Faculty of Mechanical Engineering

A STUDY ON MECHANICAL PROPERTIES OF HYBRID KENAF/KEVLAR FIBRE REINFORCED THERMOPLASTIC COMPOSITES

Ng Cher Sean

Bachelor of Mechanical Engineering (with Honours)

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A STUDY ON MECHANICAL PROPERTIES OF HYBRID KENAF/KEVLAR FIBRE REINFORCED THERMOPLASTIC COMPOSITES

NG CHER SEAN

A thesis submitted

in fulfillment of the requirements for the

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DECLARATION

I declare that this project report entitled "A study on mechanical properties of hybrid kenaf/Kevlar fibre reinforced thermoplastic composites" is the result of my own work except cited in the references.

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Signature : ....

Name : NG CHER SEAN

Date : ....

SUPERVISOR'S APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the Bachelor of Mechanical Engineering (with Honours).

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Signature : ……………………………………………………………………

Name : ASSOC. PROF. DR. SIVAKUMAR A/L DHAR MALINGAM

Date : ………………………………………………………………

ABSTRACT

Nowadays, many applications focus on the cost and the performance of the materials. A material which can be recycled and reused is preferable compared to other. A hybrid composite which consists of two or more different fibres in a single matrix has become an interesting topic in the field of fibre reinforced composite. In this project, the woven kenaf fibre and Kevlar fibre along with thermoplastic matrix polypropylene were used to fabricate hybrid composites. Different stacking sequence of composite laminates structures were introduced, which include kenaf/kenaf/kenaf [K/K/K], kenaf/Kevlar/kenaf [K/KV/K], Kevlar/kenaf/Kevlar [KV/K/KV] and Kevlar/Kevlar/Kevlar [KV/KV/KV]. Tensile, quasi-static indentation and low-velocity impact tests were carried out to investigate the effect of fibre configurations on the mechanical and indentation properties of hybrid kenaf/Kevlar fibre reinforced polypropylene composites. The ultimate tensile strength of [KV/K/KV] was found to be higher than [K/KV/K] by 71% whereas Young's Modulus of [KV/K/KV] was also higher than [K/KV/K] by 41%. Quasi-static indentation test was conducted and the result showed that [KV/KV/KV] can withstand the highest load followed by [KV/K/KV], [K/KV/K] and lastly [K/K/K]. Moreover, the low-velocity impact test was carried out using Instron drop tower impact system. The specimens were tested at different impact energy levels. The result showed the non-hybrid kenaf composites were weak against impact while hybridizing the kenaf fibre with Kevlar fibre, the result was significantly different.

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ABSTRAK

Pada masa kini, banyak aplikasi memberi tumpuan kepada kos dan prestasi bahan. Bahan yang boleh dikitar semula dan digunakan semula adalah lebih baik berbanding dengan yang lain. Komposit hibrid yang terdiri daripada dua atau lebih jenis serat yang berbeza dalam matriks tunggal telah menjadi topik yang menarik dalam bidang komposits serat. Dalam projek ini, gentian kenaf tenunan dan serat Kevlar bersama dengan termoplastik matriks polipropilena digunakan untuk mengarang komposit hibrid. Susunan filem struktur laminat komposit yang berbeza telah diperkenalkan, iaitu kenaf / kenaf / kenaf [K / K / K], kenaf / Kevlar / kenaf [K / KV / K], Kevlar / kenaf / Kevlar [KV / K / KV] dan Kevlar / Kevlar / Kevlar [KV / KV / KV]. Ujian lekapan tegangan quasi statik dan kesan impak rendah dijalankan untuk menyiasat kesan konfigurasi serat pada sifat mekanikal dan lekukan komposit polipropilena bertetulang kenaf / Kevlar hibrid. Kekuatan tegangan muktamad [KV / K / KV] didapati lebih tinggi daripada [K / KV / K] sebanyak 71% manakala Young's Modulus [KV / K / KV] juga lebih tinggi daripada [K / KV / K] oleh 41%. Ujian lekukan quasi statik dijalankan dan hasilnya menunjukkan bahawa [KV / KV / KV] dapat menahan beban tertinggi diikuti oleh [KV / K / KV], [K / KV / K] dan terakhir [K / K / K]. Selain itu, ujian impak rendah dilakukan menggunakan sistem impak menara drop Instron. Spesimen telah diuji pada tahap tenaga yang berbeza. Hasilnya menunjukkan komposit kenaf bukan hibrid adalah lemah terhadap impak sementara hibridkan serat kenaf dengan serat Kevlar, hasilnya jauh berbeza.

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LIST OF ABBREVIATIONS

FRP	Fibre-Reinforced Polymer
ASTM	American Society for Testing and Materials
QSI	Quasi-Static Indentation
LVI	Low-Velocity Impact
PEEK	Polyetheretherketone
PP	Polypropylene
PPS	Polyphenylene Sulphide
AHP	Analytical Hierarchy Process
HDPE	High-Density Polyethene
K	Kenaf
KV	Kevlar
UTM	Universal Testing Machine
SEM	Scanning Electron Microscopy

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LIST OF SYMBOL

ρ_c	- Density of composite
ρ_m	- Density of matrix material
V_m	- Volume fraction of matrix material
ρ_f	- Density of fibre material
V_f	- Volume fraction of fibres.
E_L	- Longitudinal modulus of the composite
E_f	- Modulus of the fibres
E_m	- Modulus of the matrix
E_T	- Transverse modulus of the composite
v	- Poisson's ratio of composite
v_f	- Poisson's ratio of fibre material
v_m	- Poisson's ratio of matrix material
σ_c	- Ultimate strength of composite
σ_f	- Ultimate strength of the fibre
σ_m	- Ultimate strength of material
w	- Weight
w_{kenaf}	- Weight of kenaf fibre
w_{Kevlar}	- Weight of Kevlar fibre
w_{pp}	- Weight of polypropylene
ρ_{kenaf}	- Density of kenaf fibre
ρ_{Kevlar}	- Density of Kevlar fibre

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ρ_{pp} - Density of polypropylene

V_v - Void volume fraction

ρ_{ct} - Theoretical density of composite

ρ_{cm} - Measured density of composite

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CHAPTER 1

INTRODUCTION

1.1 Background

A composite is a material made from two or more constituents with different physical or chemical properties. After combined the materials, it will produce a material with different properties from the individual components. The characteristics of composites are lightweight, high strength, high stiffness and easily mouldable to complex shapes (Mallick, 2008). Hybrid composite is known as a composite with two or more fibres with different properties embedded in a single matrix (Cheung et al. 2009).

Fibre-Reinforced Polymer (FRP) is a composite material that consists of natural or synthetic fibres embedded in polymer matrices. Nowadays, engineering fields such as automotive and aerospace use FRP in the applications of drive shaft, windmill blades and support beams. The characteristics of FRP which are high stiffness and strength, lightweight, high durability and easy to be shaped made it widely used in the engineering fields. (Senguttuvan & Lillymercy, 2015).

In general, there are two types of fibres, which are natural fibres and synthetic fibres. The characteristics of natural fibres are low manufacturing cost, lightweight and low density compared to synthetic fibres. However, synthetic fibres provide higher strength and stiffness compared to natural fibres (Puglia et al. 2008).

Thermoplastic composite materials are becoming more popular in many applications. The reason of thermoplastics become an alternative choice in fabrication compared to thermosets are the capabilities and manufacturing benefits (Farag, 2008). Furthermore, there are many pros and cons between thermoplastics and thermosets. The advantages of thermoplastics are recyclable, easy to repair by welding and high toughness while the disadvantages are poor melt flow and require a specific temperature to melt during fabrication. In contrast, the advantages of thermoset are low resin viscosity, good thermal stability and chemically resistant whereas the disadvantages are non-recyclable and non-post formable (Kabir et al., 2012).

In this study, mechanical properties and indentation properties of hybrid kenaf/Kevlar fibre reinforced composites are investigated to explore the potential of using hybrid composites in engineering applications.

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1.2 Problem statement

Nowadays, many applications focus and concern on the cost and the performance of the materials. A material which can be recycled and reused is preferable compared to other since the concept of 3R – Reduce, Reuse and Recycle is getting more and more important in daily life. Hybridizing fibres in thermoplastic composites can provide better mechanical properties and natural executions. To further understand the thermoplastic-based hybrid composites, it is important to study their mechanical and indentation properties.

1.3 Objectives

The objectives of this project are as follows:

1. To investigate the effect of fibre configurations on the mechanical and indentation properties of hybrid kenaf/Kevlar fibre reinforced polypropylene composites.
2. To analyse the morphological damage of hybrid kenaf/Kevlar fibre reinforced polypropylene composites.

1.4 Scope of project

The scope of the project is focused on only 3 layers fibre configurations of hybrid kenaf/Kevlar fibre reinforced polypropylene composites. The layup configurations of composites must be symmetrical due to the different coefficient thermal expansion of fibres. Throughout this project, thermoplastic polypropylene is used as the matrix because it is recyclable and can be shaped easily compared to thermoset. Besides that, kenaf fibre is chosen due to easily available in market while Kevlar fibre is chosen because of its amazing impact resistivity.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Literature review provides information, findings and studies of previous researchers on a particular topic. Detail and information related to this project such as properties of composite, type of fibre and mechanical properties of the hybrid composites used will be discussed. Previous researcher's works are required to enhance the understanding of this topic.

2.2 Composite

The composite is defined in micromechanics as a heterogeneous body, consisting of reinforcing elements such as fibres, particles, or crystals embedded in a matrix material. Besides that, the term 'composite' includes a variant of materials such as concrete, semi-crystalline polymers, paper, leather, bone and so on. Another significant aspect of composites is they are normally fabricated by a lamination process in which the layers are oriented in a predetermined way. Moreover, there are two main types of fibre-reinforced composites called continuous fibre and short (chopped) fibre composites. Aligning all the fibres or weaving a cloth and injection the resulting structure with a matrix material can create a continuous fibre- reinforced composites (Sendeckyj, 2016).

Composite materials are very useful in industrial aerospace, marine and recreational structures application. Basically, there are some advantages and disadvantages of composite materials. The advantages are weight reduction around 20% -50%, high impact resistance, high damage tolerance to increase accident survivability and the mechanical properties can be tailored by 'lay-up' pattern. In contrast, the disadvantages of the composite materials are higher material cost, non-visible impact damage within the composites, maintenance is different from those of metal structures. The composite materials are better than metals in term of strength-to-weight ratio, sometimes up to 20% performance (Maria, 2013).

The term 'Fibre-Reinforced Polymer' (FRP) refers to a composite which comprises fibres and a polymer matrix material. For the sake of convenience, one of the terms will be referred to as the matrix, while the others as the reinforcement. Figure 2.1 shows the composition of composite. The matrix is the continuous phase of the composite. Its function is to provide the shape to the structure. The matrix component encounters whatever forces might be imposed. The main function of the reinforcement is to provide strength, stiffness and other mechanical properties to the composites (Strong, 2008).

FRP possess low density, high stiffness and high strength characteristics. These properties make FRP become one of the best methods to enhance the structural efficiency in design of aerospace vehicles and other industrial applications (Soykok, 2013).

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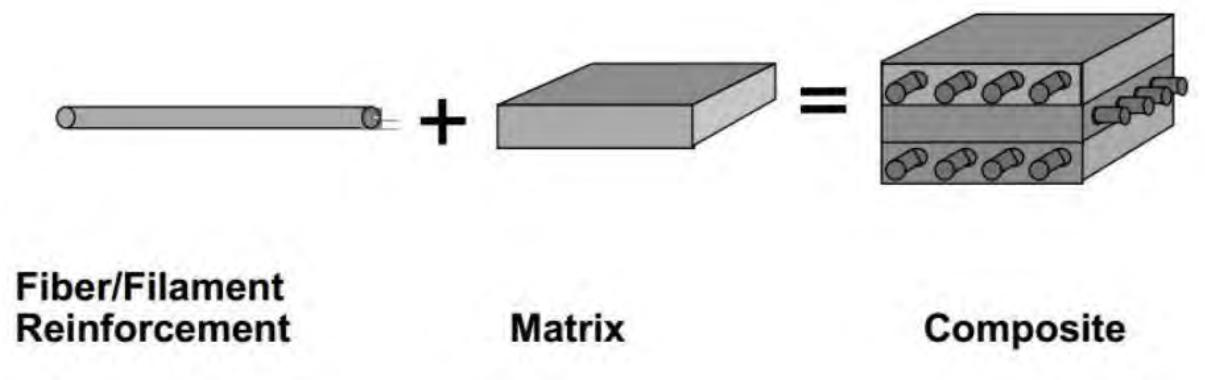

Figure 2.1: Composition of composite (Maria, 2013)

2.2.1 Matrix

Matrix material is a polymer that composed of molecules made of many simpler and tiny units called monomer. For the fibres to carry maximum load, the matrix needs to have a lower modulus and better elongation than those of fibres. Basically, the matrix material plays an important role in FRP composite. The significant functions of matrix materials are binding the fibres together and fixing them in the desired geometrical arrangement, transferring the load to fibres by adhesion or friction, providing rigidity and shape to the structural member as well as acting as a protection to the fibres against chemical, mechanical damages and impact (Potyrala, 2011).

Important characteristics that need to be considered in selecting a matrix are stiffness, strength, fracture toughness, thermal and electrical conductivity. From the manufacturing perspective, one important factor that needs to be considered in the selection of a matrix for an FRP application is the expansion of the fibre and matrix during the processing (Hensher, 2016).

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Resins are the primary component of a matrix. The resins can be categorized into two types, thermoplastic and thermosetting polymers. Thermoplastic polymers are ductile in nature compared to thermoset polymers. The molecules do not cross-link, thus thermoplastics are flexible and can be easily reformed and reshaped by heating. Several examples of thermoplastics are nylon, polyetheretherketone (PEEK), polypropylene (PP), and polyphenylene sulphide (PPS). On the other hand, thermoset polymers usually exhibit high brittleness, high rigidity and high chemical resistance. The drawbacks of thermoset polymers are they cannot be recycled and reformed. Polyester resin material is one of the thermosetting examples which is having excellent bonding characteristics. The special of polyester for FRP are low viscosity, fast cure time and dimension stability. Furthermore, another example of thermoset is epoxy resin. Epoxy resin is known for their excellent strength and creeps resistance, good adhesion to fibres, chemical and solvent resistance, good electrical properties, high glass transition temperature, low shrinkage and volatile emission during cure.

As discussed above, the thermoplastic resins offer several benefits over thermoset resins when used as matrix materials for FRP. These advantages are cost and performance-related. Cost savings can be achieved in term of infinite shelf-life of thermoplastic at room temperature. The significant performance of thermoplastic over thermoset are improved toughness and increase of temperature stability. For instance, the fracture toughness of thermoplastic resins and their composites may be 10 times than thermoset resins. Some processing temperatures for thermoplastics can be as high as 300˚C. Some properties of several FRP matrix material are shown in Table 2.1 (Benin et al. 2015).

Table 2.1: Properties of several FRP matrix material (Benin et al. 2015).

	Polyester	BMI	Polyimide	Epoxy	PEEK
Tensile Strength (MPa)	20-100	40-100	40-190	55-130	103
Tensile Modulus (GPa)	2.1-4.1	2.7-4.2	3-5	2.5-4.1	1.1
Ultimate Strain (%)	1-6	1.2-6.6	1-60	1-8	30-150
Density (g/cm^3)	1-1.45	1.2	1.3-1.4	1.1-1.3	1.3
T_g (˚C)	100-140	220-320	210-340	50-260	144
CTE (μm/m/˚C)	55-100	21-73	14-50	45-90	55

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2.3 Fibre

The term 'fibre' means a material made into a long filament with diameter up to 15µm. In the dictionary, the definition of fibre is a thread or filament from which a vegetable tissue, mineral substance, or textile is formed. In general, greater diameters increase the probability of surface defects. For continuous fibres, the aspect ratio of length and diameter can range from thousand to infinity. Besides that, the main purposes of fibres are to carry the load and provide stiffness, strength and other structural properties to the FRP. The fibres in FRP need to have the characteristics of high ultimate strength, high modulus of elasticity, low variation of strength among fibres, high stability of their strength during handling and high uniformity of diameter and surface dimension among fibres. Generally, the fibre can be classified into two groups that are natural fibres and synthetic fibres (Tuakta, 2005). Table

2.2 shows the characteristic values for the density, diameter and tensile strength of natural and synthetic fibres.

Table 2.2: Characteristic values for the density, diameter and tensile strength of natural and synthetic fibres (Akil 2011).

Fibres	Density (g/cm^3)	Diameter (μm)	Tensile strength (MPa)
Flax	1.5	40-600	345-1500
Hemp	1.47	25-500	690
Jute	1.3-1.49	25-200	393-800
Kenaf	-	-	930
Ramie	1.55	-	400-938
Nettle	-	-	650
Sisal	1.45	50-200	468-700
PALF	-	20-80	417-1627
Abaca	-	-	430-760
Oil palm EFB	0.7-1.55	150-500	248
Oil palm mesocarp	-	-	80
Cotton	1.5-1.6	12-38	287-800
Coir	1.15-1.46	100-460	131-220
E-glass	2.55	<17	3400
Kevlar	1.44	-	3000
Carbon	1.78	5-7	3400-4800

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2.3.1 Natural fibre

The demand for synthetic fibres has been increasing magnificently since 1960s, causing natural fibres to lose its market share. This phenomenon lasts for a few decades until December 2006 when United Nations General Assembly declared, the International Year of Natural Fibres in 2009. This is to enhance the awareness of consumer about natural fibres and increase the need of natural fibre products (Jawaid et al. 2011).

Natural fibres have been attracting the interest of engineers, researchers, professionals and scientists all over the world as an alternative reinforcement for fibre reinforced polymer composites due to their outstanding properties such as high specific strength, low weight, low cost, fairly good mechanical properties, non-abrasive, eco-friendly and bio-degradable characteristics (Sanjay, 2015). Natural fibres are not only strong and lightweight but also relatively very cheap (Harish, 2009). The examples of natural fibres are flax, hemp, jute, sisal, kenaf, coir, kapok, banana and so on. Besides that, natural fibres play an important role in developing biodegradable composites to overcome the current ecological and environmental issues. Although the natural fibres are lighter and cheaper, their mechanical properties are lower than glass fibres. However, the problem associated with the low mechanical properties of natural fibre based composites can be resolved through the hybridization. Apart from that, the partial incorporation of natural fibres to the glass fibre reinforced composites can make the hybrid composites to become comparatively cheaper and easy to use (Ramesh, 2013).

As previously stated, natural fibre reinforced composites are being widely used instead of synthetic fibres due to their advantages like biodegradability, low weight, low cost and better specific mechanical properties. Table 2.3 shows the comparison of the strength and weakness of natural fibres. Many authors have previously investigated composites with

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natural reinforcement and polymer matrices (Yousif, 2012). The mechanical efficiency of the FRP depends on the fibre-matrix interface and the ability to transfer stress/load from the matrix to fibres. Combining the synthetic fibres with natural fibres in the same matrix can get the best properties. The impact behaviour of the composites will be affected by the infinite material arrangement including fibres and resin types, quantities, architecture, interfaces and the production methods used (Caprino, 2001).

Table 2.3: The strength and weakness of natural fibre (Jawaid & Abdul Khalil 2011).

Strength	Weakness
High specific strength and stiffness due to low specific weight	Low strength notably impact strength
High sustainability resource with low CO_2 emission	Fluctuating quality due to weather
Low production cost	High moisture absorption property cause swelling of fibre
Friendly processing which does not cause water tool and skin irritation	Limited maximum processing temperature
Good electrical resistance	Low durability
Good thermal resistance	Poor fire resistance
Biodegradable	Poor fibre-matrix adhesion
Recyclable	Inconsistent price

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2.3.2 Kenaf

Kenaf (Hibiscus cannabinus) is a herbaceous annual plant that can survive in a wide range of environment as shown in Figure 2.2. It can grow to higher than 3 meters within 3 months even under moderate ambient condition. Kenaf is considered to be one of the highest producers of biomass among plants in terms of tons/land/time. One hectare of kenaf can produce 15-20 tons of dry matter within a short period of only 4 months. That means one hectare can yield 6500-9000 litres of ethanol by the Coskata process. Kenaf can be used as raw material for many applications such as papermaking and food industry (Kenaf Bio-Energy, 2015). There are some advantages of kenaf:

- Kenaf pulping required less use of chemical.
- Kenaf pulping consumes less energy than wood pulping due to lignin content is lower.
- Kenaf plant can remove toxic elements such as heavy metals from the soil.
- Industrial products made with kenaf fibres can be recycled.

Kenaf has a special combination of long bast and short core fibres which makes it suitable for a range of paper and cardboard products. Furthermore, kenaf also can be used in newsprint manufacturing. Newspapers made from kenaf pulp have been shown to be brighter and better looking with better ink laydown, reduced runoff, richer colour photo reproduction and good print contrast. In addition, the kenaf newsprint manufacturing requires less energy and chemicals for processing (LeMahieu, 2015).

Research works on kenaf are being carried out worldwide in USA, Australia, South America, Thailand, India and Japan. Nowadays, more resources are asked for putting into work focusing on market development instead of the standard production research (Monti & Alexopoulou, 2013). The kenaf fibres can be a source for many uses such as fabrics, building materials, furniture and others.

According to Yahaya (2014), kenaf fibre was the most suitable natural fibre for hybridization with Kevlar using the analytical hierarchy process (AHP). Moreover, kenaf flexibility was one of the critical technical properties, which allowed it to resist impact forces. Hybridization of kenaf and synthetic fibres had many advantages as it reduced dependency on petroleum, which was the source of synthetic fibres (Salman, 2015).

Figure 2.2: Kenaf plant (Mabelle, 2014)

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2.3.3 Synthetic fibre

Synthetic fibres can broadly be defined as man-made fibres from chemicals. Synthetic fibres typically based on polymers, are stronger than natural and regenerated fibres and can be manipulated to have a variety of performance characteristics. Table 2.4 shows the advantages and disadvantages of synthetic fibres.

Table 2.4: Advantages and disadvantages of synthetic fibre (IEEE, 2015).

Advantages	Disadvantages
Greater strength	Produced using fossil fuels (petroleum)
Greater durability	Use chemical which could harm humans and the environment
Less expensive production	Melt when hot
Cannot absorb water (this is an advantage or disadvantage depending on the application)	Non-biodegradable

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To make a synthetic fibre, a liquid chemical composition is forced through spinnerets, hardened and produced into a continuous strand of any length. Most synthetic fibres go through a similar production process which includes four steps.

Step 1 – A chemical process usually involving polymerization and combination of the components of the fibre. Initially, the components are solids and must be converted to a liquid state to be extruded into fibres. The materials are chemically converted, melted and turned into a thick liquid.

Step 2 – A spinning process to produce the fibres by passing the thick liquid through a spinneret. A spinneret is a device that consists of hundreds of holes with a specified diameter. The liquid is forced to flow through the spinneret holes and eventually becomes a string liquid filament. The hole in the spinneret determines the diameter of the filament, which is set in accordance with the application. Next, the extrusion is dried to a continuous filament fibre.

Step 3 - A twisting process twists the filament fibre into a yarn. The filament falls vertically from the spinneret and is caught in a large vacuum nozzle. The vacuum force keeps tension on the line as it is wound around a bobbin.

Step 4 – The twisted yarn is packaged and sent to a textile mill.

Nowadays, synthetic fibres are used in a variety of industries and applications including aerospace, clothing, construction, automotive, electrical, filtration, medical, safety and welding due to their strong resistivity and durability properties (IEEE, 2015).

2.3.4 Kevlar fibre

Kevlar fibre is also known as poly (para-phenylene terephthalamide) is a registered trademark for a para-aramid synthetic fibre. The Kevlar fibre was produced by DuPont, a chemical company. Generally, Kevlar is a high strength, lightweight, impact resistant, abrasion resistant and heat resistant material (Fibre Glast, 2017). It is a plastic that is powerful enough to stop bullets and knives, it is described as being "five times stronger than steel on an equal weight basis"

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Kevlar fibres possess high strength to weight ratio characteristic, they can withstand a temperature from -196˚C up to 450˚C and almost resistant to all types of chemicals. These all properties have made Kevlar fibres being widely employed in various applications nowadays. In spite of Kevlar fibres exhibit various advantages, they also have their numerous shortcomings. For instance, they have poor compressive strength and the wrinkles on Kevlar fibres are difficult to be removed. Moreover, it is difficult to cut and drill during trimming process unless with the use of specialized scissors like Gingher Modified Kevlar Scissors (2733-A) (Woodford, 2017). Table 2.5 and 2.6 show the tensile and thermal properties of Dupont Kevlar 29 and Kevlar 49 yarns.

To date, Kevlar fibres have been commonly used in a wide variety of structural applications. However, the most significant use of Kevlar fibres is in the military applications. For instance, bullet-proof vests and army helmets both made of Kevlar fibres due to their excellent anti-ballistic property (bullet and knife resistant). Besides that, Kevlar fibres are also being applied in sports equipment such as bicycles, snowboards, rackets and hiking boots. In addition, Kevlar fibres have been used as a material of the Mars Pathfinder spacecraft and drug-traffickers for the hulls of submarines (Dominic, 2011).

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Table 2.5: Tensile properties of DuPont Kevlar29 and Kevlar49 (DuPont, 2017).

Property	Unit	Kevlar 29	Kevlar 49
Yarn			
Type	Denier (dtex)	1500(1670)	1140(1270)
	# of filaments	1000	768
Density	$Ib/in.^3\ (g/cm^3)$	0.052 (1.44)	0.052 (1.44)
Moisture Levels			
As Shipped	%	7.0	3.5
Equilibrium from Bone-Dry Yarn	%	4.5	3.5
Tensile Properties			
Straight Test on Conditioned Yarns			
Breaking Strength	Ib (N)	76.0 (338)	59.3 (264)
Breaking Tenacity	g/d (cN/tex)	23.0 (203)	23.6 (208)
	Psi (MPa)	424000 (2920)	435000 (3000)
Tensile Modulus	g/d (cN/tex)	555 (4900)	885 (7810)
	Psi (MPa)	10.2×10^6 (70500)	6.3×10^6 (112400)
Elongation at Break	%	3.6	2.4
Resin Impregnated Strands			
Tensile Strength	Psi (MPa)	525000 (3600)	525000 (3600)
Tensile Modulus	Psi (MPa)	12.0×10^6 (83000)	18.0×10^6 (124000)

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Table 2.6: Thermal properties of DuPont Kevlar29 and Kevlar49 (DuPont, 2017).

Property	Unit	Kevlar 29	Kevlar 49
Thermal Properties Shrinkage			
In water at 212˚F (100˚C)	%	<0.1	<0.1
In dry air at 351˚F (177˚C)	%	<0.1	<0.1
Shrinkage Tension			
In dry air at 351˚F (177˚C)	G/D (cN/tex)	<0.1 (0.88)	<0.2 (1.77)
Specific Heat			
At 77˚F (25˚C)	cal/g x ˚C (J/kg x K)	0.34 (1420)	0.34 (1420)
At 212˚F (100˚C)	cal/g x ˚C (J/kg x K)	0.48 (2010)	0.48 (2010)
At 356˚F (180˚C)	cal/g x ˚C (J/kg x K)	0.60 (2515)	0.60 (2515)
Thermal Conductivity	BTU x in./(h x ft^2x ˚F) (W/ m x K)	0.3 (0.04)	0.3 (0.04)
Decomposition Temperature in air	˚F (˚C)	800-900 (427-482)	800-900 (427-482)
Maximum temperature range for long-term use in air	˚F (˚C)	300-350 (149-177)	300-350 (149-177)
Hear of Combustion	BTU/Ib (Joule/kg)	15000 (35 x 10^6)	15000 (35 x 10^6)
Poisson’s Ratio			0.36

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2.4 Woven fabric and orientation.

Woven fabrics are any textile formed by weaving method. They are made by using two or more types of yarn interweaved perpendicular to each other (Woven fabrics, 2017). On a loom, the weft is set of yarns or other materials inserted over and under the warp during the weaving process. To make thread or yarn into fabric, the warp and weft elements are used. The warp yarns are kept in stationary in tension on a frame whereas the longitudinal weft is inserted over and under the warp as shown in Figure 2.3 (Weft, 2017).

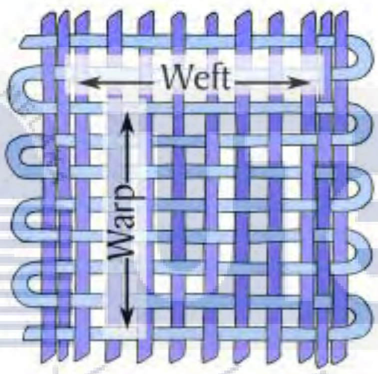

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Figure 2.3: Warp and weft pattern (Shari, 2015).

Fabrics have been developed form textile for many types of handling. They can be designed to have variable space between the fibres. The simplest weaving method is plain weave which is made from interlacing strands in alternating over-under way. There are also many different weaving arrangements such as twill, harness satin, basket, crowfoot and leno weave for various applications as shown in Figure 2.4 (Peters, 2014).

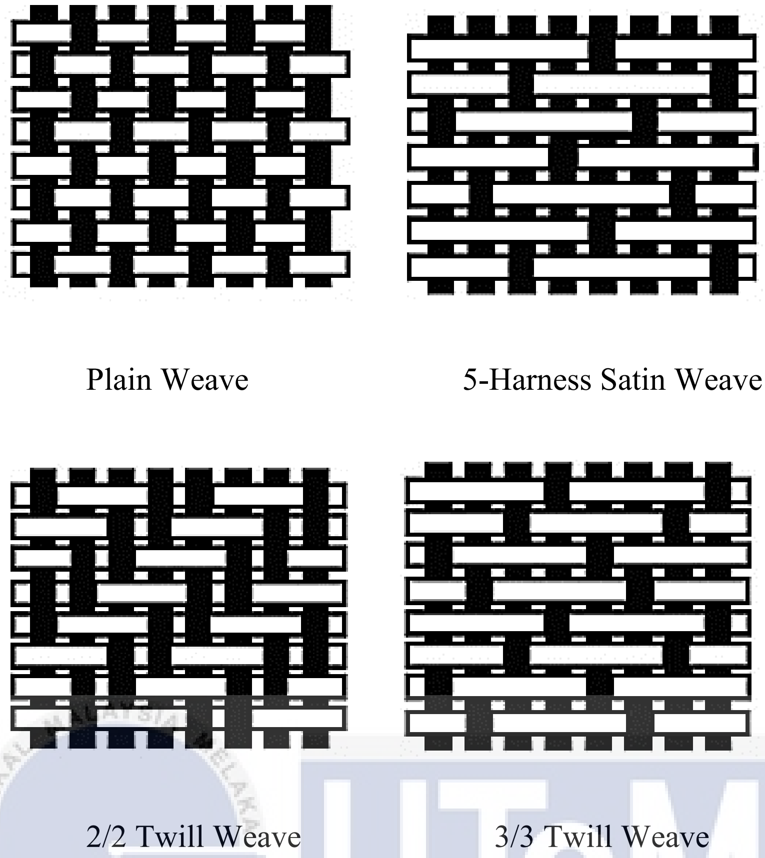

Figure 2.4: Different types of weave (Kyle, 2015).

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2.5 Mechanical properties

In general, the characteristics of FRP composites rely on the properties of matrix and reinforcing material, the orientation of fibres in matrix and their volume ratio. When a matrix is reinforced with two or more reinforcing material, the results and properties are definitely different compared with that of reinforced with only one reinforcing material. For instance, a material which composed of glass and carbon fibres has a high tensile strength, high resistance to impact and can be produced at low cost. The impact resistance of non-hybrid composites is lower if the composites were reinforced only with carbon fibres. In this study, the mechanical properties of kenaf/Kevlar fibre reinforced composites are investigated in order to allow more understanding of the characteristics of this hybrid composites.

2.5.1 Density

One of the outstanding properties of FRP composites is their low density. This property brings the advantages such as reduce the difficulty in handling, assembling and transporting of material and decrease loads applied to the assembled structure. As a result, cost reduction can be achieved.

Basically, the density of composite lies between the ranges from 0.9 to $2.3 g/cm^3$ while metal alloys have higher density, for instance 7 to $8 g/cm^3$ for steel. This low density property in composite results in high specific strength and stiffness. To determine the density of FRP that composed of different material, a simple equation can be applied based on the volume fraction of each component as shown in Eq. (2.1).

$$\rho_c = \rho_m . V_m + \rho_f . V_f \tag{2.1}$$

where ρ_c is the density of composite, ρ_m is the density of matrix material, V_m is the volume fraction of matrix material, ρ_f is the density of fibre material and V_f is the volume fraction of fibres.

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2.5.2 Young's modulus

Reinforcing fibres have a significant impact on Young's modulus of FRP composites. Type of fibres reinforcing the composite material and their orientation will affect the modulus value. Table 2.7 shows examples of three types of unidirectional fibre reinforced composite materials along with their longitudinal modulus, transverse modulus, shear modulus and Poisson's ratio. The result showed that FRP using carbon fibres and epoxy resin provides the highest stiffness in longitudinal direction while FRP using glass fibres and polyester resin possess highest stiffness in the transverse direction.

Table 2.7: Typical value of the modulus for unidirectional reinforced composite (Potyrala, 2011)

Composite (fibres/matrix)	$E_{longitudinal}$	$E_{transverse}$	G	v
	GPa	GPa	GPa	-
Carbon/epoxy	181.00	10.30	7.17	0.30
Glass/polyester	54.10	14.05	5.44	0.25
Aramid/epoxy	75.86	5.45	2.28	0.34

For a unidirectional reinforced composite, the longitudinal and transverse modulus can be calculated using the simplified formulae in Eq. (2.2) and Eq. (2.3) respectively.

$$E_L = E_f . V_f + E_m . V_m \tag{2.2}$$

$$E_T = \frac{E_f . E_m}{E_f . V_f + E_m . V_m} \tag{2.3}$$

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Where E_L is the longitudinal modulus of the composite (in the direction of fibres), E_f is the modulus of the fibres, V_f is the volume fraction of fibres, E_m is the modulus of the matrix, V_m is the volume fraction of matrix and E_T is the transverse modulus of the composite (perpendicular to the direction of fibres)

The value of Young's modulus highly depends on the orientation of fibre in the composition. Figure 2.5 shows the relationship of longitudinal and transverse modulus with respect to the angle of inclination of fibre. The graph showed that the longitudinal modulus is highest when the inclination angle of fibre is 0˚ whereas the transverse modulus reaches maximum when the inclination angle of fibre is 90˚.

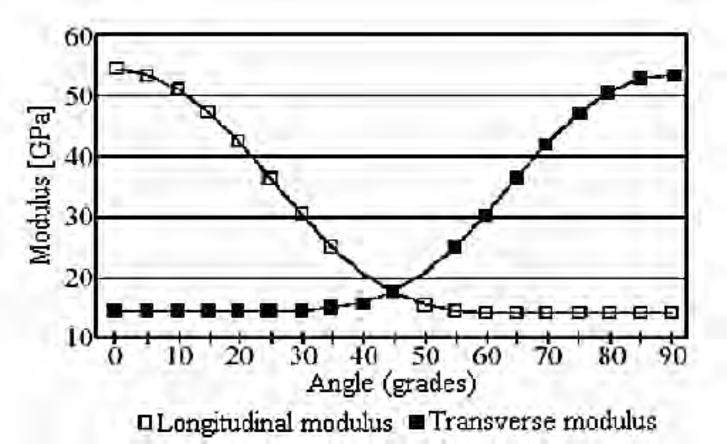

Figure 2.5: Longitudinal and transverse modulus as a function of angle of inclination of fibre (Potyrala, 2011)

2.5.3 Poisson's ratio

Poisson's ratio is a measure of the expansion of a material in two directions when it is subjected to a compression load in the third direction. The Poisson's ratio of FRP is directly affected by both weights of the components and orientation of fibres. The Poisson's ratio of composites can be estimated by applying the analogical formula:

$$v = v_f . V_f + v_m . V_m \tag{2.4}$$

Where v is the Poisson's ratio of composite, v_f is the Poisson's ratio of fibre material, V_f is the volume fraction of fibres, v_m is the Poisson's ratio of matrix material and the V_m is the volume fraction of matrix. Figure 2.6 shows how Poisson's ratio varies with the angle of inclination of the fibres.

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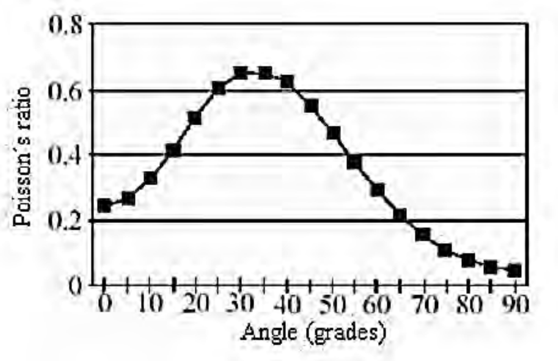

Figure 2.6: Poisson's ratio as a function of the angle of inclination of the fibres. (Potyrala, 2011)

2.5.4 Stress-strain relationship and tensile strength

Figure 2.7 shows the stress-strain curve for unidirectional fibre reinforced polymer and its respective component under tensile test. In the stress-strain curve, the maximum deformation of matrix is much larger than that of fibre. The maximum strain of composite and fibres are the same due to the brittle behaviour. Thus, the composite breaks when the strain reaches the maximum strain of the fibre. Assuming an ideal bond between fibre and matrix, Eq. (2.5) used to estimate the ultimate strength of composite.

$$\sigma_c = \sigma_f . v_f + \sigma_m . v_m \quad (2.5)$$

Where σ_c is the ultimate strength of composite, σ_f is the ultimate strength of the fibre, v_f is the Poisson's ratio of fibre material, σ_m is the ultimate strength of material and v_m is the Poisson's ratio of matrix material.

However, besides concerning failure due to tension, another mechanism of failures such as compressive failure and shear failure should be taken into account during the designation process of the composite.

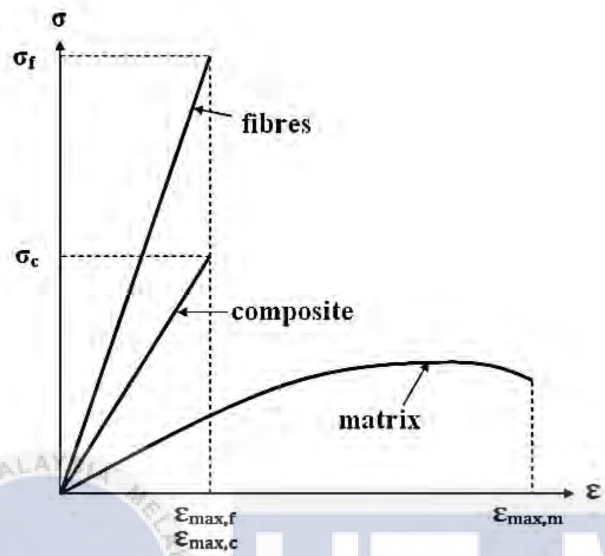

Figure 2.7: Stress-strain relationship for FRP and its components (Potyrala, 2011)

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2.6 Quasi-static indentation (QSI) penetration test

Quasi-static penetration resistance of composite structures represents the energy dissipating capacity of the structures under transverse loading without dynamic and rate effects. The penetration resistance property is usually expressed by a series of force-displacement graphs at different support conditions. Thermoset composite materials play an important role in dissipating energy due to various inter-laminar and intra-laminar, transverse shear failures, and delamination, and are critical in investigating the behaviour of composites for low-velocity impact and ballistic applications. On the other hand, thermoplastic composites are less used in high-velocity impact application due to their high-temperature processing requirements (Omer et al. 2012). However, the high delamination resistance and limited matrix cracking characteristics of thermoplastic-based composites have led to the demand of such materials in impact applications.

Suhad et al. (2017) have studied the behaviour of kenaf and aramid fibre reinforced polyvinyl butyral hybrid laminates subjected to QSI test and they found a good result in terms of the maximum load carried, impact energy absorption and damage mechanisms. Erkendirci and Haque (2012) carried out experiments to investigate the QSI resistance of a glass/high-density polyethene (HDPE) composite systems with different thicknesses. Their results showed that matrix fracture and fibre sliding failures were the primary mechanisms in QSI test for thickly walled panels.

Recent cases reported by Meredith et al. (2012) also support the result that the thickness of natural composites has a great effect on their impact properties – high thickness led to improved energy absorption, which had comparable impact properties with cut strand E-glass composite. Moreover, Yahaya et al. (2014) conducted an experiment about QSI properties of non-woven kenaf fibre/Kevlar reinforced epoxy hybrid. The result concluded that the maximum force to initiate penetration, absorbed penetration energy, and maximum load were enhanced using one layer of kenaf yarn between two layers of Kevlar.

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2.7 Low-velocity impact (LVI)

Impact with low velocity will cause excessive stress across the interface between layers with different angles, resulting in delamination after the failure of interface material. The delamination happened inside composite layers, it is not easy to characterize it without breaking the laminated structure. A report from Vijaya et al (2013) found that stacking sequences of the fibres were more important than fibre composition in determining impact toughness. The resin toughness rather than fibre strength and stiffness is the main parameter influencing the result of impact resistant properties of the composite. Besides that, they have studied the LVI of composite material to identify failure mechanisms and understand their interactions. Woven fabric composites provide better impact resistance as compared to unidirectional composites due to the interlacing of fibre drags in two directions.

In most cases, there is a difficulty in observing the damage and failure mechanism through the visual inspection when the object is tiny. According to Sevkat (2013), the impact properties of composite laminates rely on different parameters such as thickness, size and shape of impactor and laminate configuration. One of the methods to enhance the impact resistance and energy absorbing capacity of composite materials is to incorporate fibres that possess high strain failure to the host laminates, thus referring hybrid composites.

Sayer et al. (2010) conducted an experimental investigation to study the impact behaviour of hybrid composite laminates based on carbon and glass fibres. The hybrid carbon and glass fibre reinforced composites showed the highest impact resistance when carbon fibres were placed at tension side and glass fibres at impacted side.

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CHAPTER 3

METHODOLOGY

3.1 Introduction

The following part of this paper briefly describes the methodology of this project. The procedure, theory and standard involved in every process are discussed in the following section including material preparation, specimen fabrication and testing. The methodology of this study is summarized in the flowchart as shown in Figure 3.1.

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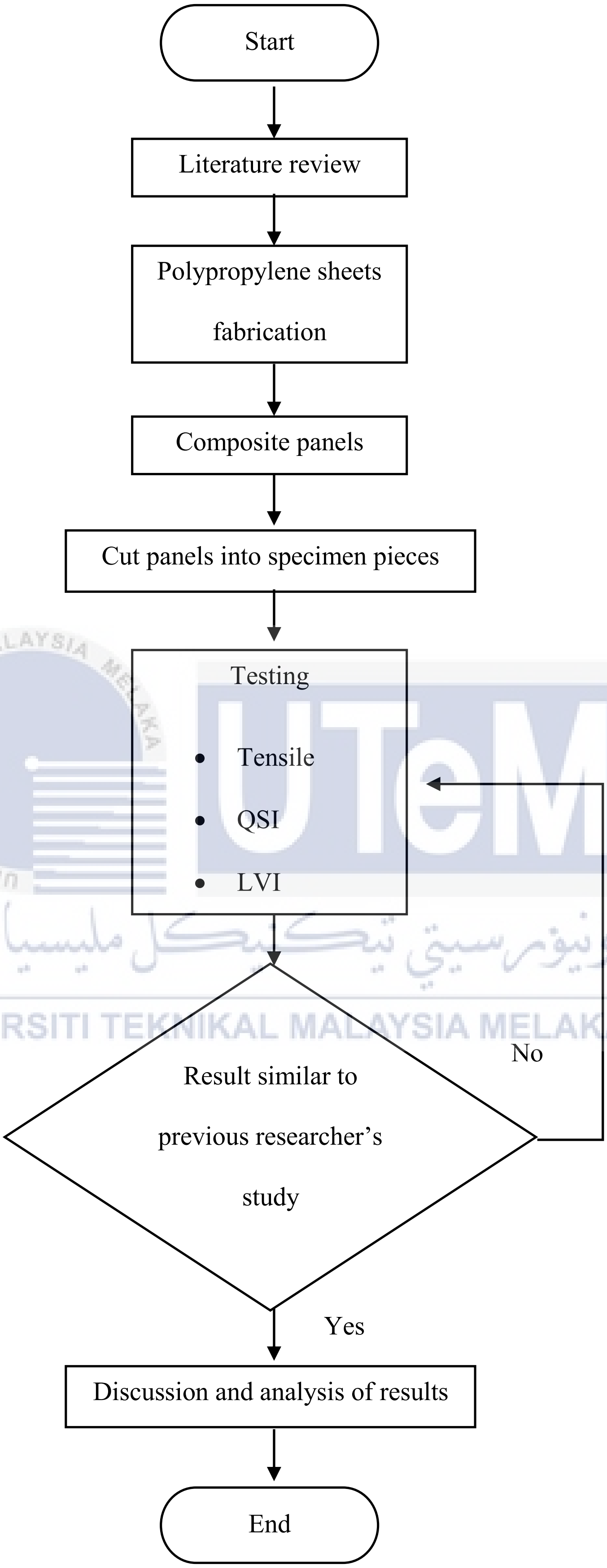
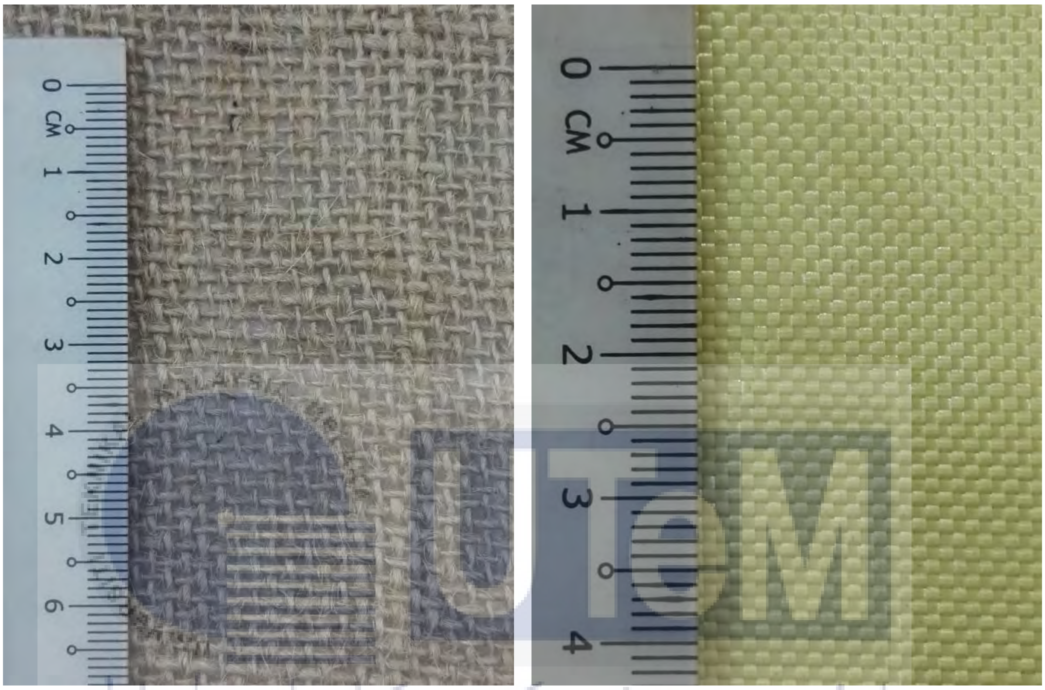


Figure 3.1: Flowchart of the project

3.2 Material preparation

The material used in the composite involved 250mm x 250mm kenaf and Kevlar fibres which are obtained from Lembaga Kenaf Dan Tembakau Negara (LKTN) as shown in Figure 3.2.



(a) (b)

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Figure 3.2: Materials used in this project. (a) Kenaf (b) Kevlar

3.2.1 Polypropylene (PP)

The PP was used as a matrix to maintain the fibres in the desired geometrical arrangement. The PP was supplied by Al Waha petrochemical company, Saudi Arabia in the form of granule. Figure 3.3 showed the PP pellets and Figure 3.4 showed the PP sheet after the hot compression process. The PP sheets were placed between the fibres in the layup composite configuration.

Figure 3.3: Polypropylene pellets

Figure 3.4: Polypropylene sheet

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3.3 Specimen fabrication

3.3.1 Hot press

First of all, the PP sheets were fabricated through the hot press compression machine as shown in Figure 3.5. PP pellets were preheated for 2 minutes prior to the hot compression process to allow the uniform heat distribution. PP pellets were then hot compressed for 2 minutes at a temperature of 175 °C and a pressure of 5 MPa to form PP sheets (Schmid, 2008). After that, the plates were removed for the cooling process until room temperature.

Different materials have different properties. Suitable temperature and pressure must apply in order to get a better specimen.

Figure 3.5: Hot press machine.

FRP fabrication processes were conducted after the PP sheet fabrication process. In this study, the K refers to kenaf fibres, KV refers to Kevlar fibres and PP refer to polypropylene sheets. K and KV fibres were stacked according to the layup as shown in Figure 3.6. Four different types of layup configurations are investigated in this study. The layup patterns are [K/K/K], [K/KV/K], [KV/K/KV] and [KV/KV/KV]. Three layers of fibres were stacked in the 3mm-thick picture frame and 5 PP films were incorporated in between each of the fibres to allow an optimum fibre impregnation. The stack was initially preheated for 4 minutes, followed by hot compression at a temperature of 175 °C and pressure of 3.5 MPa for another 8 minutes. The composite panel was cooled for 8 minutes before taken out from the hot press machine. Tensile, QSI and LVI tests were carried out to characterize the properties of hybrid composites. The mechanical tests for each of the fibre configurations were repeated for 3 times to obtain the nominal results.

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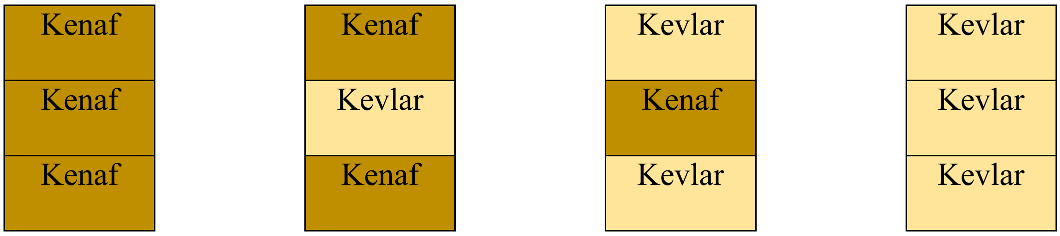

Figure 3.6: Layup configurations of composites

3.3.2 Table saw machine

The composite panels were cut using a Proxxon table saw machine as shown in Figure 3.7 after the fabrication process. The Proxxon table saw machine with a gear shape blade cut the panels according to the desired dimension. The tensile specimens were cut in accordance with ASTM D3039 while the QSI and LVI specimens were cut according to ASTM D6264 and ASTM D7136 respectively.

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Figure 3.7: Proxxon table saw machine (Conrad, n.d)

3.4 Testing

3.4.1 Tensile test

Tensile tests were conducted on the hybrid composites with different fibre configurations at a cross-head displacement rate of 2 mm/min and room temperature according to ASTM D3039 using a Universal Testing Machine (UTM) Instron 8872 as illustrated in Figure 3.8. The specimen was placed in the grip of the UTM and test is performed by applying tension slowly until it undergoes fracture. The tensile properties of each hybrid composites are recorded and analysed.

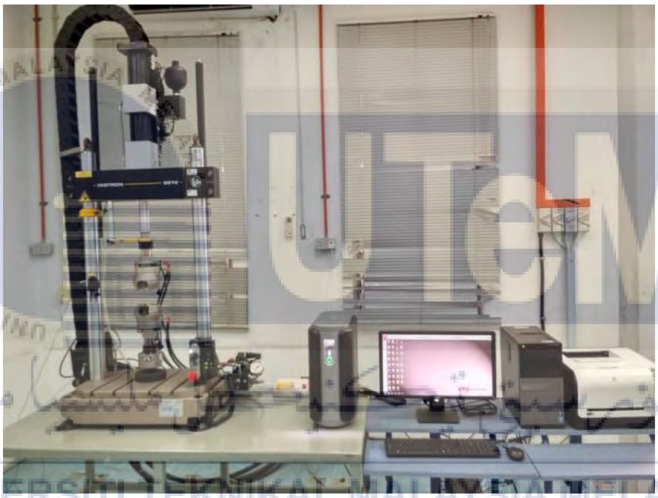

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Figure 3.8: Universal Testing Machine Instron 8872 tensile test machine.

3.4.2 Quasi-static indentation (QSI) test

The QSI test was conducted with reference to ASTM D6264 to study the damage evolution and penetration resistance behaviour of the hybrid composites using a UTM with 150kN capacity as shown in Figure 3.9. It can also be used to evaluate the effect of hybridization on the energy absorption of hybrid laminated composites under transverse loading without a dynamic effect. A series of quasi-static indentation tests were carried out using a surface-hardened steel indenter with 12.7mm diameter hemispherical tip. The test samples were bolted to the cover plate and bottom support plate by four screws at four corners. Next, the penetration resistance force-displacement curves were recorded and further evaluated.

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Figure 3.9: Universal Testing Machine Instron 5585 machine for Quasi-static indentation test

3.4.3 Low-velocity impact test

The LVI tests were carried out according to ASTM D7136 using Instron drop tower impact system Ceast 9340 machine as shown in Figure 3.10. The impactor nose has a hemispherical shape with the diameter of 12.7mm and the mass of 6.5kg. The four corners of coupon were installed to the fixture so the impact point was located at sample centre. The impact energy was fixed to be 26.8 J by changing the height of the impactor. The impact properties including peak load, energy absorption and the elongation of different hybrid composites were recorded and compared.

Figure 3.10: Instron drop tower impact system Ceast 9340

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CHAPTER 4

RESULTS AND DISCUSSION

4.1 Volume fraction and density

The volume fraction of the composite is the ratio of the volume of a constituent in the hybrid composite to the total volume of hybrid composite (Pandya et al., 2011). In this study, the densities of kenaf and Kevlar fibres are $\rho_{kenaf} = 1.40 g/cm^3$ and $\rho_{Kevlar} = 1.44 g/cm^3$ (Akil, 2011). Besides that, the matrix used in the manufacturing process was polypropylene with density $\rho_{pp} = 0.90 g/cm^3$. The equation of volume fraction of fibre is shown in Eq. (4.1),

$$V_f = \frac{v_f}{v_c} \tag{4.1}$$

where V_f is the fibre volume fraction, v_f is the volume of fibre and v_c is the volume of composite. By applying Eq. (4.2), the kenaf, Kevlar and polypropylene volume fractions can be expressed as Eq. (4.3), (4.4) and (4.5) respectively.

$$\rho = \frac{w}{v} \tag{4.2}$$

where ρ is the density, w is the weight and v is the volume.

$$V_{kenaf} = \frac{\frac{w_{kenaf}}{\rho_{kenaf}}}{\frac{w_{kenaf}}{\rho_{kenaf}} + \frac{w_{Kevlar}}{\rho_{Kevlar}} + \frac{w_{pp}}{\rho_{pp}}} \tag{4.3}$$

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$$V_{Kevlar} = \frac{\frac{w_{Kevlar}}{\rho_{Kevlar}}}{\frac{w_{kenaf}}{\rho_{kenaf}}+\frac{w_{Kevlar}}{\rho_{Kevlar}}+\frac{w_{pp}}{\rho_{pp}}} \tag{4.4}$$

$$V_{pp} = \frac{\frac{w_{pp}}{\rho_{pp}}}{\frac{w_{kenaf}}{\rho_{kenaf}}+\frac{w_{Kevlar}}{\rho_{Kevlar}}+\frac{w_{pp}}{\rho_{pp}}} \tag{4.5}$$

where w_{kenaf} is the weight of kenaf fibre, w_{Kevlar} is the weight of Kevlar fibre, w_{pp} is the weight of polypropylene, ρ_{kenaf} is the density of kenaf fibre, ρ_{Kevlar} is the density of Kevlar fibre and ρ_{pp} is the density of polypropylene.

The theoretical density of hybrid composite, ρ_{ct} was calculated by using Eq. (4.6) which is generated from Eq. (2.1) mentioned in literature review.

$$\rho_{ct} = \rho_{Kenaf} \cdot V_{Kenaf} + \rho_{Kevlar} \cdot V_{Kevlar} + \rho_{pp} \cdot V_{pp} \tag{4.6}$$

To calculate the void content of composite, the average density of hybrid composites was measured by using density meter. Void content was calculated using Eq. (4.7).

$$V_v = \frac{\rho_{ct}-\rho_{cm}}{\rho_{ct}} \tag{4.7}$$

where V_v is void volume fraction, ρ_{ct} is theoretical density of composite and ρ_{cm} is measured density of composite. The theoretical values and measured values are shown in Table 4.1.

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Table 4.1: Properties of composites

	K/K/K	K/KV/K	KV/K/KV	KV/KV/KV
Measured density (g/cm^3)	1.001	0.9368	0.9043	0.9028
Theoretical density (g/cm^3)	1.045	0.993	0.981	0.971
Void content (%)	4.21	5.66	8.48	7.03
Kenaf fibre volume fraction (%)	21.07	14.05	8.4	0
Kevlar fibre volume fraction (%)	0	4.2	7.16	13.21
Total fibre volume fraction (%)	21.07	18.25	15.56	13.21
Polypropylene volume fraction (%)	78.93	81.75	84.44	86.79

4.2 Tensile test result

The different stacking sequences of fibres were used for the tensile test. The average ultimate tensile strength of the specimens was calculated and recorded as shown in Table 4.2.

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Table 4.2: Tensile properties of tested composites ($\pm$ standard deviation)

Composites	Maximum load, F_{max} (kN)	Ultimate tensile stress, σ_{ult} (MPa)	Young's Modulus, E (MPa)
K/K/K	2.157 ± 0.384	28.759 ± 5.121	2281.437 ± 203.544
K/KV/K	4.823 ± 0.543	64.311 ± 3.247	2494.343 ± 162.875
KV/K/KV	8.035 ± 0.417	110.060 ± 5.567	2541.303 ± 236.054
KV/KV/KV	8.218 ± 0.215	109.848 ± 2.864	3028.873 ± 303.427

Figure 4.1 depicts the ultimate tensile strength and Young's modulus of composites with different fibre configurations. From Figure 4.1, non-hybrid Kevlar fibre reinforced

composites show the highest ultimate tensile strength in comparison to hybrid composites and non-hybrid kenaf fibre reinforced composites. In contrast, non-hybrid kenaf reinforced composites attest the lowest ultimate tensile strength of 28.759 MPa. It was observed that the increase of Kevlar fibre layer in the composite laminates improved the ultimate tensile strength. The improvement in the ultimate tensile strength is due to the intrinsic higher tensile strength of Kevlar fibre. When one middle layer of kenaf fibre was replaced by Kevlar fibre, improvement of 123.62 % in the ultimate tensile strength was observed. Furthermore, composite laminates with KV/K/KV fibre configuration showed the ultimate tensile strength of 110.060 MPa which is 282.7 % higher than non-hybrid K/K/K composites. However, it is interesting to note that hybrid KV/K/KV composite laminates exhibited comparable ultimate tensile strength to the non-hybrid KV/KV/KV composites. Since the ultimate tensile strength is governed by the outer layers in the composite laminates, thus hybrid KV/K/KV composites possessed the comparable ultimate tensile strength to the non-hybrid KV/KV/KV composites. Feng et al. (2017) obtained the similar trend where the hybrid glass/kenaf reinforced composite laminates with the incorporation of glass fibre in the outer layers have a comparable tensile strength to the non-hybrid glass fibre reinforced composite laminates.

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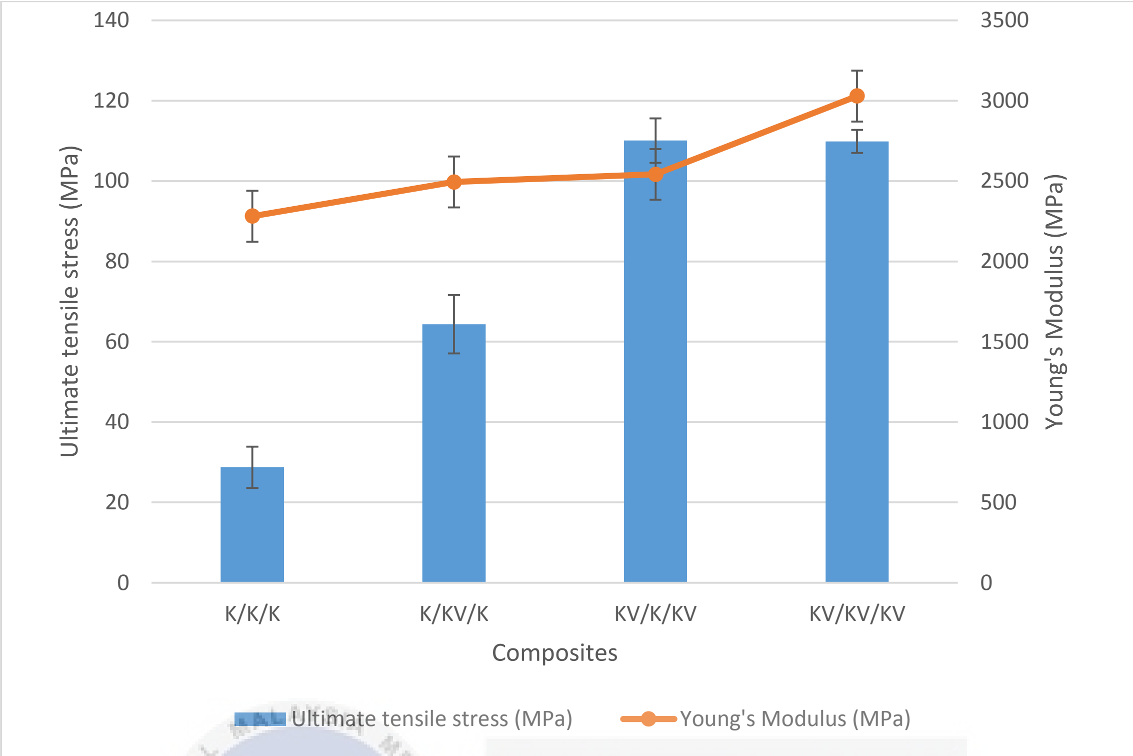

Figure 4.1: Ultimate tensile strength and Young's Modulus of composites

4.3 Quasi static indentation test result

Quasi-static indentation test was carried out to determine the penetration resistance of composites with different stacking sequences. The results of load-displacement curves and penetration energy can be obtained from the test. Figure 4.2 shows the load-displacement curve for non-hybrid Kevlar fibre reinforced composite. Basically, the curve can be divided into three regions: penetration (region A), perforation (region B) and friction (region C). According to Sabet (2008), the penetration happened after the initial linear part where the initial failure on the loaded side. A near load plateau was observed for thicker composites after initial penetration as the indenter moving through the thickness of the composites by pushing the fibres aside and matrix failure happened. For region B, the perforations began after plateau region which was shown as a decreased in penetration force as matrix failure started to occur, followed by fibre breakage. Next, the region C was the region associated with the residual frictional force of indenter and fibres. In order to obtain the energy absorption of each composite laminate, the area under the load-displacement curves was calculated and the results are shown in Table 4.3. Figure 4.3 shows the load-displacement curves of composite laminates with different stacking sequences. It was clear that KV/KV/KV composites can withstand the highest load with 4302.87N, which is followed by hybrid KV/K/KV with 3194.459N, K/KV/K with 2198.723N and lastly non-hybrid K/K/K with 845.883N. Figure 4.4 shows the maximum load and energy absorption of non-hybrid and hybrid composite laminates for quasi-static indentation test. The trend demonstrates that the effectiveness of energy absorption of composites containing Kevlar fibres is better than non-hybrid kenaf fibre reinforced composites. The perforation resistance is governed by the bending stiffness of the materials. Therefore, the incorporation of high stiffness Kevlar fibres in the composite laminates improves the perforation resistance. Moreover, it was noticed that the incorporation of Kevlar fibres in the outermost layer of composites had greater energy absorption and load resistance. In comparison with kenaf fibres, Kevlar fibres require higher penetration force and elongation to fracture. Thus, the placement of high strength Kevlar fibres in the outermost layers of the composites improves the maximum load and energy absorption.

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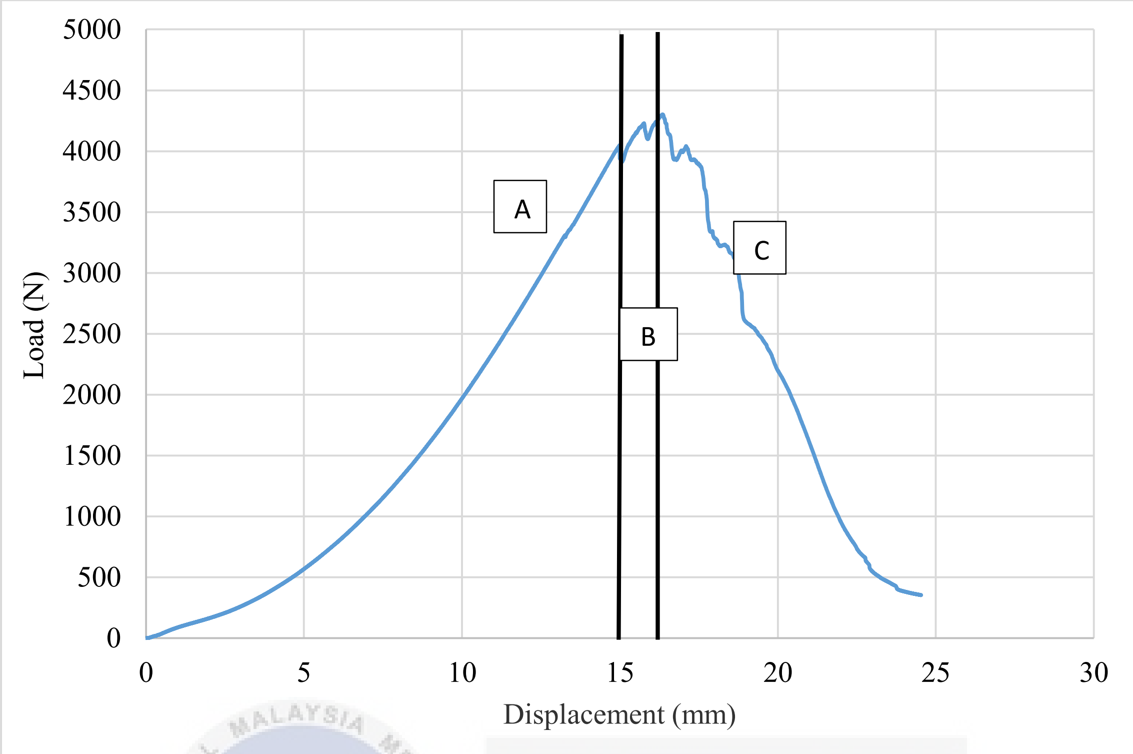

Figure 4.2: Load-displacement curve for non-hybrid Kevlar composite

Table 4.3: Energy and maximum load of composites for QSI test ($\pm$ standard deviation)

Composites	Energy absorption, E (J)	Maximum load, F_{max} (N)
K/K/K	3.320 ± 0.879	845.883 ± 107.35
K/KV/K	12.467 ± 1.312	2198.723 ± 190.447
KV/K/KV	17.141 ± 0.741	3194.459 ± 118.873
KV/KV/KV	27.633 ± 0.691	4302.87 ± 115.598

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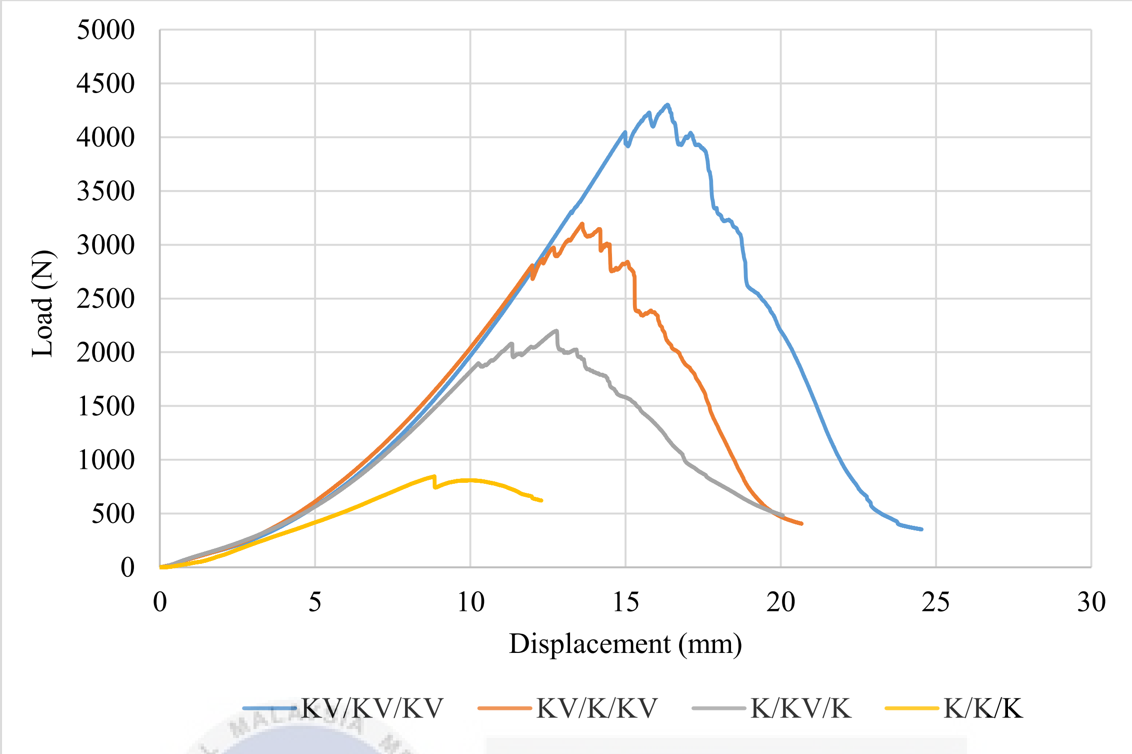

Figure 4.3: Load-displacement curves for different stacking sequences composites

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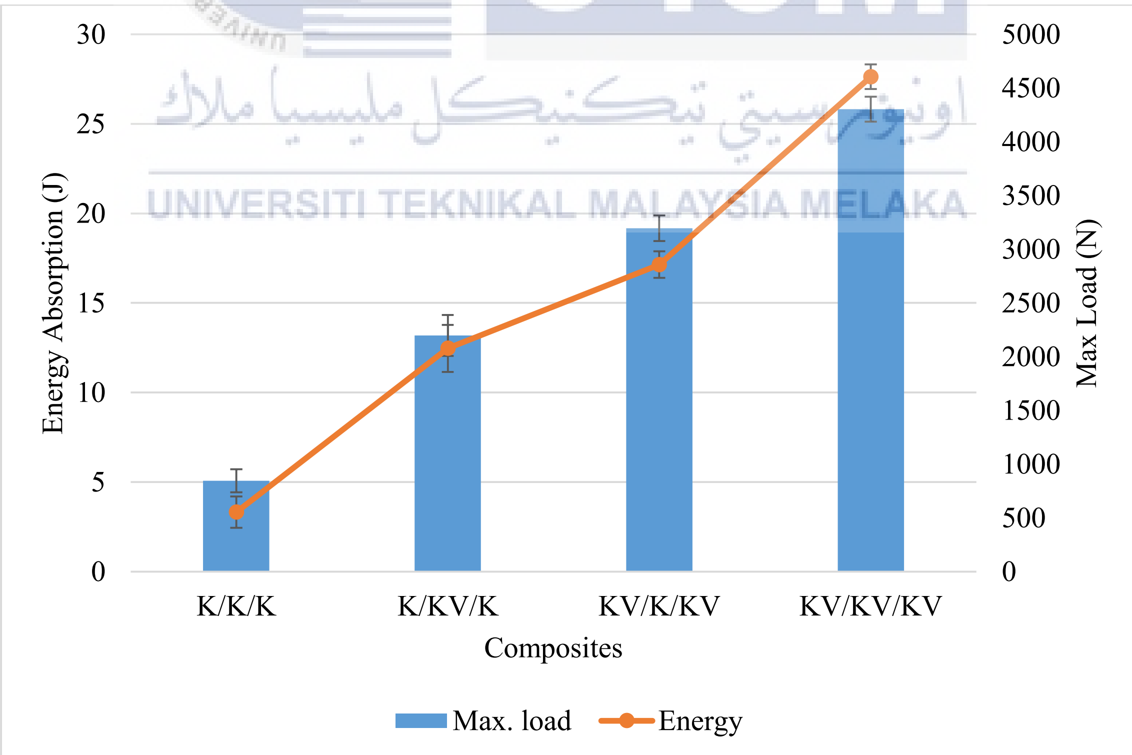

Figure 4.4: Maximum load and energy of quasi-static indentation test for composites

4.4 Low-velocity impact result

In this study, the low-velocity impact properties of kenaf/polypropylene and Kevlar/polypropylene composites were compared to those of kenaf-Kevlar hybrid composites in terms of contact force-deflection and energy absorption. Figure 4.5 shows the contact force-deflection graphs of composites with different stacking sequences and energy levels. The curves express the impact behaviour of each specimen. According to Berk (2016), there are two kinds of curve which are close and open. The close type occurs when rebounding. In this stage, the curve shows the elastic response of composite to impact. Minimum or no damage happens during this stage. Nevertheless, as the impact energy increased, the curves change from close to open type. Open type curve indicates the occurrence of almost complete failure in the composite structure. Figure 4.5 (a) shows the force-displacement curve of K/K/K composites for 10, 20 and 30J impact energy values. Penetration was observed to happen in K/K/K composites irrespective of energy levels. This explained that non-hybrid kenaf fibre reinforced composites have poor resistance to the impact loading. When hybridizing the kenaf/polypropylene composite with one layer of Kevlar fibre, the result was significantly improved. Rebounding occurs at 10J for K/KV/K hybrid composites. With the increase of impact energy to 20J and 30J, the curves change to open type and penetration have occurred. Both non-hybrid KV/KV/KV and hybrid KV/K/KV composites showed a similar trend where rebounding occurs up to 20J and then penetration occurs at 30J. The absorbed energy can be calculated from the area under the force-displacement curves. The larger the area under the curve leads to the greater energy absorbed by the composite materials.

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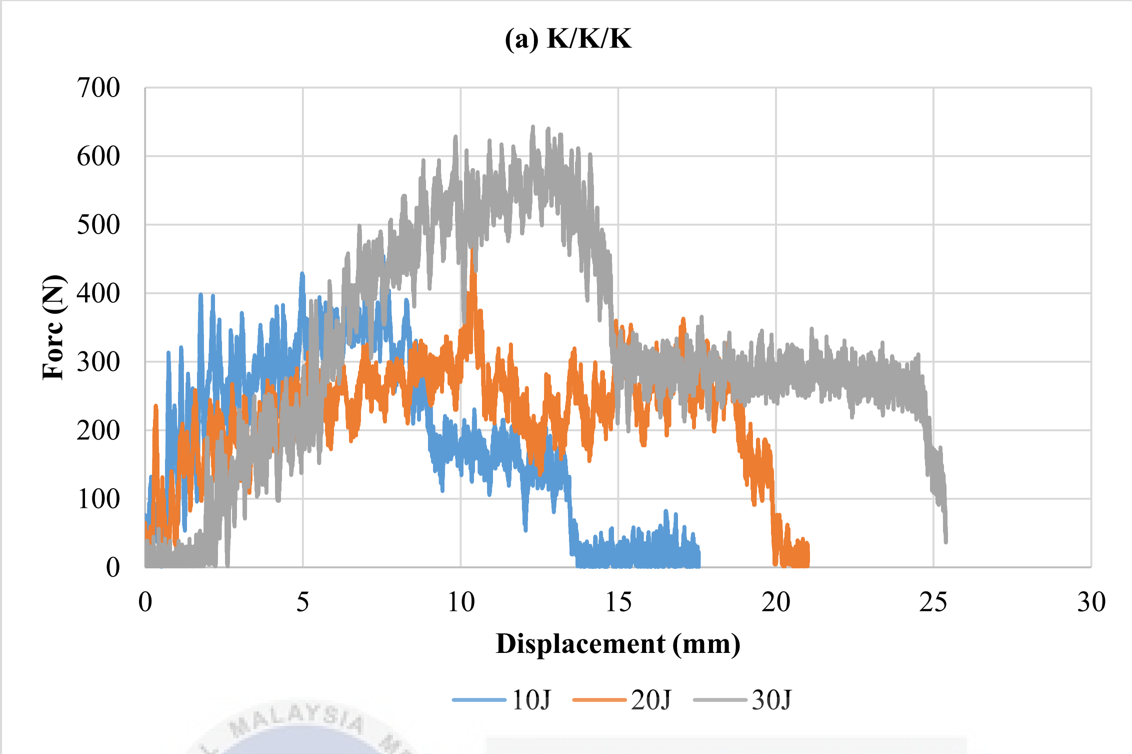

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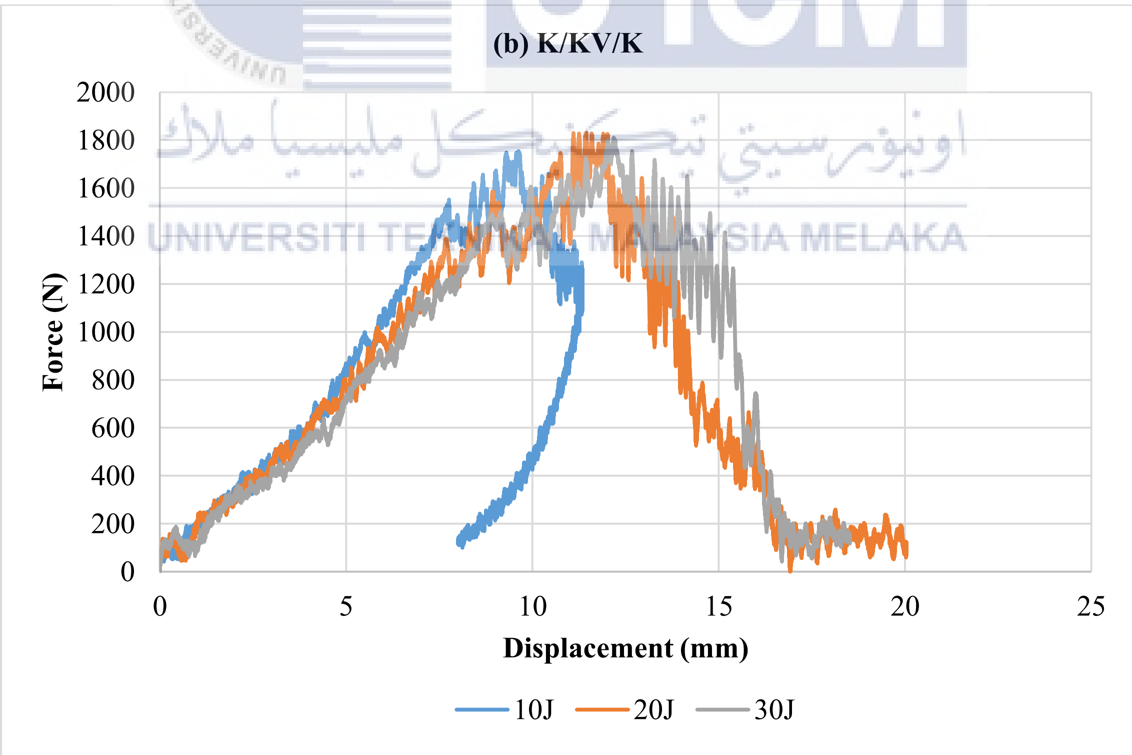

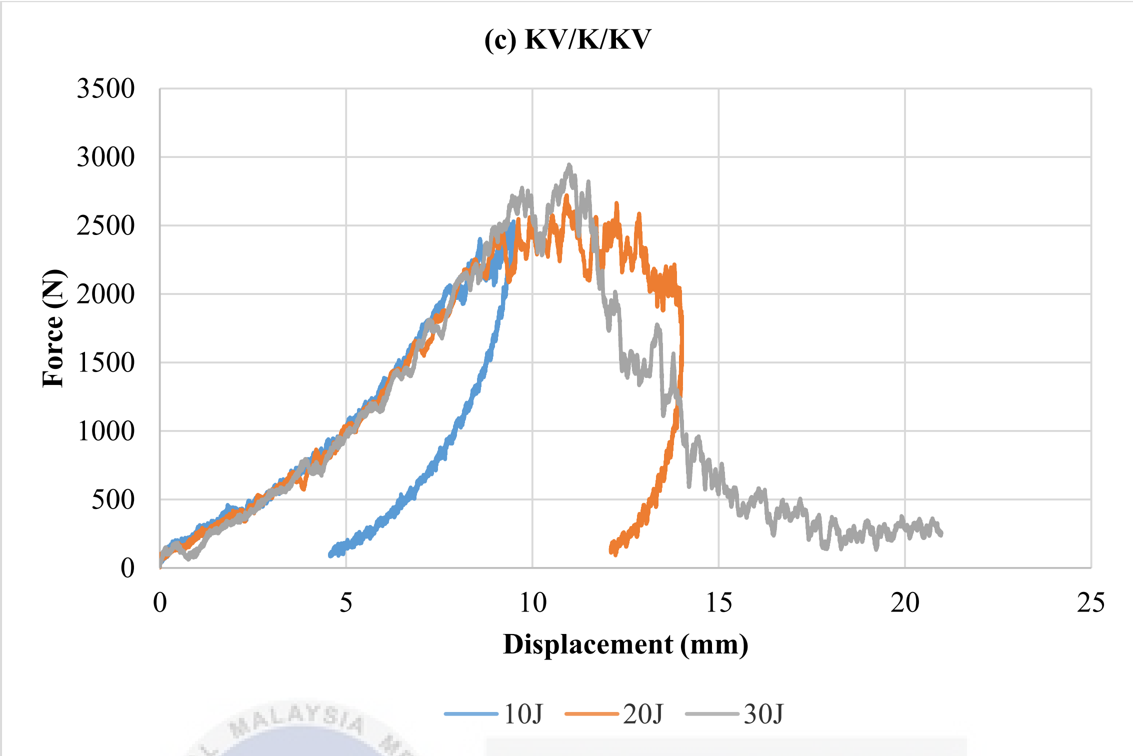

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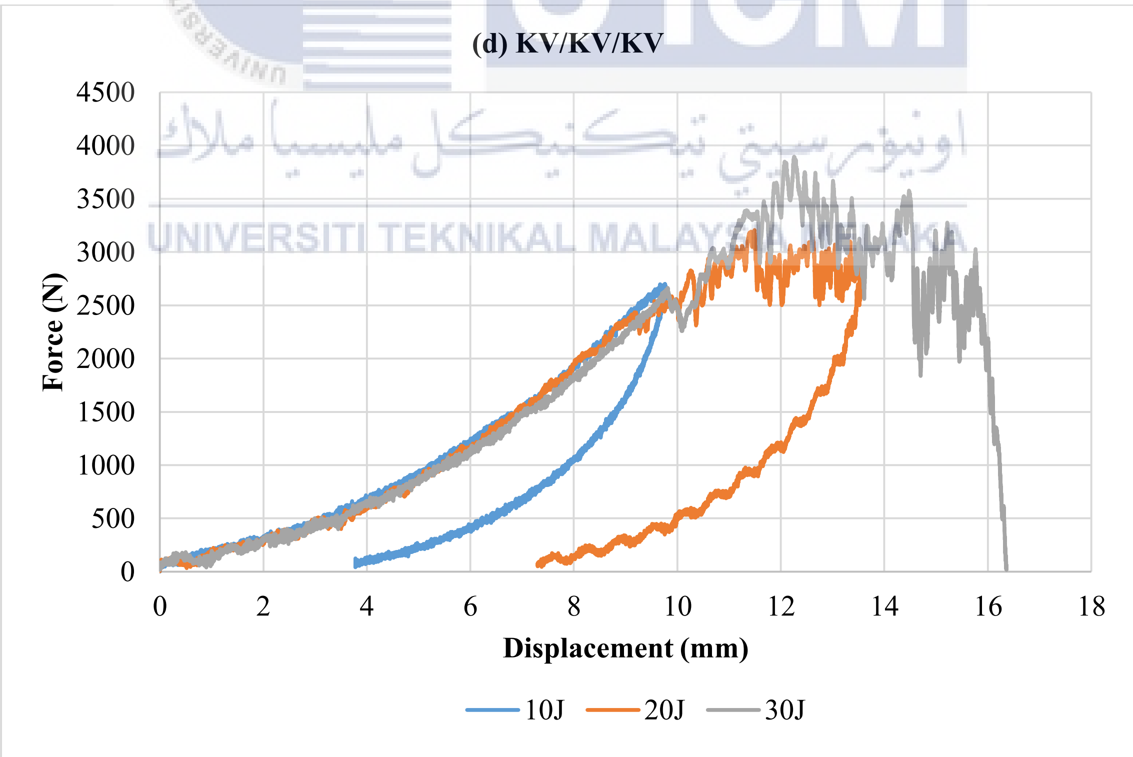

Figure 4.5: Force-displacement curves of composites with different stacking sequences

(a) K/K/K (b) K/KV/K (c) KV/K/KV (d) KV/KV/KV

Figure 4.6 represents the energy-time curves of composite laminates with different stacking sequences. According to Farzin (2017), impact energy is defined as the total potential energy that the impactor received from the test instrument during the test and transformed it to the kinetic energy that is eventually received by specimens. As can be seen in Figure 4.6(c) and (d), the impact energy was not enough for the penetration of the non-hybrid Kevlar fibres reinforced composites during the impact loading. Rebounding occurred at energy levels of 10J and 20J. However, as the energy levels increased to 30J, the penetration occurred. In contrast, the hybrid KV/K/KV composites showed a different trend in which the rebounding only happened at energy level of 10J. The penetration was observed in non-hybrid kenaf fibre reinforced composites during the impact loading regardless of different energy levels. In overall, the total energy absorbed for non-hybrid K/K/K configuration was the lowest compared to others.

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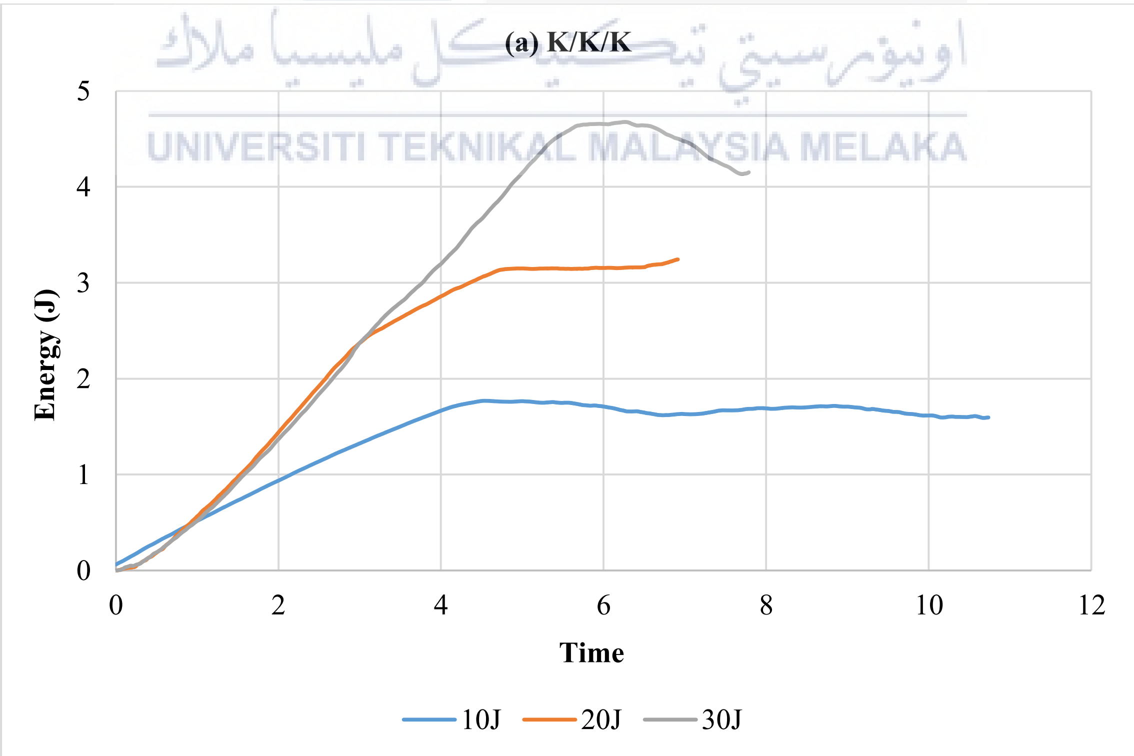

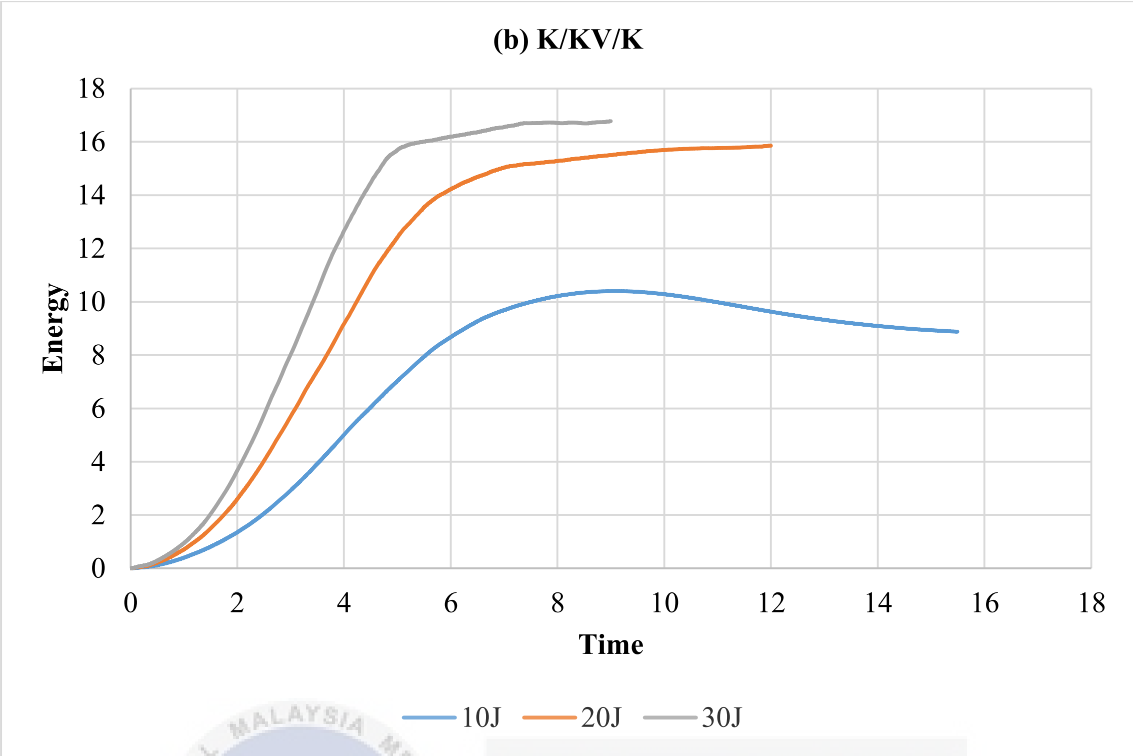

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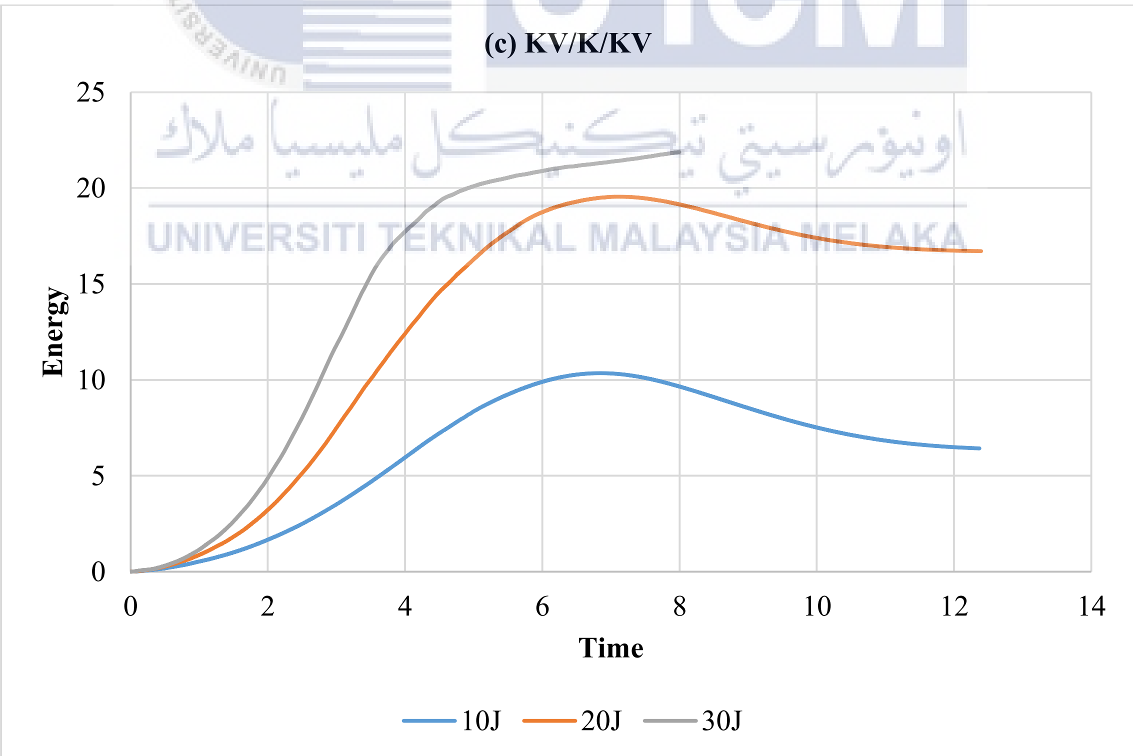

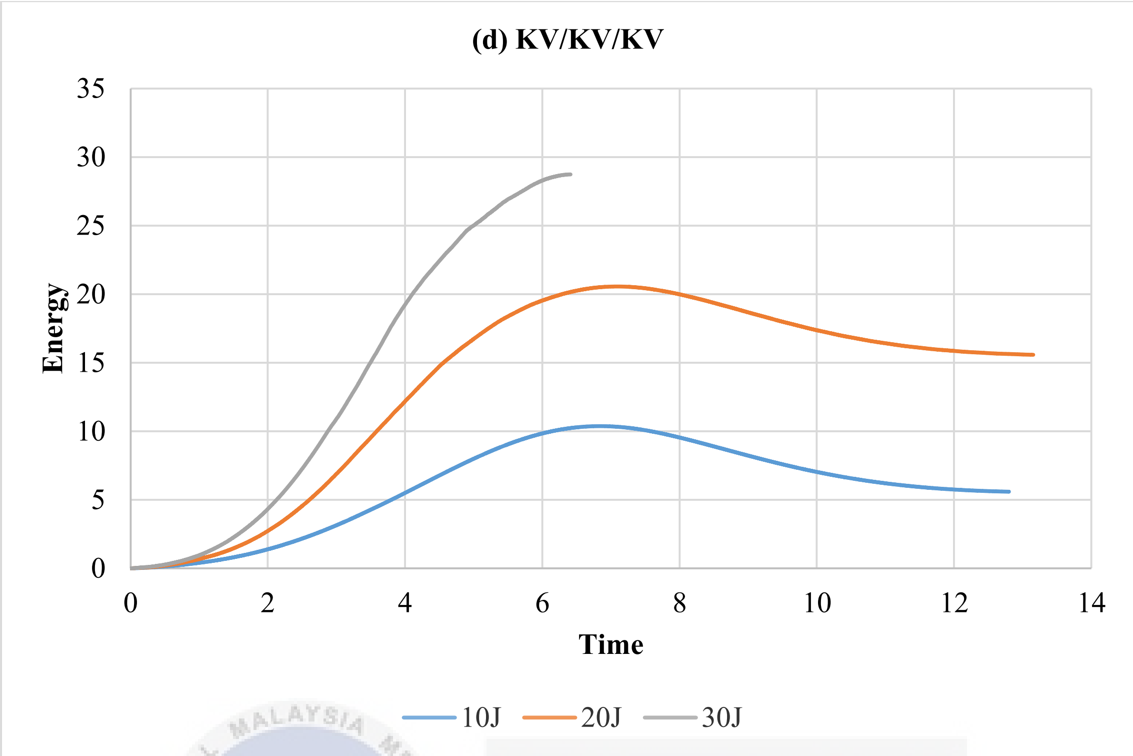

Figure 4.6: Energy-time graphs of different stacking sequences composites

(b) K/K/K (b) K/KV/K (c) KV/K/KV (d) KV/KV/KV

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4.5 Morphological Analysis

The morphological analysis of the fractured surface of specimens was examined by using the scanning electron microscopy (SEM). Figure 4.7 illustrated the SEM images of failure surface of woven kenaf/Kevlar hybrid composites due to tension loading. The failure modes observed from SEM images showed that both the reinforcement and matrix were the load carriers. This statement can be proved by Figure 4.8 which is the occurrence of fibre failure (breakage), matrix failure (cracks) and matrix debonding within the hybrid composites. Figure 4.9 showed the fibre breakage, fibre pull-out and matrix debonding happened in hybrid composite due to the poor interfacial bonding of matrix with fibres. Moreover, Figure 4.10 showed kenaf fibres failures were found in the SEM images due to its poor extension ability under a tension load.

The failure mechanism of specimens after quasi-static indentation test was carried out. Table 4.4 shows the damaged surface penetration of all different stacking configurations composites. It was obvious that all the penetrated composites exhibited an out-of-plane plastic deformation. Kenaf fibres were totally fractured due to its brittle nature whereas the Kevlar fibres exhibited fibre pull-out. Matrix failure within Kevlar fibres and delamination was taking place. For K/KV/K configuration, kenaf fibres at the front surface were compressed due to plunger punch and an exact plunger shaped cavity was created. At the rear surface, delamination of kenaf fibres happened in a spall-form when the full penetration was achieved.

Many types of failure modes can occur during low-velocity impact test such as microcracks, debonding, delamination and fibres breakage. Generally, the damage pattern depends on the mechanical properties of composites. From Table 4.5, the impact damage was not clear at the 10J energy level for all the composites except for K/K/K. It became significant as the energy level increased to 20J for K/KV/K and 30J for KV/K/KV and KV/KV/KV. Characteristics of damage in the LVI test indicated the brittle nature of kenaf fibres and high impact resistance of Kevlar fibres. When compared to non-hybrid kenaf fibre reinforced composites, the impact resistance becomes better when hybridizing another layer of fibre at the innermost layer of composites.

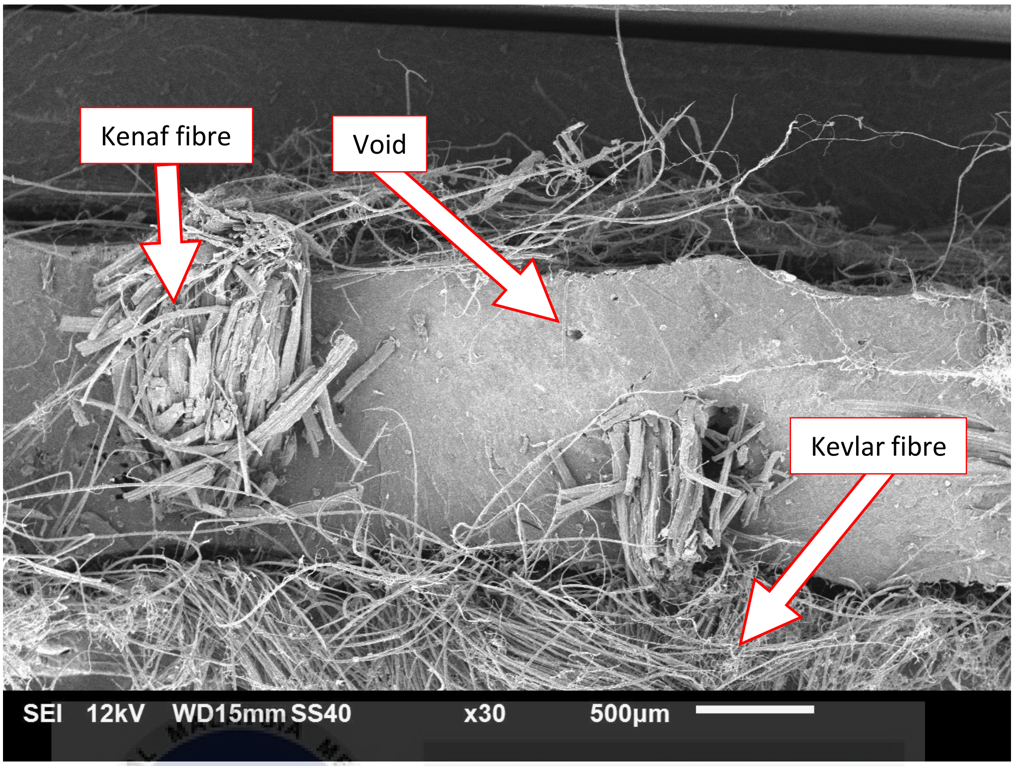

Figure 4.7: Failure surface of woven kenaf/Kevlar hybrid composites

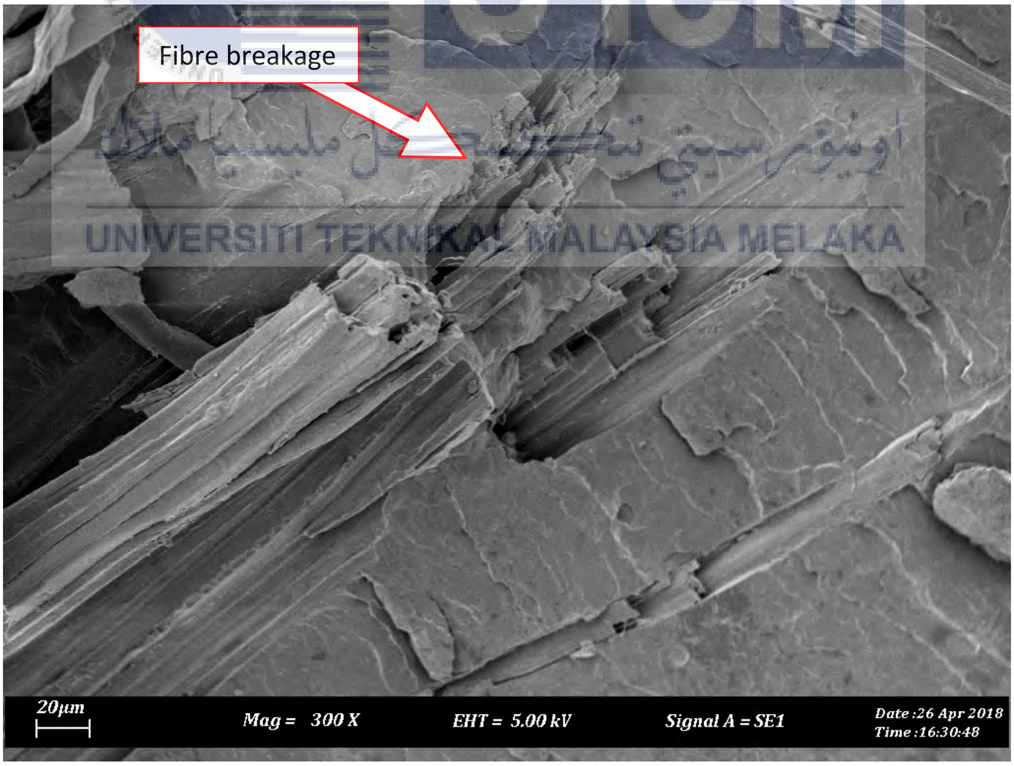

Figure 4.8: Fibre breakage of hybrid composites.

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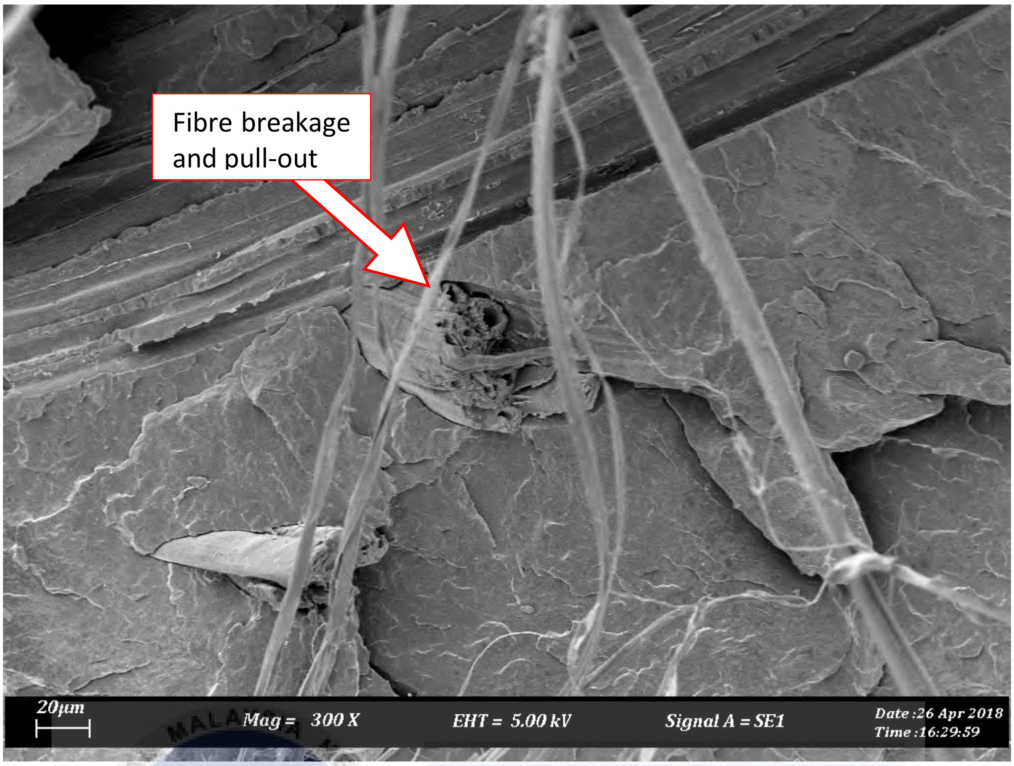


Figure 4.9: Fibre breakage and pull-out of hybrid composites.

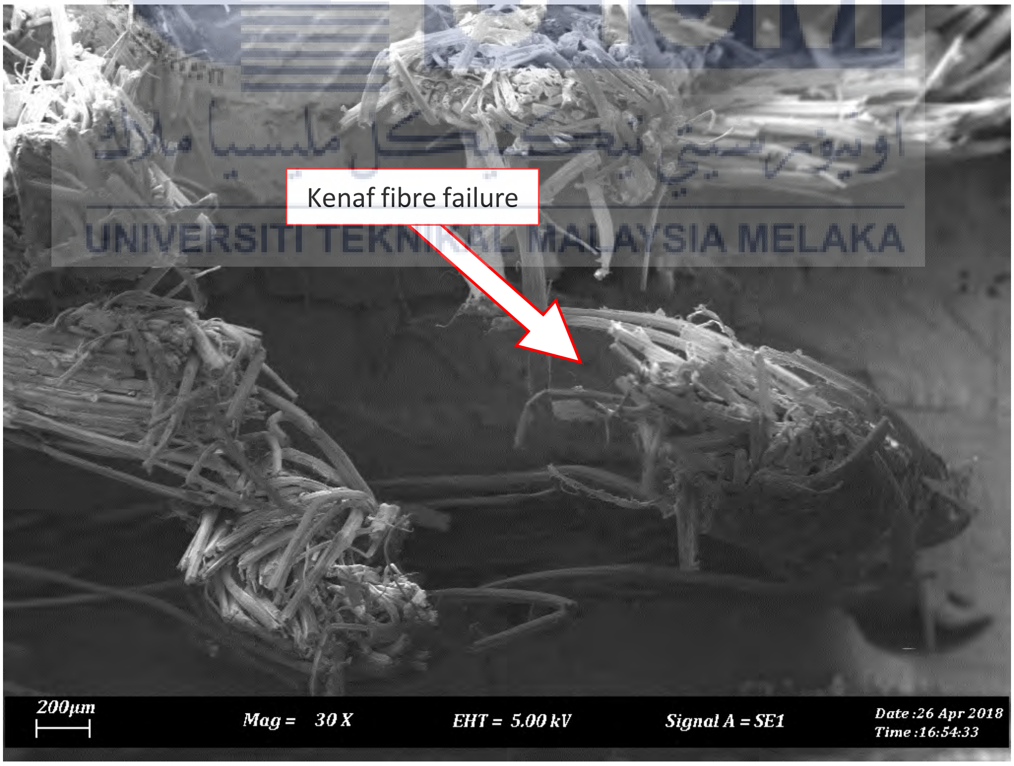
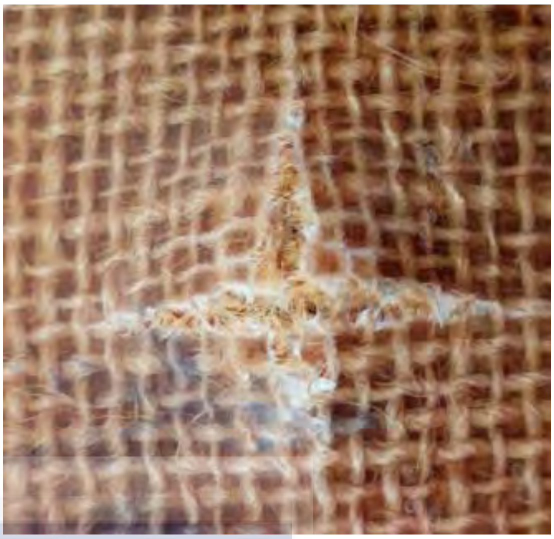


Figure 4.10: Kenaf fibre failure.

Table 4.4: Failure surface of quasi-static indentation test

Composite	Front	Rear
K/K/K		
K/KV/K		

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KV/K/KV		
KV/KV/KV		

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Table 4.5: Failure surface of low-velocity impact test

Composite		Front	Rear
K/K/K	10J		
	20J		
	30J		

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K/KV/K	10J		
	20J		
	30J		

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KV/K/KV	10J		
	20J		
	30J		

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KV/KV/KV	10J		
	20J		
	30J		

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CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this study, the effect of fibre configurations of kenaf/Kevlar fibre reinforced polypropylene composites under tensile, quasi-static penetration and low-velocity impact tests were investigated. Different stacking configurations of FRP composites which include K/K/K, K/KV/K, KV/K/KV and KV/KV/KV were fabricated. Based on the results, the following conclusions were made.

The tensile result showed that hybridizing of fibres can provide a better ultimate tensile strength for the composites. Non-hybrid Kevlar fibre reinforced composites show the highest ultimate tensile strength in comparison to hybrid composites and non-hybrid kenaf fibre reinforced composites. The hybrid FRP composites can withstand higher strength compared to non-hybrid FRP composites.

From the quasi-static indentation test, the load-displacement graphs and penetration energies were obtained. KV/KV/KV can withstand the highest load followed by KV/K/KV, K/KV/K and lastly K/K/K. Besides that, it was found that KV/K/KV with kenaf fibre at the innermost layers had greater energy absorption and load resistance compared to another hybrid sample K/KV/K due to the high penetration resistance of Kevlar fibres in the outermost layers.

In the low-velocity impact test, the specimens were tested at 10, 20, and 30J different impact energies. Force-displacement and energy-time curves were plotted to express the

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impact behaviour of FRP composites. From the experimental results, the non-hybrid kenaf fibre reinforced composites had poor resistance to impact loading. However, when replacing the kenaf fibres in the FRP with one layer of Kevlar fibres in the middle layer, the impact properties were significantly improved. In overall, the hybrid FRP composites can absorb more energy compared to non-hybrid FRP composites.

Damage morphological analysis was determined to study the fracture surface of FRP composites. SEM was used to observe the failure mechanisms of the composites. Matrix cracking was one of the failure mechanism showing the matrix carried portion of the load. The delamination of Kevlar fibres from matrix was due to weak interfacial bonding with the matrix. Moreover, the brittle nature of kenaf fibres caused the FRP composites become weak against impact loading.

In a nutshell, the effect of hybridizing have improved the mechanical properties of kenaf/Kevlar FRP thermoplastic composites. Different stacking configurations also affect the performance of FRP composites. The mechanical properties of FRP composites decreased as the content of kenaf fibres in the laminates increases.

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5.2 Recommendations

There are many aspects which remain to be improved for further investigation. In order to get a more accurate result, more experiments can be conducted by using more impact energies for the low-velocity impact test. Other than that, fabrication process is very important as it can affect the properties of composites. During the hot press process, the specimens must compress at specific pressure and temperature to reduce the void content. Then, good specimens can lead to more accurate result.

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