A STUDY ON SINGLE-LAP NOTCHED WOVEN KENAF REINFORCED POLYMER BOLTED JOINT UNDER TEMPERATURE ACTION

ANDERS HANS ANAK ROMAYNE

A thesis submitted in fulfilment
of the requirement for the award of the
Degree of Master of Civil Engineering

Faculty of Civil and Environmental Engineering
Universiti Tun Hussien Onn Malaysia

NOVEMBER 2016

DEDICATION

For my beloved mother and father, brother and sisters, uncles and aunties, my entire cousins and my friends, thank you for continue support me to achieve my scroll and our happiness.

ACKNOWLEDGEMENTS

This Master thesis would not be reality without the guidance of my main supervisor, Dr. Hilton @ Mohd Hilton Bin Ahmad. His patience and dedication in guidance me through the problems arising during the process of learning in this project are much appreciated. I would like to extend my gratitude to my co-supervior, Dr. Haris Ahmad Bin Israr Ahmad for his advice and moral support.

To all my friends from UTHM and my colleague also not forget my hometown friends, your assistance and moral support whenever I need are much appreciated.

Last but not least, I would like to acknowledge my employer, Universiti Tun Hussien Onn Malaysia (UTHM) for offering me scholarship to continue my dream to pursue Master study.

ABSTRACT

Study on natural fibers as reinforcing fibers in composite materials has started to gain interest as engineering materials due to renewability and excellent specific strength. Bolted joints requires introduction of hole that susceptible to stress concentration that leads to strength reduction, more complex when exposed to elevated temperature. Strength prediction tools are still lacking, limited success was found in semi-empirical and numerical approach. More recently, extended finite element method (XFEM) formulation has been reported in the literatures but there is no work has been carried out to incorporate the strength prediction exposed to elevated temperature. Present work predicted the notched strength and bearing stress at failures in open-hole and single-lap bolted joints woven fabric kenaf composite coupons respectively using XFEM by implementing traction-separation relationship. Strength prediction work of 2-D open hole and 3-D bolted joint models were then validated against experimental datasets tested under room and elevated temperatures as specified in the testing series. Research work concentrates on opening mode (Mode I) fracture associated with stress raisers ahead of notch tip. The experimental results showed increasing trend of notched strength and bearing stress under elevated temperature (120℃) due to matrix toughening. XFEM results were in good agreement with experimental datasets results where discrepancy less than 20% in notched coupon and within 8 – 35 % in bolted joint, better strength predictions were found in thicker and cross-ply coupons. It was found that XFEM techniques implemented able to predict the notched strength and bearing stress at failure by using thermal coefficient and specified temperature under elevated temperature with reasonable precision.

ABSTRAK

Kajian gentian asli sebagai tetulang gentian dalam bahan komposit telah menarik minat sebagai bahan kejuruteraan disebabkan mampu diperbaharui dan kekuatan spesifik yang cemerlang. Sambungan bolt memerlukan penebukan lubang yang cenderung kepada tegasan tumpuan yang menjurus kepada pengurangan kekuatan, dan lebih kompleks jika terdedah pada suhu tinggi. Kaedah untuk meramal kekuatan masih berkurangan, oleh itu penemuan yang terhad dilaporkan dalam analitikal dan numerikal. Kajian terbaru dalam kaedah unsur terhingga lanjutan (XFEM) telah dilaporkan tetapi masih belum ada kajian yang mengabungkan kekuatan komposit yang terdedah kepada suhu tinggi. Kajian ini meramalkan kegagalan tegasan bukaan dan tegasan galas masing-masing untuk kes plat bukaan dan sambungan bolt tindihan tunggal komposit fabrik tenunan gentian kenaf mengunakan teknik XFEM yang menghubungkan daya terikan-pemisahan. Kerja ramalan model 2-D untuk plat bukaan dan model 3-D untuk sambungan bolt kemudiannya dibandingkan dengan data eksperimen, di mana kedua-duanya diuji pada suhu bilik dan suhu tinggi seperti di spesifikasikan dalam siri ujikaji. Kajian ini menumpukan kepada mod bukaan (Mod I) yang berkaitan dengan pengumpulan tegasan di atas takuk bukaan. Keputusan eksperimen memberikan trend peningkatan kekuatan bukaan plat dan kekuatan galas di bawah suhu tinggi (120 ℃) disebabkan oleh pengukuhan matriks. Keputusan XFEM menunjukkan perbandingan yang baik dengan set data eksperimen di mana percanggahan diperolehi kurang daripada 20% dalam plat bukaan dan antara 8 - 35% dalam siri sambungan bolt, ramalan yang lebih jitu diperolehi dalam plat yang tebal dan “cross-ply”. Teknik XFEM yang dilaksanakan mampu untuk meramalkan kekuatan bukaan plat dan tegasan galas pada kegagalan dengan mengambilkira pekali suhu dan di bawah suhu tinggi dengan ketepatan yang munasabah.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

CDG	-	Critical damage growth
CFRP	-	Carbon fiber reinforced polymer
FEA	-	Finite element analysis
GFRP	-	Glass fiber reinforced polymer
PPS	-	Polyphenylensulfied
PP	-	Polypropylene
SEN	-	Single edge notch
RMK-10	-	Rancangan Malaysia ke-10
KFRP	-	Kenaf fiber reinforced polymer
XFEM	-	Extended finite element model
2-D	-	Two dimensional model
3-D	-	Three dimensional model
a	-	Longitudinal distance from hole edge
a_i	-	Enriched nodal D.O.F vector when cut by crack interior
t	-	Thickness laminate coupon
C	-	Compliance
d	-	Hole diameter
e	-	End-distance
E_1	-	Longitudinal young’s modulus
E_2	-	Transverse young’s modulus
E_x	-	Laminate Modulus Elastic longitudinal
E_y		Laminate modulus of elasticity transverse
G_{xy}	-	Laminate shear modulus
G_{12}		In-plane Shear Modulus (fiber direction)
G_c	-	Fracture energy
G_c^*	-	Apparently fracture energy

$H(x)$	-	Discontinuous jump shape function (in enriched element) when cut by crack interior
K	-	Elastic stiffness matrix
K_T	-	stress concentration factor
K_r	-	Crack interior
K_Δ	-	Crack tip
$N_i(x)$	-	Conventional FE (non-enriched) nodal shape function
n_i	-	Nodes in an element (*i*=1,2,3…)
n_i	-	Phantom Nodes in element (*i*=1,2,3…)
P_{MAX}	-	Maximum load
u_i	-	Conventional FE (non-enriched) nodal displacement vector
T	-	Glass transition
T_g	-	Glass transition temperature
T_{g0}	-	Dry glass transition temperature
T_{gw}	-	Wet glass transition temperature
t_n	-	Nominal traction y-direction
t_s	-	shear traction X-direction
v_{xy}	-	In-plane Volume friction
v_{12}	-	Poisson ratio
W	-	Coupon Width
X_t	-	Longitudinal tensile strength
X_c	-	Longitudinal compressive strength
Y_t	-	Transverse tensile strength
Y_c	-	Transverse compressive strength
σ^u	-	Ultimate Strength Un-Notched Laminate
σ_{coh}	-	cohesive stress
σ_d	-	Damage stress
σ_b	-	Bearing Stress
δ	-	Displacement
δ_{max}	-	Displacement at maximum
δ_{sep}	-	Displacement Separation
θ	-	Angle of bearing plane

α_1 - Thermal coefficient longitudinal

α_2 - Thermal coefficient transverse

CHAPTER 1

INTRODUCTION

1.1 Background of study

Polymer composites have emerged as important structural engineering materials in automotive, transportation, infrastructure applications as well as in civil engineering sector, mainly due to excellent specific strength and stiffness. Composite materials are one of a new class of advanced materials that are strong, possess low densities, and non-corrosive. Commercially available composite materials are carbon fiber-reinforced polymer (CFRP), glass fiber-reinforced polymer (GFRP) and Kevlar fiber-reinforced composite. Composites material are comprised of two or more distinct phase elements, including reinforcing phase (fiber, sheet or particles) and matrix phase (polymer, ceramic or metal). Polymer matrix composites production are commercially produced worldwide and used in larger engineering sectors. Two polymer types, thermoplastic and thermoset polymers are used in various types of reinforcing fibers such as man-made-fiber and natural fiber (plant, animal, mineral).

Recently, natural fibers have attracted attention in composite material research due to advantages such as renewable, environmental-friendly and cheaper option (Mittal *et al.*, 2016). Over the last decade, natural fiber has replaced material researcher interest as a substitute for synthetic fiber due to awareness of environmental issue and enforcement of stringent environmental assessment of material productions in future. Kenaf fiber exhibits superior specific strength and stiffness, less abrasive during handling and biodegradability (Nishino *et al.*, 2006). Hajnalka *et al.*, (2008) found out optimum young's modulus of fiber composites increased as the fiber fraction increased to 50%, but decreased gradually as further increased to 70%. It is well understood that performance of the composite materials was depending on the properties of the individual components and their interfacial compatibility. Various polymers were used in a study by Anuar & Zuraida (2011) that showed improvement in tensile, flexural and impact strength of kenaf fibers composites mixed with epoxy-resin polymer.

Woven reinforcement fibers are typically two-dimensional fiber consisting of interlaced orthogonal tows, which consist of two sets of interlaced yarns, warp (0°) and weft (90°). Abot *et al.,* (2004) found that reinforcing composite with fiber lay-up in general offers good dimensional stability in both warp and weft direction but low in-plane shear stiffness. Woven fabric composite materials offer advantages in enhances drapeability, more economic (one woven layer is equivalent to two unidirectional plies), good impact resilience and fatigue resistances (Ku *et al.,* 2011). Although two crossover point or "crimps" lead to a reduction in strength and stiffness, but overall mechanical properties are remaining adequate, and ability of the woven arrest crack growth and excellent absorption at the two crossover points (Belmonte *et al.,* 2004).

A comprehensive literature review relating to the damage and fracture behaviour of composite laminates containing a stress raiser has been reported extensively in the form of either a circular hole (Agarwal, 1980) or mechanically fastened joint (Ahmad *et al.,* 2014b). The tensile failure modes in these two types of problems are very similar. It is important to study the behaviour in notched problem before capturing the response behaviour in bolted joint problems. An extensive experimental study to measure bearing stress at failure as a function of failure mode in a variety of lay-ups (Belmonte *et al.,* 2004), temperature condition (Benoit *et al.,* 2012) and the effects of joint geometry (hole size and normalized joint width) (Manger, 1999) were investigated. There was lack of study had been reported on material degradation on woven fabric kenaf composite but there are some studies on other woven composites (Okutan *et al.,* 2001)

The major issue that hinders the widespread use of composite materials in structure engineering is the effect of heat in engineering material and limited amount of information regard of these material behaviour with temperature. In other sector, advance high technology military and aeronautics structure were designed to perform at elevated temperatures and assembled from a number of detachable joint components. The structures behaviour of notched and bolted joints woven fabric kenaf composite were less reported, therefore joint efficiency design of woven composites exposed to elevated temperatures is difficult due to lacking of available experimental data. Influence of temperature are great importance as the composite material may degrade in service due frequently expose to in evaluated temperature environment where temperature ranging from 100-200°C. As reported by Smith (2000), with increasing temperature, the matrix dominated properties of composite was similar influenced by softening of the matrix in particular as temperature approach the matrix glass transition temperature. Matrix dominated properties such as the transverse and shear stiffness and strength was reduced. On the other hand, modulus parallel to fibers (E_1) was relatively temperature insensitive as would be expected for a fiber dominated property.

1.2 Problem Statements

Currently, commercial fibers such as carbon and glass fibers are used excessively in production of composite materials. Commercial fibers are man-made, its aggressive production become an environmental issue as it is non-renewability, non-environmentally friendly and contain chemical contaminants. The commercial fibers are synthetically manufactured outside Malaysia, these materials are regarded as imported goods and has limited use due to high cost. As highlighted in Tenth Malaysia Plan (RMK-10), it was focused upon production of renewable resource and sustainable materials, production of natural fibers are the best option to reduce synthetic fibers production (Economic, 2010). Natural fibers are potentially used as composite reinforcement and excellent engineering material properties were reported but there are lacking in experimental works in joining assembly and if convincing, it can be utilized as local-production industry and enable broader applications of kenaf fiber composites in Malaysia (Hadi *et al.*, 2014), kenaf plants are largely planted in east coast and northern Malaysia. Kenaf fiber can be weaved into woven fabrics and classify as an important fiber reinforcing class, excellent in resisting impact and fatigue loading. However, due to crimping region exhibited, this composite class is relatively complex than non-woven composite counterparts (Saiman *et al.*, 2014).

Composite materials exposed to elevated temperature condition tends to degrades its mechanical and durability properties and these affect the structures performance and corresponding costs as a results of rehabilitation works. The polymer binder sensitive to temperature changes and leading to disintegration of fiber and matrix bonding and therefore may reduce its structural strength. Complex damage morphologies in composite plates with discontinuities such as open-hole and cut-outs is exhibited, more complex when subjected to temperature actions. Stress concentrations develop cohesive damage ahead of notch tip as tensile loading applied. Analytical approach by Aronsson & Backlund (1986) implemented simplified cohesive stress-separation relationship in their strength prediction work of GFRP plates, later work explores more comprehensive modelling based on ply-by-ply modelling known as “progressive damage modelling”. Santiuste *et al.*, (2011) used numerical approach progressive damage modelling approach to combine failure criteria (Hashin, 1980) and degradation model (Yamada & Sun, 1978) in order to study strength prediction under temperature effect by developing their own programming subroutine to predict bearing strength at failure and gave mixture of prediction accuracy. However, these approach is suitable to bearing failure mode as it was based on ply-by-ply basis, however woven fabric composites is more prominent to net-tension failure type which is associated with stress concentration.

Several parameters were involved in bolted joint problems, analytical approaches seems unrealistic as huge numbers of parameters involved. The obstacle in finite element modelling of testing coupons associated with stress concentration is the occurrence of singularity ahead of crack tip. Previously, these requires refined meshing ahead of notch tip in finite element modelling framework, however with the introduction of extended finite element framework (XFEM) techniques eliminates these requirement as it is driven by energetic approach. Ahmad *et al.*, (2013) has successfully conducted Extended Finite Element Method (XFEM) framework approach in predicting joint strength of woven fabric CFRP composites with notched coupons and single-lap bolted joints (Ahmad *et al.*, 2014b), but no study on strength prediction work under elevated temperature action has been reported. Therefore, this study explores strength prediction works of woven fabric kenaf composite by using XFEM approach by implementing physically-based traction-separation as a constitutive model on notched and bolted joints problems under temperature actions. The strength prediction were then validated against experimental dataset and to develop a methodology that is applicable to tensile failure at notched and net-tension failure in bolted joints under temperature action.

1.3 Objectives

This project is concerned with strength prediction work of notched and bolted joints woven fabric kenaf composite polymer under room temperature and elevated temperature by physically-based constitutive model to be implemented within finite element framework, explicitly used measured independently material parameter from experiment. The aim is to develop a methodology that is applicable to tensile failure at notched and net-tension failure in bolted joints under temperature action.

1.4 Scope of study

In the present study, woven fabric kenaf composite are fabricated at Universiti Tun Hussein Onn Malaysia fabrication laboratory. Firstly, kenaf yarns with diameter of 0.7 mm are orthogonally weaved using a weaving handloom machine to produce required numbers of woven (plain weave) fabric layers. Fabrication stage was carried out using in-house wet lay-up technique and bound with epoxy resin and hardener as matrix under high pressure. Polymer composite harden for 24 hours under high pressure with ratio 2:1 epoxy and hardener as mixture matrix had few drawbacks such us a very long curing process and handmade draping that generates most of the non-reversible defect of the manufacturing process.

Temperature control system from laboratory oven provides a stable temperature environment within drying exposure duration. For under elevated temperature (prescribed as 120˚C as in Table 2.4) condition, woven fabric kenaf composite coupons were dried-oven at 70 ± 5˚C for 48 hours and preserved in waterproof environment so that the testing coupons were considered as dry coupons. Mechanical testing of testing coupon were carried out within 8 hours after oven-dried. These procedures were applied in both open hole coupons and bolted joints problem.

Relevant code of practice was used as references in order to determine the in-plane tensile properties (E_x, G_{xy} and σ_0) ASTM D3039 (Standard test method for tensile of polymer matrix composite material properties) and ASTM E399-90 (Standard test method for plane-strain fracture toughness of metallic materials) was referred to measure critical strain energy release or known as fracture energy, G_c. Length change datasets were gained by using strain gauge and mechanical testing are conducted by using Universal Testing Machine under quasi-static loading with crosshead speed of 0.5 mm/min, and a load cell of 100 kN.

In the notched problem, the gauge lengths of 150 mm were used throughout the testing series. The width was kept constant as 25 mm with the hole diameter, d of 2.5 mm, 5.0 mm, and 10 mm to give d/W ratio of 0.1, 0.2 and 0.4, respectively. The mechanical testing was carried out, where applied load and strain datasets was recorded at one-second intervals using a PC data-logging package from Instron machine. In bolted joints problem, the bolt and washer size of 5 mm (commercial code as M5) was used as fastener system and assembled accordingly to single-lap joint configuration prior to finger-tight clamping load (0.5 N). Mechanical testing was conducted immediately after the implementation of bolt load to eliminate bolt relaxations.

Three-dimensional finite element analysis (FEA) framework using ABAQUS CAE Version 6.13 software package were conducted with XFEM framework approach to includes proper surface interactions, friction coefficient to allow joint load transfer, bolt load to provide through-thickness compression and washer were modelled explicitly (most previous researchers ignores the washer in their model) for simplicity. Current work emphasized on effect of temperature which explicitly included in the XFEM modelling framework. The validation works compare the discrepancies between XFEM predicted strength with experimental datasets as described earlier.

1.5 Organization of thesis

To achieve the objective of in the previous section, the study has been structure down to the following chapter. Chapter 2 gives comprehensive study of previous works of related topics that provides good background to present project work. It describes the physical characteristics of woven fabric yarns and associated reinforced polymer composites. This is followed with the description on material behaviour of composite materials under temperature actions, and mechanical properties of natural fiber to focus on implementation of kenaf fibers in composite materials. The experimental study of open hole coupon and bolted joints of composite coupons by previous researchers were described. Associated strength prediction approach in open hole problem and mechanical fastened composite coupon are further discussed.

Chapter 3 concerned on two-dimensional (2-D) finite element modelling of open hole woven fabric kenaf composite coupons using ABAQUS CAE software. Prior to modelling work, experimental framework comprised of material preparations, panel fabrication and testing series were discussed concurrently. The independent properties for physical-based constitutive model used in strength prediction works were discussed. Extended finite element method (XFEM) framework were implemented in the numerical modelling incorporated of traction-separation relationship to study open hole coupon behaviour. Benchmarking works on previous researcher and strength prediction with effect of elevated temperature of open hole problem were also conducted.

Chapter 4 describes an experimental framework for woven fabric kenaf composite coupon bolted joints. The lay-up used was a subset in open hole problem discussed in Chapter 3. A test matrix is developed on single-lap joint with different *W/d*, temperature effects, lay-up types and coupon thickness. The experimental results of these parametric variations were discussed with observations during mechanical testing and associated bearing stress at failure. The experimental results obtained from this chapter was used as a validation work of finite element modelling as reported in Chapter 5.

Chapter 5 discussed on 3-D FEA modelling of single-lap bolted joint woven fabric kenaf composite under elevated temperature and compared to experimental results as reported in Chapter 4. Pre-processing stages of modelling idealization, discretization, generation of coupon geometry and material properties as well as loading and boundary condition were elaborated. The strength predictions framework includes the sensitivity study to incorporate explicitly bolt load, loads friction transfer and contact interactions. The discrepancy with experimental bearing stress at failure of testing series in single-lap bolted joint under room and elevated temperatures were discussed.

Conclusions are presented and recommendations for future works were given in last chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter started with introduction of physical characteristic of woven fabric plies to emphasize upon undulation region, followed by discussion on the effect of extreme temperature upon strength in composite materials. Subsequent section discussed the type of natural fibers, mainly focus on physical and engineering properties of kenaf fibers. Following section discussed the notched coupons, ranging from experimental observation under room temperatures and elevated temperatures and associated strength prediction approaches. This followed with the discussion on bolted joints problem, similar subsection as given in previous (notched) section. Concluding remarks is summarized in the last section

Composite materials are manufactured by combining two or more different materials to obtain an advanced material with superior mechanical, chemical, thermal etc. that is unachievable by its constituent alone. Compared to isotropic materials such as steel or aluminium, composite materials perform relatively complex behaviour due to its anisotropic characteristics. Effects of elevated temperatures need to take into account at the early design stage, or consequences of catastrophic failures. Finite element analysis (FEA) is the most powerful tool to study the structures response of composite materials with the evolution of advanced computing technology.

.

2.2 Natural Fibers

Natural fiber is a class of hair-like materials that are continuous filaments or in discrete elongated pieces, spun to form filaments, thread, or rope to use as a material component. The implementation of natural fibers as reinforcements in polymer composites are to replace commercial synthetic fibers like glass is presently receiving increasing attention because it offers cost effectiveness, low density, excellent specific strength and renewable resources. Since 1990s, natural fiber composites are emerging as realistic alternatives to glass-reinforced composites in many applications. Natural fiber composites such as hemp fiber-epoxy, flax fiber-polypropylene (PP), and china reed fiber-PP are particularly attractive in automotive applications due to lower cost and density. Glass fibers used for composites have density of 2.6 g/cm^3 and cost between USD 1.30/kg and USD 2.00/kg. On the other hand, flax fibers density are approximately 1.5 g/cm^3 and cost between USD 0.22 and USD 1.10/kg (Foulk *et al.*, 2000).

Testing samples of 40% fiber content of. kenaf, coir, sisal, hemp, and jute combined with polypropylene binders are tested to replace glass fiber–reinforced materials (Wambua *et al.*, 2003). Polypropylene with high melting flow index was used to aid in fiber matrix adhesion and to ensure proper wetting of the fibers. Tensile strengths of all testing samples were comparable with glass fiber composites except for the coir composites, but only hemp fiber has similarity flexural strength. It was shown that increasing fiber weight fraction of kenaf fibers increased ultimate strength, tensile modulus, and impact strength. However, the composites tested showed low impact strengths compared to glass mat composites as shown in Table 2.1. Wambua *et al.* (2003) mention in his study demonstrated that natural fiber composites have a potential to replace glass under low or medium load bearing applications.

Table 2.1: Comparison between natural and glass fibers (Wambua *et al.*, 2003)

	Natural fibers	**Glass fibers**
Density	Low	Twice that of natural fiber
Cost	Low	Low, but higher than a natural fiber
Renewability	Yes	No
Recyclability	Yes	No
Energy consumption	Low	High
Distribution	Wide	Wide
CO2 neutral	Yes	No
Abrasion to machines	No	Yes
Health risk when inhaled	No	Yes
Disposal	Biodegradable	Not biodegradable

Natural fiber composites also offer environmental advantages such as reduced dependence on non-renewable energy or material sources, lower pollutant emissions, lower greenhouse gas emissions, enhanced energy recovery, and end of life biodegradability of components. Since, such superior environmental performance is an important driver of increased future use of natural fiber composites, a thorough comprehensive analysis of the relative environmental impacts of natural fiber composites and conventional composites, covering the entire life cycle, is warranted (Joshi *et al.*, 2004).

2.2.1 Kenaf Fibers

Kenaf (*Hibiscus cannabinus L.*) is a member of Malvaceae family, including okra and cotton, origin from east-central Africa and it is a herbaceous annual non-wood fiber plant (Saba *et al.*, 2015). The crop, which closely resembles jute, has been considered a potential substitute for jute in the manufacturing of cordage product since it was introduced into the United State in 1940s by Department of Agriculture (USDA). Kenaf plant can grow faster in high dry matter and can be harvested within 4 months, faster than jute. As natural fibers are closely compared to inorganic fibers, it presents some well-known advantages such as lower density and cost, also less abrasive to processing equipment, harmless, biodegradable, renewable, and their mechanical properties are comparable to inorganic fibers. Furthermore, kenaf fibers are recyclable, easily available in most countries, easy surface modification, and has relative non-abrasiveness (Li *et al.,* 2008; George *et al.,* 2001). Therefore, many ongoing research were carried out on many different aspects of kenaf fiber properties (physical, mechanical etc.), cultivating, producing and recycling process and the potential markets (Salman *et al.,* 2015).

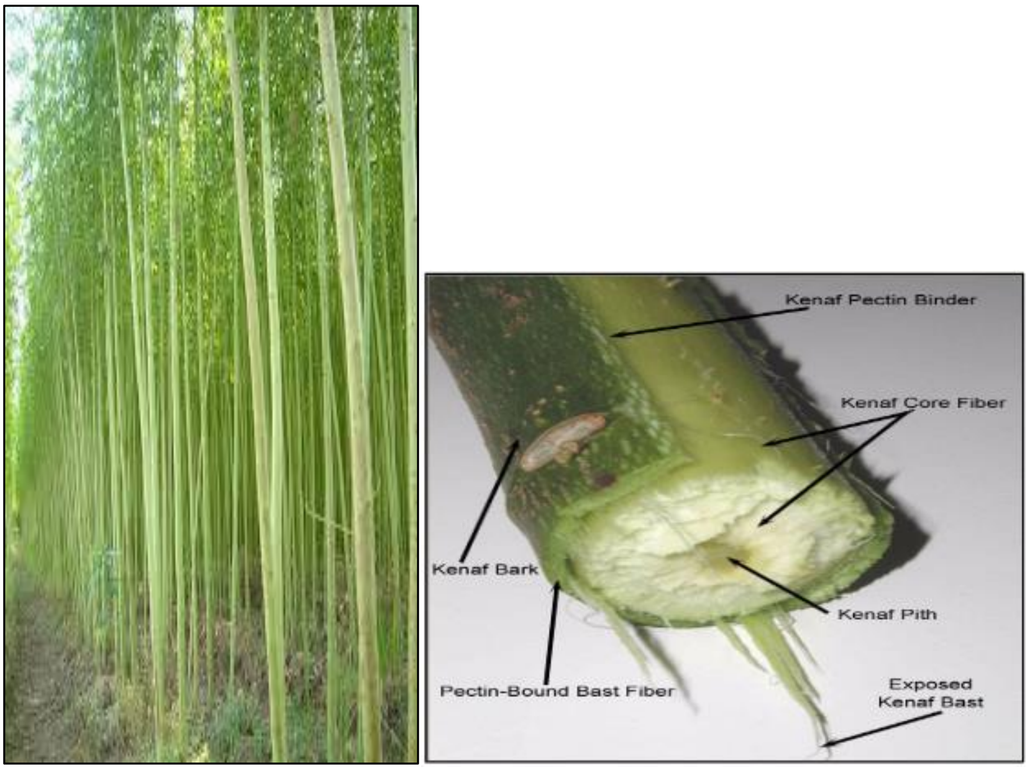

Figure 2.1: Kenaf plant and physical appereance of kenaf fiber (Karnani, 1996)

Kenaf as shown in Figure 2.1 has a bast fiber which contains 75% cellulose and 15% lignin and offers the advantages of being biodegradable and environmentally safe (Karnani, 1996). It is also a dicotyledonous plant, meaning that the stalk has three layers that is an outer cortical also referred to as “bast” tissue layer called phloem, an inner woody “core” tissue layer xylem, and a thin central pith layer which consist of sponge-like tissue with mostly non-ferrous cells (Sellers, 1999). Malaysian kenaf is composed of two distinct fibers, bast and core, with a makeup of about 35% and 65%, respectively. Bast fiber, high purity can be used in the manufacturing of high quality paper products and high purity core can be used in manufacturing particle boards, laboratory animal bedding and other high value product.; thus, separation of the fibers produces higher monetary returns over whole-stalk kenaf. Major factors involved in separation of kenaf into its two fractions include size and amount of each portion; type and number of separation machinery or processing rate through separation machinery; moisture content of whole-stalk kenaf; humidity of ambient air (Abdul Khalil *et al.*, 2010).

The traditional use of kenaf was formerly seen in manufacturing of sacking, cordage, ropes, fishing nets, etc. During the past decades, researchers have been seeking other potential markets for kenaf to take advantage from an environmental point of view. However, the success of a new crop venture needs market development. In 1992, Jobes and Dicks stated that an immediate potential market would be newsprint, poultry litter and forage. In the pulp and paper industries, kenaf has been expected to serve as an alternate non-wood fiber because it can help in reducing the deforestation worldwide and have a favorable impact on the economies of many developing and developed countries (Kaldor, 1992). Currently, commercial interest in kenaf fibers among natural non-wood fibers is growing in the fields of textile and automobile.

2.2.2 Characteristics and Engineering Properties of Kenaf Fibers

Table 2.2 showed the characteristic and properties of kenaf stems in Malaysia. Kenaf has used intensity in industry as renewable resource material. Kenaf has ability to fix CO_2 has expand global awareness as a natural fiber source. Harvesting kenaf take 4 months and able to plant in dry area. The physical properties of kenaf has determine that the maximum plant could growth about height 250 cm and the lowest was 145 cm as in Table 2.2. The maximum and minimum of kenaf diameter stem could reach 30 mm and 14 mm respectively. The density of kenaf are light in related to its dimension about 0.29 g/cm^3 and this could advantage using kenaf in replacement inorganic material.

Table 2.2: Characteristic and properties of kenaf stems, Malaysia
(Abdul Khalil *et al.*, 2010)

Characteristic / Properties	Bast	Core	Stem
Dimension (cm)	-	-	-
Height (range) (cm)	-	-	145-250
Diameter (mm)	-	-	14 - 30
Perimeter (cm)	-	-	6.60 (0.044)
Proportion (%)	-	-	-
Cross-section area	21.96(2.03)	78.04(2.51)	-
Weight proportion	32.2	68.5	-
Density (g/cm^3)	-	0.21(0.038)	0.29(0.044)
Acidity (pH)	7.13	5.21	5.87

Excellent tensile strength and modulus of kenaf fibers were reported by previous researchers (Dauda *et al.*, 2014). He found that dry woven kenaf obtain better modulus result than higher moisture content. Compression molded kenaf-PP composites had shown greater tensile strength and flexural strength compared to other natural fibers. Kenaf-PP had lower elongation at break, thus, providing higher value of tensile strength which is about 930 MPa. The properties of natural fibers showed in Table 2.3.

Table 2.3: Mechanical properties of natural fibers
(Wambua *et al.*, 2003)

Properties	**Hemp**	**Jute**	**Ramie**	**Coir**	**Sisal**	**Flax**	**Cotton**	**Kenaf**
Density, (g/cm^3)	1.48	1.46	1.5	1.25	1.33	1.4	1.51	1.4
Tensile Strength, (MPa)	550-990	400-800	500	220	600-700	800-1500	400	283-800
E-Modulus, (GPa)	70	10-30	44	6	38	60-80	12	21-60
Specific, (*E/d*)	47	7-21	29	5	29	26-46	8	22-40
Elongation at failure, (%)	1.6	1.8	2	15-25	2-3	1.2-1.6	3-10	1.6
Moisture absorption, (%)	8	12	12-17	10	11	7	8-25	-

2.3 Configuration of Woven Fabric Fiber

In polymeric composite terminology, a woven fabric was defined as a manufactured assembly of long yarn fibers to produce a flat sheet of one or more layers of fibers. These layers are held together either by mechanical interlocking of the fibers themselves or with a secondary material to bind these fibers together and hold them in place, giving the assembly sufficient integrity to be handled. Fabric types are categorized by the orientation of the fibers and various construction methods used to hold the fibers together. The four main fiber orientation categories are unidirectional, 0/90 (woven, stitched or hybrid), multiaxial, and random fibers. This work focused on woven fabrics type as described in next paragraph.

For applications where more than one fiber orientation is required, a fabric combining 0° and 90° fiber orientations are useful. Woven fabrics are made by interlacing of warp (0°) fibers and weft (90°) fibers in a regular weave pattern. The fabric's integrity is maintained by the mechanical interlocking of the fibers *(*Saiman *et al.*, 2014). Drapability (the ability of a fabric to conform to a complex surface), surface smoothness and stability of a fabric are controlled primarily by the weave style. The area weight, porosity and (to a lesser degree) wet out are determined by selecting the correct combination of fiber and thread counts (fibers/cm). Some of the commonly found weave styles are plain, twill, satin weave as shown in Figure 2.2.

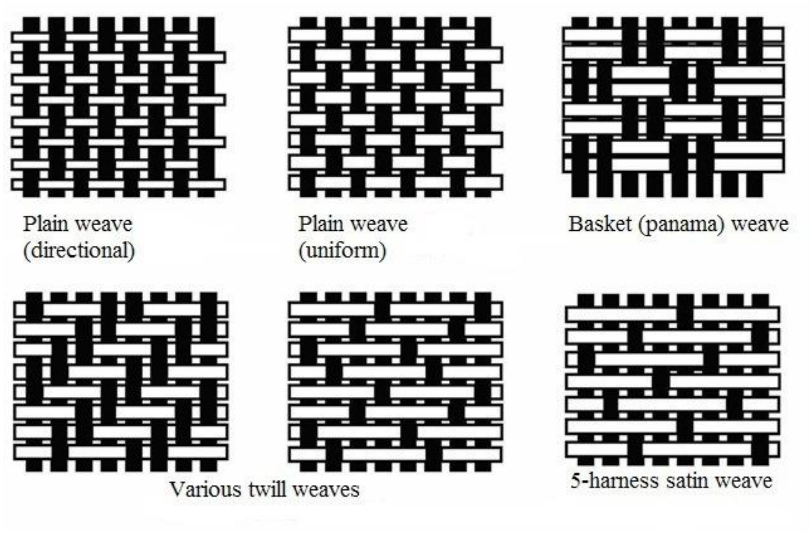

Figure 2.2: Various type of woven fabric type (Dixit & Harlal, 2013)

Plain weave fabric are symmetrical, possesses good stability and considered to fulfil consideration required to in-plane loading direction applied (Benoit *et al.*, 2011). However, it has low drapeability and high level of fiber crimp imparts relatively low mechanical properties compared with the other weave styles (Salman *et al.*, 2015). Fiber acts as a reinforcement to improve the mechanical properties of polymer and their primary function is to withstand the applied multi-loads acting on the composite. The matrix material binds the fiber yarns together, protects them, and distributes loads. Even though the mechanical properties of polymers may improve by adding filler or other agents, actual strength properties are usually accredited to the fiber properties.

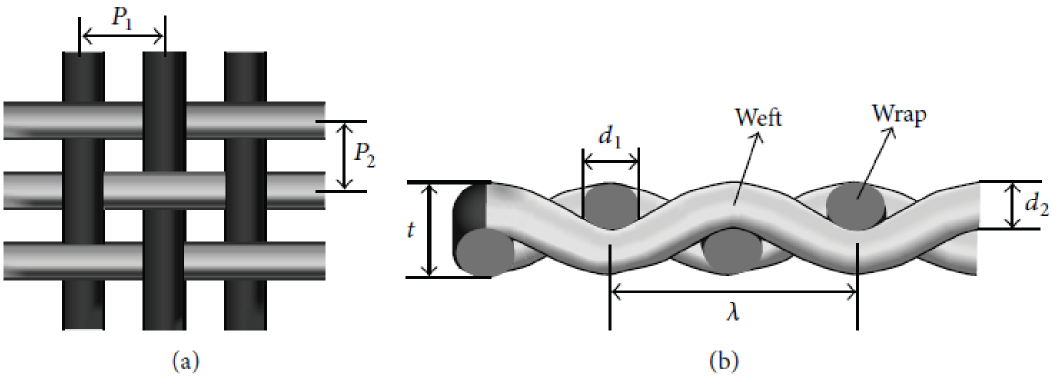

Figure 2.3: Plain weave kenaf (a) top view (b) side cross-section view (Salman *et al.*, 2015)

Figure 2.3 illustrate a plain weave fiber, P_1 and P_2 represent the distance between warp and weft. Since the woven kenaf fabric weaving using the handloom lay-up technique, the distance between warp and weft are inconsistent. The fiber diameter denotes as d_1 and d_2 with t indicated as thickness of woven. The laminate staking sequence enhance the strength in respective lamina primary loading direction. Figure 2.4 are illustration of laminate staking sequence used in the experimental work to study the strength of composite coupon. The laminate consists ± 45º degree direction stated as quasi-isotropic either combined with 0º degree direction and the cross-ply laminate consist only 0º and 90º degrees in the laminate composite coupon.

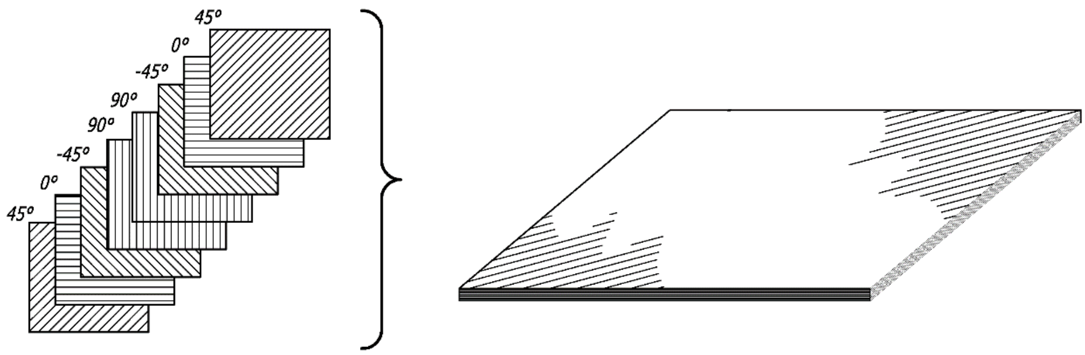

Figure 2.4: Woven laminate staking sequence direction in quasi-isotropic composite coupon

2.4 Behaviour of Composites subjected to Elevated Temperatures

There were relatively less reported work to evaluate the structures response of composite materials subjected to temperatures. Buxton & Baillie (1994) reported temperature action to composite coupon increase the bearing strength of composite coupon where moisture content removed, similar influence as fiber treatment and resin properties. Other mechanical properties such as compression strength, ultimate tensile strength, and (±45) tensile strength (which is matrix-dominated) have also been reported to decrease at elevated temperature (Zaffaroni & Cappelletti, 1998). Effect of temperature on fracture properties in composite materials has been investigated by Marom (1987), showed that interlaminar fracture energy decrease from 25% to 20% as the temperature increase from 50°C to 100°C. The interlaminar fracture surface characteristic of graphite/epoxy were also investigated and changes were observed in the amounts of fiber/matrix separation and resin fracture with increasing temperature.

Composite material may expose to low temperature conditions (-20°C or below) or high temperature conditions (50°C or above) in their 30-year service life. Exposure to low temperature of some tough polymers may make them more brittle and the modulus may increase (Schwartz, 1996). Either exposure to temperature may make composite material ductile due to decreasing of stiffness. FRP behaviour became soften, creep and distort causing buckling for load bearing structure at lower temperature of 100-200°C while at 300-500°C, polymer matrix will decomposes, releasing heat and toxic volatiles (Hollaway, 2010). The degradation due to temperature includes dehydration combine with emission of volatile components initiating at a temperature of about 260°C and rapid weight loss due to oxidation decomposition. In terms of exposure to high temperature, majority of natural fibers have low degradation temperature, where kenaf fiber degrade at 297-434°C (Aziz & Ansell, 2004).

Table 2.4: Damage morphologies with different temperatures

Temperature	Description
50ºC - 100ºC	Interlaminar fracture energy decrease from 25% to 20% as the temperature increase (Marom,1987). Temperature beyond the glass transition temperature region (T_g), the material or the polymer will become too soft and could no longer can be used in the structural material (Benoit & Taleb, 2011).
100ºC - 200ºC	FRP behaviour became soften, creep and distort causing buckling for load bearing structure at lower temperature (Hollaway, 2010). Temperature effect on the fiber-matrix interface is prominent as influenced by fiber treatment and resin properties (Buxton & Baillie, 1994).
300ºC - 500ºC	Polymer matrix will decomposes, releasing heat and toxic volatiles (Hollaway, 2010). Exposure to high temperature, majority of natural fibers (kenaf fiber) have low degradation temperature (Aziz & Ansell, 2004).

Table 2.4 showed damage morphologies with different temperatures. The temperature effect on the mechanical properties of composites derives partly from the internal stresses introduced by the differential thermal coefficients of composite components. Such internal stresses change magnitude with temperature change, in some cases producing matrix cracking at very low temperatures. Patel & Case (2002) reported that in practical applications each polymer has its own operating temperature range based on glass transition temperatures. Usually a polymer has a maximum temperature slightly below its glass transition temperature (T_g), at which the polymer transfers from rigid state to rubbery state and suffers substantial mechanical degradations. Elevated temperatures combined with humid environments were found to exacerbate the problem by further reducing T_g. They also found that from experiment findings, the ultimate tensile strength of woven graphite/epoxy material was unaffected by aging and environmental cycling conditions.

Benoit & Taleb (2011) conducted differential scanning calorimetry on resin epoxy where the initial increase of the temperature causes a gradual softening of the polymer matrix up to glass transition temperature. Further increase beyond the glass transition temperature region (T_g), the polymer became too soft and no longer able to be used as structural material as shown in Figure 2.5. The figure showed that the glass transition temperature of “dry” polymer composite material is denoted as T_{go}. When the material is full saturated with the moisture content, the “wet” glass transition temperature denoted by T_{gw}. Second, increase or decrease in temperature and/or moisture content may cause differential swelling or contraction, respectively, in constituents, and this in turn may lead to hydrothermal stress and strain. Such adverse environmental conditions may influence the failure mode and strength of composite joints. The behaviour of composite material under temperature effect subjected to stress raisers were discussed in Section 2.5.1.2 and Section 2.6.3 for open hole and bolted joints problem respectively.

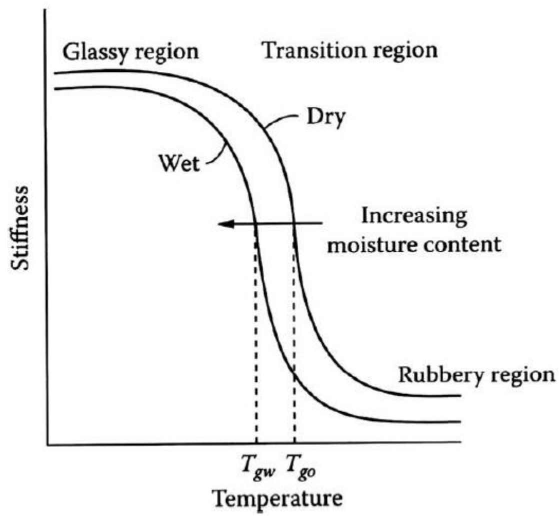

Figure 2.5: Variation of stiffness with temperature for a typical polymer matrix material (Thoppul *et al.*, 2009)

2.5 Open Hole Coupons

Stress concentration in notched coupons reduces the strength and it is dependent upon composite types, lay-up types and hole sizes. It is started with experimental observations under normal and elevated temperatures as reported by previous researchers. Next sub-section discussed on strength prediction work, earlier works lies within analytical approaches and with rapid evolution of computing technology numerical approaches is becoming popular.

2.5.1 Experimental Study on Notched Coupons

This sub-chapter focus on notches coupons to concentrate upon the behaviour of composite coupon applied to load and mechanical properties by previous researchers. Notched coupon refers to a discontinuity of composite coupon coupon, in the form of open hole, cracks or cutouts that create stress concentration to initiate crack formation and propagation. This study focused on circular hole coupon also includes the parametric study such as lay-up types, hole size and coupon thicknesses. These sections discussed the experimental study of notched coupon under room temperatures and followed by effect of elevated temperatures on notched testing coupons.

2.5.1.1 Experimental Study on Notched Coupon Under Room Temperature

Coupons with discontinuities such as notches and cutouts leads to damage zone formation and associated to strength degradation. The notch sensitivity was defined as a ratio of the notched strength to unnotched strength and its ability to accommodate fracture and failure at hole vicinity. Interlaminar damage at the notch tips provides stress relief as the notch geometry changed and correspondingly the stress concentration is reducing, therefore increasing the notched strength. Large damage zone generally provides more stress relief and hence greater notch strength. If interlaminar damage are extensive, it reduce the notched strength as individual uncoupled piles are free to fail by the fracture mode of least resistance (Harris & Morris, 1986). The damage initation and progression is depending on several factor such as staking sequence, notch geometry, testing temperature, matrix laminate, reinforcement type, hole size and shape, number of fabric lay-up and woven fabric orientation.

Effect to staking sequence and laminate lay-up, (Eriksson & Aronsson, 1990) showed 0° ply dominated laminate had higher notched strength and exhibited more damage prior to failure than ±45° and 90° ply dominated laminate. In the Harris & Morris (1986) research, they carried out a study the effect of staking sequences and showed that notched strength were varied with fiber orientation and staking sequence piles. Both them examined the laminate thickness and found that in thick laminate failure damage near notch only at outer plies but the greater laminate thickness takes less effect damage on the stress distribution prior to failure.

Whitney & Nuismer (1974) explained that for CFRP open hole laminate demonstrated stress concentration factor K_T, was approximately three for any hole sizes in quasi-isotropic notched thickness specimen, the stress drops of more steeply moving away from the hole area for small holes. They explain that hole-size effect by the fact that stress concentration is much more localized for smaller holes. The reason probably of having large flaw increased in high stressed region a large hole resulting low strength for laminate with large hole. For the larger holes, because a larger volume material is under high stresses, the probability of existence of flaws is greater, leading to lower strength. Figure 2.6 showed the coupon under tensile stress.

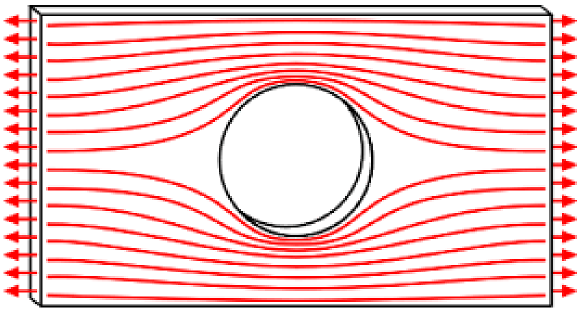

Figure 2.6: Coupon under a remote tensile stress, including the stress distribution along the ligament

Pinnell (1996) showed that fiber with high tensile strength and modulus give greater strength as they provide better resistance to fiber tensile failure and increase the ability to losses the stress concentration at the notch edge. Thermoplastic matrix system provides greater notched strength than thermoset matrix system due to toughness and strength. Experimental work has been conduct by Manger (1999) with circular hole composite coupon for cross-ply GFRP plain weave and eight harness satin weave composite. Through his observation, he found a damage zone ahead of hole edge perpendicular to the load direction comprised of micro-damage event such as delamination, transverse matrix cracking and longitudinal splitting prior to catastrophic laminate failure. Figure 2.7 showed the 8-layer damage zone with 2.5 mm circular hole diameter with damage zone was approximately 1 mm long showing tow failure. Manger (1999) found that in cross-ply plain weave laminates, damage zone was longer and narrow compare to similar coupon thickness of cross-ply eight harness satin weave laminates. The crimp region in the woven composite able to arrest the crack propagation and increased the laminate toughness. The amount of fabric layer shows an adverse effect, it showed that 8-layer plane weave coupon have lower strength than 2-layer samples for all hole sizes. Due to self-similar cracks exhibited, both cracks from hole edge perpendicular to applied load are approximately propagated equally and similar numbers of fiber tow fracture through the coupon thickness.

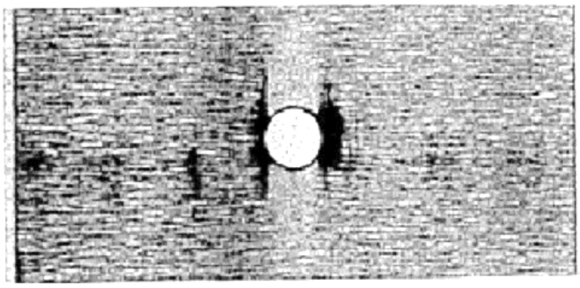

Figure 2.7: Damage zone in 8 layers weave with 2.5 mm hole diameter (Manger, 1999)

Belmonte *et al.,* (2004) also conducted investigation on CFRP woven cross-ply and quasi-isotropic plain weave and five harness satin for circular hole with various coupon thickness and hole sizes. From their experimental observation, effect of localization of damage growth prior to failure, he suggests similar damage that propagates until catastrophic failure. In his observation of the damage zone are similar to Manger (1999) with damage zone at approximately 90% of failure load. They also found that the length of the damage zone increases, propagating steadily then later failing catastrophically while width of damage zone remains constant. From Manger and Belmonte work, the damage growth at stress raisers is similar in quasi-isotropic and cross-ply GFRP and CFRP woven fabric lay-up, with matrix cracking preceding the formation of an intense damage zone containing tow fracture, together with limited amount splitting and delaminations.

2.5.1.2 Experimental Study on Notched Coupon Subjected to Elevated Temperature

The temperature action was of great importance to study as a material is weakening under temperature conditions. In service, composite materials are frequency exposed to hot environments. Benoit *et al.*, (2012) has investigated notched coupon under difference resin ductility and staking sequence under severe refers as hygrothermally aged specimen tested at 120ºC. From Table 2.5, it was found that that mechanical properties of notched coupons were decreased in quasi-isotropic laminates at room temperature than under elevated temperatures. They also found that under thermal condition helps to enhance the ductility behaviour of epoxy matrix but degrade the fiber/matrix interface, resulting in lower stiffness and strength in quasi-isotropic laminate. They concludes that weakening effect influences the strength degradation of matrix binder decreases, as a result of shear modulus, strength of the fiber/matrix bond and interlaminar shear strength decrements. Thus, the ability of the matrix to transmit load to the fiber becomes impaired under severe condition

Table 2.5: Influence of severer conditions on tensile properties - quasi isotropic laminates by Benoit *et al.*, (2012)

		Unnotched laminates			Notched laminates		
		C/PPS	C/PEEK	C/Epoxy	C/PPS	C/PEEK	C/Epoxy
Room Temperature	E_x (GPa)	41.95±0.58	46.67±0.44	45.22±0.73	-	-	-
	σ^u (MPa)	514 ± 8.04	494±10.02	532±8.81	255	265	270
Elevated Temperature	E_x (GPa)	37.72±0.43	39.63±0.68	37.14±0.34	-	-	-
	σ^u (MPa)	444±10.12	450±7.51	453±14.10	236±7.54	276±6.09	291±4.08
Influence of severe condition (%)	E_x (GPa)	27.72	24.63	19.14	-	-	-
	σ^u (MPa)	432	431	438	258	280	299

Benoite *et al.*, (2012) found that the delamination is more significant in epoxy based laminate under severe environment because of the detrimental effect of severe condition to the properties of fiber/matrix interface, as well as the decrease of the yield strength. Benoit & Taleb (2011) had carried out experimental works on notched and unnotched woven fabric coupons under elevated temperatures. Their results showed that in quasi-isotropic lay-up [0/45/0/45/0/45/0], material strength were decrease within 5-12% under temperature condition where material stiffness decrease by less than 10%. In other word, there is relative high degree retention of mechanical properties despite critical tests condition. Benoit & Taleb (2011) agreed that under elevated environment, properties of matrix binders were enhanced but were degrading the fiber/matrix interface. On the other hand, the hole sensitivity was improved slightly although seen 50% strength reduction.

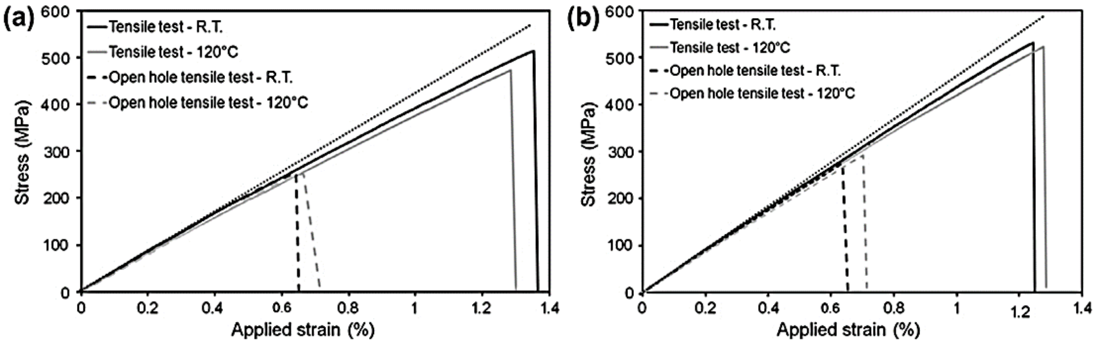

Figure 2.8: Tensile vs open hole tensile test at both temperatures on quasi-isotropic (a) C/PPS and (b) C/Epoxy by Benoit and Lakhdar (2011)

Figure 2.8 shows the comparison between carbon/polyphenylenesulfide and carbon/epoxy under room temperature and under elevated temperature. The ductility behaviour of both matrix systems is enhanced at elevated temperature but the matrix behaviour was limited in quasi-isotropic lay-up. On the other hand, the strength of fiber/matrix bond and the interlaminar shear strength were decrease as temperature increased. The result showed more extended damage near hole as splitting occurred and demonstrated plastic behaviour at high temperature.

2.5.2 Strength Prediction of Notched Coupons

This sub-section discusses the analytical and numerical approach used by previous researcher to predict strength and associated failure behaviour in open hole problem.

2.5.2.1 Strength Prediction by using Analytical Approach

As described in previous experimental observations, local damage occurred ahead of notch tip prior to catastrophic failure at a small region as reported by Manger (1999) and Belmonte *et al.,* (2001, 2004). Earlier version of analytical work was based on semi-empirical (or closed-form) with Whitney-Nuismer models are the most notable model. They proposed two criterions, namely Stress Point Criterion (PSC) and average Point Criterion (APC) to calibrate the notched strength value to their proposed expressions. This approach is based on semi-empirical approaches, therefore good prediction in both criterion is therefore not surprising.

Fracture mechanics were associated with formation of cracks due to stress as a results from applied loading. This method is easier to perform with materials that failed by brittle or experience only small yielding. All previous “characteristic distance” approaches ignore the composite softening due to the accumulation of hole edge damage prior to ultimate failure. Later, attention was focused by treating local hole tip processes as being covered throughout the thickness and localized damage extending from hole edge perpendicular to the applied load was represented by an equivalent crack (damage zone) where failure occurred when the crack reached critical size. The crack opening displacements of these cracks are controlled by state-of-the-art fracture mechanics to simulate the stress distribution within the hole edge damage zone.

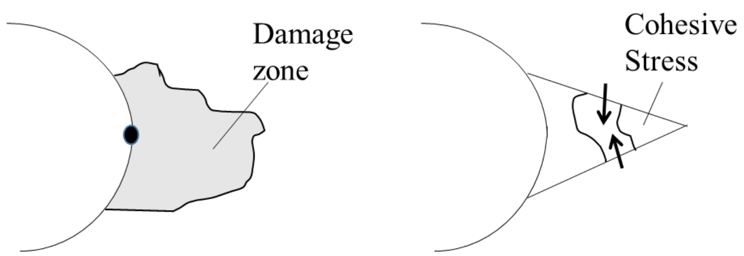

Figure 2.9 : Damage zone and equivalent crack at notch vicinity
(Backlund & Aronsson, 1986)

Backlund & Aronsson (1986) proposed a line crack with cohesive stress (or fictitious stress) acting on the crack surfaces referred to as "Damage Zone Model" (DZM) to predict tensile stress ahead of a notch to include crack propagation simulations as shown in Figure 2.9. The toughness of these composites is controlled by

REFERENCES

Abdul Khalil, H. P. S., Bhat, A. H., Jawaid, M., Amouzgar, P., Ridzuan, R., & Said, M. R. (2010). Cell wall ultrastructure, anatomy, lignin distribution, and chemical composition of Malaysian cultivated kenaf fiber. *Industrial Crops and Products*, *31*, 113–121.

Abot, J. L., Yasmin, a., Jacobsen, a. J., & Daniel, I. M. (2004). In-plane mechanical, thermal and viscoelastic properties of a satin fabric carbon/epoxy composite. *Composites Science and Technology*, *64*, 263–268.

Agarwal, B. L. (1980). Static Strength Prediction of Bolted Joint in Composite Material. *AIAA Journal*, *18*, 1371–1375.

Ahmad, H. (2012). *Finite Element-based Strength Prediction for Notched and Mechanically Fastened woven fabric Composites*. University Of Surrey.

Ahmad, H., Crocombe, a D., & Smith, P. a. (2013). Physically based finite element strength prediction in notched woven laminates under quasi-static loading. *Plastics, Rubber and Composites*, *42*, 93–100.

Ahmad, H., Crocombe, a D., & Smith, P. A. (2014a). Strength prediction in CFRP woven laminate bolted double-lap joints under quasi-static loading using XFEM. *Composites Part A: Applied Science and Manufacturing*, *56*, 192–220.

Ahmad, H., Crocombe, a. D., & Smith, P. A. (2014b). Strength prediction in CFRP woven laminate bolted single-lap joints under quasi-static loading using XFEM. *Composites Part A: Applied Science and Manufacturing*, *66*, 82–93.

Akkerman, R. (2002). On the properties of Quasi-isotropic laminates. *Composites Part B: Engineering*, *33*, 133–140.

Anuar, H., & Zuraida, A. (2011). Improvement in mechanical properties of reinforced thermoplastic elastomer composite with kenaf bast fibre. *Composites Part B:*

Engineering, *42*, 462–465.

Aronsson, C. G., & Backlund, J. (1986). Tensile Fracture of Laminates with Cracks. *Journal of Composite Materials*, *20*, 287–307.

Aziz, S. H., & Ansell, M. P. (2004). The effect of alkalization and fibre alignment on the mechanical and thermal properties of kenaf and hemp bast fibre composites: Part 1 - polyester resin matrix. *Composites Science and Technology*, *64*, 1219–1230.

Backlund, J., & Aronsson, C. G. (1986). Tensile Fracture of Laminate with Holes. *Journal of Composite Materials, 20*, 259 – 285.

Barenblatt, G. I. (1962). The Mathematical Theory of equilibrium cracks in brittle fracture. *Advance Applied Mechanics*, *7*, 55–129.

Belmonte, H. M. S., Manger I., C. I. C., Ogin, S. L., Smith, P. A., & Lewin, R. (2001). Characterisation and modelling of the notched tensile fracture of woven quasi-isotropic GFRP laminates. *Composites Science and Technology*, *61*, -597.

Belmonte, H. M. S., Ogin, S. L., Smith, P. A., & Lewin, R. (2004). A physically-based model for the notched strength of woven quasi-isotropic CFRP laminates. *Composites Part A: Applied Science and Manufacturing*, *35*, 763–778.

Benoit, V., Aucher, J., & Taleb, L. (2009). Influence of temperature on the behavior of carbon fiber fabrics reinforced PPS laminates. *Materials Science and Engineering A*, *517*, 51–60.

Benoit, V., Aucher, J., & Taleb, L. (2011). Woven ply thermoplastic laminates under severe conditions: Notched laminates and bolted joints. *Composites Part B: Engineering*, *42*, 341–349.

Benoit, V., Aucher, J., & Taleb, L. (2012). Comparative study on the behavior of woven-ply reinforced thermoplastic or thermosetting laminates under severe environmental conditions. *Materials and Design*, *35*, 707–719.

Benoit, V., Chabchoub, M., Bouscarrat, D., & Keller, C. (2016). Prediction of the notched strength of woven-ply Polyphenylene Sulfide thermoplastic composites at a constant high temperature by a physically-based model. *Composite Structures*, *153*, 529–537.

Benoit, V., & Taleb, L. (2011). About the influence of temperature and matrix ductility on the behavior of carbon woven-ply PPS or epoxy laminates: Notched and unnotched laminates. *Composites Science and Technology*, *71*, 998–1007.

Buxton, A., & Baillie, C. (1994). A Study of the Influence of the Enviroment on the Measurment of Interfacial Properties of Carbon Fiber/Epoxy Resin composites. *Composites*, *25*, 604–608.

Chang, F. ., & Chang, K. . (1987). A Progressive Damage Model for Laminate Composites Containing Stress Concentration. *Journal of Composite Materials*, *21*, 809–855.

Chang, F. ., Scott, R. ., & Springer, G. . (1982). Strength of mechanically fastened composite joints. *Composite Materials*, *16*, 470–494.

Chang, F. ., Springer, G. ., & Scott, R. A. (1984). Failure of composite laminates containing pin loaded holes-Method of solution. *Journal Composite Materials*, *18*, 255–278.

Collings, T. A. (1977). The strength of bolted joints in multi-directional cfrp laminates. *Composites*, *8*, 43–55.

Daggumati, S., Van Paepegem, W., Degrieck, J., Praet, T., Verhegghe, B., Xu, J., … Verpoest, I. (2011). Local strain in a 5-harness satin weave composite under static tension: Part II - Meso-FE analysis. *Composites Science and Technology*, *71*, 1217–1224.

Dauda, S. M., Ahmad, D., Khalina, A., & Jamarei, O. (2014). Physical and Mechanical Properties of Kenaf Stems at Varying Moisture Contents. *Agriculture and Agricultural Science Procedia*, *2*, 370–374.

Dixit, A., & Harlal, S. . (2013). Modeling Techniques for Predicting. *Mechanics of Composite Materials*, *49*, 1–20.

Economic, P. U. (2010). Tenth Malaysia Plan 2011-2015. Unit Prime Minister's Department Putrajaya.

Egan, B., McCarthy, C. T., McCarthy, M. A., & Frizzell, R. M. (2012). Stress analysis of single-bolt, single-lap, countersunk composite joints with variable bolt-hole clearance. *Composite Structures*, *94*, 1038–1051.

Ekha, J., & Schönb, J. (2005). Effect of secondary bending on strength prediction of composite, single shear lap joints. *Composites Science and Technology*, *65*, 953–965.

Eriksson, I., & Aronsson, C. G. (1990). Strength of tensile loaded graphite/epoxy laminates containing crack, open and filled holes. *Journal of Composite Materials*, *24*, 456–482.

Esendemir, U. (2008). Failure analysis of woven Glass-epoxy prepreg bolted joint under difference clamping moment. *Advance Composites Letters*, *17*, 165–175.

Foulk, J. A., Akin, D. E., & Dodd, R. B. (2000). New Low Cost Flax Fibers for Composites (pp. 2000–01–1133).

George, J., Sreekala, M. S., & Thomas, S. (2001). A review on interface modification and characterization of natural fiber reinforced plastic composites. *Polymer Engineering & Science*, *41*, 1471–1485.

Hadi, M., Basri, A., Abdu, A., Junejo, N., & Hamid, H. A. (2014). Journey of kenaf in Malaysia : A Review. *Academic Journal*, *9*, 458–470.

Hajnalka, H., Racz, I., & Anandjiwala, R. (2008). Development of Hemp Fibre Reinforced Polypropylene Composite. *Journal Thermoplastic Composite Materials*, *21*, 165–174.

Harris, C., & Morris, D. (1986). Fracture of thick laminated composite. *Experimental Mechanics*, 34–41.

Hart-Smith, & LJ. (1978). *Mechanically fastened joints for advanced composites Phenomelogical consideration and simpel analysis. Dogulas Paper 6748*.

Hashin, Z. (1980). Failure Criteria for Unidirectional Fiber Composite. *Journal of Applied Mechanics*, *47*, 329–334.

Hollaway, L. C. (2010). A review of the present and future utilisation of FRP composites in the civil infrastructure with reference to their important in-service properties. *Construction and Building Materials*, *24*, 2419–2445.

Hollman, K. (1996). Failure analysis of bolted composite Joints Exhibiting in plane failure modes.pdf. *Journal of Composite Materials*, *30*, 358–383.

Joshi, S. . V, Drzal, L. . T., Mohanty, a. . K., & Arora, S. (2004). Are natural fiber composites environmentally superior to glass fiber reinforced composites? *Composites Part A: Applied Science and Manufacturing*, *35*, 371–376.

Kaldor, A. (1992). Kenaf and Alternate Fiber for Plup and Paper Industries in Developing and Developed Countries. *Journal Composite Material*, *75*, 141–145.

Karnani, R. (1996). *Kenaf-reinforced polypropylene composites*. Michigan State University.

Kontolatis, A. (2000). *Failure of Composite Bolted Joints Made from Woven fabric GFRP Composite*. Gulidfore: University of Surrey.

Ku, H., Wang, H., Pattarachaiyakoop, N., & Trada, M. (2011). A review on the tensile properties of natural fiber reinforced polymer composites. *Composites Part B*, *42*, 856–873.

Li, Y., Hu, C., & Yu, Y. (2008). Interfacial studies of sisal fiber reinforced high density polyethylene (HDPE) composites. *Composites Part A: Applied Science and Manufacturing*, *39*, 570–578.

Manger, C. (1999). *Failure of Notched Woven GFRP Composites: Damage Analysis and Strength Modelling*. Guildford : University of Surrey.

Marom, G. (1989). *Application of Fracture Mechanics to Composite Materials*. *Composite Materials Series* (Vol. 6). Elsevier Science Publishers B.V. Retrieved from http://www.sciencedirect.com/science/article/pii/B9780444872869500140

McCarthy, C. T., & McCarthy, M. A. (2005). Three-dimensional finite element analysis of single-bolt, single-lap composite bolted joints: Part II - Effects of bolt-hole clearance. *Composite Structures*, *71*, 159–175.

Mccarthy, C. T., Mccarthy, M. A., & Lawlor, V. P. (2005). Progressive damage analysis of multi-bolt composite joints with variable bolt – hole clearances. *Composites Part B*, *36*, 290–305.

Mittal, V., Saini, R., & Sinha, S. (2016). Natural fiber-mediated epoxy composites – A review. *Composites Part B: Engineering*, *99*, 425–435.

Nishino, T., Hirao, K., & Kotera, M. (2006). X-ray diffraction studies on stress transfer of kenaf reinforced poly(l-lactic acid) composite. *Composites Part A: Applied Science and Manufacturing*, *37*, 2269–2273.

Okutan, B., Aslan, Z., & Karakuzu, R. (2001). A study of the effects of various geometric parameters on the failure strength of pin-loaded woven-glass-fiber reinforced epoxy laminate. *Composites Science and Technology*, *61*, 1491–1497.

Olmedo, Á., & Santiuste, C. (2012). On the prediction of bolted single-lap composite joints. *Composite Structures*, *94*, 2110–2117.

Patel, S. R., & Case, S. W. (2002). Durability of hygrothermally aged graphite/epoxy woven composite under combined hygrothermal conditions. *International Journal of Fatigue*, *24*, 1295–1301.

Pinnell, M. (1996). An examination of the effect of composite constitute properties on the notch strength performance of composite materials. *Composites Science and Technology*, *56*, 1405–1413.

Pisano, a. a., & Fuschi, P. (2011). Mechanically fastened joints in composite laminates: Evaluation of load bearing capacity. *Composites Part B: Engineering*, *42*, 949–961.

Saba, N., Paridah, M. T., & Jawaid, M. (2015). Mechanical properties of kenaf fibre reinforced polymer composite : A review. *CONSTRUCTION & BUILDING MATERIALS*, *76*, 87–96.

Saiman, M. P., Wahab, M. S., & Wahit, M. U. (2014). The Effect of Fabric Weave on Tensile Strength of Woven Kenaf Reinforced Unsaturated Polyester Composite. *International Colloqium on Textile Engineering, Fashion, Apparel & Design 2014*, 52–56.

Salman, S. D., Sharba, M. J., Leman, Z., Sultan, M. T. H., Ishak, M. R., & Cardona, F. (2015). Physical, Mechanical, and Morphological Properties of Woven Kenaf/Polymer Composites Produced Using a Vacuum Infusion Technique. *International Journal of Polymer Science*, *2015*, 1–11.

Santiuste, C., Barbero, E., & Henar Miguelez, M. (2011). Computational analysis of temperature effect in composite bolted joints for aeronautical applications. *Journal of Reinforced Plastics and Composites*, *30*, 3–11.

Schwartz, M. (1996). The Influence of Enviroment Effect. *Composite Material Propertise: Properties, Nodestructive, Testing and Repair*, *1*, 117–119.

Sellers, T. (1999). *Kenaf properties, processing and products. MP*. Mississippi State

University.

Smith, P. A. (2000). Carbon FiberReinforced Plastics - Properties. *Comprehensive Composite Materials*, 107–150.

Tan, S. . (1991). A Progressive Failure Model for Composite Laminates COntaning Openings. *Journal of Composite Materials*, *25*, 557–577.

Thoppul, S. D., Finegan, J., & Gibson, R. F. (2009). Mechanics of mechanically fastened joints in polymer-matrix composite structures - A review. *Composites Science and Technology*, *69*, 301–329.

Tsai, S., & Wu, E. . (1971). A General theory of strength for Anisotropic Material. *Journal of Composite Materials*, *5*, 58–80.

Tsujimoto, Y., & Wilson, D. (1986). Elasto-Plastic Failure Analysis of Composite Bolted Joints. *Journal of Composite Materials*, *20*, 236–252.

Wambua, P., Ivens, J., & Verpoest, I. (2003). Natural fibres: can they replace glass in fibre reinforced plastics? *Composites Science and Technology*, *63*, 1259–1264.

Whitney, J. M., & Nuismer, R. J. (1974). Stress Fracture Criteria for Laminated Composites Containing Stress Concentrations. *Composite Material*, *8*, 253–265.

Xiao, Y., & Ishikawa, T. (2005). Bearing strength and failure behavior of bolted composite joints (part II: modeling and simulation). *Composites Science and Technology*, *65*, 1032–1043.

Yamada, S. ., & Sun, C. . (1978). Analysis of Laminate Strength and Its Distribution. *Journal of Composite Materials*, *12*, 275–284.

Zaffaroni, G., & Cappelletti, C. (1998). Comparision of Two Acceleration Hot-Wet Aging Condition of a Glass-Reinforce Epoxy Resin. *Composite Material: Fatigue and Fracture*, *7*, 233–244.

Zahari, R., Azmee, A. H., Mustapha, F., & Salit, M. S. (2008). Prediction of Progressive Failure in Woven Glass/Epoxy Composite Laminated Panels. *Jurnal Mekanikal*, 80–91.