Simulation Study on Braided Hose Failure in Major Equipment at PETRONAS Carigali Sdn Bhd (PCSB)

by

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Dissertation submitted in partial fulfilment of

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(Mechanical)

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CERTIFICATION OF APPROVAL

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(MECHANICAL)

Approved by,

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(Ir. Dr. SUHAIMI BIN HASSAN)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ELEENA AQMAL BINTI AB RAHIM

ABSTRACT

In this study, the actual braided hose from Petronas Carigali Sdn Bhd (PCSB) was obtained in order to investigate the possible causes of failure. The hose is being assembled with inner tube of polytetrafluroethylene (PTFE) and externally braided outer tube corrosion-resistant steel (CRES). The actual prototype hose had undergone failures near the end of the fittings. The actual braided hose measurements were taken and modelled using SOLIDWORKS software. The ANSYS static structural stimulation was used to measure the stress distribution on the hose due to pressure applied with various bend shapes. The simulation was done by fixing the end of the pipe and exerting force inside the inner layer of PTFE. The results of the simulation have shown that the braided hose proved high stress near the fittings. Thus, the hose was unable to stand the pressure exerted, the reasons of failure was identified. Further analyses were done to the braided hose to investigate the other possible of failure using failure analysis method. A device was proposed to Petronas Carigali Sdn Bhd (PCSB) that can earlier detect braided hose failure.

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND OF STUDY

A hose is defined as a piece of tubing that is commonly used to move liquids or gases from one point to another. The shape of the hose is cylindrical which has circular cross section. The application of hoses is widely used in gardening, fire fighting, automobile industry and the industrial usage of transporting liquid or gas. However, in the industrial application, hoses need to withstand a high pressure and high temperature environment which hoses are made of metal. Generally, the hose used are stainless steel for corrosion prevention. Numerous applications exist that require the use of flex hoses. Therefore, a need exists to understand the mechanical properties and characteristics with great detail before ensuring that a certain flex hose is appropriate for a given scenario (Pierce & Evans, 2012).

Stainless hose are widely used and common to the plant industry as it has high physical strength combined with light weight. Besides, the flexible hose are highly resistance to fire, moisture, abrasion and penetration of external environment. The tubing of the hose is reinforced with non-rusting metal layer. Hose design depends on the application when transporting the liquid or gas. Hose can be classified by the type of service (hydraulic, pneumatic, corrosion-resistant), by material, by pressure, or by type of construction.

Hoses are classified by types which are non-metallic and metallic. The non-metallic hose are made of rubber tubing which are using the material of Polyvinyl chloride (PVC) with various colours as shown in Figure 1.1 (Spellman, 2008). PVC is light weight, low cost, good mechanical strength, and good mechanical toughness, resistant to corrosion, easy to install makes it very evident for transporting liquids.

Figure 1.1: PVC pipe (source: www.partsbridgeassociate.com)

However, metallic hose are divided into stripwound hose and corrugated hose. Stripwound hoses consist of spirals that are loosely interlocked as shown in Figure 1.2. This provides high flexibility due to its profile structure, however not resistant to leakage of pipe. Stripwound hoses are mainly used as protective hoses for light conductors and electrical lines due to its flexibility and durability. Inversely, corrugated hose are stainless steel strip that is rolled and the edges are welded together forming a thin-walled, gas-tight tube. The corrugated hoses are pressure and vacuum tight compared to stripwound hose. After corrugated, the hose are wounded with a braided sheath on the outer layer as shown in Figure 1.2.

Figure 1.2: Stripwound hose and corrugated hose (source: www.sehose.com)

1.2 PROBLEM STATEMENT

Based on the research carried out, overpressure on the PCSB pipe will be the possible cause of failure to the stainless steel hose. The outer tube of stainless steel hose with the inner tube PTFE could cause failure due to wear between the rubbing of wires and the inner tube. The possibility of material which is fatigue crack propagation which leads to overpressure will burst on stainless steel weak points.

The common area of failure is seen on the flexible connectors of the pipe because the flexible connectors are combined through welding which produced weak points of assembly. Shown by the manufacturer, the allowable pressure of the hose is 1500 psi. Hence, working pressure larger than that could lead further to the failure of the stainless steel pipe (Márquez, Fazzini, & Otegui, 2009)

As experienced by PCSB, braided hose leaked in major equipment such as turbine and generator set were undetectable and unpredictable. The unpredictable leakage cost material and time for maintenance work on the major equipment. It is important to improve the braided hose reliability and mechanism to detect the hose leak. Further analysis will be carried out to analyse the stress distribution using Finite Element Analysis (FEA) simulation software.

1.3 OBJECTIVE

The main objectives of the project are:

- To study the type and characteristics of common braided hose used in PCSB
- To analyse the stress distribution along the braided hose using Finite Element Analysis (FEA) simulation software
- To propose the possible reasons of braided hose leak in PCSB

1.4 SCOPE OF STUDY

Actual sample of PCSB braided hose is used in this study. In order to analyse and propose the possible reasons of the braided hose leak, Finite Element Analysis (FEA) was needed to check the stress distribution on the concentration points. The FEA simulation software allows the actual PCSB braided stainless steel hose to undergo simulation of stress distribution using the parameters of the braided hose. The simulation can predict the specific area of failure and detects the potential leakage location for example at the fittings, inner tube or external tube of the hose. Based on the analysis, the simulation will be compared to the actual PCSB braided hose and several possible reasons of failure are proposed.

1.5 RELEVANCY OF THE PROJECT

In order to reduce the cost and time maintenance of the braided stainless steel hose, early detection of the braided hose failure was done through simulation software. This decreases the amount of time spend on repairing and maintenance of the hose when the hose fails. PCSB can reduce a significant amount of cost and time by using the simulation software to predict the possible failure that can occur. ANSYS software was used from the university laboratory to further analyse this failure by stress distribution. The best method is to detect braided hose failure before the actual failure. This was done using ANSYS static structural to predict the specific area of failure on the braided hose.

1.6 FEASIBILITY OF THE PROJECT

Timeline for this project is within two semesters which are equivalent to 28 weeks. In this project, the ANSYS simulation software is needed to show the stress distribution on the braided hose. The ANSYS simulation software can be obtained in the laboratory, which enables the student to use in on any available time scheduled.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

The stainless steel hose are used when it is needed to absorb the heat or pressure-induced expansion of the pipe system for major equipment where the system is exposed to high external heat, corrosion or heavy rough handling, the metal hose are flexible and can withstand high pressure.

The application of the stainless steel hoses are in addition to take up misalignment or thermal expansion of the gas pressure during the operation of the turbine and generator. Vibration and noise are also absorbed from major equipment such as pumps, compressors and engines during running of the machines. The applications of stainless steel flexible connections are fuel distribution such as connections to the lube oil system.

Indirectly, increases the internal pressure strength of the hose many fold. In practical, the braided hose are placed as an external layer of stainless steel provided to the hose. According to Cho et al. (2013), flexible hoses comprising a wire spiral support embedded in a plastic pipe wall are frequently used as part of vacuum transfer or pneumatic conveying systems in a wide range of industries where powders are handled, processed or manufactured. However, the actual hose prototype is reinforced with stainless steel outer tube and polytetrafluroethylene (PTFE) inner tube protects the hose from chemical and corrosive gases. PTFE is an engineered fluropolymer; outstand to resist a broad temperature range.

PTFE polymer has a quality characteristic of polymer that is the best damping coefficient (Okularczyk, 2007). In addition, the stainless steel hose are good vibration and noise absorber, it more efficient with PTFE material as an inner tube.

2.1 FAILURE OF HOSE

Hachemi et al., 2011 mentioned that flexible stainless steel hose are used in many applications, for example to maximize the effect of vibration on piping and car engines. The hose will fail due to dynamic loads from gas and liquid pulsation. Hachemi added that small holes or crack are the initial point of failure for hoses. Therefore, the conditions of leak before break will occur most in prediction of damage. This is valuable as it enables the reduction of the failure consequences in a working environment. (Hachemi et al., 2011)

According to Pierce & Evans (2012) flex hose that did not meet the extreme operating conditions of the assembly might cause failures in industrial applications. The problem will not only cost from an operational and schedule stand point, but it also creates a significant safety risk. It is imperative that the mechanical characteristics that are display are well known and taken into consideration during the design of the assembly with the flex hoses being integral part in major engineering assemblies such as turbine and generator. In brake hoses, the combined effects of years of flexing, high pressure and exposure to the harsh environment at the lower chassis will eventually deteriorate the brake hoses (Baaser, 2007).

Marquez et al., 2009 mentioned the fracture in the wire braid could be a possible phenomenon of fatigue crack propagation in previous worn areas that was not detected earlier. The flexible hose connection was over pressured than the maximum allowable limit defined by the manufacturer. With the widely used materials hose of plastic (PE and PVC) for common hose, it is expected the polymer will age and eventually fail (Rostum, 2008).

A key factor of the presence of contaminats of hydrocarbon leads from the ignition point and following the path of flow are the reason of failure. The failure occurred on the cylinder end, near the connector or fittings of the braided stainless steel hose. There were small holes found near the connectors or fittings were caused by the thinning of the liner PTFE due to ignition. As shown in Figure 2.1, the point of failure stated is most similar failure point when compared to the actual prototype of the braided hose failure (Royals, Chou, & Steinberg, 1997).
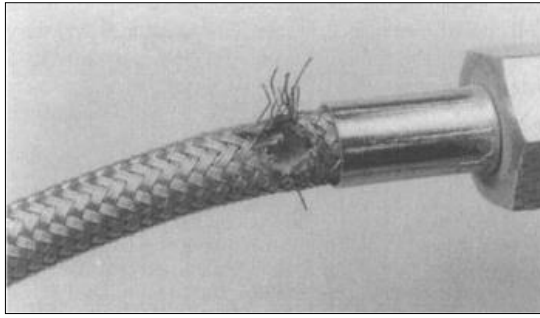
Figure 2.1: Failed section of braided hose (Royals, Chou & Steinberg)

The most common causes of failure in hydraulic hoses are the multi-plane bending that result in twisting of its wire reinforcement. The service life of a high-pressure hydraulic hose is reduced as much as 70% for twist of five degrees and a seven degree twist can result in a 90% reduction in service life. Multi-plane bending occurs from inadequate or unsecure clamping where the hose is subjected to vibration of machine or actuator movement (Voirin, 2011). The hydraulic hose are recommended to be segmented to prevent multi-plane bending as shown in Figure 2.2.
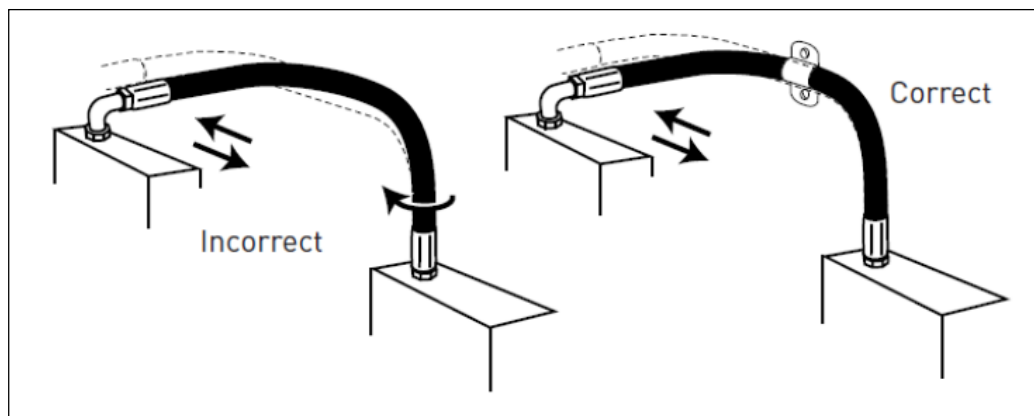
Figure 2.2: Segmenting hose to prevent multi-plane bending (source: http://www.parker.com)

Addition to the multi-bending, a failure due to hose over pressure would damage the braid and result in a longitudinal split in the inner core of the hose. The hoses inner core, causes the stress in the object to be non-uniform, where the part of the object on the outside of the bend is in tension, and the inside of the bend is in compression causes by the bending of the cylindrical object. This would result in the

outside of the bend being the most prone to failure where the area of the highest normal and shear stresses. Failure would occur starting directly on top of the outside of the bend, somewhere near the connector as shown in Figure 2.3.
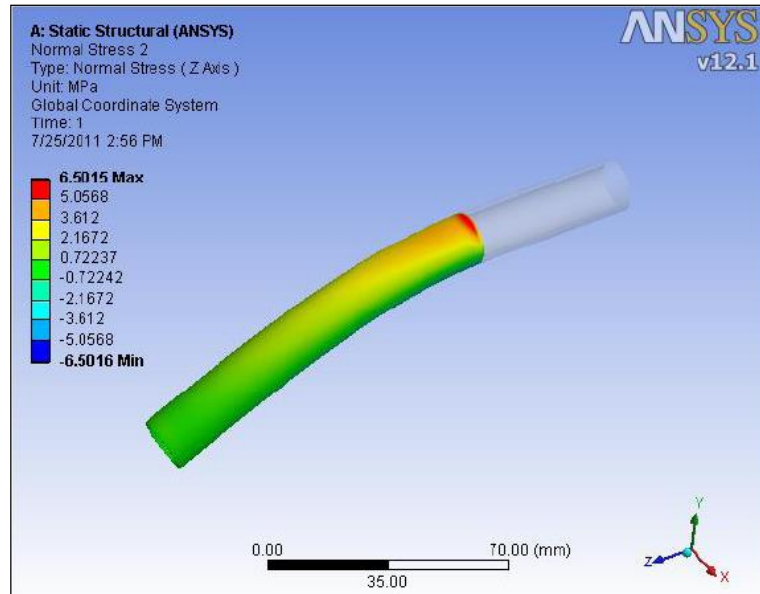
Figure 2.3: Maximum normal stress on outside of bend near connector (Voirin)

Voirin, 2011 added that once even the smallest hole or split develops in this area of the outside of the bend, it becomes a stress concentration, which greatly increases the stress at each end of this split. The stress concentration of normal stress results in sagittal tearing of the hose from the center of the split out across the top of the hose as shown in Figure 2.4.
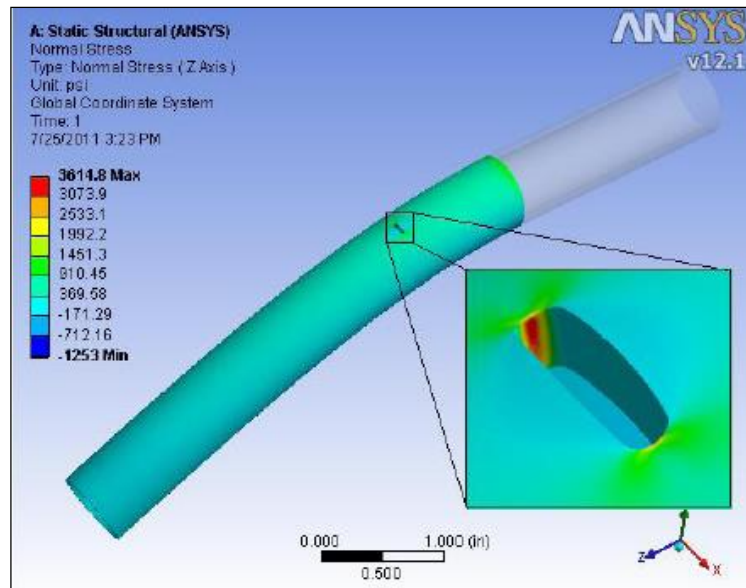
Figure 2.4: Stress concentration effects of small split increasing normal stress (Voirin)

2.2 FINITE ELEMENT ANALYSIS (FEA)

Finite element analysis (FEA) is a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects. Finite element analysis shows whether a product will break, wear out, or work the way it was designed.

According to Lee et al. (2011) using FEA, swaging part of the hose needs be analyzed because it often offers the reason why failure modes occur, like leakage as stress concentration and where in connecting part between metal and rubber part under high pressure conditions. Additional, according to Pierce & Evans (2012) due to elastic strain the braid retracted but not retract to its original position due to plastic deformation.

However, with the pressure cycle testing, the pressure needed to be much greater than maximum pressure before the elongation of the hose would continue. Finite Element model helped in better understanding of what could have caused the premature failure of the hose. The Finite Element model can be done by setting different distance from the leak hole of the pipe. This has a different corresponding frerquency value to the vibration maximum amplitude. Each node are placed to

9

indicate the different distances and in 0 degree angle to the circumferential direction of the leak hole (Liang, 2013).

Zhang & Xu (2013) suggests the method of Finite Element Analysis can be built up of identical unitcells by yarn configuration in three regions and three axis of x,y and z. With appropiate boundary conditions, the mechanical response can be simulated and deformation and stress distribution of unit cell models can be presented and the effects the braiding angle are investigated in detail. The curved yarn path in the exterior surface and corner unit cell models are considered as one straight line for the sake of simpility.

CHAPTER 3
METHODOLOGY

3.1 PROJECT WORKFLOW

This project will be done using the flowchart following sequences of project activities. This steps shown on Figure 3.1 help monitor the progress of the report which are using the method of Finite Element Analysis (FEA)
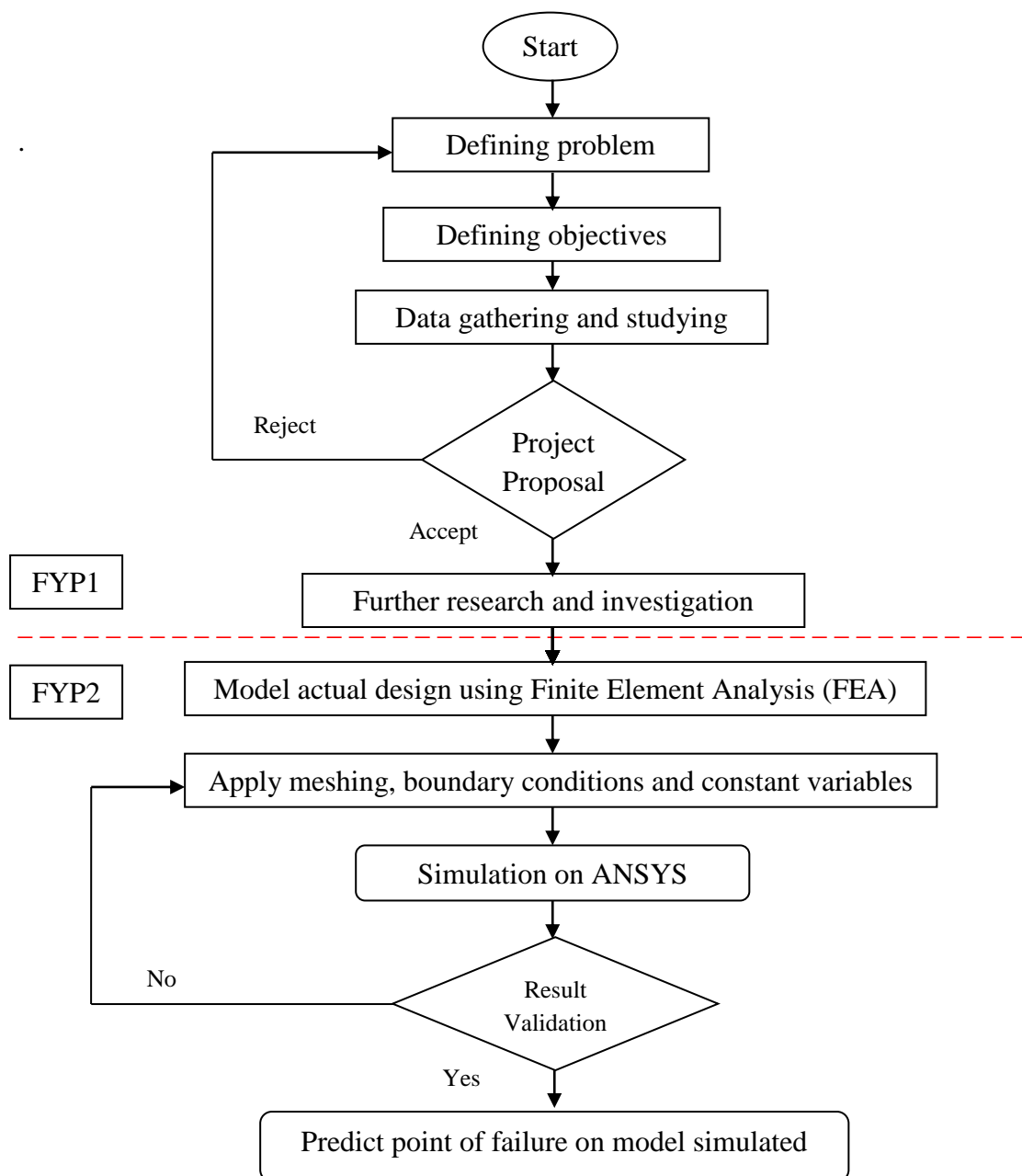
Figure 3.1: Flowchart of Finite Element Analysis

3.2 PROJECT GANTT CHART WITH KEY MILESTONES

3.2.1 Final Year Project 1

Semester	Final Year Project 1													
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Intro														
Project Topic & Actual Braided Hose Received (Process)	■	■	■											
Project Topic & Actual Braided Hose Received (Actual)	▩	▩	▮											
Research/Literature Study														
Finding Research Papers (Process)			■	■	■	■	■	■	■	■	■	■	■	■
Finding Research Papers (Actual)				▩	▩	▩	▩	▩	▩	▩	▩	▩	▩	▩
Understanding Actual Prototype (Process)			■	■	■	■	■	■	■	■	■	■	■	■
Understanding Actual Prototype (Actual)					▩	▩	▩	▩	▩	▩	▩	▩	▩	
Literature Review (Process)						■	■	▮	■	■	■	■	■	■
Literature Review (Actual)						▩	▩	▩	▩	▩				
Finite Element Analysis														
Study Software Simulation (Process)								■	■	■	■	■	■	■
Study Software Simulation (Actual)											▩	▩	▩	▩
Model Actual Prototype												▮	■	■
Profound Research														
Identify Possible Cause of Failure (Process)												■	■	■
Identify Possible Cause of Failure (Actual)											▩	▩	▩	▩
Technology to Detect Early Failure of Hose												■	■	▮
Report Submission														
Submission of Extended Proposal (Process)						■								
Submission of Extended Proposal (Actual)						▩								
Proposal Defence (Process)									■					
Proposal Defence (Actual)									▩					
Interim Draft Report													■	
Interim Report (Key Milestone)														▮
Interim Report (Actual)														▩

Legend

▮	Key Milestone
■	Process
▩	Actual

3.2.2 Final Year Project 2

Semester	Final Year Project 2														
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Finite Element Analysis															
Study Software Simulation	Process	Process	Process	Process	Process	Process	Process								
	Actual	Actual	Actual	Actual	Actual	Actual	Actual								
Model Actual Prototype							Process	Milestone							
Profound Research															
Identify Possible Cause of Failure								Process	Process	Process	Process				
										Actual	Actual	Actual	Actual		
Technology to Detect Early Failure of Hose						Milestone	Process	Process							
Report Submission															
Progress Report								Process							
								Actual							
Pre-Sedex										Process					
											Actual				
Draft Final Report											Process				
													Actual		
Dissertation (soft bound)													Process		
														Actual	
Technical Paper													Process		
														Actual	
Viva															Milestone
															Actual

Legend

Key Milestone (red)	Key Milestone
Process (blue)	Process
Actual (yellow)	Actual

3.3 BRAIDED HOSE FAILURE

In this study, the hose actual prototype used in PCSB is being assembled with inner tube of polytetrafluroethylene (PTFE) and externally braided outer tube corrosion-resistant steel (CRES). Hose braided are preferred in industrial application due to its high flexibility to adapt to the movements of the hose. Comparing to non braided corrugated hoses, braided hoses prevents longitudinal expansion of corrugated hose. The actual prototype hose undergone failure near the fittings. The Figure 3.2 shows the area of failures near the fittings of the actual hose.
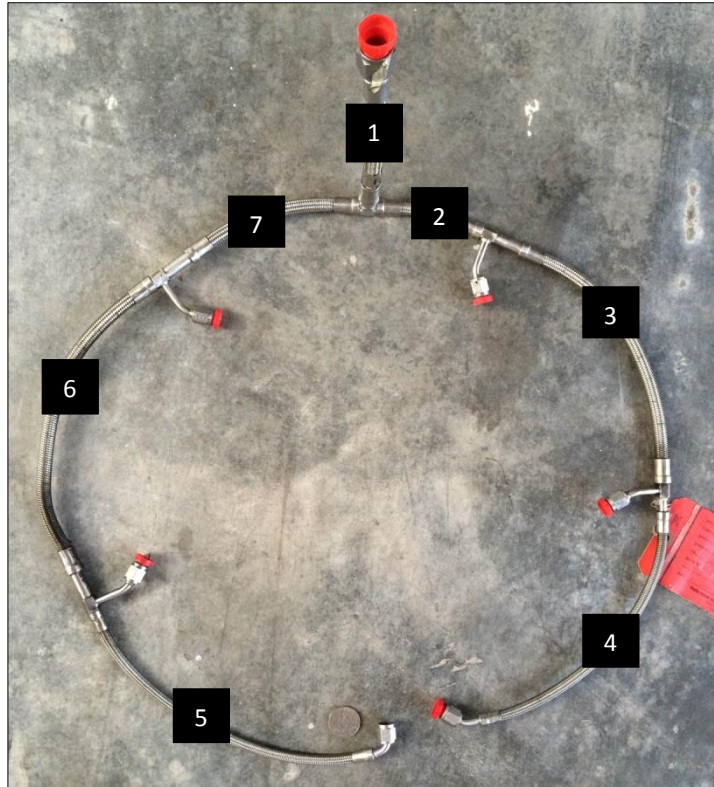

Figure 3.2: Area of failure near fittings of actual hose

3.4 MEASUREMENT OF BRAIDED HOSE

The actual braided hose was divided into section to improve the analysis study on the braided hose. This identifies the specific section of failure that occurs on the hose assembly. The Figure 3.3 shows the divided section of the hose assembly.

Figure 3.3: Braided hose assembly sections

The failure part of the hose occurs on hose section 3 and 6 (Figure 3.4 and Figure 3.5). However, hose section 3 has minimal damage and the hose is not elongated from its original diameter. In addition, hose section 6 were undergone elongation and burned. The pipe is divided into points (left end of pipe as 0 cm) according to the various diameters as shown in Table 3.1.

Figure 3.4: Hose Section 3

Figure 3.5: Hose Section 6

Table 3.4: Length and diameter of hose section 6

Length (cm)	Diameter (mm)
2	11.26
4	11.14
6	11.40
8	11.46
10	11.45
12	11.50
14	11.57
16	11.65
18	11.50
20	11.45
22	11.44

The hose are cut into cross section to identify the fitting details of the hose as shown in Figure 3.6. The end of the pipe are clamped between two layer fittings 15.27 mm away from visible hose. The length of the pipe is 220 mm for both stainless steel and PTFE excluding the fitting. Both the hose outer and inner diameter are measured using vernier caliper in the lab.

Figure 3.6: Cross section of hose fitting

3.5 MATERIAL IDENTIFICATION

The actual braided hose was received without any specifications or dimensions. The material was identified by observation and military coding on the body of the hose. The coding details are shown in Table 3.2.

Table 3.5: Military coding of braided hose

Item	Description
Military Code	MIL-DTL-25579
Title	Hose Assembly, Polytetrafluoroethylene, High temperature, Medium Pressure
Federal Supply Class (FSC):	4720 (Hose and Tubing, Flexible)

Hence, the black rubber material observed inside the actual braided pipe are identified as polytetrafluroethylene (PTFE) or commonly known as Teflon®. Thus, this identification of inner layer helped in the simulation study by inserting the specific material properties of polytetrafluroethylene (PTFE).

3.6 MODELING USING SOLIDWORKS

The modeling was done for hose section 3 and 6. Both hose 3 and 6 are assumed same length and diameter for fitting and braided pipe section for the original measurement before failure. The diameters were taken using vernier caliper obtained at the lab. The end of the pipe is extruded using SOLIDWORKS to replicate the clamping of the fitting on the hose.
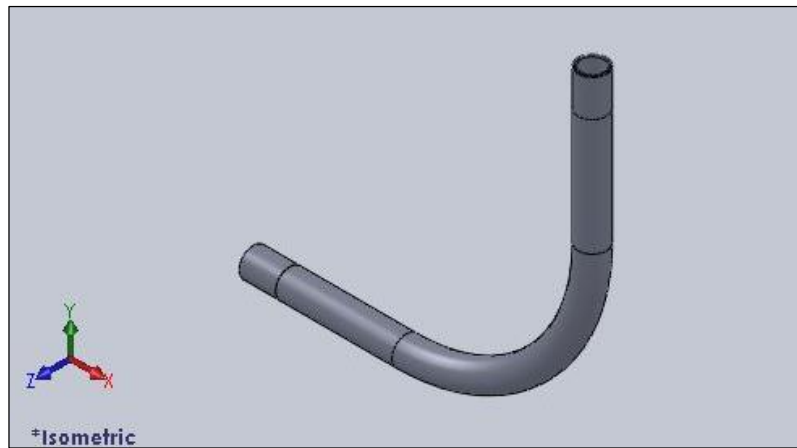
The actual braided hose are modelled in various in bend shapes. Figure 3.7, Figure 3.8, Figure 3.9 and Figure 3.10 shows the actual hose modelled in various bend shapes which are named horizontal hose, U shape hose, L shape hose and S shape hose respectively.
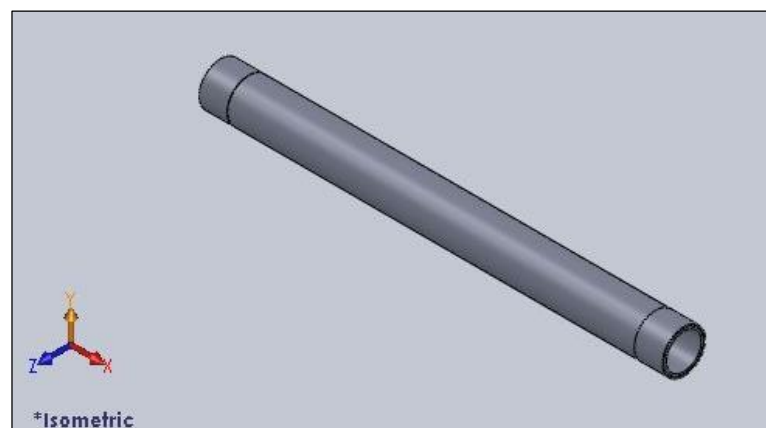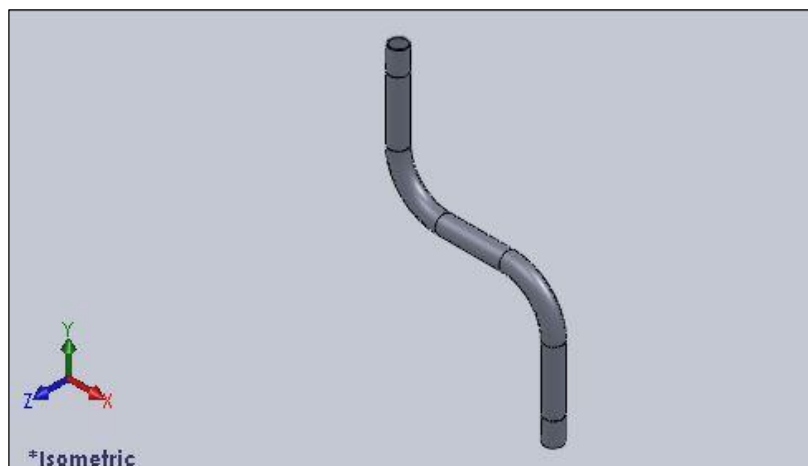

Figure 3.7: Horizontal Hose
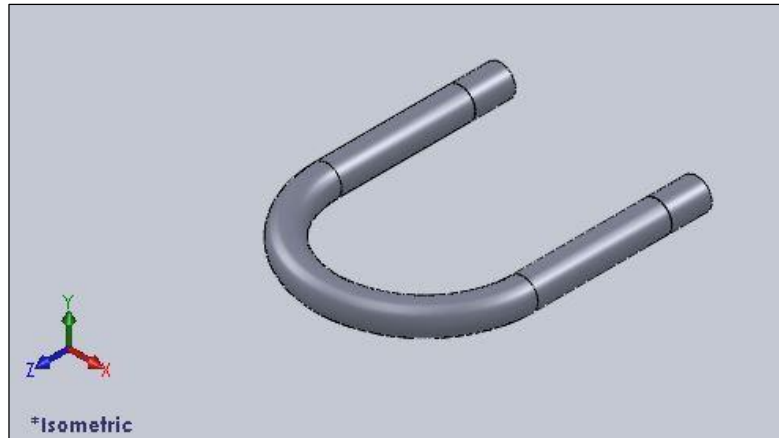
Figure 3.8: U Shape hose

Figure 3.9: L Shape hose

Figure 3.10: S Shape hose

3.7 ANSYS STATIC STRUCTURAL

Static Structural is an analysis that calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time-varying loads. A static analysis include steady inertia loads (such as gravity and rotational velocity), and time-varying loads that can be approximated as static equivalent loads. Static analysis is used to determine the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. In this project, the simulations are done by inserting the specific material properties according to the material identification. Load is applied as pressure inside the modelled hose and the ends of the pipe are fixed support replicating the clamped hose between the fittings. The static equivalent loads are applied and the solutions are based on stress distribution and deformation of the simulation.

3.7.1 Physical Properties of Solid Geometry

Physical properties of solid geometry are important in order for simulation to be done. These properties will show the characteristics of the material to withstand the loads applied during the simulation. The physical properties of the material are inserted in the simulation under Engineering Data on ANSYS static structural as shown in Table 3.3.

**Table 6.3: Physical properties of stainless steel and polytetrafluroethylene (PTFE)**

| Parameters	Unit	Stainless Steel	PTFE
Density	kg/m^3	7750	2200
Young's Modulus	Pa	1.9E+11	5E+08
Poisson's Ratio	Pa	0.31	0.46
Bulk Modulus	Pa	1.693E+11	2.0833E+10
Shear Modulus	Pa	7.3664E+10	1.7123E+09
Tensile Yield Strength	Pa	2.07E+08	2.3E+07

3.7.2 Static Structural Geometry Model

The geometry structure of braided hose is created using SOLIDWORKS software and imported into ANSYS static structural. The structure consists of hollow double layer pipe of stainless steel outer layer and inner layer PTFE with a gap of 0.5mm in between. There is four various shape of the hose imported and simulated in the ANSYS static structural which are horizontal hose, U shape hose, L shape hose and S shape hose as stated in details at section 3.6.

3.7.3 Meshing in ANSYS Workbench

Meshing is an integral part of the computer-aided engineering simulation process. The mesh influences the accuracy, convergence and speed of the solution. The mesh sizing effects the accuracy of the results has too many cells may results in long solver runs and too few many lead to inaccurate results. In this project, the ANSYS geometry has to obtain the right balanced mesh for simulation. The meshes used are by the default settings and the element size meshes are changed to 1mm. The meshing is applied to each of the modelled SOLIDWORKS geometry imported to ANSYS static structural analysis. Figure 3.11, Figure 3.12, Figure 3.13 and Figure 3.14 shows the meshing applied to geometry of horizontal hose, U shape hose, L shape hose and S shape hose respectively.
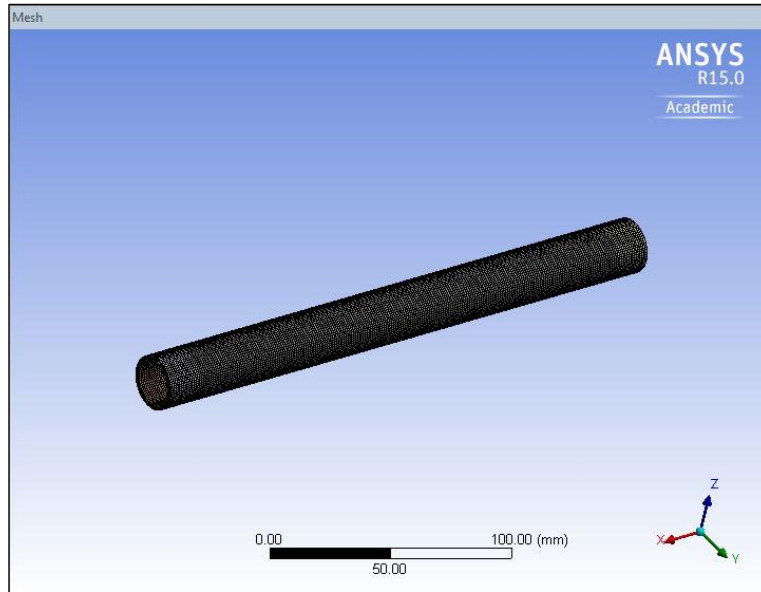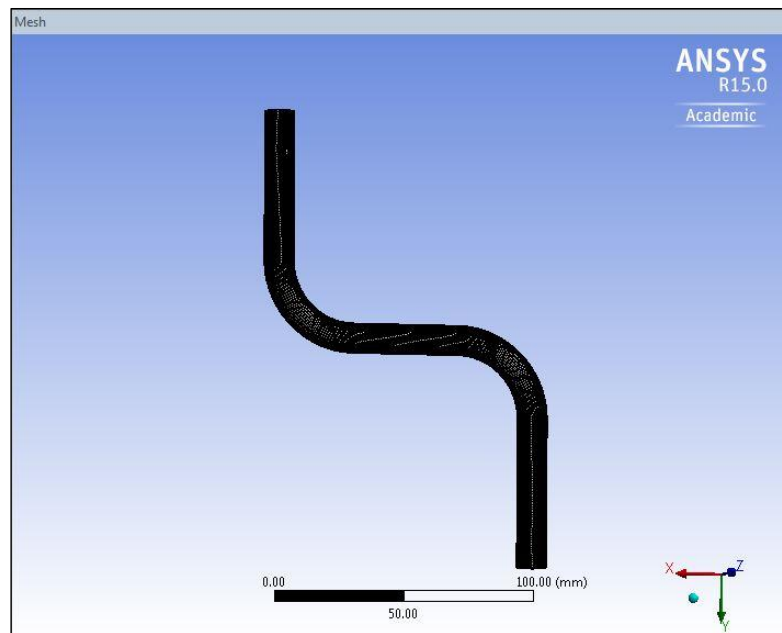
Figure 3.11: Meshing of horizontal hose
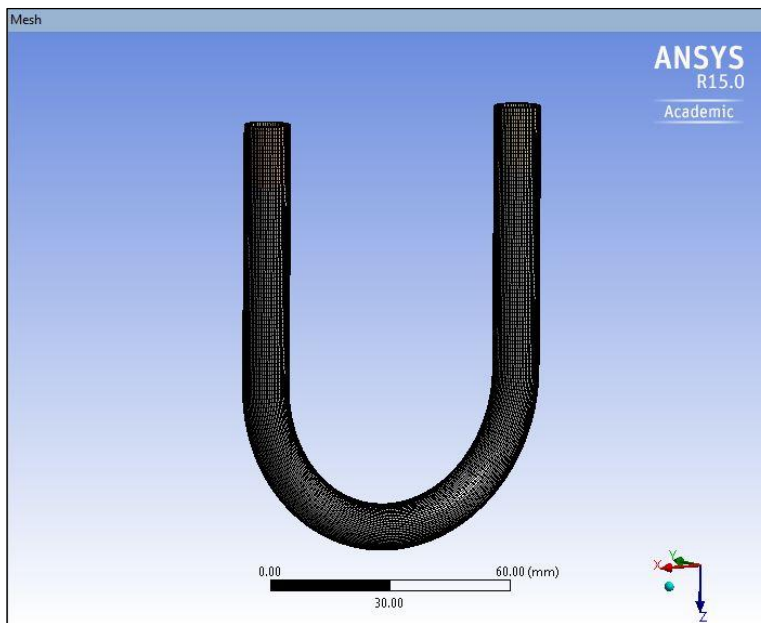
Figure 3.11: Meshing of U shape
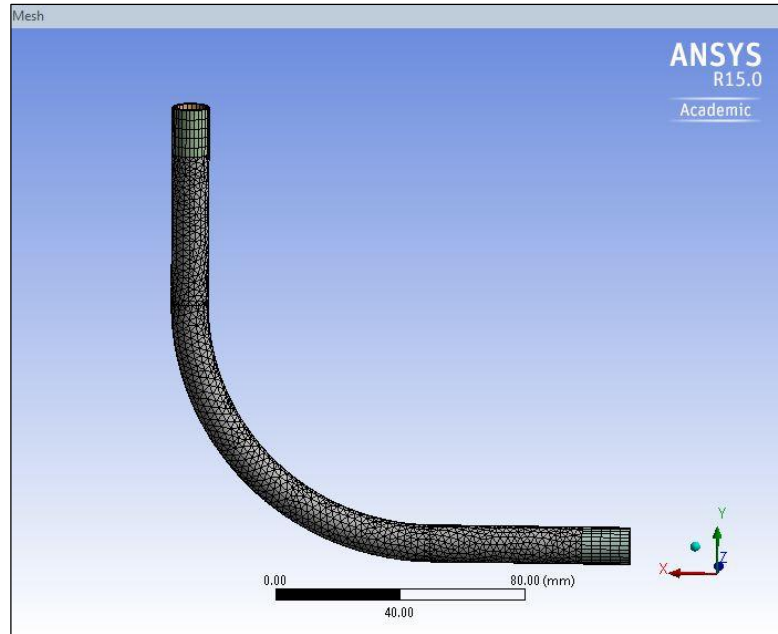
**Figure 3.13: Meshing of L shape hose**

**Figure 3.12: Meshing of S shape hose**

3.7.4 Static Structure Setup

After the meshing, the analyses settings are set on which load to apply to certain faces of the geometry. For this project, 1500 psi or equivalent to 10.342 MPa load are applied inside the layer of the polytetrafluroethylene (PTFE). This is due to

the assumed maximum load pressure according to the manufacturer of the braided hose. The ends of the hose are selected as fixed support replicating the static fittings of the hose assembly. Figure 3.15, Figure 3.16, Figure 3.17 and Figure 3.18 shows the analyses settings details for horizontal hose, U shape hose, L shape hose and S shape hose respectively.
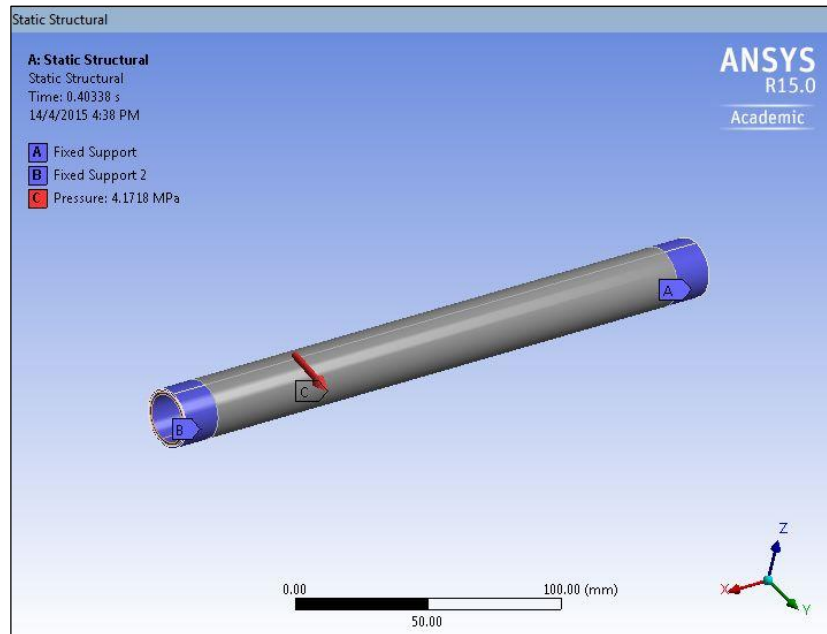
Figure 3.13: Static structural horizontal hose
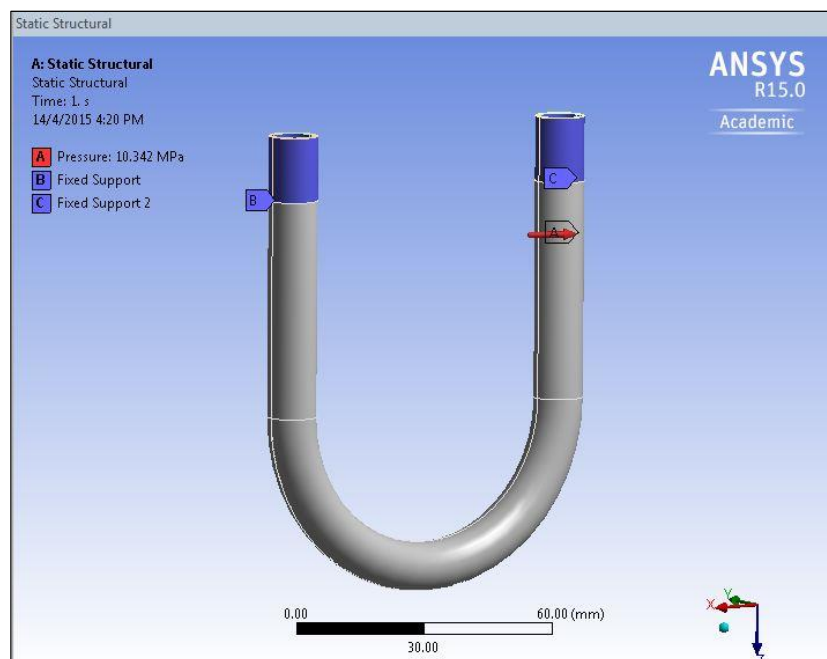
Figure 3.14: Static structural U shape hose
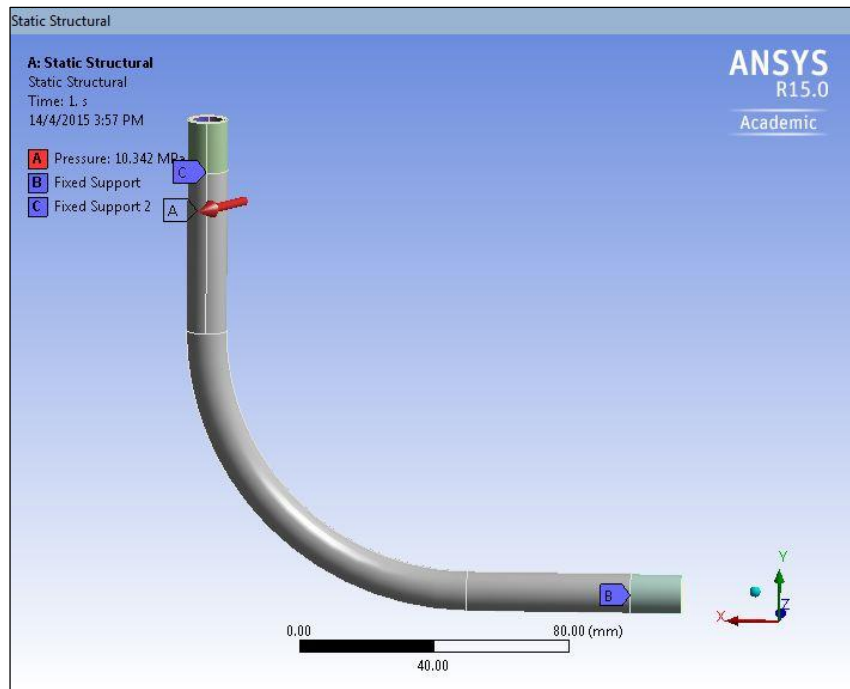
Figure 3.15: Static structural L shape hose

Figure 3.16: Static structural S shape hose

CHAPTER 4
RESULTS AND DISCUSSION

4.1 INTRODUCTION

The result is based on the ANSYS static structural simulation done on the actual model of braided hose. The braided hose failur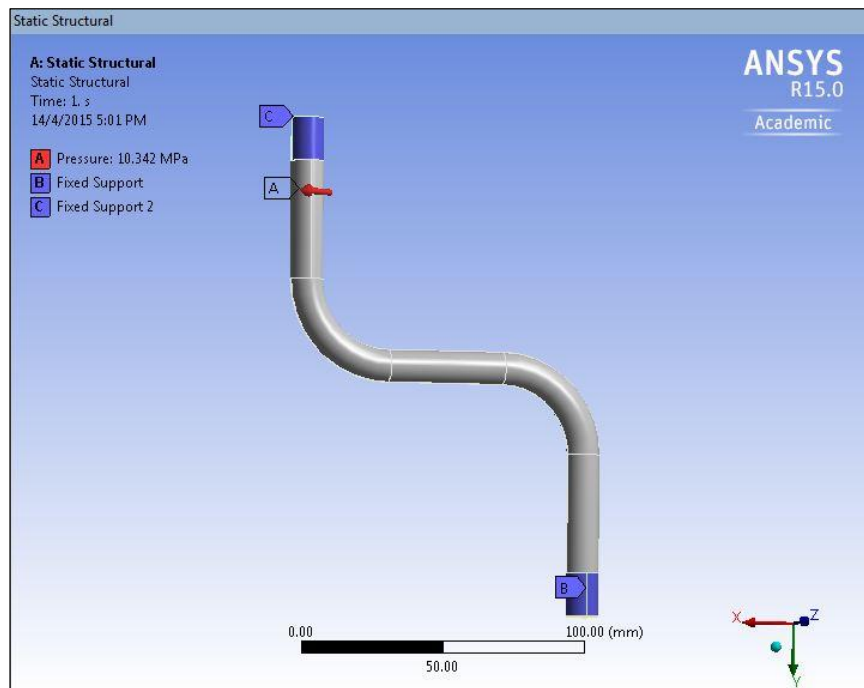es on hose section 3 and 6 are predicted through stress distribution of Von Mises equivalent stress and total deformation.

Von Mises stress is widely used to check whether the geometry will withstand a given load condition. The concept of Von Mises stress arises from the distortion energy failure theory which is distortion by volume and angular shape of the design. The hose will fail, if the maximum value of Von Mises stress induced in the material is more than strength of the material. The yield strength for stainless steel and polytetrafluroethylene (PTFE) is 207 MPa and 23 MPa respectively.

Total deformation occurs due to the braided hose expansion and elongation when the pressure is exerted to it. This deformation is due to the properties of material which involves elastic and plastic deformation. The structure is forced to expand and compress due to the pressure exerted, then the maximum deformation are observed.

4.2 BRAIDED HOSE AT HORIZONTAL INSTALLATION

The first simulation is done where the braided hose is installed in horizontal position (0 degree angle) with pressure of 10.342 MPa applied on the inside of the tube (inner layer PTFE). The end results of the simulation are captured on the Von Mises stresses and total deformation of the braided hose.

4.2.1 Von Mises Stress

Von Mises stress determines whether the design is safe for horizontal position (0 degree angle). This shows that Von Mises stress is required before the

deformation of the design occur. The Von Mises stress simulation results of braided hose with different focus on the material of the braided hose are shown in Figure 4.1 and Figure 4.2. The horizontal hose simulation results for Von Mises stress without stainless steel body and PTFE body only are shown in Appendix A.
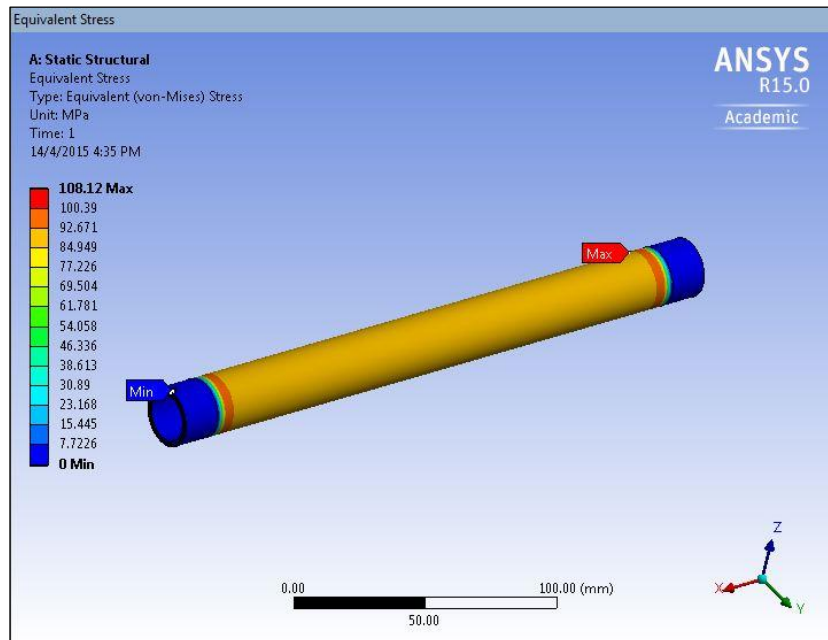
Figure 4.1: Von Mises stress on horizontal hose with full body
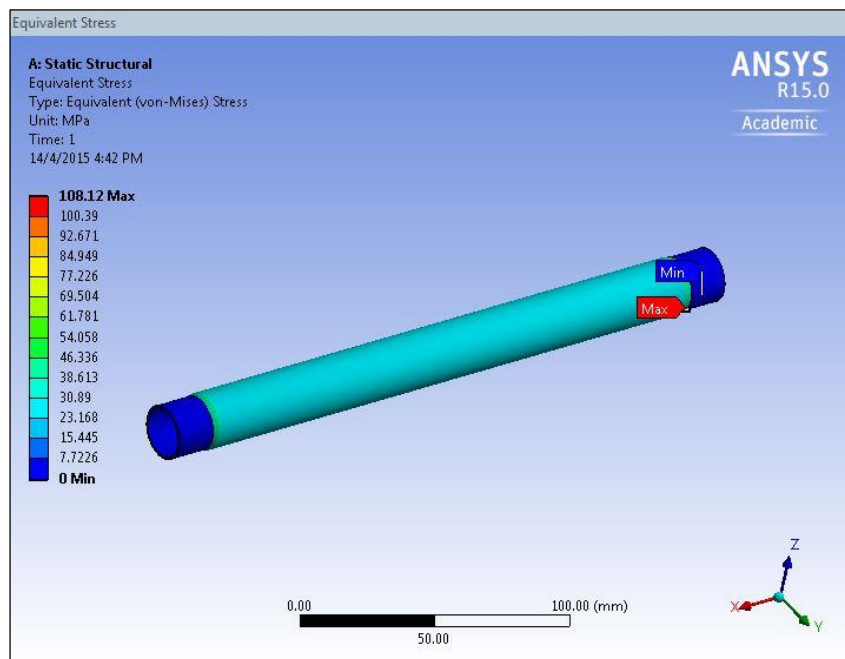
Figure 4.2: Von Mises stress on horizontal hose with PTFE

26

From the results, the maximum Von Mises stress is 108.12 MPa and the minimum is 0 MPa. According to the yield strength of the stainless steel, the design is safe. The Von Mises stress for the horizontal hose is less than the yield strength of stainless steel which is 207 MPa. By installation of horizontal position, there was no stress failure detected. The maximum stresses are mostly detected near the fittings of the hose.

4.2.2 Total Deformation

Total deformation shows the maximum point where both the material can withstand the deformation of plastic and elastic. As mentioned, the load pressure 10.342 MPa is exerted inside the PTFE layer. Figure 4.3 and Figure 4.4 illustrates the results of the total deformation for horizontal hose with different focus on the body of the braided hose. The horizontal hose simulation results for total deformation without stainless steel body and PTFE body only are shown in Appendix A.
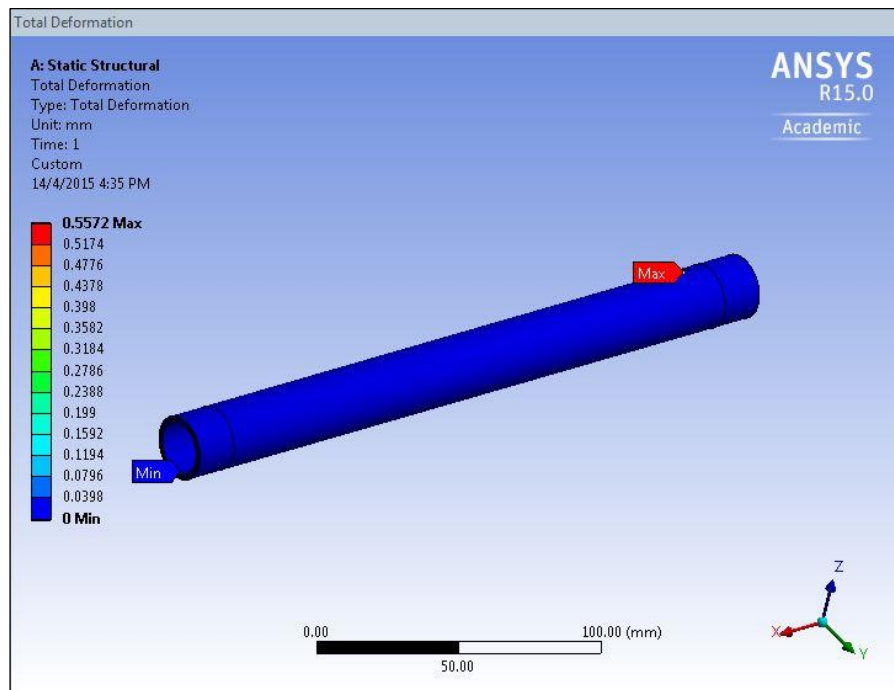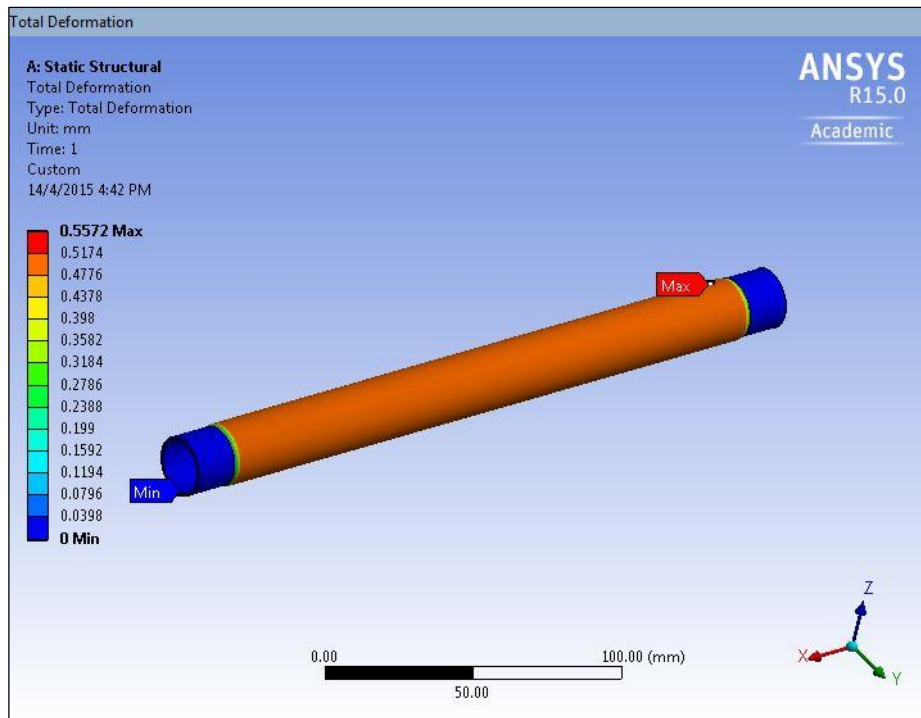

Figure 4.3: Total deformation on horizontal hose with full body

Figure 4.4: Total deformation on horizontal hose with PTFE

The results show that the maximum total deformation is 0.5572 mm for horizontal hose position. According to the observation of the results for the layer of stainless steel and PTFE, the total deformation is maximum near the fittings of the hose. Due to the pressure exerted inside the PTFE layer and fixed support at the end of the hose, the deformation is concentrated near the fittings. However, the PTFE layer did not deformed beyond the stainless steel layer as predicted.

4.3 BRAIDED HOSE AT U SHAPE INSTALLATION

The second simulation is done where the braided hose is installed in U shape position by bending the pipe. The pressure exerted is 10.342MPa. This simulation run on the hose section modeled with both end fixed and pressure is applied on the inside of the tube (inner layer PTFE). The end results of the simulation are captured on the Von-Mises stresses and total deformation of the braided hose.

4.3.1 Von Mises Stress

Von Mises stress determines whether the design is safe for U shape position of installation. This shows that Von Mises stress is required before the deformation of the design occur. The Von Mises stress simulation results of braided hose with different focus on the body of the braided hose are shown in Figure 4.5 and Figure 4.6. The U shape hose simulation results for Von Mises stress without stainless steel body and PTFE body only are shown in Appendix A.
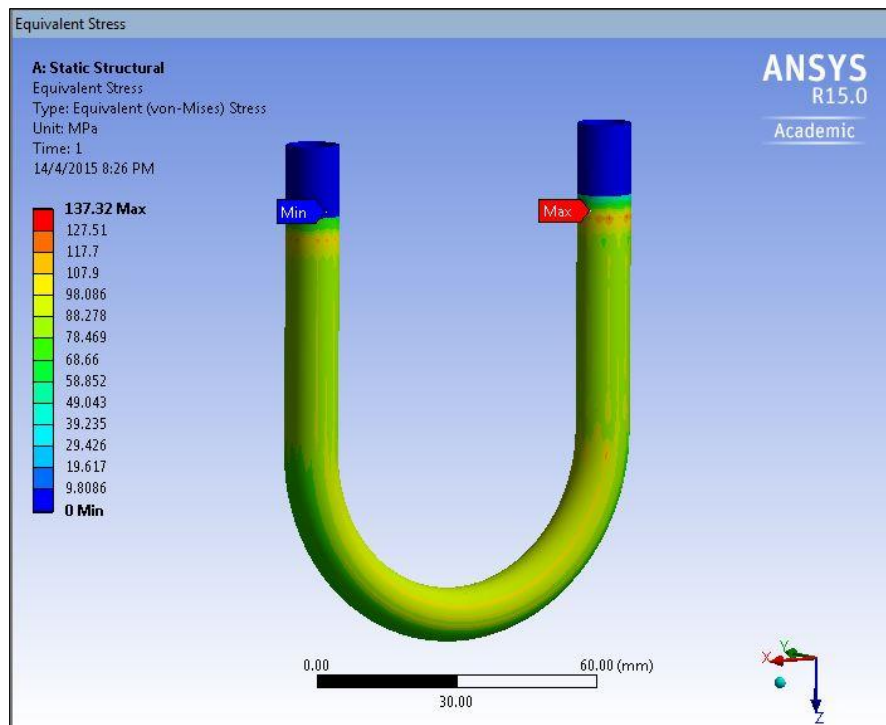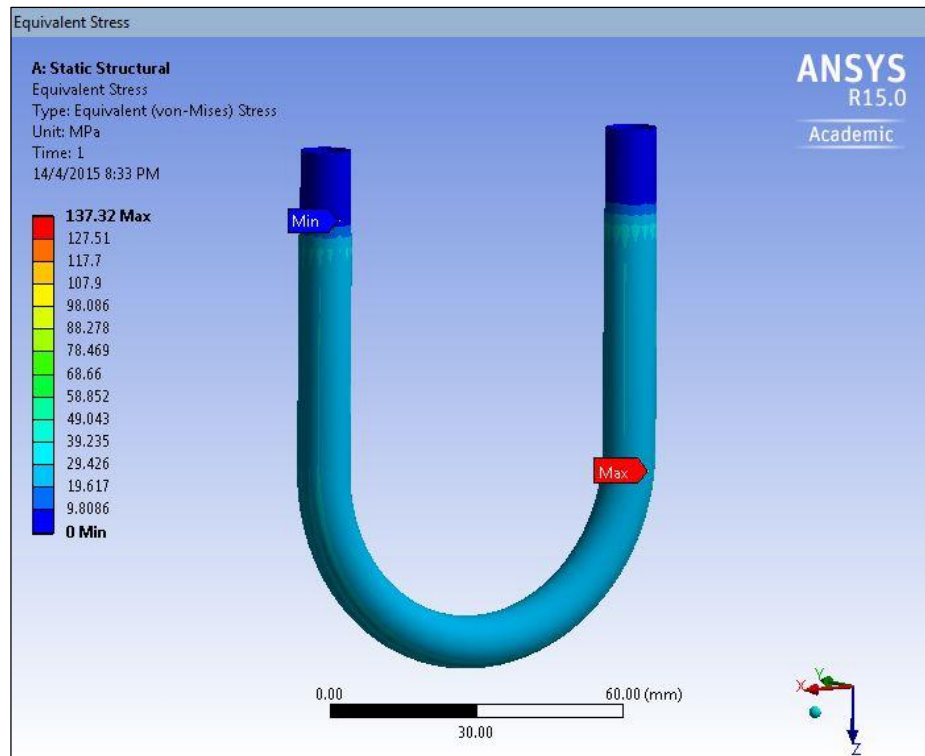

**Figure 4.5: Von Mises stress on U shape hose with full body**

Figure 4.6: Von Mises stress on U shape hose with PTFE

From the results, the maximum Von Mises stress is 137.32 MPa and the minimum is 0 MPa. According to the yield strength of the stainless steel, the design is safe. The Von Mises stress for the horizontal hose is again less than the yield strength of stainless steel which is 207 MPa. By installation of horizontal position, there was no stress failure detected. The maximum stresses are mostly detected at the bending. However, the maximum stress is detected near the fittings for U shape hose with the full body. This shows that when the hose position is full body, the stress is concentrated near the fittings compared to the bending area of the hose.

4.3.2 Total Deformation

Total deformation shows the maximum point where both the material can stand the deformation of plastic and elastic. As mentioned, the load pressure 10.342 MPa is exerted inside the PTFE layer. Figure 4.7 and Figure 4.8 illustrates the results of the total deformation for U shape hose with different focus on the body of the braided hose. The U shape hose simulation results for total deformation without stainless steel body and PTFE body only are shown in Appendix A.
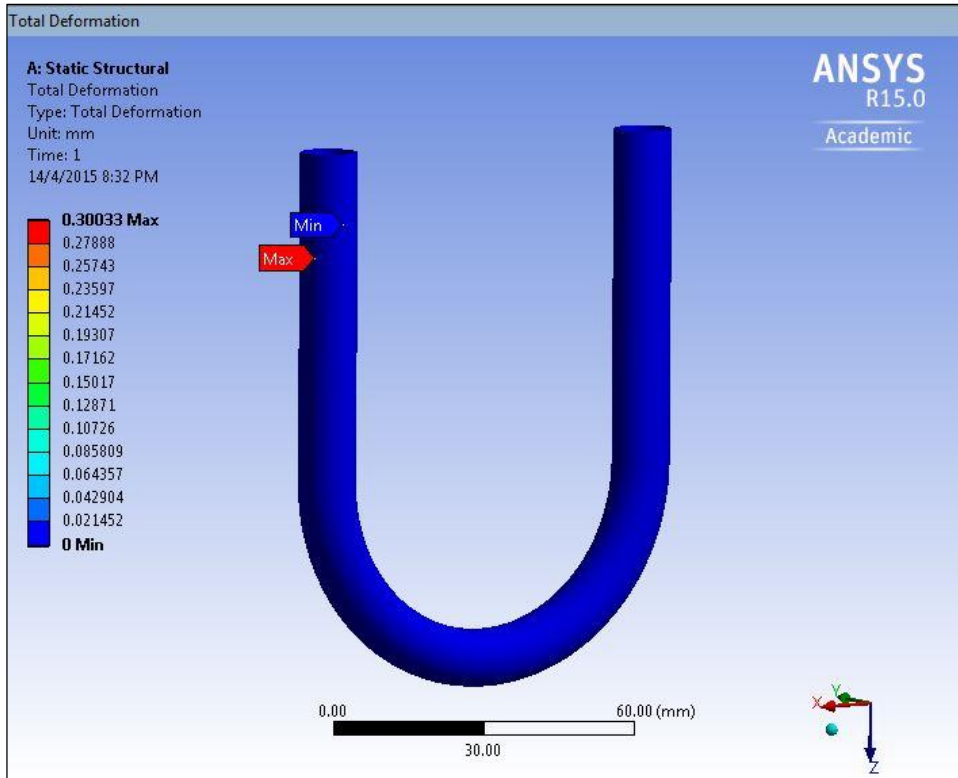
Figure 4.7: Total deformation on U shape hose with full body
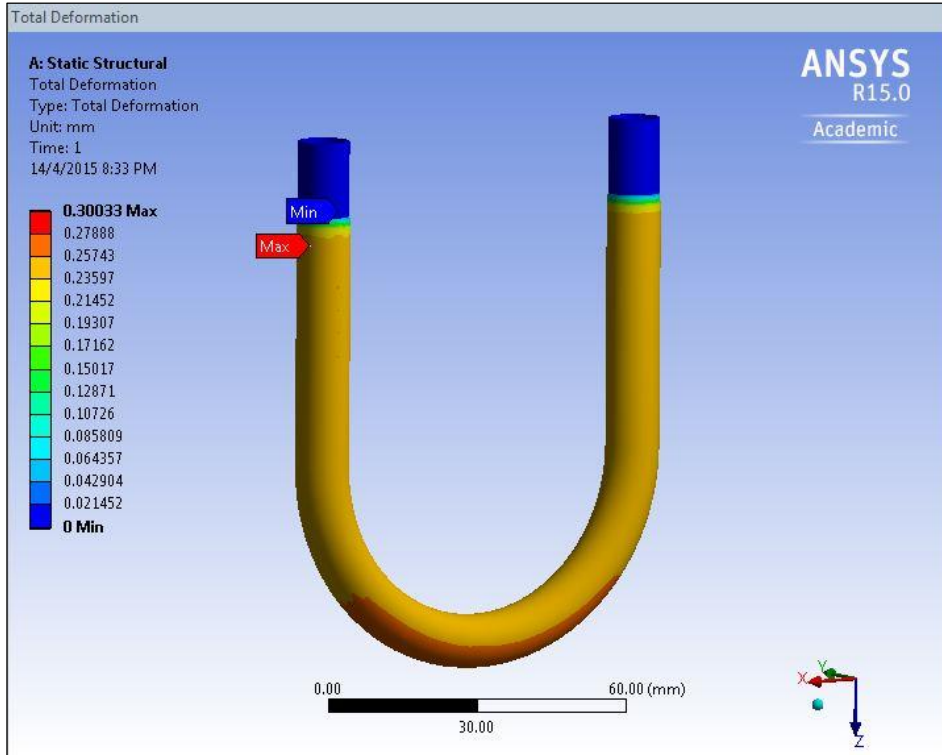
Figure 4.8: Total deformation on U shape hose with PTFE

The results show that the maximum total deformation is 0.30033 mm for U shape hose position which is less than the maximum for horizontal hose position. This indicates, horizontal position have a higher chance of deforming. According to the observation of the results for the layer of stainless steel and PTFE, the total deformation is maximum again near the fittings of the hose. Due to the pressure exerted inside the PTFE layer and fixed support at the end of the hose, the deformation is concentrated near the fittings. However, the PTFE layer did not deformed beyond the stainless steel layer as predicted.

4.4 BRAIDED HOSE AT L SHAPE INSTALLATION

The next simulation is done where the braided hose is installed in L shape position by bending the pipe. The pressure exerted is 10.342 MPa applied on the inside of the tube (inner layer PTFE). The end results of the simulation are captured on the Von-Mises stresses and total deformation of the braided hose.

4.4.1 Von Mises Stress

Von Mises stress determines whether the design is safe for L shape position of installation. This shows that Von Mises stress is required before the deformation of the design occur. The Von Mises stress simulation results of braided hose with different focus on the body of the braided hose are shown in Figure 4.9 and Figure 4.10. The L shape hose simulation results for Von Mises stress without stainless steel body and PTFE body only are shown in Appendix A.
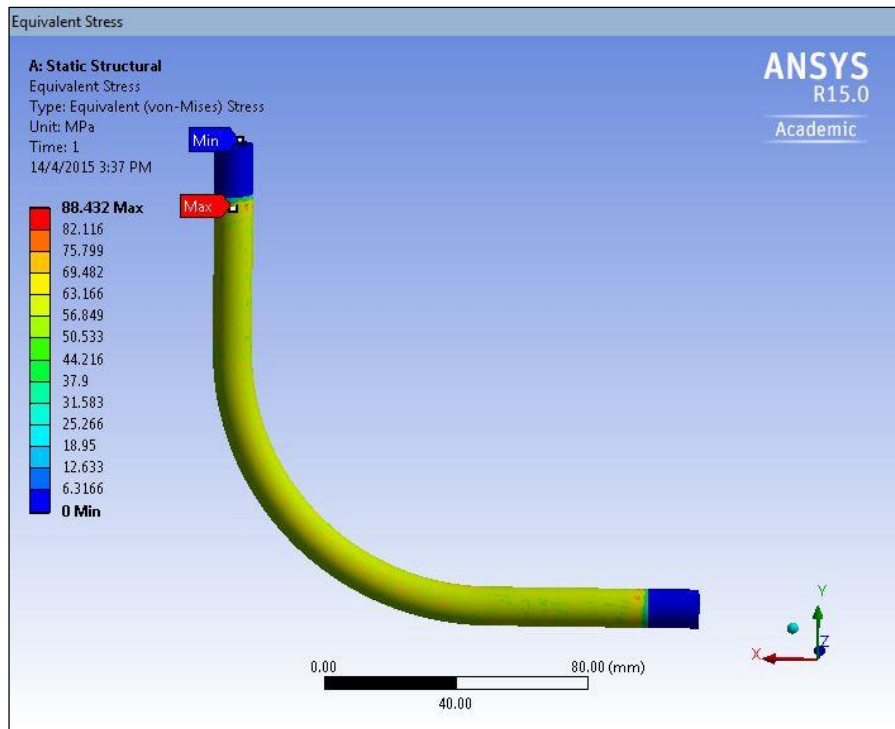
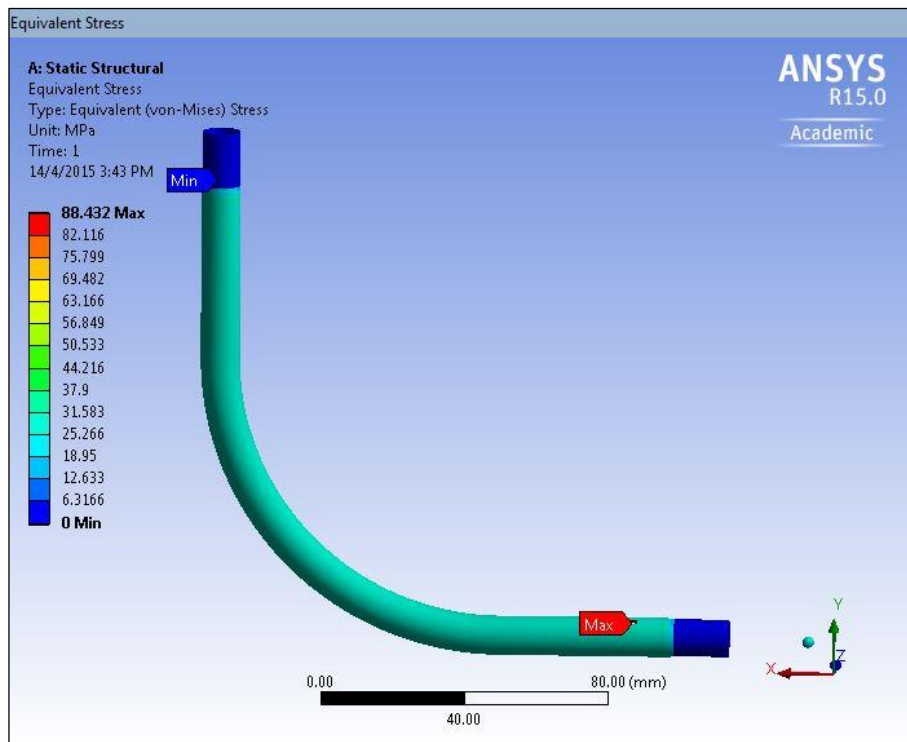**Figure 4.9: Von Mises stress on L shape hose with full body**

**Figure 4.10: Von Mises stress on L shape hose with PTFE**

From the results, the maximum Von Mises stress is 88.432 MPa and the minimum is 0 MPa. According to the yield strength of the stainless steel, the design is safe. The Von Mises stress for the horizontal hose is again less than the yield strength of stainless steel which is 207 MPa. L shape position indicates that it would produce smaller Von Mises Stress compared to horizontal hose and U shape hose installation. By installation of L shape position, there was no stress failure detected. The maximum stresses are mostly detected near the fittings with and without the stainless steel material.

4.4.2 Total Deformation

Total deformation shows the maximum point where both the material can stand the deformation of plastic and elastic. As mentioned, the load pressure 10.342 MPa is exerted inside the PTFE layer. Figure 4.11 and Figure 4.12 illustrates the results of the total deformation for L shape hose with different focus on the body of the braided hose. The L shape hose simulation results for total deformation without stainless steel body and PTFE body only are shown in Appendix A.
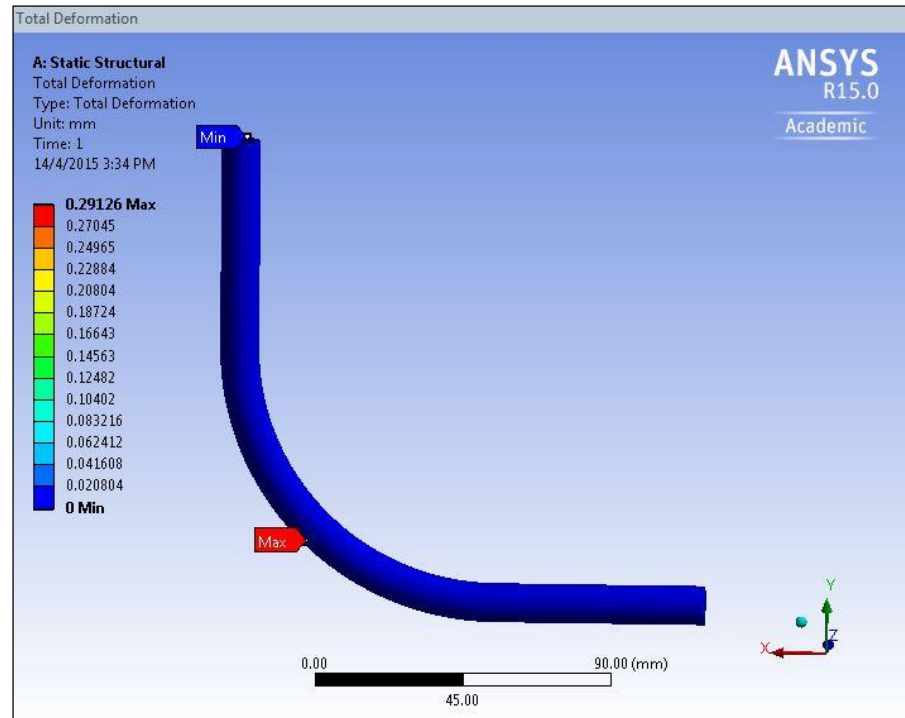
Figure 4.11: Total deformation on L shape hose with full body
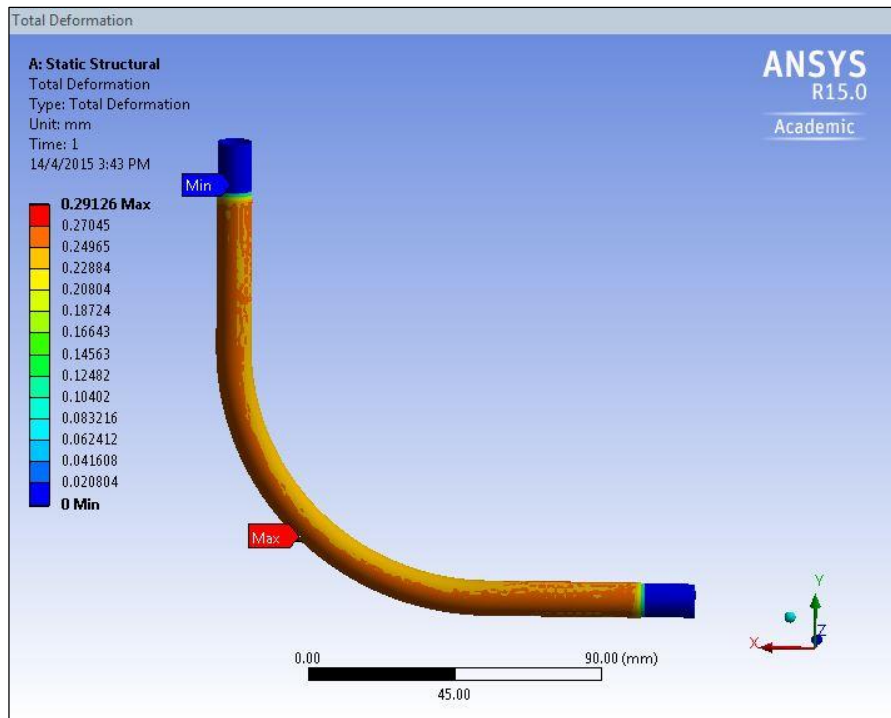
Figure 4.12: Total deformation on L shape hose with PTFE

The results show that the maximum total deformation is 0.29126 mm for L shape hose position which is less than the maximum for U shape position. This indicates, horizontal position have a highest total deformation. According to the observation, the layer of stainless steel and PTFE, the total deformation is maximum near the bending area of the hose. This proves that when the hose undergoes a slight deform in shape, the deformation concentrates at the area. However, the PTFE layer did not deformed beyond the stainless steel layer as predicted.

4.5 BRAIDED HOSE AT S SHAPE INSTALLATION

The next simulation is done where the braided hose is installed in S shape position by bending the pipe. The pressure exerted is 10.342MPa applied on the inside of the tube (inner layer PTFE). The end results of the simulation are captured on the Von-Mises stresses and total deformation of the braided hose.

4.5.1 Von Mises Stress

Von Mises stress determines whether the design is safe for L shape position of installation. This shows that Von Mises stress is required before the deformation of the design occur. The Von Mises stress simulation results of braided hose with different focus on the body of the braided hose are shown in Figure 4.13 and Figure 4.14. The S shape hose simulation results for Von Mises stress without stainless steel body and PTFE body only are shown in Appendix A.
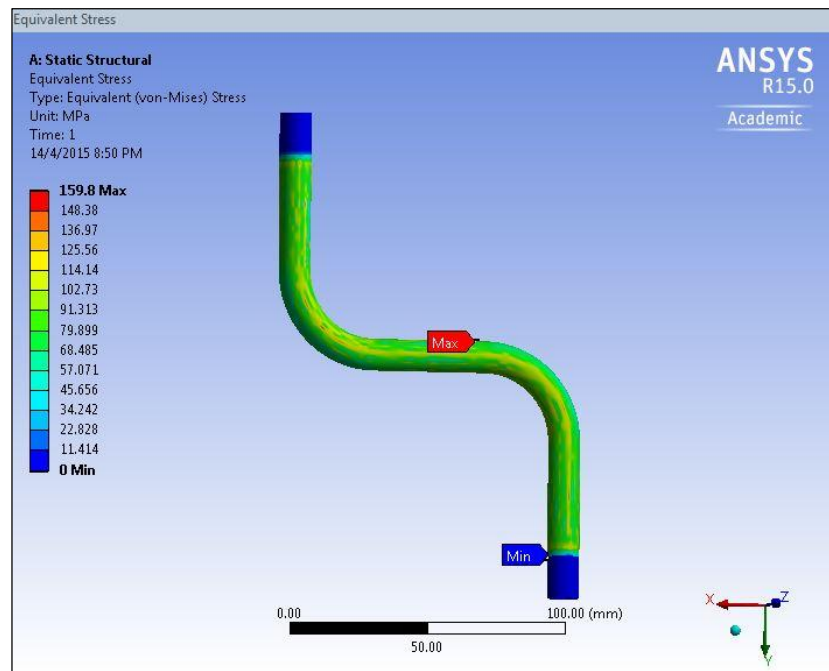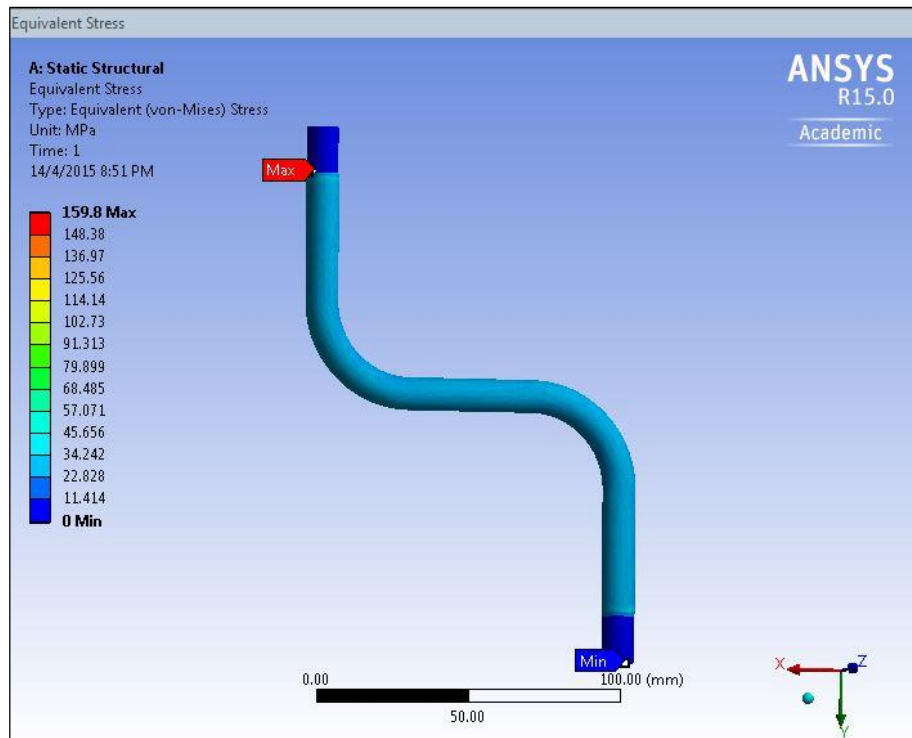

Figure 4.13: Von Mises stress on S Shape hose with full body

Figure 4.14: Von Mises stress on S shape hose with PTFE

From the results, the maximum Von Mises stress is 159.8 MPa and the minimum is 0 MPa. According to the yield strength of the stainless steel, the design is safe. The Von Mises stress for the horizontal hose is again less than the yield strength of stainless steel which is 207 MPa. However, the Von Mises stress is close to the yield strength of the stainless steel. S shape position indicates that it would produce much larger Von Mises Stress compared to the other hose installation. By installation of S shape position, there was no stress failure detected but near to failure. The maximum stresses are mostly detected near the fittings of the hose. The full body of the S shape hose indicates maximum Von Mises diverted the Von Mises stress away from the fittings.

4.5.2 Total Deformation

Total deformation shows the maximum point where both the material can stand the deformation of plastic and elastic. As mentioned, the load pressure 10.342 MPa is exerted inside the PTFE layer. Figure 4.15 and Figure 4.16 illustrates the results of the total deformation for S shape hose with different focus on the body of

the braided hose. The S shape hose simulation results for total deformation without stainless steel body and PTFE body only are shown in Appendix A.
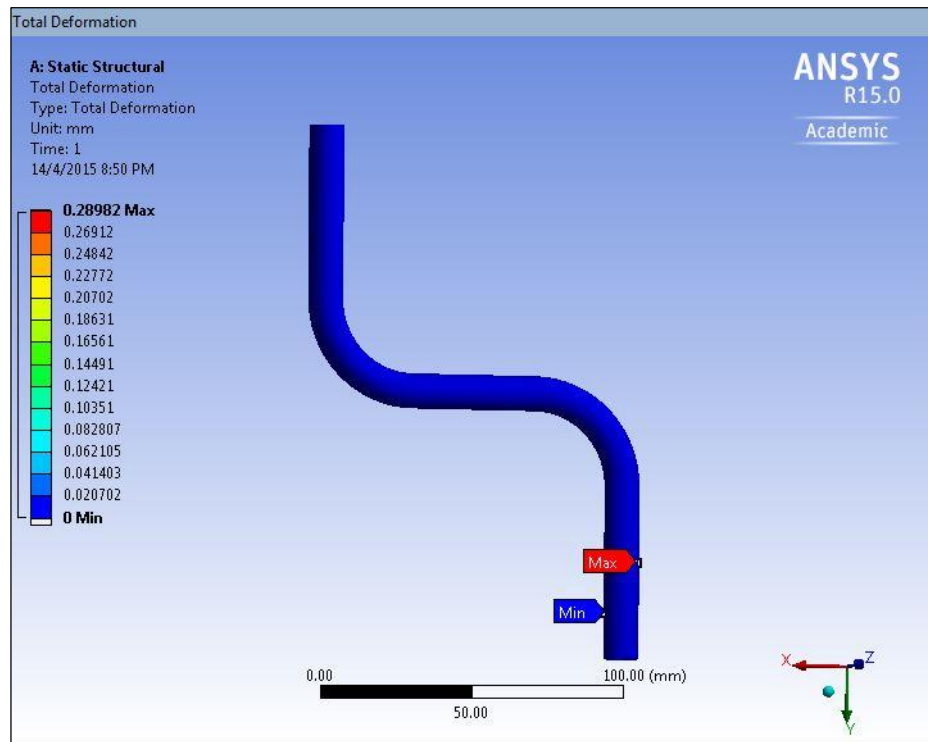

Figure 4.15: Total deformation on S shape hose with full body
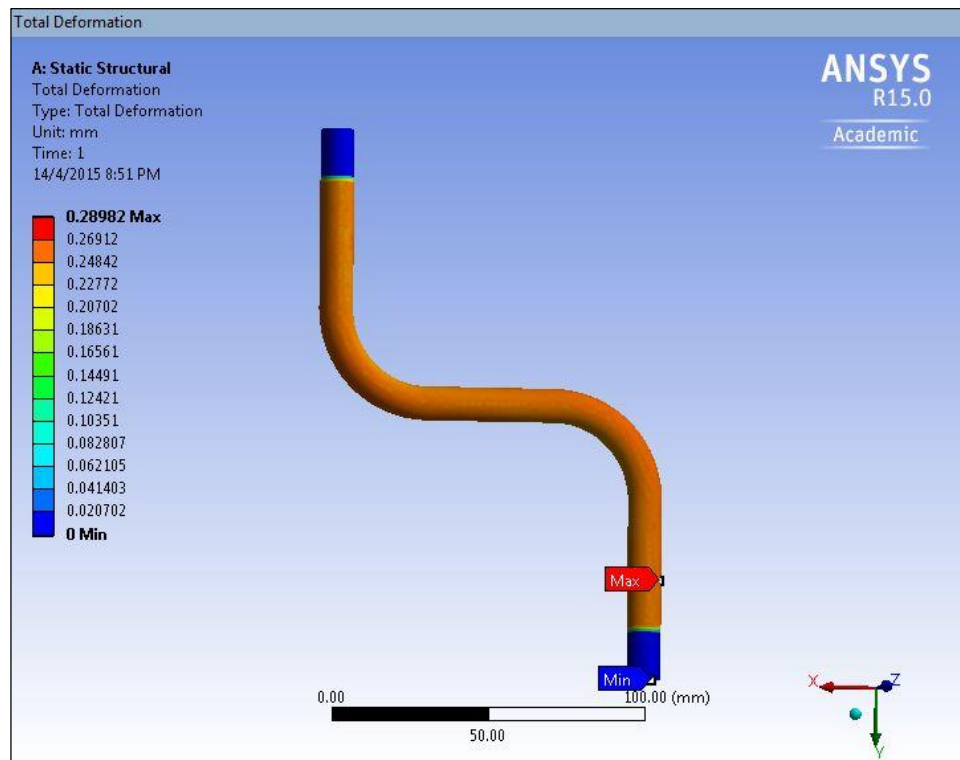

Figure 4.16: Total deformation on S shape hose with PTFE

The results show that the maximum total deformation is 0.28982 mm for S shape hose position which is smallest deformation compared to other installation position. This further proves, horizontal position have a highest total deformation. According to the observation of the results for the layer of stainless steel and PTFE, the total deformation is maximum near the fittings. Due to the pressure exerted inside the PTFE layer and fixed support at the end of the hose, the deformation is concentrated near the fittings. However, the PTFE layer did not deformed beyond the stainless steel layer as predicted.

4.6 DISCUSSION ON ANSYS SIMULATION ANALYSIS

From the results, the highest maximum Von Mises stress is 159.8MPa for S shape hose. The lowest maximum Von Mises stress is L shape hose. For the S shape hose, it is observed that the maximum stress location is between the bending of the hose. As for the horizontal hose, U shape and L shape, the Von Mises stresses occur near the fittings. From our actual braided hose failure, both hose section 3 and 6 undergo failure near the fittings. It is predicted that hose section 3 failure (located 7cm from nearest fittings) that the body is deformed to S shape, in order to get similar stress location on hose.

The total deformation results show that the horizontal position has the highest maximum deformation of 0.5572mm. The values followed by the U shape, L shape and S shape with value 0.3033mm, 0.29126mm and 0.28982mm respectively. This concludes that the total deformation does not depend on the shape has the values are close. This proves that most of the deformation occurs near the fittings of the hose except for the L shape hose which the deformation occurs at the bending area. However, both Von Mises stress and total deformation have confirmed that the maximum values of stress and deformation occurs near fittings. This concludes that the failure of the actual braided has exceeded or reached 1500 psi overpressure causing failure near point of fittings.

4.7 DISCUSSION ON FAILURE ANALYSIS

An analysis of potential failures helps designers focus on and understand the impact of potential process or product risks and failures. Several systematic methodologies have been developing to quantify the effects and impacts of failures. Failure analysis was done on the braided hose failure to further predict the causes of the situation. The failure analysis was focused on two common failure analysis techniques which are Failure Modes Effects Analysis (FMEA) and Fault Tree Analysis (FTA). Both failure analyses done are based on research papers obtained.

### 4.6.1 Failure Modes Effects Analysis (FMEA)

Table 4.2 shows the potential failure modes, the causes of failures and the effects of failure based on the different aspect of the braided hose according to the failure modes effects analysis (FMEA) method.

Table 4.1: Failure Modes Effects Analysis (FMEA) on braided hose failure

Item / Function	Potential Failure Mode(s)	Potential Cause(s) of Failure	Potential Effect(s) of Failure	Recommended Action(s)
Outer layer of stainless steel braided metal	Wear	Rubbing of inner and outer layer	Thinning of braided metal	Reduce vibration
	Distorted	Braided wire metal expansion	Misalignment of hose	Monitoring tool for pressure
	Burst	Overpressure	Exceed maximum allowable limit	Monitoring tool for pressure
Inner layer of PTFE	Hole	Overpressure	Exceed maximum allowable limit	Monitoring tool for pressure
	Thinning	Cyclic life fatigue	Leakage of fluid	Monitoring tool for cyclic load
Fittings	Leak	Weak welding points	Leakage of fluid	Leakage test
Fluid flow in hose	Contaminants	Presence of hydrocarbon	Thinning of PTFE layer	Check quality of fluid

4.6.2 Fault Tree Analysis (FTA)

The Fault Tree Analysis shows the detailed root cause of the failures based on the actual failure of the braided hose which is leakage on the hose body as shown in Figure 4.17.
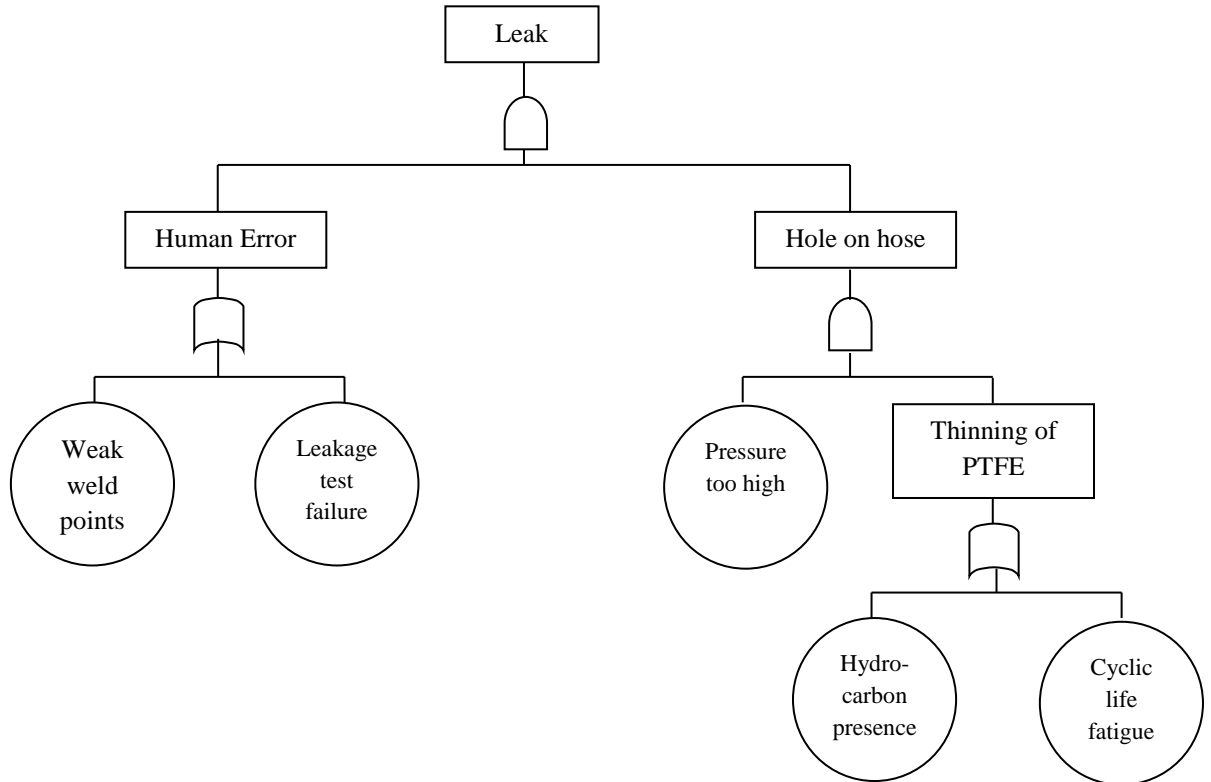
Figure 4.17: Fault Tree Analyses (FTA) on Braided Hose Leak

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Braided hose leaked in major equipment have cost in material and time consumed for maintained work. As experienced of PCSB, it is crucial to investigate on how to improve the braided hose reliability and mechanism to detect the lose leak. According to research papers found, there was no study done on industrial braided hose failure. Most studies focused on automobile hose and braided components which use finite element analysis.

From the results, the highest maximum Von Mises stress is 159.8MPa for S shape hose. The lowest maximum Von Mises stress is L shape hose which is 88.432 MPa. The total deformation results show that the horizontal position has the highest maximum deformation of 0.5572mm and lowest total deformation is for S shape hose with value 0.28982mm. The deformation has minimal effect on the braided hose failure.

However, both Von Mises stress and total deformation have confirmed that the maximum values of stress and deformation occurs near fittings. The best shape for installation is horizontal hose position for minimum stress on braided hose. To prevent the hose from multi-plane bending, the hoses should be installed with adapters. A hydraulic hose subjective to machine or actuator movement should be routed properly with bracket or installed on the wall as shown in Figure 2.2. This can prevent failure of the actual braided near point of fittings.

The main objectives are achieved as follows:

- The type and characteristics of common braided hose have been identified by has a metallic corrugated hose commonly used in the plant industry. The outer layer of the hose is stainless steel braided metal with an inner layer of polytetrafluroethylene (PTFE) or Teflon®.

- The actual PCSB braided hose are modelled using SOLIDWORKS and simulation has been done to detect the stress distribution by fixing forced at the end of the pipe.

- The possible reason of failure are predicted due to the overpressure of the hose assembly that causes maximum Von Mises stress and deformation to occurs near the fittings of the actual braided hose.

5.2 RECOMMENDATION

5.2.1 Current Project

The importance of identifying the possible reasons of failure is crucial in avoiding unnecessary failure that occurs. However, using software simulation is not adequate to analyze the point of failures it lack the actual environment. Below are recommendations for future work for the current project:

- Obtaining the actual braided hose installation position in the major equipment to insert into the ANSYS static structural modelling and simulation.

- The full modelling of hose assembly with braided wire should be done on ANSYS static structural to find the stress distribution on total deformation and Von Mises stress.

- The hose assembly should be simulation using fluid structural interaction (FSI) which is a combination of ANSYS fluent and ANSYS static structural.

- Lab test experiment should be done on hose by hydraulic pressure with shell tellus-68 hydraulic oil fluid inside the tube to simulate the actual situation on the plant site.

5.2.2   PETRONAS Carigali Sdn Bhd (PCSB)

In order to prevent future braided hose failure, the technology for detecting early hose leakage is proposed. The proposed technology is the Eaton: LifeSense intelligent hydraulic hose condition monitoring system**.**

The system detects failure related events within a hose and provides advance notification the product is approaching the end of its useful life. The notification provides sufficient time for the hose to be replaced as a normal preventive maintenance function, thereby minimizing both unscheduled downtime and the need for corrective maintenance procedures associated with traditional replacement processes.

The system comes in both wired and wireless technology to accommodate different applications with various cable length and features for the industrial field. However, only wired cables for the system are available in Malaysia. The details of the technology are attached in Appendix B.

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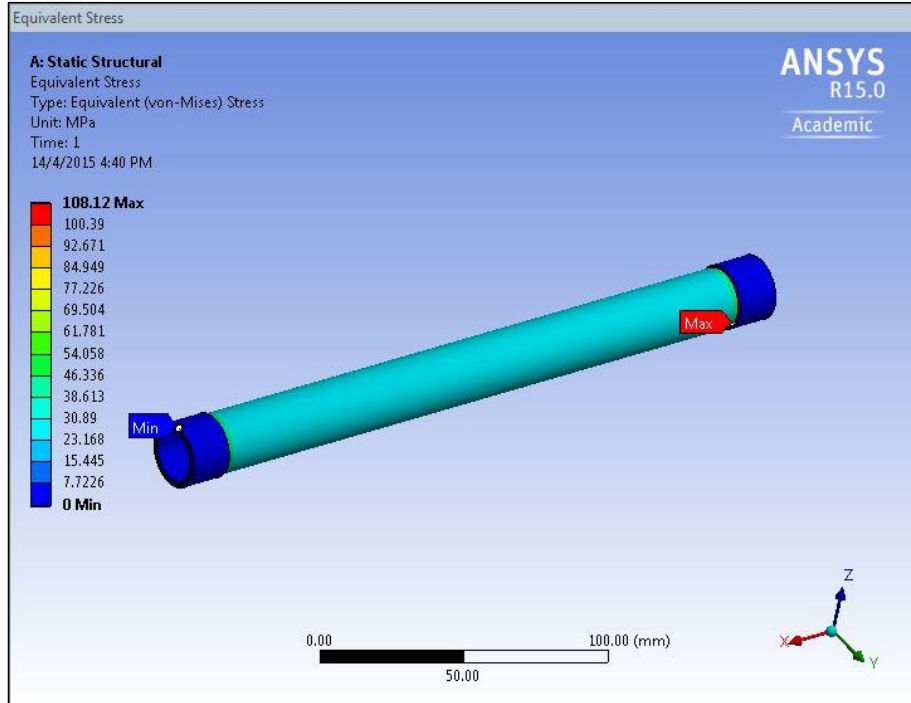
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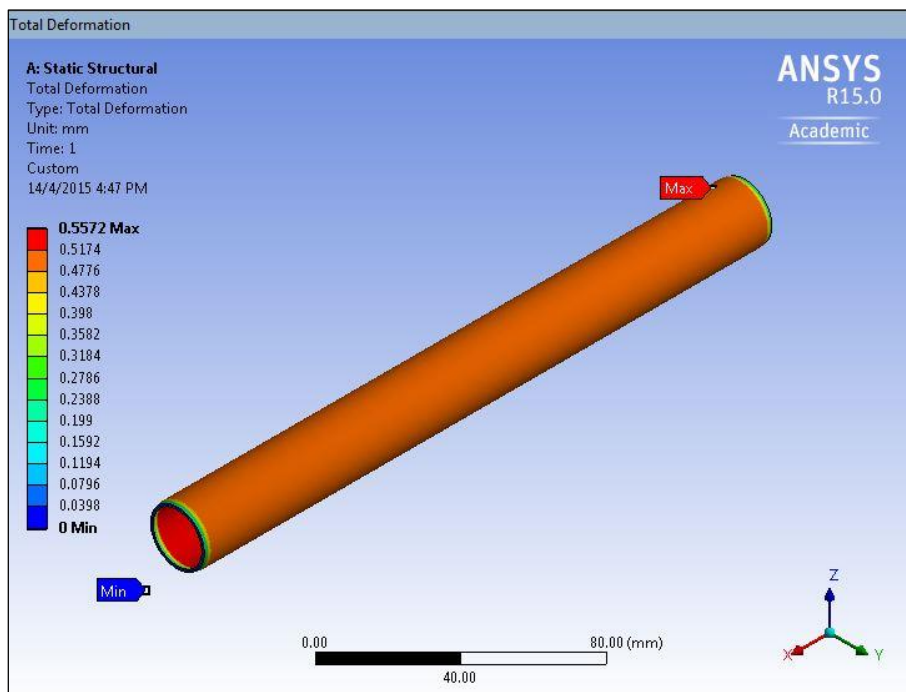
APPENDIX A

Horizontal Hose

Von Mises stress on Horizontal Hose without Stainless Steel Body
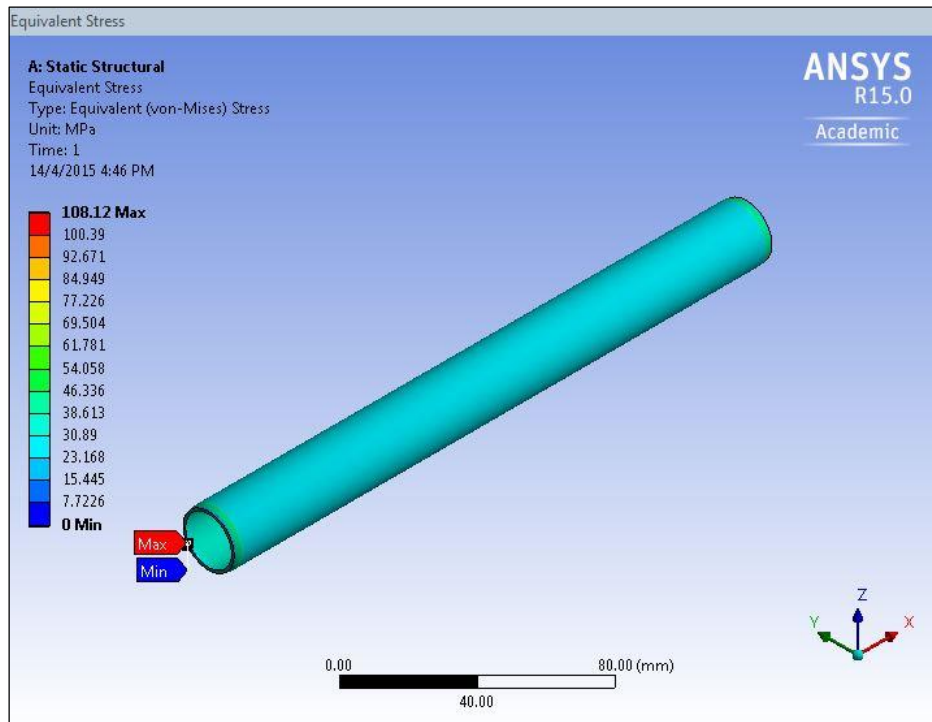
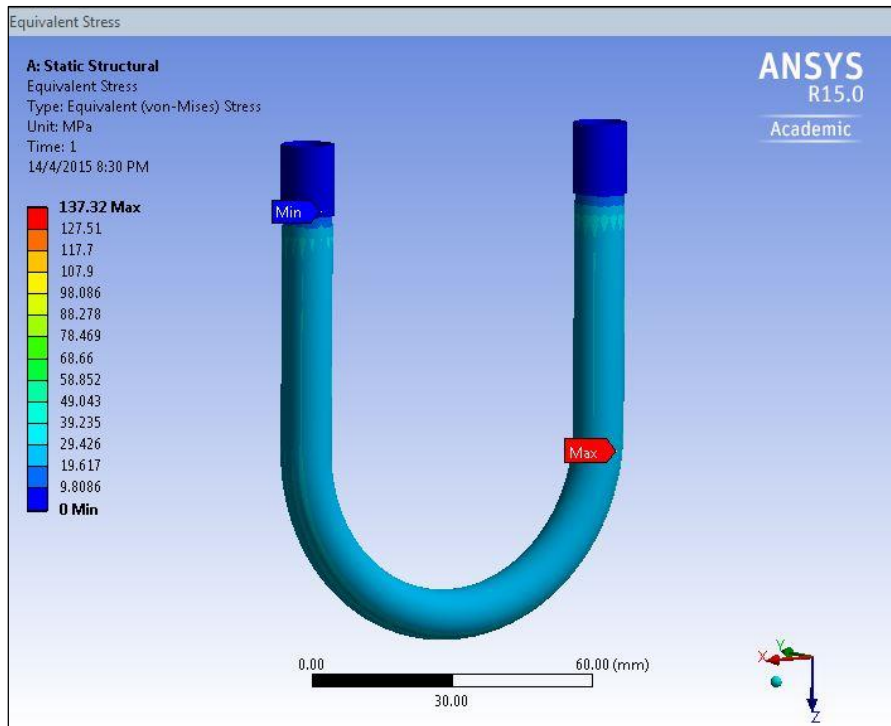

Von Mises stress on Horizontal Hose with PTFE body only
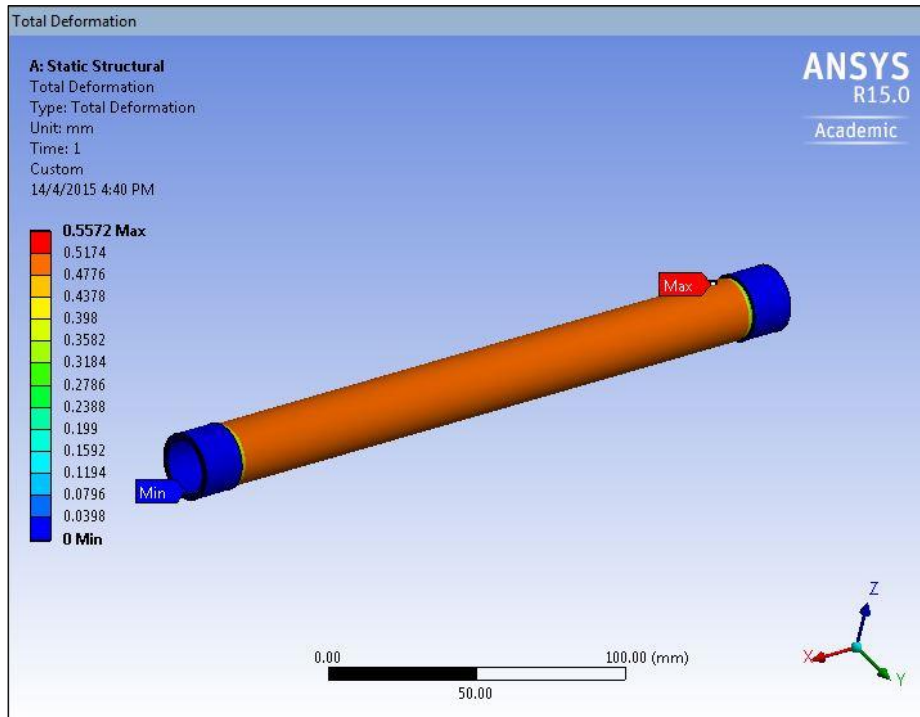
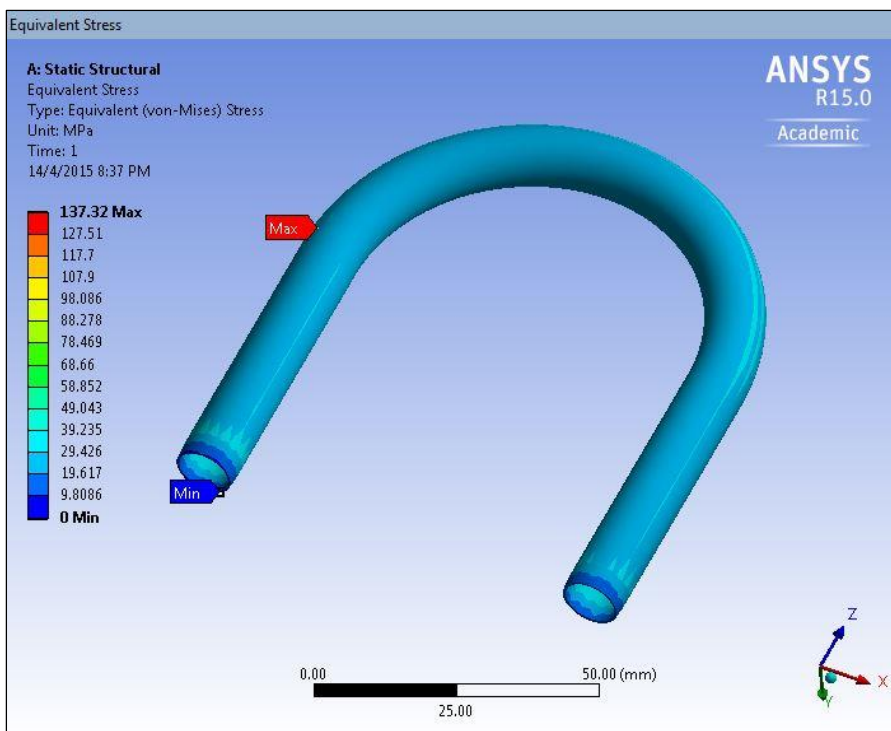Total Deformation on Horizontal Hose without Stainless Steel Body

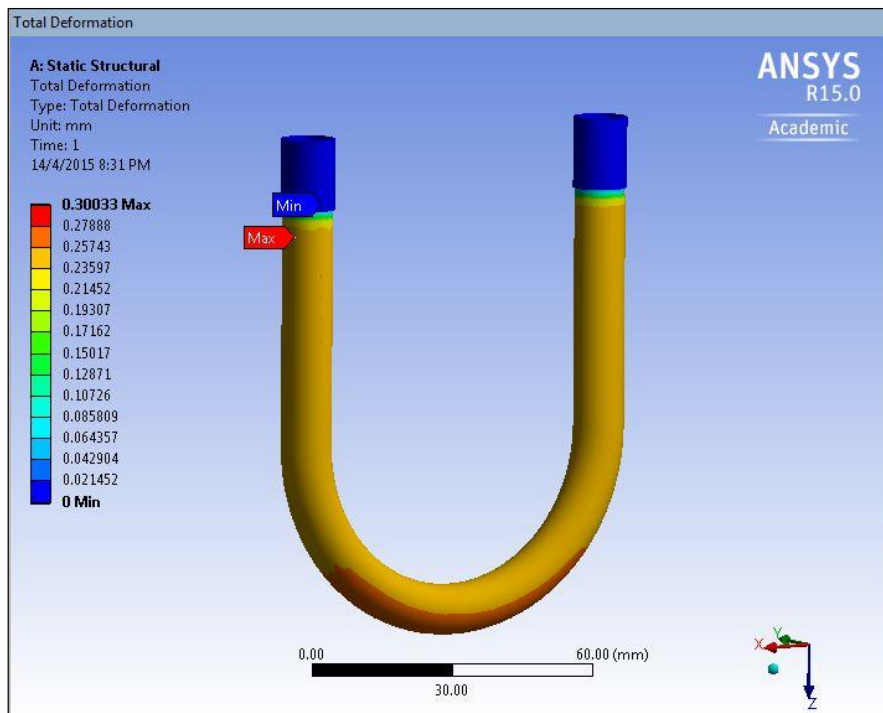Total Deformation on Horizontal Hose with PTFE body only
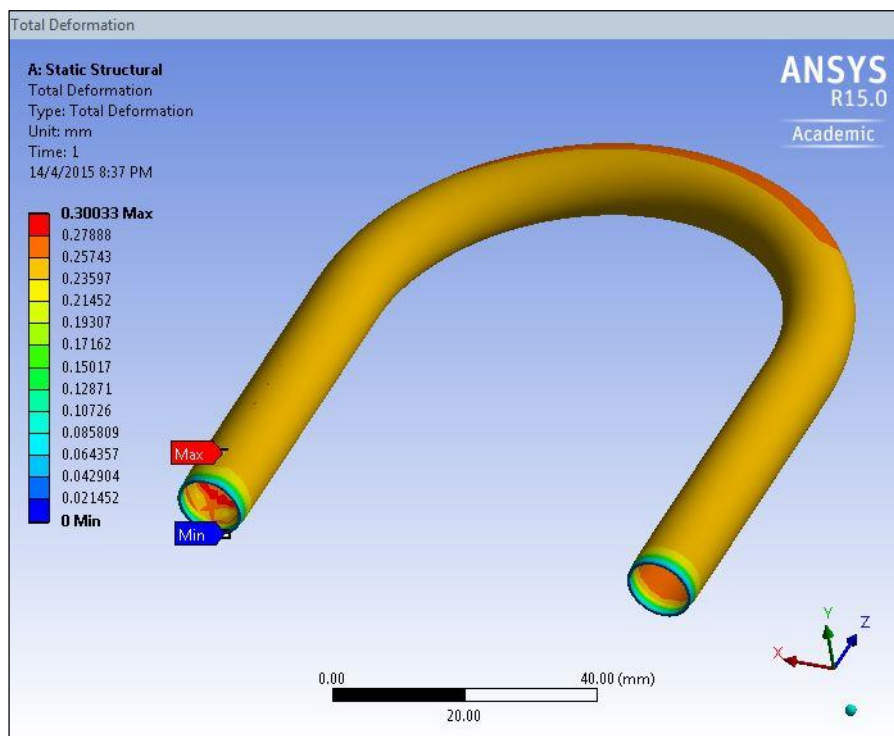
U Shape Hose

Von Mises stress on U shape Hose without Stainless Steel Body
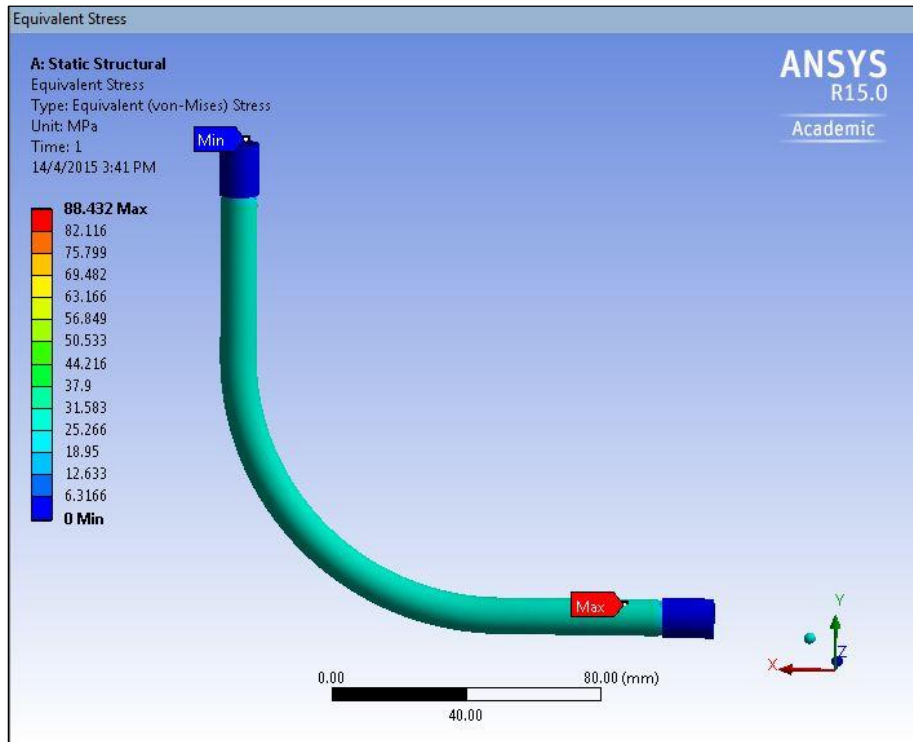

Von Mises stress on U shape Hose with PTFE body only

Total Deformation on U shape Hose without Stainless Steel Body

Total Deformation on U shape Hose with PTFE body only

L Shape Hose

Von Mises stress on L shape Hose without Stainless Steel Body

Von Mises stress on L shape Hose with PTFE body only

Total Deformation on L shape Hose without Stainless Steel Body

Total Deformation on L shape Hose with PTFE body only

S Shape Hose

Von Mises stress on S shape Hose without Stainless Steel Body

Von Mises stress on S shape Hose with PTFE body only

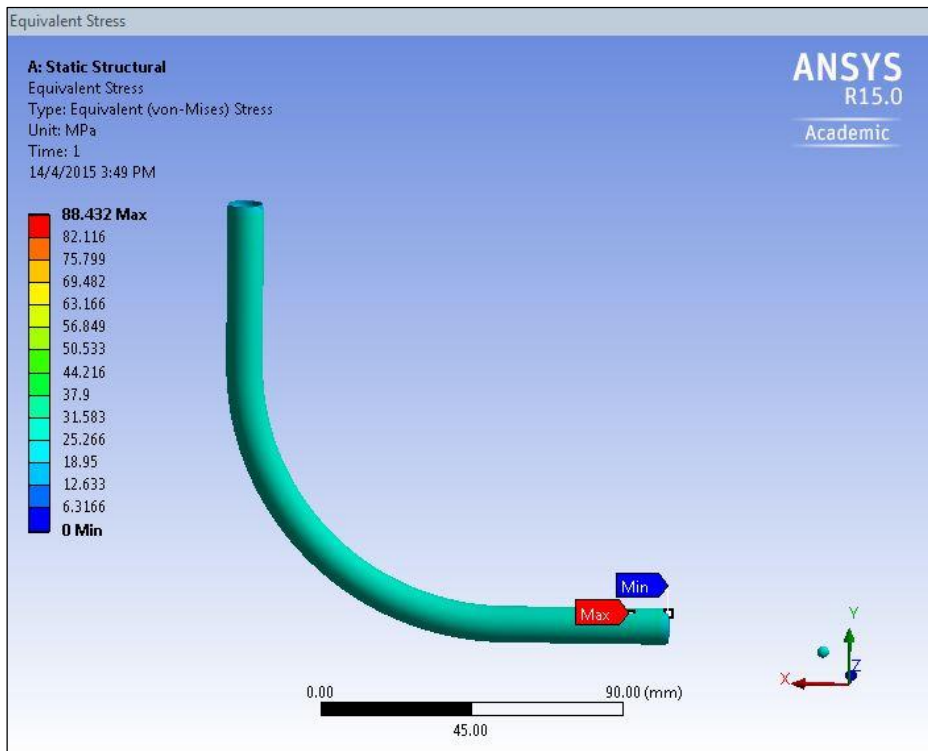Total Deformation on S shape Hose without Stainless Steel Body
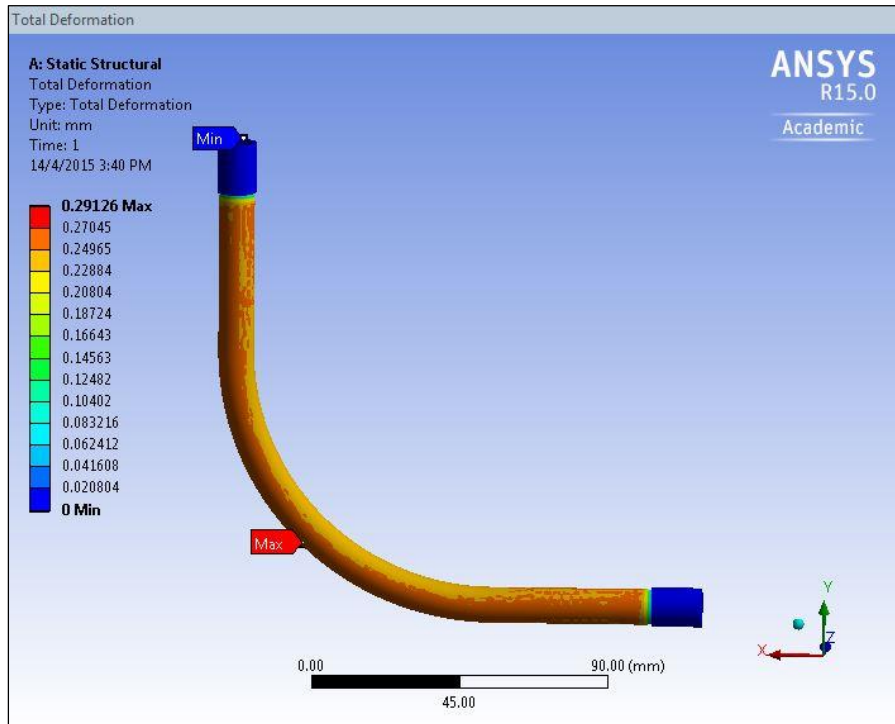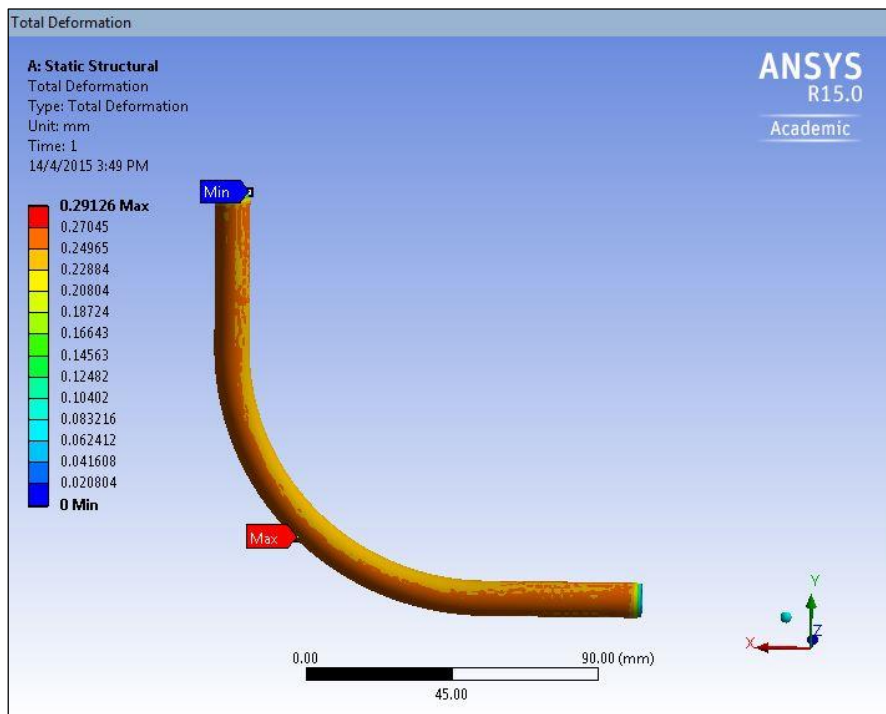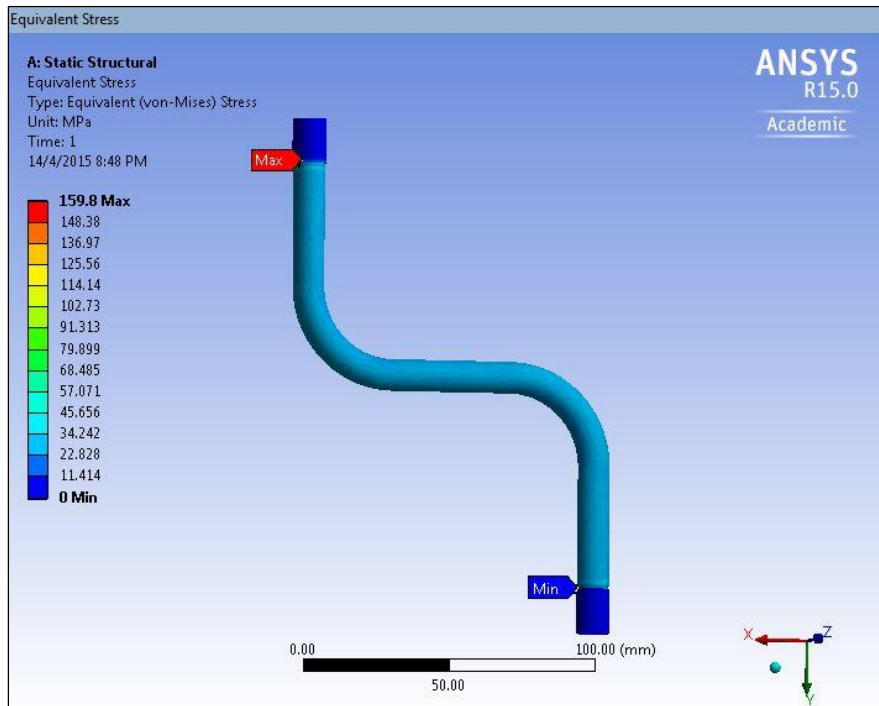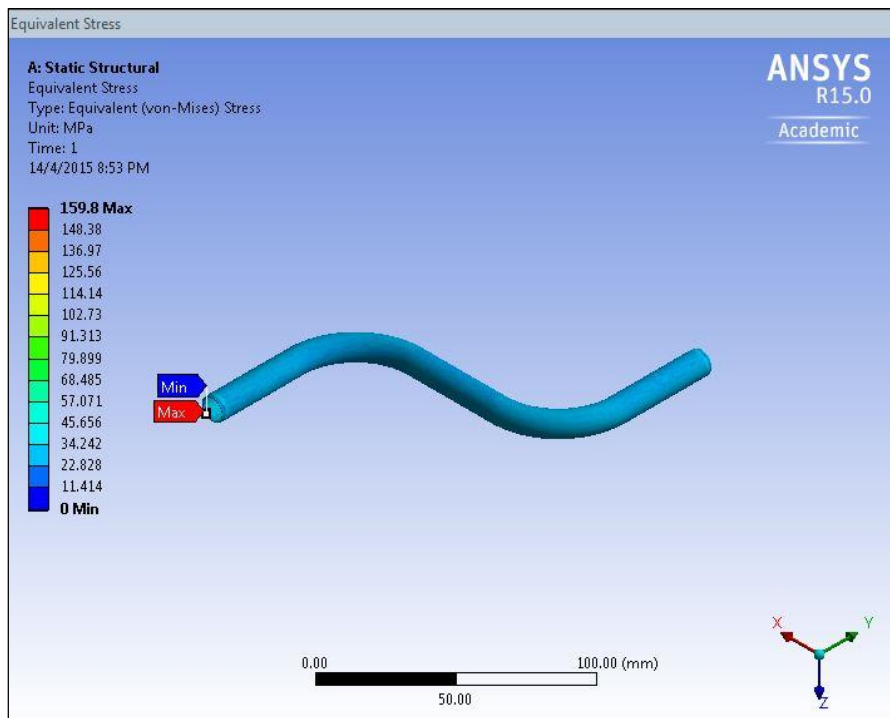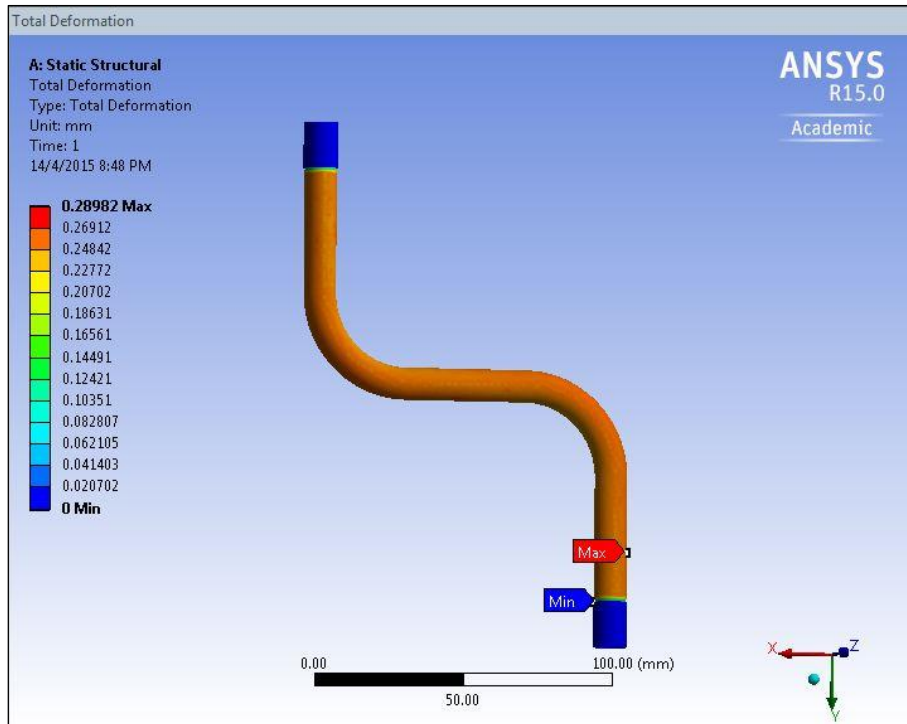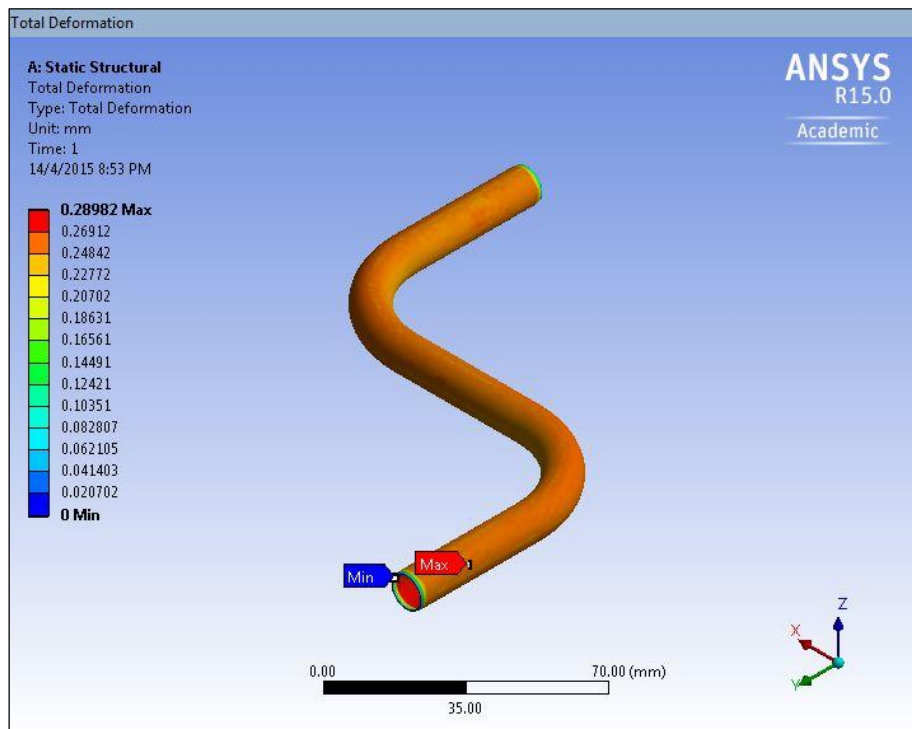

Total Deformation on S shape Hose with PTFE body only

APPENDIX B

Eaton's LifeSense®

Hydraulic Hose Condition Monitoring

Diagnostic Unit
Continuously monitors real-time data and interprets the on-going health of each hose assembly. An alert signals an impending hose failure.

Two solutions, for the way you work.

Whatever you prefer, the freedom of wireless or the simplicity of a wired device, LifeSense has a solution.

LifeSense Wired

- 12- or 24-volt direct current
- Hose diagnostic unit (HDU) continuously monitors up to 11 hose assemblies
- Alert notification on HDU
- Standard wire cable lengths available in 10, 25, 50 or 100 feet

LifeSense Wireless

- 12- or 24-volt direct current
- Diagnostic unit or gateway monitors up to 100 hoses with a 433MHz frequency communication protocol
- Sensor battery has greater than six year life
- Alert notifications on gateway, email or SMS text message via WiFi or ethernet
- Transmits operating performance data once per shift (every seven hours)
  - If an issue arises, gateway transmits data immediately
  - Sensors continually monitor hose
- Data access through web portal
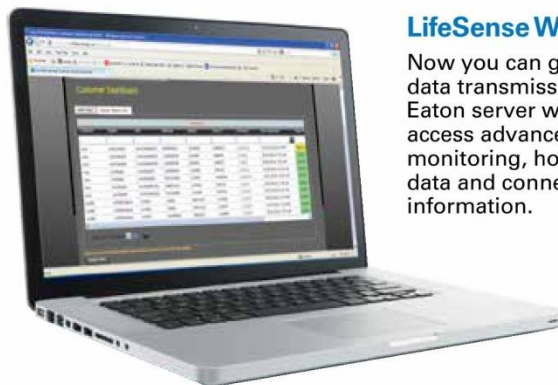
Hose
System electronically monitors entire length of hose assembly.

Sensor
Hose fitting sensor monitors and detects potential issues, and transmits data to diagnostic unit.

LifeSense Web Portal
Now you can get operational data transmission to a secure Eaton server where you can access advanced system monitoring, hose installation data and connection status information.

Innovation through Partnership

Eaton initiated a research project in partnership with Purdue University to effectively address the issue of hydraulic hose failure. The project sought to identify measurable, structural phenomena associated with hose deterioration over time and to develop the required technology to monitor these phenomena accurately. Our joint research determined that hydraulic hose failure is the final step in a consistent process that can be measured and therefore monitored to provide a reliable indication of an approaching end-of-life condition. (U.S. Patent 7,555,936)

Industry Accolades

From the time LifeSense was introduced in the Fall of 2011, it has been repeatedly recognized as one of the most technologically significant innovations to hit the hydraulic market.

We make what's important work.

Unexpected hydraulic hose failure is a significant challenge with serious consequences—consequences that can be costly. Developing a solution that would help our customers deal with hydraulic power more safely, effectively and efficiently just made sense.

The result is LifeSense®, an intelligent hydraulic hose condition monitoring system that detects failure-related events within a hose and provides advance notification the product is approaching the end of its useful life.

How does it work? The LifeSense system is based on the fact certain properties of a hose change as the hose approaches failure. We found periodically comparing samples of these properties to a baseline gave a highly reliable indicator of impending hose failure. Each hose fitting is equipped with a sensor that continuously monitors hose conditions via electrical signals which are submitted to a hose diagnostic unit that interprets the data. An alert is generated if the system identifies the hose has been compromised.

Benefits:

- Safeguards workers
- Can provide over 50 percent more hose life
- Increases reliability – detects and warns of impending failure
- Reduces risk of collateral damage
- Maximizes uptime; mitigates unexpected hose failures
- Improves maintenance operations efficiency – automates inspections, on-going and real-time monitoring
- Protects the environment – mitigates potential spills

Get the Most from Every Hose

Lab testing shows most hoses that are replaced on a time-based schedule of estimated life actually reach less than half of their safe useful life. LifeSense can extend the useful service life of hoses by over 50 percent on average and virtually eliminate the current need to guess when to replace a hose.

Improve Safety and Peace of Mind

By providing advanced warning of impending hose failure, LifeSense gives you peace of mind knowing you're working safer than ever before. Concerns about idled equipment, environmental cleanup, collateral damage and personal safety are lessened with LifeSense.

Detect and Prevent Hose Failure

Internal fatigue due to impact cycles and external abrasion are the two most common causes of hydraulic hose failure. In fact, combined they account for over 80 percent of field failures. LifeSense physically monitors hose condition so it can detect and provide timely notification of internal fatigue as well as external abrasion.

Maximize Uptime and Efficiency*

At Eaton, we recognize our customers operate in industries with high uptime requirements and where unplanned downtime can mean substantial loss in time and money. These factors are a driving force behind LifeSense. LifeSense helps safeguard against unexpected work interruptions—thus, maximizing uptime, enhancing efficiency and providing critical performance value.

Refuse Truck	Steel Mill
$3,000 per incident	**$70,000** per hour

Hydro Power	Oil Rig
$78,000 per day	**$1,000,000** per day

* Cost estimate based on Eaton proprietary study.

LifeSense Unequaled

Some hose manufacturers have developed various predictive formulas that consider time, pressure, temperature, the number of flex cycles and other factors to produce an approximation of expected hose life. In contrast, real-time monitoring of the hose through LifeSense, rather than predictive statistical models, can make your workplace safer, more productive and more profitable. LifeSense just makes sense. To find out more, contact your Eaton representative or visit **eaton.com/lifesense.**
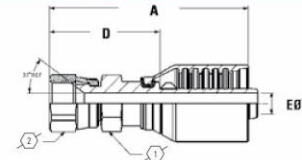
LifeSense.
It just makes sense.

LifeSense Non-Skive Fittings

Female JIC/SAE 37° Swivel
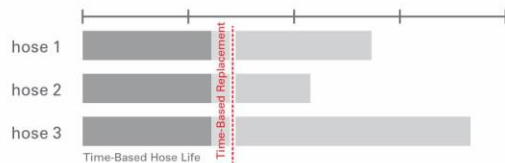
Fittings for use with hose: EC502

# Part Number	Terminal End	Thread	Hose Size		A		D Cut Off Factor		E Ø		⟨1⟩	⟨2⟩
	Dash Size		DN	Dash Size	mm	in	mm	in	mm	in	in	in
3LA8FJ8BD	-08	3/4-16	12	-08	72,8	2.87	37,4	1.47	9,1	0.36	13/16	7/8
3LA12FJ12BD	-12	1 1/16-12	19	-12	77,9	3.07	41,3	1.63	14,3	0.56	1 1/8	1 1/4
3LA16FJ16BD	-16	1 5/16-12	25	-16	91,2	3.59	46,9	1.85	20,7	0.81	1 3/8	1 1/2

Traditional Way
Time-based Replacement

hose 1
hose 2
hose 3

Time-Based Hose Life — Time-Based Replacement

Significant useful life wasted

LifeSense®
True Condition Monitoring

hose 1
hose 2
hose 3

Time-Based Hose Life — Time-Based Replacement — LifeSense®: Additional Hose Life
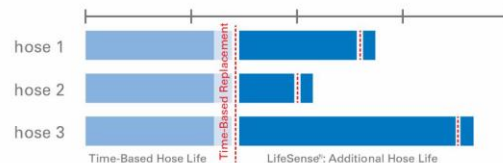
Hose life **maximized!**

Two-Wire Braid Hydraulic Rubber Hose Meets and Exceeds 2SN, EN853 Requirements

# Part Number	Hose Size	DN	Hose I.D.		Hose O.D.		Max. Operating Pressure		Burst Pressure		Min. Bend Radius		Weight		Length	
			mm	in	mm	in	bar	psi	bar	psi	mm	in	kg/m	lbs/ft	m	ft
EC502-8	-08	12	12,7	0.50	24,4	0.96	293	4,250	1,172	17,000	177,8	7.00	0.74	0.50	Bulk	Bulk
EC502-12	-12	19	19,0	0.75	30,5	1.20	215	3,125	860	12,500	241,3	9.50	0.98	0.66	Bulk	Bulk
EC502-16	-16	25	25,4	1.00	39,1	1.52	172	2,500	690	10,000	304,8	12.00	1.47	0.99	Bulk	Bulk

4:1 burst to working pressure safety factor

Construction
Tube: Synthetic rubber
Reinforcement: Two-wire braid
Cover: Synthetic rubber

Operating Parameters
Temperature Range
-40°C to +100°C
(-40°F to +212°F)

Applications
- General hydraulics
- Agricultural equipment (e.g., turf care)
- Vocational fleets - mobile refuse
- Oil and gas - offshore drill and production platforms
- Alternative energy - wind turbines
- Manufacturing - CNC, plastic injection molding

Features
- Diagnostic unit monitors real-time data of each hose assembly
- An alert signals an impending hose failure
- Highly abrasion-resistant synthetic rubber hose cover

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Powering Business Worldwide

60