

Stability of Thin Tubes of Synthetic Material for Various External Pressures and Their Suitability for Industrial Application

Kamal Batgiri ¹, Kalje A.M. ²

P.G. Student, Department of Mechanical Engineering, NB Navale Sinhagad College of Engineering, Solapur,
Maharashtra, India¹

Dean and Professor, Department of Mechanical Engineering, NB Navale Sinhagad College of Engineering, Solapur,
Maharashtra, India²

ABSTRACT: Application of thin cylindrical tubes and pipes are in general increasing in the fields of mechanical, civil, mining, mineral exploration, aerospace, marine, power plants, petrochemical industries, etc. Their behaviour under external pressure and uniform hydrostatic loading depends on chemical composition, physico-mechanical properties and manufacturing processes. Theoretical values of collapse pressure for 0.8mm thickness of PVC, Acrylic, High density plastic materials calculated as 15,18 and 18 kg/cm²: for 4.0 mm thickness as 45 and 50 kg/cm². respectively whereas carbon aluminium epoxy based composite materials of with 20 and 40mm diameter and 2 and 4mm thickness yielded 20 and 31 kg/cm². Experiments were carried out in a pressure vessel creating a uniform hydrostatic pressure up to 50 kg/cm². 0.8mm thickness of PVC, Acrylic, and carbon aluminium epoxy based composite materials of 2 and 4 mm thickness collapsed <50 kg/cm². Acrylic and PVC tubes of 4mm thick withstood to the external pressure of 50 kg/cm². Based on these stability values the pipes can be designed and used for various industrial applications.

KEYWORDS: External pressure, Synthetic materials, Buckling phenomenon, Composite materials, Pressure vessel.

I. INTRODUCTION

Thin cylindrical tubes and pipes are in general highly efficient structures and they have wide applications in the field of mechanical, civil, mining, mineral exploration, aerospace, marine, power plants, petrochemical industries, etc. The thin tubes and pipes are prone to a large number of imperfections, due to their manufacturing difficulties. These imperfections affect the load carrying capacity. Reliable prediction of buckling strength of these structures is important, because the buckling failure is catastrophic in nature. That is the reason why the characterization of tubes with respect to chemical composition, physio-mechanical properties and manufacturing processes and their quality tests for their stability are increasing and more and more engineers are being asked for the necessary skills to perform calculations in a more accurate way. Furthermore, tubes and pipes under uniform radial compression and internal pressure have been widely studied, but for external pressure and uniform hydrostatic or otherwise loading have received much less attention. In the present work it is focused for identifying synthetic tubes and testing them for different external pressure conditions and understands their applicability that can be suitable for various industries. The objective is to describe the influence of several parameters on the buckling load and collapse of synthetic tubes and pipes under external (hydrostatic) pressure as the most important parameters include diameter, wall thickness and length.

II. RELATED WORK

In the past decades, many researchers have studied the buckling problem, for instance, Von Mises, Donnel, Southwell, Timoshenko, Flügge, Tokugawa, etc., investigated the free pipe with two ends held in circular shape and presented analytical solutions respectively; Kendrick, Bryant etc. investigated the stiffened pipe and presented analytical

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017

equations taking into account the flexural rigidity of stiffener, Koter, Yamaki and others investigated the nonlinear theory of thin shells and the influence of imperfection.^{1,2,3,4,5,6,7,8,9,10,11}

Geometric imperfections caused during fabrication and construction are the main cause of the significant differences between critical buckling loads calculated using classical methods and experimental buckling loads. Very small imperfections can cause a substantial drop in the buckling load of the shell. The most effective geometrical imperfection forms which have an effect on the critical pressure are the initial ovality and thickness eccentricity.^{12,13,14,15}

III. MATERIALS AND METHODS

Numerous materials are available in the market in the form of tubes, rectangular bars, channels of various sizes, thickness and shapes. Importantly, they include Copper, Brass, Bronze, Aluminium, Aluminium alloys, Stainless Steel, Acrylic, PVC (Poly Vinyl Chloride), High density plastic, FRP (Fiber Reinforced Plastic), GRP (Glass Reinforced Plastic) etc. The basic requirements for the selection of the materials for industrial use include mainly they should be a) corrosion resistance, b) long durability, c) non-magnetic, d) high tensile strength, and e) resistance to oxidation.

Acrylic tubes such as Plexi-glass, Acrylite, Lucite, Shinkolite, Polycast are ideally suitable for industrial pneumatic delivery and conveying systems, Luxury brand merchandizing, trade show displays and decorative architectural features. Its tensile Strength 8,000 to 11,000 psi, Tensile Modulus is 350,000 to 500,000 psi; Flexural Strength is 15,000 psi; Compressive Strength is 14,500 psi. The other advantage of using acrylic sheets over glass is that they are light in weight. They are more flexible than glass, they break less easily and they are resistant to abrasion, corrosion, industrial fumes and chemicals.

Polyvinyl chloride (PVC) is the world's third-most widely produced synthetic plastic polymer, after polyethylene and polypropylene. The rigid form of PVC is used in construction for pipe and in profile applications such as doors and windows. It is also used for bottles, other non-food packaging, and cards (such as bank or membership cards). It can be made softer and more flexible by the addition of plasticizers, the most widely used being phthalates. In this form, it is also used in plumbing, electrical cable insulation, imitation leather, signage, phonograph records, inflatable products, and many applications. Properties of PVC include density 1.3–1.45 g/cm³; Yield strength 4500–8700 psi; Young's modulus 490,000psi; Flexural strength (yield) 10,500 psi; Compression strength 9500 psi; and these mechanical properties enhance with the molecular weight increasing but decrease with the temperature increasing.

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part. The reinforcing phase provides the strength and stiffness. In most cases, the reinforcement is harder, stronger, and stiffer than the matrix. The reinforcement fibers can be cut, aligned, placed in different ways to affect the properties of the resulting composite. The matrix, normally a form of resin, keeps the reinforcement in the desired orientation. It protects the reinforcement from chemical and environmental attack, and it bonds the reinforcement so that applied loads can be effectively transferred. Composite materials are generally costlier as compared to conventional materials, but still their use is becoming increasingly popular because of their significant properties. Though Aluminium (6061 grade) is much nearer in weight to carbon-fiber composite, but the composite can have twice the modulus and more than three times the strength. Composite materials are classified into different categories like Metals, Polymers, Ceramics and inorganic glasses and composites. At high temperature metals lose their strength. Ceramics and polymers are able to withstand at high temperatures, good strength and thermal expansion properties, but due to brittleness they are not good structural materials.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017

IV. THEORETICAL EXPRESSIONS

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 are tend to collapse.^{16,17,18} Such conditions generally exists during drilling operations at greater depth, piping in under water operations, ocean drilling programs, cementing operations, trapped fluid expansion, or well evacuation. Collapse strength is primarily a function of the material's yield strength and its slenderness ratio, L/D . Generally, Barlow's formula is commonly used in the industry to approximate or predict the bursting pressures of ductile thin wall tubular [(Wall/ID) < 0.1] or cylindrical materials due to ID pressurization, and generally yields conservative results or predictions. 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. This is a complex matter in which many issues must be considered such as: personnel hazard assessment and general safety; corrosion; fatigue; fabrication changes (bends, flares); codes and insurance; seismic stability; and temperatures, to name a few. 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 = ID 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, plastic, PVC, high density plastic and composite pipes has been done. The data is presented. The mechanical properties obtained in the literature and the suppliers and manufacturer of these materials is considered for all the calculations. However, for certain materials the manufacturer was not certain about the homogeneity of the material. In general two sets of tubes have been tested during the experimental stage. The average value has been taken which would represent the triple measurements.

V. EXPERIMENTAL RESULTS

Hydrostatic pressure tests are typically performed on ring stiffened cylinders, unstiffened tubes, hemi-spherical domes and other shells. For cylindrical structures, the hydrostatic design load differs from radial (lateral) pressure, which does not include the axial load. External pressures are sometimes generated by creating a partial vacuum within the specimen however, this method is only useful for shells that buckle at pressures less than atmospheric pressure.¹⁹ A comprehensive historical and technical review of pressure testing of shells, and buckling experiments and testing theory in general, is given in the works of Singer et al 1998 and 2002.^{20,21}

The main component of a typical pressure testing apparatus is the pressure chamber: a cylindrical, typically steel, vessel designed to withstand internal pressure. The pressure chamber is filled with the testing medium (e.g. water or oil) and sealed at either end once the experimental specimen has been placed inside. Pressure is increased by pumping additional testing fluid into the chamber, and monitored using a manometer or electronic pressure transducer.

Equilibrium of the system during pressurization involves compression of the testing fluid, expansion of the chamber, and deformation of the experimental specimen. The magnitude of load transferred to the specimen is therefore a

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017

function of the volume of testing fluid that is forced into the chamber by the pump, the stiffness of the pressure chamber and specimen, and the compressibility of the testing fluid. Even though most pressure testing systems are controlled by monitoring the applied pressure and adjusting the pumping rate, loading is actually achieved by applying a volume-change to the specimen via the testing apparatus, i.e. the testing fluid. As such, this system is a form of generalized displacement-control. The compressibility of a fluid is defined by its bulk modulus, B , and initial volume, V_0 . The quotient of these values can be considered an equivalent stiffness, k^* , when relating the pressure applied to a fluid, δP , to the corresponding incremental volume change, δV

$$\delta P = \frac{B}{V_0} \delta V = k^* \delta V \quad (2)$$

The main difference between a conventional pressure testing system and a typical displacement-control test apparatus is the relatively greater compliance of the pressure testing fluid compared to traditional testing frames. This is due to the high compressibility of fluids compared to solids, as shown by the relatively low values of bulk modulus for fluids (e.g. the bulk moduli of water and steel are approximately 1.6 GPa and 170 GPa, respectively). The discrepancy is compounded in pressure chambers having a large ratio of testing fluid to specimen volume, since this further reduces the stiffness of the pressure testing system compared to the specimen. This results in a relatively large amount of strain energy being built up in the testing fluid during pressurization. Traditional testing frames can improve control of the load and displacement by increasing the frame stiffness, i.e. adding material. Conversely, in a pressure testing system this can be achieved by taking away test rig material, i.e. reducing the volume of testing fluid.

In conventional pressure testing, the prescribed deformation must be transferred through the elastic and highly compressible fluid component, rather than directly controlling the deformation of the specimen. This is a problem for pressure testing of buckling-critical shells, since buckling involves a rapid change in the manner of load resistance, from largely membrane stresses to a combination of membrane and bending stresses, and is often accompanied by a substantial loss of overall stiffness. This system may be treated as quasi-static up to the occurrence of buckling, at which point the system behaves dynamically.

The large and rapid deformations associated with buckling trigger the release of strain energy stored in the compressed testing fluid, resulting in undesirable catastrophic failure if some method of reducing, slowing down or absorbing the released energy is not present. Some researchers have been able to reduce the damage at collapse by minimizing the volume of testing fluid, either by selectively proportioning their specimens and/or pressure chamber, or adding solid filler material to the test chamber. However, these options are not always practical, e.g. when using an existing pressure chamber, or when filler blocks would interfere with the instrumentation. Since conventional pressure testing systems are a form of generalized displacement-control, they are capable, in principle, of surpassing limit points in the load, although this does not rule out the possibility of snapping at limit points in the generalized displacements. In practice, the catastrophic nature of shell buckling events in combination with the associated release of energy stored in the testing fluid, means that the equilibrium path is not neatly traced beyond limit points when using traditional pressure testing methods.

VI. 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.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017

The hydrostatic test facility consists of a custom made pressure vessel with an internal arrangement for keeping the probes, a high pressure triplex reciprocating pump driven by a 3 phase 3 hp electric motor, which can deliver at 70 kg/cm² pressure head, and an electrical panel for reading indications of leakage. A saddle stand is made for the vessel to rest on, with a water tank at the bottom of the stand. The vessel has nozzle openings for the electric wires to pass through and an air vent. A pressure gauge 0-120 kg/cm² is also attached on top of the vessel. Water inlet and drain connections are made using suitable material. A weld neck flange of ASME standard SA 105, class 300 on the nozzle side of the pipe and a standard ellipsoidal end cap of SA214 as per ASME 16.9 on the other side are welded to the pipe. A blind flange head of SA 105, class 300 is bolted to the weld neck flange with 7/8" High tensile 10.5 grade (Boltsman) bolts for loading and unloading of the vessel. A cotton reinforced rubber gasket is used between the flanges. A small brass cylinder with perforated Teflon shield is placed inside the probe attached to the probe head so that it gets contacted with the leaked water immediately after entering the probe. The brass cylinder is connected to an electrical circuit through ammeters and dc power supply. Water leaked into the probe gets in contact with the brass cylinder and acts as a switch. Electric current then passes through the circuit and ammeters which shows deflection indicating the leakage. There is an audio buzzer and LED indications also. Buzzer and light indicate leakage in any of probes and ammeters identifies the failed probe. Color code is used for identification.

Probes to be tested are placed inside the vessel three at a time in any combination of sizes and closed with the blind flange head. Water is then pumped to the vessel, opening the vent screw. Once water is filled pressure builds up in the vessel which is shown by the pressure gauge. Pressure can be regulated through the bypass valve of the pump. Once required pressure is attained the delivery valve of the pump may be closed and pump may bypass the discharge to the tank. The pressure in the system is maintained even the pump is stopped, as long as there is no leakage in any form.

Now the probes inside the vessel are subjected to the external pressure of water as they do in actual borehole with water column of ~ 600 meters. If any leakage is there in the probes the water leaked into the probes first get in touch with the brass cylinder and the electric circuit is closed as body of the probe is earthed. Deflection in the Individual ammeters attached to each probe identifies which probe is faulty. There is an audio and visual indication for attention drawl of the operator. After test is completed the vessel may be drained by opening the outlet valve, and second lot of probes may be loaded and cycle continues.

SPECIFICATIONS:

MAWP and DP(Maximum Allowable Working Pressure and Design Pressure)	55 Kg/Cm ²
Operating Pressure	50 Kg/Cm ²
Relief Valve Set Pressure	55 Kg/Cm ²
Vessel Standards	
Material Specification	SA 106 B ANSI/ASME B31.1 8"NPS SCH.40 Seamless
Pressure Heads	
WLRP & BLRF flanges	SA 105, ANSI/ASME B31.1 CLASS 300
End Cap	Ellipsoidal, SA 234 WPB ANSI/ASME B 16.9
Length	1500 mm
Volume	50 Liters
Content used	Clear Water
Safety valves	2 Numbers, Spring Loaded, Reclosing type
Duration of hydro-test	Once in 2 Years
Radiography	Full Radiography Done To WLRP & ENDCAP Weld Joints (With Ir 192 Gamma Source)
Pump details	High Pressure Triplex 13 LPM, P.Max-90 Kg/Cm ² MWP- 70 Kg/Cm ²
Probe testing cycle	Three probes (samples) at a time

Table 1.Detailed Specifications of the Pressure Vessel

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017



Fig. 1. External Pressure Testing Equipment

VII. RESULTS

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 Fig. 1. 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.

Experiment 1.

The test specimen of the Aluminium, PVC pipe, and Acrylic with a length of 600 mm, diameter 32 to 42 mm (~ 20 l/d ratio), welded two solid end-plugs each end which is completely sealed at both ends and placed into the pressure chamber. As the pressure increased with a sound all the three tubes collapsed. Partially collapsed aluminium and PVC pipes are shown in figures 2 and 3. The Aluminium pipe shown in figure 2 collapsed at 28 kg/cm². Figure 3 depicts the PVC pipe collapsed at 15 kg/cm². The data is shown in the table 2.

Material	Dimension (mm)			Collapse Pressure (kg/cm ²)	
	Length	Diameter	Thickness	Experiment	Theoretical
Aluminium	600	32	0.6	28	32.13
PVC pipe	600	42	0.8	15	11
Acrylic	600	42	0.8	18	19

Table 2 External Pressure (Theoretical and Experimental) for Aluminium, PVC, Acrylic Pipes



Fig. 2 Aluminum Tube Partially Collapsed

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017



Fig. 3 Broken PVC Pipe

Experiment 2:

The test specimen of the High-Density Plastic, Composite I and Composite II with a length of 600 mm, diameter 42 mm (~ 20 l/d ratio), fused two solid end-plugs which are completely sealed at both ends and placed into the pressure chamber. All the three tubes collapsed at various intervals of external pressure in the vessel as the hydrostatic pressure increased. The data is given in table 3. Deformed High Density Plastic, Composite pipe I and II are shown in figures 4, 5 and 6. The High Density Plastic pipe collapsed at 18 kg/cm² as shown in figure 4. Figure 5 shows the deformed Composite I pipe which collapsed at 30 kg/cm². Figure 6 is deformed Composite II pipe which collapsed at 25 kg/cm².

Material	Dimension (mm)			Collapse Pressure (kg/cm ²)	
	Length	Diameter	Thickness	Experiment	Theoretical
High D plastic	600	42	0.8	18	13
Composite I	600	42	4	30	31
Composite II	600	20	2	25	24

Table 3 External Pressure (Theoretical and Experimental) for High Density Plastic and Composite Materials Pipes



Fig. 4 Deformed High Density Plastic Pipe



Fig. 5 Deformed Composite Pipe I



Fig. 6 Deformed Composite Pipe II

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017

Experiment 3:

The test specimen of the aluminium, PVC pipe, and Acrylic with a length of 600 mm, diameter 32mm to 42mm (~ 20 l/d ratio), welded two solid end-plugs shown in figure on each end which is completely sealed at both ends and placed into the pressure chamber. With the increased wall thickness all the three tubes with stood to the applied hydrostatic pressure of 48 kg/cm². The data is presented in table 4. After the experiment is completed the undeformed aluminium tube and acrylic tubes are shown in figures 7 and 8 respectively.

Material	Dimension (mm)			Collapse Pressure (kg/cm ²)	
	Length	Diameter	Thickness	Experiment	Theoretical
Aluminium	600	42	4	>50	65.71
PVC pipe	600	42	4	45	40
Acrylic	600	42	4	>50	62

Table 4 External Pressure (Theoretical and Experimental) for Aluminium, PVC, Acrylic Pipes



Fig. 7 Undeformed Aluminum Tube



Fig. 8 Undeformed Acrylic Tube

Materials	Dimension (mm)			Collapse Pressure (kg/cm ²)	
	Length	Diameter	Thickness	Experiment	Theoretical
Aluminium	600	32	0.6	22	32.13
Aluminium	600	32	1.6	>50	65.71
PVC	600	42	0.8	15	11
PVC	600	42	4	45	40
Acrylic	600	42	0.8	18	19
Acrylic	600	42	4	50	62
HDPE	600	42	0.8	18	13
Composite I	600	42	4	30	31
Composite II	600	20	2	25	24

Table 5 External Pressure (Theoretical and Experimental) for Aluminum, PVC, Acrylic, HDPE & Composite materials

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017

Variations and similarities between experimental and theoretical values:

Theoretically, aluminium had shown lesser value in practically compared to its theoretical value (Table 5). 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. PVC and High density plastic tubes of 2 mm thick had shown very poor response for external pressure. They could not withstand even up to the theoretically derived pressures. This phenomenon reflects the poor quality control while processing the materials. Due to lower the production costs generally the quality standards are not followed in the industry. Their application also is of limited nature and these kind of pipes and tubes are used for surface utilities and are not subjected to higher external pressures. Similarly, the sealing materials used for closing both the ends of the tubes are very weak and may give a way for early collapse. Acrylic material withstood for higher external pressures due to their high elastic nature. In the market such materials are available at affordable prices. However these tubes cannot stand for higher temperature. Similarly due to their elastic nature with increase of longitudinal stresses they deform. Proper care need to be taken in high end applications. Composite pipes generally show both higher and lower external pressures comparative to the theoretical and experimental values by about 3 to 5%. Mainly in these composite tubes the structural alignment of the metal fibers and their distances between the fibers control the strength of the materials in question.

VIII. NEW FINDINGS AND 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. Synthetic materials such as Poly Vinyl Chloride (PVC) and high density Plastic materials of 2 mm thick have failed in the experimental test to withstand the 50 kg/cm² external pressure. They withstood for an external pressure of 15, 45; and 18 kg/cm². These experimental values coincided with theoretical values 11, 40; and 13 kg/cm².
4. Composite materials Carbon-aluminium-epoxy with 2 mm and 4 mm thickness and 20 and 42 mm diameter have been tested for external pressure. Both of them could not withstand to 50 kg/cm² but collapsed at 30 and 25 kg/cm². These experimental values coincided with theoretical values of 31 and 24 kg/cm².
5. Synthetic materials such as Poly Vinyl Chloride (PVC) and acrylic materials of 4 mm thick can withstand above 50 kg/cm². external pressure and can be used for high end industrial applications as they are resistant to chemical reactions.

REFERENCES

- [1] Flügge, W 1960, "Stress in Shells", pp.208-218,407-432, Springer-Verlag, OHG, Berlin.
- [2] Kendrick, S. Kendrick, 1953, "The Buckling under External Pressure of Circular Cylindrical Shells with Evenly Spaced Equal Strength Circular Ring Frames -Part 1", NCRE Report No. R.211.
- [3] Donnell, L. H.1976, "Beams, plates and shells", McGraw-Hill, New York.
- [4] Southwell, R. V.1913: "On the general theory of elastic stability", Philosophical Trans., 213A, pp.187-244.
- [5] Timoshenko, S., Gere, J.M.1961. "Theory of Elastic Stability", 2nd Ed., McGraw Hill, New York, NY.
- [6] Tokugawa, T. Tokugawa, 1929 "Model Experiments on the Elastic Stability of Closed and Cross-Stiffened Circular Cylinders under Uniform External Pressure", Proc. World Engineering Congress, Tokyo, Vol.29, Paper No.651, pp.249-79.
- [7] Yamaki, N., 1969. "Buckling of circular cylindrical shells under external pressure", Reports of the Institute of High Speed Mechanics 20, 35-55.
- [8] Yamaki, N., 1970. "Influence of pre-buckling deformation on the buckling of circular cylindrical shells under external pressure", Reports of the Institute of High Speed Mechanics 21, 81-104.
- [9] Yamaki, N., 1984. "Elastic Stability of Circular Cylindrical Shells", North-Holland, Amsterdam.
- [10] Koiter, W. T., "On the stability of elastic stability for thin shells", Proc. of Symp. on the theory of shells to honor Lloyd Hamilton Donnell, Univ. Houston, pp.187-227, 1967.
- [11] Von Mises R. von Mises, "Der Kritische Aussendruck für Allseits Belastete Zylindrische Rohre", Fest Zum 70. Geburtstag von Prof. Dr. A. Stodola, Zürich, pp. 418-30. Translated and annotated by D.F.
- [12] Bulson, P. S 1983, "The Stability of Underground Cylindrical Shells" Developments in Thin-Walled Structures - 1, by J Rhodes and A. C. Walker, 53-80. Essex, England: Applied Science Publishers.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 8, August 2017

- [13] Netto, T.A. 2009, "On the effect of narrow and long corrosion defects on the collapse pressure of pipelines", Applied Ocean Research, 75-80.
- [14] Niloufari, A, Showkati, H., Maali, M., Fatemi, S.M., 2014, "Experimental investigation on the effect of geometric imperfections on the buckling and post-buckling behavior of steel tanks under hydrostatic pressure", Thin-Walled Struct.74, 59–69.
- [15] Tohid Ghanbari Ghazijahani, Hamed Sadighi Dizaji, Javad Nozohor, Tadeh Zirakian 2015, "*Experiments on corrugated thin cylindrical shells under uniform external pressure*", Ocean Engineering, 106, p 68–76.
- [16] Tohid Ghanbari Ghazijahani, Hossein Showkati 2013, "*Experiments on cylindrical shells under pure bending and external pressure*", Journal of Constructional Steel Research 88, p 109–122.
- [17] Menglan Duana, Chen An, 2014, "Prediction of the collapse pressure for thick-walled pipes under external pressure", Applied Ocean Research 47, pp 199–203.
- [18] Cleaver, P.C. O.B.E., D.C. Ae. 1936, "*The Strength of Tubes under Uniform External Pressure*", A.R.C. Technical Report, London, pp215.M. Bertalmio, G. Sapiro, V. Caselles, and C. Ballester, "Image inpainting", in Proc. SIGGRAPH, pp. 417–424, 2000.
- [19] Bryant, A.R., "Hydrostatic Pressure Buckling of a Ring-stiffened Tube, Naval Construction".
- [20] Singer J, Arbocz J, Weller T. 1998, "Buckling Experiments: experimental methods in buckling of thin-walled". John Wiley and Sons, Chichester, New York
- [21] Singer, J., Arbocz, J., Weller, T., 2002, "*Buckling Experiments, Experimental Methods in Buckling of Thin-walled*". John Wiley and Sons, Chichester, New York