

A Short Note on the Stability of Thin Aluminium Tube: A Theoretical, FEA and Experimental Approach

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ABSTRACT: Thin walled tubes, pipes and cylinders are widely used in all most all the industries. In chemical and metallurgical and processing industry the pipes and tubes are subjected to various external pressure conditions. Stability of these pipes is an important step for the engineers before designing the flow sheets. In this note aluminum tubes of 32mm diameter and 600 mm length and 0.6mm and 1.6mm thick, have been studied for the stability which had yielded based on theoretical values as 32.13; 65.71kg/cm², and by FEA method as 30.15; 65.55 kg/cm². These results are evaluated comparing with experimental studies as 22 and >50 kg/cm². The variation is attributed to inhomogeneity of the tube material and defects in manufacturing processes.

KEYWORDS: External pressure, Aluminium tubes, Buckling phenomenon, Finite Element Analysis, Pressure vessel.

I. INTRODUCTION

When uniform external pressure is applied to a tube, pipe or cylinder, during the initial stages of loading, the cross-section uniformly shrinks, maintains its circular shape up to a critical pressure. Nevertheless, at a certain stage, they collapse and deformation of the cross-section occurs abruptly in the form of ovalization. Any such collapse failure normally will develop into a propagating collapse failure, since the critical collapse pressure of a circular cylinder is several times larger than the propagation pressure. The external collapse pressure of very thin aluminium tubes is governed by classical elastic buckling formula; however, for thicker tubes more involved elasto-plastic considerations have to be taken into account. There are many factors that have some degree of influence on the external pressure that produce the collapse of a aluminium tube, among them: a) slenderness ratio (outside diameter/length) (D/l ratio), b) yield stress of the tube, c) shape of the tube sections (outside diameter shape and thickness distribution), d) residual stresses locked in the tube, and e) localized imperfections introduced either in the tubes production, in the tubes handling or due to localized wear. In the present work it is shown that external pressure on a thin aluminium tubes is calculated theoretically and Finite Element Analysis method that corroborates with experimentally determined values well within the permissible errors.

II. PREVIOUS WORK

Research work on cylindrical tube buckling under external pressure dates back to the middle of nineteenth century. In an early study, using small deflection theory, studied the stability of a thin circular elastic ring under external hydrostatic pressure.^{1,2,3,4,5,6,7} In particular, the constitutional law is taken into account assuming isotropic elastic behaviour, as well as the basic kinematics formulae are used in which the total deformation is formed as the sum of the membrane and bending strain. When a free pipe is subjected to uniform external pressure, the tangential compressive stress will be developed in pipe and increases with the external pressure. When the tangential compressive stress

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reaches a limit value, the pipe is not able to maintain its initial circular shape, and distorts unstably in buckling. For a finite long free pipe with radius R , thickness t , the buckling has been discussed^{8,9}

III. MATERIALS AND METHODS

Numerous materials are available in the market in the form of tubes, rectangular bars, channels of various sizes and shapes. Importantly, they include Copper, Brass, Bronze, Aluminium, Aluminium alloys, Stainless Steel, PVC (Poly Vinyl Chloride), Acrylic, FRP (Fiber Reinforced Plastic), GRP (Glass Reinforced Plastic) etc. They are available in various lengths, diameters and thickness. For the selection of the materials basic requirements for the tubes include a) corrosion resistance, b) easy to weld, c) durability, d) non-magnetic, e) tensile strength and f) oxidation resistance. In the present work aluminium tube is being tested for the stability under various external pressure conditions.

Properties of Aluminium: Pure aluminium doesn't have a high tensile strength. However, the addition of alloying elements like manganese, silicon, copper and magnesium can increase the strength properties of aluminium and produce an alloy with properties tailored to particular applications. Aluminium's superior malleability is essential for extrusion. With the metal either hot or cold, this property is also exploited in the rolling of strips and foils, as well as in bending and other forming operations. Aluminium is well suited to cold environments. It has the advantage over steel in that its' tensile strength increases with decreasing temperature while retaining its toughness. Steel on the other hand becomes brittle at low temperatures. Aluminium can be severely deformed without failure. This allows aluminium to be formed by rolling, extruding, drawing, machining and other mechanical processes. It can also be cast to a high tolerance. When exposed to air, a layer of aluminium oxide forms almost instantaneously on the surface of aluminium. This layer has excellent resistance to corrosion. It is fairly resistant to most acids but less resistant to alkalis. Aluminium is a non-magnetic (actually paramagnetic) material. To avoid interference of magnetic fields aluminium is often used in magnet X-ray devices. The magnitudes of Young's modulus of elasticity and Poisson's ratio are 10.0×10^6 psi and 0.33 respectively. It has a Yield Strength of 241 MPa.

IV. THEORETICAL CALCULATIONS

Numbers of theoretical expressions are suggested by various workers for calculating the limits of external pressure on thin tubes and cylinders. A simplified expression is suggested by Barlow. As external pressure exceeds internal pressure, the tubes and pipes tend to collapse. For the present study it is considered that the external pressure limit is the maximum value obtained based on Barlow's formula that calculates the internal pressure. Barlow's formula is merely a tool for burst estimation or prediction under ideal conditions at room temperature. Working pressures or allowable pressures are arrived at using a safety factor (SF) to reduce the pressure from a level where bursting failure is very likely, to where an acceptable level of risk is achieved. Many engineers will use the ultimate tensile strength (UTS) to calculate bursting pressure estimation and use the yield strength (YS) and a safety factor (SF) when arriving at working pressure estimation. Using the yield strength and safety factor (SF=1) will calculate an approximate theoretical pressure at which the tubing will begin to plastically deform.

Barlow's Formula:

$$P = \frac{2 S T}{OD (SF)} \quad (1)$$

Where,

P = Pressure (psi), T = Wall thickness (inch), OD = Outside Diameter (inch), SF = Safety factor (generally 1.5 – 10, 1 for collapsing pressure), S = Material strength (psi).

Theoretical calculations on the aluminium pipes has been done and the details are described elsewhere^{10,11}. The data is presented table 1.

International Journal of Innovative Research in Science, Engineering and Technology

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V. FINITE ELEMENT ANALYSIS

The Finite Element Analysis (FEA) has become very important to solve engineering problems, allowing solving cases that until recent time were virtually impossible by traditional mathematical methods. This required to prototype, test them and make improvements iteratively, what brought high costs both financially and in time of development. The FEA provides a mathematical model for calculating the real system, easier and cheaper to change than a prototype. However, it remains as an approximate calculating method due to the basic assumptions of the method. Therefore, prototypes are still necessary, but in lower quantity, since the first one can be well approximated to the optimum design. The finite element method as mathematical formulation is relatively new; although its basic structure has been known for quite a long time, in recent years a great development has been achieved due to the advances in computer technology. These computer advances have allowed the user applying many programs that can perform finite element calculations. Furthermore, FEA allows detailed visualization of where structures bend or twist, and indicates the distribution of stresses and displacements.

VI. FINITE ELEMENT ANALYSIS MODELLING WITH ANSYS

ANSYS is a general purpose finite element modeling package for solving different mechanical problems numerically, such as static/dynamic structural analysis, heat transfer and fluid problems, as well as acoustic and electro-magnetic problems. ANSYS is divided into three steps when analyzing and solving a problem with the finite element method:

1. Preprocessing stage: It is basically defining the problem that includes a) defining the key-points, nodes, lines, areas, volumes; b) defining element type and geometric properties and c) preparing a meshing etc.
2. Solution stage: It includes specifying the steps before solving the problem such as types of analysis to be followed either a static or a modal or a buckling, In this stage, types of load such as point load or pressure and their direction and finally the constraints associated with have to be specified.
3. Post-processing stage: In this stage results are viewed such as a) lists of nodal displacements and displacement plots, b) element forces and moments and c) stress contour diagrams.

Finite Element Analysis (FEA) was carried out on aluminium tubes with varying d/t ratio and tube thicknesses. The result of interest in this analysis was how much external pressure a tube can withstand before bursting. The linear buckling analysis was performed on all the types of pipes. Several tubes with an inner diameter of 30 mm and thickness of 0.6 mm and 1.6 mm were made using a 3D shell model and extruded to a depth of 600 mm. Elastic properties were added as per the different materials, and the material type was set accordingly.

Loads, Boundary Conditions and Mesh:

Linear quadrilateral S4R elements were used when meshing the tube. The element size was chosen to be 2 mm.

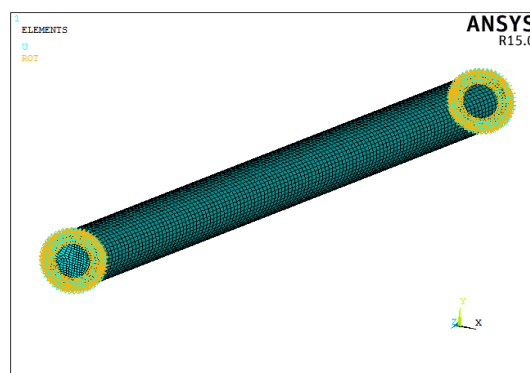


Fig 1. Boundary Conditions

International Journal of Innovative Research in Science, Engineering and Technology

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Website: www.ijirset.com

Vol. 6, Issue 9, September 2017

In figure 1 both the ends of the pipe are closed and fixed in all directions. These boundary conditions are common for the thicknesses of 0.6 mm and 1.6 mm respectively. As part of the scope of this paper, the tube was to be tested against external pressure. A pressure of 10 MPa was applied at the top surface of the tube, compressing it. This pressure was used for the linear buckling analysis. This pressure was gradually increased till the pipe buckles. The pressure at which the buckling occurs is recorded for different materials. The FEA generated model is shown in figure 2. The data is presented in the table 1.

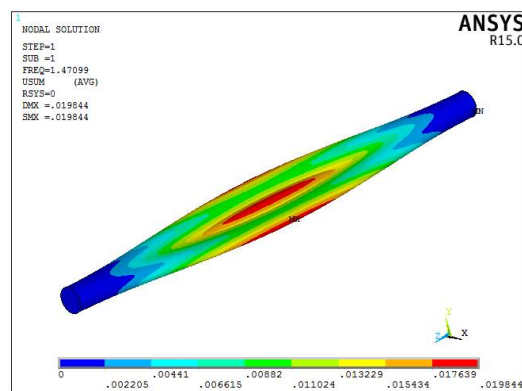


Fig. 2 Aluminium Pipe with 0.6 mm Thickness after Applying External Pressure

VII. EQUIPMENT USED

Indigenously designed pressure vessel by the Atomic Minerals Directorate for Exploration and Research (AMD), Department of Atomic Energy, Hyderabad, is used for the present study. In the test apparatus the full specimen length is exposed to the test pressure. It does not impose radial or axial restraint or axial load on the specimen, either mechanically or hydraulically, and does not apply pressure to the inside surface of the specimen. To ensure that the specimen is not axially restrained during testing, the initial clearance between the end of the specimen and the end of the test chamber must be at least 0.06 inch for a test specimen 28 inches or less in length and proportionately greater for a longer test specimen. The test chamber is equipped with a maximum reading pressure measuring device that is open to the test chamber during the test. The pressure measuring device is equipped with a dampening system to bleed pressure slowly from the device at the time of specimen collapse. The pressure measuring device is calibrated at intervals of six months by means of a dead weight tester or more frequently if there is reason to doubt its accuracy. The percentage of error within the working range of the pressure measuring device does not exceed 1.0 percent. The details are described and discussed elsewhere^{10,11}

The experimental aim is to initiate a buckling and collapse of a pipe under quasi-static steady-state conditions to measure the pressure-change in volume response and observe the post-buckling/collapse deformed configurations of the tubes. The experiments are carried out in a specially designed and fabricated pressure chamber shown in figure 3. The chamber has an inner diameter of 0.2 m and a length of 1.75 m, and its work pressure may attain 60 kg/cm². The external pressure applied on the pipe is achieved by using a single-piston pressure pump to pressurize water into the chamber, in which the pressure is in real time monitored by an electrical pressure transducer and the digital pressure gage with a precision of 1 kg/cm².

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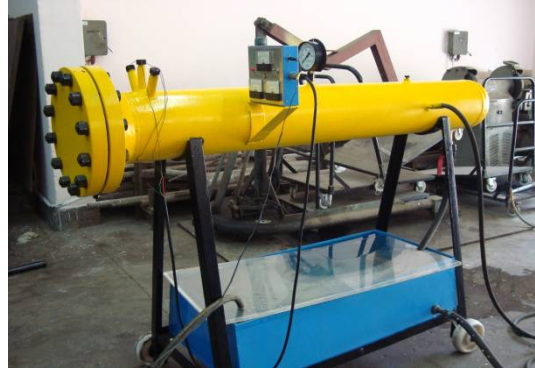


Fig 3. External Pressure Testing Equipment

Experiment :

The test specimen of the Aluminium, PVC pipe, and Acrylic with a length of 600 mm, diameter 32 mm (~ 20 l/d ratio) with thickness of 0.6mm, welded two solid end-plugs each end which is completely sealed at both ends and placed into the pressure chamber. The external pressure testing equipment has to be loaded with three tubes therefore experiments have been carried out with aluminium, PVC and Acrylic tubes. PVC and acrylic tubes were sealed with adhesive that could withstand the applied external pressure conditions. All the three tubes collapsed at various intervals of external pressure in the vessel as the hydrostatic pressure increased. At the external pressure of about 12 kg/cm² and 15 kg/cm² there were some sound as observed in the recorder. Finally, at external pressure around 22 kg/cm² there was a loud sound. The experiment was stopped and opened the pressure chamber. Aluminium tube had collapsed at 22 Kg/cm² (Table 1). The aluminium tube has shown buckling at center which is spreading towards the ends (figure 4). In the second experiment test specimen of the Aluminium, PVC pipe, and Acrylic with a length of 600 mm, diameter 32 mm to 42 mm (~ 20 l/d ratio), with 1.6 mm thickness welded with two solid end-plugs which is completely sealed at placed into the pressure chamber. Slowly the external pressure was increased up to 48 kg/cm². The upper limit of the pressure chamber is 50 kg/cm². The chamber was opened and found that aluminium tube is intact and with stood to the external pressure of 48 kg/cm². On comparing the theoretical, FEA and experimental values on aluminium tubes it is found that these tubes had shown lesser value in practically compared to its theoretical value. This phenomenon can be explained by the non-uniformity and change in the composition of the metal throughout the tube length. Chemical variations at micro domain level are observed in metals. Such heterogeneities would weaken the physical and mechanical properties.^{12,13,14,15}



Fig 4. Aluminium Tube Partially Collapsed

Materials	Dimension (mm)			Collapse Pressure (kg/cm ²)		
	Length	Diameter	Thickness	Experiment	Theoretical	FEA
Aluminium	600	32	0.6	22	32.13	30.15
Aluminium	600	32	1.6	>50	65.71	68.55

Table 1 External Pressure (Theoretical, FEA & Experimental) for Aluminum tubes

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VIII. CONCLUSIONS

1. Application of thin cylinders and tubes is increasing in recent years in mining, mineral and chemical industries during exploration and processing phases
2. Tubes and cylinders sustainable for varying external pressures such as hydrostatic and overburden is the key parameter that are paramount in defining the specifications.
3. Experiments on the tubes of aluminium with 1.6 mm thickness withstood to the external pressure of 50 kg/sq.cm. These experimental values confirmed the higher FEA values (68.55 kg/sq.cm) and theoretical values (65.17 kg/sq.cm).

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