An experimental analysis on the transverse crushing behaviour of Nano-filler reinforced composite cylindrical tubular elements

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Abstract: Thin-walled structures made of nanocomposite materials, could be employed as energy dissipating tubular elements in automobiles owing to its significant characteristics such as lightweight, fracture toughness, enhanced stiffness, and impact energy absorbing ability. The current research work aimed to investigate the transverse deformation behaviour of the hybrid aluminium-nano-filler reinforced glass/basalt fabric polymer composite cylindrical tubes under quasi-static experiments. The progressive crushing behaviour of these tubes were examined from photography. The experimental outcomes revealed that the aluminium-nano-filler reinforced composite tubes buckled displaying an ability of spreading the deformation under transverse compression. The use of multi-walled carbon nano tube fillers reduced the fibre fracturing and ultimately improved the energy absorbing ability of the tubes during crushing process. The nano filler induced tubes with more fabric plies revealed marginally better crashworthiness performance compared to the traditional aluminium-glass/basalt fabric polymer composite tubes.

Keywords: Nano composite, thin-walled structures, buckling, energy absorption, crashworthiness

1. Introduction

The deformation analysis of thin-walled cylindrical shaped aluminium tubes has gained more attention in the recent decade, owing to its potential application as energy absorbers in the crashworthiness design of automobiles [1]. Furthermore, advanced composite materials are currently employed in modern automotive vehicles because they provide superior strength, stability, light-weight, less consumption of fuel, and structural crashworthiness of a vehicle [2]. Contrary to the crashworthiness
behaviour of conventional metallic tubes, composite tubes are crushed progressively by extensive micro-fracture as a replacement of plastic buckling and can dissipate a large amount of energy [3]. It is also evidenced from the previous literature that composites with some nano filler materials might attain substantial enhancements in fracture toughness and energy absorption which could be of significant importance in designing vehicle structures [4-6]. This hybrid mixture of materials enhances impact and crashworthiness characteristics of tubes during compression.

In this perspective, Manwar Hussain et al. [7] reported that the crashworthiness and energy absorption properties of composites could be enhanced by hybridization of polymer matrix system with active nano particulate fillers reinforcements. For example, Fly-ash, graphene, carbon nano tubes, rice husk, and alumina etc.Incorporation of these nano fillers in composite material enhances interlaminar strength with proper filler dispersion in the matrix [8, 9]. Moreover, increasing these phenomena serves in enhancing mechanical properties and energy absorption capacity. Yuvan et al. [10] studied nano fillers dispersed CFRP and reported that montmorillonite nano clay modified TGDDM epoxy system increase the interlaminar fracture toughness by nano clay presence increase the flexural strength by 38%. Consequently, there is a rigorous determination now a days to increase further the energy absorbing ability of that type of bio fabric composites by altering the structure of the epoxy polymer matrix [11-14]. As a result, these major research studies report that the nano particulate fillers have the prospective to be employed as secondary strengthening agent in impact energy dissipating tubular structures for axial loading. From the existing research articles, it is perceived that limited studies have discussed the axial and oblique deformation behaviour of hybrid metal-bio fabric composite tubes. Also, inadequate research papers on the transverse crushing behaviour of hybrid aluminium wrapped bio fabric nano particle filled composite tubes was available in the literature to date.

In the present investigation, transverse crushing behaviour of the hybrid aluminium based basalt/glass fabric–multi-walled carbon nano tube fillers incorporated polymer composite tubes are studied. Different hybrid tube configurations with and without using carbon nano tube fillers were fabricated efficiently and compressed when exposed to quasi-static crushing conditions. The influence of multi-walled carbon nano tube fillers and number of fabric layers of the composite segment on the transverse crashworthiness performance is also thoroughly examined.

2. Tube Configuration

The proposed hybrid nano filler reinforced composite tubes of different configurations were successfully fabricated with an aid of hand layup technique. The tube specimens are prepared with an arrangement of an aluminium circular tube that was outwardly covered by nano filler incorporated basalt and glass fabric composite segment. Aluminium tubes have the following dimensions: length of the tube=150 mm, External diameter =70 mm and thickness=2.5 mm. A nano composite segment was prepared by mixing 2 % of multi-walled carbon nano tube fillers in the epoxy resin applied in the basalt and glass fabric layers. All the tubes were cured for 48 hours based on the curing conditions recommended in existing literature [15]. Efficiently manufactured tubes were tested in transverse crushing experiments which are shown in Figure 1.

The various tubes utilized in the present investigation is represented by the following codes.

- **A1B3G**: Aluminum tube covered with one layer of basalt and three layers of glass fabric
- **A2B2G**: Aluminum tube covered with two layers of basalt and two layers of glass fabric
- **A3B1G**: Aluminum tube covered with three layers of basalt and one layer of glass fabric
- **A1B3GN**: Aluminum tube covered with one layer of basalt and three layers of glass fabric along with nano-fillers
• **A2B2GN**: Aluminium tube covered with two layers of basalt and two layers of glass fabric along with nano-fillers
• **A3B1GN**: Aluminium tube covered with three layers of basalt and one layer of glass fabric along with nano-fillers

3. **Experimentation details**

In the current article, crushing experiments were executed to assess the crushing performance and energy absorbing ability of the recommended hybrid aluminium based basalt/glass hybrid fabric nano composite circular tubes exposed to transverse loading conditions. Effectively manufactured hybrid tube specimens were crushed from corner to corner using quasi-static compressive load as shown in Figure 2. The crashworthiness features of all the recommended hybrid aluminium-nano filled composite tubular structures were defined by calculating the crashworthiness performance indicators [16-19]. These indicators were attained from the resultant transverse crush force-displacement graphs of each tube pattern as presented in Table 1.
Table 1. Transverse crashworthiness characteristics

| S.No. | Tube reference | Weight of the tube (g) | Crushing distance (mm) | Average crushing force (kN) | Energy absorbing ability (J) | Specific energy absorption (J/g) |
|-------|----------------|------------------------|------------------------|----------------------------|------------------------------|---------------------------------|
| 1.    | A1B3G          | 130                    | 60                     | 7.94                       | 481.32                       | 3.70                            |
| 2.    | A2B2G          | 125                    | 60                     | 8.74                       | 525.18                       | 4.20                            |
| 3.    | A3B1G          | 119                    | 60                     | 10.12                      | 607.08                       | 5.10                            |
| 4.    | A1B3GN         | 132                    | 60                     | 8.84                       | 530.21                       | 4.02                            |
| 5.    | A2B2GN         | 128                    | 60                     | 9.52                       | 571.06                       | 4.46                            |
| 6.    | A3B1GN         | 123                    | 60                     | 12.49                      | 749.50                       | 6.09                            |

4. Results and Discussion

The typical buckling shapes of hybrid aluminium covered with basalt/glass fabric epoxy composite tubes with and without incorporation of multi-walled carbon nano tube fillers in a progressive manner at 4 different phases of deformation are displayed in Figure 3. While the transverse load is applied on the tube specimen, the inner aluminium segment of the circular tube structure buckled into an oval shape and the external composite portional so followed the identical outline without any fracture. While the applied load is persistent additionally, the aluminium segment buckled inwards in the midpoint and the profile looks like “8” in the horizontal direction. Nevertheless, the composite portion not followed the aluminium segment and delaminated from the aluminium segment finally, it develops an oval profile with two pivots in the horizontal and two pivots in the vertical edges of the tubular structure. Comparable buckling shapes in all the tested tube specimens were observed.
Figure 3. Progressive crushing of hybrid tube under quasi-static load

(a) Progressive crushing of tube without nano-fillers

(b) Progressive crushing of tube with nano-fillers

The comparison of final buckled shapes of hybrid aluminium covered with basalt/glass fabric epoxy composite tubes with and without incorporation of multi-walled carbon nano tube fillers are shown in Figure 4. The transversely buckled final shapes of the aluminium-basalt/glass fabric epoxy composite tube specimens showed that all the recommended tube patterns presented comparable buckling profiles during transverse crushing process, since the diameter of the tube is same. On the other hand, the delamination failure occurs in the interface of the composite portion and the inner aluminium segment could be observed, and it was not beneficial to energy absorbing ability. Thus, the presence of multi-walled carbon nano tube fillers has no noticeable influence on the buckled shapes of the conventional tube. Nevertheless, the use of multi-walled carbon nano tube fillers enhances the energy absorbing ability due to the better interfacial adhesion between the aluminium segment and the composite portion during the crushing procedure.

Figure 4. Comparison of final buckled shapes
The transverse crush force–displacement and energy absorbing ability performance of hybrid aluminium based basalt/glass fabric epoxy composite tubes with and without multi-walled carbon nano tube fillers are illustrated in Figures 4 and 5. It is observed from the plot that all the tube samples mostly buckle elastically until the occurrence of initial peak force, stable with the commencement of plastic deformation. Consequently, the curves specify a constant buckling with a regular increase in the transverse crush force. It is also perceived that the transverse crush force decreases after a certain time due to the composite fracture. The crushing curves in Fig. 4 display that the increasing the number of fabric layers does not influence the trend of the transverse crush force–deformation behaviour of the aluminium-nano composite tubes.

**Figure 6:** Transverse crush force-deformation curves (With nano-fillers)

5. Conclusions

From the outcomes obtained in this experimental investigation, main inferences are attained as below:
- The average crush force and SEA of the multi-walled carbon nano tube filled epoxy composite tubes are higher than the traditional tubes without nano fillers exposed to the identical experimental conditions by 10-20%.

- Overall results indicate that the multi-walled carbon nano tube filled composite tubes is appropriate to employ as impact energy dissipating elements due to their remarkable energy absorbing ability.

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