Composites Part B 91 (2016) 162–168

Contents lists available at ScienceDirect

Composites Part B

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

Low-velocity impact behaviour of hemp fibre reinforced bio-based epoxy laminates☆

Claudio Scarponi [a], Fabrizio Sarasini [b, *], Jacopo Tirillò [b], Luca Lampani [a], Teodoro Valente [b], Paolo Gaudenzi [a]

[a] Department of Mechanical and Aerospace Engineering, Sapienza-University of Rome, via Eudossiana 18, 00184 Rome, Italy
[b] Department of Chemical Engineering Materials Environment, Sapienza-University of Rome, via Eudossiana 18, 00184 Rome, Italy

ARTICLE INFO

Article history:
Received 24 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

This work addresses the damage resistance and post-impact damage tolerance of hemp fabric reinforced bio-based epoxy composites subjected to low-velocity impact at energies ranging from the barely visible impact damage (BVID) threshold up to perforation. A comparison is also reported with similar composites in terms of thickness and fibre volume fraction but based on a traditional epoxy matrix. The results confirmed the significant toughness of laminates based on a bio-based epoxy matrix and their superior damage tolerance compared to standard hemp-epoxy laminates, thus highlighting their potential use in semi-structural applications due to an improved interfacial adhesion with hemp fibres.

1. Introduction

The increasing use of composite materials in automotive and aeronautical/aerospace applications, coupled with the depletion of petroleum resources, is stimulating the search for materials and products with the lowest possible environmental 'footprint' with a focus on renewable raw materials. This enhanced awareness has triggered, especially in Europe, a shift towards using natural materials as a substitute for non-renewable synthetic fibres, like glass, in composites based on both thermosetting and thermoplastic polymers [1–4]. For semi- or structural applications, the use of thermosetting matrices is preferred due to their high flexibility in tailoring desired ultimate properties, leading to their high modulus, strength, durability, thermal and chemical resistance as provided by high cross-linking density.

At a first step, the reduction of the environmental impact of composite materials based on thermosets was obtained by the substitution of synthetic fibres with natural ones. Nowadays, researches are based on the replacement of petrochemical components from the matrix with bio-based renewable equivalents. Renewable resources can provide an interesting sustainable platform to substitute partially, and in some cases totally, petroleum-based polymers through the design of bio-based polymers that can compete or even surpass the existing petroleum-based materials on a cost-performance basis with high eco-friendliness values [5–8]. Thermoset materials represent less than 20% of the total plastic production and epoxy resins account for roughly 70% of the market of thermosetting polymers (not including polyurethanes) [9]. In particular, the global epoxy resins production was estimated to be 2 million tons in 2010 and is projected to reach 3 million tons by 2017 [9]. These figures explain the shift of chemical industry towards a sustainable chemistry with the use of renewable resources in order to synthesize biobased chemicals and products. It is to be emphasized that biobased sourcing does not necessarily imply biodegradability. Recently there is an increasing demand for biobased materials with a strong emphasis on performance and durability. In case of thermosetting materials, the most widely applied renewable resources include plant oils, which are triglycerides (tri-esters of glycerol with long-chain fatty acids) with varying composition of fatty acid depending on plant, crop, season and growing conditions. Recent reviews have focused on the development of cross-linked plant oils and their derivatives for thermosetting applications, such as coatings and resins [10]. Bio-

☆ 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.

* Corresponding author. Tel.: +39 0644585408.
E-mail address: fabrizio.sarasini@uniroma1.it (F. Sarasini).

http://dx.doi.org/10.1016/j.compositesb.2016.01.048
1359-8368/

Table 1
Key parameters obtained from impact tests on hemp fibre laminates.

Impact energy (J)	Peak force (N)	Maximum displacement (mm)	Absorbed energy (J)
Bio-epoxy			
5	2098.09 ± 62.03	3.84 ± 0.10	2.50 ± 0.06
10	2188.92 ± 63.40	6.18 ± 0.03	8.32 ± 0.10
15	2214.77 ± 49.33	8.60 ± 0.13	14.54 ± 0.01
20	2340.26 ± 74.42	11.02 ± 0.49	19.94 ± 0.04
40	2706.91 ± 37.28	–	29.33 ± 0.08
Traditional epoxy			
5	1765.19 ± 31.79	4.42 ± 0.08	2.64 ± 0.13
10	1873.80 ± 8.36	7.22 ± 0.05	9.51 ± 0.01
15	1970.16 ± 18.62	10.12 ± 0.11	14.91 ± 0.04
18	1980.02 ± 27.27	12.32 ± 0.14	17.84 ± 0.01
40	2462.04 ± 16.78	–	29.86 ± 0.02

based thermosetting polymers can be used as matrices in composites, both for synthetic and natural fibres. It is clear that the goal is the adoption of bio-based thermosetting matrices in the production of fully biobased materials, hence using biobased material also as filler/reinforcement. Natural reinforcements currently account for about 11% of the total volume of fibres used in composites,

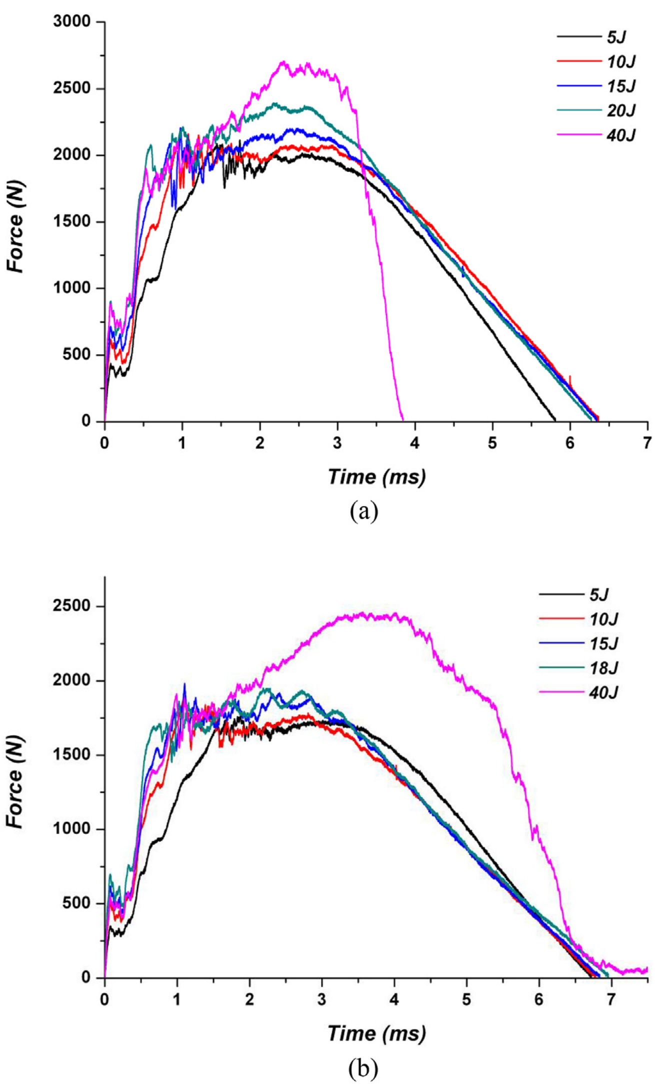

Fig. 1. Typical force vs. time response as a function of impact energy of composites based on (a) bio- and (b) traditional epoxy matrix.

with forecasts estimating 22% by 2020. Among natural fibres, hemp fibre is one of the most inexpensive and readily available bast natural fibre in Europe. It is characterized by high specific mechanical properties together with high cellulose content, which make it a material of choice as reinforcement in polymer matrix composites [11]. Vegetable oils, despite being excellent raw materials for thermosetting biopolymers, due to their availability and inexpensiveness, are usually reported to have limited thermal and mechanical properties because of the low reactivity of aliphatic epoxy groups, which results in poorly cross-linked materials [12]. In this regard, the addition of natural fibres could also partially mitigate their disappointing mechanical performance. At present, despite the growing research studies, available biobased thermoset matrices for structural applications are not known; however, not fully biobased resins but with a significant content of components coming from renewable vegetable materials, having good performance are already marketed (e.g., by Entropy Resins Inc., Eco Green Resins, LLC). Some studies have addressed the physico-mechanical behaviour of composites made with natural fibres and such bio-based resins [12–15], but their properties and their potential use for the manufacturing of natural fibre composites have not been investigated in depth. In particular, the response of such composites to low velocity impact loads is not well known, even though some recent works have addressed such topic for composites based on traditional epoxies reinforced with hemp fibres [16,17]. Such property is very important, because low-velocity impacts by foreign objects during composite structures life may occur during the phase of manufacturing, maintenance, operation and so on. The internal damage produced by impact loads can largely affect their residual mechanical properties even when barely visible impact damage (BVID) is produced. In fact, BVID can result in internal damage such as delaminations and back-face splitting, which can reduce the residual strength by as much as 60%. The inherent variability in natural fibre properties is still limiting the diffusion of natural fibre composites in semi-structural applications, also due to a non reliable understanding of their mechanical behaviour, in particular as regards their impact damage resistance and damage tolerance. The present work addresses the evaluation of the BVID threshold for hemp woven fabric reinforced bio-based epoxy laminates and their residual strength in bending. For the sake of completeness, a similar experimental campaign has been performed on equivalent composites but based on a traditional epoxy matrix, in order to highlight differences and potential limitations of bio-based epoxies.

2. Materials and methods

A plain weave hemp fabric was used with a fibre areal weight of 400 g/m^2 as reinforcement (AssoCanapa srl), while a bio-based