

Experimental Testing of Composite Tubes with Different Corrugation Profile Subjected to Lateral Compression Load

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Abstract—This paper presents the effect of corrugation profile geometry on the crushing behavior, energy absorption, failure mechanism, and failure mode of woven roving glass fibre/epoxy laminated composite tube. Experimental investigations were carried out on composite tubes with three different profile shapes: sinusoidal, triangular and trapezoidal. The tubes were subjected to lateral compressive loading. On the addition to a radial corrugated composite tube, cylindrical composite tube, were fabricated and tested under the same condition in order to know the effect of corrugation geometry. Typical histories of their deformation are presented. Behavior of tubes as regards the peak crushing load, energy absorbed and mode of crushing has been discussed. The results show that the behavior of the tube under lateral compression load is influenced by the geometry of the tube itself.

Keywords—Corrugated composite specimens, Energy absorption, Lateral crushing.

I. INTRODUCTION

THE importance of composite materials is now well known. Today the use of composite materials in different kinds of applications is accelerating rapidly. Composite materials have become common engineering materials and are designed and manufactured for various applications including automotive components, sporting goods, aerospace parts, consumer goods, and in the marine and oil industries [1].

The design of air, sea, and ground vehicles is increasingly driven by minimum weight considerations and by concerns for passenger safety. Composite structures are light, can be tailored in composition and shape, and can provide high crashworthiness when used as part of an energy-dissipating device [2].

As a part of engineering applications, composite tubes replacing metal products on many applications. High attention was given to produce composite tubes and testing it. They utilize these researches in composite crushing behavior and energy absorption. There is a considerable amount of published data on the response of composite tubes to axial crushing [3-6]. Many of these studies utilize circular cross-section tubular specimens to determine the energy absorption capability of the material. In spite of axial crushing results were appointed as the bases of transfer from one phase to another,

lateral analysis could not be ignored. It has an important influence to the real life applications. For example, in Japan, about 23 % of crash accidents resulting in lethal injury are attributed to side impact. It is thus necessary to consider not only frontal collision but also lateral collision in the design of automotive vehicles [7-8].

This paper concern of studying the effect of corrugation profile geometry on energy absorption capacity, failure mechanism, and failure mode of woven roving glass fibre/epoxy laminated composite tube. Three different profiles have been tested; Sinusoidal profile, Triangular profile, and Trapezoidal profile. They were referred in this paper in short as: RCCT, TRCT, and TZCT respectively.

II. EXPERIMENTAL SETUP

A. Geometry and Material

Three radial corrugated composite tubes with different profiles have been tested; Sinusoidal, Triangular, and Trapezoidal profile. They were referred in this paper as: RCCT, TRCT, and TZCT respectively. On addition to that, cylindrical composite tube CCT, were fabricated and tested under the same condition in order to know the effect of corrugation geometry (see Fig. 1). The specimens are made of woven roving glass fibre/epoxy 600 g/sqm. All specimens fabricated under the same conditions with a fixed number of layers equal to six.



Fig. 1 Tested specimens
(Right to left CCT, RCCT, TRCT, TZCT)

B. 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

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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 fibreglass onto a rotating mandrel of suitable circular section. The woven roving fibre is passed through a resin bath, causing resin impregnation.

C. Test Procedure

Test was carried out under the same condition for all types of specimens. Quasi-static tests were conducted by laterally compressed of specimens between parallel, flat steel platens (see Fig. 2), one static and one moving at a constant cross-head speed. Load platens were set parallel to each other prior to the initiation of the test. From three to five replicate tests were conducted for each specimen. The tests were carried out at a speed of 15 mm/min. Load and displacement were recorded by an automatic data acquisition system.



(a)



(b)

Fig. 2 (a) Corrugated specimen (RCCT) under lateral compression load, (b) Cylindrical specimen (CCT) under lateral compression load

III. RESULTS AND DISCUSSION

A. Failure Mode

For cylindrical tubes (CCT), as shown in Fig. 3(a), as the crushing load increases, the model becomes elliptical shape, and at this stage resistant load achieved its maximum value before cracks takes place. Immediately after this stage four longitudinal fracture lines are observed to have developed. The fracture lines are formed diametrically opposite to each other at about 90° angle as seen in Fig. 3(b). Further deformation leads the model to form a shape of two similar adjacent eyes. This leads to gradual increase of load. This behavior seems to continue until complete crushing when the specimen forming two flat sheets.

However, for radial corrugated tubes all kinds of specimens with different profiles (RCCT, TRCT, TZCT) have the same behavior under the effect of lateral compression load. As the load increases gradually the specimen reforming its shape to become a rectangular with dissimilar sides in Fig. 4(a). Increasing of compression load reforming the radial corrugated tube to become approximately a rectangular shape with a corresponding straight sides and a profile sides which in contact with the flat platens. Further increases of compression load causes two longitudinal fracture lines at the specimen sides. Consequently the upper and lower profile formed parts contact each other at the bottom and top points of the parts respectively in Fig. 4(b).

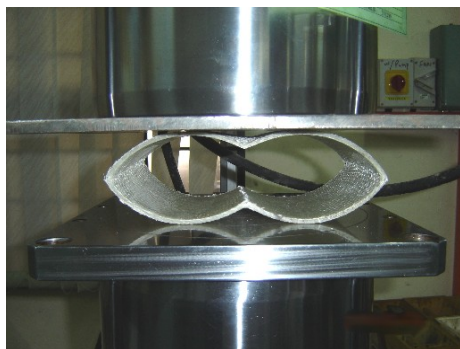
B. Crashworthiness Parameters

In order to examine the corrugation effect on the energy absorption characteristics, different parameters can be obtained. These parameters are: initial failure load P_i , specific energy E_s , crushing force efficiency CFE , and stroke efficiency SE . Results obtained were presented in Table I. The crush force efficiency (CFE) is the ratio between average crush load to the peak crush load. It is a measure of the load fluctuations that occur during the crushing of a structure. A value of unity represents the most desirable value of the CFE .

Crushing of a tube will lead to compaction of the tube. This results in a continuously increasing load level as the deformation increases. Practical use of the absorber beyond this limit would lead to load levels exceeding that is given as the maximum acceptable limit. The relative deformation of the absorber, at which compaction takes place, is referred to as the stroke efficiency (SE) of the absorber. However, specific energy is defined as the amount of energy absorbed per unit mass of crushed material. Therefore, the specific energy (E_s) that is dependent on the structure geometry was used for comparing the energy absorption models.



(a)

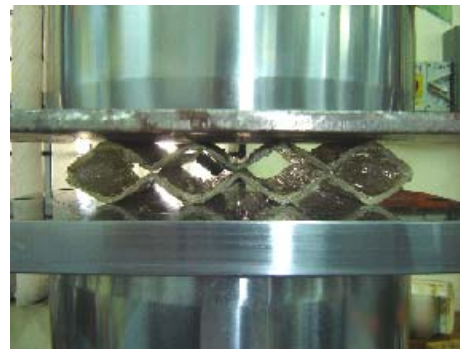


(b)

Fig. 3 Crushing of cylindrical composite tube subjected to lateral compression load



(a)



(b)

Fig. 4 Crushing of corrugated composite tube subjected to lateral compression load

TABLE I
CRASHWORTHINESS PARAMETERS OF
CCT, RCCT, TRCT AND TZCT

| Model | Initial Failure Load P_i (kN) | Max Load P_{max} (kN) | Avg. Load P_{av} (kN) | Specific Energy E_s (kJ/kg) | Crush Force Efficiency CFE (%) (kN/kN) | Stroke Effy. SE (%) (mm/mm) |
|-------|---------------------------------|-------------------------|-------------------------|-------------------------------|--|-----------------------------|
| CCT | 3.275 | 3.27 | 2.869 | 0.895 | 87.60 | 90.23 |
| RCCT | 1.618 | 3.03 | 2.714 | 0.809 | 89.34 | 97.12 |
| TRCT | 1.024 | 1.71 | 1.023 | 0.207 | 59.75 | 97.82 |
| TZCT | 1.200 | 2.48 | 1.373 | 0.314 | 55.21 | 90.63 |

C. Load Displacement Curve

Typical load-displacement curves were presented to exemplify the effect of corrugation profile on the crushing behaviour and energy absorption capability of CCT, RCCT, TRCT and TZCT models when subjected to lateral compression load as shown in Fig. 5. Lateral crushing exhibits minimum fluctuating load specimens crushing length.

The behaviour of lateral crushing of TRCT and TZCT models was exactly like the behaviour of RCCT model. This can be easily understood from load-displacement curve. The three curves of corrugated tubes (RCCT, TRCT, and TZCT) were mostly coincides each other. However there was a valuable difference between the results of these three corrugated tubes and the cylindrical tube (CCT). The CCT mode recorded much higher initial failure load than corrugated tubes. It is about two to three times higher. Changing of corrugation profile did not affect much the crushing behaviour and energy absorption of composite tubes when subjected to lateral compression load. In spite of corrugation shape, radial corrugation allows the tube to deform elastically with a minimum resisting force at early stages of crushing. This stage followed by forming of two

longitudinal fracture lines at the tube sides that leads to separate the tube to two corrugated sheets. When these sheets meet each other, here a slight difference was existed (if any), due to the difference in corrugation profile. At this stage, the structures form a shape of serious of honeycombs in case of trapezoidal profile, and a serious of parallelograms in the case of triangular profile. But for any case, it was observed that at this stage load increases sharply until the end of crush.

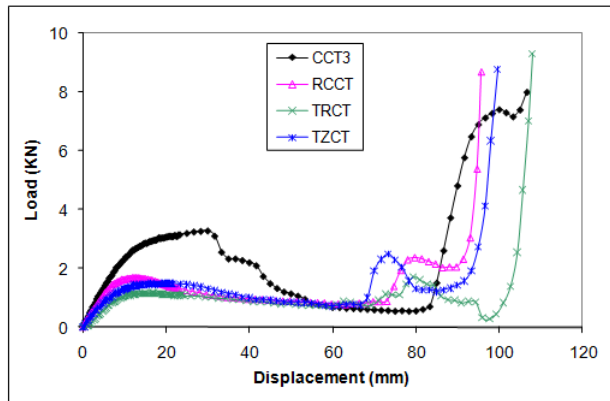


Fig. 5 Load-Displacement curve
CCT, RCCT, TRCT, TZCT

IV. CONCLUSION

Changing of corrugation profile did not affect much the crushing behaviour and energy absorption. In spite of corrugation shape, radial corrugation allows the tube to deform elastically with a minimum resisting force.

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