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Original Research Article

Axial splitting of empty and foam-filled circular composite tubes – An experimental study

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ABSTRACT

This paper studies the effects of polyurethane foam-filler on the axial splitting process of circular composite tubes under the axial quasi-static loading, experimentally. A shear mode of failure in circular composite tubes is initiated by crushing the tube onto a conical die to absorb the energy. The effects of conical die angle, number of fiber fabric layers, resin type and also, diameter and fiber fabric type of the tubes on axial load, energy absorption and specific absorbed energy by the structure are studied. Experimental results show that the polyurethane foam-filler increases energy absorption capability by the tubes. Also, it is found that in the investigated domain, composite tubes with smaller diameters are better energy absorbers, comparing with the composite tubes with larger diameters. Experiments show that foam-filled circular tubes under the axial compression in the splitting process works as good energy dissipater.

1. Introduction

Thin-walled tubes made from various ductile metals have been used widely as collapsible energy absorbers in structural crashworthiness applications, such as automotive and aeronautical industries to protect occupants and cargo [1]. Jimenez et al. [2] presented an experimental study on energy absorption capability by two different glass-polyester composite profiles. Niknejad et al. [3] presented a theoretical formula to predict folding force of polyurethane foam-filled square columns. Then, Niknejad et al. [4] derived some theoretical relations to predict instantaneous axial force of circular metal tubes during the axial splitting process by theoretical and experimental methods.

Reviewing the previous works shows that effects of resin properties and resin processing parameters on crushing behavior of composite tubes [5], behavior of core and core-less composite elliptical thin-walled tubes subjected to quasi-static axial loading [6], specific absorbed energy behavior of axially crushed composite tubular energy absorber devices [7,8], crashworthiness characteristics of natural silk/epoxy composite square tubes [9] were investigated, experimentally. In some cases, to increase energy absorption capability of thin-walled structures, foam-filler is used. Niknejad et al. [10] presented quasi-static crushing performance of empty and

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polyurethane foam-filled E-glass/vinylester composite tubes under the radial loading. In contrast to metal tubes, few studies [11–13] have been conducted on composite tubes with foam-filler materials. Solaimurugan and Velmurugan [14] studied effects of mode I interlaminar fracture toughness on specific absorbed energy by stitched glass/polyester composite cylinders under axial compression. Warrior et al. [15] demonstrated that plug initiators can give higher specific absorbed energy than flat platens in axial crush of quasi-isotropic composite tubes.

In this article, a shear failure mode is initiated in circular composite tubes by crushing the tube into a conical die to absorb considerable amount of kinetic energy. The effects of geometrical characteristics of circular composite tubes such as diameter, resin type, fiber fabric type and number of layers and also, conical die angle and polyurethane foam-filler on the value of energy absorption and axial load are investigated during the splitting process, experimentally.

2. Experimental setup

2.1. *Geometry, material and fabrication process*

Composite tubes were made of woven E-glass fibers and two resins of vinylester and polyester. Different specimens and their geometrical characteristics are listed in Table 1. Fibers were impregnated with a resin by drawing them through an in-line resin bath and wound over a mandrel. The fiber fabric was weaved at a 30°/−30° configuration. Two different foams were used to fill the circular composite tubes (Foam 1 and Foam 2) with different densities of 60.11 and 110.16 kg/m^3, respectively. Also, plateau stresses of the mentioned foams are equal to 1.88 and 2.85 MPa, respectively. The fiber strips were weaved in two forms to manufacture the tubes: woven planes by the fiber strips with the width of 2.1 mm (Fiber 1) and 3.4 mm (Fiber 2). Thicknesses of the plane tissues by Fiber 1 and Fiber 2 are 0.3 and 0.5 mm, respectively. Some conical dies were made of hardened steel. Tubes with different characteristics were tested to investigate the effects of diameter, fiber fabric types, number of fiber fabric layers, and types of resin and also, angle of conical die on absorbed energy and axial load of the tubes during the splitting process.

2.2. *Test procedure*

The braided composite tubes were compressed in a DMG machine, model 7166, with the computer controller and data attainment system. The experimental set-up of a composite tube that was filled by the polyurethane foam and placed on an external die is sketched in Fig. 1. In the figure, D, α, and P are inner diameter of tube, angle of conical die, and applied axial force on tube, respectively. Also, Fig. 2 shows sketch of experimental set-up of nosing process on a composite tube that was compressed between a rigid platen punch and a rigid internal conical die. Four different external die angles equal to 80°, 100°, 120°, and 140° were selected for external conical dies. The axes of die, tube and testing machine were carefully aligned. All the axial compression tests were performed in quasi-static condition with loading rate of 5 mm/min. Fig. 3

Table 1 – Characteristics of the specimens.

Specimens code	D (mm)	Fiber fabric	Fiber fabric layers	Resin	Length (mm)	Mass (g)	Foam-filler	Crack created	Die angle (°)
CS-01	40.00	Fiber 1	3	Vinylester	70	65.73	–	6	80
CS-02	40.00	Fiber 1	3	Vinylester	70	65.73	–	7	100
CS-03	40.00	Fiber 1	3	Vinylester	70	65.73	–	7	120
CS-04	40.00	Fiber 1	3	Vinylester	70	65.73	–	8	140
CS-05	50.00	Fiber 2	6	Vinylester	81	165.23	–	6	120
CS-06	40.00	Fiber 1	3	Polyester	70	56.55	–	5	100
CS-07	40.00	Fiber 1	3	Polyester	70	56.55	–	5	120
CS-08	50.00	Fiber 1	3	Vinylester	81	97.29	–	7	120
CS-09	50.00	Fiber 1	4	Vinylester	81	105.00	–	8	120
CS-10	50.00	Fiber 1	6	Vinylester	81	167.11	–	6	120
CS-11	40.00	Fiber 1	3	Polyester	70	60.55	–	–	100 (Nosing)
CS-12	40.00	Fiber 1	3	Polyester	70	60.55	–	–	120 (Nosing)
CS-13	50.00	Fiber 2	3	Vinylester	81	71.39	–	6	120
CS-14	50.00	Fiber 2	4	Vinylester	81	104.32	–	6	120
CS-15	50.00	Fiber 1	3	Polyester	81	71.33	–	6	120
CS-16	40.00	Fiber 1	3	Vinylester	70	76.19	Foam 1	6	80
CS-17	40.00	Fiber 1	3	Vinylester	70	76.19	Foam 1	6	100
CS-18	40.00	Fiber 1	3	Vinylester	70	76.19	Foam 1	7	120
CS-19	50.00	Fiber 2	3	Vinylester	81	82.57	Foam 1	6	120
CS-20	50.00	Fiber 1	3	Polyester	81	85.22	Foam 1	7	120
CS-21	50.00	Fiber 1	6	Vinylester	81	177.56	Foam 1	6	120
CS-22	50.00	Fiber 1	3	Vinylester	81	101.12	Foam 1	8	120
CS-23	50.00	Fiber 2	3	Vinylester	81	99.69	Foam 2	7	120
CS-24	50.00	Fiber 1	3	Polyester	81	86.49	Foam 2	7	120
CS-25	50.00	Fiber 1	6	Vinylester	81	191.88	Foam 2	6	120
CS-26	50.00	Fiber 1	3	Vinylester	81	103.66	Foam 2	6	120