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Experimental and numerical investigation of dynamic plastic behavior of tube with different thickness distribution under axial impact

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ABSTRACT

In this study, the dynamic behavior of uniform thickness, stepped thickness and functionally graded thickness tubes under axial impact are investigated experimentally and numerically. A striking mass has been used to impact tubes. Experimental tests are performed by using gas gun and numerical results are obtained by FE simulation. The effect of thickness distribution on shortening, energy absorption, axial force and buckling shape of tubes are investigated. It is found that a change in thickness distribution of tube can convert the buckling shape from buckling with mild folds to progressive buckling and vice versa. In addition, it is found that stepped thickness tube can be an approximate of functionally graded thickness tube which in this case almost, their behavior is identical. This study reveals that stepped thickness and functionally graded thickness tubes in comparison with uniform thickness tube absorb the same energy with more shortening and less peak load or less mean load; thus, they are better energy absorption specimens. With comparing experimental and numerical results, it is found that there is a good agreement between them.

1. Introduction

Tubes have been becoming increasingly popular in different industries due to their economic, lightness and efficiency. Because of their high energy absorption capacity, long crushing distance and high ratio of energy absorption into weight, one of their most important applications is in the energy absorption systems. Thus, investigation on dynamic behavior of tubes is significant. This paper aims to study the dynamic behavior of uniform thickness, stepped thickness and functionally graded thickness tubes under axial impact.

The dynamic behavior of uniform thickness tubes was investigated experimentally [1], numerically [2–5] and theoretically [6–8] by different researchers. Florence and Goodier [1] experimentally investigated the plastic buckling of tubes subjected to axial impact. In this paper, results of shortening, impact duration, half-wave number and buckling shape of tubes were reported.

Finite element analysis was used to investigate the buckling of tubes subjected to axial impact [2–5]. By studying the effects of material properties, shell geometry, boundary and loading conditions on energy absorption and buckling shape of tubes by Karagiozova and Jones [2], it was found that a large proportion of the initial kinetic energy is absorbed through a shortening mechanism in steel tubes, whereas aluminum tubes absorb the energy with folding mechanism. Karagiozova and Jones [3] explored the influence of approximation of strain hardening modulus on the type of buckling shape (plastic or progressive buckling) and also the effect of axial inertia on initiation and development of buckling shape of tubes under axial impact. In the dynamic plastic buckling "the whole length of a tube wrinkles before the large radial displacements develop [3]", and in the dynamic progressive buckling "the folds in a tube form consecutively [3]". Energy absorption characteristics of tubes under axial loading were studied using nonlinear finite element software LS-DYNA by Tai et al. [4]. This study revealed that with assuming of equal cross sectional for two different materials, the energy absorption of tube made of high strength steel is higher than the energy absorption of tube made of mild steel. With investigation the effect of different parameters such as material properties, geometry and impact velocity on the peak load of the tube which was subjected to axial impact, an approximate equation for estimation of peak load at a relatively low velocity ($v_0 < 40$ (m/s)) was proposed by Chen and Ushijima [5].

Lepik [6] studied the buckling improvement of elastic-plastic tubes under axial impact with Galerkin method. Axial impact of elastic-plastic tubes with linear strain hardening material was studied using a discrete model by Karagiozova and Jones [7]. It was found that inertia

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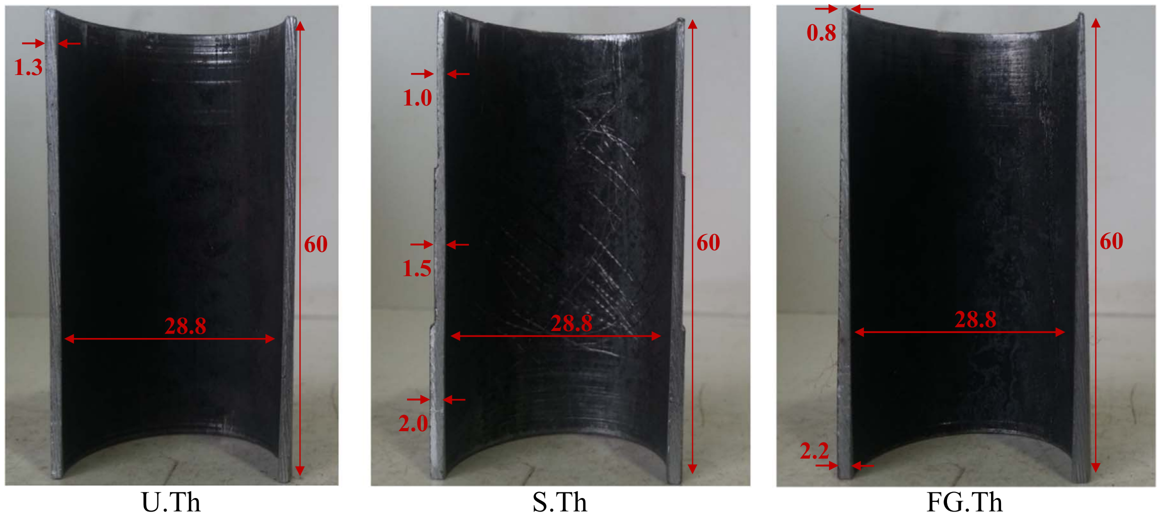

Fig. 1. Thickness, radius and length of U.Th, S.Th and FG.Th tubes (All dimensions are in millimeters (mm)).

properties of striking mass and shell geometry strongly affect the buckling shape. The plastic buckling of tubes under axial impact was investigated theoretically by Wang and Tian [8]. In this study, two types of loading were investigated and the results of shortening, time duration, half-wave number and buckling shape of tubes were reported.

The axial crushing of grooved tubes was investigated by different researchers [9–13]. Mirmohammadsadeghi et al. [11] numerically and experimentally investigated the axial crushing of grooved tubes. In this study, the results of energy absorption, mean crushing load and initial buckling load of grooved tubes with different geometric dimensions were presented. It revealed that the crushing behavior and energy absorption of grooved tubes can be controlled by different groove distances. The effect of low density, low strength polyurethane foam on the energy absorption of circumferentially grooved tubes was investigated analytically and experimentally by Darvizeh et al. [13]. This study revealed that circumferentially grooves prevent Euler buckling. Also, it was found that used foam increase specific energy absorption approximately twice that of the empty tubes.

For improving of energy absorption properties and reduction of initial peak loads, sinusoidal patterns corrugated tubes were used. Buckling modes and energy absorption properties of sinusoidal patterns corrugated tubes under axial impact were investigated by Liu et al. [14]. In addition, the numerical analysis of aluminum foam filled corrugated single and double circular tubes under axial impact was investigated [15].

Moradpour et al. [16] performed a study on axial crushing behavior of aluminum and mild steel circular tubes with circular holes on their surface. The effect of rows number, holes number and hole diameters were investigated on axial crushing behavior of tubes. It was found that in both of aluminum and mild steel circular tubes, symmetrical crushed tubes and favorable performance will be obtained when rows number is 5, holes number in each row is 12 and the diameter of each hole is

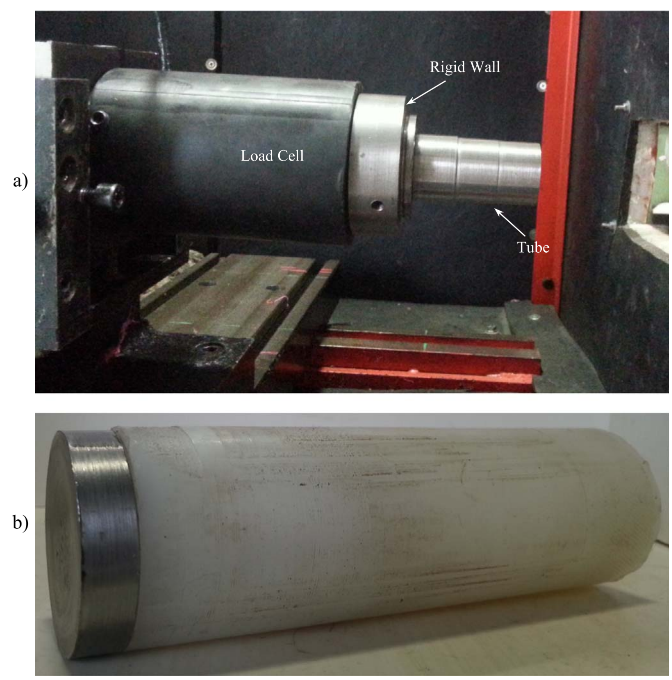

Fig. 3. Stationary tube and striking mass (a) tube on the rigid wall, (b) striking mass.

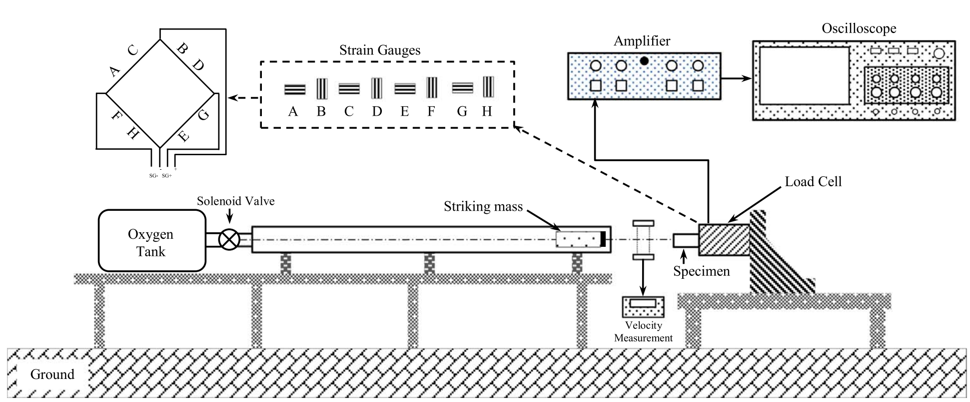

Fig. 2. Schematic diagram of experimental apparatus.