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Experimental and Numerical Study of Lateral Collapse of Square and Rectangular Composite Tubes

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***Abstract* -**Impact is one of very important subjects which always have been considered in mechanical science. Nature of impact is such that which makes its control a hard task. Therefore it is required to present the transfer of impact to other vulnerable part of a structure, when it is necessary ,one of the best method of absorbing energy of impact, is by using Thin-walled tubes. These tubes collapses under impact and with absorption of energy, it prevents the damage to other parts.

Purpose of recent study is to survey the deformation and energy absorption of tubes with different type of cross section (rectangular or square) and with similar volumes, height, mean cross section thickness, and material under lateral loading. Lateral loading of tubes are quasi-static type and beside as numerical analysis, also experimental experiences has been performed to evaluate the accuracy of the results. Results from the surveys is indicates that in a same conditions which mentioned above, samples with square cross section ,absorb more energy compare to rectangular cross section, and also by adding the number of layers of samples, energy absorption would be more.

Keywords: absorbed energy, lateral loading, quasi-static, composite tube

1. Introduction

Energy absorbers, because of their great applications, have a significant importance in industry. Energy absorbers devices that transfer the kinetic energy to the other kinds of energy and its main purpose is to reduce the damaging force which is transfer to the structure. Survey of lateral load to tubes has been considered as an important group of energy absorbers by the researchers.

Gupta and his colleagues surveyed the lateral load on the structures' with rectangular and square cross section and showed that the shape of cross section is influential to amount of energy absorption [1].

Gupta the parameters such as type of cross section, thickness, and also coefficient of friction, and showed that by increasing wall thickness, the rate of energy absorption increases .he also argued about effect of cross section on the rate of energy absorption and by surveying factor of friction, and its variation showed that, this factor does not have significant effect on the rate of energy absorption. In the next researches, Gupta and his colleagues surveyed the lateral loads on the tubes [2]. They simulate it by offering a theatrical model for tubes deformations and dividing the different region of tube's cross section from different types of deformation point of view, and compared the distribution of stress and strain in different parts of cross section. Then they analyzed the ratio of diameter to their wall thickness and found that by in increasing this ratio, the energy absorption, decreases .Selection of the best shape of energy absorbers, and reduction of harmful forces to structure is valuable, and lot of research has been made for this subjected [3]. Mahdi and Hamouda studied the energy absorption capabilities of composite hexagonal ring systems. They concludedthat the ring geometry and arrangement significantly influenced the crashworthiness of composite hexagonal ring system[4]. Elgalai et al studied the crashworthiness behavior of laminated corrugated tubes[5]. Similar tubes were studied experimentally and numerically by Abdewi et al. [6,7]. The behavior of radially stiffened glass/epoxy tubes was studied by Mahdi and Sebaey [8]. Ajdari et al. [9] studied the in-plane dynamic crushing of 2D honeycombswith both regular hexagonal and irregular arrangements. Sun et al. [10] investigated the crushing of multi-layer regularlyarranged circular honeycombs, More geometries can be found in[11,12] . In this paper , more surveys has been performed on energy absorption of rectangular and square cross section with varying in number of layers, experimentally and numerically.

2. Experimental Samples

Sample of tubes with thin wall thickness and with different geometrical shapes (square, rectangular with dimension ratio of 1.5:1) with the high of 100 mm, mean area of 190 mm, from material of E-glass and Epoxy according to characteristic in table 1 has been selected. The samples made have been shown in figure 1.

Table. 1. Specifications of the tubes

Specimen Section shape	hight (mm)	Thickness (mm)	Section Dimensions(mm)
Rectangular	100	1.5	Cross section 57*38
square	100	1.5	Edge 47.5

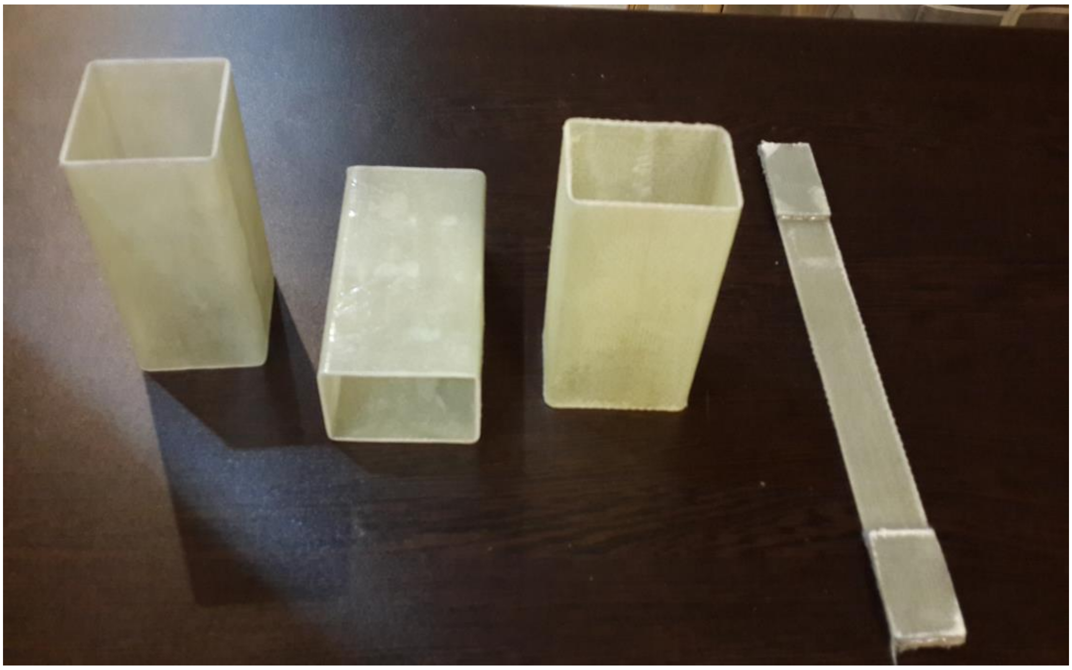


Fig. 1. prepared samples with different sections for performing experiments

3. Performance Of Tensile Test To Obtain The Stress-Strain Curve

Tensile test by using INSTRON device, model 8305 (figure 2) and based on ASME was performed on the samples which are made from of E-glass and Epoxy sheet, which ultimate stress equal to 392.982 MPa obtained. Stress-strain curve from the tensile test has been shown in figure 3 and the samples during tensile
test experimental test in this experiment are shown in figure 4.


Fig. 2. Instron 8305

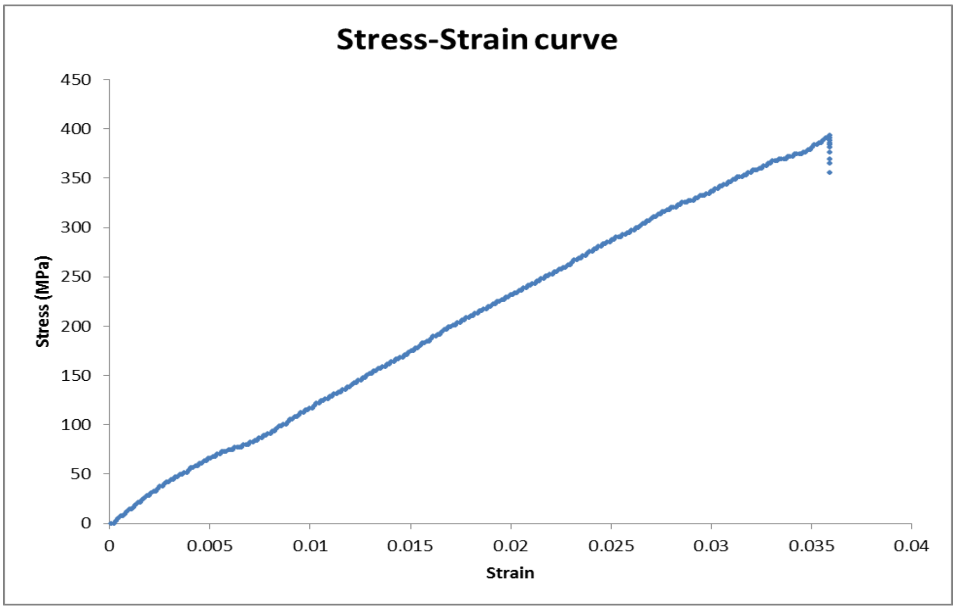


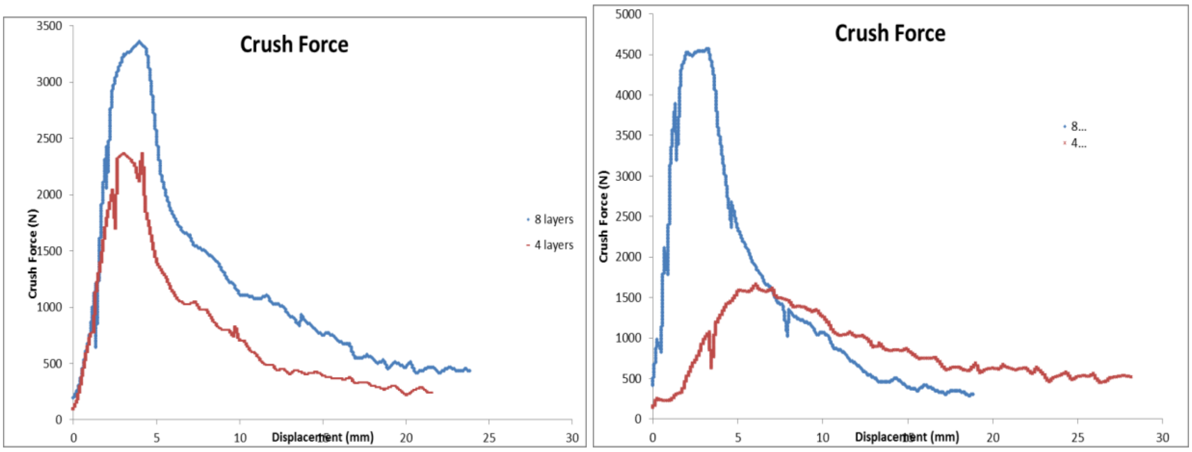
Fig. 3. Stress- strain curve (result of tensile test)


Fig. 4. The samples during tensile test (experimental test)

4. Experimental Test

Experimental test of lateral loading with quasi-static method and with speeds of 20 millimeters per second has been performed with INSTRON test device and load-displacement curve which is obtained from this curve and the rate of absorbed energy in each sample were calculated by considering the cross sectional area.

The curves which are obtained from samples with rectangular and square cross section , have been shown in figures 5, and also the samples with rectangular and square cross sections ,before loading and after loading have been shown in figure 6.



(rectangular) (square)

Fig. 5. Load-displacement curve which has been obtained from experimental test on the rectangular and square tubes with loading speed of 20 mm/s

Rectangular square

Fig. 6. Samples with rectangular and square tubes under loading Right: before loading left: after loading

After performing the tests and obtaining load-displacement curves, at the end of compression processing, energy absorption will be obtained from the area under load-displacement curve in tables 2 and 3 crushing length, peak load, mean force and absorbed energy at the end of process for the samples with rectangular and square cross section and also with different loading speeds have been compared with each other.Three tests with the same conditions are carried out for each case that the first number in the code of table below shows the number of tests and the second number shows the number of layers that samples are made.The material of layer is E-glass and Epoxy.

Table. 2. The comparison between rate of energy absorption, mean force and crushing length which has been obtained from experimental test by varying in the number of layers with rectangular tubes

Specimen Code	Rate of loading (mm/s)	Crushing Length (mm)	Peak Force (N)	Mean Force (N)	Absorbed Energy (J)
D1-R4	20	21.52	2368.9	801.62	17.251
D2-R4	20	21.48	2364.5	802.65	17.241
D3-R4	20	21.40	2360.2	805.51	17.238
D1-R8	20	23.85	3355.5	1199.91	28.618
D2-R8	20	23.75	3349.7	1204.54	28.608
D3-R8	20	23.70	3345.4	1206.54	28.595

Table. 3. The comparison between rate of energy absorption, mean force and crushing length which has been obtained from experimental test by varying in the number of layers with square tubes

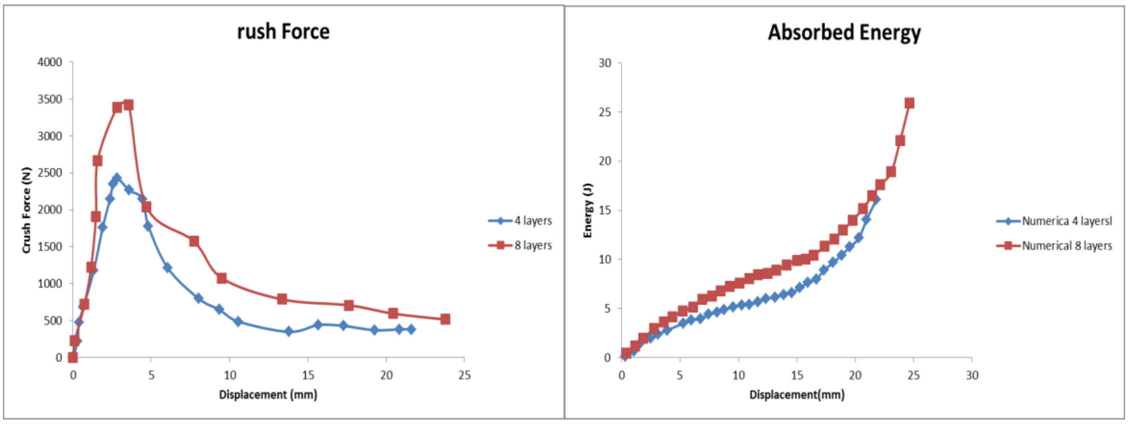
Specimen Code	Rate of loading (mm/s)	Crushing Length (mm)	Peak Force (N)	Mean Force (N)	Absorbed Energy (J)
D1-S4	20	28.15	1660.94	849.66	23.918
D2-S4	20	28.10	1659.62	851.38	23.924
D3-S4	20	28.07	1657.91	852.68	23.935
D1-S8	20	18.84	4565.22	1530.2	28.829
D2-S8	20	18.80	4563.87	1533.82	28.836
D3-S8	20	18.78	4562.96	1535.72	28.841

5. Numerical Simulations

To perform quasi-static loading simulation in different samples, first the part of each sample, according to required dimension which is developed between two solid plates, is simulated by software package of FEM27, such that, the lower plates is fixed and the upper plates is moving downward and vertically with speed of 20 mm/s. Type of samples is shell with the thickness 1.5 mm and also the coefficient of friction between two end plates and each sample is taken 0.2 kind of material for the end plates is No. 20 (rigid) have been selected. Mechanical characteristic of the experimental samples is shown in table 4. Lateral loading simulation on all the samples has been performed by using LS-DYNA package and the results of rectangular and square cross section were compared with the results of experimental method. Comparison for peak load and absorbed energy at the end of compression process, shown the difference less than ten percent between these two methods therefore we could use this package with more confident. Load-displacement curves and also the curve for energy-displacement of samples with rectangular and square cross sections which is obtained from simulations are shown in figures 7and 8.

Table. 4. Mechanical properties of specimens tested

Property	Mass Density (kg/m3)	Young Modules (GPa)	Poisson's Ratio	ultimate stress (MPa)
composite	1997	48.14	0.191	392.982

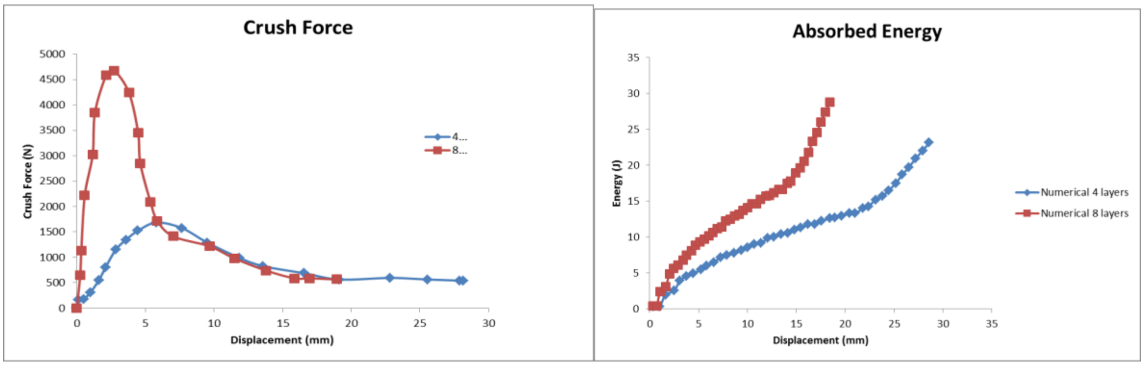


(Load-displacement) (Energy-displacement)

Fig. 7. Load-displacement and Energy-displacement curves which has been obtained from numerical Rectangular tube with different layers

6. Comparison and Conclusion

After performance of quasi-static tests, results are compared and the geometry of cross section in absorbing energy, peak force and mean force were surveyed which their results are given in table 5 and 6, and also Load-displacement curves for samples with rectangular and square cross section with loading speed of 20 mm/s which is obtained from numerical analysis and experimental test have being compared in figure 10.



(Load-displacement) (Energy-displacement)

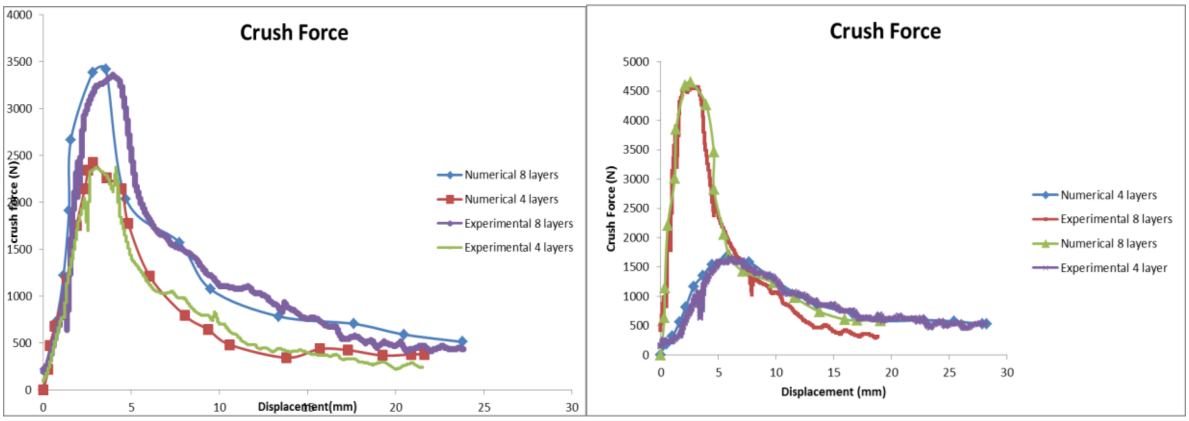
Fig. 8. Load-displacement and Energy-displacement curves which has been obtained from numerical Square tube with different layers

Table. 5. The comparison of result of numerical simulation and experimental loading in a rectangular tube

Specimen Code	Number of layer	Absorbed Energy (J) (Numerical)	Absorbed Energy (J) (Experimental)	Difference (%)
D-R4	4	17.731	17.243	2.75
D-R8	8	27.287	28.607	4.61

Table. 6. The comparison of result of numerical simulation and experimental loading in a square tube

Specimen Code	Number of layer	Absorbed Energy (J) (Numerical)	Absorbed Energy (J) (Experimental)	Difference (%)
D-S4	4	24.649	23.925	3.02
D-S8	8	30.721	28.835	6.54



(rectangular) (square)

Fig. 10. The load-displacement curves for rectangular and square section tubes obtained from experiments and simulations are compared with different layers

7. Conclusion and Summary

By considering the results from the researches it is noted that:

1. By changing the geometrical shape of cross section the rate of absorbing energy, changes and with changing the cross section from rectangular to square absorbing energy, increases.
2. As it are notices from tables 5, 6 with adding the number of layers absorption of energy also increases.
3. 3-with review of peak force with rectangular or squre section under loading , it is indicated that with increase layers, peak force will be increased and also by review of peak force on the sample with rectangular or squre cross section peak force is less in the sample with rectangular cross section,which is the optimum cross section for absorbing energy.

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