EXPERIMENTAL AND NUMERICAL STUDY ON AXIAL COMPRESSION OF METAL TUBES WITH HOLES

[1]JAFAR ROUZEGAR, [2]MOHAMMAD ELAHI

[1,2]Department of Mechanical and Aerospace Engineering, Shiraz University of Technology, Shiraz, Iran
E-mail: rouzegar@sutech.ac.ir

Abstract- The main objective of this research is to investigate the effects of presence of holes in circular metal tubes on the deformation modes and load-displacement diagrams, during axial compressive loading, experimentally and numerically. For this purpose, some intact and perforated tubes with two, three and four holes in their mid-height were prepared and were subjected to the axial load between two rigid plates in quasi-static condition. The deformation modes of tested tubes is described and their load-displacement diagrams are sketched. Also, all of the experimental results compared with the numerical results. The numerical simulations are performed by ABAQUS finite element package. Good agreements are observed between experimental results and finite element simulations.

Keywords- Axial load, Experimental,Hole, Metal tube,Numerical.

I. INTRODUCTION

Over the last few decades, energy absorption systems have been developed in automobile and aerospace industries in order to increase the occupant safety and decrease damage of vehicles equipment in accidents. Circular metal tubes are one of the most common shapes of tubular energy dissipating devices that absorb kinetic energy of impact by collapsing in concertina and diamond modes under quasi-static and dynamic axial loading. A few methods have been suggested to improve energy absorption capability of these structures like, expanding metal tubes by rigid tubes, using filler substances such as metal and polymeric foams and externally reinforcing by composite materials [1]. Gupta and Gupta [2] investigated axial compression tests on circular tubes made of aluminum and mild steel, both in as-received and annealed conditions. They investigated some parameters such as length to diameter and diameter to thickness ratios, and also existence of some cut-outs in the form of circular holes with different diameter, number and position. Hanefi and Wierzbicki [3] presented a simplified analytical model for static crushing of externally reinforced metal tubes. The classical Alexander's solution was modified to take into account the contribution of compound metal/composite wall. The mean crushing force and the length of local folding wave were derived from this model where these parameters were in good agreement with the experimental data. Song et al. [4] studied axial impact crushing behavior and energy absorption efficiency of circular metal tubes wrapped externally with glass/epoxy composite. Predicted instantaneous velocity and displacement were compared with experimental results. Bouchet et al. [5] analyzed crushing behavior and practical adhesion of multi-material structures under dynamic compression conditions, experimentally. Multi-material structures were made by wrapping a carbon/epoxy composite around an aluminum alloy circular tube. Arnold and Altenhof [6] investigated energy absorption characteristics of extruded aluminum alloy square cross-sectional tubular specimens, with and without the presence of dual centrally located circular discontinuities under quasi-static compressionloading. Babbage and Mallick [7] performed an experimental investigation on static axial crush performance of aluminum–composite hybrid tubes. The unfilled and foam-filled hybrid tubes were tested and it was shown that thestatic axial crush performance of both round and square hybrid tubes can be improved using E-glass fiber/epoxy overwrap. Guden et al. [8] investigated the effect of foam filling of E-glass woven fabric polyester composite tube and aluminum/polyester composite hybrid tube on the quasi-static crushing behavior, experimentally. For comparison, empty aluminum, empty composite and empty hybrid tubes were also tested. Two crushing modes, progressive and catastrophic, observed in the testing of empty composite and empty hybrid tubes. The progressive crushing mode resulted in higher crushing loads and hence higher SAEs. Taheri-Behrooz et al. [9] studied the critical axial load of perforated E-glass/epoxy tubes using numerical and experimental methods. The effect of various parameters such as the tube diameter, wall thickness,size and number of perforation were investigated in this research. Good correlation obtained between the experimental and numerical results. According to the results, intact and perforated tubes showed similar instability mode shapes under axial loading. However, the critical load and global stiffness of the perforated tubes were considerably reduced.

The main objective of the present study is to investigate the effects of presence of holes at the mid-height of aluminum tubes under axial compression loading on the deformation mode and load-displacement diagram. Some specimens with different number of holes at the mid-height were tested. Also, experimental results are compared with the numerical results obtained using ABAQUS finite element package.

II. DETAILS EXPERIMENTAL

In order to investigate the effect of discontinuities in form of holeson energy absorption capacity, some aluminum tubes were cut out to desired length and tested under axial compression loading. Three similar specimens of each condition were prepared and tested to affirm repeatability of the experiments. The tubes were subjected to axial compression loads between two rigid plates of a Zwickuniversal test machine in quasi-static condition with the crosshead speed of 5 mm/min. One specimen was intact and other specimens had two, three or four holes with diameter of 3 mm. According to Fig. 1, the holes were laterally drilled at the mid-height of specimens. This figure shows schematic view of the specimens.

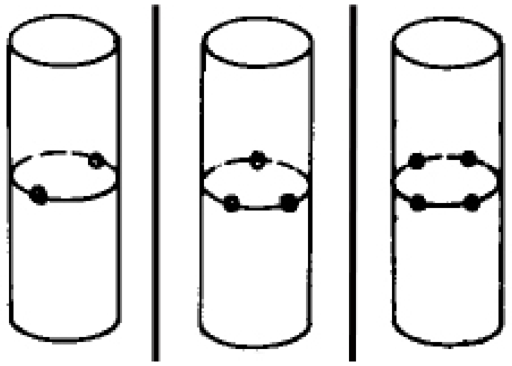

Fig.1. Schematic view of perforated specimens.

Also, Table 1 shows geometrical characteristics of specimens.

Table 1: Geometrical characteristics of intact and perforated specimens.

Specimen No.	Inner diameter (mm)	Thickness (mm)	Length (mm)	Mass (gr)	Number of holes	Holes diameter (mm)
AM-01	25	2	60	23.91	0	–
AM-02	25	2	60	23.6	2	3
AM-03	25	2	60	23.45	3	3
AM-04	25	2	60	23.36	4	3

Mechanical properties of the specimens are neededfor finite element simulation. Simple tensile test has been used to obtain mechanical properties.So, some dumbbell shape specimens of the aluminum tubes were prepared according to standard ASTM E8M. The stress-strain diagram of aluminum alloy is shown in Fig. 2.Table 2 shows material properties of the aluminum tubes.

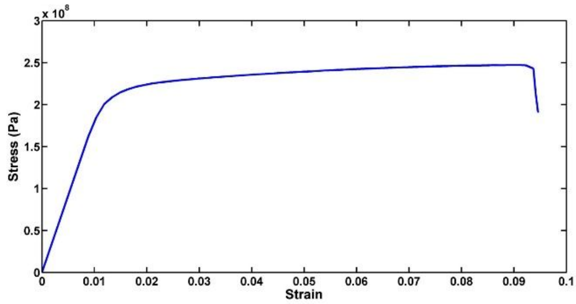

Fig.2. Stress-strain diagram of aluminum alloy.

Table 2: Material properties of aluminum tubes.

Material type	Young's modulus (GPa)	Yield stress (MPa)	Ultimate tensile strength (MPa)
Aluminum alloy	75	205	246.76

III. RESULTS AND DISCUSSION

In order to verify the response of intact and perforated composite-metal tubes under axial loading, four sets of tests were designed and performed. An intact specimen and three perforated specimens with two, three and four holes at the mid-height were tested and their deformation modes and load-displacement diagrams were compared with each other. Also, the experimental results were compared with finite element simulations using ABAQUS package.

When the axial load was applied to an intact specimen, the collapse started by formation of a ring at the bottom of the tube. Then by increment of axial loadtwo other rings were created. So, the load-displacement diagram of intact specimen has three peak loads that each peak load represents formation of a ring. The load-displacement diagrams and the deformation modes of specimen AM-01 obtained by ABAQUS simulations are compared with experimental results, in Fig. 3. Figure 4 compares load-displacement diagram and deformation mode of specimen AM-02 (the specimen with two holes) obtained by ABAQUS simulations and experiments. In the both experimental and numerical results, first ring was formed at the mid-height of tube. After formation of first ring in the experimental test, tube was collapsed from the mid-height and no other ring was formed afterwards. But in the numerical test, after formation of first ring, two other rings were formed at the bottom and top of the tube that caused two peak loads in the load-displacement diagram of ABAQUS simulation. Despite the differences between numerical and experimental deformation modes of specimen AM-02, the load-displacement diagrams of them have good agreement with each other. In the tubes with three and four holes at the mid-height, collapse started with formation of first ring at the mid-height of the tube. This location is the weak point of the tubes due to existence of the holes.

Afterwards by increasing the displacement in these tubes, second and third rings were created below and above the first ring at the mid-height of the tubes. So, existence of holes changes the deformation modes of tubes under axial load. Figures 5 and 6 compare the load-displacement diagrams and deformation modes of specimen AM-03 (the specimen with three holes) and specimen AM-04 (the specimen with four holes), obtained byABAQUS simulations and experimental tests. As seen in these figures, numerical and experimental results are in good agreement for both specimens AM-03 and AM-04.

CONCLUSIONS

In this paper, deformation modes and load-displacement diagrams of intact and perforated metal tubes with two, three and four holes at the mid-height have been investigated under axial compressive loading. The specimens compressed axially between two rigid platesof a Zwickuniversal test machine in quasi-static condition. The experimental results have been compared with the numerical simulations. The finite element analyseswere performed using ABAQUS package. The perforated tubes had approximately similar deformation modes. First peak-loads of load-displacement diagrams appeared when the first ring was formed at the mid-height of tubes. Also it was observed that the experimental and numerical results arein good agreement.

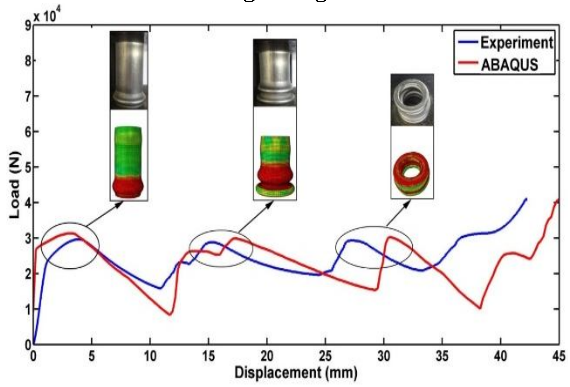

Fig.3. Comparison of load-displacement diagrams and deformation modes of specimen AM-01 obtained by ABAQUS simulation and experimental test.

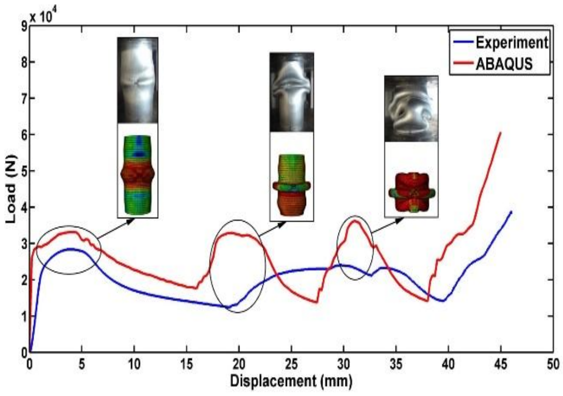

Fig.4. Comparison of load-displacement diagrams and deformation modes of specimen AM-02 obtained by ABAQUS simulation and experimental test.

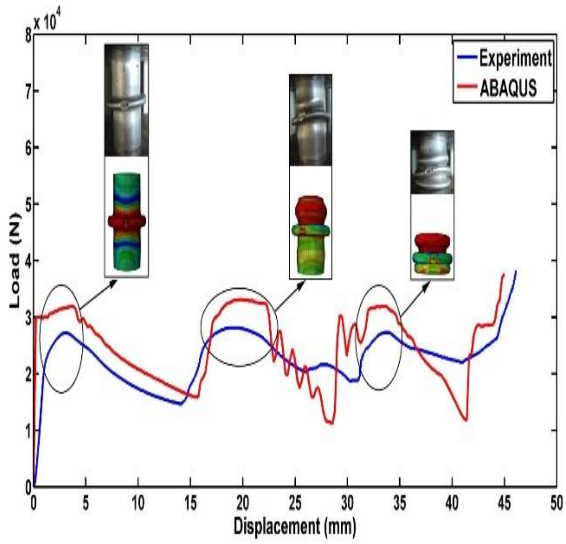

Fig.5. Comparison of load-displacement diagrams and deformation modes of specimen AM-03 obtained by ABAQUS simulation and experimental test.

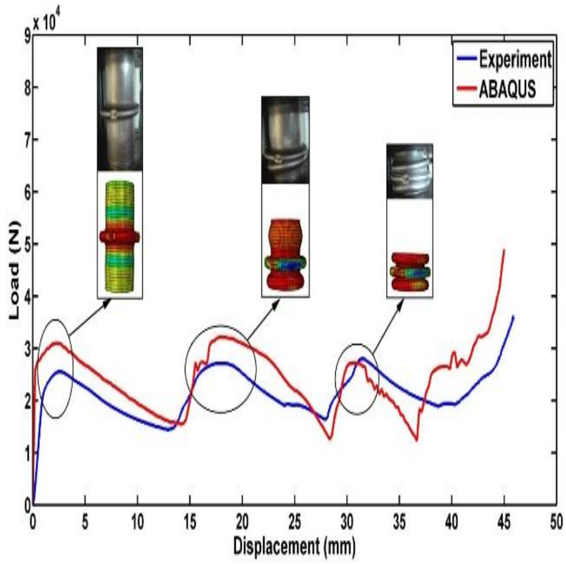

Fig.6. Comparison of load-displacement diagrams and deformation modes of specimen AM-04 obtained by ABAQUS simulation and experimental test.

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