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FATIGUE LIFE ANALYSIS OF NATURAL FIBRES

BY

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ABSTRACT

FATIGUE LIFE ANALYSIS OF NATURAL FIBRES

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Nowadays, the natural fibres are extensively used as cost-cutting in the materials and manufacturing industry. It is best to be considered as the most potential replacement for the glass fibres which are widely used in the market right now. The use of the natural fibres composites are due to two aspects, which are for environmental and economical in developing countries. Even though natural fibres have many advantages, due to their low-cost and low density, but they are not totally free of problems. Since very little is known about the properties of these natural fiber composites, this thesis involves testing of those composites. The testing is done in two stages where the monotonic testing is performed first producing the stress-strain (σ- ε) diagram and tensile strength (UTS). Then, the loading parameters are designed for the fatigue life analysis to obtain the stress-life (S-N) curve. The textile architecture of the natural fibres also analyzed using CCD (charge-coupled device), and the comparison between the natural fibres using polyethylene and polypropylene matrix are exhibited. From the results, it shows that the natural jute fibres using polypropylene matrix selected to be the best materials among the natural fibres where it satisfied the purpose of design as a good material not only to withstand stresses but also to be reliable and satisfy the fatigue life.

TABLE OF CONTENTS

CHAPTER Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1 INTRODUCTION

Fatigue can be defined as a cyclic process which occurred at stresses below the monotonic yield strength. Fatigue can be caused by varied uncertainties parameters, including the material's phenomenon that influences the physicality of fatigue in a structure. It were discovered in the post-incident by Versailles in 1842 and since then; many engineers and researches developed many models and analysed the fatigue. It is very crucial to predicting the fatigue especially in designing something related with safety of a human being. Different methods in predicting fatigue life were developed and studied by many researchers around the world. The process of choosing the fatigue life model is an important decision where each of the models has their own function.

The concept of fatigue is very simple, where when a motion is repeated, and the object that is doing the work becomes weak. This same principle is seen in materials where the material is subject to alternating stresses for over a long period. Most of the structural failures occur due to the growth of fatigue crack (Mohanty et al. 2011). Examples of where fatigue crack growth (FCG) may occur at springs, turbine blades, airplane wings, bridges and bones. As the structural members experience multiple loads and unload, their failure stress level may decrease. In industrial such as the aircraft industry, testing is required to ensure the aircraft did not fail before a certain number of cycles due to the safety and cost.

The fatigue life model produces the fatigue properties such as fatigue limits, stress – life (S-N) data, strain – life (ε -N) data, fatigue crack growth (da/dN – ΔK) data. It also the fracture toughness for the final failure and this prediction model is varies with different type of amplitude loading such as variable amplitude loading (VAL) or even constant amplitude loading (CAL). Despite the huge development in the prediction of the fatigue life, somehow still the simplest prediction models are being used by the engineers in their research and development projects. Thus, the most favourable among researches is to do the experimental works whenever a particular problem arouses. However, it also creates a huge problem because the cost, time and the complexity of the geometry make more difficult (Richard, Sander, Fulland, & Kullmer, 2008) (Simonsen & Tornqvist, 2004).

The fatigue life can be categorized into two phases that are the initiation period and propagation period. Figure 1.1 shows the representation of both phases and the stages of fatigue failure. The fatigue is a progressive process where the damage will starts to develop slowly within the initiation period. Then it will accelerates very quickly until if fails.

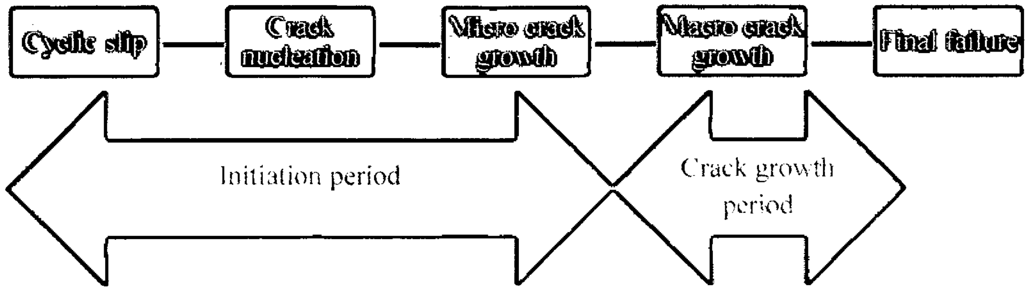


Figure 1.1: The typical fatigue life phases

1.2 THE PROPAGATION OF FATIGUE CRACK GROWTH

The fatigue crack propagation can be divided into three regions that known as the region I for short cracks, region II for long cracks and region III which the final fracture occur as reported by (Totten, 2008). In region I, once a crack is initiated, the fatigue crack will propagates along the high shear stress planes (45°), as schematically represented in Figure 1.2.

The crack will propagate until it is slowed by a microstructural barrier such as a grain boundary that cannot comply the initial crack growth direction. Thus, grain refinement is capable of increasing the fatigue strength of the material by inserting a large quantity of microstructural barriers, for examples, the grain boundaries. This is to overcome the stage I of the crack propagation. Surface of mechanical treatments such as shot peening and surface rolling; can contribute to an increase the number of microstructural barriers due to the flattening of the grains.

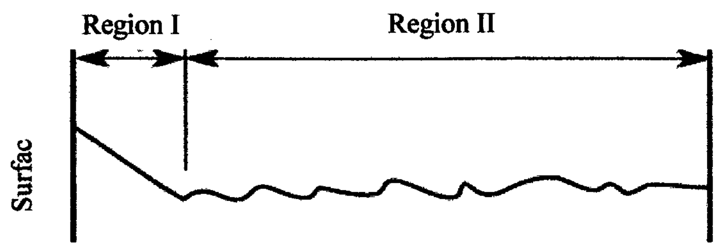


Figure 1.2: Region I and II of fatigue crack propagation

Source: (Totten, 2008)

For the region II, the stress intensity factor (K) will be increased due to the crack growth or higher applied loads, and then the slips will start to develop in different planes yet, close to the crack tip and initiating the region II. The region I is 45° orientated with respect to the applied load and the crack propagation in the region II is perpendicular to the load direction, as shown in Figure 1. A very crucial characteristic of region II is that the presence of surface ripples known as "striations" are visible with the help from scanning electron microscope. Note that, not all engineering materials will exhibit the striations and they are clearly be seen in many ductile alloys such as aluminium and pure metals.

At the final region, the crack growth will be controlled by static modes of failure and it is very sensitive to the load ratio, microstructure of the material and stress state that is plane stress or even plane strain loading. One of the regions will correspond to the stable fatigue crack growth and presents a smooth aspect due to the friction between the crack wake faces. Sometimes, concentric marks known as "beachmarks" can be seen on the fatigue fracture surface.

1.3 PROBLEM STATEMENT

Currently, the fatigue life of the composite materials expended since 1980 and in these recent years, more efforts have been made to develop the fatigue properties for the natural fibres. Natural fibres have become one of the rapidest interests among researches nowadays, and much development has been made including in automotive industries (Shah, Schubel, Cilfford, & Licence, 2013).

However, certain aspect of the natural fibre still, hasn't yet discovered, and plenty of different types of plant never investigated (Gassan, 2002). It has been brought to our attention that, green and eco-friendly products are widely used and obtained a huge market on this day materials industries. From the smallest things which can be found in the household to the biggest objects which used in heavy machinery, people start to look up for the environment and change their lifestyles and begin to worry about the planet earth. Thus, it is the right time to introduce the natural fibre to the fatigue and expend the types of materials used in the industry.

1.4 RESEARCH OBJECTIVES

Based from the background research overview, the main objectives of this study are to evaluate the fatigue life of the natural fibre which provided by Athena Engineers. So, there are several objectives which need to be accomplished, such as:

i. To perform fatigue testing of the natural fibre following the ASTM D3479 for the polyethylene specimen.

ii. To develop a fatigue life data and properties of the natural fibres.

iii. To compare between the material of the natural fibre from the experiment.

It is hoped that the study will produce the results thus accomplishing all the objectives which listed above.

1.5 SCOPE OF STUDY

This research concentrates on the experimental works of the fatigue life of the natural fibre. The specimens that provided by the Athena Engineers are limited and already fabricated before it received by the Northern Illinois University (NIU). The fatigue test will be performed using CAL and the S-N data will be produced as the results. A comparison will be made between the type of the specimens and type of the materials. The contribution of this research clearly by having the fatigue data and handed it over to the Athena Engineers to improve their development for the natural fibre.

So, to ensure that the research will go smoothly without penetrating the boundary if the research, the scope of the study is established, as follows:

i. Using all specimens and materials provided by Athena Engineers without any modification.

ii. Using fatigue test apparatus during experiment.

The next chapter will present about the research background and a basic understanding regarding the fatigue life prediction models; the fatigue works for composite materials and also overview of the accelerated fatigue testing

CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of the literature review presented in this chapter is to investigate the extent to which the previous researchers have conducted studies in the field of fatigue, especially at a constant amplitude loading (CAL). In this chapter, the fatigue test for composite materials will be reviewed and this is intended to provide an overview of the application of natural fibres in the field of fatigue. Overall, the literature review can be divided into three major groups, namely fatigue life approaches, fatigue test in composite materials and the accelerated fatigue testing.

2.2 FATIGUE LIFE PREDICTION APPROACHES

The failures of structural integrity usually were caused by varied uncertainties parameters, including the material's phenomenon that influences the physicality of fatigue in a structure (Mohanty, Verma, Ray, & Parhi, Application of adaptive neuro-fuzzy inference system in modeling fatigue life under interspersed mixed-mode (I and II) spike overload, 2011) (Leonel, Chateauneuf, & Venturini, 2012) (Riahi, Bressolette, & Chateauneuf, 2010). The total life of a structure can be expressed as a combination of crack initiation and crack propagation period.

When a structure subjected to a cyclic stress, which is above the endurance limits, fatigue can occur, and it will lead to the structural failure. The crack will increase proportionally with the number of cycles, and there is a little or no indication of plastic deformation occurred. There are three models that are popular for fatigue life models, which are the stress – life (*S-N*) model, strain – life (ε -*N*) model and fatigue crack growth (da/dN - ΔK) model (Stephens, Fatemi, Stephens, & Fuchs, 2000).

(El-Zeghayar, Topper, & Soudki, 2011) studied on the crack growth under variable amplitude loading and explained thoroughly on changes in fatigue crack closure and crack opening stress. This study presents a methodology for modelling changes in crack opening stress level and fatigue damage using data derived from periodic underload fatigue tests of smooth specimens for three steels with a diverse hardness. The predicted crack closure stress levels are modelled under constant and variable amplitude loading.

(Beretta & Carboni, 2011) discuss the application of predictive crack growth algorithms to the propagations of cracks in A1N steel axles. First and foremost, the constant amplitude crack propagation tests on small-scale were carried out together with experiments on full-scale axles. Variable amplitude tests were performed and the results were then analysed using a simple ''no-interaction'' algorithm.

(Yin, Fatemi, & Bonnen, 2010) studied on fatigue behaviour of case-hardened steel specimens where it was investigated under VAL conditions including two-level load tests, periodic overload tests, and service load history tests. Fatigue life predictions were made using a two-layer model based on case and core material fatigue properties and compared to the experimental results.

(Bao & Zhang, 2010) studied on the crack growth behaviour in aluminium alloys 2324-T39 and 7050-T7451 subjected to flight-by-flight load spectra at different low-stress truncation levels. Based form the study there are several aspects in both the practical fatigue testing and the development of predictive models. The first aspect is to perform the laboratory sample tests are used to demonstrate that the elimination of certain low-range loads will not change the characteristic of the crack growth and have little influence on crack growth life while considering the scale of time saving. The second aspect is the requirement of life prediction tools. Fatigue crack growth (FCG) behaviour and life prediction methods under the constant amplitude loads (CAL) have been well established for commonly used aluminium alloys.

(Lee, Glinka, Vasudevan, Ivyer, & Phan, 2009) studied on the fatigue crack growth (FCG) behaviour of 7075-T651 aluminium alloy under constant and variable amplitude loadings. In the study of the constant amplitude load, the loading frequency was 10 Hz while in the study of variable amplitude load, the average loading frequency was about 5 Hz.

Many methods based on prediction are using numerical simulation derived by codes and it is proven more easily than complex manual calculation (Kocańda & Jasztal, 2012). The use of computational intelligence (CI) can be used to predict the fatigue life such as artificial neural network (ANN), genetic algorithm (GA) and just a few years before, the application of the adaptive neuro-fuzzy inference system (ANFIS) was introduced for fatigue crack growth rate prediction. ANFIS is one of the most recent techniques to solve fatigue problems with a high rate of success (Mohanty, Verma, & Parhi, Prediction of mode-I overload-induced fatigue crack growth rates using neuro-fuzzy approach, 2010). ANFIS is an end product of ANN combined together with fuzzy logic where it is a combination of advantages from both applications (Tahmasebi & Hezerkhani, 2010). Among researchers which put their efforts in the neuro fuzzy fields are (Mohanty, Verma, Ray, & Parhi, Application of adaptive neuro-fuzzy inference system in modeling fatigue life under interspersed mixed-mode (I and II) spike overload, 2011) (Mohanty, Verma, & Parhi, Prediction of mode-I overload-induced fatigue crack growth rates using neuro-fuzzy approach, 2010) (Tahmasebi & Hezerkhani, 2010) (Mohanty, Verma, & Ray, Prediction of fatigue crack growth and residual life using an exponential model: Part II (mode-I overload induced retardation), 2009) (Vassilopoulos & Bedi, 2008) (Reddy, Janardhana, & Reddy, 2009) (Mahmut, 2011) (Han, Zeng, Zhao, Sun, & Ma, 2011). It now has started to develop the popularity among the new researchers where the application of neuro-fuzzy not only restricted in system engineering but also in solving mechanical issues in this fatigue case study.

Similar to the ANFIS, CANFIS is still new to being compared with, and the results of combining the adaptable fuzzy inputs with the neural networks gave an immediate and accurate prediction. The operation of CANFIS can be equivalent with the fuzzy inference system which is an adaptive to the process. For the fatigue field, the CANFIS can offer new opportunities to solve difficult and complicated problems. Compared with other numerical software, the CANFIS is able to provide an accurate life prediction based on the experimental results. Moreover, the S-N curve behaviours are easily achievable and look like with the trial behaviour respectively. It has proven, only 50% to 60% amount of the experimental data is enough to produce a good and high accuracy of S–N curves [10]. The aim of this study is to perform three point bending fatigue test where the results obtained is compared with the prediction using the CANFIS. The CANFIS was developed using programming software before the results from the experiment can be upload as the inputs.

2.3 FATIGUE TEST FOR COMPOSITE MATERIALS

(Gassan, 2002) in his study performed a study of tension-tension fatigue for different type of fibre, which affecting the fatigue behaviors. The fibre of the specimen consists of two types, which are flax and jute and both have a different resins. For the fatigue test, the stress ratio, R was fixed at 0.1 whilst the frequency set as 10 Hz. The constant amplitude loading test was performed using MTS machine and the 25mm extensometer used to record the strain data continuously. The results of the experiment then plotted between specific damping capacities versus applied maximum load for each 10^4 cycles (Figure 2.1).

(Savastano, Santos, Radonjic, & Soboyejo, 2009) performed a study of fracture and fatigue for natural fibre-reinforced cementitious composite. The experimental was performed using fatigue crack growth (FCG) method using single edge notched bend (SENB) specimen. The three-point bending test used Questar QM100 telescope to identify the crack growth. The reason is the crack initially unstable and usually cannot be seen by naked eyes. So, by using the telescope not only it allows to see the crack but also can be measured easily without taking the specimen out and place it under a microscope. The stress ratio for the fatigue test was 10 for pre-cracked and 0.1 when the crack growing

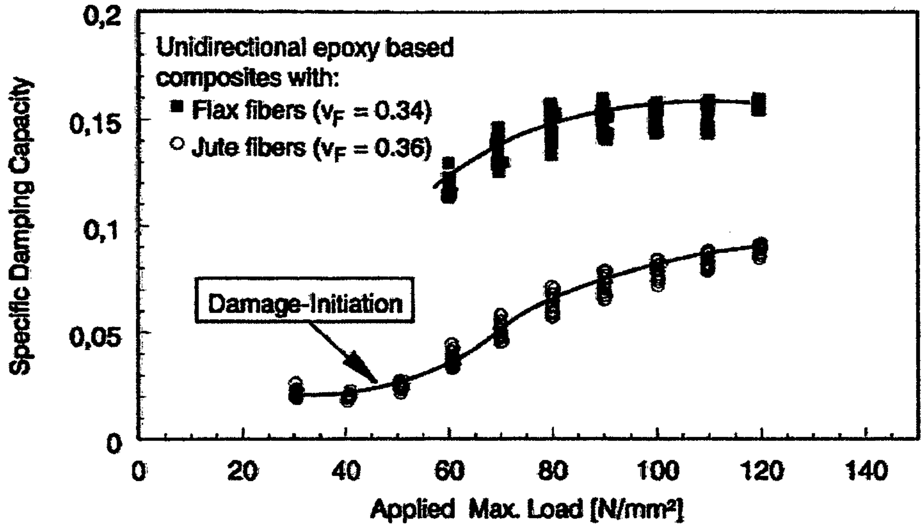
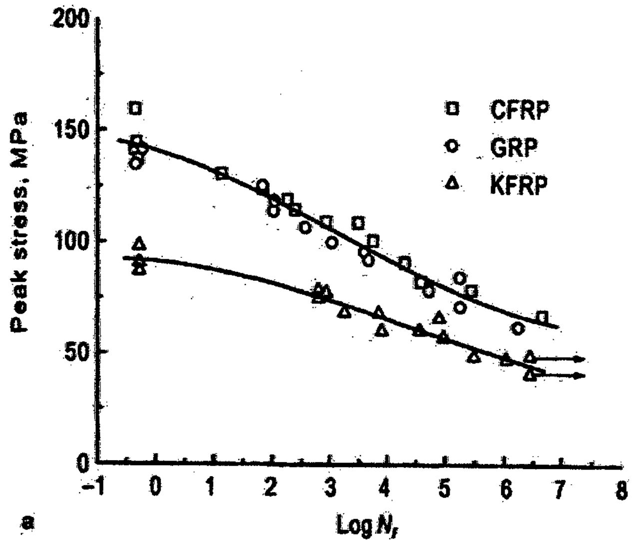


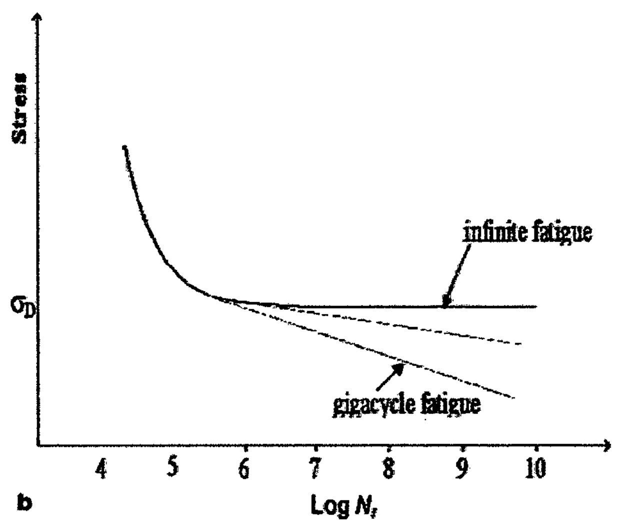
Figure 2.1: Specific damping capacity vs. applied maximum load

Source: (Savastano, Santos, Radonjic, & Soboyejo, 2009)

(Bathias, 2006) conducted a study for fatigue damage between metals and composite materials. It is very essential to understand the advantages and disadvantages of each material because each has their own capabilities. For the last of thirty years, the composite materials were often known as the metal substitution and widely used in aircraft components generally. However, in the year 2001, the carbon fibre reinforces plastic (CFRP) which used for Airbus aircraft was one of the reasons why the airplane crashed. So, good understanding of the materials is crucial because the carbon fibre fatigue limit varies according to types of fibres and the resins. Comparison between metal and composite's material consist of five different perspectives, including damage at the microscopic level, endurance limits, effect of loads in fatigue, stress concentration and impact. It can be concluded that the fatigue limit for the composite materials is greater than metals as shown in Figure 2.2 and the composite materials is less sensitive for notch according to the fatigue results.



(a)



(b)

Figure 2.2: S-N curves of (a) composite materials and (b) metal.

Source: (Bathias, 2006)

(Shah, Schubel, Cilfford, & Licence, 2013) perform fatigue life study of plant fibre composites (PFC) and compared with glass fibre reinforced plastic (GFRP). The main objective of the study is to provide sets of fatigue data of the PFC are which fabricated on vacuum infusion. The comparisons were made between the PFC and E-glass / polyester GFRP for fibre, content of fibre, architecture of the textile and effect on the stress ratio. The composites were manufactured using compression molding under vacuum infusion where the resin introduced. Four types of PFC, the static and cyclic tests, were performed following tension-tension test using constant amplitude loading with frequency of 10Hz. The effect of stress ratio 0.1, 0.3 and 0.5 for tension-tension was performed for all composite's specimens. Figure 2.3 shows the results for the effect of fibre (jute, hemp and flax). The flax, F20 gives the highest stress followed with jute and hemp. Figure 2.4 shows the S-N diagram which comparing the fatigue test results of PFC and GFRP. It is very clear that the GFRP outperforms the PFC by far.

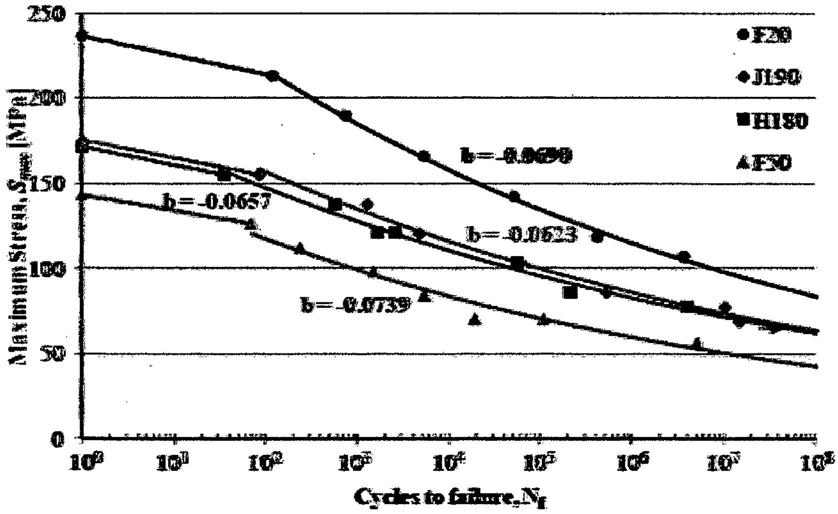


Figure 2.3: S-N diagram for PFC's with fatigue strength coefficient, b.

Source: (Shah, Schubel, Cilfford, & Licence, 2013)

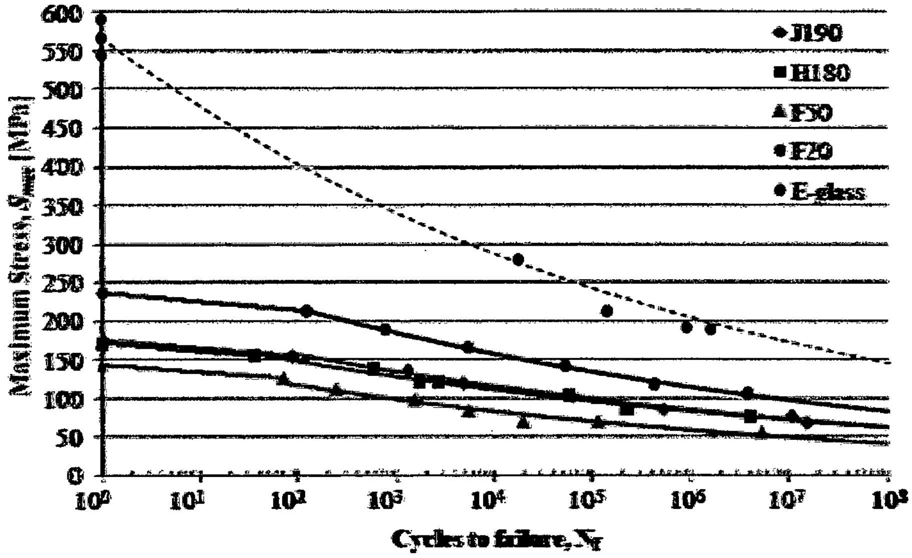


Figure 2.4: S-N diagram for PFC and GFRP for tension-tension fatigue test.

Source: (Shah, Schubel, Cilfford, & Licence, 2013)

The architecture of the composites influenced the fatigue performance hence. It is important to understand about the textile architecture. In this study, three different types of textile architecture were tested which uniaxial 0°, 90° and biaxial 45°. Figure 2.5 showing the S-N diagram for the F50 with various of architecture. The ultimate tensile strength (UTS) for 0° uniaxial is three times the 90° uniaxial and 45° biaxial. All three composites have the same content of fibre, but the biaxial has the slowest degradation to be compared with both uniaxial. Figure 2.6 shows the normalized S-N diagram for uniaxial and multiaxial for PFC and GFRP. Again, the GFRP outperforms the PFC's with the highest ratio of UTS for uniaxial over biaxial. The worst results showed by the triaxial that the lowest among the others GFRP.