EFFECT OF WINDING ANGLE DUE TO INTERNAL PRESSURE IN HYBRID POLYMER-METAL CYLINDRICAL COMPOSITE

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by

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All praise is due to Allah. May Allah’s peace and blessings be upon the one after whom there is no other prophet.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ROV	Remotely Operated Underwater Vehicle
FEM	Finite Element Method
FEA	Finite Element Analysis
FE	Finite Element
PDE	Partial Differential Equation
CP	cathodic protection
AMREC	Advanced Material Research Centre
AFP	Auto Fiber Placement

LIST OF SYMBOLS

σ_{app}	Apparent hoop stress
P	Load applied to the structure
Ag	Cross-section area of the specimen
σ_{11c}	Longitudinal compressive strength
σ_{22c}	Transverse compressive strength
τ_{12}	In-plane shear strength
E	Young Modulus
V	Poison's ratio
r_i	Inner radius
$\emptyset_o$	Outer diameter
X_t	Tensile strength
Y_t	Transverse strength
X_c	Compressive strength
Y_c	Transverse compressive strength
s	Shear strength
σ_{11}, σ_{22}	Normal stress component along the principle material directions
σ_{max}	Maximum stress of the structure
σ_u	Ultimate stress of the structure

KESAN SUDUT LILITAN DISEBABKAN OLEH TEKANAN DALAMAN KEPADA HIBRID POLIMER KOMPOSIT-LOGAM BERBENTUK SILINDER

ABSTRAK

Struktur hibrid polimer-logam berbentuk silinder mengunakan polimer jenis gentian kaca dan logam aloi sebagai pelapik yang dikenakan tekanan dalam tinggi masih dalam peringkat pembangunan. Gentian kaca dengan susunan kuasi-isotropic menyaluti keluli tahan karat adalah fokus utama dalam kajian ini. Dengan mengunakan model struktur hibrid komposit berbentuk silinder dalam kaedah unsur terhingga (FEM), ketegangan dan tekanan letupan dapat disimulasikan. Berdasarkan rekaan model struktur hibrid komposit berbentuk silinder, contoh bagi struktur hibrid komposit berbentuk silinder dapat dihasilkan. Akhir sekali, melalui kaedah eksperimen cakera ujian belahan, beberapa ujikaji telah dijalankan. Ujikaji ini dijalankan untuk mendapatkan nilai tegangan sebenar terhadap struktur dan juga untuk memerhati urutan kegagalan yang berlaku. Berdasarkan keputusan simulasi dan eksperimen, komponen polimer komposit gagal sebelum keluli tahan karat gagal dan seterusnya membawa kepada kegagalan keseluruhan.

EFFECT OF WINDING ANGLE DUE TO INTERNAL PRESSURE IN HYBRID POLYMER-METAL CYLINDRICAL COMPOSITE

ABSTRACT

The hybrid cylindrical composite structure using glass polymer types and metal alloy as the liner subjected to high internal pressure is still under development stage. Glass-fiber with quasi-isotropic lamination overwrap stainless steel is selected to be the main focus in this research. By modelling the hybrid cylindrical composite structure using finite element method (FEM), the stress and burst pressure are simulated. Based on the design of the hybrid cylindrical composite structure, sample of hybrid cylindrical composite structure are fabricated. Finally, through an experiment known as the split disk test, a series of tests were conducted. These tests were carried out to obtain the actual stress value of the structure and to observe the sequence of failure that occurred. Based on the simulation and experimental result, the polymer composite component failed first before the stainless steel, which leads to the catastrophic failure.

CHAPTER 1

INTRODUCTION

First chapter is written and structured in 11 sections as to provide general information on the work that has been conducted. In the first section, the product design and development of this work are presented and the further elaboration subsequently in the section that discuss design functionality, general structure and hybrid selection that have been used. Second section discussed about the hybrid cylindrical structure, while FEM mentioned in third section has been utilized before the construction of the prototypes. Experiment method and failure analysis has been utilized to validate the simulation and to observe the response of the structure. The necessity to evaluate mechanical performance are stated under the problem statement section, follow by the establishment of research objection. Scope of research and overview of the structure of this thesis is given in the final section.

1.1 Research Background

Cylindrical tube structure has long been known as a structure to transfer, transport and storage pressurized fluid or oil. These systems are widely used for internal and external pressure application. These types of structure have been used in various internal pressure applications such as in pressure vessel, transportation trucks, gas tank, hydrogen storage, pipeline system, fuselage body, and etc.

Other than that, cylindrical structure also acts as a main structure on the pipeline and equipment protector from external pressure and water penetration for pressure hull in underwater application. Traditionally, carbon steel and cast iron are the most common materials for this kind of structures. However, these materials introduce their own problem such as easily corroded, low resistance to impact, high weight and etc. In certain service conditions, alloys steels are used. Different methods have been introduced to overcome the weakness in corrosion resistance such as wrapping the external surface of cylindrical structure with corrosion resistance agent or using *cathodic* protection (CP). In addition, high weight also causes problems during the transportation and installation of the structure.

Nowadays, there are many selected materials that can be used to produce cylindrical structures, which varies from alloy metals to composite materials. However, some limitation has been observed especially in manufacturing aspect, especially in attaining the desired dimension as well as the specific design depends on the selection material. Composite is commonly used in aircraft industry as it reduces the structure weight of the aircraft without affecting the aircraft performance. Other than that, composite have some advantages such as high strength to weight ratio, light weight structure, corrosion resistance and ease in the fabrication process. Composite material has also been utilized to produce the cylindrical structures. In oil and gas industry, pipeline in well casing and oil field gathering line made from composite material has been utilized for more than 30 years and still in service (Liu 2001). However, due to its limitation in porosity characteristics, the composite structures can only deal with service for low pressure application.

In order to overcome this problem, hybrid polymer composite with metal liner for cylindrical structure has been introduced. This structure has been used in high pressure pipeline and cryogenic pressure vessel. The structure would enable the composite material to withstand the applied load whilst the metal liner is used to prevent any leakage. This kind of concept can be used for external and internal pressure application. However, only a few studies have been done for this kind of structure and there still so many things to be explored. Most of the current researches focus on the winding and stacking effect of composite material and also the behavior of the hybrid cylindrical structure as well as the optimization of the shape (Vedvik & Gustafson 2008; Zheng & Liu 2008; Hocine et al. 2009; Lifshitz & Dayan 1995; Kabir 2000; Vafaeesefat & Khani 2007; Chapelle & Perreux 2006).

1.2 General Structure and Material Selection

Today, there are a number of the cylindrical structure designs and each of the designs has their own unique advantages over the other. Detail evaluation study of the wall architecture is important to improve the efficiency, characteristic and performance of the structure. Some of them are designed to reduce the bending effect while the other is to reduce the maintenances of the structure (Walker & Smith 2003; Wild & Vickers 1997). With regards to the geometrical attributes of the vessel, the effect on the selection shape on the performance of the structure has been discussed. Out of all known shapes, only curvature shape is considered more seriously in pressurized operating environment. This is due to the absence of sharp edges or pointed angles that introduce high concentrated stress to the region.

In addition to the above factors, stacking and sequence of composite materials are also required for consideration. As the strength and characteristic of the composite structures depend on the fabrication process, the structures' performances also depend on the stacking sequence. This process must also ensure that the selected sequence will not increase the chances of defect and flaw to occur during manufacturing process. The defects that commonly related to unsuitable composite sequence are delamination and warpage. Generally, hybrid composite/metal structure is described as the combination of metal as the liner and the main structure are tailored from composite material. Metal liner acted as the leakage preventer and is located at the inside of the structure. This component is adhesively bonded to composite materials on its outside surface. Shell structures are made from composite materials and also used as the main structure to carry the applied load.

In order to achieve the desired structural specification, detail description on laminated sequence of the structure should be carefully considered, as stacking sequence of composite laminate determines the performance of the structure. For example, the sequence degree of the composite, the bonding between high strength and stiffness fibre with matrix resin certainly affect the characteristic of the composite. The most common composite fibres are glass, aramid and carbon fibre, while the matrixes are usually made from epoxy, polyester and vinyl-ester (Liu 2001). On the other hand, the most common type of liner materials is elastomeric, thin wall structure or load sharing metal materials.

1.3 Hybrid Cylindrical Structure

A hybrid composite/metal has been developed for several high pressure applications either for pipeline industries and pressure vessel. This hybrid structure which is made of a metal liner overwrapped with composite material has many advantages over the construction from one material only. Compare to construction using traditional metal alloy, the hybrid composite/metal structure has the advantages, such as it provides a considerable weight-saving due to the light-weight but high strength to weight ratio characteristic. It also can be optimized accordingly by the design specification due to ease of composite fabrication, and lay-up tailor ability. Lastly, the outermost composite surface may protect the entire inner structure from the external corrosion, thus does not require frequent corrosion protection to be used on the metallic structure and fewer maintenance processes as no repaint or coating is required.

On the other hand, the inner metallic liner of the hybrid composite/metal structure introduces some advantages over structure used in the monolithic composite material. The internal liner can serve as a seal, which may effectively solve the problem of leakage under high pressure application and composite porosity characteristic. Other than that, a beneficial compressive residual stress state could also be introduced, a similar concept as autofrettage on an all metal thick-walled pressure vessel structure (Wang et al., 2010). Subsequently, the hybrid of the polymer composite/metal liner in cylindrical structure provides a lighter design without compromising the performance due to the composite high strength-to-weight ratio and high stiffness-to-weight ratio characteristic of composite material. Leakage problem can be reduced or eliminated due to the ductility characteristic of the metallic liner.

In addition, catastrophic failure can also be delayed with most metals experience plastic deformation region before necking, in stark contrast of composite properties. Metallic liner can also act as heat emission in certain operating condition such as ROV (Remotely operated Underwater Vehicle) pressure hull to reduce the heat generated by electronic components, hence the thermal stress. There are a number of techniques have been utilized in fabrication of cylindrical pressurized hybrid structure. All the approaches can be considered depending on the availability of the raw materials. Usually for metal alloy, rolling technique and follow by wielding is the most common technique in fabrication for multiple sizes of circular cylindrical dimension.

However, there is also fabrication using palpation technique for standardized structures. Several fabrication techniques can be utilized depending to the physical types of composite material, either in ribbon, fabric or chopped fibre. The most common fabrication technique using the fibre ribbon is filament winding technique while lay-up approach is used for construction using fabric composite. Spraying on the cylindrical mould can also be using from chopped fibre.

It was found that, there are many types of flaws may happen during the fabrication process. Flaws such as void, shrinkage, debonding and, etc could disturb the performance of composite structure. For that, some additional method has also been introduced to composite fabrication technique in order to reduce these flaws and most importantly to produce high quality of composite structures.

In some of the industries, especially in aerospace industries, other than using pre-impregnation fibre (a standard ratio mixture of fibre and matrix in fabric composite that have been semi-cured), vacuum bagging and autoclave have been introduced to the system with the aim of getting a high quality of composite product. Both additional methods can also be used in other composite applications. All of these innovative manufacturing methods have their own advantages over each other, with the same aim that is to achieve greater performance of the composite product while reducing time, cost, material and labour work in composite structure manufacturing.

1.4 Problem Statement

Hybrid concept provides greater advantages such as light weight construction, ease of fabrication, high corrosion resistance, sealants from leakage, heat emission, less maintenance cost, and low payload as compared to those of monolithic materials. Nonetheless, there are still lacked of available studies on mechanical performance of the structure, modeling using finite element analysis (FEA), material selection, behaviour of the structure, failure analysis and etc. With this, the development of hybrid structure still requires extensive research as a robust and reliable hybrid structure relies upon the performance and behaviour between its composite and metallic component.

Hence, the main focus of this study is concentrated on the effect of winding angle due to internal pressure in hybrid cylinder polymer composite with metal liner. It covers the aspects of design, analysis using finite element method, and testing of the hybrid cylindrical structures. In general, this dissertation discussed mainly about the mechanical performance of the hybrid cylindrical structure subjected to internal pressure.

1.5 Objective

The main research goal is to evaluate the mechanical performance of the hybrid cylindrical composite structure subjected to internal pressure. In order to reach the aim/goal, several objectives are outlined as follows:

1. To design a hybrid cylindrical structure using polymer-metal composite
2. To analysis the effect of winding angle on burst pressure and hoop stress using FEM
3. To develop the prototype of hybrid composite structure for pressure vessel and cylindrical piping

1.6 Research Scope and Thesis Outline

The framework of the research and development of the hybrid cylindrical composite structure is outlined in Figure 1.1.

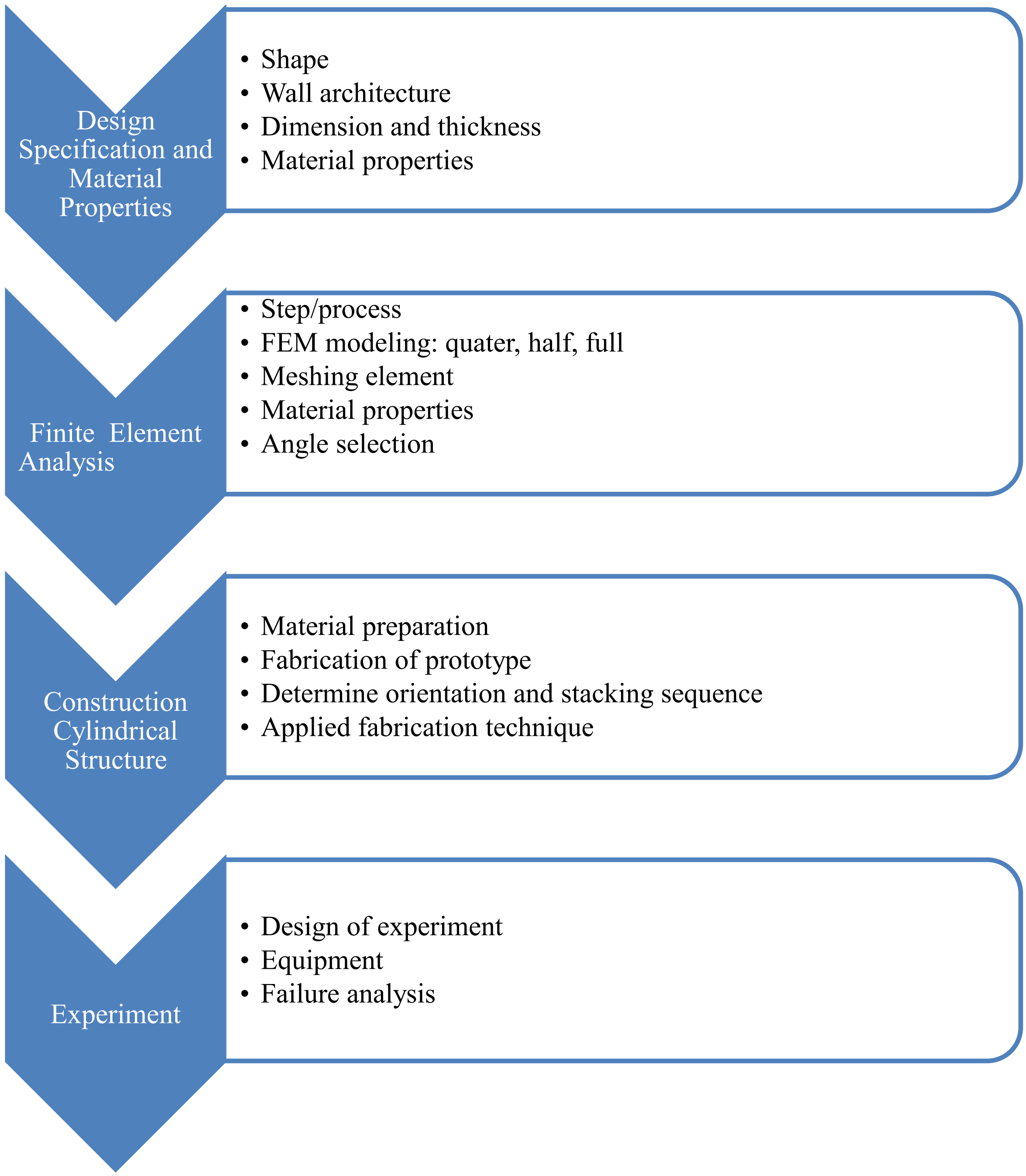

Figure 1.1: Scope of Research

In this study, there are four significant group of scope that been categorized, which cover from design concept of cylindrical composite structure, FEA on the structure, fabrication of the prototypes and experiment validation, as shown in Figure 1.1. Design stage is more concentrated on the shape of the structure, structure wall architecture, wall thickness and dimension of the structure.

In the modeling of the FEA, the focus is mainly about procedure that has been done using commercial finite element (FE) software which included the meshing element between the shell and solid element, selected types of material and the analysis using FEM approach. After finalizing the structure design and through the analysis of the simulation result, the next phase is to develop the prototype of the structure. Several procedure and precaution need to be followed in order to create quasi-isotropic properties of composite cylindrical pressurized structure.

Other than that, several techniques to improve the fabrication of filament winding are introduced. Vacuum bagging process is introduced to this technique to reduce the tendency of wrinkles to the product while wet lay-up method is used to lay the fabric types of glass fibre to the structure. Fabric E-glass is used to make sure that the load force is distributed uniformly inside the structure. The importance of this fabrication phase is to ensure that this design specification can be implemented and to observe any related problems that occur during the manufacturing process. Some of this sample is used in the follow-up phase of the experimental validation.

For the experimental approach, techniques known as a split disk test is utilized. The split disk test is the easiest and simplest experiment to determine the behaviour and strength characteristic by simulating the applied load to the cylindrical structure to represent the internal pressures that have been applied. This experiment used ESH300KNM, an ultimate test machine that been attached with a special device (consist of 2 joints arm and 2 hemisphere) to run this specific test. All the result, behaviour and problem arise in this experimented has been described briefly.

1.6 Research Scope and Thesis Outline

The organization of the dissertation is summarized in table 1.1.

Table 1.1 : Organization of the Thesis

CHAPTER	CONTENT
1	Project overview, background and objective
2	Literature review
3	Methodology: 1 – Design specification 2 – FEM 3 – Experiment
4	Result and Discussion
5	Conclusion and Recommendation

Chapter 1 elaborate briefly about the project overview which is the current issue related cylindrical structure and their problems. Several methods had been discussed to improve their performance and eliminate the arise problem. Chapter 1 also presents the objective and research scope. Literature review in chapter 2 discusses about previous work conducted by the previous researchers. Some design and development of cylindrical structure are discussed as well. The common problem for cylindrical structure design and their architectures which related to the internal and external pressure concept are mentioned in Chapter 2. At the end of chapter 2, summary of the finding and the brief methodology of this research are presented. Three subsection of methodology had been divided in chapter 3, based on the phase of the research that had been done. These subsections have been categorized as the design specification of hybrid cylindrical composite/metal liner, finite element analysis (FEA) for structural modelling and analysis, and lastly experimental testing and failure analysis.

During phase 1 or design specification, this section elaborates on the design shape and dimension of the structure as well as the wall architecture design concept. Selection of the material is crucial in this stage as it will affect the analysis by FEA and experimental result during the experimental study. Stacking sequence and composite sequence are also included. As for phase 2, studies utilized FE software had been done to model the hybrid structure and perform the analysis for structural performance. The behaviour of the structure as the load been applied is the main focuses in this stage. The experimental work has been utilized to validate the simulation data with the test data.

In final phase, a comprehensive experimental study is performed to observe the structural performance and its behaviour. A relative assessment of the hybrid structure, loaded with tensile stress, is provided. This laboratory study served as a platform to evaluate the FEA of the cylindrical structure. The study of pressurized cylindrical structure consists of the product development which consists of design specification, followed by modelling analysis by FEA software, subsequently by fabrication of the prototype of the structure and finally, the experimental study and failure analysis. Chapter 4 present all the result and discuss the findings that have been obtained. Results of FEA simulation as well as the observation from the experimental study had been discussed here. Some justification on the result obtained is mentioned as well. The final chapter consists of the conclusion of the project. Some review reflected the achieved objectives are stated. The recommendations for the future work are also been suggested in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

Recent literatures have been reviewed and presented in 8 sections as to study the published literatures of previous research that related to cylindrical hybrid composite-metal liner structure. This chapter contained review of research related to cylindrical structure, its general structure and design functionality. The concept of hybrid cylindrical design had been reviewed as well as the material selection. Further on, the manufacturing methods of cylindrical structure are also be reviewed. Follow by that is the method of design validation and analysis, which consists of design parameter, FEA, experimental method and failure analysis. In the conclusion of this chapter, some explanation for the gap of previous research and the current work is presented.

2.1 Overview of Cylindrical Structure

As introduced in chapter 1, cylindrical structures are an essential structure for fluid transportation and storage. Traditionally, metal alloy is the most common material for this kind of structure. Due to the increasing use of advanced composite material in structure application in the past several decades in marine, aerospace, petroleum, domestic, industrial and military application, researchers tend to introduce the polymer composite as an alternative material for this structure.

Commonly, composite cylindrical structure or pipeline is made from long fiber reinforced polymer composite plastic, and filament winding technique is the most popular technique that has been utilized in the fabrication process. Mechanical properties for the end product of composite material are limitless as it can be influenced by the scatter of design variable and multiple composite manufacturing techniques. Since this kind of structure is more widely used in various engineering fields, nowadays, it has become subject of numerous types of research work that cover development of theories, numerical analysis, material selection, and experimental work (Rahim et al. 2009; Hocine et al. 2009; Rahim et al. 2011; Zu et al. 2010; Osse & Lee 2007; Akçay & I. Kaynak 2005; Xia et al. 2001, Vafaeesefat 2009; Vafaeesefat & Khani 2007).

2.2 General Structure and Design Functionality

The best structure for pressurized application is sphere. However, cylindrical structure is the typical structure used in industry either for the storage, transfer or transport of the pressurized fluid. Circular cylinder has long been the basic concept for various pressurized applications due to its performance, characteristic and advantage comparing to other structure types. A number of researchers have been performed to enhance and increase the performance on this structure (Hocine et al. 2009; Rahim et al. 2011; Zu et al. 2010). Furthermore, cylindrical structure either in the pressure vessel or pipelines is generally large and used in pressurized environment, in turn required a large amount of material for their construction.

Researchers tend to make this structure to be lighter but more stiffened, in order to maintain its structure while resisting the applied load. In addition, the structure must be corrosion, fatigue, impact, thermal stress and shock resistance. To achieve these goals, it is essential to choose a low cost-per-weight material system and a manufacturing process that performs to requirements (Rahim et al. 2009; Hocine et al. 2009; Rahim et al. 2011; Zu et al. 2010; Osse & Lee 2007; Akçay & I. Kaynak 2005).

2.2.1 Typical Design Structure for Pressurized Application

As the main function of the structure is to withstand the pressurized fluid, it is important to determine the shape of the structure as it can affect the other parameters in the design criteria. The most common shapes of the structures that related to pressurized fluid are sphere, ellipsoid, cone, cylinders and combination of this shape (Rahim et al. 2009). Several shapes have been studied by the previous researchers to get its best optimization design methods.

The main contribution in shape analysis is the thickness of the structure can be minimized, with the internal volume of the structure is increased while reducing the weight of the structure. With this, the total cost of the product can be reduced (Xia et al. 2001; Vafaeesefat 2009). In order to perform structural shape analysis, the study of structural failure and damage behaviour is required to be carried out as its represent the structure load-carry capability (Akçay & I. Kaynak 2005; Vafaeesefat 2009; Vafaeesefat & Khani 2007; Liang et al. 2002).

2.2.2 Design Functionality of Cylindrical Structure

After the introduction of composite into the engineering field, the implementation of composite had also been applied to the cylindrical structure. The common fabrication technique of cylindrical structure using composite material is by using filament winding technique. This concept is known as filament-wound composite shells of revolution and widely used in various applications, such as pipelines, pressure vessel, tanks for gases and liquids. Information such as the number of layers, stacking sequence and sequence, geometry of the structure and mechanical characteristic are important for stress analysis as there are the decision factors in the strength of the structure (Kim et al. 2005).

However, manufacturing effect such as the filament-winding mosaic pattern can affect stress and strain of composite structure (Morozov 2006). Morozov found that the mechanical behaviour of thin-walled filament-wound composite shell is sensitive to the filament winding patterns, and the stress and strain distributions are affected by the size of the triangular mosaic unit and their numbers per unit of length in both longitudinal and circumferential (hoop) directions (Morozov 2006). One of the innovative design alternatives for the cylindrical structure is sandwich structure. Sandwich structure construction consists of a pair of high–strength, relatively thinner, stiff layers (facings), bonded to one low density, flexible layer (core), light weight, high stiffness, high structural efficiency and high durability (Kemmochi, et al. 2001; Xia et al. 2000; Takayanagi et al. 2002; Kobayashi et al. 2007).

Due to the advantage of composite, such as reduced weight, superior corrosion resistance, improved hydrostatic strength, and etc. have made the construction of cylindrical structure using composite provide superior over the use of steel. Structure efficiency of this construction depends strongly of its core configuration and fibrous composite as face sheets. Different core configurations generate different sandwich mechanic behaviour and the core configuration can be solid, cellular, honeycombed and corrugated. The hybrid concept utilized the sandwich concept as well as composite filament-winding patterns and thin wall architecture is utilized together in this study. In this concept, the composite component carried the load stress while the metal component prevents leakage from occur.

2.3 Hybrid Cylindrical Structure

Composite material show high potential to be used as an alternative material in manufacturing the cylindrical structure. Li et al. (2009) have concluded in their study that the desired mechanical performance and properties of the structure can be achieved just by adjusting the winding angle. Instead of their apparent advantage, Kabir (2000) stated that the composite component alone lack of stiffness and strength to adequately withstand the loads of a large structure. These types of material have leakage issue for high pressure application. Hocine et al. (2009) state that vessel manufactured with only composite material deals with leakage due to its porosity characteristic. To overcome this drawback, the materials are coated on metal liner, and this concept is regarded as a hybrid system, where the liner provides the sealing and corrosion resistance while fiber composite is charged to resist loading of high internal pressure.

Some of the advantage of this approach is it ensure a perfect participation between the liner and composite hull; it allows reaching weight saving up to 50% in comparison with all metal vessels and deals with the physical and mechanical properties of materials without neglecting geometry shape of vessels (Wang et al., 2010, Kabir, 2000). Using composite for the bulk of the vessel could help achieve a more corrosion-resistance structure, especially when used on combined with corrosion-resistance metals such as stainless steel and aluminium. Hybrid composite/metal systems have emerged as a viable alternative to conventional construction and manufacturing methods, due to ease of manufacturing complex shape of relatively little increment cost, when compared to fabrication with metals.

Some researchers have utilized other kinds of concepts to improve the mechanical properties of the structures well as to fulfil the design requirement (Kabir 2000; C. U. Kim et al. 2005; Kobayashi et al. 2007; Naruse et al. 2001). One of those concepts is to introduce a liner concept in filament wound structure. The advantage of liner concept is its can reduce the failure regarding of fluid leakage (Osse & Lee 2007). As the load is applied internally to the structure, stress of the composite structure can result in a crack in wall structure that leads to the contained fluid leakage out of the structure.

Commonly, there are three classes of the liner which is elastomeric, thin-metal liner, and load sharing liner. The liners that act as leakage preventer are adhesively bonded to the composite materials, which are used as the load carrier. For composite, the most common fiber used in industries are glass, aramid and carbon fiber, while the matrix materials are is usually epoxy, polyester or vinyl-ester resin. The most common liner materials are elastomeric and metallic alloys. Concepts of hybrid polymer composite-metal construction in pressurized cylindrical type's structure application are widely used in various applications such as hybrid composite domestic gas cylinder, CNG composite vessel, cryogenic pressure vessel, and compressed hydrogen storage (Rahim et al. 2009; Antunes et al. 2008; Choi et al. 2004; M.-G. Kim et al. 2008)

2.4 Material Selection for Hybrid Composite-Metal Cylindrical Structure

One of the keys in determining the mechanical properties and characteristic of the structure is to choose the appropriate material. In selecting the suitable material to be used, several important issues need to be evaluating first.

The price and availability of the material need to be considered. It is more practical and cost effective to use available material in the market then choosing a special alloy mixture or a rare material that will increase manufacturing cost. Another aspect in making economic design is by designing a structure according to standard size of the selected material. Strength, stiffness and density of the material also need to be considered. Depend to the design requirement, total weight of the structure can be reduced while increasing the structure strength by just changing the types of material. Welding is a common structural joint technique. This technique can also be introduced in cylindrical structure manufacturing. However, for certain types of material; the strength of the structure can be reduced on the welding region. Choosing suitable material for welding construction is important to ensure strength of the structure in the welding region (Yousefpour 2000).

On the other hand, for application exposed to the corrosion agent, choosing material with corrosion resistance characteristic is the essential in design concept. The need to apply extra coating resistance can be eliminated and this reduces the total cost of the product. Depending on the design requirement, characteristics such as fatigue and load resistance can also be considered during the material selection process. In order to achieve the desired structural performance, the strength/characteristic and performance of the material need to be reviewed as they are directly related. Common materials that have been used in fabricating the cylindrical structures include CFRP, GFRP, aluminium alloy, titanium alloy and stainless steel structure.

Composite materials have a wide range of application in aircraft structure, space vehicle, underwater vehicle, domestic and industry application and are replacing their conventional counter parts, i.e. metallic material. Composite are known for their superior strength and stiffness-to-weight ratios as compared with metals. High specific properties of composite materials over metals can reduce the weight of the cylindrical structure. One of the advantages of using composite material is that the structure lay-up configuration can be tailored in unidirectional, cross-ply or quasi-isotropic laminates configuration. The basic composite materials can be pre-impregnated or a raw material either in ribbon fiber or woven fabric bath with epoxy material.

All of these advantages give composite material the ability to be tailoring their material properties to fulfil the design requirement. Previous studies showed that instead of using conventional metallic, one could reduce the weight of the pressure vessel between 2 to 3 times by using the composite pressure vessel. Other than making the structure lighter but stronger, it also a cost-effective material compared to the other (Kabir 2000). Commonly, there are four typical types of unidirectional continuous fiber composite, which is Boron-Epoxy, T-300-Epoxy, Kevlar 49- Epoxy and E-glass-Epoxy (Mallick 1993). Typical mechanical properties of unidirectional continuous fiber composite are shown in Table 2.1.

Table 2.1 : Typical Mechanical Properties of Unidirectional Fiber Composite (Mallick 1993)

Property	Boron-Epoxy	T-300-Epoxy	Kevlar 49-Epoxy	E-Glass-Epoxy
Density, g/cm3	1.99	1.55	1.38	1.80
Tensile properties				
Strength, MPa (ksi) 0^0	1585(230)	1447.5(210)	1379(200)	1103(160)
90^0	62.7(9.1)	44.8(6.5)	28.3(4.1)	96.5(14)
Modulus GPa (Msi) 0^0	207(30)	138(20)	76(11)	39(5.7)
90^0	219(2.7)	10(1.5)	5.5(0.8)	4.8(0.7)
Major Poisson's ratio	0.21	0.21	0.34	0.30
Compressive properties				
Strength, MPa (ksi) 0^0	2481.5(360)	1447.5(210)	276(40)	620(90)
Modulus, GPa (Msi) 0^0	221(32)	138(20)	76(11)	32(4.6)
Flexural properties				
Strength, MPa (ksi) 0^0	-	1792(260)	621(90)	1137(165)
Modulus, GPa (Msi) 0^0	-	138(20)	76(11)	36.5(5.3)

The most common fiber that been used in industries is glass fiber. Other that cheap and easily obtained, it also has high stiffness to weight ratio and strength to weight ratio compares to other materials.