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Crushing behavior of new designed multi-cell members subjected to axial and oblique quasi-static loads

S. Pirmohammad *, S. Esmaeili Marzdashti

Department of Mechanical Engineering, Faculty of Engineering, University of Mohaghegh Ardabili, Ardabil 179, Iran

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ABSTRACT

A new design of multi-cell devices was proposed in this paper, and evaluated in terms of crashworthiness capability under quasi-static axial and oblique (9°, 18° and 27°) loading. The structures studied in the present paper were single and multi-cell members made up of two straight columns with the same shape of cross-section connected together by several ribs. They included several sectional configurations such as triangle, square, hexagon and circle with different scales (i.e. 0, 0.25, 0.5, 0.75 and 1). Finite element code LS-DYNA was used to simulate the crashworthiness behavior of the proposed members under quasi-static loads. Several crashworthiness indicators including SEA, F_{max} and CFE were obtained at different crushing angles for all the columns, and a powerful decision making method known as COPRAS was then implemented to choose the best energy absorber with the criteria of having higher specific energy absorption and lower initial peak force. From the COPRAS calculations, the multi-cell members with inner tube and scale number of 0.5 were selected as the better energy absorbers, and the column with circular cross-section was also found to be the best energy absorbing device.

1. Introduction

There has been a great deal of activities on crushing behavior of thin walled structures made of aluminum alloys due to its low cost and high weight-stiffness efficiency. Increased demands on safety caused that the majority of these activities being focused on the use of these structures in energy absorbing components. The main goal of these researches was to enhance the crashworthiness capacity of the aluminum tubes by employing different geometries, reinforcements, triggers and cross sections. For example, Langseth and Hopperstad [1] experimentally studied the static and dynamic crushing behavior of square aluminum tubes at different wall thicknesses and impact velocities. Their investigation showed that the dynamic mean force was significantly higher than the static force for the same axial displacement, which indicated a strong inertia effect. Numerical simulations performed by Langseth et al. [2] on the aluminum tubs demonstrated that the mean crushing force highly depended on the impact velocity. Moreover, the mass ratio between the projectile and specimen did not affect the mean crushing force. AlaviNia et al. [3] experimentally and numerically studied the effect of collapse initiators on energy absorption characteristics of square tubes under oblique quasi-static loads. Their results showed that the collapse initiators in most of the specimens changed deformation mode from general buckling to progressive buckling and also decreased the peak load considerably. In another study, Abbasi et al. [4] numerically investigated the crashworthiness capacity of square, hexagonal, and octagonal single tubes as well as a newly introduced tube with 12-edge cross-section. They concluded that the crashworthiness capacity was improved as the number of corner increased. They then changed the angle of this new tube to optimize the crashworthiness capacity.

A great number of researches have been reported on the straight tubes with circular, square, rectangular or multi-corner cross-sections. These tubes have been used in a variety of applications like in the vehicles, train, road barriers, etc. as energy absorber. Chen and Wierzbicki [5] studied the axial crushing of straight multi-cell columns with square cross-section analytically and numerically. They derived closed-form solutions for the mean crushing force of these columns, and the solution was demonstrated to match very well with the numerical results. Hou et al. [6] investigated crashworthiness of the straight hexagonal columns for different sectional profiles. A comparison has been made between these columns using response surface method, and the crashworthiness merits of them have been quantified. In another task, Kim [7] considered new types of trigger having four square tubes at the corner. These structures showed dramatic

* Corresponding author.
E-mail address: s_pirmohammad@uma.ac.ir (S. Pirmohammad).

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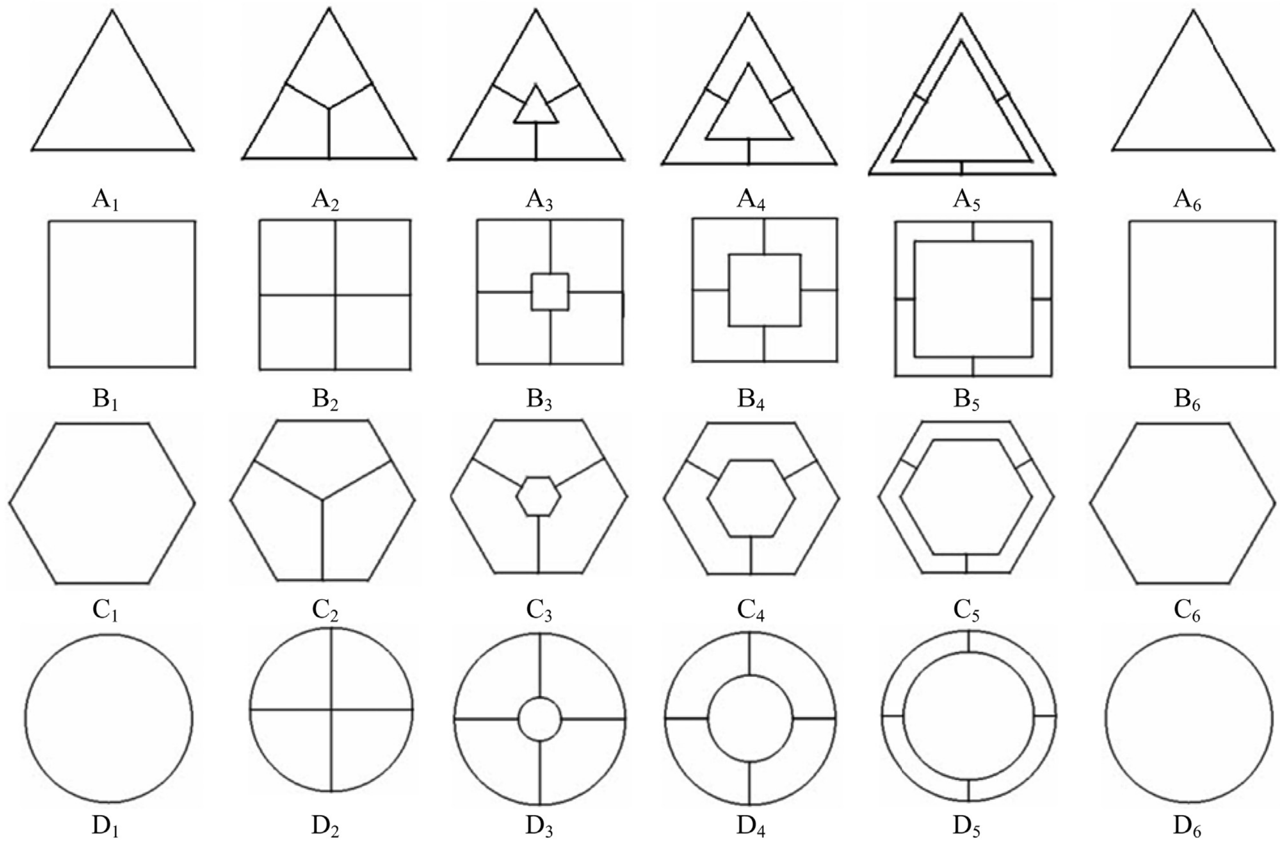

Fig. 1. Schematic of triangular, square, hexagonal and circular columns. Subscripts 2, 3, 4, 5 and 6 correspond to the scales (a/b) of 0, 0.25, 0.5, 0.75, and 1, respectively, and the subscript 1 corresponds to the single tubes with the thickness of 2 mm. (a): side length of the inner tube. (b): side length of the outer tube.

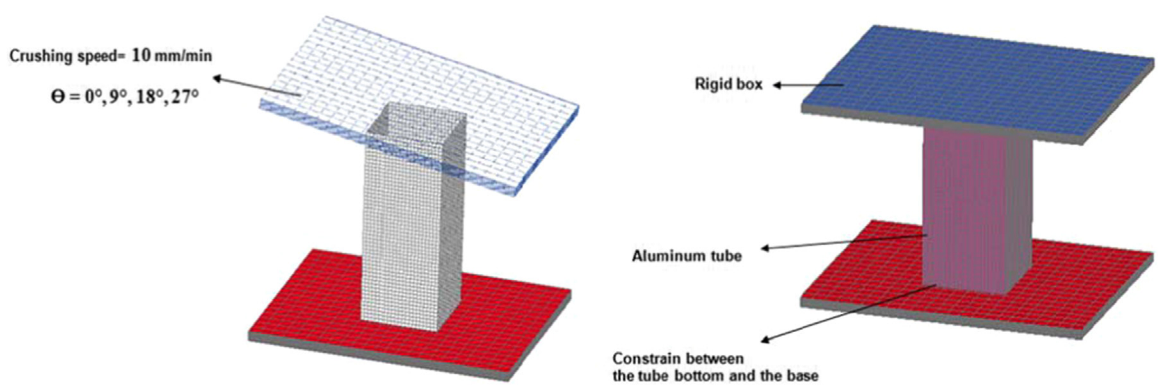

Fig. 2. Boundary and loading conditions assumed in the finite element modeling.

Table 1
Mechanical properties of aluminum AA6060 in elastic zone.

Property	Symbol	Value
Young's Modulus	E	68 GPa
Yield stress	σ_Y	214 MPa
Ultimate stress	σ_u	241 MPa
Elongation at break	e_b	12%

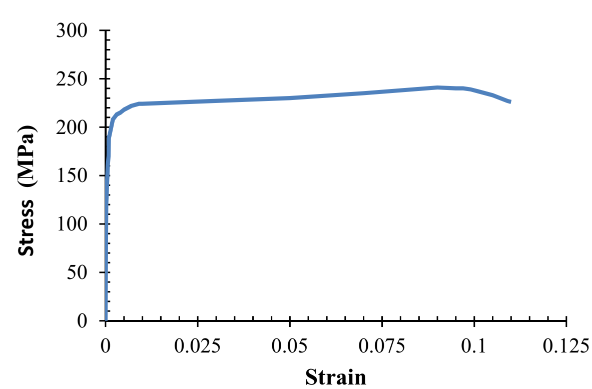

Fig. 3. Plastic stress-strain behavior of aluminum AA6060.

improvements over the conventional square column. The introduced structure was then optimized to achieve high specific energy absorption capacity. Liu [8] provided an optimum design for square tubes. He used response surface method to optimize this structure. In another work, Liu [9] studied crashworthiness of