Composites Part B 91 (2016) 144–153

Contents lists available at ScienceDirect

Composites Part B

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

Damage tolerance of carbon/flax hybrid composites subjected to low velocity impact☆

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ARTICLE INFO

Article history:
Received 23 November 2015
Received in revised form
8 January 2016
Accepted 27 January 2016
Available online 6 February 2016

Keywords:
A. Polymer-matrix composites (PMCs)
B. Impact behaviour
D. Mechanical testing
Natural fibres

ABSTRACT

Hybrid laminates produced using carbon (C) and flax (F) fibre epoxy prepregs were fabricated with two different stacking sequences based on the presence of flax fibre laminates as outer layers and carbon as inner layers (FCF) or vice versa (CFC). Pure flax and pure carbon fibre reinforced laminates were also fabricated as a reference. Experimental tests were performed, which included four-point bending, falling weight impact tests at energies ranging from 5 to 30 J with determination of the barely visible impact damage (BVID) and post-impact flexural tests. As a whole, CFC proved slightly superior to FCF as for flexural performance, although the presence of flax laminates on the outside guaranteed a higher impact damage tolerance, acting as hindrance to crack propagation in the laminate. Specimens impacted at 10 J were also subjected to tensile tests monitored by Digital Image Correlation (DIC) that allowed preliminary identification of peculiar failure modes of the hybrid laminates.

1. Introduction

Information on falling weight impact (IFW) performance of composites including plant fibres, such as jute, flax, hemp, sisal, etc., appears still quite limited, despite the fact that IFW represents an important way of assessing the suitability of these materials to a possible semi- or structural use. In this regard, hybridization may increase the flexibility of composite materials, also in terms of impact performance [1]. In the specific case of plant fibres, hybridization represents a significant strategy to reduce on one side weight and carbon footprint of composite materials, whilst retaining a sufficient mechanical performance to permit not only cosmetic applications [2,3]. Hybrids including plant fibres were fabricated most frequently with glass fibres, which are typically reported to improve most mechanical properties and at the same time reduce property variability and moisture sensitivity [4–12]. Very few works regarding hybrid composites reinforced with flax and carbon fibres can be found in literature likely due to the significant difference in price and stiffness between natural and carbon fibres [13,14]. Despite this lack of data, carbon/plant fibre hybrid composites may have some role especially for the possible combination of properties, since plant fibre composites might allow different modes of damage propagation and dissipation and possibly even have some effect on the inherent brittleness (limited toughness) of carbon fibre composites. Also they might be of interest in view of particular applications, where the importance of impact performance coupled with weight as low as possible is paramount. This can be of interest to the automotive sector, where e.g., carbon/sisal hybrid composites have been proposed [15], and potentially also to the aerospace interiors sector, where attention to plant fibres was scant so far. There is a wide variety of natural fibres that can be used as reinforcements in composite materials. Flax, hemp and sisal are the most widely used because of their properties and availability. In particular, flax fibres have attracted the

☆ The results of this work have been presented at the 5th International Conference on Innovative Natural Fibre Composites for Industrial Applications, Rome 15–16 October, 2015.

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http://dx.doi.org/10.1016/j.compositesb.2016.01.050

Table 1
Summary of the different configurations manufactured and tested.

Specimen	Stacking sequence	Number of flax layers	Number of carbon layers	Overall fibre volume fraction (%)
F	$[(0/90)_4/0]_S$	18	–	56 ± 0.1
C	$[(0/90)_3/0]_S$	–	14	59 ± 0.2
FCF	$[(0_2/90_2)^F/(0_2/90_2)^C/0^C]_S$	8	10	62 ± 0.1
CFC	$[(0_2/90_2)^C/(0_2/90_2)^F/0^F]_S$	10	8	60 ± 0.1

attention of many researchers in the composites industry due to their better properties, when compared to other natural fibres. Particularly, the tensile strength and Young's modulus of flax ultimate fibres are equal to about 450–1500 MPa and 27.6–38 GPa, respectively. With a density of around 1450 kg/m^3, the specific properties of these fibres are comparable with those of E-glass ones [16,17]. These promising properties have triggered studies on the use of such fibre as a potential reinforcement in polymer matrix composite materials [18–20], and during the last years flax has been the most widely used natural fibre in the European automotive industry, representing more than 70% of the natural fibres consumed in the year 2000 [13]. In this framework, the aim of the present experimental work is to suggest the replacement of some carbon fibres with flax ones with the objective of obtaining a more environmentally friendly and low-cost composite for semi-structural applications while increasing the damage tolerance of carbon fibre reinforced composites when subjected to impact events. The use of flax fibres is also motivated by their high damping properties and energy absorption [21–24]. The combination of the damping properties of flax with the well-known high performances of carbon fibres has been recently exploited on an industrial level for manufacturing bicycles (*Museeuw bikes*) and tennis rackets (*Artengo*). Impact resistance of hybrid composites has been extensively investigated, as toughening is one of the main reasons for fibre hybridization and impact resistance is strongly related to toughness. Impact resistance in terms of energy absorbed during a penetrating impact, damaged area after a non-penetrating impact and residual properties after impact are all governed by

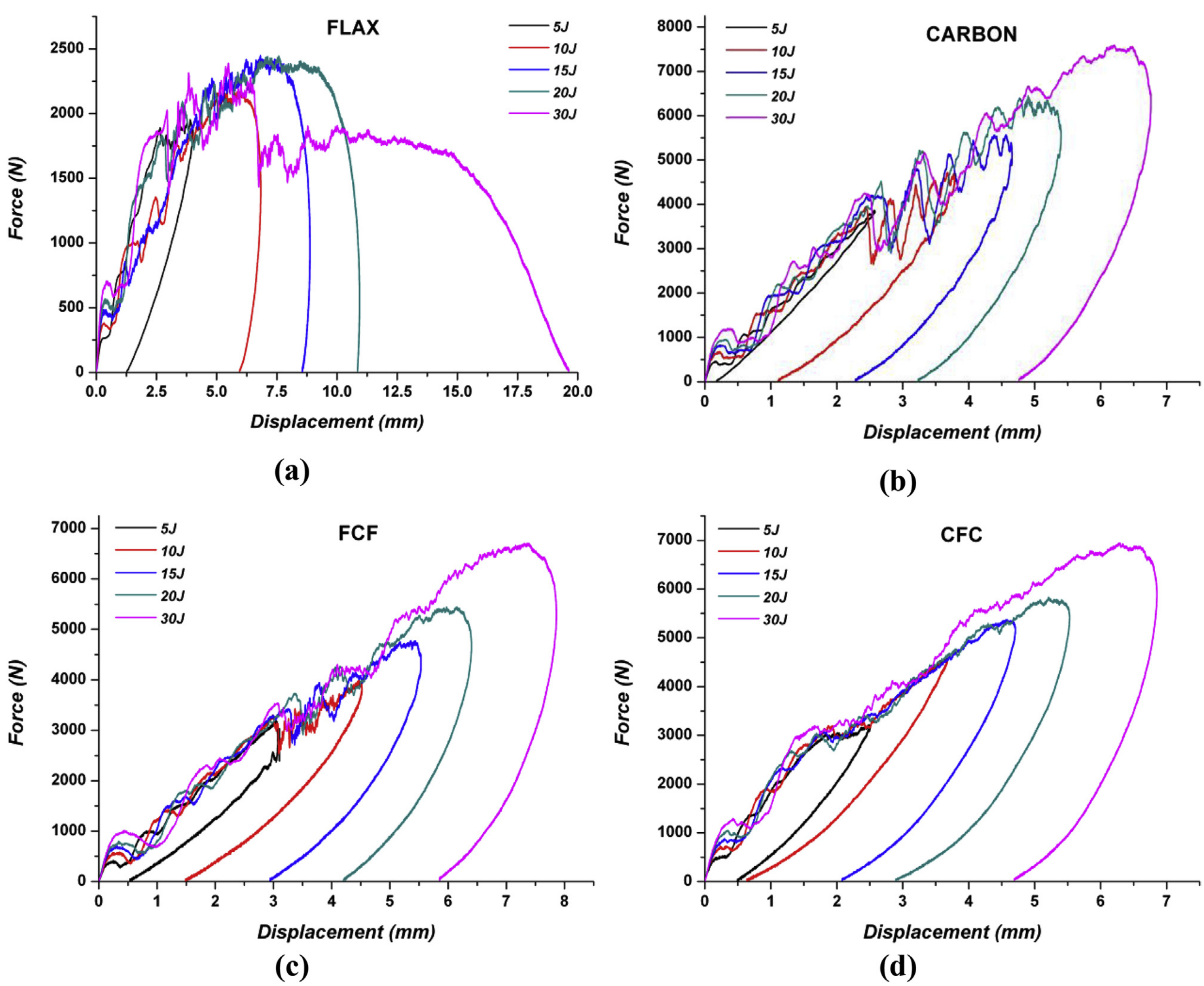

Fig. 1. Typical force–displacement curves as a function of impact energy and configuration.