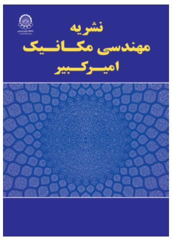

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Numerical Behavior Study of Expanded Metal Tube Absorbers and Effect of Cross Section Size and Multi-Layer Under Low Axial Velocity Impact Loading

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ABSTRACT: In this paper, the performance of the Expanded Metal Tube absorbers under axis impact loading was investigated. A cylindrical expanded metal sheets is used as an energy absorber. Thin-walled expanded metal sheets, despite their low weight, have high energy absorption capacity. The cellular direction of expanded metal sheets will have a large impact on the absorber behavior. In this study, a sheet with angle α=0 is used to create a cylindrical Expanded Metal Tube absorber. In this study, to evaluate the performance of energy absorption caused by the collapse and to achieve maximum energy absorption, a numerical study of the effect of the cross-section size and making the absorber a multi-layer one on the energy absorption behavior has been discussed. Numerical studies have been performed by the ABAQUS Finite Element Method software. The output of ABAQUS software is displayed in form of the force-displacement diagram. In this study, numerical investigation of collapse, force-displacement and the effective parameters have been carried out. From the results obtained, it was observed that increasing the size of the cross-section and making the absorber multi-layer , will have a significant effect on the initial maximum crushing force and energy absorption capacity and making the absorber a multi-layer improves the crushing efficiency.

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1- Introduction

The use of thin-walled structures is increasing in energy absorbers applications. The overall performance of this type of structures under various loading conditions has improved. Thin-walled structures have a high energy absorption capacity, therefore, they are utilized as energy absorbers in various industries. Bumpers and absorbers dissipate the kinetic energy of the impact though collapse of the structure and plastic work. Such bumpers are irreversible and cannot be reused after deformation. Therefore, studies are mostly focused on material properties, geometric parameters, and the presence or absence of defects in the structural behavior aiming at achieving higher energy absorption capacity [1-4]. Graciano et al. [5, 6] were first to study expanded metal energy absorbers under pseudo-static loading. Studies on this kind of absorber show that collapse mechanism and energy absorption capacity depends on the direction of the cells. They conducted experimental and numerical studies to improve the energy absorption capacity and reduce the initial maximum force of the absorbers. Further studies have been conducted regarding the number of cells in cross section and the type of cross section (circular and square) to improve the performance of these absorbers.

In recent years, the behavior of expanded metal tubes under static and pseudo-static loadings has been studied. In this study, the behavior of the absorbers under dynamic and impact loading was investigated. The collapse mechanism of the expanded metal sheets depends on the direction of the cells. [7] Expanded metal sheets in the shape of a cylinder with two cell directions of α=0 and α=90 degrees were tested.

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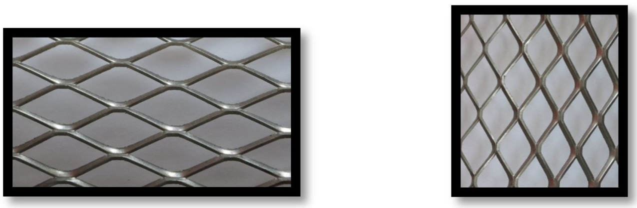
Fig. 1 shows the expanded metal sheets and the cell directions and Fig. 2 show the cell size.



a) α=0 b) α=90

Figure 1. Cells direction

Figure 2. Collapse of tubes

2- FEM Simulation

ABAQUS software was used for numerical simulations. ABAQUS is capable of simulating dynamic and impact loadings [7]. The simulated expanded metal tubes had a different diameter. All models had the same diameter. They were of the same cell sizes l_1=35 mm and l_2=30 mm and

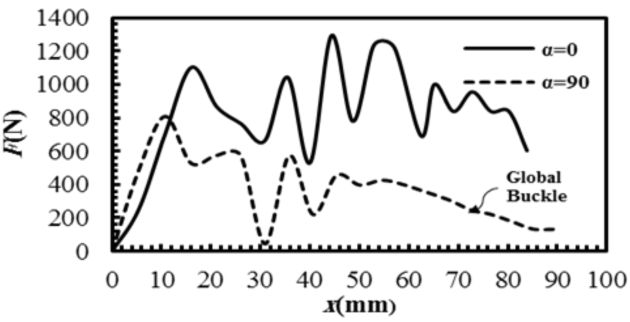


Figure 3. Force-displacement curve for tubes with cell angle α=0 and α=90

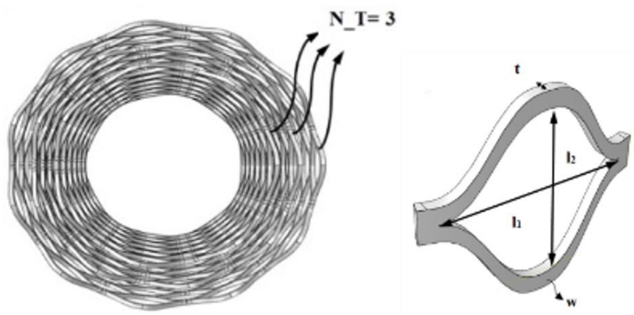


Figure 4. Multi-layer tube

wall thickness t=2 mm. The characteristics of the models are shown in Table 3. the number of circular cells, N_C, and the number of longitudinal cells, N_L, Number of Tube, N_T (Fig. 7). Steel sheet with elasticity modulus of E = 211 GPa, Poisson's ratio of υ=0.3, and density of ρ=7800 Kg/m^3 was used in the simulations. The initial peak force (P_{peak}), mean force (P_m), energy absorption (E_a), and shape factor (η) are the parameters used for measurement of energy absorber. The parameters are calculated using Eq. (1) through (4).

$$E_a = \int_{x_2}^{x_1} F(x)dx \quad (1)$$

$$P_{mean} = \frac{E_a}{x_2 - x_1} \quad (2)$$

$$\eta = \frac{\mathrm{P_{mean}}}{\mathrm{P_{peak}}} \quad (3)$$

$$SEA = \frac{E_a}{W_m} \quad (4)$$

Table 1. Specifications of the models

Specimens	L (mm)	D (mm)	N_C	N_L	N_T	W_m (gr)
EMT1	202	100	7	6	1	175
EMT 2	202	120	9	6	1	211
EMT 3	202	140	11	6	1	247
EMT 4	202	160	12	6	1	283
EMT 5	202	180	15	6	1	319
EMT 6	202	120	7-9	6	2	376
EMT 7	202	140	7-9-11	6	3	633
EMT 8	202	160	7-9-11-12	6	4	916
EMT 9	202	180	7-9-11-12-15	6	5	1235

2- 1- Studying single-layer expanded metal tubes

First, single-layer expanded metal tubes are studied. Single-layer tubes have different cross-section diameters. Respectively, their cross-section diameter increases and its

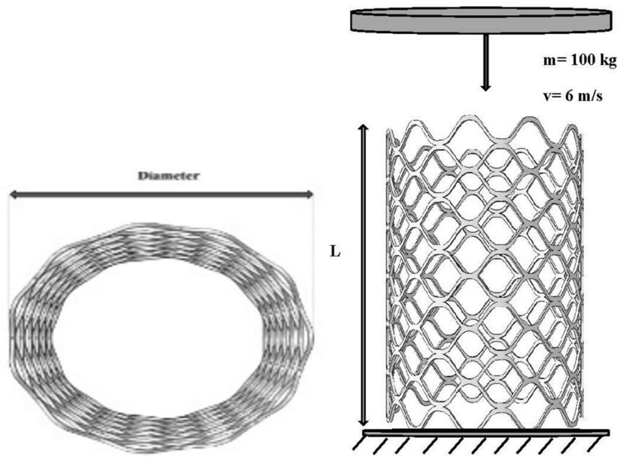


Figure 5. Boundary condition and loading

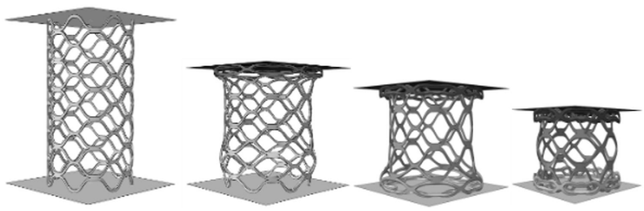


Figure 6. Collapse of EMT1

effects on the tube behavior is investigated.

2- 2- Studying multi-layer expanded metal tubes

Here, we investigate the behavior of multi-layer expanded metal tubes. Multi-layer expanded metal tubes are concentric cylinders placed within each other and their effect on collapse behavior and energy absorption capacity is studied. Fig. 5 shows the way that tubes collapse. As can be seen, the tube collapse is symmetrical and each layer absorbs impact energy by its crushing of cells on each other.

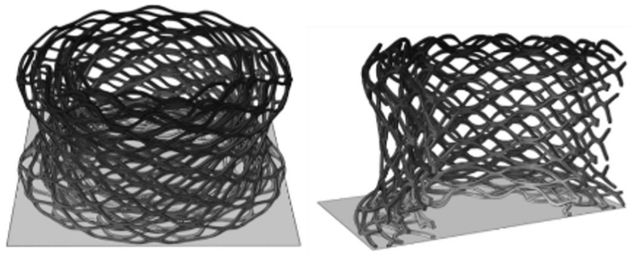


Figure 7. Collapse of multi-layer

Table 2. Results of single layer EMT tubes

Specimens	P_{peak} (N)	P_{mean} (N)	δ (mm)	E (J)	L/δ	η	SEA
EMT1	7743.11	5620.74	146.60	824	72.6 %	0.73	4.7
EMT2	8793.17	6253.04	144.15	902	71.4 %	0.72	4.3
EMT3	8931.01	6901.46	140.55	970	69.6 %	0.77	3.9
EMT4	11136.70	7465.97	136.62	1020	67.6 %	0.67	3.6
EMT5	14111.60	7649.87	136.12	1026	67.4 %	0.54	3.3

Table 3. Results of multi-layer EMT tubes

Specimens	P_{peak} (N)	P_{mean} (N)	δ (mm)	E (J)	L/δ	η	SEA
EMT6	15420.50	14939.78	108.77	1625	53.8 %	0.97	4.3
EMT7	25522.70	22676.77	79.20	1796	39.5 %	0.89	2.8
EMT8	33231.60	31227.15	57.45	1794	28.5 %	0.94	1.9
EMT9	47947.70	40044.74	44.70	1790	22.2 %	0.83	1.4

3- Conclusions

All expanded metal tube energy absorbers of cell angle α=0 collapse symmetrically under impact loading which leads to high energy absorption capacity. Such types of tubes have low weight due to their structure. Increasing the cross-section size of the tube increases its resistance against crushing and increases the maximum initial force required to overcome the initial resistance. By increasing the cross-section, number of cells in the circular area will increase and this in turn increases the absorption capacity of the tube energy. In order to increase the energy absorption capacity, we can use multi-layer tubes. Multi-layering of the tubes leads to absorption of the collapse by each layer and increase in the tube capacity. Shape factor or crushing force efficiency (η) is a parameter considered in designs. As can be seen in the results, this factor is almost the same for all samples in single-layer tubes. In multi-layer tubes, we see increase in this factor indicating that multi-layer tubes have a high crushing efficiency.

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