Available online at www.sciencedirect.com
ScienceDirect
International Journal of Impact Engineering 34 (2007) 708–720
INTERNATIONAL JOURNAL OF IMPACT ENGINEERING
www.elsevier.com/locate/ijimpeng

Experimental and numerical studies of impact axial compression of thin-walled conical shells

N.K. Gupta*, Venkatesh

Department of Applied Mechanics, Indian Institute of Technology, Hauz Khas, New Delhi 110016, India

Received 31 July 2005; received in revised form 21 February 2006; accepted 25 February 2006
Available online 12 May 2006

Abstract

Impact axial compression experiments on aluminium conical shells of semi-apical angles varying from 6.84° to 65.35° and the mean diameter to thickness (D/t) ratios varying from 22.32 to 79.29 were conducted on a gravity drop hammer set-up. Typical histories of their deformation, variation of shell thickness along the length, load–deformation curves, energy absorbing capacity, and mean collapse loads obtained from the experiments are presented. Influence of the semi-apical angles, D/t ratios, thickness, depth, and top and bottom diameter values of the shell on their modes of collapse and energy absorption capacities are discussed. The shells are numerically simulated and analysed in detail by using the finite element code FORGE2. The material was modelled as rigid-viscoplastic. The experimental and computed results are compared. Typical contours of equivalent strain, equivalent strain rate, different stress components and velocity distribution are presented. The impact response of the shells is compared with their static response.

Keywords: Conical shells; Semi-apical angle; D/t ratios; Numerical simulation; Mode of deformation

1. Introduction

Postlethwaite and Mills [1] performed the axial crushing tests on conical shells of semi-apical angles of 5–20° and studied their energy absorption capacity. Analysis and experimental results were presented on the axisymmetric buckling of stainless steel and aluminium-truncated conical shells of semi-apical angles of 5° by Ramsey [2]. The analysis of a conical shell subjected to a centrally applied point load has been reported by De Oliveria and Wierzbicki [3] as part of their studies on crushing analysis of rotationally symmetric plastic shells. They assumed that the conical shell deforms as an inverted conical shell with a toroidal surface at the top due to a point load at the centre. The semi-apical cone angles of the inverted cone are assumed to be same as that of the shell considered for the analysis. They have proposed the expressions for the prediction of load–deformation behaviour and for the radius of the toroidal surface at the top. Mamalis and Johnson [4] have studied the axial compression of aluminium conical frusta of semi-apical cone angles 5–10° under quasi-static loading. The load–deformation behaviour, initial peak load, mean collapse load and various modes of

*Corresponding author. Tel.: +91 11 26591178; fax: +91 11 26581119.
E-mail address: nkgupta@am.iitd.ernet.in (N.K. Gupta).

0734-743X/$ - see front matter
doi:10.1016/j.ijimpeng.2006.02.008

collapse have been reported from the experimental observations. The initial peak load and the mean collapse load is found to increase with increase in slenderness ratio (t/d) of the conical frusta. They observed that in all the cases, the collapse is initiated with an axisymmetric ring and then it develops into non-symmetric diamond pattern. Mamalis et al. [5] have also performed the axial compression on steel thin-walled frusta of semi-apical angles 5° and 10° at elevated strain rates. The load–deformation behaviour and the collapse modes in this case are similar to those reported in [4]. Mamalis et al. [6] proposed an analytical model for the frusta collapsing in concertina mode, in which the effects of slenderness ratio (t/d) and semi-apical angles on the modes of collapse, initial peak load and mean collapse load have been studied. The crumpling in the concertina mode of PVC thin-walled conical frusta of semi-apical cone angle of 14.35° under axial compression has also been reported. It is reported in [6] that the mode of collapse is "concertina" in case of high t/d; otherwise the progressive collapse is in diamond mode. The results from the proposed analytical model have been compared with the experimental results of PVC frusta reported in [4,5] and these showed good agreement. Mamalis et al. [7] later reported the extensional axial collapse of thin PVC conical shells of semi-apical angles 5°, 10° and 14.35°. The mode of collapse was found to be same as that reported in [4,5]. They have also proposed an analytical model for the prediction of the mean collapse load for conical shells collapsing in diamond mode, by using the concepts of stationary and inclined rolling plastic hinges of constant radius observed in experiments. Mamalis et al. [8] have also proposed an analytical model for the progressive extensible plastic collapse of thin-walled conical shells collapsing in diamond mode after the formation of an initial ring. For the experimental validation of the theoretical model, PVC conical frusta, cylinders and cones were tested in axial compression. The load–deformation behaviour obtained from experiments is found to match well with the predictions of the analytical model. Gupta et al. [9] reported quasi-static axial compression of conical frusta of large semi-apical angles. The various modes of collapse and load–deformation curves obtained from experiments are presented and an analytical model is proposed for the prediction of load–compression and energy–compression curves. Results obtained from the analytical model match well with the experiments. Gupta et al. [10] applied the finite element code FORGE2 to simulate the axial compression of the tubes of round cross-sections, and obtained the deformed shape and crushing load at different stages of the process. Previous studies seem to have considered the shells of relatively small semi-apical angles, i.e., less than 15°, and also experiments available on impact axial compression are very few. A number of analytical models have been proposed over the years, but the complexity of many impact events often limits the general use of closed-form analytical solutions. It is imperative to use numerical methods to solve this class of problems.

The present paper deals with an experimental and numerical study of the collapse of aluminium conical shells, of semi-apical angles varying over a wide range from 6.84° to 65.35° and D/t values varying from 22.32 to 79.29, when subjected to the impact of a drop hammer. Typical histories of their deformation, variation of shell thickness along the length, load–deformation curves, energy absorbing capacity, and mean collapse loads obtained from the experiments are presented. Influence of the semi-apical angles, D/t ratios, thickness, depth, and top and bottom diameters of the shell on their modes of collapse and energy absorption capacities are discussed. The shells are numerically simulated and analysed in detail by using the finite element code FORGE2. The material was modelled as rigid-viscoplastic. The experimental and computed results are compared. Typical contours of equivalent strain, equivalent strain rate, different stress components and velocity distribution are presented. These impact results have been compared with the corresponding static response of the shells.

2. Experiments

Aluminium sheets of thicknesses 1, 1.5, 2, and 2.5 mm were commercially obtained, and the conical shells required for the present experimental work were made from these sheets by the process of spinning [9]. All the shells were annealed by soaking them at 300 °C in the furnace for 1 h, and allowing them to cool in the furnace for 24 h.

The specimens employed can be divided in four sets, viz, shells of (i) different semi-apical angles and constant thickness; (ii) different thickness and constant semi-apical angles; (iii) same semi-apical angles, different depths and constant bottom diameter; and (iv) same semi-apical angles, different depths and constant top diameter. Modes of collapse and energy absorbing capacity of the shells and influence thereon