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Three Point Bending Behavior of Woven Glass, Aramid and Carbon Fiber Reinforced Hybrid Composite Tube

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In this study, bending behavior of hybrid composites reinforced by different type of fibers is investigated experimentally. In the preparation of composite samples with different number of layers having the same thickness and woven shaped glass, aramid and carbon fibers are used and three-point bending test is carried out to determine bending behavior. It is seen from the test results that, regardless of fiber type, the load bearing capacity and energy absorption capability are increased by increasing layer number. As a result of evaluation of hybrid composites containing different fibers with respect of load-carrying capability and energy absorbing capacity, aramid-fiber reinforced composite with 2 and 4 layer provides better performance. T + 2GF + 2CF + 2AF specimen can be preferred in between 10 layered hybrid tubes and T + 2GF + 2AF + 6CF and T + 2GF + 2CF + 6AF specimens in 10 layered hybrid tubes. Load carrying capacity of hybrid tubes increased 7 times and energy absorbing capacity 9.6 times, respectively.

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1. Introduction

Aluminum, one of the lightweight metals, has been widely used in a variety of components for vehicles due to its advantages of superior strength and corrosion resistance. On the other hand, the reduction in weight may also be achieved simply using extruded tubular components. Tubular or thin-walled structures have been used for increasing energy absorption efficiency and safety, as well as reliability. In modern cars, extruded thin-walled aluminum components are used in the front and rear bumpers, crash boxes, longitudinal space frames and other safety components such as side-door impact beams, engine cradles, and suspension components. Instead of a beam made of steel, a properly designed composite bar provides an important advantage with respect to the lightness and safety of the structure [1]. Many researchers have done studies on externally fiber reinforced thin walled tubes. Lee et al. [2] investigated bending deformation and energy absorption characteristics of aluminum-composite hybrid tube beams. Specific maximum moment and specific absorbed energy of beams increased by about 105% and 120% compared with empty tube beams, respectively. Shin et al. [3] investigated energy absorption capability and failure mechanisms of aluminum-hybrid square tube beams wrapped with glass-fiber reinforced polymer (GFRP) under bending collapse loads, and compared those results with calculation results from modified theoretical models. Haedir et al. [4, 5] investigated the potential of carbon-fiber reinforced polymer (CFRP) sheets for enhanced strength, stiffness and ductility of reinforced steel circular hollow section beams. Bambach et al. [6–8] showed that the application of externally bonded CFRP delays local buckling and subsequently results in significant increases in elastic buckling stress, axial capacity and strength-to-weight ratio of square hollow sections thin-walled steel tubes under axial compression. Jung et al. [9] experimentally investigated the ultimate bending moments and energy absorption capability of aluminum square tube beams reinforced by GFRP.

In this paper, we present experimental studies done systematically on bending behavior of glass, aramid and carbon fiber reinforced hybrid composite beams.

2. Experimental studies

In this study, bending behavior of woven fiber reinforced hybrid-composite tubes obtained by strengthening woven glass, aramid and carbon fiber reinforcing layers were investigated in a systematic experimental procedure. The outer diameter, wall thickness and length dimensions of tubes made of 6063-T5 aluminum are 30, 1 and 270 mm, respectively. The reinforcement components utilized in specimen preparation are twill-structured glass fiber (GF) (280 g/m^2), twill-structured aramid fiber (AF) (170 g/m^2) and plain-structured carbon fiber (CF) (200 g/m^2) for external reinforcing. Fiber materials offer a range of mechanical properties that include less-dense, high-strength and high-stiffness, which occur at various levels in an epoxy adhesive matrix depending upon the fiber characteristics, such as their size, the percentage of fiber reinforcement, and the orientations of fibers [4]. The thicknesses of each fiber layer of four layers were applied as 0.25 mm for both of the glass and carbon fiber reinforcements.

The technical specifications of the main carrier tubular beam and the reinforcement materials used are shown in Table. These values were determined by applying the

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TABLE

Technical specifications of main carrier tubular beam and the reinforcing components.

No	Comp.[a]	Density [kg/m^3]	Density [g/m^2]	Elastic modulus [GPa]	Yield strength [MPa]	Tensile strength [MPa]	Elongation at break [%]
1	T	2700	–	69	215	245	11
2	GFRP	–	280	14.3	–	220	1.6
3	AFRP	–	170	19	–	357	1.9
4	CFRP	–	200	42	–	340	0.9

[a]T: Aluminum tube, GFRP: glass fiber reinforced polymer, AFRP: aramid fiber reinforced polymer, CFRP: carbon fiber reinforced polymer.

tensile test to the specimens taken from the related materials [10]. In terms of the experimental systematic, test specimens were prepared in different combinations in order to evaluate the influence of kinds of fiber, layer thickness and orientation of hybrid fiber. The general appearances of the prepared test specimens and three types of fibers are shown in Fig. 1.

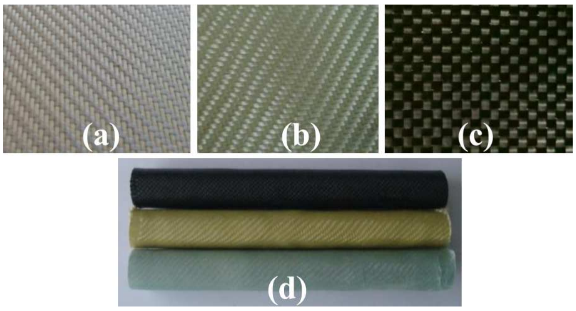

Fig. 1. (a) 280 g/m^2-twill woven glass fiber, (b) 170 g/m^2-twill woven aramid fiber, (c) 200 g/m^2-plain woven carbon fiber, (d) view of prepared hybrid composite test specimens.

Load measurements in experimental setup used for bending tests were performed with 10 t capacity-load cell. The outer diameter, wall thickness and length dimensions of bending test specimens were 30, 1 and 270 mm, respectively. Length/diameter ratio was provided as 7 by specifying 210 mm distance between supports.

3. Experimental results

Load-displacement curves obtained from bending tests with using woven glass, aramid and carbon fiber are given in Fig. 2.

Figure 2 shows that bending load and bending resistance increased with increasing layer number. Also displacement value of failure initiation in fiber layer is decreased with increasing layer number. Maximum improvement is obtained in aramid reinforced composite beam because of higher mechanical properties of epoxy reinforced aramid. Early failure was seen in carbon reinforced composite tubes rather than others. This behavior can be explained by tension test of carbon fiber reinforced epoxy. Carbon fiber showed more brittle behavior than the other in tension test.

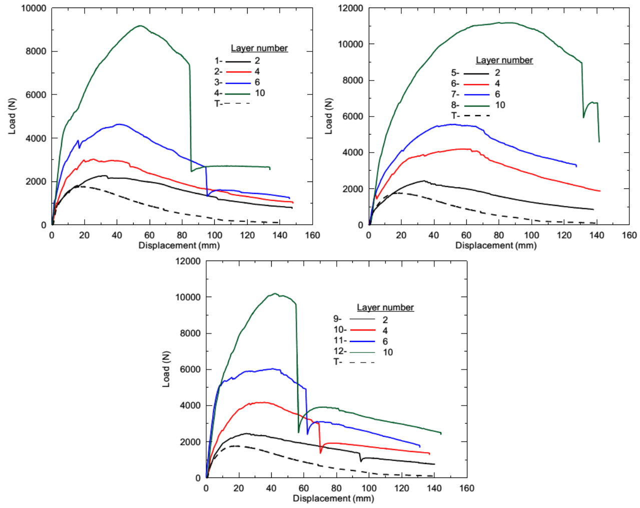

Fig. 2. Load-displacement curves of 2–4–6–10 layer numbered glass, aramid and carbon reinforced hybrid composite tubes.

Maximum improvement in the bending load is 5.2, 6.4 and 5.8 times according to the unreinforced tube, respectively. Energy absorbed capacity of glass, aramid and carbon fiber reinforced composite tubes increased 6.4, 8.8 and 5.9 times, respectively.

Load displacement curves of 4–6–8–10 layered hybrid composite tubes are given in Fig. 3. Glass fiber using on outer surface of tube is not considered due to low strength value in specimen combinations. It is possible to say that the hybrid composite have aramid layer on outer surface of tube displayed ductile behavior and failure occurred at higher displacements. This is because aramid fiber has a high tensile strength and high elongation against the other fiber material (Table).

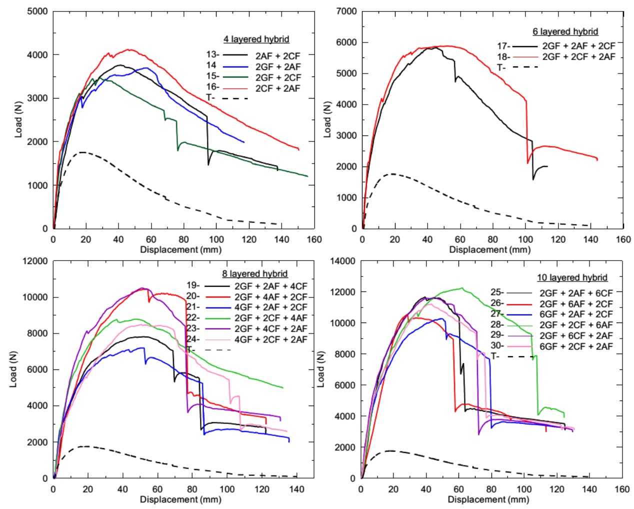

Fig. 3. Load–displacement curves of glass, aramid and carbon fiber reinforced hybrid composite tubes.

In 4 layered hybrid tubes, 16 numbered specimen has a highest load carrying capacity (LCC) and energy absorbed capacity (EAC). LCC and EAC are increased 2.3 and 3.3 times according to the unreinforced tube. In 6 layered hybrid tubes, 18 numbered specimen has a highest load carrying capacity and energy absorbed capacity. LCC and EAC are increased 3.4 and 4.8 times according to the unreinforced tube. In 8 layered hybrid tubes, 23 numbered specimens has a highest LCC and EAC. LCC and EAC are increased 6 and 7.1 times according to the unreinforced tube. In 10 layered hybrid tubes, 28 numbered specimen has a highest load carrying capacity and energy absorbed capacity. LCC and EAC are increased 7 and 9.6 times according to the unreinforced tube. Specific load carrying capacity and specific energy absorbed capacity of these specimens are increased 2.2 and 3 times, respectively.

Fig. 4. View of specimens after the bending test.

Figure 4 shows the view of tests specimens after the bending test. In bending, the crack initiates at the bottom of the tube, and then propagates with increasing displacement. Upon tearing, there was a sudden decrease in the load–displacement curves after the tearing of fiber (Figs. 2, 3). It is interesting that fiber and tube failures are the characteristic views of the composite specimens.

4. Conclusions

1. Bending load and bending resistance increased with increasing layer number. Aramid fiber reinforced hybrid composite tubes have a high LCC and EAC among the glass and carbon fiber reinforced composite tubes.

2. LCC and EAC are increased 6.4 and 8.8 times in aramid reinforced 10 layered composite hybrid tube between glass and carbon reinforced composites tubes.

3. LCC and EAC are increased 7 and 9.6 times according to the unreinforced tube in 10 layered hybrid tubes.

4. LCC and EAC of composite hybrid tube which consist of three types of fiber are higher than the composite tubes which consist of one type of fiber.

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