UNIVERSITI PUTRA MALAYSIA

FATIGUE ANALYSIS OF WOVEN INTRAPLY CARBON/KEVLAR REINFORCED EPOXY HYBRID COMPOSITE AT AMBIENT AND BELOW AMBIENT TEMPERATURE

NURAIN HASHIM

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By

NURAIN BINTI HASHIM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

August 2019

DEDICATION

This thesis is dedicated to the only one God, Allah S.W.T the master of all humankind.

To my parents (Hashim Abd. Ghani and Puziah Abd. Manaf), siblings (Along, Angah, Asri and Aiman) and the whole family, for their dedications and inspirations.

To myself, that able to hold on, learn and grow regardless of all the struggles.

To my best circle of friends, who always being the company during my Ph.D journey
To all friends, acquaintances and strangers who directly and indirectly helped me grow mentally and spiritually.

将来の私のため、将来に大好きな人のため、将来に私から生まれた子供たちのため.

神様、ありがとうございました。

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman: Assoc. Prof. Dayang Laila Abang Abdul Majid, PhD
Faculty: Engineering

Investigations on fatigue behaviour of aircrafts' composite structure at different temperature environment are important since it was reported that most aircraft's structural failures were due to fatigue. In addition, cyclic loading of composite structures also experiences self-heating, which affects fatigue. Composite materials based on fabric constructions for aerospace structures are usually made up of woven fabric fibres with multitude of ply orientations and stacking sequences. Carbon/Kevlar reinforced epoxy composite is one example with improved impact resistance compared to homogeneous CFRP and still maintains its high tensile strength and fatigue strength. However, fundamental understanding on how hybrid composites affected by fatigue remains an active research topic. This work seeks to establish the tensile and low-cycle fatigue behaviour of woven intraply carbon/Kevlar reinforced epoxy hybrid composites at ambient and low temperatures. The effects of self-heating to the fatigue life and how different environmental temperature affect the self-heating were also investigated. A cooling chamber was designed to provide the cold environment for both tests. In this work, coupon shape of woven intraply carbon/Kevlar reinforced hybrid composites were fabricated and tested at three different directions at tensile and fatigue tests. Concurrently, thermocouples were attached at the samples' surfaces for self-heating analysis. Differ from common unidirectional composite, best tensile strength was obtained at 0°, followed by 90° and 45° fibre direction as Kevlar fibre plays as the dominant role at 90° fibre direction. Tension-tension fatigue tests in ambient temperature were done at 0°, 45° and 90° fibre directions. Best fatigue strength found at 90° direction as it has the lowest life degradation rate, which is 4.1% of its UTS. However, only fatigue data at carbon direction is agreeing with the mean curves plotted using the MLE method. S-N curves have larger scatter for samples tested at 45° and 90°, where the life cycles can be seen to be divided into two different stages. At low temperature, hybrid composite samples were only tested in tensile test and fatigue test at 0° direction, at 0° C, -5°C and -10°C. This material showed higher tensile strength but more brittle properties at low temperature. The fatigue behaviour was improved as the life degradation rate at sub-zero temperature decreased from 5.2% to around 3% of its UTS. For self-heating observation, internal heat generation is significantly influenced by the fibre structures and its stiffening properties,

not the stress level. At lower temperature, the heat generation also found to be influenced by the tensile modulus but did not affect the materials' fatigue properties. All the results showed that the existence of different fibres in intraply hybrid composite gives large difference in tensile and fatigue properties. Low temperature condition also had affected the hybrid composites' tensile and fatigue properties significantly.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ANALISIS KELESUAN KOMPOSIT EPOKSI DIPERKUAT DENGAN FABRIK HIBRID KARBON/KEVLAR DALAM SUHU AMBIEN DAN BAWAH SUHU AMBIEN

Oleh

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Ogos 2019

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Penyelidikan terhadap tingkah laku kelesuan struktur komposit pesawat udara pada suhu ambien dan bukan ambien adalah penting kerana majoriti kegagalan struktur pesawat adalah disebabkan oleh kelesuan. Semasa dikenakan kitaran daya, bahan komposit juga mengalami pemanasan sendiri, yang mempercepatkan kelesuan. Bahan komposit yang berasakan gentian untuk struktur aeroangkasa biasanya terdiri daripada gentian yang ditenun rapat dengan pelbagai orientasi dan susunan. Sebagai contoh, epoksi komposit yang diperkuat dengan karbon/Kevlar mempunyai rintangan hentaman yang lebih baik dari komposit yang dengan hanya gentian karbon dan pada masa yang sama masih mempunyai kekuatan tegangan dan kelesuan yang tinggi. Jenis komposit hybrid ini biasa digunakan dalam pesawat komersil Airbus A380 dan A310. Gabungan hibrid karbon / Kevlar ini diketahui akan mempunyai kekuatan tegangan dan kelesuan yang lebih baik dengan peratusan gentian karbon tertentu. Komposit intra-lapisan yang terdiri daripada pelbagai jenis gentian juga telah dilaporkan mempunyai peningkatan dalam kekuatan tegangan dalam penyelidikan yang terdahulu. Walau bagaimanapun, pemahaman asas sifat kelesuan dalam komposit hibrid masih lagi aktif sebagai topik penyelidikan. Tujuan kerja penyelidikan ini adalah untuk menganalisa dan memahami tingkah laku kelesuan komposit hibrid epoksi yang diperkuat dengan karbon /Kevlar pada kitaran tegangan rendah pada suhu ambien dan suhu rendah. Penyelidikan ini juga menyelidik kesan pemanasan sendiri kepada sifat kelesuan komposit dan juga bagaimana ia dipengaruhi oleh perbezaan suhu sekitar. Ruang penyejuk telah direka untuk menyediakan persekitaran yang sejuk. Komposit dipotong dalam bentuk kupon dan diuji pada tiga arah yang berbeza dalam ujian tegangan dan ujian kelesuan. Pada masa yang sama, termogandingan dilekatkan pada permukaan sampel untuk analisis pemanasan. Berbeza dengan komposit dengan susunan gentian sehala, kekuatan tegangan terbaik untuk komposit hybrid ini diperoleh pada arah sudut 0° diikuti oleh 90° dan 45°. Ini kerana gentian Kevlar bertindak sebagai dominan pada arah 90°. Ujian kelesuan di suhu ambien juga dilakukan pada sudut arah 0°, 45° dan 90°. Kekuatan kelesuan terbaik didapati pada arah 90° dengan catatan degradasi hayat bahan yang terendah sebanyak 4.1% daripada kekuatan tegangannya. Bagaimanapun, hanya data dari sampel yang diuji pada arah 0° didapati mematuhi garis linear MLE metod. Garis linear yang diplot untuk sampel yang diuji pada arah 90° and 45° kelihatan lebih berselerak dan kitaran hayat bahan terdiri

daripada dua peringkat yang berbeza. Pada suhu rendah, sampel komposit hibrid hanya diuji dalam ujian tegangan pada arah 0° pada suhu 0°C, -5°C dan -10°C. Bahan ini menunjukkan kekuatan tegangan dan sifat rapuh yang lebih tinggi pada suhu rendah. Tingkah laku kelesuan bertambah baik pada suhu rendah daripada 0°C, dimana kadar degradasi hayat bahan menurun dari 5.1% kepada 3% daripada nilai kekuatan tegangan. Untuk fenomena pemanasan sendiri bahan pada suhu ambien, penjanaan haba dalam struktur komposit tidak dipengaruhi oleh magnitud tegangan, tetapi sangat dipengaruhi oleh susunan dan sifat mengeras gentian. Pemanasan sendiri pada suhu rendah pula menunjukkan penjanaan haba juga dipengaruhi oleh modulus tegangan tetapi tidak mempengaruhi sifat kelesuan bahan. Keputusan penyelidikan menunjukkan bahawa kewujudan gentian yang berbeza dalam komposit hibrid dengan susunan intra-lapis telah memberikan perbezaan yang besar dalam sifat tegangan dan kelesuan. Keadaan suhu yang rendah juga didapati mempengaruhi sifat tegangan dan kelesuan komposit hibrid dengan ketara.

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Nurain binti Hashim
August 2019

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Signature: : ______________________
Name of Member of Supervisory Committee : ______________________

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LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
AE	Acoustic Emission
ASTM	American Society for Testing and Materials
C-C	Compression-Compression
CFRP	Carbon Fibre Reinforced Polymer
CLD	Constant Life Diagram
CNTs	Carbon Nanotubes
CSM	Chopped Strand Mat
CTE	Coefficient Thermal Expansion
DSC	Differential Scanning Calorimetry
DTG	Differential Thermogravimetric
FAA	Federal Aviation Administration
FRP	Fibre Reinforced Polymers
GFRP	Glass Fibre Reinforced Polymer
HE	High Elongation
KFRP	Kevlar Fibre Reinforced Polymer
LE	Low Elongation
MLE	Maximum Likelihood Estimation
PAEK	Polyaryletherketone
PBT	Polybutylene Terephthalate
PEEK	Polyetheretherketone
PMI	Polymethacrylimide
PVA	Polyvinyl Alcohol
SEM	Scanning Electron Microscope
T-C	Tension-Compression
TGA	Thermogravimetric analysis
T-T	Tension-Tension
UD	Unidirectional
UTS	Ultimate Tensile Strength
VaRTM	Vacuum Assisted Resin Transfer Mould
VI	Vacuum Infusion

CHAPTER 1

INTRODUCTION

1.1 Background

Fibre Reinforced Polymer (FRP) composite materials are generally known as heterogeneous materials because it has two different constituents in one structure. The first constituent acts as the reinforcement, which are the fibres and can be in continuous or discontinuous form. The second constituent is the matrix that plays the role as the load transmitter inside the composite structures. Composite materials are naturally had been existed since the ancient time, where the Egyptian used the fibres from papyrus plant as the structure of their boats and sails and straws as the reinforcement in their mud wall structures (Herakovich, 1998). As composite materials are known for its high strength and light properties in general, what actually makes it popular and in the structure industries are its ability to be designed with specific strength and stiffness by tailoring the fibre directions and stacking sequences. Thus, researchers and engineers had been exploiting composite materials domestically in various kinds of technologies that need structures to be designed in a lighter and stronger form such as aircraft structures, wind turbines and bridges since the early of 1960s (Wang *et al.*, 2011).

Until recent, one of the biggest industries that actively exploiting FRP composite is the aircraft and aerospace industry. As replacing metals with FRP composites can reduce the weight of the aircrafts' structure, these materials has been used widely for exterior structures of the aircrafts such as radome, fairings, horizontal stabilizer and rudder. It was also reported that in 2014, usage of composite materials in commercial aircraft structures had increased by 10.7% (Mazumdar, 2015) and it was estimated that there will be a rapid increase of 290% of aerospace demand for Carbon Fibre Reinforced Polymer Composite, CFRP in between 2012 to 2020 (Mazumdar *et al.*, 2018). To make sure that these FRP materials are safe as the aircraft structures, these materials must fulfil the design specifications given by the Federal Aviation Administration (FAA). Based on the material qualification for composite materials given in the technical report (Tomblin *et al.*, 2003), the composite materials' reliability for aircraft structures must be determined by running several material characterization tests to make sure that its mechanical properties meet the aircrafts' design specifications. In addition, the design also must minimize the thermal effects and ensure that each points of stress concentration are at low risk of any catastrophic fatigue failure during operating. Thus, mechanical characterization test like static and compression test, impact test and fatigue test done in various environmental conditions are crucial in developing the FRP composite materials for aeronautics and astronautics applications.

1.2 Carbon/Kevlar hybrid composite materials

FRP composites known to be superior in strength and lightweight compared to metal. However, its drawbacks in several aspects limited it applications in the industry. For examples, composites with glass (GFRP) and Kevlar (KFRP) as reinforcements with epoxy matrix have low strength and low maximum temperature regardless of its high flexibility. The most commonly used carbon fibres reinforced composite (CFRP) also has its weakness, which is its superiority in stiffness makes it too sensitive to impact. In addition, as carbon fibre is a very good heat and electric conductor, its susceptibility to lightning makes CFRP not suitable to be used in aircrafts' radome structure.

To make use of these fibres to its fullest potential in each application, researchers came up with hybridization in the CFRP composite materials. Through hybridization, improvement doable on the material's properties that do not reach specific requirements by only using a single type of fibres/matrices. Hybridizing in the composite materials can be done in two ways, which are hybridizing the fibres or hybridizing the matrix. For hybridizing fibre in composites, Low Elongation fibres (LE) will be used together with High Elongation Fibre (HE) in one matrix. Addition of high strength LE fibres will increase the hybrid composites' load sustaining capability and LE fibres can be delaying its strain failure, thus improves the impact resistance of the homogeneous FRP without reducing too much of its strength.

To get the best positive hybrid effect (i.e. increase in failure strain, increase in tensile strength), several configurations were applied in hybridizing different fibres in these composite materials. The most common methods are shown in figure 1.1, which are interlayer/interply, intralayer/intraply and intrayarn. Interply configuration is the method where different fibre sheets were stacked onto one another and fabricated into composite. Fibre cloth used in interply method can be in form of chopped strand mat (CSM), unidirectional (UD) or woven types. On the other hand, intraply configuration is where two or more different fibre yarns were weaved together in one cloth and in intrayarn, all the fibres were mixed in one bundle of yarn. Intraply fibres or also known as woven fibre fabrics are also much easier to manufacture and lower cost compared with the UD fibres (Karaduman *et al.*, 2017). In addition, there are also not much of difference in terms of cost between the homogeneous fibres and the woven hybrid fibres found in the market. Woven fibre composites were already exploited in the aircraft industries like in Boeing 737-300, woven (twill) carbon fibre composite were used as its winglets structures (Liu *et al.*, 2016). However, even though hybrid composites were reported to be already used in the aircraft industry, the fibres structures were not publicly mentioned.

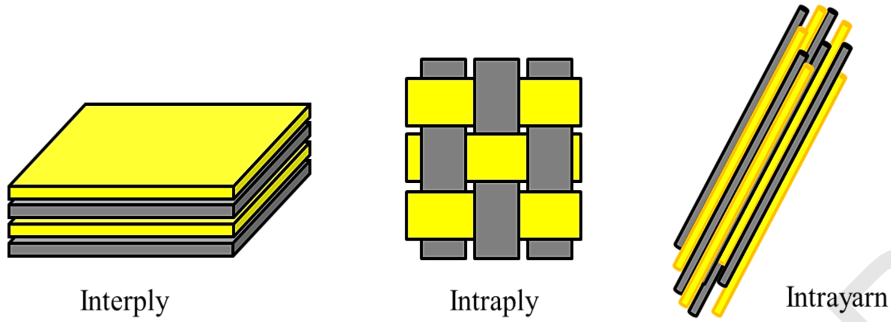

Figure 1.1: Methods of Hybridizing Fibres in Composite Materials

For hybridized CFRP composites, carbon fibres used usually referred as the low elongation fibre (LE) and hybridized with high elongation fibre (HE) like glass, Kevlar and natural fibres. In one of the earliest work on hybridizing CFRP composites (Dorey *et al.*, 1978), it was reported that hybrid of carbon/glass FRP composites could not resist high impact load due to the large gap of modulus between carbon and glass fibres. Other work (Richardson and Weisheart, 1996) also reported that hybridized fibres with bigger modulus mismatch are much more complex to be designed. Thus, this work suggested that hybridizing carbon fibres with aramid (Kevlar) fibres, which have higher modulus than glass fibres were seen to be better in improving CFRP impact resistance. In addition, hybridizing Kevlar with carbon fibres will cost lesser than producing the homogeneous Kevlar fibres composite. The positive hybrid effect of carbon/Kevlar hybrid composite on its compression strength and impact resistance were already proven in the previous works (Gustin *et al.*, 2005; Muhammad *et al.*, 2015; Kartal and Demirer, 2017). Until recent, carbon/Kevlar hybrid composites had been used widely in the commercial aircraft structures such as pylon fairing access panel of Airbus A380. In figure 1.2, it showed that carbon/Kevlar hybrid composites were used as the structures of the tail components the Airbus A310 aircraft.

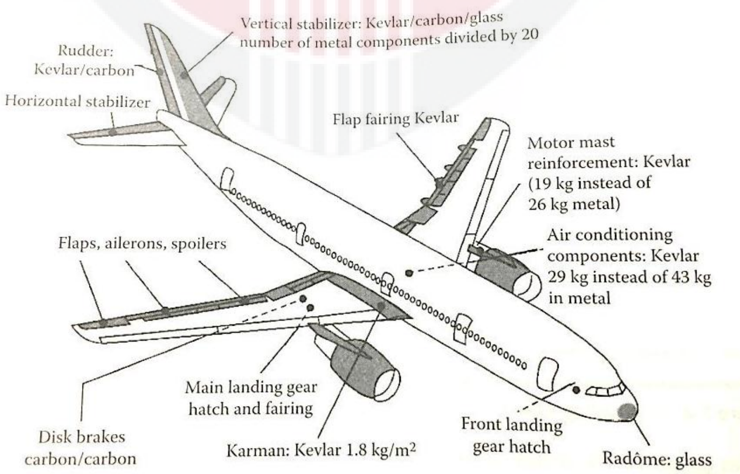

Figure 1.2: Applications of Carbon/Kevlar Hybrid Composite in Components of Airbus A310 (Gay and Hoa, 2007)

1.3 Fatigue of composite materials

Fatigue damage is failure that occurs when the properties of the material changes due to the repeating stresses applied under its Ultimate Tensile Strength (UTS). Fatigue performance and its damage failure mechanism rely on the knowledge of composite materials, as it is very important in designing structures. In addition, it has been widely used these days as the main materials of gigantic and critical structures like bridges, wind turbine blades and aircraft. Despite the improving manufacturing processes, accidents that caused by fatigue phenomenon in aircrafts are still occurring. Previously, it was predicted that within period of ten years, major aircraft accident due to fatigue damage will likely to occur every week (Bathias and Pineau, 2013). According to (Findlay and Harrison, 2002), based on the assessment of failure modes, it was also found that the incidence of fatigue failure has the highest distribution with 25% in aircraft and 55% failures on the engineering and aircraft components, respectively.

Fatigue test is one of the conservative methods for predicting the life of a material and its behaviour during experiencing cyclic loading. Generally, fatigue test can be categorized into three categories such as mechanical fatigue test, thermo-mechanical fatigue test and thermal fatigue test (Mall and Ermer, 1991). A mechanical fatigue test is the most common test that works by applying cyclic loading to a specimen in ambient temperature with constant pressure and constant amplitude. The mechanical fatigue test also be conducted at constant non-ambient temperature (isothermal). Meanwhile, thermo-mechanical fatigue test is conducted with both cyclic loading and cyclic temperature that varies from sub-zero temperatures until extremely high temperatures and rely on the application of the materials. On the other hand, a thermal fatigue is a test in which there is no load applied onto the specimens. Fatigue failure that occurs during this test initiated and propagated by the thermal stresses occurs due to the temperature changes for the material experienced (Gabb *et al.*, 1990)

Characteristics of fibre reinforced composite (FRP) is different from metallic materials because it is generally consisting of fibres and matrix. Several parameters like fibre volume used, resin types, fabricating methods and fibre-stacking sequences contribute to the multitude of material characteristics of the composite materials. Therefore, its fatigue behaviour is also different from the common metallic materials, which the brittle composite materials will not deform plastically, and its fatigue failure usually occurs abruptly with combinations of several failures like delamination, matrix failure and fibre failure (Vassilopoulos and Keller, 2011). As the load applied during the fatigue test is also in cyclic pattern, this process will naturally generate excess energy in a form of heat. For low thermal conductivity composite materials, the heat generated usually will accumulate inside the structures and resulted with self-heating phenomenon (Katunin *et al.*, 2010). Thus, the effect of generated heat also must be taken into careful considerations when conducting fatigue test on composite materials.

1.4 Problem statement

From a review work on hybrid composites in (Swolfs *et al.*, 2014), extensive research on the tensile properties of hybrid composites had been done by many researchers and well understood. However, most of the works done on the behaviour of hybrid composites under several loading condition, such as in flexural, impact and fatigue tests were found to have several contradictions and unclear patterns results. This review also reported that even though there are many works that had been extensively investigated the mechanical properties of hybrid composite materials, there are still limited studies done on the fatigue resistance.

Investigations on fatigue behaviour of several types of hybrid composite in ambient temperature were already reported in several literatures reviewed. Most of the studies conducted the fatigue tests to investigate the effect of layup sequences of different fibres in carbon/glass hybrid composites (Dickson *et al.*, 1989; Shan and Liao, 2002; Belingardi *et al.*, 2006; Wu *et al.*, 2010; Pandya *et al.*, 2011; Murugan *et al.*, 2014; Poyyathappan *et al.*, 2014) Carbon/aramid hybrid composites were also had been studied in these works (Fernando *et al.*, 1988; Marom *et al.*, 1989). Most of these works used interply fibre sequences in their hybrid composites but detailed investigation on the hybrid composites with woven(intraply) fibre sequences are still lacking. In addition, in woven structures, where the fibres arrangement is closer and dominant fibres are different at 0° and 90° directions, very limited works had reported the mechanical properties and fatigue behaviour at each fibre loading respectively.

On the other hand, mechanical properties and impact resistance on the interply and intraply carbon/Kevlar fibres hybrid composite was proved to have positive hybrid effect in these works (Gustin *et al.*, 2005; Salehi-khojin and Mahinfalah, 2007; Wan *et al.*, 2007; Kartal and Demirer, 2017). However, it was clear that there was an absence of research work done on the fatigue behaviour of carbon/Kevlar hybrid composite in both ambient and non-ambient temperature. In addition, most of the previous investigations, (Botelho *et al.*, 2009; De Baere *et al.*, 2011) were only considering the fatigue behaviour of its respective homogeneous composites. Other types of hybrid composites, which is carbon/glass hybrid also investigated in (Gururaja and Harirao, 2013) and Kevlar fibres with hybrid matrix in (Ferreira *et al.*, 2013). Surprisingly, the only fatigue study done on carbon/Kevlar hybrid composites was done in (Fernando *et al.*, 1988), which was only focusing on its fatigue properties at unidirectional direction. This work reported that Kevlar does not affect the fatigue strength of unidirectional carbon/Kevlar composites at a certain percentage of volume ratios. There was still no extensive investigation on the fatigue behaviour of hybrid composites with woven structures of both carbon and Kevlar fibres. Its fatigue behaviour with woven fibre structures might have similar pattern or different results compared to what had been reported before.

In addition, the literatures reviewed also showed that there are still lack of study on how the environmental changes affect the self-heating process and the damage progression on hybrid composites. FRP composites applied in aircraft structure will generally experiencing large range of temperature changes during its operation due to weather conditions and engines' operation (Gay and Hoa, 2007; Administration, 2008). As aircrafts' skin experience high temperature rise due to the friction during operating (Council, 1996), it will also experience low temperature environment, which ranges between ambient to -15°C during the cold weather on the ground. Therefore, to ensure that this type of hybrid composite is reliable to be exploited in aircraft structure, extensive ambient and below ambient fatigue testing at different fibre directions are required to establish the useful life of the woven carbon/Kevlar hybrid composites.

Other than heat applied from the environmental condition, some works in (Mortazavian *et al.*, 2015; Katunin, 2017) reported that at certain frequency and stress level, self-generated heat also accelerated the damage progression in composite structures. From the experimental results done in these works (Shah and Tarfaoui, 2014; Peyrac *et al.*, 2015; Katunin, 2017; Katunin *et al.*, 2017), self-heating in homogeneous composites was found to have significant effect to its fatigue behaviour. However, no work can be found on reporting the self-heating effect to hybrid composites' fatigue behaviour. In hybridized fibre composites, different Coefficient of Thermal Expansion (CTE) of fibres might give different effect to the hybrid composites' properties during the self-heating process. Moreover, there is also no work can be found on investigating the environmental temperature effect to the self-heating process. Thus, effect of temperature increase by the generated heat during cyclic loading on the fatigue behaviour of hybrid composites also needed to be investigated.

1.5 Research objectives

This research work will contribute on analysing the fatigue behaviour of the hybrid composite with reinforcement of woven intraply carbon/Kevlar fabrics and epoxy matrix and both ambient and below ambient temperature. Through this work, the tensile and fatigue behaviour of the hybrid composites will be established not only one but at three different fibre directions, where different fibre types play the dominant role. Through the analysis done on its fatigue behaviour at ambient temperature, we can learn and understand on how the hybrid composites degrades and estimate its life cycles when applied to repeated tensile load under its maximum tensile strength. In addition, by conducting the fatigue tests at lower temperature, how temperature changes affect its life degradation pattern, life cycles and material properties can be understood.

In addition, analysis on the self-heating process also will help us on understanding what parameters that significantly caused the phenomenon. It also will help us on understanding how the extra heat generated during the fatigue loading process can affect the hybrid composite materials' degradation process at both ambient and low temperature.

The objectives of this research work are as follows

- To establish the tensile properties of woven carbon-Kevlar fibres reinforced epoxy hybrid composites at different loading directions at ambient temperature.
- To investigate the tension-tension fatigue behaviour of hybrid composite at different fibre directions in ambient temperature environment.
- To analyse the effect of below ambient temperature environment to the hybrid composite's tensile properties and fatigue properties.
- To assess the effect of stress level and loading direction to the self-heating process during fatigue loading.
- To investigate the effect of self-heating process to the fatigue behaviour of hybrid composites at ambient and below ambient temperature environment.

1.6 Scope of research

The current work mainly investigated the fatigue behaviour of plain-woven carbon/Kevlar reinforced epoxy hybrid composites. Hybrid composites were first tested under tensile loading and the ultimate tensile strength value obtained from the tests will determine the stress level applied during fatigue loading. Tensile tests and fatigue tests at ambient temperature were done at three different loading direction, which at carbon direction (0°), Kevlar direction (90°) and 45° direction. Fatigue tests were conducted at constant frequency, which is 10 Hz and constant amplitude, R = 0.1. Fatigue test mode was in tension-tension mode as subjecting the materials with compression force might require extra fixtures to prevent buckling. For tensile and fatigue tests at low temperature, hybrid composites were only tested at carbon fibre direction. This was because hybrid composites showed some stiffening effect during fatigue tests at both Kevlar and 45° direction. As this work will only focus on the influence of environmental temperature to the hybrid composite's fatigue behaviour, fatigue tests at low temperature were only done at carbon fibre direction to avoid the influence of stiffening effect to the hybrid composites. For tests done at low temperature level, small temperature ranges were chosen, which is from 0°C, -5°C and -10°C. This temperature range was chosen based on two factors. The first factor is because of the nonlinearity of modulus changes and CTE in matrix and fibres at very low temperature. The second factor is because of the cooling chamber capability where it can only operate at constant temperature and at long time at minimum of -10°C.

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The student was born in Negeri Sembilan on 10th May 1987. She started her early education at Sek. Keb. Batu Kikir and further her secondary education at Sekolah Menengah Sains Tuanku Jaafar, located in Kuala Pilah, Negeri Sembilan.

After obtaining her SPM, she then pursued her studies in Ambang Asuhan Jepun, Universiti Malaya, under the Rancangan Persediaan Ke Jepun (RPKJ) programme by Look East Policy founded by Tun. Dr. Mahathir Mohamad. After two years of preparation on the Japanese Language, she then was sent for her first degree to Kyushu University in Fukuoka, Japan. Her bachelor's degree in mechanical engineering was obtained on 2012. She started her first job as a purchasing engineer at Panasonic Industrial Devices, Shah Alam, Selangor. After nine months of working, she then moved to Balakong, Selangor and started working in Research and Development department at ISC Micro Precision Sdn. Bhd. She pursued her master's degree in Innovation and Engineering Design as part time in Universiti Putra Malaysia and finally graduated on February 2015. She also quit her job as an engineer at ISC Micro Precision Sdn. Bhd after a year and works as a research assistant for six months at Universiti Putra Malaysia before starting her Ph.D on March 2015.

On February 2018, she then was working back in the manufacturing industry as a process engineer at Production Engineering department in Hosiden Electronics Sdn. Bhd, which located at Bandar Baru Bangi, Selangor. She is now currently working under the Production Control Department at Shimadzu Manufacturing Asia Sdn. Bhd, located at Bandar Sri Sendayan, Negeri Sembilan.

LIST OF PUBLICATIONS

Published works

Hashim, N., Abdul Majid, D.L., Zahari, R., Yidris, N., (2017) 'Tensile Properties of Woven Carbon/Kevlar Reinforced Epoxy Hybrid Composite' *Materials Science Forum* 890, pp.20–23. https://doi.org/10.4028/www.scientific.net/msf.890.20

Hashim, N., Majid, DL, Uda, N, Zahari, R & Yidris, N., (2017) 'Vacuum infusion method for woven carbon/Kevlar reinforced hybrid composite', IOP Conference Series: *Materials Science and Engineering*, vol. 270, no. 1, 012021. https://doi.org/10.1088/1757-899X/270/1/012021

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Hashim, N., Abdul Majid, D. L, M.Baitab, D., Yidris, N. and Zahari, R., (2019), 'Tensile Properties of Woven Intra-Ply Carbon/Kevlar Reinforced Epoxy Hybrid Composite at Sub-Ambient Temperature' In*: Reference Module in Materials Science and Materials Engineering*. [online] Elsevier. Available at: https://doi.org/10.1016/B978-0-12-803581-8.11567-X

Alaa, M. R., Abdul Majid, D.L, Uday, M.B, Ishak, M.R, **Hashim, N.**, (2017) 'Effect of Equal Channel Angular Pressing on Yield Stress and Fatigue Properties of Al 6063 Alloy', *Journal of Engineering and Applied Sciences*, 18(4), pp. 53

Conferences/Symposiums

Title	:	Tensile properties of woven carbon/kevlar reinforced epoxy hybrid composite
Authors	:	**Nurain Hashim**, Dayang Laila Abdul Majid, Rizal Zahari, Noorfaizal Yidris
Conference	:	5th International Conference on Material Science and Engineering Technology
Venue/Year	:	Tokyo University, Japan/2016

Title	:	Vacuum infusion method for woven carbon/Kevlar reinforced hybrid composite
Authors	:	**Nurain Hashim**, Dayang Laila Abdul Majid, Nobuhide Uda, Rizal Zahari, Noorfaizal Yidris
Conference	:	AEROS Conference
Venue/Year	:	Putrajaya/2017

Title	:	Tensile Properties of Woven Intra-ply Carbon/Kevlar Reinforced Epoxy Hybrid Composite at Sub-ambient Temperature
Authors	:	**Nurain Hashim**, Dayang Laila Abdul Majid, Rizal Zahari, Noorfaizal Yidris
Conference	:	Symposium and Workshop on Materials and Characterization
Venue/Year	:	Universiti Putra Malaysia/2018

Title	:	Effect of fiber loading directions on the low cycle fatigue of intraply carbon-Kevlar reinforced epoxy hybrid composites
Authors	:	**Nurain binti Hashim**, Dayang Laila Abang Abdul Majid, El-Sadig Mahdi, Rizal Zahari, Noorfaizal Yidris.
Conference	:	21st International Conference on Composite Structures
Venue/Year	:	University of Bologna, Italy/2018

Research Attachment

Laboratory	:	Aerospace Structures and Structural Dynamics Lab, Department of Aeronautics and Astronautics, Graduate School of Engineering, Kyushu University.
Supervisor	:	Prof. Nobuhide Uda
Date	:	1st October 2016 to 31st December 2016
Country	:	Fukuoka, Japan
Sponsorship		School of Graduate Studies, UPM & Kyushu University Friendship Scholarship

Work in progress

1. Fatigue behaviour of woven carbon/Kevlar reinforced epoxy hybrid composite at low temperature.
2. Effect of self-heating to hybrid composite's fatigue behaviour at ambient and low temperature.

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