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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

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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:

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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 Reinforcced Polymer (FRP) adalah bahan baru yang semakin diterima oleh jurutera. Penggunaanya didalam bahan struktur sejak kebelakangan ini telah membuktikan kelebihannya. 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.

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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 addiction 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 it-self. 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