



**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**Fatigue Life Prediction Model for Fiber Reinforced Polymer  
Composites**

This report submitted in accordance with requirement of Universiti Teknikal Malaysia  
Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering  
(Manufacturing Design) (Hons.)

by

**MOHD GHAZALI KADIR BIN SULAIMAN**

**B051010166**

**880122-10-5141**

**FACULTY OF MANUFACTURING ENGINEERING**

**2014**

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: Fatigue Life Prediction for Fiber Reinforced Polymer Composites

SESI PENGAJIAN: 2013/14 Semester 2

Saya **MOHD GHAZALI KADIR BIN SULAIMAN**

Mengaku membenarkan Laporan PSM ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. \*\*Sila tandakan (✓)

SULIT

(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)

TERHAD

(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

TIDAK TERHAD

Disahkan oleh:

DR. TAUFIK

Senior Lecturer

~~Faculty of Manufacturing Engineering~~

Universiti Teknikal Malaysia Melaka

Hang Tuah Jaya

Cop Rasmi: 76100 Durian Tunggal, Melaka

Alamat Tetap:

NO.31 JALAN PERMAI 2,

TAMAN AIR HITAM PERMAI

43000 KAJANG. SELANGOR.


Tarikh: 20/06/2014

Tarikh: 20/6/2014

\*\* Jika Laporan PSM ini SULIT atau TERHAD, silalampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

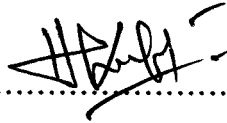
## DECLARATION

I hereby, declared this report entitled “Fatigue Life Prediction for Fiber Reinforced Polymer Composites” is the results of my own research except as cited in references.

Signature :   
Author's Name : MOHD GHAZALI KADIR BIN SULAIMAN  
Date : 12/6/2014

## APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Design) (Hons.). The member of the supervisory committee is as follow:



DR. TAUFIK  
*Senior Lecturer*  
Faculty of Manufacturing Engineering  
Universiti Teknikal Malaysia Melaka  
Hang Tuah Jaya  
76100 Durian Tunggal, Melaka

## **ABSTRACT**

Fiber reinforced polymer (FRP) composite is a new construction material, gradually gaining acceptance from engineers. Their use as structural materials in recent years has proved their advantages. Its advantages over traditional construction materials are its high tensile strength to weight ratio, ability to be molded into various shapes, and potential resistance to environmental conditions, resulting in potentially low maintenance cost. These properties make FRP composite a good alternative for innovative construction. This report presents the basic information of FRP composite, including its mechanical behaviors and manufacturing processes. Then the application of FRP composite in manufacturing engineering is investigated. One is the design of FRP itself, which combination of FRP materials are better and second is the design of the structure. From these two studies determined which combination of FRP composite and structural design will provide a good fatigue life and suitable factor of safety.

## ABSTRAK

Komposit Fiber Reinforced Polymer (FRP) adalah bahan baru yang semakin diterima oleh jurutera. Penggunaannya didalam bahan struktur sejak kebelakangan ini telah membuktikan kelebihanannya. Berbanding bahan tradisional yang sebelumnya, FRP mempunyai kekuatan yang tinggi, keupayaannya untuk dibentuk menjadi pelbagai bentuk serta dapat menampung keadaan perubahan cuaca. Hal ini menyebabkan kos penyelenggaraannya rendah. Ciri-ciri ini menjadikan komposit FRP ini merupakan alternative yang baik untuk pembinaan inovatif. Projek ini akan membentangkan maklumat asas FRP komposit, termasuk ciri-ciri mekanikal dan proses pembuatannya. Kebolehan penggunaan komposit FRP didalam kejuruteraan pembuatan juga akan dikaji dengan mengenal pasti kombinasi FRP mana yang lebih sesuai digunakan dan juga reka bentuk stuktur yang bagaimana dapat memberikan gabungan yang baik. Daripada kajian ini, akan dikenal pasti gabungan mana yang akan memberikan hayat lesu dan factor keselamatan yang baik.

## ACKNOWLEDGEMENT

Praise to Allah S.W.T because of His blessing, I have completed this report as schedule. I would like to take this opportunity to express the deepest appreciation to my supervisor Dr.Taufik, who has given all the necessary guidance, shown the attitude and the substance of a genius. He continually and persuasively conveyed a spirit of adventure in regard to this study, and an excitement in regard to teaching. Without his supervision and constant help this dissertation would not have been possible. Also, to all my lecturer who taught me from the basic, my family and friends who has assisted me in any way during the period of finishing this report. Thank you for all your love and keeping me in your thoughts and prayer.

## TABLE OF CONTENT

<b>ABSTRACT</b>	<b>I</b>
<b>ABSTRAK</b>	<b>II</b>
<b>ACKNOWLEDGEMENT</b>	<b>III</b>
<b>TABLE OF CONTENT</b>	<b>IV</b>
<b>LIST OF FIGURES</b>	<b>IX</b>
<b>LIST OF TABLES</b>	<b>XII</b>
<b>LIST OF ABBREVIATIONS</b>	<b>XIII</b>
<b>CHAPTER 1</b>	<b>1</b>
<b>INTRODUCTION</b>	<b>1</b>
1.1 Background of Study	1
1.2 Problem Statement	4
1.3 Objective	5
1.4 Scope of Study	6
<b>CHAPTER 2</b>	<b>7</b>
<b>LITERATURE REVIEW</b>	<b>7</b>
2.1 Fiber Reinforced Polymer Composite	7
2.1.1 Background	7
2.1.2 Introduction to Fiber Reinforced Polymer Composite	8
2.2 Components in Fiber Reinforced Polymer Composite	9
2.3 Fibers	9



2.3.1	Forms of Fibers	10
2.3.2	Types of Fibers	12
2.3.2.1	Glass Fibers	12
2.3.2.2	Carbon Fibers	13
2.3.2.3	Aramid Fiber	14
2.4	Matrix	15
2.4.1	Components of Matrix	16
2.4.1.1	Resins	16
2.4.1.2	Fillers	16
2.4.1.3	Additives	17
2.5	Fiber Matrix Bonding	17
2.6	Mechanical Properties	17
2.6.1	Density	18
2.6.2	Modulus	18
2.6.3	Poisson's Ratio	19
2.7	Stress-Strain Relationship and Tensile Strength	20
2.8	Fiber Reinforced Polymer Manufacturing Process	21
2.8.1	Hand Lay-Up Process	22
2.8.2	Spray-Up Process	23
2.8.3	Pultrusion	23
2.8.4	Filament Winding	24
2.8.5	Resin Transfer Molding	25
2.9	Structural Profiles of Fiber Reinforce Polymer	26

2.10	Advantages and Disadvantages of FRP Composite Materials	27
2.10.1	Advantages of FRP Composite Materials	27
2.10.2	Disadvantages of FRP Composite Materials	28
2.11	Internal and External Reinforcement for Building Elements	28
2.11.1	Internal Reinforcement	28
2.11.2	External Reinforcement	29
2.12	Example of Fiber Reinforcement Polymer Composite Application in Engineering	30
2.12.1	Bridge	30
2.12.2	Building	31
2.12.3	Structure	32
<b>CHAPTER 3</b>		<b>33</b>
<b>METHODOLOGY</b>		<b>33</b>
3.1	Introduction	33
3.2	Start	35
3.3	Problem Statement	35
3.4	Concept Design	36
3.4.1	Three Concept Design	36
3.4.1.1	Bridge Concept Design	37
3.4.1.2	Square Plate Concept Design	37
3.4.1.3	I-Beam Concept Design	38
3.4.2	Parameters in Selected Design	38
3.4.3	2D Drawing of Selected Design	39

3.4.3.1	I-Beam with Fillet and Thickness 10mm	39
3.4.3.2	I-Beam with Fillet and Thickness 20mm	40
3.4.3.3	I-Beam without Fillet and Thickness 10mm	40
3.4.3.4	I-Beam without Fillet and Thickness 20mm	41
3.5	Design of Fiber Reinforced Polymer Composite	41
3.6	Longitudinal and Transverse Modules	42
3.7	Poisson's Ratio	43
3.8	Simulation	44
3.9	Result and Discussion	45
3.10	Example of Expected Result	45
3.10.1	Fatigue Life	46
3.10.2	Factor of Safety	47
3.11	Conclusion	48
<b>CHAPTER 4</b>		<b>49</b>
<b>RESULTS AND DISCUSSION</b>		<b>49</b>
4.1	Introduction	49
4.2	Structural Fatigue Tool Analysis	51
4.2.1	Fatigue Life	51
4.2.1.1	Structural with Fillet 10mm and Thickness 10mm	51
4.2.1.2	Structural with Fillet 10mm and Thickness 20mm	52
4.2.1.3	Structural without Fillet and Thickness 10mm	53
4.2.1.4	Structural without Fillet and Thickness 20mm	54

4.2.2	Fatigue Damage	55
4.2.2.1	Structural with Fillet 10mm and Thickness 10mm	56
4.2.2.2	Structural with Fillet 10mm and Thickness 20mm	57
4.2.2.3	Structural without Fillet and Thickness 10mm	58
4.2.2.4	Structural without Fillet and Thickness 20mm	59
4.2.3	Fatigue Safety Factor	60
4.2.3.1	Structural with Fillet 10mm and Thickness 10mm	60
4.2.3.2	Structural with Fillet 10mm and Thickness 20mm	61
4.2.3.3	Structural without Fillet and Thickness 10mm	62
4.2.3.4	Structural without Fillet and Thickness 20mm	64
4.3	Structural Linear Buckling Analysis	65
4.3.1	Structural with Fillet 10mm and Thickness 10mm	65
4.3.2	Structural with Fillet 10mm and Thickness 20mm	66
4.3.3	Structural without Fillet and Thickness 10mm	67
4.3.4	Structural without Fillet and Thickness 20mm	68
4.4	Discussion	70
4.5	Conclusion	73
	<b>CHAPTER 5</b>	<b>74</b>
	<b>CONCLUSION AND RECOMMENDATION</b>	<b>74</b>
5.1	Conclusion	74
5.2	Recommendation	75
	REFERENCES	76
	APPENDIX	79

## LIST OF FIGURES

Figure 2.1: Various Form of Roving	10
Figure 2.2: Example of Surface Reinforcement	11
Figure 2.3: Glass Fiber Fabric	13
Figure 2.4: Carbon Fiber Fabric	14
Figure 2.5: Aramid Fiber Fabric	15
Figure 2.6: Longitudinal and Transverse Modulus as a Function of Angle of Inclination of the Fibers	19
Figure 2.7: Poisson's ratio vs of angle of inclination	20
Figure 2.8: Stress-strain relationship for FRP	21
Figure 2.9: Hand Lay-Up Process	22
Figure 2.10: Spray-Up Process	23
Figure 2.11: Pultrusion	24
Figure 2.12: Filament Winding Process	25
Figure 2.13: Resin Transfer Molding Process	26
Figure 2.14: Range of FRP Profile Available on Market	27
Figure 2.15: Bridge deck reinforced with FRP bars	29
Figure 2.16: Methods of FRP External Reinforcement	30
Figure 2.17: Fredrikstad Bridge	31
Figure 2.18: Classroom Made From FRP	32
Figure 2.19: FRP Composite Structure	32
Figure 3.1: Methodology flow chart	34

Figure 3.2: Bridge Concept Design	37
Figure 3.3: Square Plate Concept Design	37
Figure 3.4: I-Beam Concept Design	38
Figure 3.5: I-Beam with Fillet	39
Figure 3.6: I-Beam with Fillet	40
Figure 3.7: I-Beam without Fillet	40
Figure 3.8: I-Beam without Fillet	41
Figure 3.9: Simulation Flow Chart	44
Figure 3.10: Fatigue Life Analysis	46
Figure 3.11: Factor of Safety	47
Figure 4.1: Types of Racks	50
Figure 4.2: Force and Fixed Support Apply	50
Figure 4.3: Fatigue Life for R10T10	51
Figure 4.4: Result of Fatigue Life for R10T10	52
Figure 4.5: Fatigue Life for R10T20	52
Figure 4.6: Result of Fatigue Life for R10T20	53
Figure 4.7: Fatigue Life for T10	53
Figure 4.8: Result of Fatigue Life for T10	54
Figure 4.9: Fatigue Life for T20	54
Figure 4.10: Result of Fatigue Life for T20	55
Figure 4.11: Fatigue Damage for R10T10	56
Figure 4.12: Result of Fatigue Damage for R10T10	56
Figure 4.13: Fatigue Damage for R10T20	57
Figure 4.14: Result of Fatigue Damage for R10T20	57
Figure 4.15: Fatigue Damage for T10	58

Figure 4.16: Result of Fatigue Damage for T10	58
Figure 4.17: Fatigue Damage for T20	59
Figure 4.18: Result of Fatigue Damage for T20	59
Figure 4.19: Fatigue Safety Factor for R10T10	60
Figure 4.20: Result of Fatigue Safety Factor for R10T10	61
Figure 4.21: Fatigue Safety Factor for R10T20	61
Figure 4.22: Result of Fatigue Safety Factor for R10T20	62
Figure 4.23: Fatigue Safety Factor for T10	62
Figure 4.24: Result of Fatigue Safety Factor for T10	63
Figure 4.25: Fatigue Safety Factor for T20	64
Figure 4.26: Result of Fatigue Safety Factor for T20	64
Figure 4.27: Total Deformation for R10T10	65
Figure 4.28: Result of Total Deformation for R10T10	66
Figure 4.29: Total Deformation for R10T20	66
Figure 4.30: Result for Total Deformation for R10T20	67
Figure 4.31: Total Deformation for T10	67
Figure 4.32: Result of Total Deformation for T10	68
Figure 4.33: Total Deformation for T20	68
Figure 4.34: Result of Total Deformation for T20	69
Figure 4.35: Safety Factor Graph for Each Structure	71
Figure 4.36: Comparison between T20 (Left) and R10T20 (Right)	71
Figure 4.37: Total Deformation Graph for Each Structure	72

## LIST OF TABLES

Table 2.1: Properties of glass, aramid and carbon fibres	12
Table 3.1: Typical values of the FRP composites	42
Table 4.1: Result of All Analysis	70



## LIST OF ABBREVIATIONS

ANSYS	-	Analysis System
CFRP	-	Carbon Fiber Reinforced Polymer
FEA	-	Finite Element Analysis
FRP	-	Fiber Reinforced Polymer
PAN	-	Polyacrylonitrile
PEEK	-	Polyetheretherketine
PP	-	Polypropylene
PPS	-	Polyphenylene Sulfide
UTS	-	Ultimate Tensile Stress

# CHAPTER 1

## INTRODUCTION

### 1.1 Background of Study

Fiber-reinforced polymer (FRP), also Fiber-reinforced plastic, is a composite material made of a polymer matrix reinforced with fibers. Aerospace, automotive, marine, and construction industries commonly used FRPs in their field. Composite material is a material that occur naturally or being engineered. It is made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct within the finished structure. The final aim is to create a material with perfect properties such as strong and stiff, often with a low density (Fibre Reinforced Plastic, Wikipedia, accessed Nov 2013).

A fiber-reinforced polymer composite is defined as a combination of a polymer matrix either a thermoplastic or thermoset resin, such as polyester, isopolyester, vinyl ester, epoxy and phenolic, a reinforcing agent such as glass, carbon, aramid or other reinforcing material such that there is a sufficient aspect ratio such as length to thickness, to provide a discernable reinforcing function in one or more directions (Ehlen, 1999).

The first fiber-reinforced plastic was Bakelite. Initially, Dr. Baekeland looked for a replacement for Shellac (made from the excretion of lac beetles), because many

chemists have begun to realize that many natural resins and fibers were polymers, so Dr. Baekeland do some research on the reactions of phenol and formaldehyde. The first material that he produced from the reaction is soluble phenol-formaldehyde shellac called “Novolak”. This Novolak was not become a market success, then Dr. Baekeland turned to developing a binder for asbestos which is at that time was molded with rubber. In 1905, Dr. Baekeland produces the world’s first synthetic plastic which is called bakelite. This is done by controlling the pressure and temperature applied to phenol and formaldehyde (Trueman, 2013)

The mass production scale of polymer began in the middle of 20th century. The mass production conducted at appropriate time, when the material and production cost is low. In addition with the combination of new production technologies and new product categories, it makes mass production of polymer more economical. This production reached its peak in the late of 1970s when world polymer production surpassed that of Steel, making polymers the ubiquitous material that it is today. Fiber-reinforced plastics have been a significant aspect of this industry from the beginning. There are three important categories of fiber used in FRP, glass, carbon, and aramid (Fibre Reinforced Plastic, Wikipedia, accessed Nov 2013).

Fiber reinforced polymer are composites used in almost every type of advanced engineering structure, with their usage ranging from aircraft, helicopters and spacecraft through to boats, ships and offshore platforms and to automobiles, sports goods, chemical processing equipment and civil infrastructure such as bridges and buildings. The usage of FRP composites continues to grow at an impressive rate as these materials are used more in their existing markets and become established in relatively new markets. A key factor driving the increased applications of composites over the recent years is the development of new advanced forms of FRP materials.

This includes developments in high performance resin systems and new styles of reinforcement, such as carbon nanotubes and nanoparticles. The fiber reinforced polymer composites are increasingly being considered as an enhancement to substitute for infrastructure components or systems that are constructed of traditional civil engineering materials, namely concrete and steel. FRP composites are lightweight, no-corrosive, exhibit high specific strength and specific stiffness, are easily constructed, and can be tailored to satisfy performance requirements.

The FRPs have very low weight and a high strength-to-weight ratio, high tensile strength, and high fatigue resistance. They do not exhibit chloride corrosion problems, which has been a continued challenge for bridge engineers. This results in lower maintenance costs. It has also been observed that FRP composites maintain their superior qualities even under a wide range of temperatures (Tang and Podolny, 1998).

Other highly desirable qualities of composites are high resistance to elevated temperature, abrasion, corrosion, and chemical attack. Some of the advantages in the use of composite structure include the ease of manufacturing, fabrication, handling, and erection, which can result in short project delivery time (Sahirman, et al., 2002).

Due to these advantageous characteristics, FRP composites have been included in new construction and rehabilitation of structures through its use as reinforcement in concrete, bridge decks, modular structures, formwork, and external reinforcement for strengthening and seismic upgrade (Jain, 2012).

To ensure the infrastructure deterioration can be reduced or even eliminated entirely, engineers would prefer to use the material that has to prolong and extend the service lives of existing structures while also enabling the design and construction of durable new structures. As the solution, fiber reinforced polymers, a relatively new class of non-corrosive, high-strength, and lightweight

materials, have, over the past 15 years or so, emerged as practical materials for a number of structural engineering applications (Fitzwilliam, 2006).

FRP is a material that has a high advantage in strength and light weight, the automotive and aerospace industry has taken full advantage of this superiority for more than 50 years. As their name suggests, these materials are composed of high-strength fibers embedded in a polymer matrix. The fibers in FRPs are extremely strong and stiff, and the matrix binds them and enables them to work together as a composite material. As FRP is a material that can reduce cost to a structure that requires using for a long period of time, the use of FRP has been a rapid expansion for over the past 15 years in structural engineering applications (Fitzwilliam, 2006).

## **1.2 Problem Statement**

Due to FRP's superior fatigue and corrosion properties, it has become a popular choice to replace heavier metal in structural construction. Although they may be less susceptible to fatigue failure than metals, fatigue can still occur. This will happen when environmental factors such as temperature and humidity become significant. Composite fatigue failure is generally driven by fatigue failure in the polymer matrix (Hashin and Rotem, 1973).

Before Fiber-reinforced polymer was used, there are some deficiencies in the creating of a structure. High load on structure cause harder, slowest and more expensive installation. Besides, it will require larger cranes to be used. To bring larger section of a structure to a site will consume time and extra cost. Indirectly it will need more energy, transportation and even money just because of it have high load on structure.

Before using FRP composite material, the structure will have less superior durability. Structure will be more quickly eroded due to atmospheric

degradation. The constantly changing of weather condition in this country will affect the surface of the structure and will directly give impact to the structure itself. This will result in more frequently maintenance of the structure and will also cause cost. Regular used and constant load given to the structure will produce vibration and will decrease the lifespan of the structure.

FRP composite materials have developed into economically and structurally viable construction materials for over the last two decades. FRP is a new material that is in high demand nowadays. It is known that FRP are lightweight, with good crash properties and noise and also vibration reducing characteristics. Besides, it also can increase the lifespan of a structure. To find out how far the ability of FRP can goes, an experiment and analysis should be implemented. Without effective tools, systems and procedures, this analysis cannot be done perfectly. In order to get precise answer, some CAD tools and technologies such as ANSYS and SolidWork have to be used. This analysis will be more focused on a I-beam structure so that the result of the analysis can be consider as an alternate for the whole manufacturing engineering.

### **1.3 Objective**

The objective of the project as follows:

- To investigate design parameters of FRP
  - Which combinations of FRP composite are more better
- To analyze the fatigue of design structure in combination of FRP
  - How far the selected FRP material can withstand
- To design a structure in combination of FRP for manufacturing application
  - Leverage the use of FRP in manufacturing application

## **1.4 Scope of Study**

This study is related to the prediction of fatigue life for fiber reinforced polymer composites bonding. The study is more based on design parameters in combination of FRP materials. Furthermore, it will be more focused on manufacturing engineering. The study involve in some types of structure design concept which finally only one design will be selected. From the structure design that has been selected, two types of geometry will be used as variables, which are fillets and the thickness of the structure. As this study also involves in FRP material, three types of FRP material will be applied to the structure to be analyzed by using software called Analysis System (ANSYS). Finally from the analysis, we will know what type of geometry and FRP material that suitable to combine into the structure so that it can be used in manufacturing engineering. The main thing that can determine the structure chosen is from design with high fatigue life prediction and appropriate factors of safety.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 Fiber Reinforced Polymer Composite**

For years, manufacturing engineers have been in search for alternatives to steels and alloys to combat the high costs of repair and maintenance of structures damaged by corrosion and heavy use. For example, cost estimates for maintenance of highway bridge decks composed of steel-reinforced concrete are up to \$90 billion/year. Since the 1940s, composite materials, formed by the combination of two or more distinct materials in a microscopic scale, have gained increasing popularity in the engineering field. Fiber Reinforced Polymer is a relatively new class of composite material manufactured from fibers and resins and has proven efficient and economical for the development and repair of new and deteriorating structures in civil engineering ( Natalie, 2002).

##### **2.1.1 Background**

Fiber reinforced polymer composite (FRP) was originally only used in niche application during the second world war. Nowadays, FRP has been used in various fields. Composite are two chemicals that were mixed to become a new substance. Composite are now commonly use, ranges from goods appliances to