An experimental investigation of the effect of specimen shape and geometry on the energy absorption of fiberglass composite tubes

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The purpose of this work is to investigate the effect of the dimensions of composite tubes on their specific energy absorption capacity. Experimental investigations were carried out on three geometrical different cylindrical composite tubes subjected to compressive loading. More over a radial corrugated composite tube was subjected to the same load conditions in order to examine the varying of shape influence on the energy absorption of composite materials. Initial results indicate that for cylindrical tubes, diameter to thickness ratio has a significant effect on the energy absorption. Reduction in tube d/t ratio results in an increase in energy absorption. More over results show also radial corrugated composite tubes exhibit higher total energy absorption than cylindrical composite tubes.

I. INTRODUCTION

Composite materials are currently the hottest topic of researchers in chemistry, chemical engineering, electrical engineering, material science, mechanical engineering, and sold and structural mechanics. Composite materials are used in a variety of engineering structures, including aerospace, automotive, and underwater structures, as well as in medical prosthetic devices, electronic circuit boards, and sports equipment [1]. Composite materials are ideal for structural applications where high strength-to-weight and stiffness-to-weight ratios are required. Aircraft and spacecraft are typical weight-sensitive structures in which composite materials are cost-effective [2]. Fiber reinforced composite materials have been shown to be efficient energy absorbing materials for application to aerospace and automotive structures [3]. There is a considerable amount of published data on the response of composite tubes to axial crushing. Most of this work is concerned with the use of composites in applications where energy absorption under crash conditions is an important requirement [4]. Structural geometry was found one of the important parameters that effecting the capability of energy absorption [3,5].

This paper is dealing with the experimental investigation of axial crushing of composite tubes through two stages. Firstly, a cylindrical composite tubes with different specimen geometry have been subjected to quasi-static axial compressive load. The best result found with respect to specimen dimensions were used to fabricate a radial corrugated composite tube. Testing of the radial corrugated composite tube was conducted as a second stage of this work in order to examine the influence of specimen shape and geometry on the energy absorption capability of composite materials.

II. EXPERIMENTAL DETAILS

IIa. Material and Geometry

Different types of specimens have been tested in order to achieve the main goal of this work. The research starts with fabricating a different Cylindrical Composite Tubes **(CCT)** with respect to its diameter (see Fig. 1). Another type of specimen was fabricated under the same conditions in a form of Radial Corrugated Composite Tube **(RCCT)**. All structures are made of woven roving glass fibre/epoxy 600 g/sqm. All specimens were fabricated under the same conditions with a fixed number of layers (n) equal to six. The height (h) for all structures is same, however the mean diameter (d_m) of RCCT is the same as the diameter of CCT3 (see Fig. 2). Mean diameter of RCCT is the average of the diameter at the upper and lower tips of RCCT. Details on specimens' geometry are given in Table I.

IIb. Fabrication Process

The principle of wet winding process was used for the fabrication of all types of specimens. However, there is a difference in the details of fabrication process for each type due to the difference of the final shape need to be produced. A hand-lay-up process was used for the fabrication process. The tube was fabricated by rolling the woven roving fibre glass onto a rotating mandrel of suitable circular section. The woven roving fibre is passed through a resin bath, causing resin impregnation.

FIG. 1. Three different sizes of cylindrical specimens (CCT1, CCT2, and CCT3).

FIG. 2. Cylindrical and radial corrugated specimens (CCT3, and RCCT).

TABLE I. Description of woven roving composite tubes specimens.

Type of tube	No. of layers *n*	Wall thickness *t* (mm)	Height *h* (mm)	Specn. weight *w* (g)	Tube diameter *d* (mm)	dim. to thk ratio *d/t*	No. of tested spcs.
CCT 1	6	3.70	150	515	190	51.35	2
CCT 2	6	3.70	150	445	169	45.67	5
CCT 3	6	3.70	150	320	120	32.43	5
RCCT	6	3.70	150	410	120	-	5

IIc. Test Procedure

Test was carried out under the same condition for all types of specimens. Static uniaxial compression load was applied using an Instron 8500 digital-testing machine with full scale load range of 250 KN. Load platens were set parallel to each other prior to the initiation of the test. Five replicate tests were conducted for most of specimen. The tests were carried out at a speed of 15 mm/min. Load and displacement was recorded by an automatic data acquisition system.

III. RESULTS AND DISCUSSION

There are two crushing patterns were noted for the tested specimens: either fracture or bend. Specimens with high d/t ratio (CCT1, CCT2) exhibit a crushing mode similar to that of metallic tubes. That is in the crushed region the woven roving glass fiber plastically deforms. Fig. 3 shows a typical load-displacement curve with crushing photos of Cylindrical Composite Tube with a biggest diameter (CCT1). As shown, the maximum load achieved was 26.513 KN; the tube starts deformed from its upper portion. As the compression load increases, the deformation progresses in a bending form. However, the crushing load fluctuates slightly until the end of crushing where the specimen folded completely. Subsequently, load increases sharply.

The specimen with a *d/t* ratio of 45.67 (CCT2) crushes in a similar form that has a *d/t* ratio of 51.35 (CCT1). As shown in Fig. 4, CCT2 records higher initial crushing load (29.146 KN) than CCT1. However CCT3, which has a *d/t* ratio of 32.43, crushed in different manner. As shown in Fig. 5 the CCT3 was crushed progressively from one end by splaying mode. As the load increased initially the micro-fragmentation was observed at the upper portion of the tube. Initial crushing load was recorded as 53.387 KN followed by a sudden fall down of the load. As the load picked up again, the tube wall expanded outward and cracked. With the platen moving downward the longitudinal cracks advanced by splitting the tube wall into many segments. These segments were forced by the axial load to bend outwards in the shape of fronds.

The radial corrugated composite tube (RCCT) also failed by splaying mode similar to that of the CCT3 type. However, the RCCT did not exhibit regular-shape fronds like those of the CCT tubes (see Fig. 6). RCCT was fabricated with a mean diameter (d_m) equal to the diameter of CTT3 (see Table I). However the number of layers and specimen height was fixed for all kinds of specimens. When the RCCT was compressed, the tube wall expanded and splayed outward. Initial crushing load for RCCT was the highest among all tested specimens (57.534 KN). As shown in the Figure the axial compression load was slightly fluctuating along the crushing of the first half of the specimen. As the flat platen moving down further, the load drops down gradually due to the reduction of the resistance to compressive load at the second half of RCCT crushing. Finally the load rose up sharply at the end of crushing.

IV. CRUSHING LOAD AND ENERGY ABSORPTION

Typical crush load-displacement curves of those four different composite tubes are shown in Fig. 7. Among them the radial corrugated composite tube exhibits the highest crush load throughout the crushing process, and the cylindrical composite tube with *d/t* ratio of 51.35 shows the lowest crush load.

By looking to the curves carefully it is noted that the tubes crushed with the same failure mode as described in the previous section have similar crush load-displacement curves. The curves of the CCT3 and RCCT tubes crushed by the splaying mode vary most regularly with sharp teeth. On the other hand, the curves of the CCT1 and CCT2 tubes crushed by folding mode are most smooth and flat without sharp teeth and large load variation. The mean crush loads of those four tubes were respectively calculated and given in Table II. Among them the RCCT tube has the largest value of 48.478 KN. The CCT3 tube has the second largest value of 33.939 KN. Specific total energy absorption was also calculated and listed in Table II. Radial corrugated composite tube recorded the highest total specific energy absorption. However, for cylindrical composite tubes, it is noted that as *d/t* ratio increases, the total specific energy absorption decreases. Obviously there is a small difference for specific energy absorption between CCT1 and CTT2. However significant difference was observed between CCT2 and CCT3. The reason behind that was due to the small difference of diameter between CCT1 and CCT2 meanwhile, the diameter of CCT3 is much larger than CCT2.

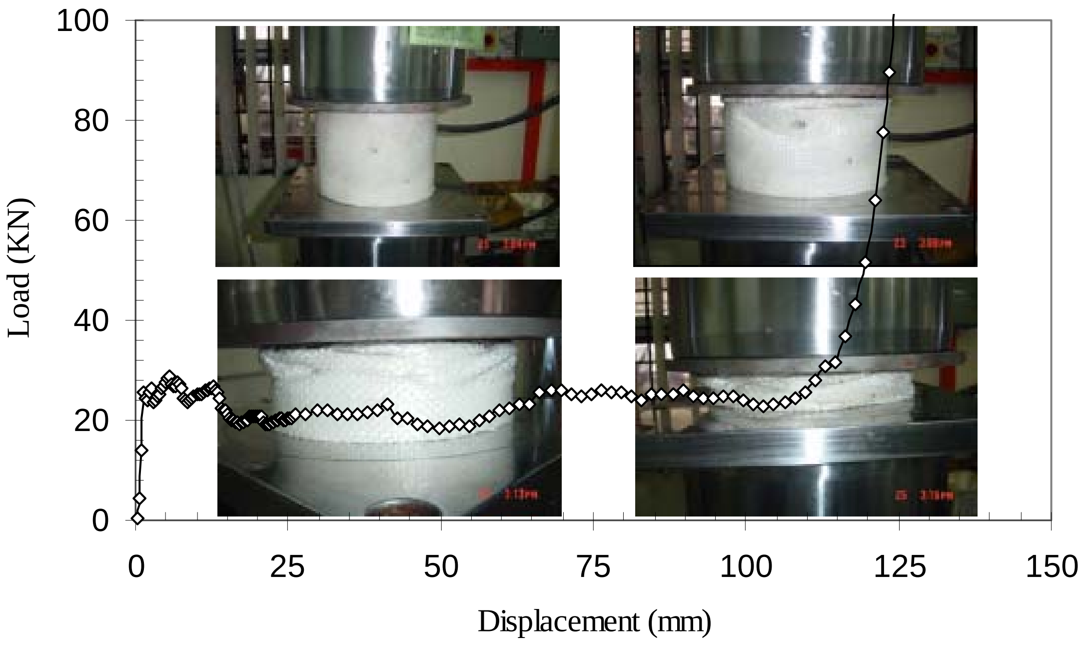

FIG. 3. Load-displacement curve and deformation history of CCT1.

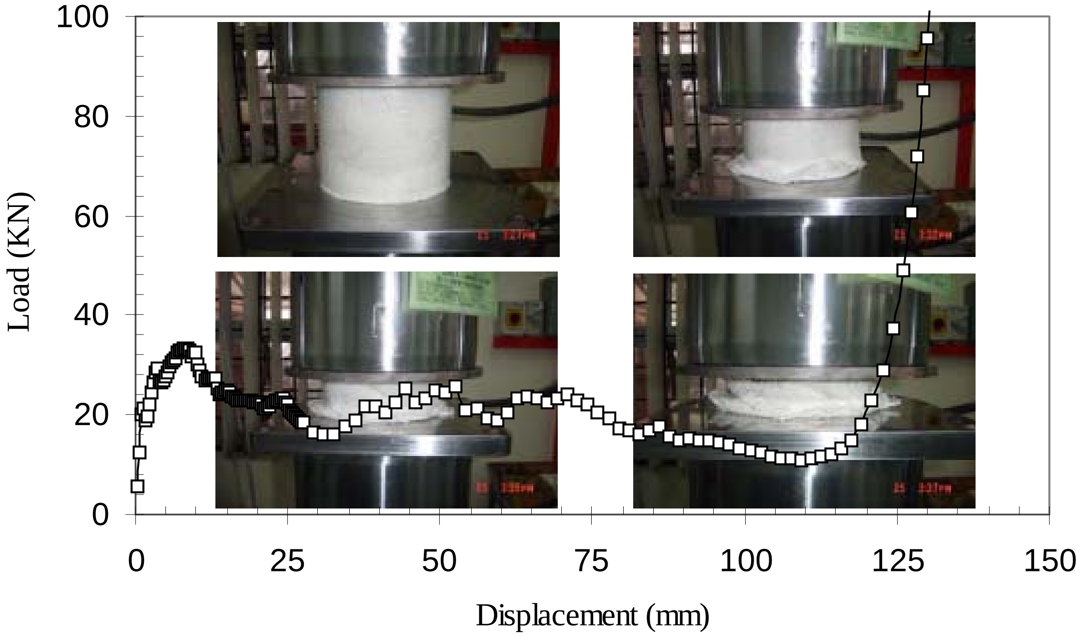

FIG. 4. Load-displacement curve and deformation history of CCT2.

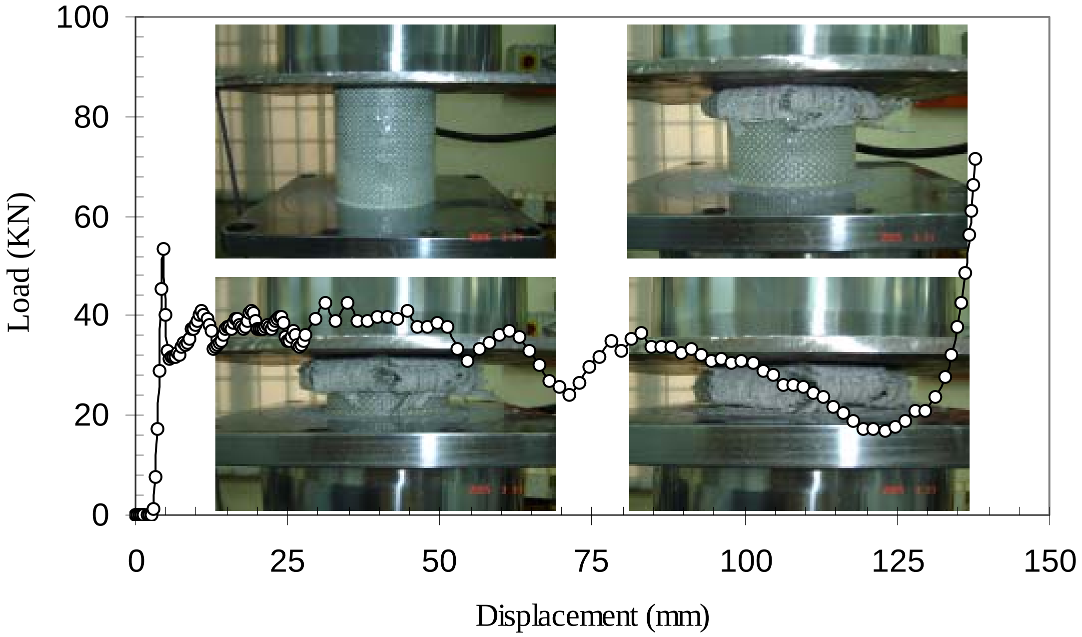

FIG. 5. Load-displacement curve and deformation history of CCT3.

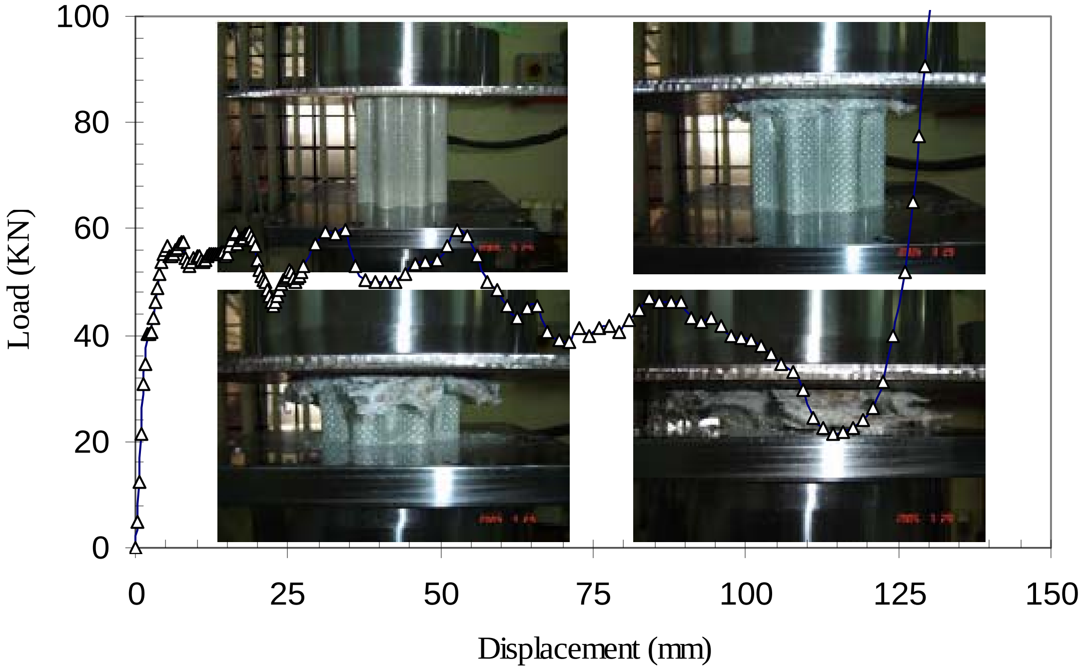

FIG. 6. Load-displacement curve and deformation history of RCCT.

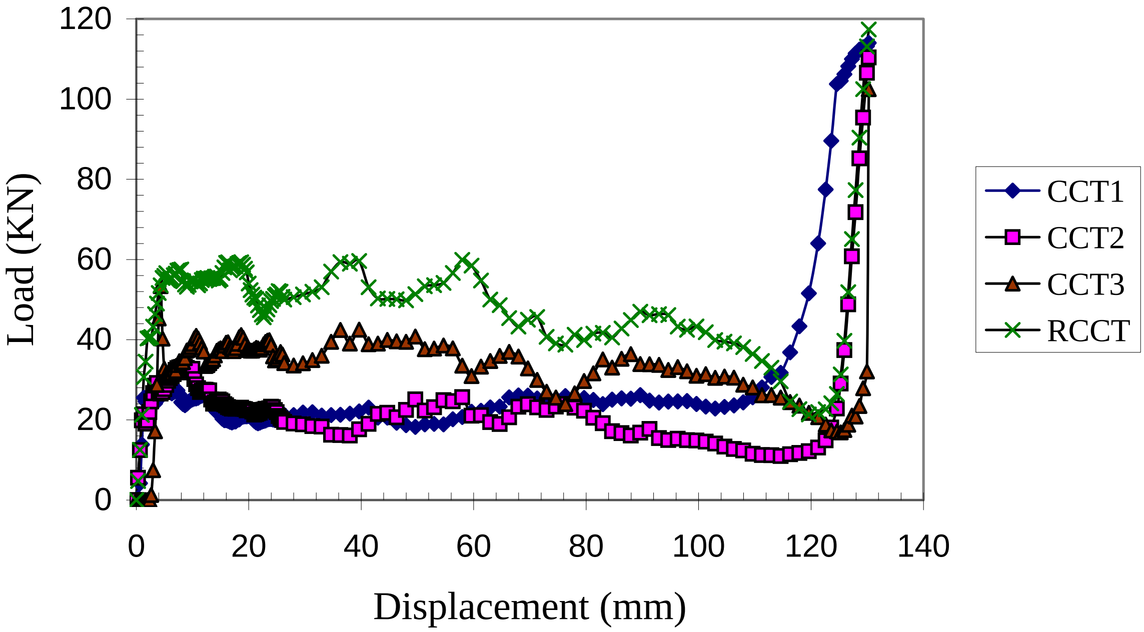

FIG. 7. Load-displacement curve of CCT1, CCT2, CCT3, and RCCT.

TABLE II. Crashworthiness parameters of tested specimens.

Specimen type	Max. load P_{max} (KN)	Mean load $\overline{P}$ (KN)	Tol energy abs. E (J)	Specific energy abs E_s (Kj/Kg)	CFE (%)	SE (%)
CCT1	26.513	22.944	2472.860	4.198	86.530	73.070
CCT2	29.146	22.261	2395.597	4.578	76.370	81.730
CCT3	53.387	33.939	3911.868	9.792	63.570	89.950
RCCT	57.534	48.478	5686.260	11.940	84.260	83.960

V. CONCLUSION

In this paper we have presented experimentally the investigation of the effect of the dimensions of composite tubes on their specific energy absorption capacity. The energy absorption capability and crushing modes of composite materials and structures has been evaluated through an extensive test program. It is found that specimen geometry significantly effect the energy absorption capability of composite material. The results show that, as *d/t* ratio decreases, the energy absorption capability increases. In addition, it is seen that radial corrugated tube exhibits higher energy absorption capability than cylindrical composite tube. Load displacement curves have been obtained corresponding to tubes of varying shape and geometry.

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