SURFACE FRACTURE MODE ANALYSIS OF FRP COMPOSITE PIPE BY MICROSCOPIC TECHNIQUE

NUR AMIRA BINTI SHAMSUL NIZAM
B041310192
BMCS
amirashmslnizam@gmail.com

Projek Sarjana Muda

Supervisor: DR. OMAR BIN BAPOKUTTY

Faculty of Mechanical Engineering
Universiti Teknikal Malaysia Melaka

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NUR AMIRA BINTI SHAMSUL NIZAM

A report submitted
in fulfillment of the requirements for the Bachelor of Mechanical Engineering
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Faculty of Mechanical Engineering

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DECLARATION

I declare that this thesis entitled "Surface Fracture Mode Analysis Of FRP Composite Pipe By Microscopic Technique" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : NUR AMIRA BINTI SHAMSUL NIZAM

Date : 16/6/17

APPROVAL

I hereby declare that I have read this work and in my opinion it is adequately based on the scopes and quality for the degree of Bachelor of Mechanical Engineering (Structure & Material) with honour.

Signature : .....

Supervisor's Name : DR. OMAR BIN BAPOKUTTY
PENSYARAH KANAN
FAKULTI KEJURUTERAAN MEKANIKAL
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Date : 16/6/2013

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ABSTRACT

Fibre-reinforced composite (FRP) material are found widely used nowadays in various industries such as offshore, aerospace, medical science and also in construction industries. The application of fibre-reinforced composite material have overcome the use of conventional materials such as steel, timber and concrete due to the composite material characteristics which are high in stiffness, toughness, strength with low density that could contribute in reducing manufacturing and transportation cost. However, the environmental effect on the FRP followed by several failure of FRP when overload stress provides interests to study different performance of fracture surface of FRP as fracture mode of FRP could be only one mode or even more than one mode depends on the force act on it and also surrounding that may change the mechanical properties of the advanced material. This paper is an attempt to study the fracture surface of FRP composite and uncover the failure mechanism that may occur in the composite due to high load applied on it by visual and microscopic technique. The cause of the failure, the performance and propagation of the surface fracture may be determined by careful and thorough observation. Visual inspection of the fractured surface of FRP composite is to determine the most critical fracture part that can be seen with our naked eyes as before using any other microscopic instrument, the first step in fracture inspection is visually observe any fracture that can be seen visually. Digital Microscopic image analyser is used to observe the fractured surfaces of glass and epoxy composite in further detail to reveal the failure modes of the FRP such as delamination, fibre breakage, de-bonding between fibre and matrix and fibre pullout region that may weaken the performance of the composite. The tensile test results shows the predictable pattern of brittle FRP pipe material resulting the objectives of this project have been achieved as several mode of failure on the surface of FRP pipe composite were revealed due to tensile load act on it.

ABSTRAK

Bahan komposit serat pengukuh (FRP) digunakan secara meluas pada waktu in dalam pelbagai industry seperti industry luar pesisir, aeroangkasa, sains perubatan dan dalam industri pembinaan. Aplikasi bahan komposit serat pengukuh telah mengatasi penggunaan bahan konvensional seperti besi, kayu dan konkrit disebabkan oleh karakter bahan komposit yang tinggi kekakuan, tinggi kekuatan dengan rendah ketumpatan yang akan menyumbangkan kepada pengurangan kos pembuatan dan pengangkutan. Namun, keadaan sekeliling memberi kesan kepada FRP diikuti dengan beberapa kegagalan FRP apabila dikenakan tekanan terlalu tinggi menarik minat untuk mengkaji kepelbagaian prestasi retak permukaan FRP memandangkan mod keretakan FRP boleh jadi satu atau lebih daripada satu mod bergantung kepada daya yang dikenakan ke atas FRP dan juga keadaan sekeliling yang boleh mengubah sifat mekanikal bahan termaju tersebut. Kertas kerja ini adalah mengenai kajian keretakan permukaan komposit FRP dan mendedahkan mekanisme kegagalan yang berlaku dalam composite disebabkan oleh daya yang terlalu tinggi dikenakan dengan pemerhatian visual dan teknik mikroskopik. Penyebab kegagalan, prestasi dan propagasi keretakan permukaan boleh didapati dengan permerhatian teliti. Pemerhatian visual keretakan permukaan komposit FRP adalah untuk mengenal pasti bahagian keretakan yang paling kritikal yang boleh dilihat dengan mata kasar memandangkan sebelum menggunakan alatan mikroskop yang lain, langkah pertama dalam pemerhatian keretakan adalah mengenal pasti secara visual apa-apa keretakan yang boleh dilihat secara kasar. Mikroskop Digital Analisa Imej digunakan untuk memerhati retak permukaan komposit kaca dan epoxy dengan lebih mendalam untuk mendedahkan mod kegagalan FRP seperti delaminasi, kerosakan serat, terputus ikatan antara serat dan matrik dan tarik keluar serat yang boleh melemahkan prestasi komposit. Keputusan daripada ujina daya menunjukkan corak yang diramal untuk bahan paip FRP yang rapuh menjurus kepada pencapaian objektif project dimana beberapa mod kegagalan pada permukaan paip FRP telah didedahkan akibat daripada daya yang dikenakan.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABREVIATIONS

SUBSCRIPT	DEFINITION
FRP	Fiberglass reinforced plastic
SEM	Scanning electron microscope
AFM	Atomic Force Microscope
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials

CHAPTER 1

INTRODUCTION

1.1 Background

Fiberglass reinforced plastic (FRP) is a composite material that has many unique characteristics that makes it different from conventional metallic materials and even other plastics. There are four basic categories in typical structural materials which are metals, polymers, ceramics and composite. Composites material basically a combination of two or more structural materials. As for FRP, it is a composite of a polymer (the resin) that acts as a binder providing impact resistance, compressive strength and corrosion resistance and a ceramic (the glass fibers) that provides the strength and stiffness (Schmit K., 1998).

FRP piping system offers complete solution in offshore industry against highly corrosive fluids at various pressures and temperatures, adverse soil and weather conditions (especially in oil exploration, desalination, chemical plants, fire mains, dredging, portable water) due to its ability to withstand high pressure and other characteristics such as corrosion resistance, flexibility and lightweight that helps to reduce high construction cost. Other than that, the effect of rupture free of FRP pipe under certain shocks make this FRP pipe system more reliable in offshore industry (Krissakti G., 2002).

Figure 1.1: FRP pipe

Figure 1.2: FRP piping system applied in industry

In some cases, layers of FRP composites undergoes delamination cracking because of poor interlaminar fracture resistance. As stated by Kumar Deb S. and Chiranjeevee in their thesis on 'Revealing Failure modes of FRP composites', when further loading act on the composites, the interlaminar cracks will start to propagates effecting the structures to be weakens. Therefore, by introducing small amount of fibres in the thickness direction of the laminate, the damage tolerance and suppression of delamination crack initiation on the rate of interlaminar crack growth can be enhanced. Interface between reinforcing fibres and matrix plays an important roles in properties of FRP composite as the effectiveness of load transfer through the interface depends on the chemical and mechanical bonding in the process to produce the composite material. Kumar Deb S. ad Chiranjeevee also stated that the fiber-matrix interface controlled the mechanical behaviour of composite material where

the properties effect the quality of the FRP composite behaviour due to the role of interface in transferring and distributes stress between fibre and matrix.

Therefore, it is important to know the quality of the material rather than focusing on the quantity in terms of cost, strength, fatigue cycle and other properties of the material. As in this project, we focuses on the interface of fibre and matrix composites of FRP and to observes, study and reveal fracture mode of FRP composites after undergoes tensile load on it to know the quality of combination and composition of both fibre and matrix. Other than that, the purpose of this project is to determine the weaknesses of the FRP composites whether the fibre or the matrices is the reason failure happens in the composition by observing and analysing the fracture surface of the FRP using visual inspection cracks that can be seen with naked eyes and further details of the fracture surface using Digital Microscopy image analyser.

1.2 Problem Statement

DIALOG is a leading integrated technical services providers in the oil, gas and petrochemical. This company produces fabrication services specialized in FRP piping system in offshore industry. Currently, DIALOG have come out with new composition of the join part of FRP pipe. Many mechanical tests, pressure test regarding the strength of their new material where they focuses on the quantity research for their material. So, we proposed an idea to do an analysis focusing on the quality of the composites where we focuses to do analysis on the fracture modes of the FRP composites. Therefore, DIALOG is interested in giving opportunity to conduct the analysis as it is important to know the quality and reliability of the materials itself (fibers and resin) and the fracture mode of the composites to know the weakness of the materials by scanning the fracture surface of the FRP. From there, we could know if there is any weakness on the interface or the structure of the composite especially the composites produced by DIALOG is a new material that act as joint part of FRP piping system.

1.3 Objectives

The objectives of this research are as follow:

1. To obtain mechanical properties of joint part of FRP pipe
   - Maximum tensile stress
2. To characterise fracture surfaces of FRP composite pipe through visual inspection analysis and microscopic analysis using Digital Microscopic image analyser and to relate the findings with the mode of loading.

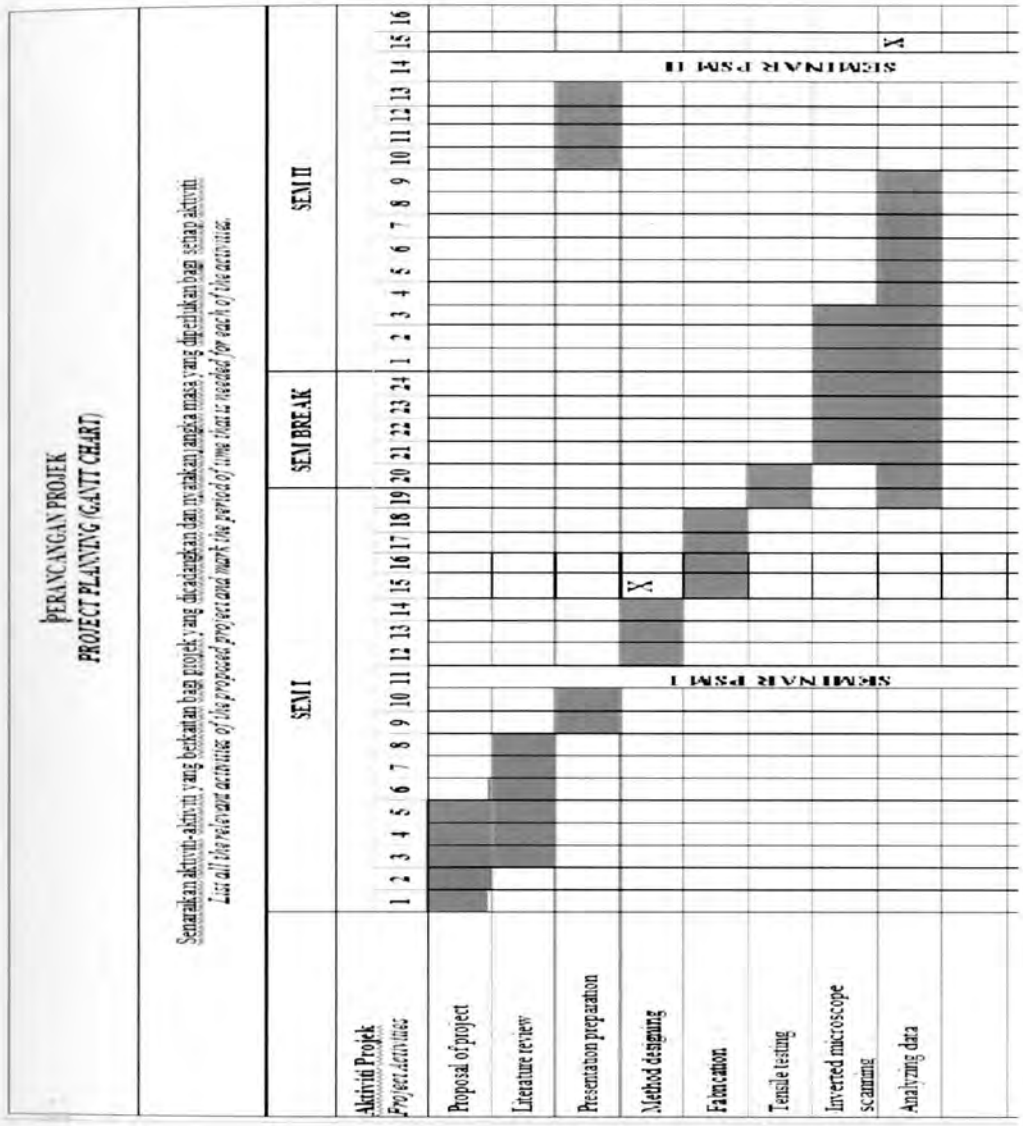
1.4 Scope of study

The scope of this study will covers:

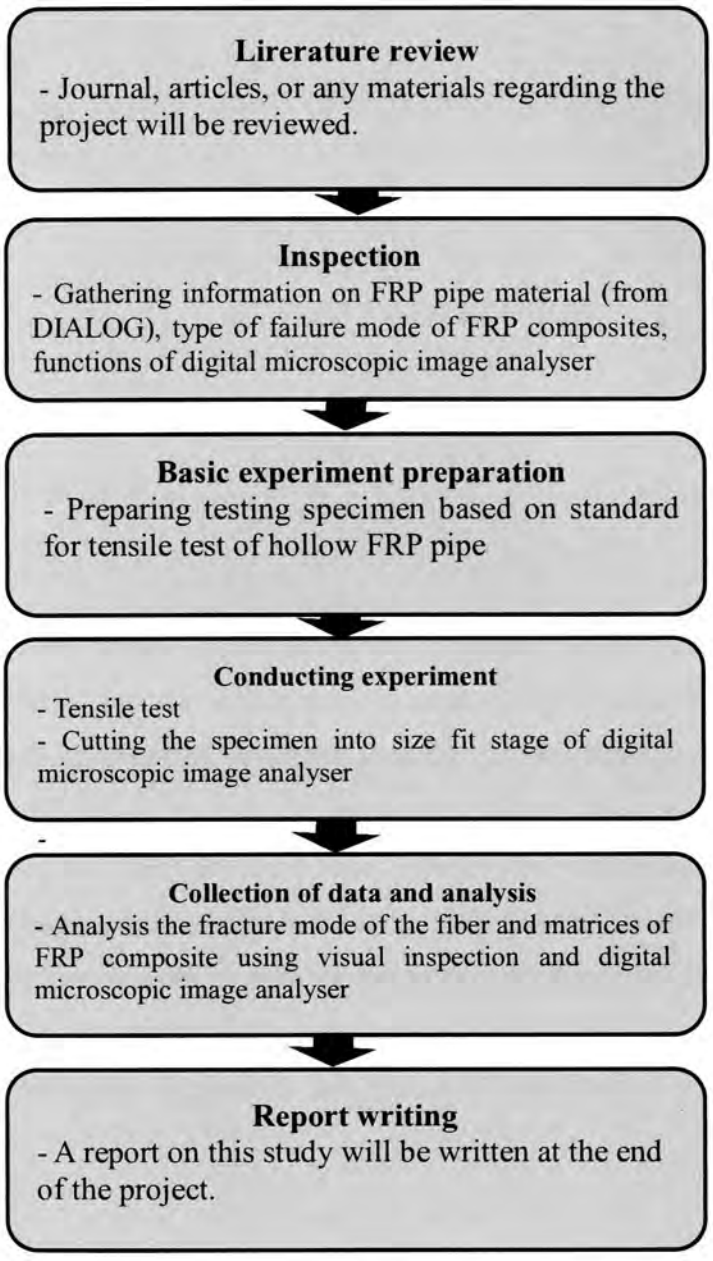
1. Only surface fracture of the FRP composite due to tensile test is considered neglecting other effects such as vibration and surrounding.
2. Material is tested and data is collected for strength analysis neglecting other properties such as bending effect and the fracture surface of the tested material is analysed.
3. This project only covers one type of testing method which is tensile test and one type of analysis which is surface fracture analysis using 2 ways of inspections which are visual inspection and Digital Microscopic image analyser where the tensile test and surface fracture analysis is done on FRP pipe composites neglecting other type of testing, analysis or software.

1.5 Project planning

1.5.1 Gantt chart



1.5.2 Methodology Flow chart



CHAPTER 2

LITERATURE REVIEW

2.1 Composites

Composite materials is getting more establishing themselves in industries as a useable engineering materials and are widely used in most of the engineering production around the world particularly in terms of structural process. As for example, most industries such as aircraft, automobile, electronic and also medical industries relies on fibre-reinforced plastic as the main material for their products where these fibre-reinforced plastic are consistently designed, manufactured and used in those industries. Composite material is actually a mixture of two or more distinct phases such as matrix phase and dispersed phase where the composite material have bulk properties that is very different from those of any of the constituents. In simpler words, basically composites material is a combination of two or more structural materials.

In composite, matrix often present on the greater quantity and it is the main constituent that is continuous in composite. Matrix material could be ceramic, metallic or polymeric. As for the second constituent commonly known as reinforcement that act to enhance the properties other constituents which is the matrix. Commonly, reinforcement can be classified into 2 which are fibrous reinforcement or particulate reinforcement. Particulate reinforcement have dimensions that are nearly equal in all directions where the arrangement of the particulate reinforcement could be random or with a preferred orientation. As for fibrous reinforcement, it

is categorized based on its length which is bigger than its cross-sectional size where the ratio of length to the cross-sectional size is known as aspect ratio that can be differ considerably.

The primary phase, which is the matrix have a continuous character. Matrix is usually more ductile and less hard phase. It holds the dispersed phase and shares a load with it. The second phase (or phases) is embedded in the matrix in a discontinuous form. This secondary phase is the reinforcement that is called dispersed phase. Dispersed phase is usually stronger than the matrix, therefore it is sometimes called reinforcing phase. Composites could be classified into 3 based on geometry which are particle-reinforced composites, fibre-reinforced composites and structural composites. Figure below shows further details on each types of composites:

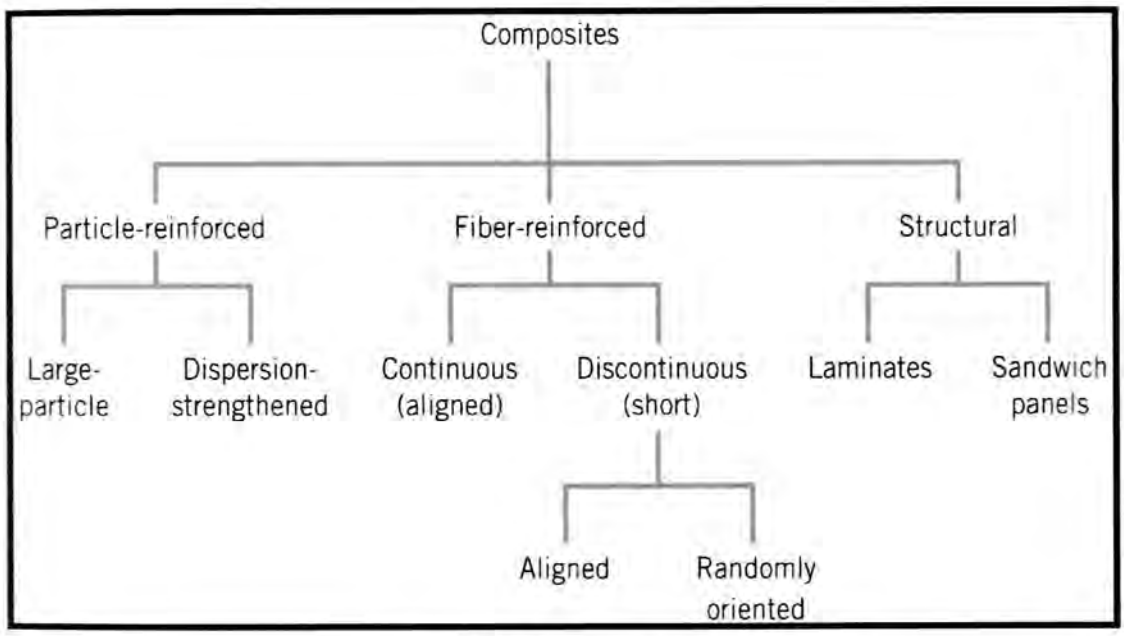


Figure 2.1: Classification of composites

Source: BMCB4463 slides, 2017

The success of composited materials as replacements of conventional material could be due to:

- High strength to weight ratio where composite material comes with low density but with high strength that could reduce manufacturing and transportation cost
- High creep resistance
- High tensile strength at elevated temperature where composite material could with high temperature better than conventional material and it would could replace metal in term of corrosion resistance.
- High toughness

2.2 Fibre Reinforced Polymer

Fibre Reinforced Polymer (FRP) are widely used nowadays in the aerospace, offshore, construction and automobile industry due to its advantages that can replace heavy metal use in those industries. FRP is a composites material made up with fibres bonded together with the help of organic polymers (resin system) that makes the material stronger compared to metals and other traditional materials. In recent, FRP is used in piping system of oil and gas industry due to its light weight structure, corrosion resistant with high stiffness and strength making FRP an ideal material to replace heavy metallic piping systems. Besides of its superior thermo-chemical properties where FRP have high strength and stiffness and light weight with excellent corrosion resistance, other inherent advantages of FRP material compared to traditional materials are magnetic transparency, design flexibility and long-term durability under harsh service environments. In addition, composites material can be three to five times stronger, two to three times stiffer and much more lighter than metals such as steel and aluminium where composites materials are dimensionally stable, aesthetically pleasing and cost effective with better durability and lower maintenance that the conventional materials (Hota V.S. GangaRao & P. V. Vijay, 2010).

Table 2.1: Merit Comparison and Rating between FRP and Steel

Source: (Hota V.S. GangaRao & P. V. Vijay, 2010)

Property (Parameter)	Merit/Advantage (Rating)		Rating Scale
	FRP	Steel	
Strength/stiffness	4-5	4	1: Very Low
Weight	5	2	2: Low
Corrosion resistance/ Environmental Durability	4-5	3	3: Medium 4: High
Ease of field construction	5	3-4	5: Very High
Ease of repair	4-5	3-5	
Fire	3-5	4	
Transportation/handling	5	3	
Toughness	4	4	
Acceptance	2-3	5	
Maintenance	5	3	

Note: Higher rating indicates better desirability of the property

FRP is in composite plastics class that specially contains fibre materials mix up with matrix with the help of resin system. Composition of FRP uses fibres to mechanically increase the strength and elasticity of the plastics itself while matrix is the pure plastic material that is tough but this material is low plasticity. So matrix is reinforced with fibres which is stiffer and stronger to produce composite material known as FRP that is higher in strength and elasticity where the advantageous of reinforcing these materials (final product) depends on the mechanical properties of both fibres and matrix, volume percentage of both materials when mixed up with one another and length and degree of orientation of fibres within the matrix.

Although the reinforcement of both materials exhibits to a better mechanical properties of FRP material, there are several structural failure mode that could occur. These failures occurs when tensile forces stretch the matrix beyond the fibres that could cause shear of FRP at the interface between fibres and matrix. Other than that, when tensile forces is close to the end of the fibres is more than the maximum forces the matrix could withstand will cause failure mode where the fibres will be separated from the