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Review

Fibre properties and crashworthiness parameters of natural fibre-reinforced composite structure: A literature review

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ABSTRACT

Several natural fibres such as hemp, flax, sisal, kenaf and jute have been used in different industrial applications. Recently, natural fibres have drawn the interest of researchers, engineers and scientists as substitute reinforcements for fibre reinforced polymer (FRP) composites tubes. Due to their fairly good mechanical properties, low cost, high specific strength, environmentally-friendliness and bio-degradability, ease of fabrication, and good structural rigidity, these materials can be used in an extensive range of applications, including aerospace and the automotive industry. Previous studies focused on how to introduce the natural fibres into industrial applications and the replacement of synthetic fibres with natural fibre materials. The tensile properties of natural fibre reinforce polymers are mainly influenced by mechanical properties such as tensile properties, flexural properties, and impact strength are strongly affected by fibre content. Furthermore, the overall tensile and flexural properties of natural fibre-reinforced polymer hybrid composites are highly dependent on the aspect ratio, moisture absorption. The geometric designs such as geometry and shapes and triggering and non-triggering and filled and non-filled was found that significantly affected the crashworthiness parameters and specific energy absorption of natural fibre reinforced polymer composite tubes. Furthermore, the compressed data, which is based on the maximum values, reported in the literature, it can be observed that the woven flax fabric circular tube exhibits high energy absorption capability and CFE. This result contributes to the increased ability to use natural fibres in vehicle manufacture and thus increases the sustainability of this industrial sector. This paper presents an overview of the developments made in the area of natural fibres reinforced composites, in terms of their physical and mechanical properties, and crashworthiness properties. Several uncertainties affecting the experimental results were discussed.

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1. Introduction

Fibre reinforced polymers (FRP) are composite materials comprised of a polymer matrix combined with high-strength fibres such as glass, aramid and carbon. Although these composite materials exhibit excellent mechanical properties, they also give rise to environmental pollution due to their non-degradability [1,2].

Currently, traditional reinforcement materials such as glass and carbon fibres are increasingly being replaced by advanced composite materials, e.g., natural fibre-reinforced polymers (NFRP). It is expected that use of fibre/polymer composites will expand in the near future due to the many advantages offered by these materials such as high strength, low weight and corrosion resistance [3]. Natural fibres such as hemp, kenaf, jute, sisal and bamboo have been studied due to their mechanical properties and their potential use in composite materials. These natural fibre-reinforced composites are finding applications in the construction industry, with a projected yearly US demand increase of as high as 60% [4–6].

Natural fibre-reinforced composites are an alternative to the ever depleted petroleum resources and have therefore received increasing attention from scientists and society. Because they are biodegradable, environmentally friendly, lightweight, inexpensive, and exhibit interesting physical and mechanical properties (high specific stiffness, low density and relatively high processing flexibility and good strength), natural fibre based composites are attractive for manufacturers and scientists. They are considered to be excellent materials for use in construction, automobiles and furniture production [7–10].

In particular, crashworthiness has attracted much attention, especially for the evaluation of crushing behaviour and the energy absorbing capability of various composite shapes. In automotive engineering, crashworthiness is defined as the capability of a vehicle to protect its occupants and passengers from serious injury and harm or death in case of accidents or sudden impacts of a specified magnitude. Crashworthiness is related to energy absorption through controlled failure modes that enable the maintenance of a gradual decay in the load profile during energy absorption [11,12].

Studies of natural fibre-reinforced plastic (NFRP) have been carried out for special geometric shapes of composite tubes that are mainly intended for automobile crashworthy applications due to their favourable strength, weight and corrosion resistance [13–16].

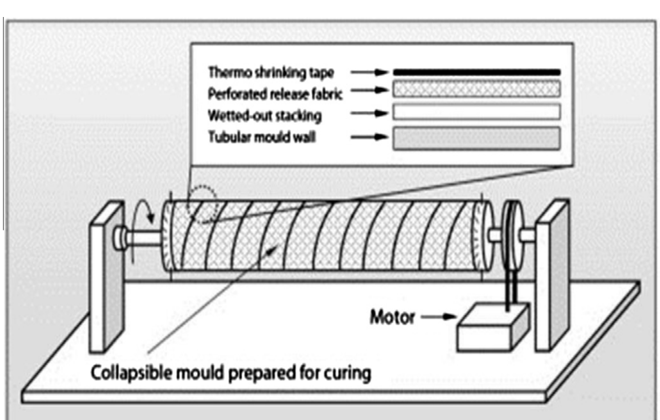

Fig. 1. Diagram of the rotating sample stand used during gelling and curing [18].

Several researchers reported that a well-designed NFRP composite can exhibit better energy absorption than metals; natural composite materials such as kenaf, silk and hemp fibre-reinforced composite tubes subjected to axial crushing will undergo fracture to obtain energy absorption rather than the fibre deformation exhibited in metal tubing [17–19]. As reported previously [20], delamination, local buckling, and bending failure modes make the largest contributions to energy absorption.

The effects of factors such as fibre orientation on axial crushing behaviour were studied experimentally in natural fibre-reinforced composite tubes. Bartosz et al. [18] carried out an experimental investigation to study the behaviour of axially crushed hemp yarns/epoxy composite tubes. Five fibre orientation angles of designed winding orientations of 10°, 30°, 45°, 60° and 90° were studied. The tube samples were prepared with the pin filament winding technique, as shown in Fig. 1. It was found that the highest stress and modulus were observed for the reinforcements oriented at 10° to the main axis. Four compression collapse modes were observed for the tested NFC tubes, namely micro-buckling, diamond shape buckling, concertina shape buckling and progressive crushing [18].

In another study, Yan et al. [15] investigated the effects of inner diameter, length-to-diameter ratio and tube thickness on flax fibre-reinforced epoxy circular tubes, and the crashworthiness characteristics of these tubes were evaluated. The energy absorption capability of flax/epoxy composite tube depends strongly on tube geometry. Specimens of considerable length with multiple composite plies exhibit a higher energy absorption capacity.

Rectangular woven natural silk/epoxy composite tubes were also used for studies of axial crushing using a trigger mechanism. Eshkoo et al. [20] investigated the effect of the trigger mechanism on axial crushing capability. They concluded that the failure mechanism proceeded in two stages, namely (i) tear onset and (ii) tear propagation, which included progressive buckling and delamination. The composite tubes exhibited only progressive, not catastrophic failure.

In this paper, several studies that were performed in order to understand the axial and lateral crushing capability of NFRP composites are described. The objective of this paper was to summarise recent research on the parameters that influence crashworthiness characteristics such as peak load, specific energy absorption and crash force efficiency.

2. Mechanical and physical properties of natural fibres

Various researchers have studied the physical and mechanical properties of natural fibre-reinforced polymer composites [21–24]. The mechanical and physical properties of natural fibres are very important for industrial applications and can contribute to the use of natural fibres in numerous applications. Lower density leads lower-weight structures in the automotive industry and aerospace applications [25–28]. Mechanical properties such as tensile properties, flexural properties, and impact strength are strongly affected by fibre content, as shown in Fig. 2 [29]. Compared with oil palm epoxy composites, the tensile properties of jute oil palm fibre hybrid composites are enhanced substantially