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Axial splitting of composite columns with different cross sections

H. Assaee [a,*], J. Rouzegar [a], M.S. Saeedi Fakher [a], A. Niknejad [b]

[a] Department of Aerospace and Mechanical Engineering, Shiraz University of Technology, P.O. Box 71555-313, Shiraz, Iran
[b] Mechanical Engineering Department, Faculty of Engineering, Yasouj University, P.O. Box 75914-353, Yasouj, Iran

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ABSTRACT

The research investigates the axial splitting of E-glass/vinylester and E-glass/polyester composite columns with identical perimeters but different cross sections on polygonal aluminum dies, and the elimination of restrictions on the initial slit in the classical splitting process. A novel technique for the construction of mandrels using polystyrene foam is developed. Composite columns are produced by winding the fiber fabric layers around the mandrels using coarse and fine E-glass woven fibers. The deformation modes and energy absorption behavior of columns during the long stroke of the splitting process are compared. The effects of the initial slits, various cross sections, side lengths, number of fiber fabric layers, resin type, fiber fabric type and angle of polygon dies on the splitting and curling of the structures are investigated. The results of this study reveal that alternating cross sections of columns may affect deformation modes and energy absorption parameters.

1. Introduction

Over the past few decades, various investigations were launched by researchers and engineers to increase the ability and range of composite materials in the field of crashworthiness. A structure's crashworthiness is a major factor in vehicle design, as it helps protect the vehicle's occupants from serious injuries or death in case of accidents. To that end, the energy absorption capabilities of components are very important in improving a vehicle's crashworthiness. In the aerospace and transportation industries, structures are usually built from materials with high strength and stiffness-to-weight ratios, and hence composite materials often achieve these characteristics adequately [1]. On the other hand, composite materials have relative advantages in terms of specific energy absorption, weight and maintenance [2]. It is also interesting to note that relatively low-cost glass/epoxy composites absorbed up to twice the specific energy of steel [3].

Many researchers have investigated the behavior of columns and tubes under various loadings. Axial splitting and tube curling are known as efficient energy absorption methods due to their large stroke-to-length ratio. Compared with axial buckling and the inversion mode with no cracking, operating loads for splitting tubes are significantly lower. However, due to large strokes in the splitting condition, the total energy absorbed can often be as high as the energy absorbed by other methods.

Ezra and Fay [4] studied energy absorbers for improving passenger survivability in aircraft crashes. They found that splitting circular tubes is an efficient system based on specific energy dissipation (energy-to-mass ratio). Reddy and Reid [5] conducted experiments on circular metal tubes and compressed them axially between a plate and a curved die. They found that another advantage of this mechanism is a steady-state deformation with a constant force, which is desirable for minimizing damage criteria over the total available stroke. Warrior et al. [6] carried out some axial compression tests on polymer composite tubes with flat platen and curved initiators. They found that large radius initiators cause the tubes to split, after which the energy is primarily dissipated through friction and axial splitting. Niknejad et al. [7] investigated the splitting behavior of empty and polyurethane foam-filled circular composites tubes under axial quasi-static loading. They studied the effects of semi-angle of conical dies, number of fiber fabric layers, resin and fiber fabric types, and tube diameter on energy absorption characteristics during the splitting process.

Very few studies have yet been carried out on different geometrical shapes of composite columns under the axial crushing process. The progressive crushing process depends on the mechanical properties of the fiber and resin, as well as on fiber orientation and the geometry of the tubes [8]. However, for the same parameters, different values of absorbed energy can be achieved by changing only the geometry of composite structures [9]. Palanivelu et al. [10] investigated the crushing performance of nine different geometrical shapes of small-scale composite tubes. Specifically, they studied the effects of geometry, dimension and

* Corresponding author.
E-mail address: assaee@sutech.ac.ir (H. Assaee).

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triggering mechanisms on the progressive deformation of small-scale composite tubes. They found that the crushing characteristics and corresponding energy absorption of special geometrical shapes are better than those for standard geometrical shapes such as square cross sections. Thronton and Edwards [11] concluded that circular cross sectional composite tubes are more effective than square and rectangular cross sectional composite tubes. Jimenez et al. [12] studied the energy absorption capability of open sections such as "I" sectional E-glass/polyester composite tubes. They found that the energy absorption capability of the "I" section profile is 15% smaller than that of square cross sectional composite tubes.

A review the previous works revealed that the splitting and curling of tubes has considerable advantages in comparison with other energy absorbing systems. Moreover, the various geometry and cross sections of composite structures are critically important variables that affect the specific energy absorption. In our present research, a novel method is used for the fabrication of composite columns with different cross sections. The corresponding dies with different cross sections are prepared and the columns are axially compressed on polygon and conical dies. Energy absorption parameters are then compared to find an optimized energy absorber. As well, the effects of different cross sections, side lengths, initial slits, angle of dies, number of fiber fabric layers and fiber and resin materials are studied to ascertain the energy absorption and crushing behaviors of the structures under investigation.

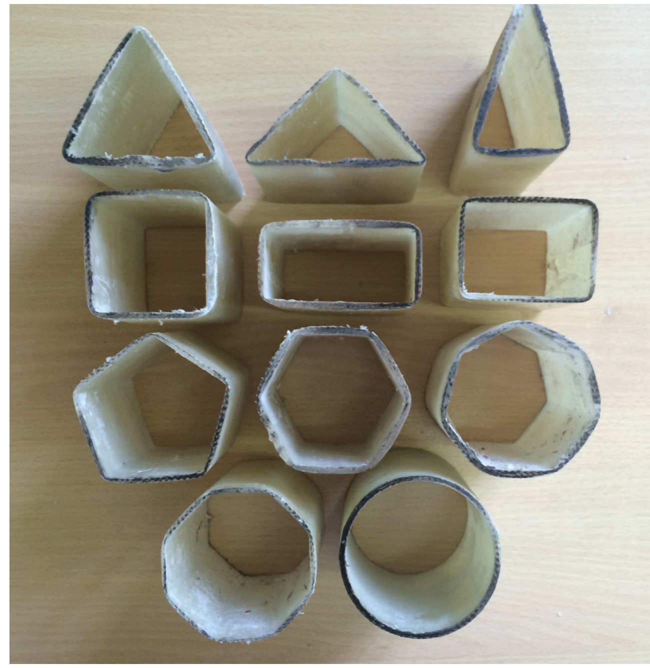

Fig. 1. Fabricated composite columns with different cross sections.

2. Experiments

2.1. Geometry, material and fabrication process

In order to investigate the deformation modes and energy absorption parameters of composite columns with different cross sections during the splitting process, a novel method was used for the fabrication of columns and dies. Different mandrels were fabricated using a hot wire-cutting polystyrene foam system, and composite layers were wrapped around the mandrels using a hand lay-up technique. Fabric mats were pre-tensioned during the fabrication process to ensure all specimens had the desired thickness and that no air was trapped between the layers. All samples were fabricated from woven E-glass fiber fabric mats. All samples were made of fine or coarse fiber mesh woven rovings. The ends of the fabricated columns were cut to desired lengths. Fig. 1 shows different cross sections of columns used in this investigation.

It should be noted that the present author's past experience in the splitting process of composite columns revealed that in order to provide a steady-state splitting process of composite polygon columns, the equivalent polygon dies are required. In most of the research on splitting, metallic columns with circular cross sections were used. Moreover, dies with different angles were made of mild steel and heat-treated to increase surface hardness to remain non-deformed during the tests. As far as composite columns are concerned, the requirement of using steel dies is done away with in this research and light-weight aluminum dies are used instead, making them an ideal choice for automotive and aerospace applications in terms of reducing the structural weight and fuel consumption. Thus, the corresponding polygonal dies were cast in Aluminum. Fig. 2 shows a conical hardened steel die and various cross sections of aluminum die castings with different angles that are used in this investigation.

Details of design variables, geometry and materials are given in Table 1.

The length and perimeter of the cross section of all composite columns were 90 and 240 mm, respectively. The design variables

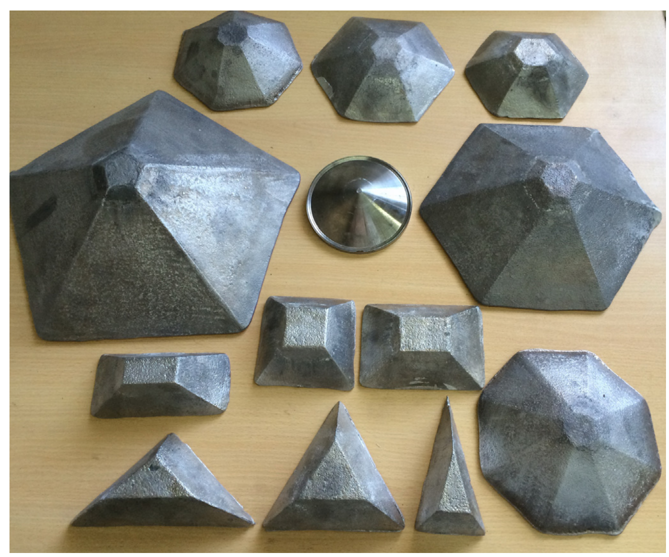

Fig. 2. Fabricated conical hardened steel die and different cross sections of aluminum die castings.

considered in the current study are: cross section, resin and fiber materials, number of fiber fabric layers, initial slits, side lengths, and angle of dies.

In order to give an insight to mechanisms of energy absorption some uniaxial tensile tests were performed on the laminates equal to those used for fabrication of composite columns. The laminates were made by stacking three layers of fine glass fiber mats and vinylester resin. The results of mentioned tests are presented in Fig. 3.

2.2. Experimental setup

The composite columns were axially compressed between a rigid plate of a testing apparatus and dies during a quasi-static loading using a Zwick machine. The axes of the die, tube and testing machine had been carefully aligned.