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Effect of triggering and polyurethane foam-filler on axial crushing of natural flax/epoxy composite tubes

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ABSTRACT

In this study, empty and polyurethane-foam filled flax fabric reinforced epoxy composite tubes were longitudinally crushed under quasi-static compression. The effects of foam-filler (density of 160 kg/m^3, two diameters of 64 and 86 mm), tube thickness (2, 4 and 6 plies of laminate), and triggering (45° edge chamfering) and the combination of triggering and foam-filler on the crushing characteristics and energy absorption capacity of these tubes were investigated. The test results indicate that the observed primary failure mode was progressive crushing for all the specimens. Foam-filled tubes have better crashworthiness than empty tubes in total absorbed energy, specific absorbed energy and crush force efficiency. The presence of triggering has no significant effect on total absorbed energy and specific absorbed energy of the empty tubes. However, the crush force efficiency of triggered tube is significantly larger compared to the non-triggered one. In addition, the triggering minimises the force variation of the tubes from the average crush force and in turn a more stable progressive crushing is achieved. The foam-filled and triggered tubes have better crashworthiness than the empty tubes in all the aspects. Compared with either triggered or foam-filled tubes, the triggered and foam-filled tubes have larger values in average crush load and crush force efficiency. In terms of total absorbed energy and specific absorbed energy, the triggered and foam-filled tubes have values always larger than those of the tubes with triggering only, but these values are either larger or smaller than the tubes with foam-filler only.

1. Introduction

The application of fibre reinforced polymer composites is increasing rapidly in automotive [1,2], civil engineering [3–6], and marine engineering [7] sectors because of their high specific strength and the high specific stiffness. In automotive engineering, with an increase in fuel price in recent years and the concern of better fuel economics in cost and fuel reserves, there has been an increased interest in the development of lightweight vehicles. Therefore, fibre reinforced polymer composites are used to aid mass reduction and reduce dioxide emission in order to meet the legislative demands [8].

As a matter of fact, mass is an important criterion in addition to crashworthiness in the automotive engineering sector. Lower mass corresponds with lower fuel consumption and fewer environmental hazards [9]. Crashworthiness is defined as the capability of a vehicle to protect its occupants from serious injury or death in case of accidents of a given proportion [10]. Crashworthiness is concerned with the energy absorption through controlled failure modes that enable the maintenance of a gradual decay in the load profile during energy absorption [11].

In the last decade, the widely used reinforcement materials for polymer composites are glass and carbon fibres. Previous studies [e.g. 12–15] indicated that carbon/glass fibre reinforced polymer composite materials have the potential as good energy absorbers. However, these synthetic fibres are energy intensive to manufacturing, with glass 54.7 MJ/kg and carbon requiring 300 MJ/kg due to the numerous high temperature processes [16,17]. Nowadays, because of market demand and government legislations for environmentally friendly materials, the use of bio-fibres to replace carbon/glass fibres in polymer composites has gained popularity [18]. Bio-fibres are cost-effective with low density and embodied energy. These are biodegradable and non-abrasive. In addition, they are readily available and their specific mechanical properties are comparable to those of glass fibres used as reinforcement [19].

To date, only a few studies have considered natural fibre reinforced polymer composites for energy absorption applications, e.g. Oshkovr et al. [20] and Eshkoor et al. [21] used silk fibres while Yan and Chouw [22] investigated flax fibres. The studies by Oshkovr et al. [20] and Eshkoor et al. [21] on silk/epoxy tubes showed that generally buckling (either local buckling or

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mid-length buckling) and hinge formation are the two main characteristics of woven silk/epoxy tubes, displaying a catastrophic failure. The study by Yan and Chouw [22] showed that flax/epoxy composite tubes crushed in a brittle manner with a progressive crushing pattern with favourable specific energy absorption capability [22].

Like glass/carbon fibre reinforced polymer tubes, due to their brittleness, the force variation of woven flax/epoxy composite tubes from the average crush force is large [22]. Indeed, these variations should be small in order to reduce the injuries to occupants [23]. Therefore, to further enhance the crashworthiness of flax/epoxy tubes during crushing, cellular materials such as foams might be applied, making these structures like sandwich structures. Additionally, the use of triggering generally causes a stable crushing in glass or carbon fibre reinforced polymer tubes [e.g. 10,14]. Therefore, the use of triggering might be also beneficial for the reduction in force variations for flax/epoxy composite tubes. Based on the best knowledge of the authors, the effect of foam-filler and triggering on natural fibre reinforced composites as energy absorbers is rarely studied. Therefore, this study experimentally investigates the effects of triggering and polyurethane-foam filler and their combined effect on axial crushing crashworthiness characteristics of flax fabric reinforced epoxy composite tubes.

2. Experiments

2.1. Tube geometry

In this study, considering the triggering and foam-filler effects, four types of tube configuration are considered: (1) empty flax/epoxy circular tube without triggering, termed as FFRP, (2) empty flax/epoxy circular tube with triggering, termed as FFRP-T, (3) polyurethane-foam filled flax/epoxy circular tube, termed as PU-FFRP, and (4) polyurethane-foam filled flax/epoxy circular tube with triggering, termed as PU-FFRP-T. The triggering type considered is 45° chamfering around the edges of the tubes. Fig. 1 gives the tubes with different configurations.

For each tube configuration, two tube inner diameters (D) are used, i.e. 64 and 86 mm and the length-to-diameter ratio (L/D) of

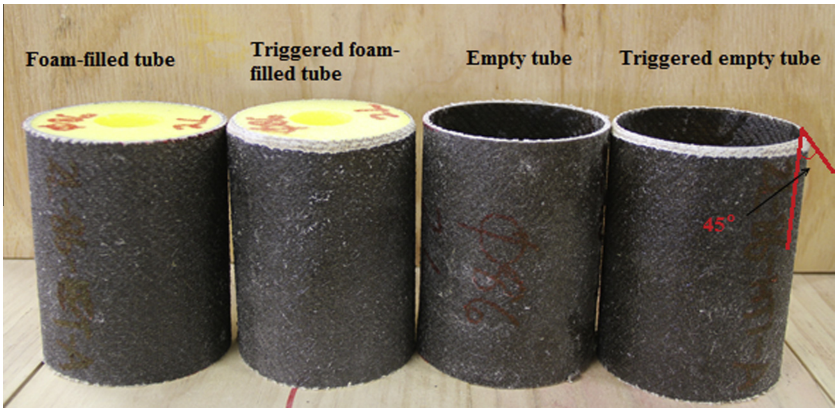

Fig. 1. Flax/epoxy composite tubes with different configurations.

Table 1
Specimens for axial compression test.

Specimen type	Inner diameter D (mm)	Flax fabric layers (N)	Length L (mm)	Mass m (g)	Triggering	Foam filler
FFRP-D64-N2	64	2	96	76.8	–	–
FFRP-T-D64-N2				75.7	Yes	–
PU-FFRP-D64-N2				83.9	–	Yes
PU-FFRP-T-D64-N2				83.0	Yes	Yes
FFRP-D64-N4	64	4	96	143.0	–	–
FFRP-T-D64-N4				142.1	Yes	–
PU-FFRP-D64-N4				151.3	–	Yes
PU-FFRP-T-D64-N4				150.2	Yes	Yes
FFRP-D64-N6	64	6	96	196.2	–	–
FFRP-T-D64-N6				195.4	Yes	–
PU-FFRP-D64-N6				203.2	–	Yes
PU-FFRP-T-D64-N6				201.6	Yes	Yes
FFRP-D86-N2	86	2	129	130.9	–	–
FFRP-T-D86-N2				129.1	Yes	–
PU-FFRP-D86-N2				151.9	–	Yes
PU-FFRP-T-D86-N2				150.0	Yes	Yes
FFRP-D86-N4	86	4	129	241.8	–	–
FFRP-T-D86-N4				239.7	Yes	–
PU-FFRP-D86-N4				266.1	–	Yes
PU-FFRP-T-D86-N4				264.4	Yes	Yes
FFRP-D86-N6	86	6	129	335.1	–	–
FFRP-T-D86-N6				333.1	Yes	–
PU-FFRP-D86-N6				358.7	–	Yes
PU-FFRP-T-D86-N6				356.7	Yes	Yes

For each specific type, three tubes are fabricated and the average mass is reported.