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Energy absorption performance of concentric and multi-cell profiles involving damage evolution criteria

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ABSTRACT

Many advantages are attributed to concentric and multi-cell columns, respect to single cell structures, which made them useful for applications in automobile design. The current paper analyzes the effect of cross-section on the crashworthiness performance of concentric and multi-cell profiles. Numerical analyses were performed considering damage evolution criteria using Abaqus/Explicit. Structures with triangular, square, hexagonal and circular base cross-sections were considered. In all cases, the structures were made of aluminum alloy EN AW-7108 T6 and modelled with ductile, shear and Müschenborn-Sonne Forming Limit Diagram (MSFLD) damage initiation criteria. The structures were axially loaded/impacted using a striker of 500 kg with an initial velocity of 10 m/s. Booth concentric and multi-cell structures showed an increase in energy absorption (E_a) as their cross-section tend to form a circular shape. The best performance was obtained by the profiles with circular cross-sectional base. In regard to profiles with triangular shape, an increase in crush force efficiency of 76.4% and energy absorption of 60.32%, was observed. Likewise, a better performance of specific energy absorption (SEA) for multi-cell profiles, relative to concentric structures, was obtained in the range from 33% to 57.92%. Finally, we end our study with a typical application in automotive crashworthiness design.

1. Introduction

Aluminum thin-walled structures are widely used in the automobile industry as passive energy absorbers when undergoing plastic deformations. One of the most important advantages of thin-walled structures is their relatively low weight and large energy absorption capacity. These characteristics increase the safety of the passengers and the lightness of the car which reduces fuel consumption. The use of structures made of aluminum alloys reduces the total weight of the vehicle by ~25% with respect to steel structures [1]. In this sense the use of bi-tubular and multi-cell profiles have recently gained importance relative to their single profile counterparts. Goel [2] made an attempt to improve the energy absorption of thin concentric cylindrical tubes by replacing the inner tube with half cylindrical shells acting as stiffeners along the circumference of the external tube. The author obtained a better energy absorption performance by incorporating stiffeners to the single and concentric tubes. Nia and Khodabakhsh [3] analyzed the effect of radial distance of concentric tubes on the energy absorption capacities. They studied several circular concentric arrangements with different radial distances. It was determined that a dimensionless distance of 0.66 between two tubes, yields the highest value of specific energy absorption. On the other hand, besides concentric structures, the use of multi-cell profiles to enhance the energy absorption performance has gained importance. Zhang et al. [4] defined a multi-cell profile as a number of plates connected with each other at various angles and with different edge connectivity. The main multi-cell cross-sections analyzed in the literature are based on square [5,6] and other polygonal shapes such as triangular [7], hexagonal [8], octagonal [9] and circular [10]. Fang et al. [11] studied the effect of cell number on square multi-cell profiles under axial and oblique loads. The numerical results showed that, increasing the number of cells improves the energy absorption. However, an undesirable increase of peak load is also obtained during axial impact. Hong et al. [12] conducted an experimental analysis to improve the energy absorption of thin-walled multi-cell structures with triangular and Kagome lattices. They determined that the multi-cell lattice tubes are more weight efficient for

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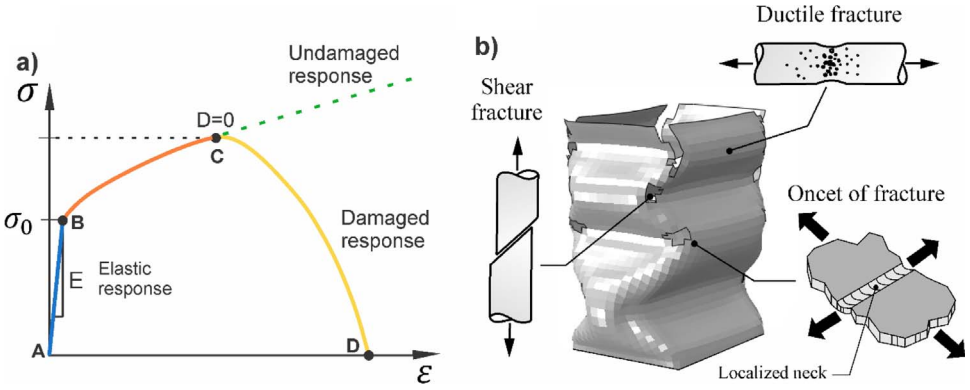

Fig. 1. Importance of damage modelling, where, a) stress vs strain curve for typical metals and b) failure mechanism on thin-walled structures, based [24].

Table 1
Material parameters for aluminum alloy EN AW-7108 T6 [24].

Elasticity Path B-C	**Young Modulus**		**Poisson Coefficient**	**Density**
	70 GPa		0.33	2700 kg/m^3
Plasticity Path A-B	**Model**			
	Isotropic with different strain rate			
Damage Criteria Path C-D	**Parameter**		**Ductile failure parameters**	**Shear failure parameters**
	Equivalent plastic strain in equibiaxial tension at ductile	ε_T^+	0.44	-
	Equivalent plastic at strain in equibiaxial compression	ε_T^-	1494	-
	Material parameter in ductile fracture curve	k_0	8.6304	-
	Equivalent plastic at strain in equibiaxial tension shear	ε_S^+	-	0.35
	Equivalent plastic at strain in equibiaxial compression	ε_S^-	-	1.2
	Material parameter in shear fracture curve	f	-	2.05
	Shear Parameter	k_s		3

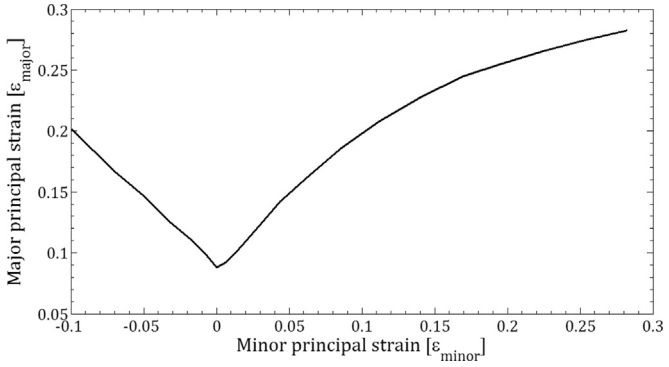

Fig. 2. Forming limit curve for aluminum alloy EN AW-7108 T6 specimens for dynamic case [20].

energy absorption respect to single-cell tubes. Qiu et al. [13,14] deduced analytical formulas for the mean crushing load on hexagonal multi-cell profiles based on the simplified super folding element method. Likewise, they carried out a numerical analysis to determine the crashworthiness behavior of several configurations of hexagonal profiles under axial and oblique load. The analytical equations can be used in crashworthiness optimization. As conclusion an optimized hexagonal cross-section was presented. On the other hand, comparative analysis of different multi-cell cross sections has been carried out in order to find the optimal one. For this purpose, Pirmohammad et al. [15] analyzed multi-cell structures with triangular, square, hexagonal and circular cross sections. They carried out FEM simulations using different scales on the structures under quasi-static axial and oblique loads. From their results the best crashworthiness behavior was obtained by the multi-cell member with inner tube. Similarly, Nia et al. [16] carried out a comparative analysis of energy absorption of simple multi-cell structures with different triangular, square, hexagonal and octagonal sections. They found a better performance of energy absorption per unit mass for hexagonal and octagonal multi-cell profiles. In all the studies mentioned above, numerical simulations have been a strong component to predict the crashworthiness of multi-cell profiles. However, when ductile materials such as aluminum are impacted, the failure and fracture behavior should also be modelled numerically to get reliable results. In this regard, some attempts to capture failure and fracture behavior have been carried out by implementing damage initiation criteria [17–19]. Hooputra et al. [20] presented a comprehensive approach for predicting failure of structures based on macroscopic strain and stresses. This approach requires the use of a several failure mechanisms such as necking, and ductile and shear fracture (HDD). The effectiveness of this approach was determined by comparing numerical and experimental results for a double chambered profile made of aluminum EN AW-7108 T6. Finally, Estrada et al. [21] introduced ductile and shear damage initiation criteria to evaluate the effect of circular discontinuities on the crashworthiness performance of square profiles.

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