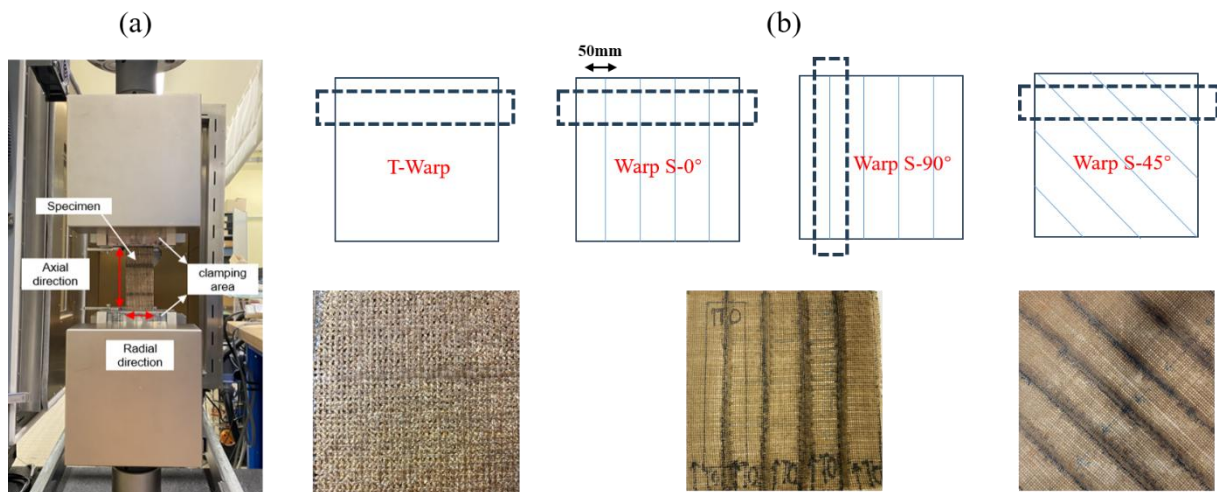


Figure 2. (a) Tensile test equipment, (b) Design of preperg samples.

To conduct the tests, temperatures were systematically varied to evaluate the properties of the flax/PA12 preperg fabrics and tapes. PA12, with a melting point of 180°C, was tested at temperatures above and below this threshold.

Bending Test

The bending stiffness of textiles significantly affects their drape [12] and stabilizes in-plane deformation [13–15]. Increased stiffness enlarges wrinkle size while reducing their number [16]. The cantilever bending test originates from the studies by Peirce and Kawabata [17]. The device includes a metal component for securing the sample in a cantilever structure under its self-weight, a high-temperature chamber, and an optical unit to capture images of the folded sample (Fig. 2).

Results indicate that the fabric forms a bending angle under its self-weight, while at high temperatures, the bending angle satisfies Equation (1), assuming the sample is non-stretchable and

slip-free. Equation (1) correlates the bending angle (θ) with the fabric's self-weight (M) and final elongation (L), enabling the calculation of bending stiffness.

$$G = ML^3 \left(\frac{\cos \frac{1}{2}\theta}{8 \tan \theta} \right) \quad (\text{Eq. 1})$$

3. Results

3.1 Tensile behavior

The results of tensile tests at 190°C for preperg parts with different warp and weft directions are shown in Fig. 3, with five tests performed for each orientation. The curves in Fig. 3(a) depict the tensile responses of samples prepared using different cutting methods. Among the samples, the Warp S-90° configuration demonstrated the highest maximum tensile load. This superior performance is attributed to the increased loading capacity and larger cross-sectional area of the double-layer tape. Conversely, the S-0° warp and S-0° weft laminated strips exhibited significantly lower tensile loads. The observed failure of the strip joints and the sharp load reduction were primarily due to inadequate adhesion in the overlapping regions of the strips at elevated temperatures.

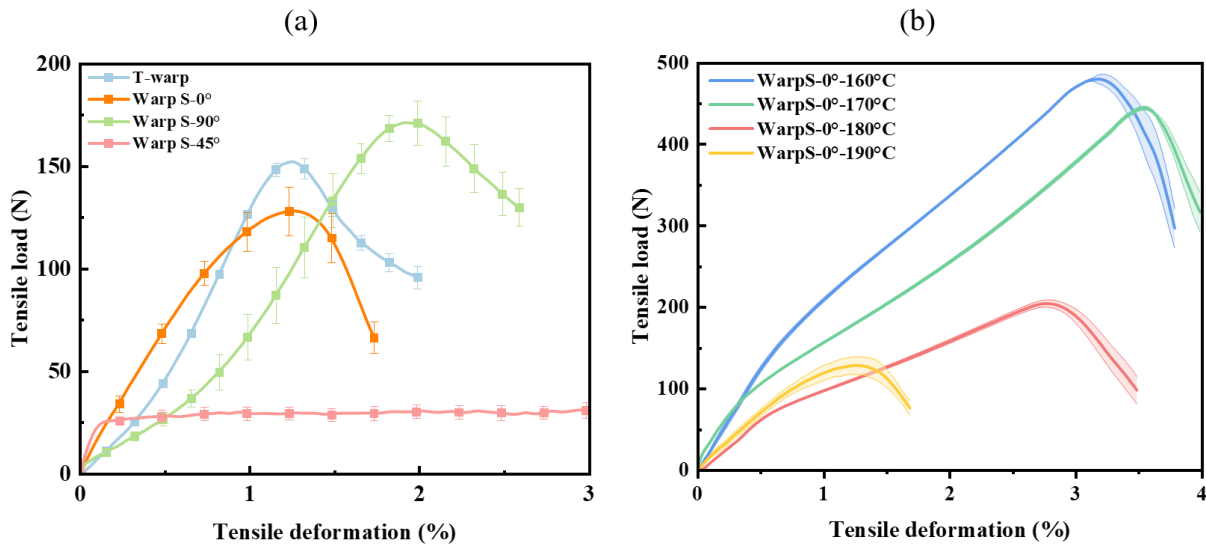


Figure 3. (a) Load vs. strain for prepergs with different cutting directions (b) Load vs. strain under temperature variation.

Fig. 3(b) illustrates the evolution of displacements and forces at different temperatures, demonstrating that thermodynamic behavior strongly depends on temperature, with the maximum load varying in a complex manner. Below the melting point, the maximum load gradually decreases as the temperature rises. This occurs because thermoplastic materials transition from a glassy to a rubbery state during heating, where molecular chains gain partial mobility without fully melting. At this stage, the material can undergo limited deformation and shaping. Above the melting point, the maximum load decreases sharply. This sharp decline occurs because when the temperature exceeds the melting point of PA12, the material transitions to a liquid state, effectively eliminating friction. Maintaining the appropriate temperature range near the melting point produces a more defined molding effect.

3.2 Bending behaviour

Fig. 4 shows the flexural properties of radially striped pre-wetted parts for samples with different inclinations. The flexural modulus decreases gradually with increasing temperature and the pre-wetted parts without stripes show a sharp decrease in flexural modulus after 180 degrees Celsius

when they enter the stage where PA12 starts to melt. The flexural modulus of Warp S-0° is higher than that of Warp S-90° and Warp S-45° when compared to the strip-laid pre-wetted parts, which also indicates a lower bending capacity (i.e., permissible degree of bending). The fiber orientation of the samples in Fig. 2(b) shows that Warp S-0° is loaded with weft yarns, which also reflects the fiber orientation advantage of the material.

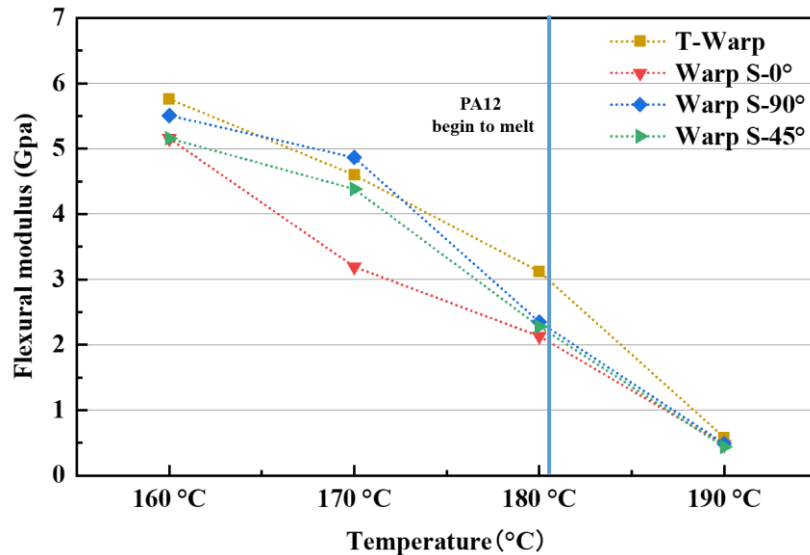


Figure 4. Changes in flexural modulus at different temperatures.

4. Conclusions

In this paper, the thermomechanical characterization of the tensile and in-plane bending properties of pre-impregnated pieces made from linen/PA12 2 × 2 twill fabric lay-ups is presented. Data were recorded for different cutting directions and at different temperatures during the thermoforming process and showed the differences in tensile properties of pre-impregnated wetted parts made of thermoplastic materials under the tape lay-up process. A comparison of the thermal properties of the tape-laying pre-infiltrated pieces showed a gradual decrease in fabric strength with increasing temperature, especially when the test temperature exceeded the melting point of PA12, where the strength decreased sharply. In conjunction with the results of the bending experiment, it was clarified that the effect of different cutting directions on the in-plane deformation of pre-infiltrated parts is closely related to the orientation of the material yarns. The tape lay-up technique improves the freedom of the material in the thermoformed state.

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