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Lateral Crushing of Square and Rectangular Metallic Tubes under Different Quasi-Static Conditions

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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 loading with different speeds. 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 increscent in speed of loading, energy absorption would be more.

***Keywords*—**absorbed energy, lateral loading, quasi-static.

I. 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]. In this paper , more surveys has been performed on energy absorption of rectangular and square cross section because of different, and varying speed of quasi-static loading , experimentally and numerically.

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II. 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 aluminum with yield stress 130 Mpa according to characteristic in table 1 has been selected. The samples made have been shown in figure 1.

TABLE I
SPECIFICATIONS OF THE TUBES

Environment Section (mm)	high (mm)	Thickness (mm)	
190	100	1.5	Specifications of the Tubes

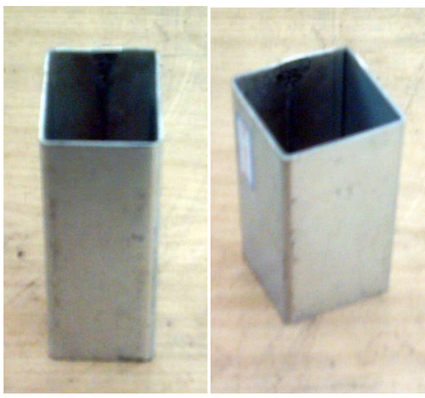


Fig. 1 prepared samples with different sections for performing experiments

III. 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 aluminum sheet, which ultimately yield stress equal to 130 MPa obtained. Stress-strain curve from the tensile test has been shown in figure 3 and the samples tested in this experiment are shown in figure 4.

Fig. 2 Instron 8305

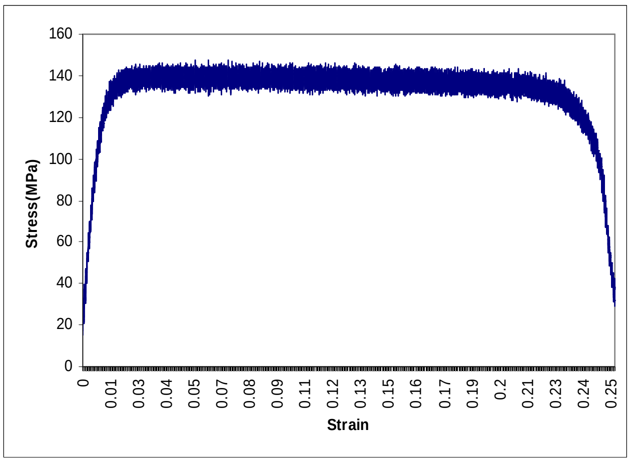


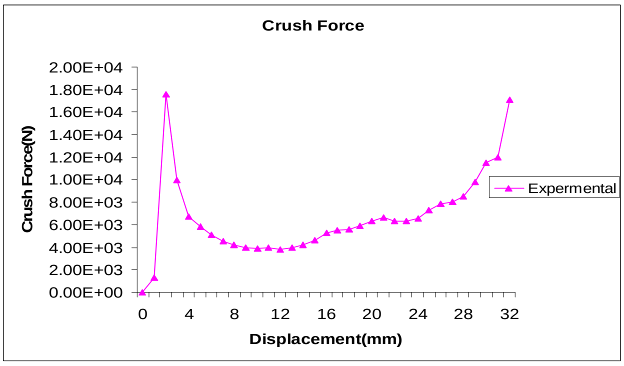
Fig. 3 Stress- strain curve, result of tensile test

Fig. 4 The samples after tensile test experimental test

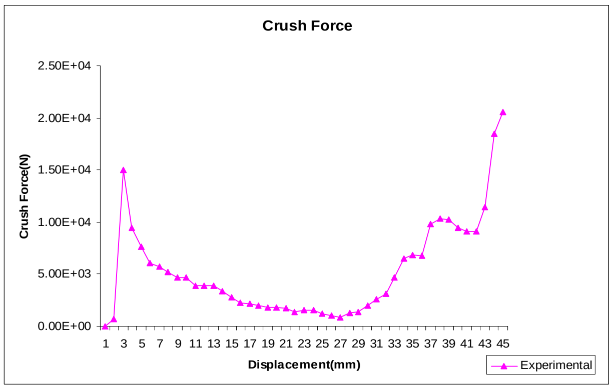
IV. Experimental Test

Experimental test of lateral loading with quasi-static method and with speeds of 100,150,300 and 450 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 is 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.

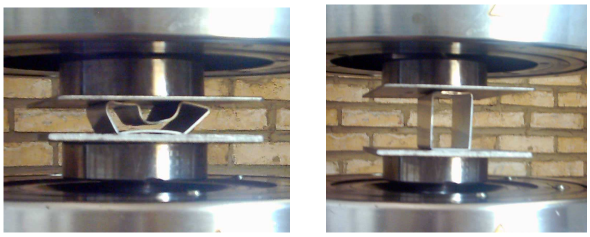


(rectangular)

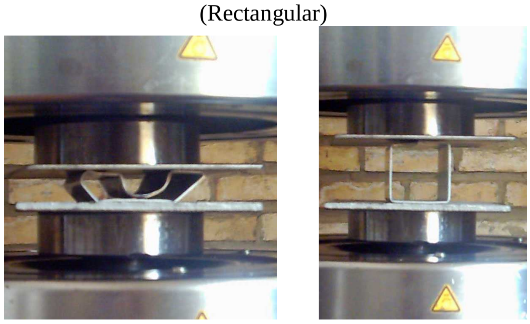


(square)

Fig. 5 Load-displacement curve which has been obtained from experimental test on the rectangular and square tubes with loading speed of 100 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.

TABLE II
THE COMPARISON BETWEEN RATE OF ENERGY ABSORPTION, MEAN FORCE AND CRUSHING LENGTH WHICH HAS BEEN OBTAINED FROM EXPERIMENTAL TEST BY VARYING IN THE RATE OF LOADING WITH RECTANGULAR TUBES

Specimen Code	Rate of loading (mm/s)	Crushing Length (mm)	Peak Force (N)	Mean Force (N)	Absorbed Energy (J)
RV_0	100	30	17800	6166.6	185
RV_1	150	30	11500	6433.33	193
RV_2	300	30	9700	6966.6	209
RV_3	450	30	8800	7266.6	218

TABLE III
THE COMPARISON BETWEEN RATE OF ENERGY ABSORPTION, MEAN FORCE AND CRUSHING LENGTH WHICH HAS BEEN OBTAINED FROM EXPERIMENTAL TEST BY VARYING IN THE RATE OF LOADING WITH SQUARE TUBES

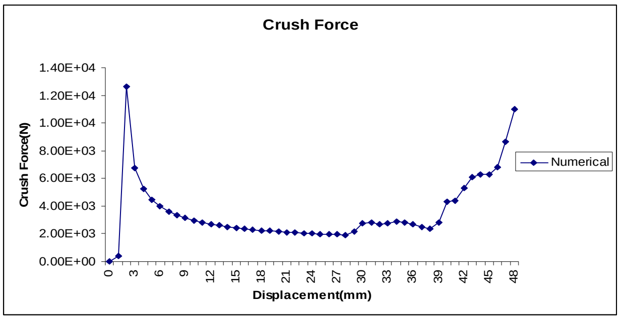
Specimen Code	Rate of loading (mm/s)	Crushing Length (mm)	Peak Force (N)	Mean Force (N)	Absorbed Energy (J)
SV_0	100	41	15000	4560.97	187
SV_1	150	41	9400	4853.65	199
SV_2	300	41	7800	5292.68	217
SV_3	450	41	7300	5512.19	226

V. NUMERICAL SIMULATIONS

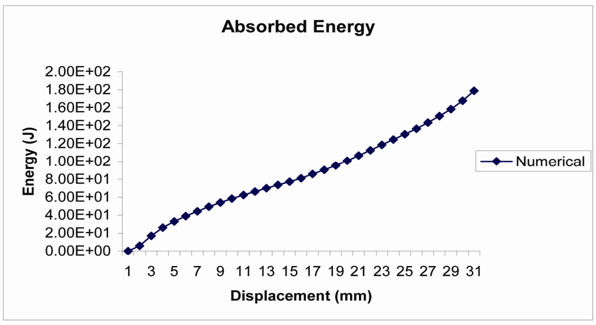
To perform quasi-static loading simulation in different samples, first the part of each sample, according to required dimension which is developed between two solid plates, is simulated by software package of FEM27, such that, the lower plates is fixed and the upper plates is moving downward and vertically with different speeds. 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) and for experimental sample No. 24 (Mat-piecewise-linear-plasticity) 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 and also the shapes for simulated samples, after applying the load and after compression process are shown in figure 9.

TABLE IV
MECHANICAL PROPERTIES OF SPECIMENS TESTED

Property	Mass Density (kg/m3)	Young Modules (GPa)	Poisson's Ratio	Yield stress (MPa)
Aluminum	2705	70	0.33	130

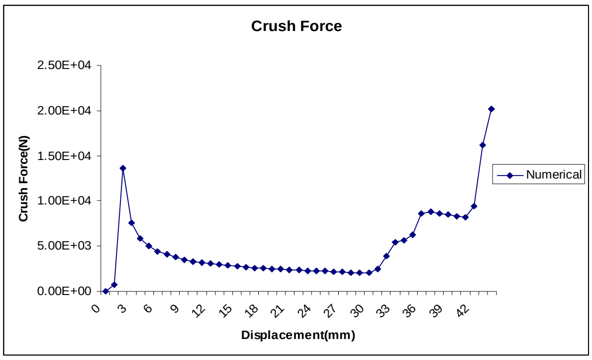


(Load-displacement)

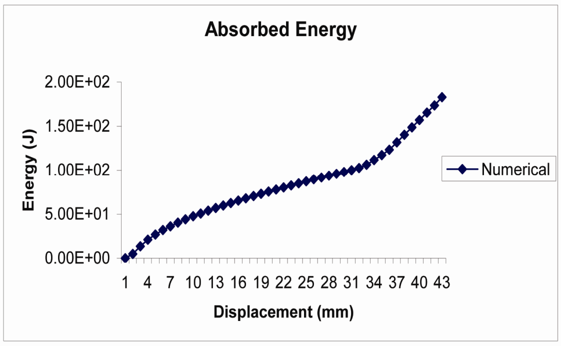


(Energy-displacement)

Fig.7 Load-displacement and Energy-displacement curves which has been obtained from numerical Rectangular tube with loading speed of 100 mm/s

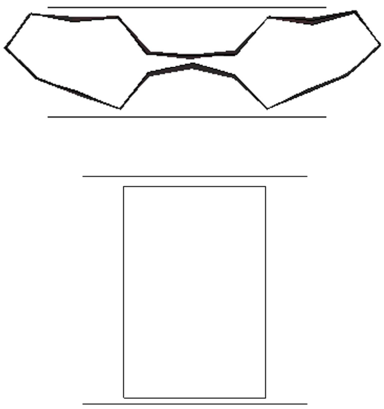


(Load-displacement)

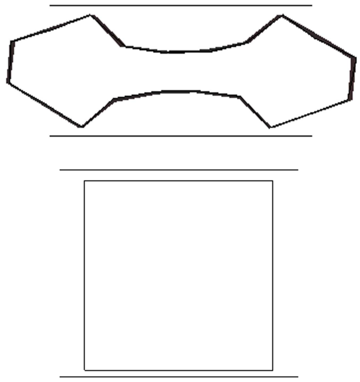


(Energy-displacement)

Fig. 8 Load-displacement and Energy-displacement curves which has been obtained from numerical Square with loading speed of 100 mm/s



(Rectangular)



(square)

Fig. 9 Simulation of sample with rectangular and square cross section under loading condition right: before loading left: after loading

VI. Comparison and Conclusion

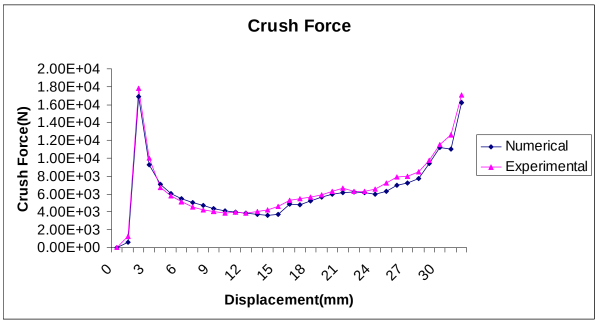
After performance of quasi-static tests, results are compared and the rate of effect in amount of loading, and the geometry of cross section in absorbing energy, peak force and mean force were surveyed which their results are given in table 5 and 6, and also Load-displacement curves for samples with rectangular and square cross section with loading speed of 100 mm/s which is obtained from numerical analysis and experimental test have being compared in figure 10. To compare the deformation, during the collapse process these tubes which are taken from numerical analysis and experimental test at the same moment, have being compared in figure 11.

TABLE V
THE COMPARISON OF RESULT OF NUMERICAL SIMULATION AND EXPERIMENTAL LOADING IN A RECTANGULAR TUBE

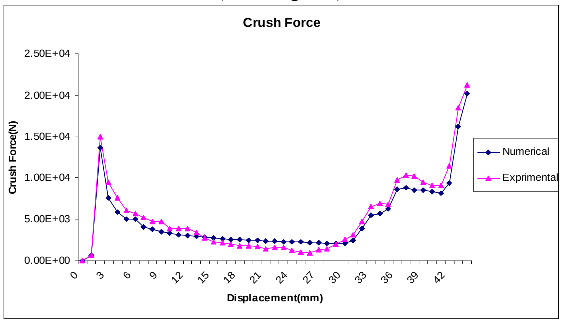
Specimen Code	Rate of loading (mm/s)	Absorbed Energy (J) (Numerical)	Absorbed Energy (J) (Experimental)	Difference (%)
RV_0	100	179	185	3.24
RV_1	150	182	193	5.69
RV_2	300	197	209	5.74
RV_3	450	203	218	6.88

TABLE VI
THE COMPARISON OF RESULT OF NUMERICAL SIMULATION AND EXPERIMENTAL LOADING IN A SQUARE TUBE

Specimen Code	Rate of loading (mm/s)	Absorbed Energy (J) (Numerical)	Absorbed Energy (J) (Experimental)	Difference (%)
SV_0	100	183	187	2.13
SV_1	150	186	199	6.53
SV_2	300	204	217	5.99
SV_3	450	211	226	6.63

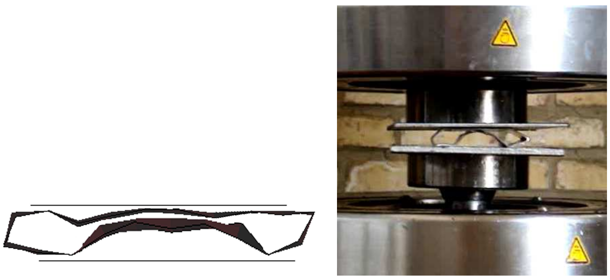


(Rectangular)

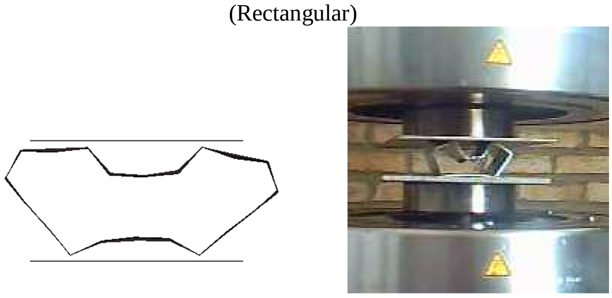


(square)

Fig. 10 the load-displacement curves for rectangular and square section tubes obtained from experiments and simulations are compared with loading speed of 100 mm/s



(Rectangular)



(square)

Fig. 11 Sample with rectangular and square cross section tubes under loading condition, during collapse process right) numerical analysis left) experimental test

VII. 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 increasing the speed of loading rate of absorption of energy also increases.

3- With review of peak force with rectangular or square section under different loading condition, it is indicated that with increase of loading speed, peak force will be lowered and also by review of peak force on the sample with rectangular or square cross section peak force is less in the sample with square cross section, which is the optimum cross section for absorbing energy.

References

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