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A study on mechanics of collapse of combined geometry metallic shells

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ABSTRACT

The combinations of shell structures give discontinuity to their load path and hence play major role in force-displacement behaviour of shell structures subjected to different types of loadings. In this paper thin aluminium shells having combination of shell geometries are tested to study their modes of collapse and associated force-displacement variations occurred during their large plastic deformation. The study is conducted on four categories of shell structures which are obtained through the combination of simple cylinder, frusta and hemisphere. The four categories are; Category 1 is simple cylinder as control shape, Category 2 is Cylinder with frusta, Category 3 is Cylinder with frusta with hemisphere and Category 4 is Cylinder with two frusta. The large plastic deformation was obtained by axially compressing these combined geometry shells between two flat plates experimentally using Instron machine and computationally using LSDYNA Finite Element code. The combined geometry shells behaviour during their large plastic deformation was understood with the help of force-displacement graphs for different geometrical changes. The associated change in mode of collapse is also presented and discussed. It was found that change in geometry influences large plastic deformation process and as a result force-displacement variation and associated modes of collapse.

1. Introduction

The wide varieties of shell structures are used for day-to-day life ranging from a miraculous big architecture to small structure. Shell structures are also widely used in automotive, aerospace, heavy engineering, armoured and in construction industry due to their capability to carry large loads while keeping the lower weight and thereby lesser cost. Thin shells of various shapes have been used in many structural crashworthiness applications due to their energy absorbing capacity in the plastic deformation. Shell structures response is very complex to different types of loadings. Highly transient like impact and quasi-static loading makes the shell structure response more complex. The participating parameters to responses are shape, thickness, diameter, diameter to thickness ratio of the shells and the physical state of the shell. Conical shells are used over a wide range; especially in the applications of aerospace and armaments as the nose cones of missiles and aircraft. Understanding of collapse process of combined geometry shell structures can be employed in investigation of ship collision.

In past, many studies were carried out by different researchers on shell structures subjected to different types of loadings including quasi-static, impact and ship collision [1–19]. Different tools and techniques including finite element analysis were employed to investigate the collapse of shell structures. Nia and Hamedani [1] experimentally and numerically studied the deformations and energy absorption capacity of thin walled tubes with various sections (circular, square, rectangular, hexagonal, triangular, pyramidal and conical). The tubes of same volume, height, average sectional area, thickness and material were subjected to axial quasi static loading. The results of simulations were in good agreement with the experimental data. They found that the section geometry considerably affects the energy absorption. The circular tube has the maximum energy absorption capacity and average force among all investigated sections.

Gupta and Gupta [2] performed axial compression on aluminium spherical shells of R/t values ranging from 25 to 43 under central loading, to identify their modes of collapse and to study the associated energy absorption capacity. In experiments all the spherical shells were found to collapse due to formation of an axisymmetric inward dimple associated with a rolling plastic hinge. A Finite Element computational model of development of the axisymmetric mode of collapse was also presented. Experimental and computed results of the deformed shapes and their corresponding load–compression and energy–compression curves were presented and compared to validate the computational model. The computed variations of the different strains and stresses were also studied. On the basis of the computational results mechanics of the development of the axisymmetric inward dimple mode of collapse was presented, analyzed and discussed. Gupta and Gupta [3] also

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performed experimental and theoretical studies on buckling of thin and thick spherical shells having R/t ratio between 15 and 50. The samples were compressed between two parallel flat plates. They found that the relatively thick shells deform axisymmetrically and major load is resisted by the rolling plastic hinges. When the thickness is reduced considerably, the inward dimpling is followed by non-symmetric multiple number of lobes which were caused by the formation of stationary hinges. The collapse behaviour of aluminium thin conical shells having combined geometry with spherical cap at top under both quasi-static and impact loading was studied by Gupta et al. [4]. Three dimensional numerical simulations were carried out for all the samples using LS-DYNA software. The obtained results were compared with the experiments. They found that the relatively thick shells deform axi symmetrically and the major load is resisted by the rolling plastic hinges. When the thickness is reduced considerably, the inward dimpling is followed by multiple numbers of nonsymmetrical lobes which are caused by the formation of stationary hinges. Gupta [5] also experimentally and computationally studied the collapse behaviour of the aluminium thin walled conical shells having variation in wall thickness along their height. The samples were axially compressed between two parallel platens. The samples were having semi-apical angles between 7 and 9 with D/t values ranging between 26 and 49. All the conical shells were found to collapse with the formation of an axisymmetric mode of collapse due to development of the associated plastic hinges. It was also found that the wall thickness is one of the geometric parameters responsible for the initiation of mode of collapse.

Alghamdi [6] reviewed the common shapes of collapsible energy absorbers and the different modes of deformation. Common shape included circular tubes, square tubes, frusta, struts, honeycombs, and sandwich plates. Common modes of deformation for circular tubes included axial crushing, lateral indentation, lateral flattening, inversion and splitting. Experimental investigation on circular frusta was studied by Aljawi et al. [7]. In his experiment the effects of wall thickness, frustum angle and material on inversion were investigated. Finite element (FE) modelling and analysis of the deformation modes were also done. The samples were manufactured by manual spinning process of aluminium; few were made of mild steel and nylon plastic. These frusta were inverted with quasi-static loading by the use of a 10-ton Instron universal testing machine (UTM), at a constant crosshead speed of 10 mm/min. Other samples were inverted using a free-falling drop hammer facility (DHF) of 6.0 m maximum drop height, and a free-falling hammerhead of up to 6.9 kg. It was verified that the average load increases, nearly linearly, with increasing angle of frustum and thickness. For high values of height 'h' to thickness 't' ratio, specific energy of deformation was found less than that for lower values of h/t. Finite Element predictions of the deformation process were generally in good agreement with the experimental findings. Reid [8] used plastic deformation mechanism in axially compressed metal tubes as impact energy absorbers. The tubes collapsed in axisymmetric and non-axisymmetric modes. The characteristics of a number of metal components proposed as impact energy absorbers were reviewed. Progressive buckling, inversion and splitting were discussed and areas for future work identified. The buckling of thin-walled square section tubes filled with polyurethane foam was also described. Gupta and Gupta [9] also performed experimental and computational study of collapse of the aluminium metallic shells having combined tube–cone geometry subjected to axial compression between two parallel plates. Samples were having top one third lengths as tube and remaining bottom two third length as truncated cone having semi-apical angle about 23°. The influence of the shell thickness and cone angle on its mode of deformation was studied. It was found that the collapse process of all samples was initiated by development of an axisymmetric fold followed by a plastic zone of increasing length. Computationally effect of semi-apical angle was studied and it was found that mode of collapse governs by the semi-apical angle. Collapse process of thin walled single geometry frusta were also studied to predict their energy absorbing capacity [10–13]. Experiments were performed to develop the analytical model of collapse process to obtain load-compression behaviour. Large deformation of ship components occurs during collision and impact and has been studied by some of the researchers [14–19] in detail in recent past. The collapse study of combined geometry shells can also be employed in such complicated structural applications.

Good numbers of studies have been made on single geometry shell structures considering continuity in geometry but only a few investigations are available which focus on development of mode of collapse of shell structures having combination of different shapes. The mode of collapse of shell structures is dependent on the combination of geometrical shapes also. Due to the change in the load path during compression of such samples their collapse process becomes very complicated and remains dependent on the process parameters such as wall thickness, geometry, R/t ratio. Further; the complexity of deformation process often limits the general use of closed-form analytical solutions. Therefore, it is essential to use advance numerical methods to study this class of problems. Here in this paper three dimensional computational models of the compression process of different samples having combined geometry have been developed using LS-DYNA commercial code to understand their collapse mechanism. Three types of combined geometry shells; Cylinder with frusta, Cylinder with frusta with hemisphere and Cylinder with two frusta are compressed to investigate their mode of collapse with associated force-displacement and energy-displacement variations. The mechanics of collapse of such shell samples is studied and discussed using experimental observations and FE simulations and reported here. Effect of combination of geometry on deformation behaviour and energy absorbing capacity are the main parameters investigated in the paper.

2. Experiments

The experimental part of the investigation comprises of preparing test samples, determining the sample material parameters and performing the compression tests. The deformation behaviour was captured in force and displacement form and associated mode of collapse.

2.1. Samples preparation

Four types of aluminium samples including cylinder closed at one end and three types of combined geometry shell samples were prepared and shown in Fig. 1. These can be specified as category 1–4 as shown in Fig. 1. The geometrical details of all category samples are given in Fig. 1(b) and Table 1. Minimum three samples of each type were tested to check the repeatability. Sample of Category 1 is a simple cylinder and taken as control shape. Sample of Category 2 is combination of cylinder with frusta by providing cylinder at top and frusta at bottom. Sample of Category 3 is combination of cylinder with frusta with hemisphere by providing cylinder at top and hemisphere at bottom with frusta at middle. Sample of Category 4 is combination of Cylinder with two frusta by providing cylinder at top and two frusta at bottom and middle. All the samples were closed at top.

The experiments were conducted on four categories of samples. Photographic view and typical details are shown in Fig. 1(a) and (b) respectively. The first category of geometry is simple cylinder. In second category, a frusta shape is made at the bottom, to the first category. The top average diameter was 68 mm. The sample height ranged from 140 mm to 205 mm. Commercial available aluminium plates of thickness 1.5 mm were procured from the market to prepare the samples of different categories. The wall thicknesses of all samples were about 1.2–1.5 mm. The variation in wall thickness at different locations was observed due to their preparation using spinning process. Typically variation in wall thickness is shown in Fig. 1(b) for one specimen of category 1 having semi-apical angle less than 15°. The second category samples were made up of frusta having semi-apical angle more than 15° and less than 15°. As a result two types of samples were tested