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The plastic instability of clamped-clamped conical thin-walled pipe reducers

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ABSTRACT

The analytical study for plastic deformation of clamped–clamped conical reducer pipe under internal pressure does not deduce a closed form expression for the pressure at plastic instability. The presented study employs finite element analysis (FEA) to estimate the internal pressure at instability for conical reducers made of different materials and having different dimensional configurations. Forty dimensional configurations, classified as medium type, and five types of materials have been included in the analysis using ABAQUS package. A correlation expression is derived by nonlinear regression to predict the instability pressure. The proposed expression is verified for other dimensional configurations out of the above used forty models and for other materials. Experiments have been conducted by pressurizing conical clamped-clamped reducers until bursting in order to verify the finite element models. Comparison of instability pressures, strains and deflections at specific points along the conical surface shows satisfactory agreement between analysis and experiments.

1. Introduction

Conical shells are commonly used in many industrial applications; pressure vessels, tanks, and reducers in piping systems. Flanged conical reducers are preferred as they provide an easy way for replacement, periodic inspection, shipping and maintenance.

Solution for the elastic response of very long conical shells has been discussed in many text books and publications, thus giving meridional and circumferential stress components of closed conical shells under internal pressure. Timoshenko [1] has presented general governing equations for the stresses generated in shells of revolution with rigid ends as a result of internal pressure including conical and cylindrical shells. Cui, Pei and Zhang [2] introduced several classes of solutions - using Thomson and Hankal functions - for the higher order differential equation that have been deduced for conical shells with clamped ends. However, their analysis has not resulted in a closed form expressions which are handy enough to be used by engineers. Finite element analysis (FEA) was applied to solve the problem of clamped-clamped conical shells under internal pressure by Sundarasivarao and Ganesan [3]. They have considered the elastic behavior of cones having half apex angles (α), 30°, 45° and 60°. It has been shown that the meridional stress is maximum at the ends but the maximum hoop stress exists at the mid span of short cones and near the large end for long ones.

Several researchers have studied the limit loads of conical shells made of rigid-perfectly plastic material obeying Tresca's yield surface. Limit analysis of conical shells subjected to lateral distributed loading together with internal pressure have been investigated respectively by Hodge [4] and Kuech and Lee [5]. Diamond yield surface is also adopted by Jones and Ich [6] to analyze the conical shallow shell. Plastic Instability as a failure mode of internally pressurized closed conical shells without end constraints has been studied by Adibi [7]. Analytical expressions have been derived to predict the instability pressure similar to that of cylindrical shells.

The previous literature review indicates that it is not feasible to solve analytically the problem of plastic instability of a pressurized cylindrical containers or conical reducers that contain discontinuity because of its geometry or end constraints. Finite element analysis (FEA) may be thus devoted to solve such problems. Xue et al. [8] predicted the burst pressure using ANSYS software [9] for a cylindrical shell with a slight thickness variation and a cylindrical shell with a small hole. The study has shown that Barlow equation presented by Moser [10] is a good predictor of the burst pressure of cylindrical shells. FEA was also used by Wang et al. [11] to determine the burst pressure and the fracture location of pressurized cylinders with hillside nozzle. The analysis has been verified by

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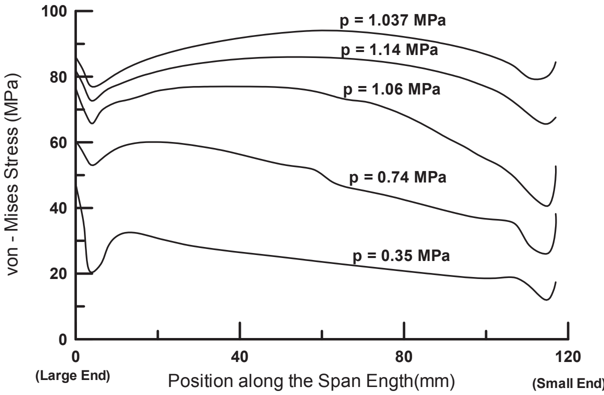

Fig. 1. von-Mises Stress distribution along the span length for a conical reducer during running the static Ricks step of ABAQUS. (a = 30 mm, b = 70 mm, t = 07 mm and $\alpha = 20°$. (The material is aluminum.)

carrying out experimental burst tests. Xue et al. [12] have established a parametric FEA study for cylindrical shell intersections and the burst pressure has been detected using the "arc length method" i.e. "Ricks Step method". A correlation expression for the bursting pressure has been developed by modeling multiple dimensional configurations that cover most practical cases. The analysis has shown agreement with the experimental results of Wang et al. [11].

In this paper, clamped-clamped conical shells (as conical pipe reducers with flanged ends) are analyzed using FEA software ABAQUS [13]. The local bending generated at the flanged locations causes stress discontinuity and affects the failure of the reducer. Plastic instability pressure is determined for forty dimensional configurations and the results are employed in a parametric study. An expression for the instability pressure is deduced by correlating the pressure at instability with the geometrical configuration and the material parameters. The results of FEA are verified experimentally by pressurizing conical reducers - made of different metallic alloys - up to bursting.

2. Finite element model

The finite element software ABAQUS [13] is used in modeling and analyzing the problem. The studied model is a cone with fixed boundary conditions at the flanged ends. The diameters at ends, cone thickness and length/or the half apex angle are the main dimensions of the cone. Two nodes axi-symmetric shell elements are chosen for modeling. Static, Ricks step in ABAQUS is employed to indicate the pressure at instability.

2.1. Failure criterion

According to references [8,11,12], the instant of plastic instability in pressurized axi-symmetric shells takes place when the slope of pressure-strain curve vanishes and hence the pressure attains its maximum value. After this instant, the contained volume increases and the pressure decreases and the slope of pressure-strain curve drops till the occurrence of fracture.

Fig. 1 resulting from FEA illustrates the variation of von-Mises stress values along the length of a conical reducer at different pressure values. The reducer in this model is made of aluminum and having a span length of 118 mm, thickness of 0.7 mm, half apex angel of 20° and the radii of the large and the small ends are 70 mm and 30 mm respectively. The origin of length measurement exists at the large end. The figure shows that Mises stresses are higher with increasing pressure till it reaches to a value of 1.14 MPa which represents its pressure at instability. After this point, the stresses are still increasing while pressure begins to drop (reduces to p = 1.037 MPa) due to further contained volume increase associated with wall thinning. Fig. 2 reveals the effective plastic strain

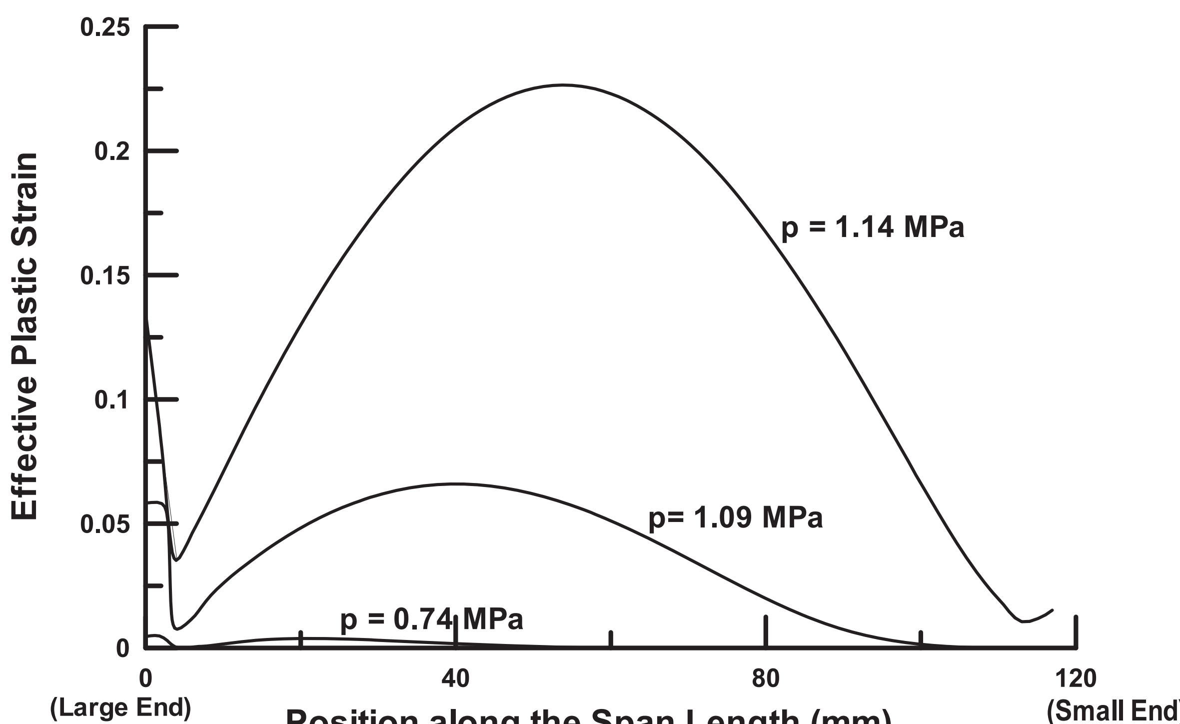

Fig. 2. Distribution of the effective plastic strain along the span length of a conical reducer at different pressures. (a = 30 mm, b = 70 mm, t = 07 mm and $\alpha = 20°$. (The material is aluminum.)