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Parametric Study of Effective Variables in the Behavior of Composite Energy Absorbers

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Abstract- Nowadays, the energy absorption systems are used in many different industries and structures to reduce injuries. The usage method of these absorbers is different based on the type of occurrence and the amount of energy absorption. Thin-walled cells like plate, shell, firm and cured sandwich plates, etc. have the most application in the energy absorbers and these structures can tolerate the large movements, subjected to compressive loads and impact.

In this article the study of crashworthiness and energy absorption of CFRP composite thin-walled structures with square cross section, using the finite elements method have been done, and the resulted maximum and average values of crushing force and the amount of energy absorption are compared with experimental analysis results, and the variation of different parameters such as fibers angle, the dimensions of cross section and its thickness is studied.

Keywords- *thin-walled cells, energy absorption, composite, CFRP, finite elements method.*

I. INTRODUCTION

The development and analysis of energy absorber structures is one of the important discussions mooted in the mechanic of impact, and one propounded prevalent example in this context is the study of energy absorber that is placed under the dynamic and quasi-static load as a result of the collision of a picky substance. The identity of loading type and the energy absorber response should be considered in analyzing the impact in the energy absorbers. The application of this branch in engineering is prepared in different problems such as vehicle accidents, security of nuclear reactors, coastal structures and etc. Note that in the energy absorption issue, a good absorber is one that can convert more proportion of kinetic energy to other kinds of energy.

The energy absorbers have different shapes and materials based on the amount of energy absorption, maximum value of their tolerable force, and their application. Meanwhile, the behavior of thin-walled structures under the various kinds of loading [1-3] has been studied in many years, these structures can tolerate the large movements, subjected to compressive loads and impact. Different researchers have studied the crumpling behavior of pipes and thin-walled cans under the dynamic and quasi-static axial loading [4, 5]. In almost all of these researches the energy method and upper bound theory are used as the analyzing method of structure.

Timoshenko and Gere [6] have demonstrated the deformation mode of thin-walled pipe under the axial load. They have stated in their article that if the proportion of pipe diameter to thickness of pipe parapet (D/h) is small the symmetric axial deformation mode, which is named ring mode shape or concertina, happens and for the large values (D/h) the asymmetric mode shape will happen, that is named lozenge mode shape.

An approximate analysis on the thin-walled cans under dynamic loading has been presented by Wierzbicki and Akerstorm [7]. They stated that the dynamic crashing force is equal to the quasi-static crashing force in which the correction factor that results based on strain rate is applied and they viewed the strain rate to be influenced by the initial velocity of collision and the material kind.

Mamalis & et al. have studied the crashworthiness behavior of the composite rectangular thin-walled tubes [8], this group has considered experimental and numerical analysis of the thin-walled tubes reinforced with aluminum and polymer foams with quasi-static loading based on the amount of energy absorption.

Composites are a class of advanced materials that because of their special abilities have been noted by designers. Beside these particular abilities, the behavior of composites is an orthotropic behavior that causes the complexity of relations and consequently the complexity of their analyzing and designing process compared to ordinary metallic materials.

In this article the considered energy absorber is a thin-walled cell with rectangular cross section that its material is CFRP composite.

II. EXPERIMENTAL ANALYSIS

Experiment method: for the experiment of CFRP tube, hydraulic press system with the capacity of 1000 KN is used. These experiments are considered for quasi-static loads with velocity of 7 mm/min and the strain velocity of 2.6×10-3 S-1. For dynamic loading a velocity of 5.4 m/s have been given to the impactor [9].

The measured values for this experiment are the following: P_{max} the maximum bound of force, E_{abs} the energy resulted from composite crushing which equals to the area under the force-displacement curve, P the average value of endurance force of the composite tube.

The experiments are done in 23±3 ° C and the impactor of rigid body is considered with the weight of 80 Kg.

Experiment materials: the experiment sample is considered the CFRP composite tubes with square cross section and side value of 100×100 mm and circle corner with the radius of 8 mm [9]. The angles of CFRP composite layers are considered [±0].

The results obtained from this experiment are shown in table 3, 4. Two mode shapes are observed for different loadings.

First mode shape: the shape mode resulted from quasi-static loading for length of L = 51 mm (Figure 1),

Second shape mode: the shape mode resulted from dynamic loading for length of L = 50.7 mm (Figure 2).

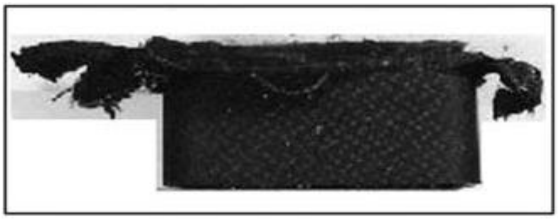
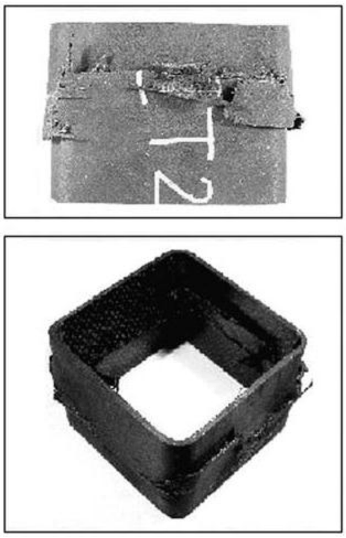


Figure1. Mode shape 1 - destruction resulted from quasi_static load



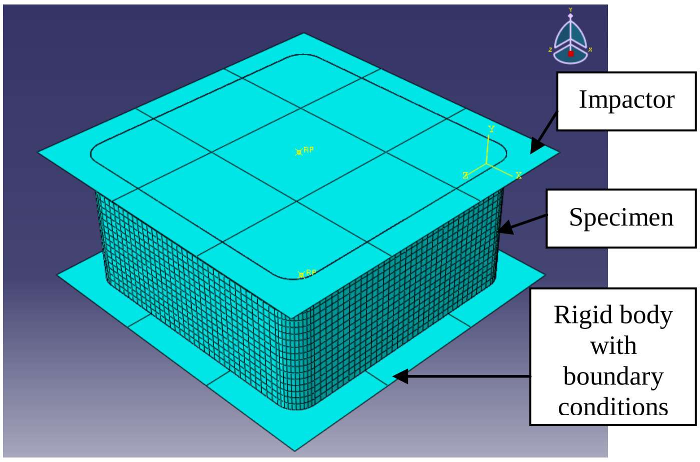
Figur2. Mode shape 2 - destruction resulted from dynamic load

III. FINITE ELEMENTS ANALYSIS

Modeling of nonlinear finite elements thin-walled pipes and cans under the quasi-static and dynamic axial loading have been studied for many years using the commercial software such as ABAQUS, LS-Dyna, Dyna3D, Oasys. In this experiment one piece with a certain weight is released from a certain distance and collides to a thin-walled can.

ABAQUS is a set of powerful modeling programs which is based on finite elements method, and has the ability of solving the problems from a simple linear analysis to the most complex nonlinear modeling. This software has an expanded set of elements that any kind of geometry can be modeled figuratively using these elements. It also contains many engineering material models and makes possible a high ability in modeling the materials with different properties and behaviors such as metals, plastics, polymers, and composites [10]. Different methods and expanded mathematical relations are used in nodule to nodule solution progress, in finite elements analysis. ABAQUS uses the numerical ways to integrate the different quantities in the volume of one element. This software calculates the behavior of material in each integration point of one element using Gauss quadrature method, and if the continuum elements are used one of the two full and reduced integration choices, that has an important influence on the precision of problem solving, should be selected.

Finite elements modeling of the composite thin-walled structure: numerical modeling of this structure is done dynamically. In this model three substances as shown in figure 3 are considered and one substance with a certain weight based on the type of loading and with certain velocity collides with CFRP sample in a certain time.



Figur3. Numerical analysis of CFRP energy absorber

Dynamic modeling of the composite structure is realized in ABAQUS/Explicit. Dynamic Explicit analysis is selected in the step module. To define contact between tube and itself as a result of crushing, a plate is defined that contains both internal and external sides of thin-walled piece. Since it is possible that different parts of element have contact with each other during the process, a self-contact is defined for that element. The touching behavior containing friction with penalty friction formulation and the friction factor of 0.1 for this contact have been defined. To apply the disorders at the both ends of cell two rigid plates are defined that in one side one of the plates is connected to the tube using the Tie order and a 80 Kg mass with 5.4 m/s velocity applies to the reference point of this rigid plate for dynamical simulation. The plate connected to tube is bound in all directions except in the direction of applying the velocity. The other rigid plate is bound in all directions. The considered element is S4R. Finally, by defining Job and executing that, the destruction force and the amount of absorbed energy are considered for different states.

Characteristics of the CFRP sample are given in table 1:

Table 1. Mechanical properties of CFRP thin - walled cell

Properties	Value	Row
Density (ρ)	1549 (Kg / m^3)	1
Elasticity modulus in longitudinal direction(a)	19900 (Mpa)	2
Elasticity modulus in transverse direction(b)	20020 (Mpa)	3
Shear modulus	3700 (Mpa)	4
Poisson ratio between (a) and (b) directions	0.048	5
Poisson ratio between (b) and (a) directions	0.042	6

Table2. Geometrical properties of the square thin - walled cell

Properties	Number of layers	Length L(mm)	Thickness T(mm)	Row
Test with axial static load of AC specimen	14	51	3.78	1
Test with axial dynamic load of DC specimen	14	50.7	3.73	2

The problem is solved in two ways: static and dynamic, and after obtaining the results and comparing them with the experimental values at dynamic loading conditions, change the values of fiber angle, the dimensions of square, and the thickness in the dynamic load case in order to compare the variations of the maximum destruction force have been done.

IV. RESULTS

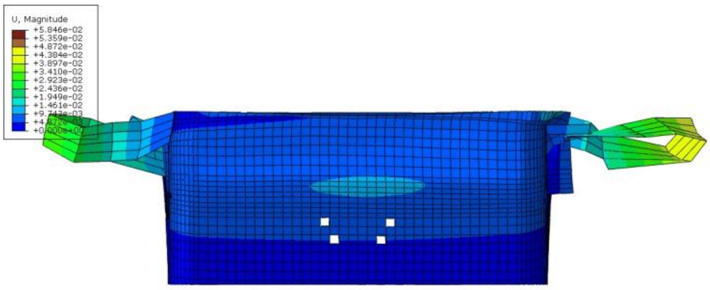
The results obtained using numerical solution of ABAQUS, and their comparisons with the mentioned experimental results are shown in tables 3 and 4.

Table3. ABAQUS result and comparison with experimental result for static loading

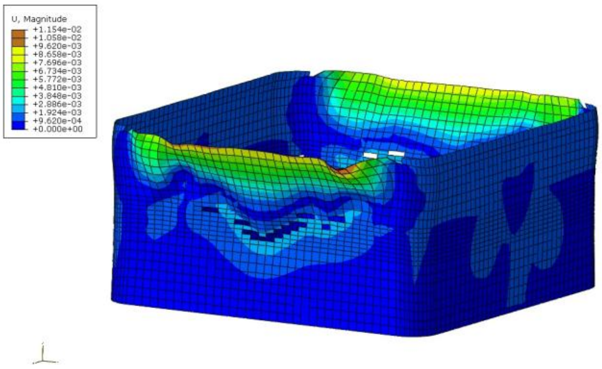
Properties	Static loading AC		Row
Test type	Experimental	Finite elements	
Mode shape	First mode	First mode	1
Maximum crushing force (KN)	219	297.27	2
Average crushing force (KN)	70.60	68.22	3
Energy absorption (J)	1950	1870.48	4

Table4. ABAQUS result and comparison with experimental result for dynamic loading

Properties	dynamic loading DC		Row
Test type	Experimental	Finite elements	
Mode shape	First mode	First mode	1
Maximum crushing force (KN)	319	297.70	2
Average crushing force (KN)	104.70	98.74	3
Energy absorption (J)	1664	1612.21	4



Figur4. Firs mode shape resulted from static load obtained from finite elements solution



Figur5. First mode shape resulted from dynamic load obtained from finite elements solution

Table5. Maximum loads of destruction versus variations in fiber angle thickness and square dimensions

Specimen	Number of layers	Thickness [mm]	Angle	Cross section dimensions mm×mm	Maximum force (KN)
1	14	3.78	[±0]	100×100	297.70
2	14	3.78	[±30]	100×100	235.39
3	14	3.78	[±45]	100×100	211.773
4	14	3.78	[±60]	100×100	257.825
5	14	3.78	[±90]	100×100	329.04
6	14	2.8	[±0]	100×100	225.64
7	14	4.2	[±0]	100×100	327.86
8	14	5.32	[±0]	100×100	415.32
9	14	6.3	[±0]	100×100	533.32
10	14	3.78	[±0]	80×80	277.95
11	14	3.78	[±0]	120×120	381.10
12	14	3.78	[±0]	140×140	487.59

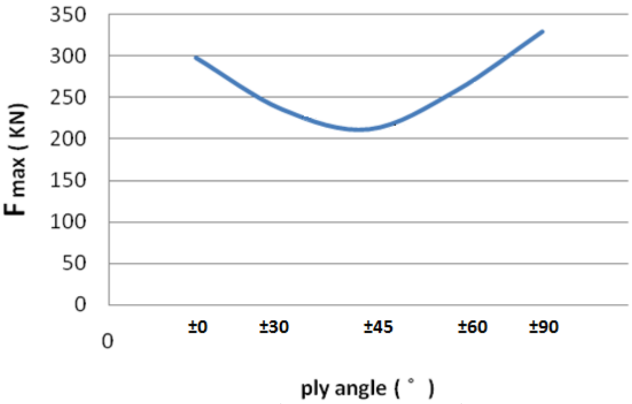


Figure6. Comparison of maximum crushing force with ply angle variation

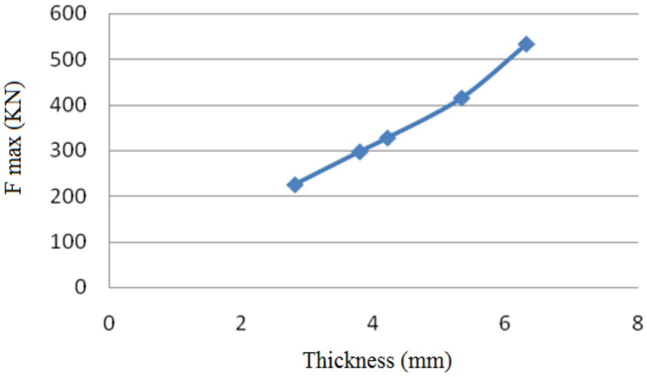


Figure7. Comparison of maximum crushing force with thickness increase (0 ^{0} Ply Angle and 100×100mm square section)

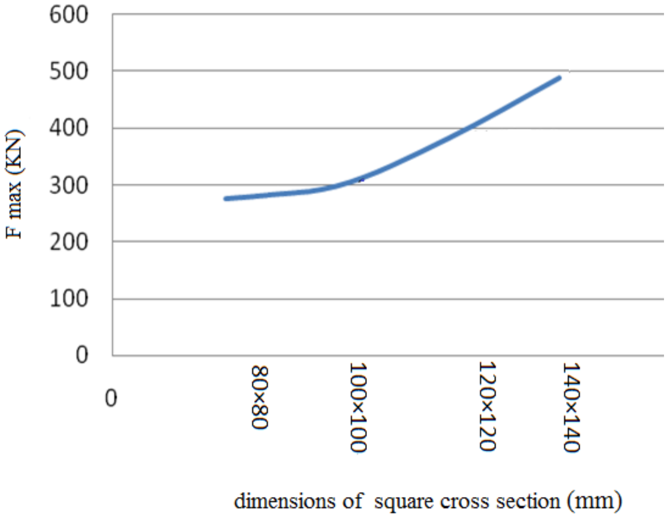


Figure8. Comparison of maximum crushing force with Change in the dimensions of square cross section of tube (0 ^{0} Ply Angle and 3.78 mm thickness)

V. CONCLUSION

In this article the finite elements analysis of CFRP cell under the dynamic and static loads was accomplished and it had a good conformance with the experimental results. It was observed that with fibers in the direction of force applying or in the orthogonal direction a maximum value of force is tolerable, and the tube is more strengthened against the input load and also with an increase in thickness and tube dimensions the structure will have been more persistent.

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