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Impact behaviour of flax/epoxy composite plates

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ABSTRACT

This paper presents an experimental investigation of the impact behaviour of flax/epoxy composite plates submitted to low-velocity transverse impact. Low energy drop-weight impact tests have been performed on two types of quasi-isotropic flax/epoxy composites, rectangularly shaped with edges lengths of 142 mm × 94 mm and 2.85 mm thick. Residual properties have been assessed by compression after impact tests. A detailed description of damage development, especially the increase of the rear face crack with respect to the impact energy is given by the microscopic observation. The influence of impact damage on the residual strength is described. A loss of 15%–30% in compression resistance was noticed for specimens impacted by 10 J. Dynamic effects appeared negligible and a good concordance was found between quasi-static three points bending and low energy impact loadings.

1. Introduction

Synthetic fibres reinforced composite materials have been widely used for structural applications due to the weight reduction made possible by their high specific mechanical properties. In the past decade, bio-sourced materials reinforced with vegetal fibres, such as flax, hemp, jute and sisal have gained popularity due to sustainable development requirements and cost-effectiveness [1,2]. Yan et al. [2] suggested that, when considering mechanical performance, cost and yield, flax, hemp and jute are the most promising bio-fibres that can be used instead of glass fibres in composite materials. Recent studies [3–5] have also confirmed the high potential of vegetal fibre reinforced composites (VFRC) as suitable materials for engineering applications due to their significant mechanical properties. However, it is known that improvements of the intrinsic fibre properties, fibre/matrix interfacial bonding and the long-term behaviour in environmental conditions can increase confidence in the use of VFRC. Regarding the mechanical performances of VFRC, only a few studies can be found about impact behaviour [6–9].

Rectangular thin plates are generally described as flat surfaces having a shortest edge to thickness ratio higher than 10. Their analysis requires in-plane and through-thickness properties as well as boundary conditions for the specimen stiffness. Under impact loading, thin plates tend to bend, while thicker plates are likely to undergo compression failure before bending.

The accidental impact at low velocity on flat or cylindrical structures, possibly due to tool drop, hailstone strike, runway debris, etc., has been studied for their possible damage inducing in composites, and the evolution of these damages during fatigue loading. Even with low incident energy, considerable through-thickness damage, while invisible to the naked eye can be created, causing significant reduction of strength, durability and stability of the structure [10,11]. Therefore numerous studies have been performed on that topic for conventional composite structures. Guillaumat et al. [12,13] developed an experimental design methodology to study the influence of testing parameters on impact response. Authors concluded that the consideration of the coupling effect of the mass-velocity of the impactor was more relevant than the incident energy alone.

Some authors have studied the impact behaviour of VFRC, in particular with flax reinforcement. These materials offer comparable quasi-static specific mechanical properties similar to those of glass fibre [4]. Bledzki et al. [6] have investigated the influence of fibre content and void fraction on the low velocity impact response of 2 mm thick flax/epoxy composite plates. The study showed an increase in the damage threshold, maximum contact force and stiffness with the fibre content, while the lost energy and the maximum deflection decreased. Rodriguez et al. [7] presented a comparative study of the impact response of different natural fibres

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and glass fibre reinforced composites with a fibre volume fraction of 30%. Flax fibre based composites exhibited the highest impact energy absorption among natural fibre reinforced composites. This justified the choice of using flax fibre reinforcement in the present study. Siengchin and his co-workers [8,9] have investigated the effect of nanoparticles on the impact response of flax woven composites. The experimental results revealed that the presence of SiO_2 or Al_2O_3 particles in flax/polyethylene or flax/PLA laminates reduces the peak force under impact tests. Authors suggested that the particles have promoted the local crack growth and reduced the ductility. The crashworthiness of flax fibre reinforced composites has been investigated by Yan et al. [14] by quasi-static compression test. Results have shown that the flax/epoxy composite tubes have a specific absorption of 41 J/g, which is higher than that of the stainless steel and aluminium tubes.

It is clear from the literature that residual properties after impact are of prime importance when applying damage tolerance concepts. Therefore, many authors have tried to correlate the residual tension or compression strength with impact energy and damage mechanisms. The Compression After Impact (CAI) test is a proven method to measure the residual properties of impacted composite panels. The objective of this test is to assess the damage tolerance of composite specimens by in-plane compression loading, which may cause local buckling initiated by the impact-induced inter-laminar debonding, leading to the premature collapse of the specimen. Many authors tried to evaluate the influence of impact parameters on the CAI resistance. Among their results, it has been pointed out that parameters such as impactor nose geometry (sharp, hemispherical, flat) [15], stitch quality of layers [16], stacking sequence [17,18] and preload could influence significantly the impact response and thus the CAI results. Sanchez-Saez et al. [17] have shown that plates having Quasi-Isotropic (QI) $[45/0/90]_s$ stacking sequence exhibited less normalized CAI reduction than $[0/90]_{3s}$ and woven laminate specimens. Aktas et al. [18] have also noticed a higher CAI strength in QI $[0/90/45/-45]_s$ glass/epoxy laminates than in cross-ply $[0/90/0/90]_s$ laminates. For this reason, the QI layout is chosen in this study.

All these previous studies tell us that although many authors have worked on the damage development of impacted thin composite plates, the impact response and the residual properties of VFRC have still not been thoroughly investigated. The present paper addresses these problems. First, damage developed at different levels of energy, is described based on microscopic inspection of impacted specimens. From the parameters of the impact responses (contact time, bearing capacity deflection, energy absorption and CAI strength), the influence of specimen orientation is evaluated. Finally, the dynamic effect is revealed by comparing the impact response and the quasi-static bending response.

2. Materials and specimens

The composites examined in this work were reinforced with Hermès flax fibres impregnated with SR 8200/SD 8205 epoxy resin system. The fibres took the form of non-crimp balanced fabric with an areal weight of 235(16) g/m^2. The standard deviations are indicated in brackets. Quasi-Isotropic composite panels having $[0/90/45/-45]_{2s}$ stacking sequence, were fabricated by hand lay-up in a hot press machine at 60 °C under 7 bars for 8 h [3]. This manufacturing process resulted in flat plates with a thickness (e) of 2.85 (0.07) mm. The measured fibre volume content, porosity fraction and density were of 44.0 (1.1)%, 0.72 (0.34)% and 1280 (10) kg/m^3 respectively (ASTM D 3171-11).

According to the Classical Laminates Theory (CLT), the in-plane properties are theoretically identical for quasi-isotropic stacking sequence $[0/90/45/-45]_{2s}$ whatever the sample orientation with respect to the in-plane loading. However, the out-of-plane bending properties vary with the specimen orientation as shown in the polar diagram [19,20] plotted on Fig. 1, with the x axis corresponding to the fibre direction in the outer layer, i.e. 0°. The moduli were computed from the mechanical properties of a flax/epoxy unidirectional composite having similar fibre content (Table 1).

From this plot (Fig. 1), it can be seen that the bending modulus at 0° is 13.06 GPa, which is 19% higher than at 90° of 10.98 GPa. In this study, the samples were subjected to impact and quasi-static bending tests, two sorts of out-of-plane loading. For these tests, the rectangle-shaped specimens, with length and width of 142 and 94 mm, were cut-out from the quasi-isotropic composite plate along 0° and 90° direction. This resulted in specimen plates of $[0/90/45/-45]_{2s}$ and $[90/0/-45/45]_{2s}$ lay-ups along their longer edge. Thereafter they were referred to as QI_0 (Fig. 2a) and QI_90 (Fig. 2b), respectively.

3. Experimental methods

In the analysis of the damage mechanisms in thin composite plates under low velocity and energy impact, degradation will be localized in the vicinity of the contact point. For this reason, the problem can be split in two parts by first looking at the damage induced by the projectile-sample interaction, and second, by examining the influence of the impactor's velocity on damage mechanisms. Two series of tests have therefore been performed for dynamic and quasi-static configurations. Finally, CAI tests were performed in order to investigate the interaction between impact damage and residual resistance.

3.1. Impact test

Since the impact speed of accidentally falling objects is often of only a few m/s, the falling weight impact setup is the most appropriate apparatus to reproduce low energy impacts that may occur in service or during handling. In the present study, the low velocity impact tests were performed using a drop weight machine designed by I2M (Institut de Mécanique et d'Ingénierie de Bordeaux, France) [12]. This machine is equipped with an anti-rebound system to avoid further damage after the first impact. A laser sensor is used to measure the displacement of the impactor. Throughout the tests, post-mortem inspection has shown that no penetration or perforation occurred, hence, the deflection of the specimen was considered equal to the impactor displacement after the initial contact. This means that the indentation of the striker was neglected. A piezoelectric sensor was incorporated in the

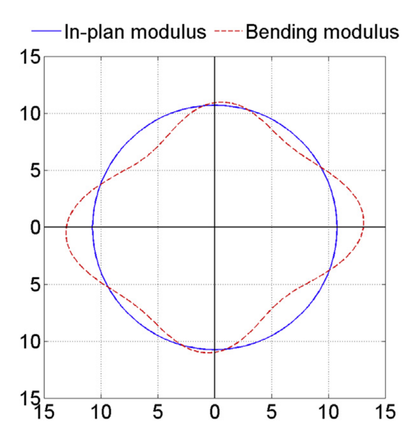

Fig. 1. Polar diagram of membrane and bending moduli of $[0/90/45/-45]_{2s}$ flax/epoxy laminate. The 0° orientation is referred to as the abscissa. Unit in GPa.