DEVELOPMENT OF SHORT TERM HYDROSTATIC TEST FOR PVC PIPES

MOHAMAD NABIL BIN NOR AZMAN

Thesis submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2013

This thesis is dedicated to:

Nor Azman bin Ahmad

Nor Zariah binti Ismail

Nor Azira Maiza binti Nor Azman

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature
Name: MOHAMAD NABIL BIN NOR AZMAN
ID Number: MC09006
Date:

ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude towards Allah Almighty for giving strength to finish this thesis. I am also grateful and would like to express my sincere gratitude to my supervisor Dr Ahmad Syahrizan for his ideas, invaluable guidance, and constant support in making this research possible. He has always impressed me with his outstanding professional conduct and his strong conviction for science. I appreciate his constant help from the first meeting for the FYP to these concluding moments. I am truly grateful for his tolerance of my naive mistakes and his commitment in order to help me finishing my degree.

My sincere thanks go to all my friends especially my partner Adzmil which help me in my research and members of the staff of the Mechanical Engineering Department, UMP, who helped me in many ways and made my stay at UMP pleasant and unforgettable.

I acknowledge my sincere gratitude to my parents for their love, dream and sacrifice throughout my life. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals.

ABSTRACT

This thesis deals with experimental design for the short term hydrostatic test for the Polyvinyl Chloride (PVC) pipes. The objective of this thesis is to design or develop an experimental setup in determining the burst pressure of a PVC pipes by the means of internal pressure. The thesis describes the experimental procedures to determine the burst pressure of the PVC pipes. The experimental value obtained is then compared to the theoretical value calculated from an existing formula. The samples used are designed using computer aided software which is SolidWork. The samples are then fabricated and tested based on the setup designed. From the result obtained, the value of experimental burst pressure is indeed different from the theoretical burst pressure.The result is then compared again with other formula basely for metal pipes in order to check the validity of the equations to be used for PVC pipes. Based on the result, the equations are not too suitable to be used as the different between the values from the main equation with the values calculated from other standard are too big. The result obtained from the experiment setup is also consistence as thus making a possible design to be proposed to the Department of Malaysian Standard as one of the test for the short term hydrostatic test in MS 628 standard.

ABSTRAK

Tesis ini membentangkan rekaan eksperimen untuk ujian hidrostatik jangka pendek untuk paip jenis PVC. Objektif yang perlu dicapai oleh kajian tesis ini adalah untuk mereka atau mencipta satu eksperimen yang boleh digunakan untuk mendapatkan tekanan yang boleh memecahkan paip PVC dengan cara memecahkannya dari dalam. Di dalam tesis ini juga terdapat prosedur–prosedur yang perlu diikuti untuk mendapatkan tekanan tersebut. Tekanan yang diperolehi melalui eksperimen ini kemudiannya akan dibandingkan dengan tekanan yang diperoleh melalui kiraan menggunakan formula yang sedia ada untuk melihat perbezaan di antara kedua-duatekanan. Melalui perbandingan ini kita dapat lihat yang tekanan yang didapatkan melalui eksperimen adalah lebih tinggi berbanding tekanan yang didapatkan melalui kira-kira menggunakan formula. Tekanan yang didapatkan melalui kira-kira kemudiannya akan dibandingkan lagi dengan tekanan yang diperoleh melalui formula-formula lain yang lebih sesuai untuk paip besi. Hal ini adalah untuk melihat kesesuaian formula tersebut untuk digunakan untuk paip PVC.Melalui perbandingan ini kita boleh katakan yang formula tersebut tidak sesuai kerana perbezaan tekanan itu agak besar. Selain itu, keputusan yang diperoleh melalui eksperimen ini agak konsisten dan ini membolehkan rekaan eksperimen ini dihantar ke badan yang mengawal standard di Malaysia seperti SIRIM untuk dimasukkan ke dalam standard MS 628 sebagai rekaan eksperimen untuk ujian hidrostatik jangka pendek.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Dm_{min}	Minimum outside diameter
T_{min}	Minimum wall thickness
s	Circumferential hoop stress
d	Maximum depth of defect
c	Maximum width of the defect
l	Maximum length of the defect
D	Outside diameter of pipe
σ_y	Yield strength
M	Folias Factor / Bulging stress
σ_f	Flow stress

LIST OF ABBREVIATIONS

AWWA	American Water Works Association
ASTM	American Society for Testing and Materials
ASME	American Society of Mechanical Engineers
BS	British Standard
cPVC	Chlorinated Polyvinyl Chloride
DNV	Det Norske Veritas
DSM	Department of Standards Malaysia
EDC	Ethylene Dichloride
FEM	Finite Element Method
MS	Malaysian Standard
PVC	Polyvinyl Chloride
SIRIM	Standards and Industrial Research Institutes of Malaysia
UKWIR	United Kingdom Water Industry Research
uPVC	Unplasticized Polyvinyl Chloride
USA	United States of America

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

PVC or Polyvinyl chloride is one of the materials which had been widely used plastic throughout the world nowadays aside from polyethylene and polypropylene. From the usage in supplying water for domestic and industrial used to the transferring of waste materials either in form of liquids (chemicals) or gas. The global demand for PVC pipes nowadays had increased 4.6 percent annually through 2012 to 8.2 billion meters or 18.2 million metric tons (The Freedonia Group, 2009). However, the usage of PVC pipes in piping throughout Malaysia is still about only 10 percent compared to the 60 to 70 percent of PVC pipes global usage (Bernama, 2008). PVC pipes can be divided into two which are unplasticized PVC (uPVC) and chlorinated PVC (cPVC). This research paper will go deeply in the experimental design in obtaining the burst pressure of a uPVC straight pipe. The experiment will more toward short term hydrostatic test. The final design of the experiment will then be proposed to the Department of Standards Malaysia as the design of experiment to test the PVC pipes in terms of short term hydrostatic test. This experiment will only test the capability of the MS 628 pipes which is the PVC pipes used in the water supply, Department of Standards Malaysia (DSM, 1999). This experiment will also compare the result obtained from a perfect straight pipe and the pipe with defect on it. The only defect used in this study is gouge. The other defects such as crack are not used because it is hard to produce a control-sized of a crack. Apart from that, corrosion is not suitable as plastic material such as PVC is resistant against corrosion, flexible, and easy to handle (Farshad, 2006).

1.2 STATEMENT OF PROBLEMS

Polyvinyl chloride pipes or PVC pipes are widely used as a medium to supply water to house and to the industry. The process of transferring the water from the reservoir to the customers is involved the pumping of water into the pipes. Hence, making the pressure inside the pipes increased and this has also increased the risk of the pressure to exceed the burst pressure of the pipes. The value of the burst pressure varies among the PVC pipes as they have different thickness, size of nominal diameter and also standard. Although the standards either Malaysian Standard (MS) 628, British Standard (BS) 3505 or even American Standard Testing and Material (ASTM) D1784 - 11 has stated the example of method that can be used to measure amount of internal pressure that can be withstand by the pipes but however, the actual pressure will always be different compared to the theoretical value. Therefore, this research will be focusing on showing the actual burst pressure of a perfect uPVC pipe and pipe with defect is lower or higher compared to the theoretical burst pressure of a perfect pipe and the one with defect in equation (1).

$$P_{burst,act} \neq P_{burst,theoretical} \qquad (1)$$

The Department of Malaysian Standard is the one that that control all the standards used in Malaysia. MS 628, the standard and specifications for the unplasticized PVC (uPVC) pipes for water supply. However, there are no detail explainations on the method to perform the short term hydrostatic test although all the other test such as heat reversion test and long term hydrostatic test have detailed explaination in each step of the experiment including the samples. Besides that, as the usage of PVC pipes are not in a very critical area such as oil and gas, there are only a few researches in terms of the burst pressure of the PVC pipes.

1.3 OBJECTIVE

The objectives of this research are:

(i) To determine the burst pressure of a perfect straight pipes and the pipes with defects.
(ii) To compare the burst pressure obtained from the experiment with the theoretical value obtained from calculations.
(iii) To suggest a new design of experiment for the short term hydrostatic test for MS 628 pipes.

1.4 PROJECT SCOPES

The burst pressure test is run for the mean of determining the quality of the pipes and also to find the remaining strength of the pipes when a defect is introduced to the pipes. The burst pressure test however must be referring to specifications to either three of the specifications recognized in Malaysia which are the MS 628, BS 3505 and ASTM D1784 – 11. Following the specifications stated inside the report produced for MS 628 is the best as the idea to do this experiment is due to the absence of the design of experiment for the short-term hydrostatic test inside the MS 628 standard. The method of the experiment is to design the rig first. Then, all the materials are prepared and the rig is fabricated. The samples for the experiment is prepared following the specifications such as the length of the samples must be between 250 mm and 750 mm, Department of Standards Malaysia (DSM, 1999). The test will firstly determine the burst pressure of a perfect pipe and followed by the burst pressure for the pipe with the presence of defect. For this paper, the defect introduced will only be in form of gouge. The experimental result will then compared with the result acquired from the calculation. Then, analysis and discussion of the result is done and a conclusion is made based on the analysis.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will provide the review on the title of the research with respect to the research produced by other people which is taken from the journal, article and books. The previous researches may use other defects such as creep and corrosion and compare the burst pressure that obtained either by experimentally, theoretically or using the Finite Element Analysis. This chapter will also discuss about the history behind polyvinyl chloride (PVC), the MS 628 pipes and the defects existed in the pipelines. This chapter will also discussed one the general review on PVC pipes in terms of mechanical properties and specifications on the PVC pipes present throughout the world these days.

2.2 STANDARD AND SPECIFICATION

All areas of study especially engineering are very delicate when involving the standard of requirements for a materials. Every material had their own standard and specifications and this include PVC pipes as well. Almost every continent in the world had a standard to be follow and Malaysia is one of the countries that had their own standard although the standard is derived from other country's standard. The Malaysian Standard (MS) is derived from the British Standard (BS). United States of America (USA) also have their own standard called American Society for Testing and Materials or ASTM.

In Malaysia, the department that responsible in updating the standards is Department of Standards Malaysia (DSM). They are responsible in approving and giving accreditation of a new standard. DSM has appoints Standards and Industrial Research Institutes of Malaysia (SIRIM Berhad) as an agent to improve and produce the standard. SIRIM is also responsible in distributing and selling the Malaysian Standard. There will be a committee formed every time a new standard is proposed. The committee is made of professionals such as engineers either from SIRIM or other companies, consumers such as owner of companies and also users. The number of representative inside a committee is balanced for each group.

The PVC pipes are produced by the factories according to the standards and specifications produced by the Department of Standards Malaysia (DSM) such as MS 628 and MS 762. The pipes that I am using for my research now are the pipes that under the specifications released under the standard MS628. MS628 is derived from British Standard (BS) 3505:1986 which is the standard for transferring cold potable water or supplying water. This standard is for uPVC pipes only. This standard is be divided into three parts; Part 1 is about pipes, Part 2 is about joints and fittings for use with unplasticized PVC pipes while Part 3 is about the guide to install the pipes. Part 2 is divided into two subdivisions; the first part is about uPVC joints and fittings while the second part is about solvent cement. For industrial uses, the specifications can be seen inside the paper for Malaysian Standard (MS) 762. This specification is taken from BS 3506. The standards and specifications released by the SIRIM Berhad already stated the entire required test that crucial in order for straight pipes and also the joints and fittings to be approved as a good product. The tests are:

(i) Heat reversion test
(ii) Resistance to acetone test
(iii) Impact strength test
(iv) Short term hydrostatic test
(v) Long term hydrostatic test
(vi) Fracture toughness test

(vii) Opacity test

(viii) Effect of materials on water quality

However, the report is lack of the design of the experiment for the short term hydrostatic test. The report only stated the specifications for the experiment to be valid but did not proposed the design of experiment that can be used in order to check the hydrostatic pressure of the uPVC pipes. Therefore, one of my objectives is to design an experiment for the short term hydrostatic test and if possible, proposed it to the SIRIM. There are many defects on PVC pipes that may lead to the failure of the pipes but the one that been introduced to the pipes during the experiment is gouge defect as shown in Figure 2.1.

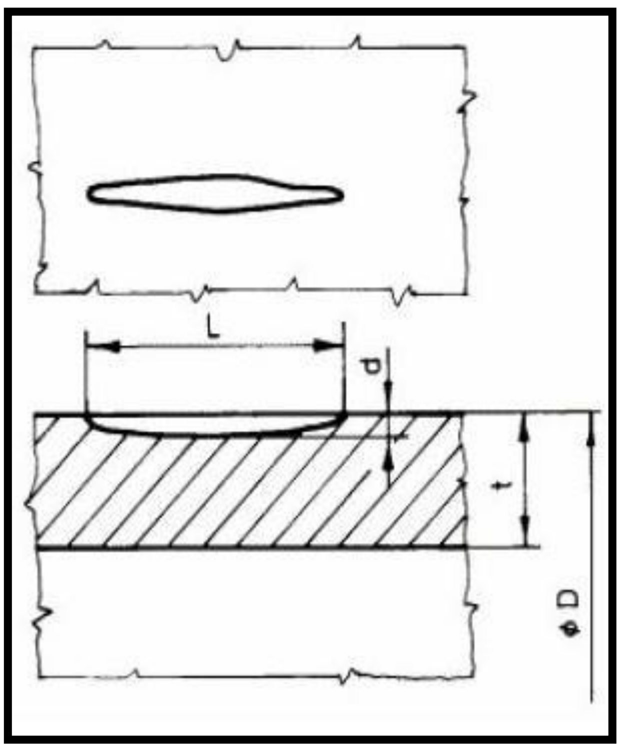

Figure 2.1: Gouge defect

Source: Dr Abdel-Alem (2000)

2.3 POLYVINYL CHLORIDE (PVC)

2.3.1 General on PVC

Plastic industry had actively increased in numbers in 1940s but only in 1970 the use of plastic in engineering material had really step up (Edwards, 1998). The end of the nineteenth century is the time where two of the newly found industry which are the acetylene and chlorine industry facing overproduction. Hence, scientists that lived during that time had to struggle to find a new product that can be formed by forming the two products and PVC is the surfaced. PVC is generally accepted to be discovered in 1912, the same year a production process of PVC is reported (Mulder and Knot, 2008). When the PVC was firstly introduced, the materials are said to be brittle and degraded when exposed to heat and lights.

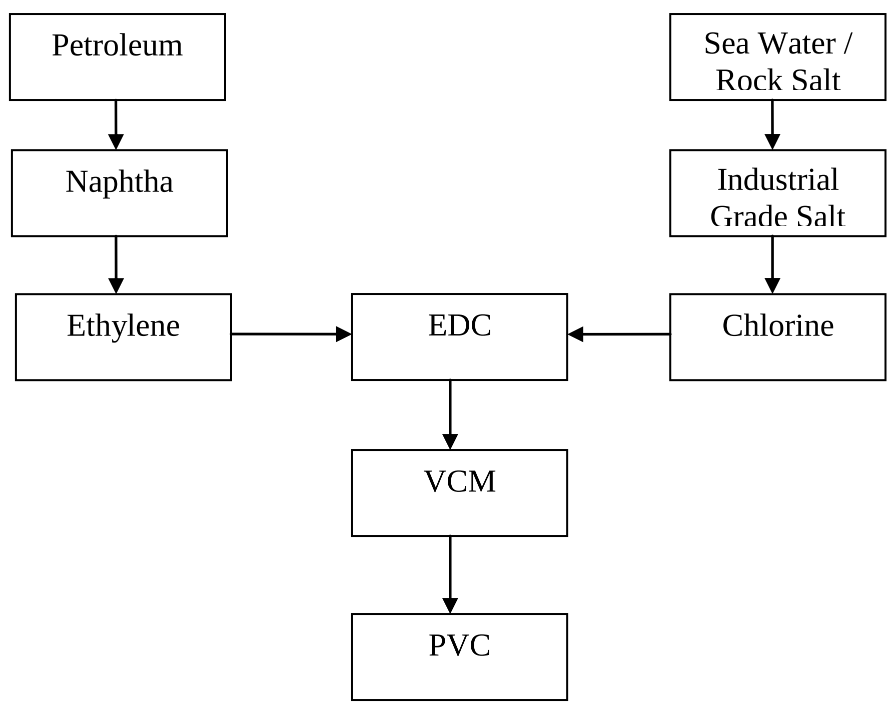

Figure 2.2: Flow chart in the production of PVC

Source: www.pvc.org

From the above Figure 2.2, the production of PVC is started from petroleum refining industry and salt industry. The naphtha produced is then processed to become ethylene while the salt will go through electrolysis to produced caustic soda and chlorine. Both ethylene and chlorine will then be combined to become EDC or ethylene dichloride before being processed to become vinyl chloride and finally become polyvinyl chloride or PVC.

2.3.2 PVC Pipes

Figure 2.3: PVC pipes

Source: www.all-about-pipe.com

PVC pipes as shown in Figure 2.3 are the most common materials that presence in the piping system nowadays. The characteristic of the PVC material which is chemically resistance allows it to be used as industrial piping system for waste disposal especially chemical and toxic wastes. PVC pipes are also been used to supply water for domestic and industrial used. However, the standard and specifications for each purpose are different in order to preserve the longevity of the pipes used. This is because different standard had different physical and mechanical properties. As examples the PVC pipes used for the potable of water domestically are different from the PVC pipes used in industry. The strength and durability between the pipes are different as the pipes used in industrial area can withstand higher pressure than the pipes used for supplying water. PVC pipes are actively used to replace steel pipes in every area including sewage and water supply due its chemically resistant, low cost and easy to join the pipes. Advantages of PVC pipes in piping system are:

(i) Corrosion resistance
(ii) Chemical resistance
(iii) Low thermal conductivity
(iv) Flexibility
(v) Low friction loss
(vi) Lightweight
(vii) Variety of joining method
(viii) Weather resistance (Chasis, 1998)

PVC pipes can be divided into three types which are normal PVC, unplasticized polyvinyl chloride (uPVC) and chlorinated polyvinyl chloride (CPVC). Nowadays, uPVC is the pipes used in supplying water for domestic and industrial used. CPVC is one of the latest PVC pipes family that contains high amount of chlorine compared to PVC and uPVC. PVC pipes are recognized by their colour. Each colour represents different uses. The colour and their uses are as shown in Table 2.1:

Table 2.1: PVC pipes' colour and their uses

Colour	Uses
Blue	Water main
Red	Fire main
Purple	Reclaimed water main
Green	Sanitary sewer and forcemain
White	All applications
Orange	Telecommunications
Grey	Electrical conduit
Yellow	Gas distribution

Source: www.all-about-pipe.com

Plastic pipes not only lose their strength when exposed to high temperature, but also when exposed to low temperature (Cruz et al., 2010). CPVC pipes are then introduced as a solution for supplying high temperature of water. CPVC is a material produced by adding more time to the chlorination process and this postchlorination allows the material to has extended maximum service temperature from 21°C to 99°C (Chasis, 1998). CPVC pipes are then used as a medium for transferring hot water as the additional chlorine reduces the pipes' reaction to heat as cPVC had higher strength when experiencing high temperature compared to PVC and uPVC pipes that had their strength reduced. Table 2.2 below shows the dimensions of uPVC available in markets nowadays:

Table 2.2: The dimensions of uPVC available in markets

Nominal Size	Outside Diameter		Wall Thickness							
			Class B (6 Bar)		Class C (9 Bar)		Class D (12 Bar)		Class E (15 Bar)	
Inch	Min. mm	Max. mm	Min. mm	Max. mm	Min. mm	Max. mm	Min. mm	Max. mm	Min. mm	Max. mm
½	21.2	21.5							1.7	2.1
3/4	26.6	26.9							1.9	2.5
1	33.3	33.8							2.2	2.7
1.1/4	42	42.5					2.2	2.7	2.7	3.2
1.1/2	48	48.5					2.5	3	3.1	3.7
2	60	60.7			2.5	3	3.1	3.7	3.9	4.9
3	88.4	89.4	2.9	3.4	3.5	4.1	4.6	5.3	5.7	6.6
4	113.7	114.9	3.4	4	4.5	5.2	6	6.9	7.3	8.4
5	139.4	141	3.8	4.4	5.5	6.4	7.3	8.4	9	10.4
6	167.4	169.1	4.5	5.2	6.5	7.6	8.8	10.2	10.8	12.5
8	218	220.2	5.3	6.1	7.5	9	10.3	11.9	12.6	14.5
10	271.6	274.4	6.6	7.6	9.7	11.2	12.8	14.8	15.7	18.1
12	332.2	325.5	7.8	9	11.5	13.3	15.2	17.5	18.7	21.6
14	353.7	357.3	8.5	9.8	12.6	14.5	16.7	19.2		
16	404.3	408.5	9.7	11.2	14.5	16.7				

Source: www.epco-plastics.com

2.3.3 Physical and Mechanical Properties of PVC Pipes

PVC is a thermosetting plastic or in other word, it can only be molded and formed once. The action of molded and formed for the second time will lead to the loss of some of the important characteristics. The properties of PVC vary according to the steps in making it. This is because sometimes there are the presences of additives to the PVC in order to increase the strength and durability of the PVC material. Additives such as plasticizers, impact modifiers, processing aids, fillers, lubricants and stabilizers play an important role in the structural strength of the PVC materials. The morphology of the resin particle of polyvinyl chloride is complex that the physical and mechanical properties of the PVC can be affected due to the changes at the degree of fusion. Moreover, both physical and mechanical properties of the PVC can be affected by free volume, crystallinity and orientation (Yarahmadi et al., 2003). The addition of plasticizers such as low-molecular-weight plasticizers decreases some of the mechanical properties such as hardness, modulus and tensile strength. However, it also improved the low-temperature flexibility, elongation and the ease of processing of the PVC [Pita et al., 2002). Table 2.3 showed the mechanical characteristics of a uPVC pipe.

Table 2.3: Mechanical properties of uPVC pipes

Property	**Unit**	**Value**
Density	Kg/m^3	1400 – 1460
Tensile Strength	MPa	45 – 50
Elongation	%	80 – 150
Compressive Strength	MPa	59
Modulus of Elasticity	MPa	3000
Specific Heat Capacity	kJ/kg.K	240
Linear Expansion	mm/m/°C	0.08
Volume Resistivity	Ohm/cm	10^{15}
Flammability	Self extinguish	Self extinguish

Source: www.hedley-international.com

In order to obtain all the mechanical properties such as the tensile strength and modulus of elasticity, tests such as a tensile test is done. The test is done following the ASTM D638 and the workpiece used follow the standard given in ASTM D882. The example of the workpiece is like thin film and sheets such as shown by Figure 2.4 below. For test to find elongation, the method used will follow the standard and specification which had been stated inside the standard ASTM D4551 – 12. The example of test method for elongation according to ASTM D4551 - 12 is also a tensile test.

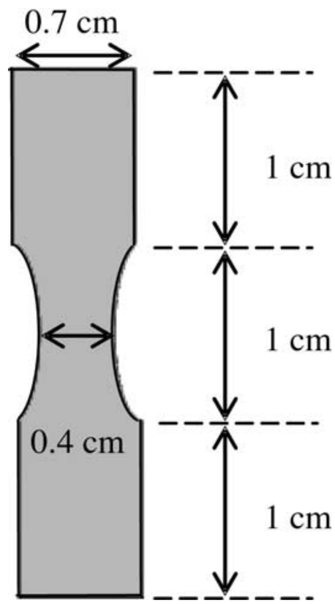

Figure 2.4: Tensile test specimen

Source: Rie et al. (2005)

2.4 BURST PRESSURE

Burst pressure is sometimes defined as the point at which something such as a valve or hose will fail as a result of pressure, and it may also be defined as the point right before failure will occur. In either case, burst pressure could be considered an expression of the maximum pressure which something can endure before it will break. It is important to consider burst pressure when designing any sort of system which is used with pressured materials such as water, gas, and various fluids, whether that system is the radiator in a car or a municipal water system.

A number of factors can influence burst pressure. Knowing the parameters, an engineer can calculate burst pressure and work backwards to determine which kinds of components could be used. Example of calculation that can be used to predict the burst pressure due to internal pressure is Barlows Equation that had been used by the industry for years. Obviously, one major factor is the material being used to make a valve, pipe, or holding chamber. The quality of the material and its thickness can determine how much pressure it will withstand. Another factor is maintenance; a brand new valve is less likely to fail than an old valve, and a well maintained valve is less likely to break than one which has been neglected.

2.4.1 Barlows Equation

The hydrostatic pressure capacity of PVC pipe is related to the following variables:

(i) The ratio between the outer diameter and the wall thickness (dimension ratio).
(ii) The hydrostatic design stress for the PVC material.
(iii) The operating temperature.
(iv) The duration of the stress applied by the internal hydrostatic pressure.

The pressure rating of the PVC pipes can be deduced by dividing the long term capacity of the pipes with safety factor of the pipes. Many engineers will use the ultimate tensile strength (UTS) to calculate bursting pressure estimation and use the yield strength and a safety factor (SF) when arriving at a working pressure estimation. Using the yield strength and no safety factor (SF=1) will calculate an approximate theoretical pressure at which the tubing will begin to plastically deform. Although the pipes usually can withstand a pressure higher than the pressure rating of the pipes, the true strength of a pipe in terms of applied internal hydrostatic pressure must be deduced from its long-term strength (Vinidex, 2012). Global has accepted that Barlows formula or equation which showed the relationship between internal pressure in the pipe, the diameter and wall thickness and the circumferential hoop stress developed in the wall can be used to predict the burst pressure of a pipe.

$$P = \frac{2T_{min}s}{(Dm_{min} - T_{min})} \qquad (2)$$

Where,

P = internal pressure (MPa)

T_{min} = minimum wall thickness (mm)

s = circumferential hoop stress (MPa)

Dm_{min} = minimum outside diameter (mm)

2.4.2 ASME B31G

The ASME B31G is developing based on full scale tests of pressured to failure corroded pipes. It allows determination of the remaining strength of the corroded pipes and estimating of the maximum allowable operating pressure. However, the B31G criterion contains some simplifications. Another shortage, is the possibility of only proving he pipe integrity under internal pressure, other stresses are not taken into account. There is also restriction in assessable defects, namely the corroded area depth cannot be greater than 80% of the wall thickness and not less than 10%. This method is based on the measurement of the longitudinal “extent of the corroded area”. It is considered the depth and longitudinal extent of corrosion, but ignores its circumferential extent. The corroded area is approximated depending on the defect length as parabolic or rectangular shape. Short longitudinal extent of corrosion areas are approximated by the parabolic shape and longitudinal extent of corrosion areas are approximated by the rectangular shape.

Burst (failure) Pressure of corroded pipe (P_f)

The burst pressure for the corroded pipe can be calculated in terms of short defect and long defect. The area however differs according to the shape of the defects such as rectangular and parabolic.

(i) Short defect

$$P_f = \frac{2t\,\sigma_f F}{Do}\left[\frac{1-\left(\frac{2}{3}\right)\left(\frac{d}{t}\right)}{1-\left(\frac{2}{3}\right)\left(\frac{d}{t}\right)/M}\right] \qquad (3)$$

(ii) Long defect

$$P_f = \frac{2t\,\sigma_f F}{Do}\left[1 - \frac{d}{t}\right] \quad (4)$$

- **M (Folias Factor)**

  $$M = \sqrt{1 + 0.8\left[\frac{l^2}{(Do)(t)}\right]^2} \quad (5)$$

- **L (Axial extent to defect)**

  $$L\begin{cases} \le \sqrt{20\,Do\,t} \\ > \sqrt{20\,Do\,t} \end{cases} = \begin{cases} A = \frac{2}{3}dl \\ A = dl \end{cases} \quad (6)$$

- **A (Area)**

  A = dL (rectangular)

  A = $\frac{2}{3}$ dL (parabolic) (7)

  A = 0.85 dL (approx. average of rectangular and parabolic)

2.4.3 RSTRENG

RSTRENG is a modified B31G based on real shape of corrosion defects. The basic difference between the modified B31G methods can be taken as a simple calculation with an approximate geometric shape, while RSTRENG takes into account the actual profile of the defect. In order to more accurately represent the real corrosion area an effective area method was proposed to estimate the remaining strength of the corroded pipe. The equation is as follow:

$$P_f = \frac{2t\,\sigma_f}{Do}\left[\frac{1-\left(\frac{A_d}{A_O}\right)}{1-\left(\frac{A_d}{A_O M}\right)}\right] \quad (8)$$

Flow stress is given:

$$\sigma_f = \text{SMYS} + 60\text{MPa} \qquad (9)$$

Bulging factor is given:

$$M= \sqrt{1 + 0.6257\left[\frac{l^2}{(Do)(t)}\right] - 0.003375\left[\frac{l^2}{(Do)(t)}\right]^2} \qquad (10)$$

A_d donates the effective area of a complex corrosion profile, and A_d = Lt is the cross-section area with the maximum defect length. This effective area method permits to determine accurate corroded area using the discrete method, and thus to determine more accurate corroded burst pressure for real corrosion defect. A personal computer code called RSTRENG was developed to facilitate the analysis of corroded area via the effective area method. Thus, RSTRENG is often used to represent the effective area method.

For a machined rectangular defect, the metal loss area is A_d = dL and becomes:

$$P_f = \frac{2t\,\sigma_f}{Do}\left[\frac{1-(\frac{d}{t})}{1-(\frac{d}{t})/M}\right] \qquad (11)$$

If the defect is very long, the bulging factor is assumed to being finite, and reduces to:

$$P_f = \frac{2t\,\sigma_f}{Do}\left[1 - \frac{d}{t}\right] \qquad (12)$$

2.4.4 Modified ASME B31G

The B31G methods were found to be too conservative and has been modified, the new method called Modified B31G or 0.85 areas method. One of the most significant changes to the original B31G method is defect geometry approximation. This method removes were some conservation by changing the flow stress limit to SMYS + 69 MPa

(10ksi). This is very close to conventional fracture mechanism definition of the flow stress, the average of yield and ultimate strength as shown in equation (13). This modification results in the change of the failure equation, which is also dependent on the limit on defect length.

$$P_f = \frac{2t\ \sigma_y}{Do}\left[\frac{1-0.85(\frac{d}{t})}{1-0.85(\frac{d}{t})/M}\right] \qquad (13)$$

2.4.5 DNV-RP-101

DNV-RP-F101 or Det Norske Veritas, the Recommended Practice contains another approach for corrosion assessment. It is based on allowable stress design, where the failure pressure of the pipe is calculated and multiplied by safety factors. These factors may be based on design factor. The equations account directly for the accuracy in sizing the corrosion defect. Hence, the increase allowable pressure obtained by improving the accuracy of inspections can be seen immediately.

The DNV-RP-101 recommends the assessment of corroded pipelines subject to internal pressure and internal pressure combined with longitudinal compressive stress (DNV, 2010). Moreover, this new criterion provides an assessment procedure for single defect, interacting defects and complex shape defects as shown in equation (14).

$$P_f = \frac{2t\ \sigma_u}{Do-t}\left[\frac{1-(\frac{d}{t})}{1-(\frac{d}{t})/M}\right] \qquad (14)$$

M (Folias Factor) is given by:

$$M = \sqrt{1 + 0.31\left[\frac{l^2}{(Do)(t)}\right]} \qquad (15)$$

2.4.6 SHELL92

Shell has adopted a code to determine a maximum safe pressure pipelines. The equation (16) to calculate the maximum safe pressure is almost similar to the B31G Criterion.

$$P_f = \frac{2t\ 0.9\sigma_u}{Do - t}\left[\frac{1-(\frac{d}{t})}{1-(\frac{d}{t})/M}\right] \quad (16)$$

M (Folias Factor) is given by:

$$M = \sqrt{1 + 0.8\left[\frac{l^2}{(Do)(t)}\right]} \quad (17)$$

2.4.7 Academic Papers that Involved Study of the Burst Pressure

Burst pressure or collapse pressure of a straight pipe can occur due to the ageing or due to the presence of defects on the pipes itself. The ageing and defects that occur had altered the mechanical properties of the pipes especially the strength and the durability of the pipes. The overexposed to the ultraviolet (UV) light can also lead to the occurrence of burst pressure. This is because the UV light will react to the chlorine presence inside the material of PVC, making it to become decrease in the strength, leading to the failure of the pipes (Walker Jr., 1981). The increase in the amount of temperature that surrounds the PVC pipes will lead to the decreased in the strength and durability of the pipes. Thus, the pressure capacity of the pipes will be reduced and proper maintenance will be needed in order to prevent any leakage, American Water Works Association (AWWA, 2002).

During the times before the introduction of Finite Element Analysis, scientists can only predict the lifespan of a PVC pipe using various kinds of experiments. However, nowadays the use of Finite Element Analysis has helped all the researches to acquire more accurate result in predicting the time or the pressure and load where the pipes will begin to fail. The Finite Element Analysis is very helpful in analyzing the structure of the pipes. By the help of FEM, scientists can then focus more on other things such as the parameter and deriving equations that can be used to solve numerical difficulties (Mackerle, 2004). The use of FEM also helps delicate analysis as the nowadays FEM software is very detailed that even a complex structure can be analyzed (Neilson et al., 2010).

Prediction of the bursting pressure used in a critical application that is an important consideration in design for a safety and reliability. It is very important to know the value of maximum pressure. The test is to determine at the point when the ligament failed. From the test, the point when ligament failed can be determined. Test result shows that burst pressure decreases with increase gouge length. All specimens show bulging deformation around defect area and occurred at the bottom of the defect area with crack. The result pressure value and decrease with increase radial displacement.

There are several researches that involved in studying the PVC pipes. The strength of corroded pipes subjected to internal pressure was analyzed using two types of analysis which are the volumetric method and limit analysis. The volumetric method is by analyzing the schematic elastic-plastic stress distribution along notch ligament and notch stress intensity virtual crack concept while the limit analysis is using NFAD or notch adapted failure assessment diagram (Meliani et al., 2011).

The slow crack growth on PVC-U pipes was studied by applying fracture mechanics on a physical probabilistic failure model using a Monte Carlo simulation model. Based on Weibull distribution, the Monte Carlo simulation showed maximum defect size which then produced an output of number of new pipe segments installed for each year simulation and the failure years of each segments. The actual failure rates which been taken from UKWIR database are then compared the result from simulation (Davis et al., 2007).

Another example was the study on the effect of corrosion to the collapse pressure of the pipelines. They used the result from the experiment and simulation using Finite Element Analysis and compared with each other. Using different defect geometries, a parametric study is done in order to check the level of influence of each geometry toward the collapse pressure. The result obtained then showed that the different collapse modes can occur due to different geometries. The relation between defect and pipe ovality and the internal and external pressure and position of the defect can also affect the collapse mode (Netto et al., 2007).

A notch-like-defect is also decreases the fracture and fatigue resistance of the pipes together with the crack produced due to external stress (Meliani et al., 2011). Another paper then had used two types of parameter method that involved FEM in order to determine the gouge effect in a pipe submitted to internal pressure. The methods are Notch Stress Intensity Factor (NSIF) and effective T-stress. The flow of the analysis is the fracture toughness of a notched specimen is shown using Volumetric Method, followed by modified failures assessment diagram and lastly, the two parameter methods (Meliani et al., 2010).

There are several types of main defects which are:

(i) Gouge
(ii) Dent
(iii) Crack
(iv) Groove
(v) Corrosion (Cosham, 2003)

Another defect that not mentioned by Cosham in his paper is creep. Creep can be seen in many materials used in engineering and it is said to be the defect that limit the longevity of a material (Mackerle, 2004). Creep will grow little by little under operating stress and load and then produce a small fracture. The small fracture will then combined and become a major fracture and this lead to the failures of the pipes (Jelwan et al., 2013). A dent reduces the PVC pipes' static and cyclic strength. A dent is a permanent plastic deformation at the circular cross section of the pipes. Dent can be divided into five types which are smooth dent, kinked dent, plain dent, unconstrained dent and constrained dent (Cosham, 2003).

There are also some papers that research on the prediction of when will a pipe collapse due to internal pressure. The prediction is produced by comparing the experimental result with the result obtained from the calculation derived by using the least square method (Netto, 2010). The research is about to compare the experimental result of collapsed pressure of damaged pipes with the theoretical result calculated using a formula as shown below:

$$\frac{P_{def}}{P} = \left[\frac{1-\frac{d}{t}}{1-\frac{d}{t}\left(1-\left(\frac{c}{\pi D}\right)^{0.4}\left(\frac{l}{10D}\right)^{0.4}\right)}\right]^{2.675} \quad (18)$$

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, the work flow of this research will be explained in details. The research which is the development of short term hydrostatic test for PVC pipes requires me to design an experiment in order to determine the amount of pressure required to burst a PVC straight pipes. The overall flow of this research can be seen in Figure 3.1. The flow of this research includes the design of each part that will be used in the experiment and buying the materials needed to run the experiment. The part designed included the straight pipes, end caps, nipple and the assembly of these three parts. The assembled part will then connected with a hand pressure test pump which using a hydraulic principle.

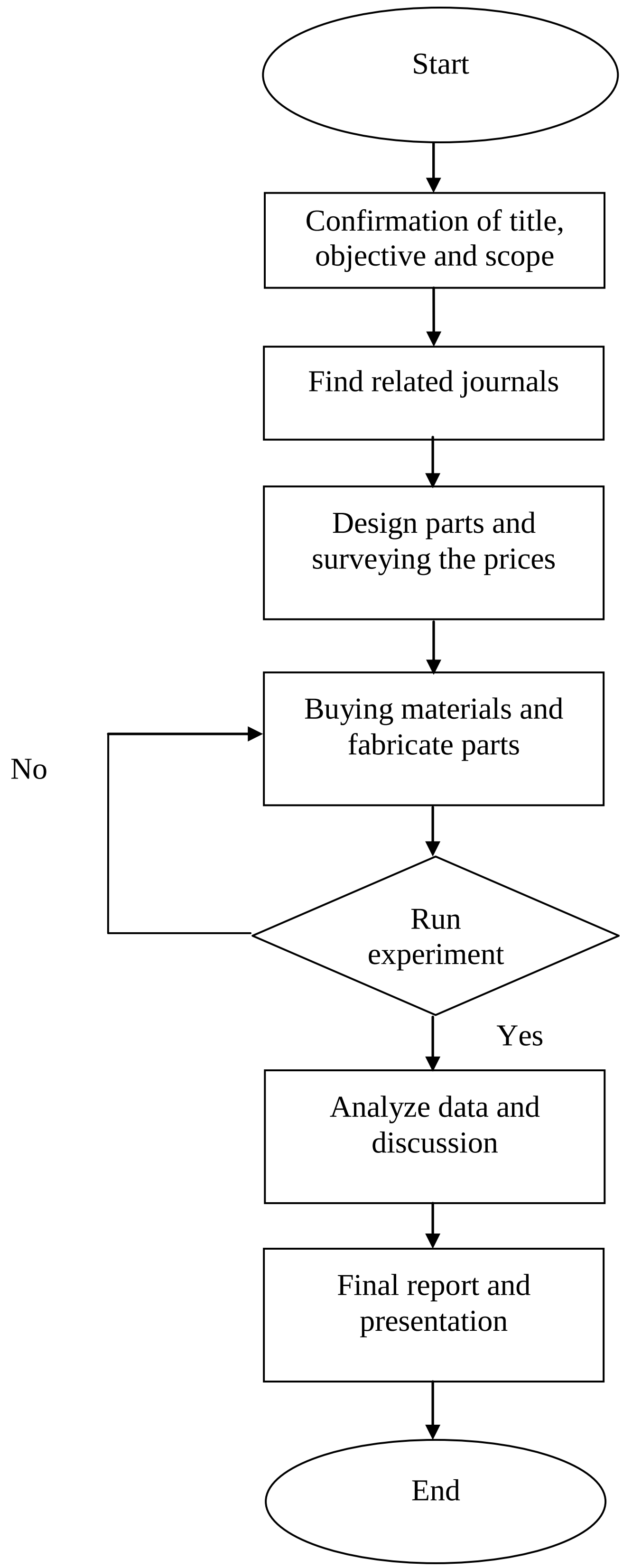

Figure 3.1: Flow chart for the production of the thesis

3.2 DESIGN OF EACH PART

Before preparing for an experiment, we must first design the part that we will be using for the experiment. Figure 3.2 to Figure 3.5 is the design used to construct the sample for the experiment.

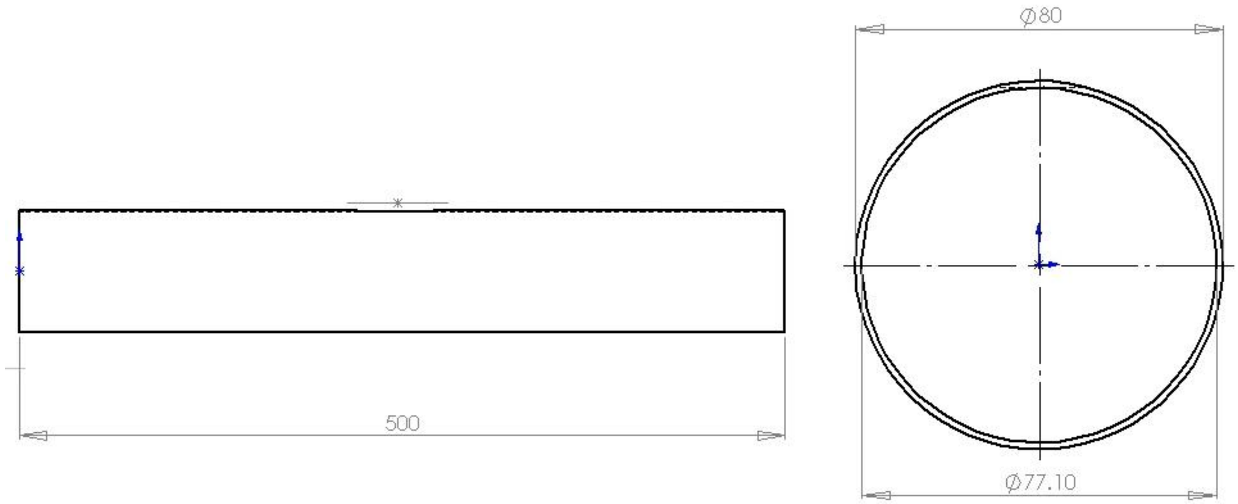

Figure 3.2: Straight pipe

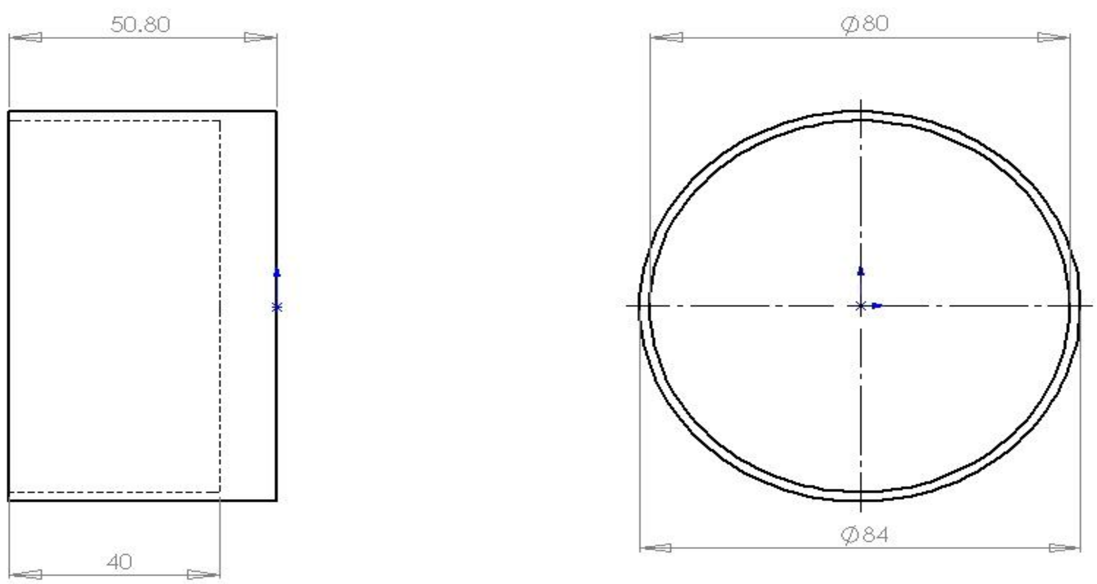

Figure 3.3: End cap

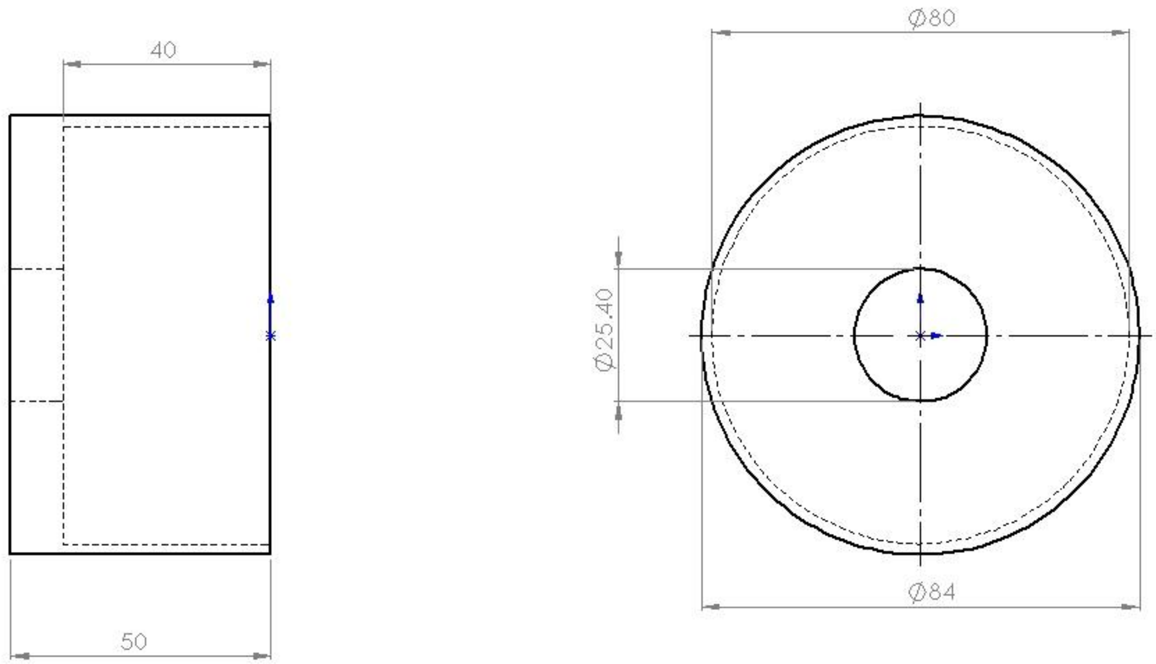

Figure 3.4: End cap with holes

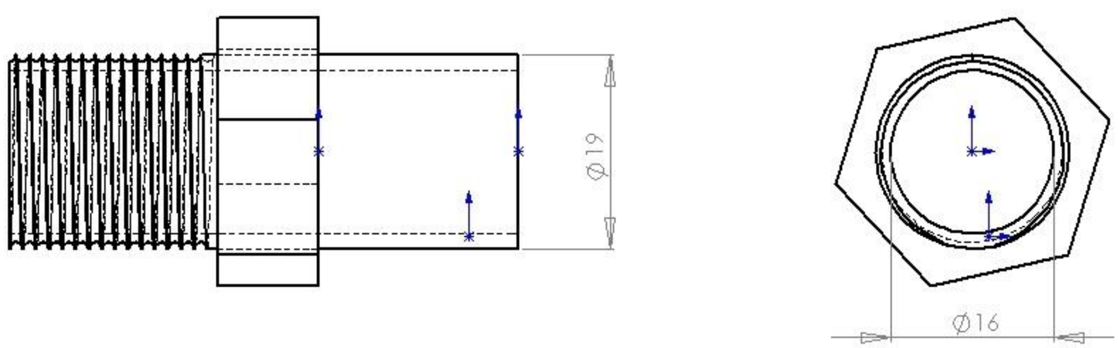

Figure 3.5: Nipple connector

The straight pipe and end cap will then be assembled together with the nipple to form a sample as shown it Figure 3.6 that will be used to determine the burst pressure of the PVC pipes. The assembled straight pipe will then connect with the pump.

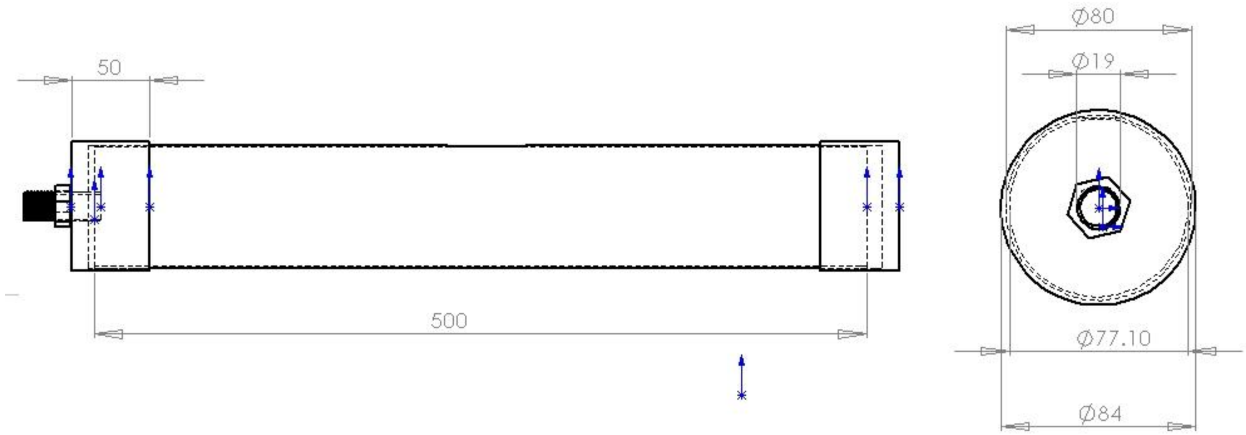

Figure 3.6: The assembly

Figure 3.7: SY 100X Hand Pressure Test Pump

The pump is bought from the supplier at Kuantan rather than fabricating one because the aim of this research is not about making a pump but to study the burst pressure of PVC straight pipes. The type of pump used is the manual hydraulic pump brand SY 100X Hand Pressure Test Pump as shown in the Figure 3.7 above.

3.3 EXPERIMENT SETUP

The design of this research's experiment is consist of a pump and sample of experiment connected by hose and connectors. The water is supplied from the pipe to the hydraulic pump which then transferred the water into the sample through the hose. The pipe will then experience an increase in the internal pressure before experiencing burst pressure. The setup of the experiment is shown below in Figure 3.8.

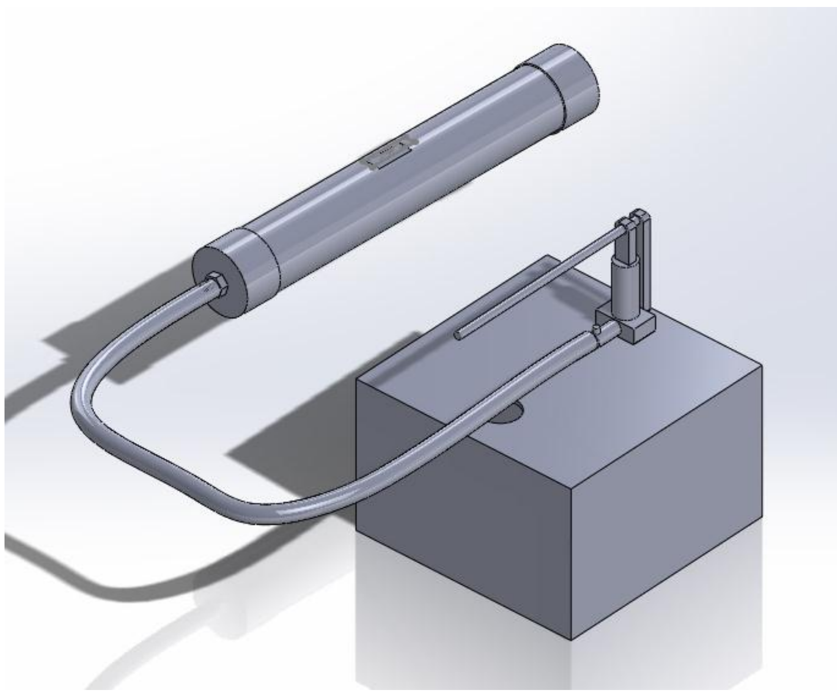

Figure 3.8: Experiment setup

3.4 LIST OF MATERIALS

Before running an experiment, as usual, the list of materials must be prepared so that the prices for the materials can be surveyed first. The prices are needed for the making of the bill of materials. Figure 3.9 to Figure 3.15 below are the lists of materials:

(i) 3” Straight Pipes

Figure3.9: Straight pipes

(ii) 3” PVC End Cap

Figure 3.10: 3” PVC end cap

(iii) ½” Nipple Connector

Figure 3.11: ½” nipple connector

(iv) PVC Solvent Cement

Figure 3.12: PVC solvent cement

(v) PTFE Tape

Figure 3.13: PTFE Tape

(vi) Araldite Epoxy

Figure 3.14: Araldite epoxy

(vii) Hose

Figure 3.15: Hose

3.5 PROCEDURE

The procedure for the experiment in order to study the PVC pipes' burst pressure can be divided into three stages. The first one is the steps for the assembly of the sample and the second one is the procedure for the experiment. The last procedure is for the theoretical result.

3.5.1 Steps to assemble the sample

1) Cut a 3" straight pipe into a length between 400 mm to 500 mm.
2) Drill a hole through the end cap in order to connect it with the nipple connector. The dimension of the hole is the same as the connector's dimension.
3) Clean the surface where the straight pipes and the cap will be bonded in order to remove any thing that will lower the percentage of boding between both surfaces.
4) Apply the PVC solvent cement at the place where the straight pipe will be joined with end cap and also place where the end cap will be joined with the nipple connector.

5) Put the surfaces together and hold them firmly for thirty seconds in order to produce a tight connection.
6) Remove all the excess solvent cement as quickly as possible to prevent unwanted chemical attack on exposed joints.
7) The joint should not be disturbed or strained for 5 minutes after jointing.
8) Allow the cement to dry for about more than 24 hours according to the instruction given at the container.

3.5.2 Steps for the experiment

1) Fill the straight pipe with water and check whether there is any leaking at the connection. If there is no leaking, then the experiment can be continued. If there is a leak then apply the solvent cement at the leaking place again.
2) Connect the hose with the pump and at the connector of the assembled straight pipe.
3) Start the experiment by pumping the test pump at a consistent speed until the PVC pipe fails.
4) Check the pressure gauge at the same time the PVC pipe fails.
5) If there is a leak after the pressure had been exerted, apply Araldite epoxy at the leaking place in order to further secure the area.
6) Introduce a gouge defect at the middle of a new straight pipe using a drill size of 2.0 mm. Make sure that the defect is not applied until a hole through the wall is formed.
7) Repeat steps 1 until 4.
8) Repeat step 6 and 7 using different drill sizes of 3.0 mm, 4.0 mm and 5.0 mm.
9) Record the result in Table 3.1.

3.5.3 Steps for the theoretical result

1) Use equation (2) in order to find the theoretical result for the perfect pipe.
2) Use equation (18) in order to find the theoretical result for the damaged pipes.
3) List the result in Table 3.2.
4) Compare the result of the theoretical result with experimental result by putting the result inside Table 3.2.
5) Further calculate the theoretical result of the burst pressure by using other existed burst pressure formula such burst pressure for ASME B31G, modified ASME B31G, RSTRENG, DNV-RP-101 and SHELL92 in order to determine whether these equations are also valid for PVC pipes.
6) Record the burst pressure obtained by the other equations in Table 3.3.

3.6 TABLE OF RESULT

The results obtained from experiments are recorded in Table 3.1 and Table 3.2 while theoretical results obtained from calculations are recorded in Table 3.2. The tables are as shown as follow:

Table 3.1: Experimental result

Defect’s Size (mm)	Burst Pressure (MPa)
No defect	
2.0	
3.0	
4.0	
5.0	

Table 3.2: Comparison between experimental and theoretical result

Defect (mm)	Experimental Collapse Pressure (MPa)	Theoretical Collapse Pressure (MPa)
None		
2.0		
3.0		
4.0		
5.0		

For the theoretical results obtained from calculation by using the formula mainly for metal pipes, the values of burst pressure are recorded in Table 3.3 below.

Table 3.3: Theoretical result by using equations for metal pipes

Standard	Collapse Pressure for 2 mm(MPa)	Collapse Pressure for 3 mm(MPa)	Collapse Pressure for 4 mm(MPa)	Collapse Pressure for 5 mm(MPa)
ASME B31G				
RSTRENG				
Modified ASME B31G				
DNV-RP-101				
SHELL92				

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In this chapter, the result and the discussion on the result will be explained. The result of this research is obtained from the experiment that had been designed before and from calculating the formula obtained from other research. Both the result will be compared in order to determine whether the actual value of the burst pressure obtained from the experiment is bigger than the theoretical value obtained from the calculation using formula. In the result, there will be the comparison between the main formula used for the theoretical value with other formula from ASME, in order to see the effectiveness of the formula. The results of the research will then be discussed together the limitations that occurred or faced during the research was in progress.

4.2 RESULTS

4.2.1 Experimental burst pressure

Several experiments had been conducted in order to determine the actual burst pressure of the PVC pipes due to internal pressure. The experiments involved pipes with no defect and the pipes with defect introduced on them. The results obtained from the experiments can be seen in Table 4.1 below:

Table 4.1: Experimental burst pressure

Defect (mm)	Collapse Pressure (MPa)
None	0.57
2.0	0.55
3.0	0.54
4.0	0.52
5.0	0.50

4.2.2 Theoretical burst pressure

4.2.2.1 Perfect pipe

In order to obtain the theoretical result for the perfect PVC pipe, the formula used is as shown below. The calculation is using the Barlows Equation that widely used in predicting the burst pressure:

$$P = \frac{2T_{min}s}{(Dm_{min} - T_{min})}$$

Where,

P= internal pressure (MPa)

T_{min} = minimum wall thickness (mm)

s = allowable stress (MPa)

Dm_{min}= minimum outside diameter (mm)

Example of calculation:

$P = \frac{2(2.9)(6.9)}{(80 - 2.9)}$

$P = 0.52\ MPa$

4.2.2.2 Pipe with defect

For the theoretical result, we will be using the formula derived by (Netto, 2010).

$$\frac{P_{def}}{P} = \left[\frac{1 - \frac{d}{t}}{1 - \frac{d}{t}\left(1 - \left(\frac{c}{\pi D}\right)^{0.4}\left(\frac{l}{10D}\right)^{0.4}\right)}\right]^{2.675}$$

Where,

P_{def} = collapse pressure of the defective pipe (MPa)

P = collapse pressure of the perfect pipe (MPa)

D = outside diameter of the pipe (mm)

d = maximum depth of the defect (mm)

c = maximum width of the defect (mm)

l = maximum length of the defect (mm)

t = wall thickness of the pipe (mm)

Example of the calculation:

P = 0.52MPa

D = 80 mm

d = 1 mm

c = 5 mm

l = 5 mm

t = 2.9 mm

$$\frac{P_{def}}{0.52} = \left[\frac{1-\frac{1}{2.9}}{1-\frac{1}{2.9}\left(1-\left(\frac{5}{\pi(80)}\right)^{0.4}\left(\frac{5}{10(80)}\right)^{0.4}\right)}\right]^{2.675}$$

$$P_{def} \quad = 0.500\ MPa$$

The burst pressure obtained from the calculation can be seen in Table 4.2 and the comparison between experimental result and theoretical result can be seen in Table 4.3. From the result shown in Table 4.3, the actual burst pressure obtained from the experiment is bigger that the theoretical burst pressure obtained by using formula. This can be seen from both the burst pressure of a perfect pipe and also the values from the defective pipes. Both have shown that the actual burst pressure is bigger than the value obtained theoretically. As example, the value of burst pressure obtained from the experiment for the perfect pipe is 0.57 MPa while the value of burst pressure obtained by using formula is 0.520 MPa.

From Table 4.3, the different between the defective pipes' burst pressure is very small. From this we can conclude that if the defect introduced to the pipes is in terms of different sizes but constant depth, the burst pressure will only had a small different. This can be said that the sizes in terms of length and width did not influence the burst pressure of the pipes too much. However, if the defects are introduced in terms of different depths, the burst pressure may show a significant different according to the calculation.

Table 4.2: Theoretical burst pressure based on calculations

Defect (mm)	Collapse Pressure (MPa)
None	0.520
2.0	0.510
3.0	0.507
4.0	0.504
5.0	0.500

Table 4.3: Comparison between experimental and theoretical burst pressure

Defect (mm)	Experimental Collapse Pressure (MPa)	Theoretical Collapse Pressure (MPa)
None	0.57	0.520
2.0	0.55	0.510
3.0	0.54	0.507
4.0	0.52	0.504
5.0	0.50	0.500

4.2.2.3 Other Equations

(i) ASME B31G

$$P_f = \frac{2t\ (1.1\sigma_y)}{Do}\left[\frac{1-\left(\frac{2}{3}\right)(\frac{d}{t})}{1-\left(\frac{2}{3}\right)(\frac{d}{t})/M}\right]$$

M (Folias Factor) is given by:

$$M = \sqrt{1 + 0.8\left[\frac{l^2}{(Do)(t)}\right]}$$

(ii) RSTRENG

$$P_f = \frac{2t\ \sigma_f}{Do}\left[\frac{1-(\frac{d}{t})}{1-(\frac{d}{t})/M}\right]$$

Flow stress is given:

$$\sigma_f = \text{SMYS} + 60\text{MPa}$$

Bulging factor is given:

$$M = \sqrt{1 + 0.6257\left[\frac{l^2}{(Do)(t)}\right] - 0.003375\left[\frac{l^2}{(Do)(t)}\right]^2}$$

(iii) MODIFIED ASME B31G

$$P_f = \frac{2t\ \sigma_y}{Do}\left[\frac{1-0.85(\frac{d}{t})}{1-0.85(\frac{d}{t})/M}\right]$$

M (Folias Factor) is given:

$$M = \sqrt{1 + 0.6257\left[\frac{l^2}{(Do)(t)}\right] - 0.003375\left[\frac{l^2}{(Do)(t)}\right]^2}$$

(iv) DNV-RP-101

$$P_f = \frac{2t\ \sigma_u}{Do - t}\left[\frac{1-(\frac{d}{t})}{1-(\frac{d}{t})/M}\right]$$

M (Folias Factor) is given by:

$$M = \sqrt{1 + 0.31\left[\frac{l^2}{(Do)(t)}\right]}$$

(v) SHELL92

$$P_f = \frac{2t\ 0.9\sigma_u}{Do - t}\left[\frac{1 - (\frac{d}{t})}{1 - (\frac{d}{t})/M}\right]$$

M (Folias Factor) is given by:

$$M = \sqrt{1 + 0.8\left[\frac{l^2}{(Do)(t)}\right]}$$

The theoretical value obtained from the main equation is then compared with other equations taken from standard that usually used for metal pipes such as ASME B31G, modified ASME B31G, RSTRENG, DNV-RP-101 and SHELL92. The reason why the results are compared with these equations is to determine whether metal pipes' equations are valid in calculating the burst pressure for PVC. From the result shown in Table 4.4, we can see that only RSTRENG is highly unsuitable to be used for PVC pipes as the value of burst pressure is too high compared to value from main equation and experiment. For the equations for the other four standards which are ASME B31G, modified ASME B31G, DNV-RP-101 and SHELL92, the different between the values are not too visible compared to the result shown by RSTRENG. Therefore, it can be used but it is not recommended to use equations for metal pipes as it is not accurate.

Table 4.4: Theoretical burst pressure by using equations for metal pipes

Standard	Collapse Pressure for 2 mm (MPa)	Collapse Pressure for 3 mm (MPa)	Collapse Pressure for 4 mm (MPa)	Collapse Pressure for 5 mm (MPa)
ASME B31G	0.549	0.548	0.546	0.544
RSTRENG	5.235	5.217	5.193	5.163
Modified ASME B31G	0.499	0.498	0.496	0.494
DNV-RP-101	0.518	0.517	0.516	0.515
SHELL92	0.465	0.463	0.460	0.457

4.3 DISCUSSION

Figure 4.1 below shows that the sample is still in a good shape while in Figure 4.2 the pipe had experienced the burst pressure. The different between a perfectly intact pipe and a damaged pipe can be seen by just using observation. This is because a perfect pipe as shown in Figure 4.1 is grey in colour. However, after the pipe experienced burst pressure the colour grey had been reduced until it almost fully changed into white in colour. This is because the pipe had been undergone expansion due to increasing internal pressure produce by using the hydraulic pump. The white colour is the symbol when the pipe is undergone expansion.

Figure 4.1: Perfect pipe

Figure 4.2: Pipe that experienced burst pressure

The burst pressure of the PVC pipe occur in form of changing in the colour of the pipe as shown in Figure 4.2, small crack as shown in Figure 4.3 or large crack. The reason why there is several condition of defect after burst pressure is because of the consistency in pumping the pressure into the pipes. If the pressure is produced consistently fast, the pipe will experience a large crack as a result from a burst pressure. The small crack occurred as the pressure is introduced inconsistently to the pipe. When a pipe is at the final moment of experiencing burst pressure and a less pressure is introduced then only a small crack will occur.

Figure 4.3: Defect due burst pressure

For the defective pipes, the damages introduced to the pipes are different in terms of length and width while the depth of the damages remained the same which is 1 mm as shown in Figure 4.4. The actual burst pressures for the defective pipes are also higher than the values obtained from the calculation. For example, the value of burst pressure obtained from the experiment for a pipe with defect of 2 mm is 0.55 MPa while the theoretical value for the burst pressure for the same case is 0.510 MPa. However, based on the Table 4.3, we can see that the result for both actual and theoretical burst pressure is equal to 0.50 Mpa.

From both of the results, we can conclude that the actual burst pressure which obtained from experiments is bigger than the value of burst pressure obtained theoretically.

Figure 4.4: Defect introduced in form of gouge

The reason why the experimental values are higher compared to the theoretical values is because the composition of the samples used for the experiments. The composition of the PVC pipes used in the experiment cannot be taken for granted as different structures of the pipes can lead to different pressure although the different may not be very visible. In this case, the different is quite visible with different between the pressure is about 0.05MPa. Apart from that, the value of the pressure stated in the standard is actually the safety factor of the pipes or the pressure rating of the pipes. This value can be said to be the maximum allowable pressure that can be subjected to the pipes. Although the actual value may be higher but the value was standardized at a value higher than the actual ones as to prevent any collapse happened due to excessive pressure experienced by the pipes. For this experiment, the pressure rating of the pipes is 0.6 MPa. From the experiment, the pressure required for the pipes to burst is 0.57 MPa while the theoretical value is 0.520 MPa. From these results, we can see that the pressure rating standardized for the pipes is 0.6 MPa, higher than the value of the actual and theoretical burst pressure. On the other hand, the value of burst pressure obtained by using calculation especially the equations used in predicting the damaged pipes burst pressure are not accurate as there is a significant difference between these two types of defects in that the defect depth profile for a machined defect generally has a more or less uniform depth whereas the depth profile for a real defect is irregular and cannot be characterized by a simple shape. Because a majority of the burst capacity models approximates the defect profile by a simple shape that depends only on the defect length and maximum defect depth, the difference in the defect profile between machined and real defects implies that such an approximation has a larger impact on the prediction accuracy for real defects than that for machined defects.

During the time where the experiments were conducted, there are several problems and limitations that we encountered. As example, there were leakages occurred during the experiments. This is because the lack of experiences handling with PVC pipes and joining them with connectors. The building of the samples for the experiment as example need a very thorough work as the connection need to withstand high pressure in order to make sure that the pressure is released at the body of the PVC pipe rather than broke out at the connections. A long period of time was used in order to perfect the experiment before the real experiment was finally conducted. Apart from that, there are also with the price to make the samples. This is because components such as PVC cap is very costly and once the cap is joined with the PVC pipes, the cap cannot be reused as it stick with the pipes almost permanently. Therefore, if there is a mistake then a new cap had to be bought this means more money. Besides the cap, the Araldite as shown in Figure 4.5 below, that been used as the final touch up to strengthen the bonding between the cap and the pipe is also very costly.

Figure 4.5: Araldite Epoxy

Figure 4.6: Application of Araldite Epoxy at the joint

One set of Araldite can only be enough for one set of experiment if the joint between straight pipes and cap are fully covered by the epoxy as shown in Figure 4.6. Thus, the need to finish up a sample is almost equal to a set of Araldite itself. Therefore, the cost to conduct the research is quite high. The items for the experiment are also sometimes very hard to be found. As example, the hydraulic test pump that had been used for the research is hard to be found. Besides that, the chemicals that supposedly to be used to clean the surface of the pipes before the PVC cement is put onto the surface is very hard to be found. Therefore, the Araldite had to be introduced in order to add more strength to the bonding between the PVC pipes and the caps. Apart from that, there is a time when the leakage is uncontrollable that the joint had to be covered by using plastic welding as shown in Figure 4.7. However, PVC welding is uncommon here that it is not available inside the lab and also at the surrounding area. The only place that available and known to have PVC welding is in Penang and thus, traveling to Penang is necessary in order to use the PVC welding.

Figure 4.7: PVC welding

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter will review on the conclusion of this particular research, whether all the objectives had been achieved or not. There are also several recommendations that had been included in this chapter that can be used by other researchers in order to improve the results of the experiment or to increase the efficiency of the research. The recommendations are generally about ways to overcome the limitations and obstacles that had been or might be faced in order to complete the research.

5.2 CONCLUSION

As a conclusion, this research had successfully achieved all the objectives that had been stated in Chapter 1. The first objective is to determine the burst pressure of a perfect pipe and also damaged pipes. From the experiment, the value of the burst pressure for the perfect pipe is 0.57 MPa. The results for the damaged pipes are 0.55 MPa, 0.54 MPa, 0.52 MPa and 0.50 MPa for the defect with size of 2.0 mm, 3.0 mm, 4.0 mm and 5.0 mm respectively. Thus, the first objective had been achieved. Next, the second objective is to compare the burst pressure obtained from the experiment with the theoretical value obtained from calculations. From the result obtained, the value of the theoretical burst pressure calculated using the equation for perfect pipe and equation for damaged pipe can be seen. The comparison between experimental value and theoretical value can be also clearly seen in the result.

The third objective, which is the last one for the research is to suggest a new design of experiment for the short term hydrostatic test for MS628 pipes. As stated inside the problem statement, the standard released by the Department of Malaysian Standard was not included with the design of experiment for short term hydrostatic test. Unlike the other test that came with a detailed procedure and experimental set up, the Appendix D, which is the section for the short term hydrostatic test only came with a very simple description on the test specimen, apparatus, procedure and sampling method. There is no specific and detailed explaination on the experimental set up for the test. Therefore, this research can be proposed as the possible experimental set up for the short term hydrostatic test inside the MS628 standard. This is because the value of the burst pressure obtained from this experimental set up is consistence and not too far with the burst pressure obtained from calculation.

There are some additional works that had been done such as comparing the result obtained from the main equation with other equations from other standards such as ASME B31G, RSTRENG, PCORRC, Modified ASME B13G, DNV and SHELL92. This comparison is made in order to determine whether the other equation such as the ASME which is basically for metal like the other standards is relevant to be used for the PVC pipes. Based on the result shown in Chapter 4, some of the equations can be used such the equation for DNV but there are also equations that not valid to be used such as RSTRENG as the different between the burst pressure from the experiment and RSTRENG’s equation is too big. However, it is not recommended to use metal pipe’s equation as the value of the burst pressure is not accurate and questionable.

5.3 RECOMMENDATIONS

There are several limitations and obstacles that had been encountered during the completion of this research. As examples, the leaking at the join between the end cap and the PVC pipes. Therefore, here are some recommendations that can be taken into account in order to further improve the experiment and hopefully the results as well:

(i) Use of plastic welding or PVC welding is very suitable if one wants to prevent any leakage at the joint or to produce a better joint strength.

(ii) Apply primer on the surface of the pipe before applying the PVC cement in order to improve the contact between the cap and the straight pipes. This is because primer is a chemical solution that not just cleans the surface of the pipes but also act as an agent to make the bonding become stronger.

REFERENCES

All-About-Pipe.com. PVC Pipe (online). http://www.all-about-pipe.com/pvc-pipe.html (3 December 2012).

American Water Works Association. 2002. *PVC Pipe: Design and Installation*. American Water Works Association.

Bernama. 2008. Major PVC Pipes Players Agree On Quality Standards (online). http://www.bernama.com/bernama/v3/printable.php?id=329978 (24 May 2012).

Chasis, D.A. 1988. *Plastic Piping System*. Industrial Press Inc.

Cruz, J., Davis, B., Gramann, P. and Rios, A. 2010. A study of the freezing phenomena on PVC and CPVC pipe systems. *68th Annual Technical Conference of the Society of Plastic Engineers 2010 (ANTEC 2010)*. **1**: 225-267.

Cosham, A. 2003. The effect of dents in pipelines - Guidance in the pipeline defect asessment manual (online). http://www.penspen.com/Downloads/Papers/Documents/EffectofDentsinPipelines.pdf (5 December 2012).

Davis, P., Burn, S. and Gould, S. 2007. A physical probabilistic model to predict failure rates in buried PVC pipelines. *Reliability Engineering & System Safety*. **9**: 1258-1266.

Department of Standards Malaysia. 1999. *Specification for Unplasticized PVC (uPVC) Pipes for Water Supply: Part 1: Pipes (First Revision).*

Edwards, K. L. 1998. A designers' guide to engineering polymer technology. *Materials & Design*. **19**(1-2): 57-67.

Epco. 2011. *Continuing Quality in PVC-U Pipes.*

epco. 2013. PVC-U Metric Pipes, Fittings & Valves Technical InformationPVC-U Metric Pipes, Fittings & Valves Technical Information (online). http://www.epco-plastics.com/PVC-U_metric_technical.asp (3 December 2012)

Farshad, M. 2006. Plastic pipe systems. *Plastic Pipe Systems: Failure Investigation and Diagnosis*. **1**: 1-27

Hashem El-Sayed, A.A. 2000. *Oil and gas Pipelines Design, Maintenance and Repair.* Slide. Cairo University : Faculty of Engineering

Hedley Industrial Group. 2012. General Properties of uPVC Pipe Material (online). http://www.hedley - international.com / index.php?option = com_content&view = article & id = 118&Itemid =121 (5 December 2012)

Jelwan, J., Chowdhury, M. and Pearce, G. 2013. Design for creep: A critical examination of some methods. *Engineering Failure Analysis*. **27**: 350-372

Mackerle, J. 2004. Creep and creep fracture/damage finite element modeling of engineering materials and structures: an addendum. *International Journal of Pressure Vessels and Piping*. **5**: 381-392.

Meliani, M. H., Azari, Z., Pluvinage, G and Capelle, J. 2010. Gouge asessment for pipes and associated transferability problem. *Engineering Failure Analysis*. **17**: 1117-1126.

Meliani, M.H., Matvienko, Y. G. and Pluvinage, G. 2011. Corrosion defect assessment on pipes using limit analysis and notch fracture mechanics. *Engineering Failure Analysis*. **1**: 271-283.

Mulder, K. and Knot, M. 2001. PVC plastic: a history of systems development and entrenchment. *Technology in Society*. **23**: 265-286.

Neilson, R., Wood, J., Hamilton, R. and Li, H. 2010. A comparison of plastic collapse and limit loads for single mitred pipe bends under in-plane bending. *International Journal of Pressure Vessels and Piping*. **10**: 550-558.

Netto, T. A. 2010. A simple procedure for the prediction of the collapse pressure of pipelines with narrow and long corrosion defects - Correlation with new experimental data. *Applied Ocean Research*. **10**: 132-134

Netto, T. A., Ferraz, U.S. and Botto, A. 2007. On the effect of corrosion defects on the collapse pressure of pipelines. *International Journal of Solids and Structures*. **22-23**: 7597-7614.

Pita, V.J.J.R., Sampaio, E.E.M. and Monteiro, E.E.C. 2002. Mechanical properties e valuation of PVC/plasticizers and PVC/thermoplastic polyurethane blends from extrusion processing. *Polymer Testing*. **21**: 545-550.

Rie Ito. Seshimo. F. Haishima, Y. Hasegawa, C. and Isama, K. 2005. Reducing the migration of di-2-ethylhexyl phthalate from polyvinyl chloride medical devices. *International Journal of Pharmaceutics.* **1-2**: 104-112

The Freedonia Group. 2009. Global Demand for Plastic Pipe to Rise (online). http://www.pipelineandgasjournal.com/global-demand-plastic-pipe-rise
(3 December 2012).

Vinidex. 2012. Pressure consideration (online). http://www.vinidex.com.au/technical/pvc-pressure-pipe/pressure-considerations/ (3 March 2013).

Walker Jr., R. P. 1981. The effects of UV aging on PVC pipe. *Proceeding s of the International Conference on Underground Plastic Pipe*. 446.

Yarahmadi, N., Jakubowicz, I. and Hjertberg, T. 2003. The effects of heat treatment and ageing on the mechanical properties of rigid PVC. *Polymer Degradation and Stability*. **1**: 59-72

APPENDIX A

Gantt Chart FYP 1

	W1	W2	W3	W4	W5	W6	W7	W8	W9	W 10	W 11	W 12	W 13	W 14
Confirmation of title, objective and scope														
Searching related journals														
Design parts and surveying the prices														
Buying materials and fabricate parts														
Run experiment														
Proposal presentation														

APPENDIX B

Gantt Chart FYP 2

	W1	W2	W3	W4	W5	W6	W7	W8	W9	W 10	W 11	W 12	W 13	W 14
Run Experiment														
Analyze Data and Discussion														
Draft Report														
Report Submission and Presentation														

APPENDIX C

Short-term hydrostatic test

C1. Form of test specimen

Each test specimen shall be a piece of a pipe with a free length between fittings equal to 10 times the outside diameter of the pipe or subject to a minimum of 250 mm and a maximum of 750 mm. The specimen may consist of straight pipe, end cap and nipple connector.

Nominal Size	Outside Diameter		Wall Thickness							
			Class B (6 Bar)		Class C (9 Bar)		Class D (12 Bar)		Class E (15 Bar)	
Inch	Min. mm	Max. mm	Min. mm	Max. mm	Min. mm	Max. mm	Min. mm	Max. mm	Min. mm	Max. mm
½	21.2	21.5							1.7	2.1
3/4	26.6	26.9							1.9	2.5
1	33.3	33.8							2.2	2.7
1.1/4	42	42.5					2.2	2.7	2.7	3.2
1.1/2	48	48.5					2.5	3	3.1	3.7
2	60	60.7			2.5	3	3.1	3.7	3.9	4.9
3	88.4	89.4	2.9	3.4	3.5	4.1	4.6	5.3	5.7	6.6
4	113.7	114.9	3.4	4	4.5	5.2	6	6.9	7.3	8.4
5	139.4	141	3.8	4.4	5.5	6.4	7.3	8.4	9	10.4
6	167.4	169.1	4.5	5.2	6.5	7.6	8.8	10.2	10.8	12.5
8	218	220.2	5.3	6.1	7.5	9	10.3	11.9	12.6	14.5
10	271.6	274.4	6.6	7.6	9.7	11.2	12.8	14.8	15.7	18.1
12	332.2	325.5	7.8	9	11.5	13.3	15.2	17.5	18.7	21.6
14	353.7	357.3	8.5	9.8	12.6	14.5	16.7	19.2		

Table C1. Dimensions of PVC pipes available

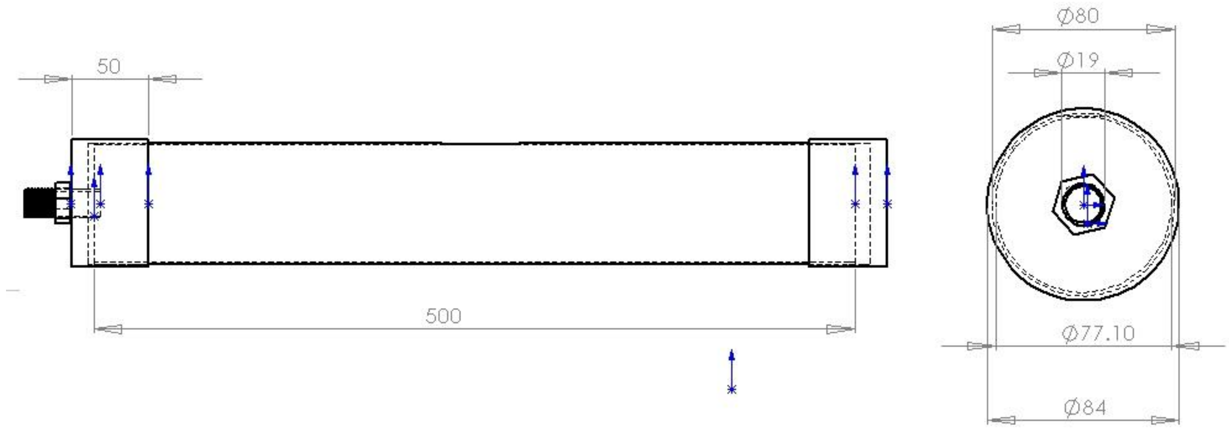

Figure C1. Example of test specimen

C2. Apparatus

The apparatus consists of equipment that permits the application of a controlled hydrostatic pressure to the specimens to an accuracy of ± 2%. The example of equipment that can be used is SY 100X Hand Pressure Test Pump that can be purchased from engineering shops.

C3. Procedure

C3.1 To assemble the sample

1) Cut a 3" straight pipe into a length between 400 mm to 500 mm.
2) Drill a hole through the end cap in order to connect it with the nipple connector. The dimension of the hole is the same as the connector's dimension.
3) Clean the surface where the straight pipes and the cap will be bonded in order to remove any thing that will lower the percentage of boding between both surfaces.
4) Apply the PVC solvent cement at the place where the straight pipe will be joined with end cap and also place where the end cap will be joined with the nipple connector.
5) Put the surfaces together and hold them firmly for thirty seconds in order to produce a tight connection.

6) Remove all the excess solvent cement as quickly as possible to prevent unwanted chemical attack on exposed joints.
7) The joint should not be disturbed or strained for 5 minutes after jointing.
8) Allow the cement to dry for about more than 24 hours according to the instruction given at the container.

C3.2 To run the experiment

1) Fill the straight pipe with water and check whether there is any leaking at the connection. If there is no leaking, then the experiment can be continued. If there is a leak then apply the solvent cement at the leaking place again.
2) Connect the hose with the pump and at the connector of the assembled straight pipe.
3) Start the experiment by pumping the test pump at a consistent speed until the PVC pipe fails.
4) Check the pressure gauge at the same time the PVC pipe fails.
5) If there is a leak after the pressure had been exerted, apply Araldite epoxy at the leaking place in order to further secure the area.
6) Introduce a gouge defect at the middle of a new straight pipe using a drill size of 2.0 mm. Make sure that the defect is not applied until a hole through the wall is formed.
7) Repeat steps 1 until 4.
8) Repeat step 6 and 7 using different drill sizes of 3.0 mm, 4.0 mm and 5.0 mm.

C4. Sampling and assessment of results

The result should be taken after the pipe had been successfully bursted. The value of the pressure during the pipe experienced burst pressure is recorded.