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A numerical investigation of dynamic plastic buckling behaviour of thin-walled cylindrical structures with several geometries

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ABSTRACT

In this study dynamic buckling behaviors of an aluminum alloy cylindrical shell with axial linear variable thickness, discontinuity and conical shaped have been numerically investigated for high velocity impact by means of finite element method. The validation of finite element model was provided by the results of previous studies in literature. Throughout study commerce finite element package program LS-DYNA3D was used and all simulations were fulfilled as explicitly. According to results obtained, the minor changes in the geometry are able to convert the dynamic plastic buckling into dynamic progressive buckling behavior. This study indicates that which of the dynamic buckling or progressive buckling mechanism will be dominant is sensitive to geometrical properties for cylindrical aluminum alloy shells under the high velocity impact.

1. Introduction

The investigation of the dynamic plastic buckling behavior of structural elements such as thin-walled tubes under axial impact loading has become an important research area for last two decades [1]. During buckling the collapse mechanism of the structural element is strongly controlled by the events occurring at the initial stage of impact. For this reason, in recent years, the several studies, which were conducted to determine the effect of wave propagation to the plastic bucking behavior, has more focused on onset of plastic buckling [1–6]. These studies revealed that two buckling mechanisms are active in the initial stages of impact loading. These are dynamic progressive buckling and dynamic plastic buckling mechanisms. Which of these mechanisms will be dominated depends on impact mass and velocity besides the geometric and material properties of the structure. In general, the high speed impact causes dynamic plastic buckling under some special conditions whilst low speed impact leads to dynamic progressive buckling [2]. During the dynamic plastic buckling, a uniform axial deformation along the length of structure occurs, which properly half-wave buckling lobes therefore arise. On the other side, during dynamic progressive buckling, the plastic deformation locally occurs and, no deformation indication associated with half-wave buckling lobes along almost all length of tube is observed just before the collapse starts. In other words, the dynamic progressive buckling can be called as the deformation mechanism that the influence of axial inertia is negligible. Depending on these collapse mechanisms, the crash parameters such as maximum crash force and absorbed energy amount vary.

Karagiozova and Jones [7] studied dynamic behavior of aluminum cylindrical shell elements, subjected to axial impact. They concluded that the buckling response of the material with no strain rate sensitive could be either dynamic plastic buckling or dynamic progressive bucking depending on their inertia properties whereas it could always be dynamic progressive for strain rate sensitive material. In a similar study, Karagiozova et al. [2] founded that the respectively thicker shell elements having larger strain hardening behavior had a tendency to show plastic dynamic buckling and, on the other side, the thinner shell elements having smaller strain hardening behavior had a tendency of dynamic progressive buckling. It was numerically found by Karagiozova and Jones [4] that in the determination of kind of buckling mechanism the material model and tangent modulus were efficient. Wang and Tian [8] investigated the development of local buckling and the interaction between axial wave and buckling mechanism by deriving non-linear dynamic equations in incremental form. They considered the axial wave front as a moving boundary in their analysis. As a result, they observed that the initial buckling occurred in a place near the impacted end of bar in the way of half-wave deformation lobe and, then it developed a post-buckling mode with several half-wave deformation lobes as the axial compression wave propagated forward. To investigate dynamic axial buckling of cylindrical shell element, an experimental study was carried by Ren et al. [9] using Kolsky bar techniques (Split

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Hopkinson Bar Pressure). The experimental results revealed the existence of two critical impact velocities that axisymmetric buckling or non-symmetric buckling modes occurred. These two critical impact velocities were also defined by Ming et al. [10] and Hongwei et al. [11], with similar studies to each other.

Although simplified analytical models are directly applicable, they contribute to the model development and intelligibility of the axial buckling mechanism. For example, Yu et al. [12] provided comments on the response of plastic zone besides interaction of elastic and plastic stress waves by using perfectly plastic material model.

Lepik [13] investigated the buckling of elastic–plastic cylindrical shell considering the influence of stress wave propagating along shell. The dependency of plastic wave velocities on stress state and the direction of wave propagation were shown by both Karagiozova [1] and Karagiozova and Jones [14] with the studies carried out by using thin-walled rectangular tubes.

Wang and Tian [3] studied the dynamic plastic buckling of geometrical imperfect bar under elastic–plastic axial compression wave by obtaining two characteristic equations for two characteristic parameters, provided that the Governing equations had non-zero solutions satisfying boundary and continuity conditions. Two characteristic parameters were the critical load parameter and dynamic-characteristic parameter associated with lateral inertial effects. These two parameters and dynamic buckling modes were exactly calculated from the solution of the characteristic equations.

In this study, the dynamic plastic buckling behaviors for the aluminum alloy cylindrical tubes under the three different geometrical parameters such as axial linear variable thickness, a discontinuity in thickness and conical shaped were numerically investigated. For the cylindrical tube with axial linear variable thickness, the effect of the various t_1/t_2 (t_1, the thickness of impact end and t_2, the thickness of fixed end of tube) ratios to dynamic plastic buckling was researched. For the cylindrical tube with a discontinuity in thickness, the discontinuity was modeled as a thickness difference in impact end (proximal end). Therefore, the effect of such a discontinuity to dynamic plastic buckling was investigated by considering the geometrical intensity. In the last part, for the conical tubes the dynamic plastic buckling effects were examined based on the cone angle. All simulations were explicitly run in LS-DYNA3D finite element trade software. The results of all simulations fulfilled evaluated by means of the graphs composed from the curves regarding both circumferential and axial strain distributions at the mid-surface along tube length besides the deformation modes.

2. Numerical model and validation

2.1. Geometry and material properties

The geometry and material properties considered in this study were selected in parallel to the model used by Karagiozova [2] due to compatibility and comparison. For the uniform thickness cylindrical tube, the geometry and material properties are given in Fig. 1 and Table 1. In the table, the L, E, E_h, σ_o and ρ show the tube length, elasticity modulus, strain hardening modulus (tangent modulus), yield stress and material density, respectively.

In the literature, the experimental studies, which were fulfilled over the cylindrical shell elements made of elastic–plastic materials with high strain hardening, showed that an axisymmetric buckling generally emerged in cases of the ratio of inner diameter to thickness ($2r/t$) between 10 and 40 values [15,16]. Thus, it can be easily understood that the selected geometric dimensions for tube (Table 1) guarantee the formation of axisymmetric buckling during axial impact. In this context, using this behavior, the finite element models were composed in the form of axisymmetric.

For aluminum alloy, it was assumed that it exhibits isotropic hardening behavior and also, has a linear hardening as shown in Fig. 1b. The strain rate was not taken into consideration throughout this study. Fig. 2 shows the axisymmetric shell models in the schematic manner, on which are parametrically studied. In the figure, the geometric parameters, whose effects to dynamic plastic buckling to be investigated, can be clearly seen. Also, for all shell

Table 1
The dimensions and material constants related to uniform thickness cylinder.

r, (mm)	t, (mm)	L, (mm)	E, (GPa)	E_h, (MPa)	σ_o, (MPa)	P, (kgm^{-3})
11.875	1.65	106,68	72.4	542.6	295	2685

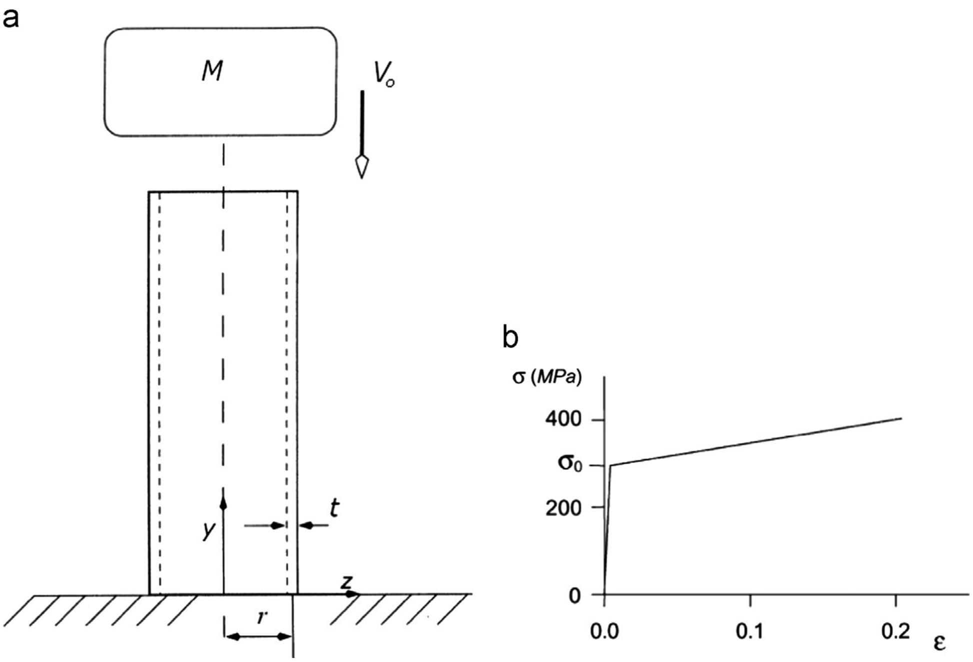

Fig. 1. The specifications of the model; (a) crash model, and (b) the true stress–strain curve of aluminum alloy [2].