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Parametric Study of Effective Variables in the Behavior of S-Shaped Composite Structure

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Abstract- S-shaped structure with square section considered as low fence of car chassis. There are geometrical variables for this structure such as length as width of thin-walled structure, radius and arc angle of S-shaped axis, width and thickness of square section. In addition, variables related to CFRP such as number and angle of fibers can be having significant effect on performance of CFRP absorber energy. The principle aim of this paper is parametric study on CFRP S-shaped energy absorber. 30 various FEM model of structure is created with various values in four input variables and then amount of energy absorption and amount of peak crushing force calculated for any models and in the end, a table is presented according to four inputs and three outputs.

Keywords- *S-shaped structure,CFRP, FEM, Peak crushing force,*

I. INTRODUCTION

Nowadays, the energy absorption systems 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.

Higher-speed transportation increases the probability of traffic accidents that, in turn, causes serious damages to passengers. Design of auxiliary metal structure or structural components capable of sustaining prescribed loads and dissipating undesirable energies while undergoing plastic deformation is one of the prime means of energy absorption systems. Therefore, the crash characteristic of energy-absorbing component has received considerable attention over the past decades. As a highly simplified model of the front side member of a vehicle body, which plays an important role in absorbing energy during collision, various investigators in previous works have studied the crushing behavior of the S-shaped structures.

Composites are a class of advanced materials that because of their special abilities 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.

Simplified model of the s-shaped energy absorber depicted in Figure1. According to this figure any variation of geometric parameters which are denoted as radius of curvature (R), curve angle (α), section width (C), wall thickness (t), and offset of two-end par (D) will lead to new design and new behavior. It should be note that both the straight lengths and oblique length are derived variables, depending on the values of the curve angle and curve radius. In this paper, numerical analysis performed to obtain peak crushing force and absorption energy of the s-shaped CFRP energy absorber with respect to geometrical design parameters and CFRP parameters. In this way, dynamic simulation of considering structure performed using commercial software ABAQUS/Explicit. Such comparisons show good accuracy of the analytical approach presented in this paper.

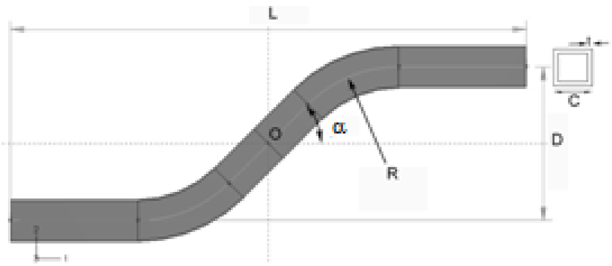

Figure 1. simplified model of S-shaped energy absorbed

II. REVIEW OF PREVIOUS WORKS

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] 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 named lozenge mode shape. Figure2 show these modes.

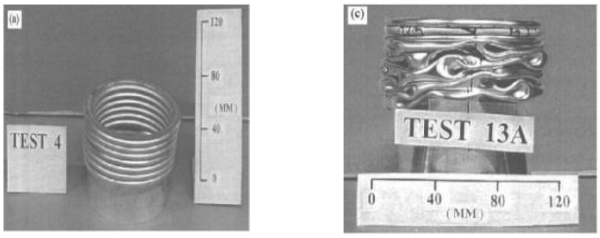

Figure 2. Deformation modes in Timoshenko experimental analysis

Wierzbicki and Akerstorm [7] have presented an approximate analysis on the thin-walled cans under dynamic loading. 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.

Alexander presented an analytical solution for the problem of energy absorber [8]. He considered ring mode shape for deformation of his thin-walled structure for evolution of average crushing force as shown in figure 3. The amount of crushing force according his method equal to:

$$P_m = 6Yh\sqrt{Dh} \quad (1)$$

In which, Y is yield stress, D is pipe diameter and h is pipe wall thickness

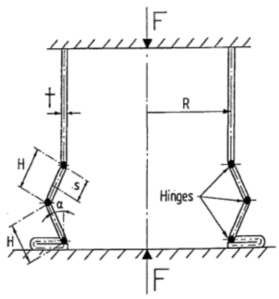

Figure 3. Deformation mechanism for thin-walled pipe under Alexander assumptions

Non-liner FEM modeling of thin-walled pipes and cans under quasi-static and dynamic have been studied for many years by using commercial software such as LS-Dyna, ABAQUS, Oasys and PAM-crush. Otboshina compared his FEM modeling with experimental Timoshenko analysis. In his model, a body with specified mass has been left and hit with thin-walled can. FEM model and deformation modes are shown in figure 4 [9].

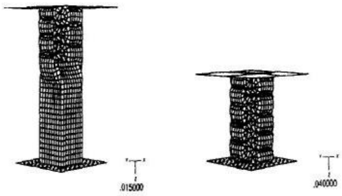

Figure 4. deformation and FEM model of shell structure under axial load

Structural components of the front of the car body to avoid interference with other components are usually curved. One of the most important structural components of front of the car engine compartment that absorb most of car accident energy is the S-rail. Some previous works have studied crushing behavior of the s-rail experimentally, numerically and analytically. Ni [10] represented the impact response of curved box beam using both numerical methods and empirical formulas. Kim and Wierzbicki [11] addressed the design aspect of front side rail structure of an automobile body concerning weight efficiency and crush energy absorption. They investigated various method of internal strengthening in order to improve structural crashworthiness and performance. Kim and Wierzbicki [12] derived the analytical solution of crushing resistance of thin-walled S-shape frames with rectangular cross-section and compared the results with those of numerical simulation. Zheng and Wierzbicki [13] represented a combined experimental, analytical and numerical study on the quasi-static axial crushing of thin-walled aluminum S-rail with circular cross-section. Hosseini- Tehrani [14] showed that a hybrid S-frame made of steel and aluminum gives better characteristic regarding passenger safety and weight efficiency.

Mamalis & et al. have studied the crashworthiness behavior of the composite rectangular thin-walled tubes [15], 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.

III. FEM ANALYSIS OF CFRP S-SHAPED STRUCTURE

ABAQUS is a set of powerful modeling programs, which 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. 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. This paper is focused on FEM analysis of CFRP S-shaped energy absorbed for evaluation amount of energy absorption and peak crushing force by using ABAQUS/Explicate software. For this purpose we define 3 steps in following.

A. *Geometrical modelling*

S-shaped thin-walled structures as shown in Figure 1 can be considered as a simplification of low railing the front chassis of car and this is one of the most important structural components that absorb most of car accident energy. The geometrical parameters of this structure are shown in figure1. As you can see, the structure is perfectly symmetrical about the point O, is made up of two-curved arm and two straight parts. Geometrical parameters are including constant and variable parameters. Constant parameters are length of structures(L) equal to 1m , width(D) equal to 0.3m, thickness of each fiber(t) equal to 0.25 mm and arc radius(R) that is calculated using by following equation:

$$R \cong \frac{D}{2(1-\cos\alpha)} \quad (2)$$

Variable parameters included two groups' parameters. First group related to S-shaped structure including width cross-section (C) ranging between 40 to 70 mm and angle of S-shaped structure (α) ranging between 35° to 55°. Second group related to composite parameters including fiber angle(Ө) ranging between 0° to 90° and number of fiber (n) ranging between 4 to 10fiber. As you can find in Table 3, 30 different FEM models of considered structure have been created using by variable parameters.

B. *CFRP modelling*

Considered material for this paper is CFRP. CFRP composite made up carbon fiber with highly resistant in a polymer matrix. Carbon in the composite is main load-bearing member and has large strength and stiffness in tension load. Polymer matrix holds fiber in place and suitable arrangement. This member act as transfer load in between carbon fiber. In addition, maintain them from environmental damage caused by high temperatures or humidity. Mechanical properties of the CFRP are shown in Table 1.

TABLE I. MECHANICAL PROPERTIES OF CFRP

Properties	sign	unit	Value
Density	ρ	Kg/m^3	1549
Elasticity modulus in longitudinal direction	E_1	Gpa	145
Elasticity modulus in transverse direction	E_2	Gpa	8.9
Poisson's ratio	ν_{12}	-	0.33
Shear modulus	G_{12}	Gpa	5.6
	G_{13}	Gpa	5.6
	G_{23}	Gpa	4.48

Initial damage in composite based on the earliest point decline in the hardness of materials. Hashin Theory is considered for damage of composite in ABAQUS/Explicate [16]. This damage criteria are calculated by four parameter related to primary damage mechanism consist of tension and pressure in fiber and these parameter in matrix. Amount of these parameter are given in Table2.

TABLE II. HASHIN DAMAGE VARIABLES FOR CFRP

property	Sign	value	unit
Tensile strength in fiber direction	X^T	2.41	Gpa
Compressive strength in fiber direction	X^C	0.8	Gpa
Tensile strength in the perpendicular fiber direction	Y^T	51	Mpa
Compressive strength in the perpendicular fiber direction	Y^C	0.2	Gpa
Longitudinal shear strength	S^L	120	Mpa
Transverse shear strength	S^T	120	Mpa
Shear stress contribution coefficient	α	0	-

C. *Dynamic modelling of Impact*

Finite element modeling related to this job is created in ABAQUS/Explicit. This stage is including some modules consist of Step, Interaction, Load, Mesh and Job. In Step module, we chose Dynamic/Explicit method for solve FEM model and consider time equal 0.04s for impact process. For crushing simulation in composite, marking STSTUS (some failure models) is essential in output. Increasing the number of spaced time intervals to 100 numbers for extraction of accurate solution. In Interaction module, because of composite failure we have to define a general contact between all surfaces with 0.1-friction coefficient and tangential behavior type.

Impact simulation was modeled using by main structure and two rigid plates. A rigid plate with fixed DOF in all direction and another plate with 500 KG mas and 10m/s velocity toward S-shaped structure direction and fixed DOF in all direction except speed direction. Tie interaction is considered for contact between rigid plated and thin-walled S-shaped structure with 0.01telorance. In this case, element type is S4R element for meshing process. In final, we defined a job for this issue and run script for solution this problem.

All above steps are done for different geometrical models that described in the previous step and after finished solution in each model, we can evaluate amount of absorbed energy, peak crushing force and weight of structure. In visualization of each model, firstly amount of final velocity related to top rigid plate are written after 0.04s. So absorption energy calculated with following equation:

$$E = 1/2\, m\, (V_1^2 - V_2^2) \quad (3)$$

Then, for calculated of peak crushing force, we earn reaction force related to bottom plate and then drag Force-Displacement curve. Area under this curve is amount of energy and highest point of this curve about force is Peak Crushing Force related to CFRP structure. Finally, weight of structure is evaluated using by earn volume. Amounts of these three objective functions in conjunction with geometrical parameters are shown in Table 3:

TABLE III. THREE OBJECTIVE FUNCTIONS VALUES IN CONJUNCTION WITH GEOMETRICAL PARAMETERS FOR 30 FE MODELS

Model	α(°)	C(mm)	n	Ɵ(°)	m(KG)	E(J)	Fmax(N)
1	35	40	10	0	0.6175	13371.91	295.09
2	35	45	9	15	0.6335	16560.98	157.97
…	…	…	..	…	…	…	…
9	40	45	10	30	0.7067	8.01	8959.975
10	40	50	9	45	0.7146	8.15	8394.375
…	…	…	..	…	…	…	…
18	45	55	9	75	0.7951	9.77	1136.775
19	45	60	8	90	0.7771	9.6	1960
…	…	…	..	…	…	…	…
22	50	40	6	45	0.3907	9.04	4569.6
23	50	45	5	60	0.3700	9.66	1671.1
…	…	…	..	…	…	…	…
29	55	40	7	60	0.4559	9.59	2007.975
30	55	45	6	75	0.4444	9.92	398.4

Crushing modes of 1 and 21 models are shown in figure 5 and 6. One of the main results of FE analysis of S-shaped structure is derive of displacement-Force curve. In this curve, amount of absorption energy equal to area under this curve and peak crushing force about each model can be given. In following, Force-displacement of 5 and 6 model are shown in 7 and 8 Fig:

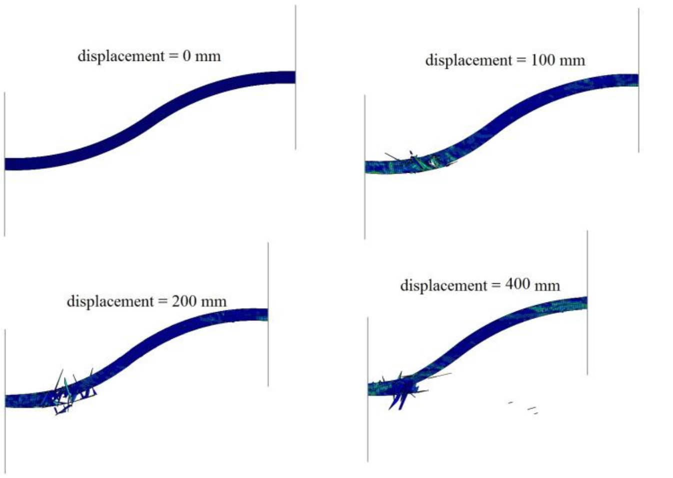

Figure 5. Crushing modes of model No.1

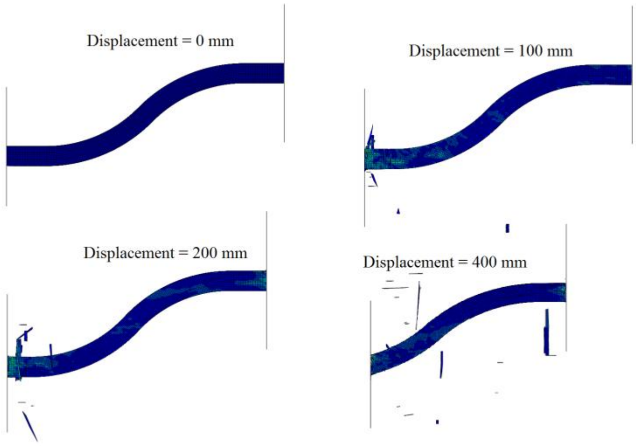

Figure 6. crushing modes of model No.21

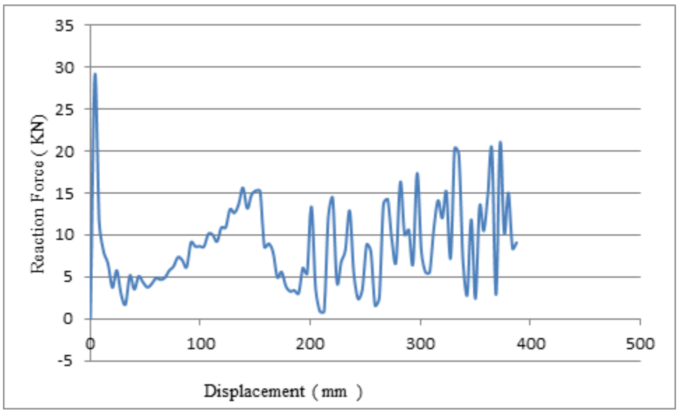

Figure 7. Force-displacement cure od model No.5

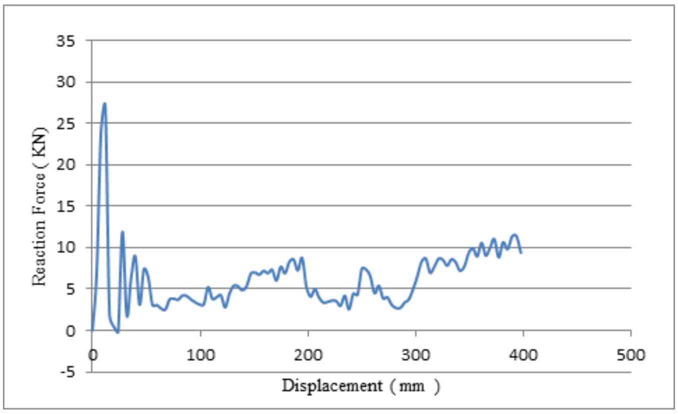

Figure 8. Force-displacement cure od model No.6

IV. CONCLUSION

In this paper, the finite element analysis of CFRP S-shaped structure under impact load has been done. Evaluated number for three objective functions will be used for optimization of this structure with same objective functions. Comparison between this type of energy absorber to other reference models show high performance of considered structure and can be improve behavior of structure using by change in variable parameter that surveying in previous stage such as n, C, ϴ and α.

REFERENCES

[1] Johnson W, Mamalis AG. Crashworthiness of vehicles. London: Mech. Engg. Publications Ltd., 1978.

[2] Johnson W, Reid SR. Metallic energy dissipating systems. Applied Mechanics Review 1978; 31(3):277–88.

[3] Jones N, Wierzbicki T, editors. Structural crashworthiness. London: Butterworth and Co. Publishers, 1983.

[4] Jones N, Abramowicz W. Static and dynamic axial crushing of circular and square tubes. In: Reid SR, editor, Metal forming and Impact Mechanics. Oxford, Pergamon Press, 1985:225.

[5] Mamalis AG, Johnson W. The quasi-static crumpling of thin walled circular cylinders and frusta under axial compression. Int. J. Mech. Sci. 1983;25:713–32.

[6] Timoshenko S. P, Gere J.M. Theory of Elastic Stability. McGraw Hill Book Co, 1961.

[7] Wierzbicki, T. Akerstrom, T. Dynamic crushing of strain-rate sensitive box columns. Proceeding of 2nd Con of vehicle structural mechanics, SAE 70592, (1997).

[8] Alexander JM.. An approximate analysis of the collapse of thin cylindrical shells under axial loading.Quart. J. Mechs. And Applied Maths. 13:1–9. 1960

[9] Otbushin, a.. *detailed validation of a non-linear* finite element code using dynamic axial crushing of a square tube. Int. J. Impact engineering. S0734-743x. 1997

[10] Ni, C. M., "Impact Response of Curved Box Beam Columns with Large Global and Local Deformations.Proceedings of the 14thStructures," Structural Dynamics, and Materials Conference, King of Prussia, PA, U.S.A. AIAA pp. 73-401 (1976).

[11] Kim, H-S. and Wierzbicki, T., "Effect of the Cross-Sectional Shape on Crash Behavior of a 3-D Space Frame," Impact and Crashworthiness Laboratory Report No. 34, MIT (2000).

[12] Kim, H. S. and Wierzbicki, T., "Closed-Form Solution for Crushing Response of Three-Dimensional Thin-Walled S Frames with Rectangular Cross-Sections," International Journal of Impact Engineering, 30, pp. 87-112 (2004).

[13] Zheng, L. and Wierzbicki, T., "Quasi-Static Crushing of S-Shaped Aluminum Front Rail, "International Journal of Crashworthiness, 9, pp. 155-173 (2004).

[14] P. Hosseini-Tehrani and M. Nikahd, Two materials S-frame representation for improving crashworthinessand lightening, Int. J. Thin-Walled Struct. 44 (2006),

[15] G. Mamalis, D.E. Manolakos, M.B. Ioannidis, D.G.Chronopoulos ,P.K.Kostazos. On the crashworthiness of composite rectangular thin-walled tubes internally reinforced with aluminum or polymeric foams: Experimental and numerical simulation. Composite Structures 89 (2009) 416–423

[16] Z.Hashin,*Failure Criteria For Unidirectional Fiber Composites*, Journal of Applied Mechanics, 47, 329–334.1980

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