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Low velocity impact performance of stitched flax/epoxy composite laminates

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ABSTRACT

This paper presents an experimental investigation of the effect of through-thickness natural fibre stitches on the low-velocity impact response of the woven flax/epoxy composite laminates with the purpose of extending their use to higher performance applications. Two impact energy levels were selected to produce a perforated and a non-perforated damage state in stitched/unstitched composites for study. Twistless flax yarn and twisted cotton thread were used to stitch at an equivalent stitch areal fraction for all laminates of the same thickness. Unstitched cross-plies $[0/90]_{4s}$ of continuous flax fibres were also manufactured at a similar thickness for benchmarking of energy absorption and fracture mechanisms. Comparison of the damage sustained in the unstitched and stitched natural fibre composites showed that while delamination was not the predominant damage mode in both laminates, stitching does facilitate the propagation of in-plane cracks. The experimental findings revealed that stitching with thicker yarn (Flax) led to a lower ratio of absorbed energy per area of damage as well as energy absorbed for full penetration.

1. Introduction

Over the last decade, the use of natural fibres (NFs) as reinforcement in the polymer composites is becoming more common due to their promising properties such as high specific stiffness, good acoustic insulation and vibration damping, and lower environmental impacts [1,2]. These advantageous of NFs make them suitable reinforcing fibres to replace man-made glass fibres in many nonstructural and semi-structural applications, and such substitutions are becoming increasingly common in the transportation and sport goods industries [3–5].

Among the various NFs available for composite reinforcement, flax fibres are commonly used due to their availability in long and minimally twisted forms for composite applications, and generally better performance in terms of strength and stiffness per density. However, to utilize the maximum load carrying capacity of the flax fibres, it is necessary to use them in the long continuous unidirectional (UD) or textile woven forms, with optimally twisted yarns in the laminate composites [6,7]. For instance, Bensadoun et al. [8] observed that the laminates with better fibre alignment such as in UD and Quasi-UD forms, owned the higher static strength and stiffness, as well as the best fatigue characteristics.

In general, the transverse performance of composite laminates is a concern when they are known to suffer low velocity incidents such as tool drops, stone or debris strike, etc. The damage size and type caused by an impact generally determine the residual properties of the structure made of composite laminates [9–12]. Hence, low-velocity transverse impact behavior of composite laminates has always been one of the main design considerations in many applications [13,14]. This behavior is even more critical when a lower-strength reinforcing fibre (e.g. from natural origin) is used. The low-velocity impact response and post impact behavior of NF composites laminates have been studied by a number of authors [15–24] to understand their failure characteristics under impact loading. Dhakal et al. [21] showed that the low-velocity impact properties of non-woven hemp fibre laminates with higher volume fraction (V_f) in terms of impact energy absorption are as good as the chopped mat E-glass fibre composites with equivalent V_f. It was also observed that the fibre weave architecture and V_f can significantly influence on the impact parameters such as impact

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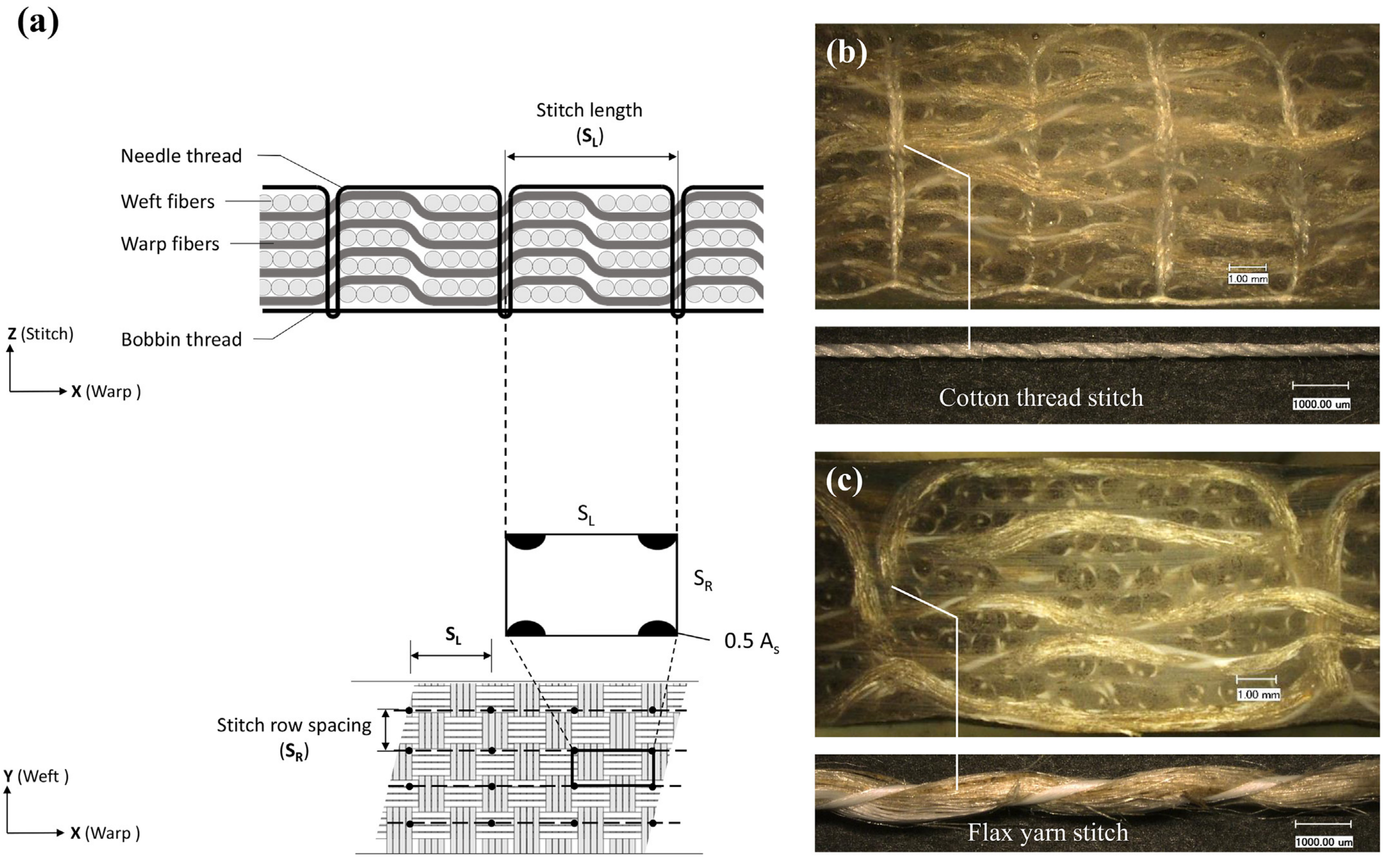

Fig. 1. (a) Schematic view of a stitched preform and definition of stitch parameters; a cross-section of (b) cotton thread, and (c) flax yarn stitched flax fibre composite [31].

resistance, energy absorption and the impact peak force of the bio-composite [16]. Furthermore, woven laminates, compared to un-woven fibre mat, had better impact performance through the fabric cross-over points by distributing the impact stress. In another study carried out by Santulli et al. [24], the drop-weight impact test results indicated that impact resistance and energy absorption of the mat hemp fibre composites are higher than that of the unidirectional (UD) and cross-ply (0/90) laminates. Vasconcellos et al. [19] has reported the experimental results of the impact resistance of plain weave hemp/epoxy composite laminates at three different impact energies and their post impact behavior by means of tensile and tension-tension fatigue tests. They observed that the influence of impact damage on the residual tensile stiffness of the impacted specimens was very small.

Through-thickness stitching is a well applied technique to improve the interlaminar fracture resistance of many synthetic fibre composites [25–27] under impact loading. Although stitching can affect the other properties such as tensile strength, impact resistance and damage tolerance of the composite laminate [28,29], it remains a common technique used in the production of non-crimp fabrics.

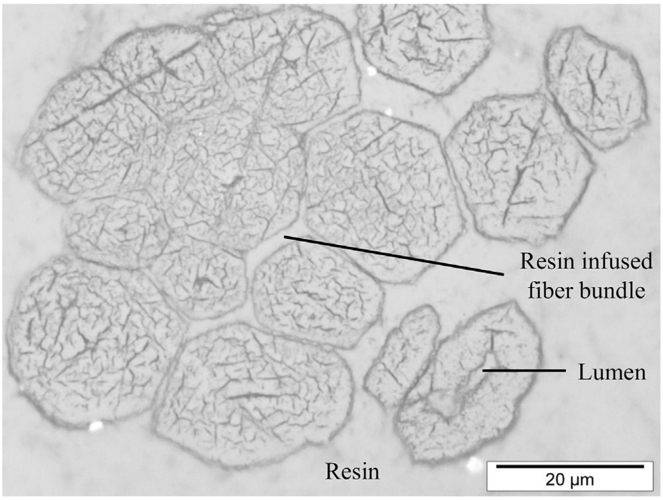

Fig. 2. Optical micrograph of cross-section of a resin infused flax fibre bundle.

Table 1
Summary of the composite lay-up, notation and stitch parameters used for the manufactured flax fibre laminates.

Flax Lamina preform	Laminate nomenclature	Areal density of lamina [g/m^2]	Layup	Stitch material	Stitch Density × 10^{-2}	V_f (%)
4 × 4 Plain Weave	PW0	500	$[0]_4$	–	0	31 ± 2
	PWC		$[0]_4$	Cotton	0.92	
	PWF		$[0]_4$	Flax	1.03	
Unidirectional	UD0	110	$[0/90]_{4s}$	–	0	40 ± 2