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Quasi-static Axial Compression of thin-walled Circular Composite Tubes

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Abstract

Assessing the behavior of composite structures which are subjected to impact loads is one of the important subjects in the field of mechanical sciences. Using thin-walled tubes which collapsed and absorbed the impact energy is a well-known method to prevent damages to the other parts of the structures. In this paper, deformations, crushing length, peak load, mean force and energy absorption capacity of thin-walled circular composite tubes are investigated both experimentally and numerically. In order to experimental study, three circular composite tubes were fabricated and subjected to quasi-static axial load. Also, a finite element model was constructed and analyzed under same conditions using FEM27 and LS-DYNA software packages. The results of simulations are in good agreement with the experimental data and show that the section geometry has considerable effect on the energy absorption. The circular composite tube has the most energy absorption capacity and the most average force among all investigated sections.

Keyword: Absorbed energy, axial compression, circular composite tube, experimental setup, finite element method.

1. Introduction

Nowadays, energy absorbers are widely applicable in structures construction, aerospace and vehicle industries. The main purpose of energy absorbers is to reduce and damp the impact energy which is applied to the structure. Vehicles are used extensively and a large number of horrible accidents related to them occur widely. Hence, increasing the safety of passengers is a valuable aim and a lot of investigations are carried out in this region. Using energy absorbers is an appropriate option for this purpose. These parts have different shapes and are made from different materials such as low density metals and composites. Crushing behaviors of thin-walled structures have received extensive attention [1–5] for their applications in energy absorbers, such as blast resistant walls, protective doors, and anti-crash bumpers. Crushing behaviors of collapsible cellular energy-absorption devices with circular and elliptical cross-section were investigated by Mahdi and Hamouda [6]. Hou et al. [7, 8] suggested a multi-objective optimization method for the crashworthiness design of thin-walled tubes.In last decades, composite materials are used as energy absorbers in vehicles due to their high stiffness and strength, and low weight. In designing these parts, investigation of their collapse behavior and energy absorption capacity during impact is necessary. To date, a wide variety of studies have been done about these structures, especially about thin-walled tubes. Alexander [9] accomplished the first studies on the collapse of cylindrical tubes under axial loads to access relations for designing nuclear fuel tanks. Inversion of tubes and inversion specifications were studied by Al-Hassani et al. [10]. Mamalis et al. [11] presented a new theoretical model for collapse of steel conical tubes based on experimental observations. Abramowicz and Wierzbicki [12] studied crushing of thin-walled structures with polygon sections considering fixed plastic hinges. Abramowicz and Jones [13] calculated the average crushing load of square tubes under axial static loads. Mamalis et al. [14] studied the effect of circular grooves around outer surface of cylindrical tubes on the buckling load, experimentally, and showed that these grooves can control the maximum load of collapse. Chirwa [15] investigated the inversion of thin walled tubes with varying thickness, both analytically and experimentally, and showed that energy absorption capacity of these tubes is about 50% higher than those of tubes with constant thickness. Aljawi and Alghamdi [16] studied the inversion collapse of frusta using ABAQUS software. They divided inversion of frusta into three types: external flattening, internal flattening and folding mode. Alghamdi [17] made an overview about collapsible energy absorbers. Aljawi et al. [18] investigated energy absorption of steel square tubes both experimentally and numerically and observed that the maximum collapse load reduces about 10% when these tubes are filled with foam. Tarigopula [19] studied quasi static and dynamic loading of simple and top-hat tubes experimentally and concluded that energy absorption of top-hat tubes is bigger. Hong et al. [20,21] and Fan et al. [22] revealed the plastic

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deformation and energy absorption of triangular tubes in axial compression experiments. However, performances of these tubes under lateral crushing are rarely reported. Rejab and Cantwell [23] revealed that triangular corrugated-core sandwich panels would take on a trapezium shape in crushing. Gupta et al. [24] presented experimental and computational investigations on the lateral crushing behaviors of rectangular and square metallic cells, which collapsed around two sets of plastic hinges. Abdewi et al. [25] studied the lateral crushing behaviors of radial corrugated composite cells. McShane et al. [26] studied the dynamic buckling of inclined struts and built a three-hinge plastic buckling model.

In this paper, deformation modes and energy absorption capacity of thin-walled composite circular tubes are investigated and compared both experimentally and numerically. Composite tubes are made and tested under quasi-static loading and their crush loads are investigated. Also, the test process is simulated and the crush loads are obtained for modeled samples using a finite element code. Finally, the experimental and numerical results are compared together.

2. Experimental investigations

To investigate the carry loads and energy absorption capacity of composite tubes, some samples are made from E-glass / Epoxy composite material. The tube were made of four-layer laminate which composed of +45 and -45 plies. All samples have circular tube shape with constant wall thickness. The geometrical specifications of the samples for crush test are presented in Table 1. Also, a standard sample is made for simple tension test. The made samples are shown in Fig. 1.

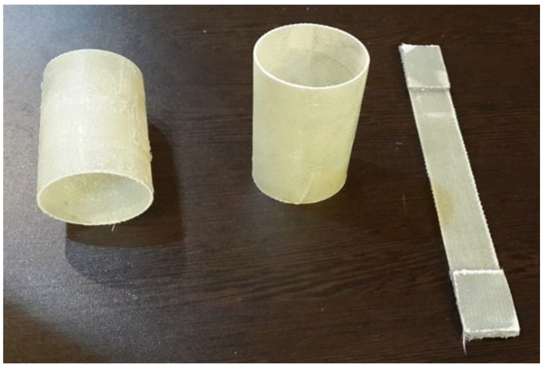

Fig. 1. Prepared circular tube samples

Table 1. Specifications of the samples

Diameter (mm)	Height (mm)	Thickness (mm)
50	100	1.5

2. 1. Simple tensile test

Before the crush test, to obtain the Stress-Strain curve of used composite material and its tensile behavior, a simple tension test was performed. The test was carried out by the INSTRON model 8305 set up based on ASME standard test procedure. Fig. 2 shows the INSTRON device. The stress-strain curve obtained from the tensile test are shown in Fig. 3. It can be seen that the used E-glass / Epoxy composite material has ultimate stress equal to 392.982 MPa which is occurred at the fracture strain of about 3.7%.

Fig. 2. INSTRON model 8305

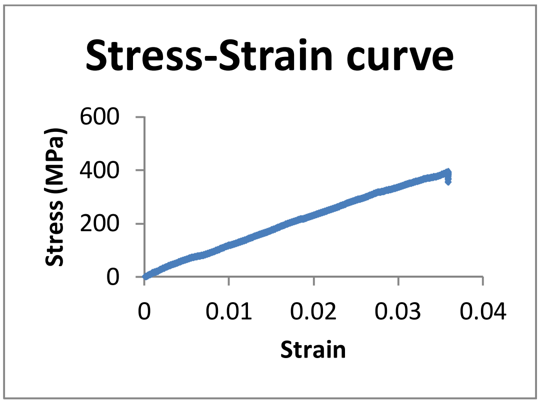

Fig. 3. Stress- strain curve of the E-glass / Epoxy composite material

2. 2. Crush test

To investigate the composite tube behavior subjected to impact load, a quasi-static method was performed using INSTRON test device. This machine has two jaws which the upper one is stationary and the lower one can move with a predefined velocity in a specific distance. The load is exerted by the hydraulic system up to 600 KN. The specimen is a set between the jaws and the load-displacement curve is plotted during deformation. In this test, the longitudinal compressive load was applied to the samples with speed of 20 mm/s. Three tests with the same conditions are carried out for each case and the values of the maximum force (the first peak load) and the maximum displacement (crushing distance) are determined from the load-displacement curve. The value of the absorbed energy is calculated from the area under load-displacement curve and the mean force value is calculated by dividing the absorbed energy to the displacement. Fig. 4 shows a sample during the test. The test ends when the samples completely collapse. Fig. 5 shows the collapsed samples at the end of loading. The load-displacement curve is obtained from the test setup.

3. Finite element modeling

To simulate the quasi-static crush test, a model of composite tube sample with same dimensions was constructed and analyzed in FEM27 software package.

Fig. 4. A circular composite tube during crush test

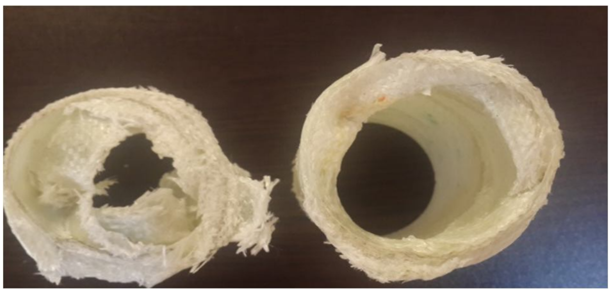

Fig. 5. Failed samples after loading

The test process was simulated using two rigid solid plates as jaws which the lower plate was fixed and the upper one was moving downward with speed of 20 mm/s. Axial loading simulation on the sample has been performed by using LS-DYNA package. The material properties of the model were taken from the tension tests. The composite shell elements with thickness of 1.5 mm was used for modeling of the sample and rigid material elements was used for rigid plates. The mechanical characteristic of the sample is shown in Table 2. Proper contacts between the tube elements and the end plates were defined. In order to supply appropriate condition for deformations, "contact automatic surface to surface title" and "contact automatic single surface title" are used for the tube-rigid part elements and the tube elements with each other, respectively. The finite element model of the tube during the loading is shown in Fig. 6. The coefficient of friction between two end plates and the sample is taken 0.2. Deformation shapes of the tested and the simulated sample after applying the axial load are shown in Fig. 7. It can be seen that the sample have same behavior in both figures.

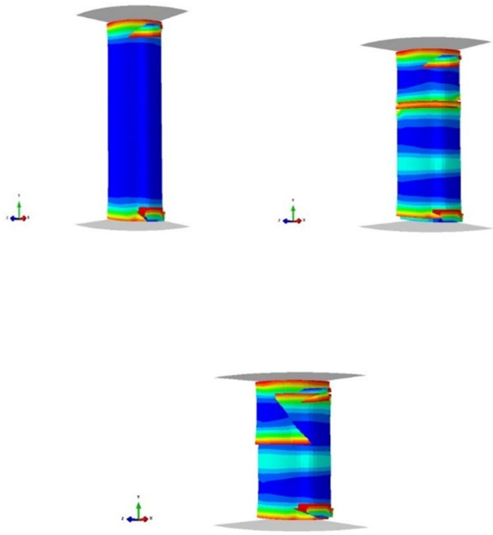

Fig. 6. Finite element model of the tube during the loading.

Table. 2. Mechanical properties of the tested specimens

Mass Density (kg/m^3)	Young Modules (GPa)	Poisson's Ratio	Ultimate stress (MPa)
1997	48.14	0.191	392.982

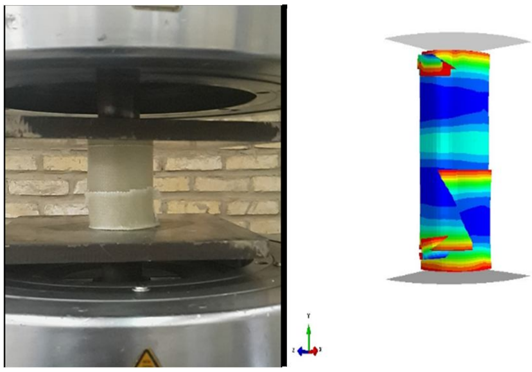

Fig. 7. Deformation of the sample during the axial loading, left: experiment, right: simulation;

4. Results and Discussion

In this section, the obtained results of test process and the numerical simulation are presented and compared. The load-displacement curves for the sample with circular cross section and loading speed of 20 mm/s which is obtained from numerical analysis and experimental test have been compared in Fig. 8. It can be seen that an excellent agreement exists between the test results and the numerical calculations. It is noticed that the peak force is the most dangerous for the structures. This loud can be obtained from the first peak in the load-displacement curve.

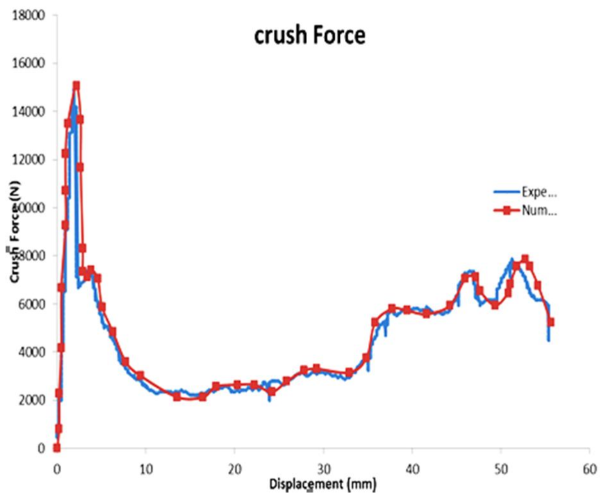

Fig. 8. The load-displacement curves for circular section tubes

Table 3 presents the crushing length, peak load, mean force and absorbed energy of the three tested samples and the simulated one. It can be seen that the simulated results are in good agreement with experimental results. The difference between numerical and experimental absorbed energy is only 2.69 percent which confirms the accuracy of the present numerical finite element simulation. Also, other calculated numerical parameters are very close to the experimental ones. The variation of absorbed energy versus of the vertical displacement of the simulated sample is shown in Fig. 9.

5. Conclusion

In this paper, deformations, crush force and energy absorption capacity of thin walled circular composite tubes were investigated both experimentally and numerically. In order to study experimentally, three circular composite tubes were fabricated and subjected to quasi-static axial load. Also, a finite element model was constructed and analyzed under same conditions. The obtained results confirm that the simulation results are in good agreement with the experimental data. Based on the obtained results, it can be summarized that the circular tubes have exhibited an effective and stable energy absorption phenomenon under axial compression load.

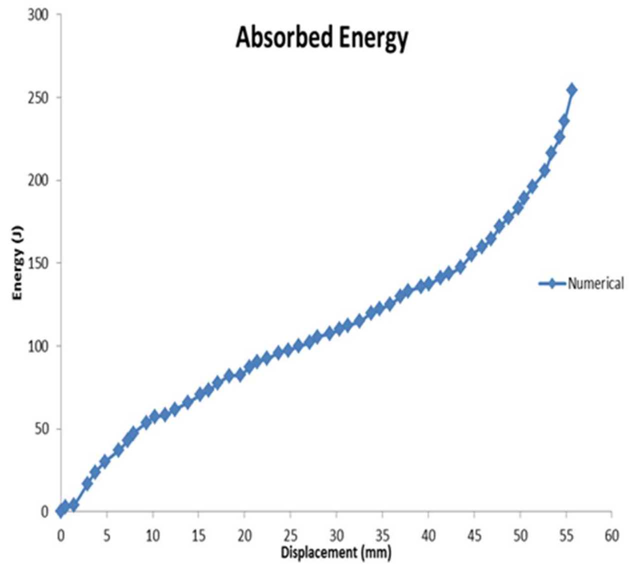

Fig. 9. Energy-displacement curve of the simulated sample

Table 3. Energy absorption rate, mean force and crushing length of the tested samples

Specimen Code	Rate of loading (mm/s)	Crushing Length (mm)	Peak Force (N)	Mean Force (N)	Absorbed Energy (J)
Test sample 1 D-C1	20	55.40	14899.1	4466.10	247.422
Test sample 2 D-C2	20	55.10	14900.2	4490.58	247.431
Test sample 3 D-C3	20	54.98	14901.1	4500.49	247.436
Simulated Sample	20	55.73	15262.8	45011.66	254.080

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