Faculty of Mechanical Engineering

THE IMPACT BEHAVIOUR OF HYBRID KENAF/GLASS FIBRE REINFORCED COMPOSITES

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Degree of Bachelor of Mechanical Engineering

2018

THE IMPACT BEHAVIOUR OF HYBRID KENAF/GLASS FIBRE REINFORCED COMPOSITES

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A thesis submitted
in fulfilment of the requirements for the
Bachelor of Mechanical Engineering (with Honours)

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that his project report entitled "The Impact Behaviour of Hybrid Kenaf/Glass Fibre Reinforced Composites" is the result of my own work except as cited in the references.

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Date : ..……………...…………………………………

APPROVAL

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

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ABSTRACT

In this study, woven kenaf/glass reinforced composites have been experimentally investigated. Hybrid composites were fabricated by hot press technique. Hybrid composites consists of woven glass fibre and woven kenaf fibre at symmetrically configuration. Non-hybrid glass/polypropylene and kenaf/polypropylene were also fabricated for comparison purpose. Tensile test was conducted using universal testing machine at speed of 2.00 mm/min. While for the quasi-static penetration test was conducted under crosshead speed of 1.27mm/min with 12.7mm diameter indenter. The low-velocity impact test was conducted by using drop-weight machine to study the impact resistance of the specimens. Failure mode of the tests samples were carefully examined. The results from the study showed that the hybrid samples influenced the impact resistance and tensile properties compared to non-hybrid kenaf and glass reinforced composites. It could be seen that the specific energy absorption for glass hybrid with kenaf was the highest among all test specimens. These finding inspired further exploration of hybrid composite for kenaf/glass reinforced composite for other applications.

ABSTRAK

Dalam Kajian, serat kenaf/kaca tenunan yang diperkuatkan komposit teleh dieksperimen siasatkan. Hibrid komposit telah difabrikasikan oleh Teknik hot press. Hibrid komposit terkandung serat kaca tenunan dan serat kenaf tenunan dalam keadaan konfigurasi yang simetri. Kaca/polipropilena dan kenaf/polipropilena juga difabrikasikan untuk tujuan perbandingan. Ujian tegangan dijalankan dengan universal testing machine dengan kelajuan 2.00mm/min. Ujian kuasi-static penembusan dijalankan di bawah kelajuan silang 1.27mm/min dengan in penderma garis pusat 12.7mm. Ujian halaju rendah hentaman dijalankan dengan mesin drop-weight untuk kaji rintangan hentaman spesimen. Sampel ujian diperiksakan dengan teliti dengan hormatnya mod kegagalan. Semua hasil kajian untuk kajian ini menunjukkan hibrid sampel menpengaruhi ritangan hentaman dan sifat tegangan semasa berbanding dengan bukan hibrid kenaf dan kaca perkuatkan komposit. Ini boleh ditunjukkan oleh penyerapan tenaga tertentu oleh hibrid kaca dengan kenaf adalah tertinggi antara semua spesimen ujian. Pendapatan ini dipercayakan dapat memberi inspirasi untuk exploraition selanjutnya untuk hibrid komposit kenaf/kaca perkuatan komposit dalam aplikasi lain.

ACKNOWLEDGEMENTS

First and foremost, I am greatly thankful to my final year project supervisor, Assoc. Prof. Dr. Sivakumar A/L Dhar Malingam from Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka for his guidance and support on my final year project. The completion of this project could not have been possible without his participation and assistance.

I would also like to thanks to all the technician from Composite Laboratory Faculty of Mechanical Engineering, Material Testing Laboratory Faculty of Mechanical Engineering, and Structure Laboratory Faculty of Mechanical Engineering for their assistance and advices on analysis work.

A special thanks to PhD student Mr. Ng Lin Feng and master student of Faculty of Mechanical Engineering Mr. Kathiravan Subramaniam for sharing their valuable experience and wisdom through out of this project. A big thanks to my friends and family for their support and encouragement all time.

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LIST OF ABBEREVATIONS

FRP	Fibre reinforced polymer
PP	Polypropylene
PET	Polyester
PVC	Poly vinyl chloride
ROM	Rule of Mixture
GFRP	Glass fibre reinforced plastic
CFRP	Carbon fibre reinforced plastic
HDPE	High density polyethylene
UTM	Universal testing machine
GKG	Glass/Kenaf/Glass polypropylene hybrid composite
KGK	Kenaf/Glass/Kenaf polypropylene hybrid composite
GGG	Glass/Glass/Glass polypropylene non-hybrid composite
KKK	Kenaf/Kenaf/Kenaf Polypropylene non-hybrid composite
QSI	Quasi-Static Indentation
LVI	Low Velocity Indentation
SEM	Scanning Electron Microscopy

LIST OF SYMBOLS

P_H	-	Properties of hybrid composite of two components
P_1	-	The corresponding property of the first system
P_2	-	The corresponding property of the second system
V_1	-	Relative hybrid volume fraction of the first system
V_2	-	Relative hybrid volume fraction of the first system
ρ	-	Density of the material
m	-	Mass of material
v	-	Volume of material
ρ_c	-	Density of composite
ρ_m	-	Density of matrix
V_m	-	Volume fraction of matrix material
ρ_f	-	Density of fibre
V_f	-	Volume fraction of fibre
v_f	-	Volume of fibre
v_c	-	Volume of composite
V_v	-	Void content
ρ_{ct}	-	Theoretical density of composite
ρ_{cm}	-	Measured density of composite

CHAPTER 1

INTRODUCTION

1.1 Background

Composite is a material where it is made from two or more constituent materials with significantly different physical or chemical properties. The outcome composite has significantly different characteristics of the individual components. The composite is usually widely used in the modern industrial applications as result of its advantages such as low production cost, relatively lightweight, high strength and stiffness. (Faris et al., 2013). Fibre reinforced polymers (FRPs) are composite that made from a mix of fibres and polymer. FRPs are widely used in almost every type of advanced engineering structure from aircraft, helicopter to boat and automobiles, civil infrastructures such as bridges and buildings. Fibre-reinforced polymer composites are also widely applied in modern industry. This attract many researches to carry out study on FRP to develop environmental fibre materials. (Rajesh et al., 2016).

There are two categories of fibre available in the market, synthetic fibres and natural fibres. Synthetic fibres are man-made fibres such as glass, nylon and aramid while natural fibres come from nature, for example, kenaf, jute, hemp and cotton. The hybridization of synthetic fibre and natural fibre can enhance mechanical properties and environmental performance, along with low production costs which are promising for many applications. With a wide understanding of mechanical properties such as indentation behaviour, it can increase significantly the uses of the hybrid composite in a variety of fields. (Yahaya et al., 2014).

There are two major synthetic matrices mainly used in industry, Polypropylene (PP) and Polyester (PET). The properties of PP like relative low density, lightweight to operate, superior tensile properties, good chemical resistance, hydrophobicity, and the relatively inexpensive cost of production has made it popular in use compared to PET (Hafsa, 2016). Also, PP can be reused which significantly reduces the cost of purchasing. Nevertheless, PP has strong hydrophobic and a non-polar properties make it capable to protect the hydrophilic natural fibres (Garkhail et al., 2000).

1.2 Problem Statement

In the past few decades, the use of fibre reinforced composites has been growing explosively. Generally, they are in lightweight, making them an ideal choice for many lightweight applications. However, natural fibre reinforced composites often suffer from a lack of toughness. Hence, hybridisation of synthetic fibres and natural fibres can improve most of the mechanical properties and environmental performance in terms of stiffness, strength, ultimate failure strain and impact resistance. The other advantages of hybrid fibre are that they are particularly with low fabrication cost and able to use in many applications. In this study, mechanical properties of hybrid kenaf/glass fibre reinforced polypropylene composites are investigated to maximize their uses.

1.3 Objective

The objectives of this project are as follows:

1. To determine the effect of different woven layup configurations on tensile analysis of hybrid kenaf/glass fibre reinforced composites.
2. To determine the effect of different woven layup configurations on the quasi-static indentation and low-velocity impact behaviour of hybrid kenaf/glass fibre reinforced composites.

1.4 Scope of Project

The test samples in this project are hybrid laminates woven kenaf/glass reinforced composite and the non-hybrid laminates which are glass/polypropylene and kenaf/polypropylene composite. This project focused on the tensile and impact resistance of the laminates. The results obtained are compared to investigate the best laminates. The tests conducted are tensile test, quasi-static indentation and low-velocity impact test. The tests are in accordance to respective ASTM D3039 for tensile test, ASTM D6264 for quasi-static indentation and ASTM D7136 for low-velocity impact.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A literature review is an important element in research, which provides information on previous studies regards to the research topic. The aims of the literature review are to define the scope of the problem and relate the study to previous studies by comparing and contrasting different author's opinions on an issue.

2.2 Fibre Reinforced Polymer

Fibre reinforced polymer, also known as FRP, is a composite material that made up of polymers matrix embedded with high-strength fibres, for example, glass, carbon and aramid (Groover, 2010). The polymer can be classified into two categories, thermoplastics and thermosets. Thermoplastic materials are currently favour used as matrices in the fabrication of composite. The most typically used thermoplastics are polypropylene (PP), polyethylene (PE), and polyvinyl chloride (PVC); the most utilised thermosets are phenolic, epoxy and polyester resins (Ku et al., 2011).

There are several methods to fabricate fibre reinforced polymers, with tools or a mould. The mould can be divided into concave female mould, male mould or mould that completely enclose the part with a top and bottom mould. The methods which can be used to fabricate FRP are hand layup method (wet/dry), compression molding, filament winding, bladder molding and etc (Sahas et al., 2017)

Fibre reinforced polymer composites are widely used in many applications because of their relatively good mechanical properties. When compared with a metallic material, FRPs have several advantages such as high strength, higher stiffness, better fatigue resistance, lightweight and remarkable designability. The functionality of FRP composites increase dramatically, specifically in weight and environmental crucial structures such as aircrafts, vehicles and wind blades (Xu et al., 2017). Moreover, in automobile field, the weight of the vehicle is one of the huge factors that impede the achievement of sustainable development which is energy saving and environmental care purpose. Also, the rate of carbon dioxide emission from the vehicles has been restricted by emission-reduction standards. Hence, to achieve lighter-weight automobiles, the most predominant method is by replacing the main parts with lighter weight materials. FRP composites are an alternative material as they have high specific modulus and strength especially relatively lightweight compared to the metallic material. Therefore, the automobile industry has introduced the use of FRP composite in for a long time to manufacture vehicles which are environmental-friendly, energy saving and lightweight (Wang et al., 2017). FRP composite have many applications because of the ease of processing, price is low and better mechanical properties. In electronic packaging application, FRP composites can be a substitute for metal materials particularlly the combination of metallic fibre with polymeric matrix is an attractive material (Sakthivel, 2013).

To enhance the performance of FRP for example high impact and tensile strength, high thermal resistance, good interfacial adhesion between reinforcements and matrix, dimensional stability and etc, many studied have been broadly carried out to design better FRP composites (Lee et al., 2017). One of the ways to improve mechanical properties is to introduce reinforcing filler, for example, glass and carbon fibres. These fibres able to improve the mechanical strength up to ten times to fifty times.

The previous study showed that glass or carbon fibre reinforced polymer composites are preferred materials applied in aircraft and aerospace engineering industries as the materials possess characteristics such as high specific strength-to-weight ratio and non-corrosivity can save fuel, especially in the designs of on-road and in-air vehicles (Hung et al., 2017). Zhang stated in the report that glass fibre composite increasingly used to replace steel in the automotive industry. GFRP and CFRP manage to reduce vehicle weight up to 20-35% when using GFRP and 40-60% when using CFRP (Zhang et al., 2012).

2.3 Hybrid Composite

Hybrid composite is a merge of two or more different group of fibres with matrices. Different fibres with their own advantages, hybridization able to take full advantage of the best properties of the constituents and balance out each other fibre deficiency (Sanjay et al., 2017). The fibres can be in categories of natural or artificial fibres. The possible outcomes of hybrid composites are synthetic-synthetic fibres composite, natural-natural fibres composite or both synthetic and natural fibres composite. Hybrid composites have lighter weight and low cost in comparison to the composites with single type of fibre. The disadvantages of non-hybrid composites are over-strength and not-cost-competitive (Hung et al., 2017).

Hybrid composites offer some advantages over non-hybrid fibre reinforced composites (Boopalan et al., 2013). In usual cases, hybridisation is interlaminate and intralaminate. Interlaminate, which is also known as simply laminate, contains depositing layers built from a variety of fibres; intralaminate contains depositing layers entangled within one layer (Almeida et al., 2013).

Hybrid composite materials have wide applications in the field of engineering due to low cost, strength-to-weight ratio and ease of manufacturing. These hybrid composites bring about stiffness, strength and ductility, which cannot be achieved by single fibre reinforced composites. Hybrid composites increase fatigue life, elevate fracture toughness and lower notch sensitivity in a comparison with the single fibre reinforced composites (Srinivas et al., 2012).

By hybridizing with high strength synthetic fibres, the properties of natural fibre reinforced composites can be improved. The formation of hybrid composites involves the interspersion of the two (2) or more varieties of fibres in a common matrix. The significant adjustment to the mechanical properties of the composites is known to be the reason of the incorporation of fibres (man-made or natural) into a polymer (Jawaid, 2011b). Previous studied showed hybridization of lignocellulose and synthetic fibres, for example, glass and carbon fibres able to improve the stiffness, strength as well as moisture resistance of the hybrid composite (Busu et al., 2010).

The strength of the hybrid composites can be affected by several factors such as the properties of fibre, length of the individual fibre, the orientation of fibre, fibre to matrix interface bonding, the aspect ratio of fibre content, extent of intermingling of fibre and arrangement of both the fibres and failure strain of individual fibres. The fibres with high strain compatible able to obtain a maximum hybrid result (Jawaid et al., 2011a).

Rule of Mixture (ROM) Eq. (2.1) can be used to theoretically predict the properties of hybrid composite of two components.

$$P_H = P_1 V_1 + P_2 V_2 \tag{2.1}$$

Where P_H is the property to be investigated, P_1 is the corresponding property of the first system and P_2 the corresponding property of the second system. V_1 and V_2 are relative hybrid volume fraction of the first and second system. $V_1 + V_2 = 1$ (Sreekala et al. 2002).

2.3.1 Matrix

Matrix is a medium that is used to hold or bind reinforcement together as a composite and at the same time acts as a layer of protection for the reinforcement towards the environmental damage and provide ability to transfer load. The two classes of the matrix are thermoset and thermoplastic which are mainly used in composite applications (Kabir et al., 2012). The common examples of thermoset matrices are unsaturated polyesters, epoxy and phenolics. The common examples of thermoplastic matrices are polypropylenes, polyethylene and elastomers.

There are many reasons to promote the selection of PP as a matrix in the composite fabrication process. The main benefit of PP is their relatively low processing temperature which is especially required in the fabrication process of natural fibre based composites due to the low thermal stability of natural fibres. Most of the natural fibre has an average degradation temperature below 200°C. Due to the limitation of low degradation temperature of natural fibres, thermoplastic with a low processing temperature is preferable to be used as matrix. The melting point of polypropylene is identified through the search of the maximum temperature of a differential scanning calorimetry chart as the melting of polypropylene takes place across a range. Most commercial PP possess levels of crystallinity in the range between 40% and 60%, which are the intermediate level. Isotatic polypropylene has a melting point of perfectly 171°C while commercial isotactic polypropylene has a melting point in the range between 160°C to 166°C in dependence on atactic material and crystallinity (Quazi et al., 2011).

Apart from that, polypropylene also offers the advantages such as low price, high toughness, low density, relatively high thermal stability, high chemical resistance and recyclable (Reis et al., 2007**).** Polypropylene has a number of beneficial characteristics which enhance the application, such as high heat distortion temperature, transparency, flame resistance and dimensional stability. As a matrix material, PP provides attractive qualities for the manufacture of composites. PP is also very appropriate for filling, reinforcing and blending. One of the most favourable methods to produce natural-synthetic polymer composites is polypropylene with natural fibrous polymers (Quazi et al., 2011).

Polypropylene polymer can be made by polymerizing propylene molecules. There are three major sources of polypropylene. The first source of propylene monomer is sub-product from the steam-cracking process of naphtha. Naphtha is a valuable fraction of crude oil. Secondly, propylene monomer can be obtained from gasoline refining process and lastly, which is the recent new process, propylene monomer is produced by dehydrogenated propane. (Quazi et al., 2011).

2.3.2 REINFORCEMENT

The reinforcements for hybrid composite are usually from fibre group. Fibre which has superior mechanical properties able to withstand a load in the fibre reinforced polymers matrix composites. The two classes of fibres which are available in the market are natural and synthetic fibres. Figure 2.1 shows the classification of natural fibres and synthetic fibres (Jawaid, M., 2011a).

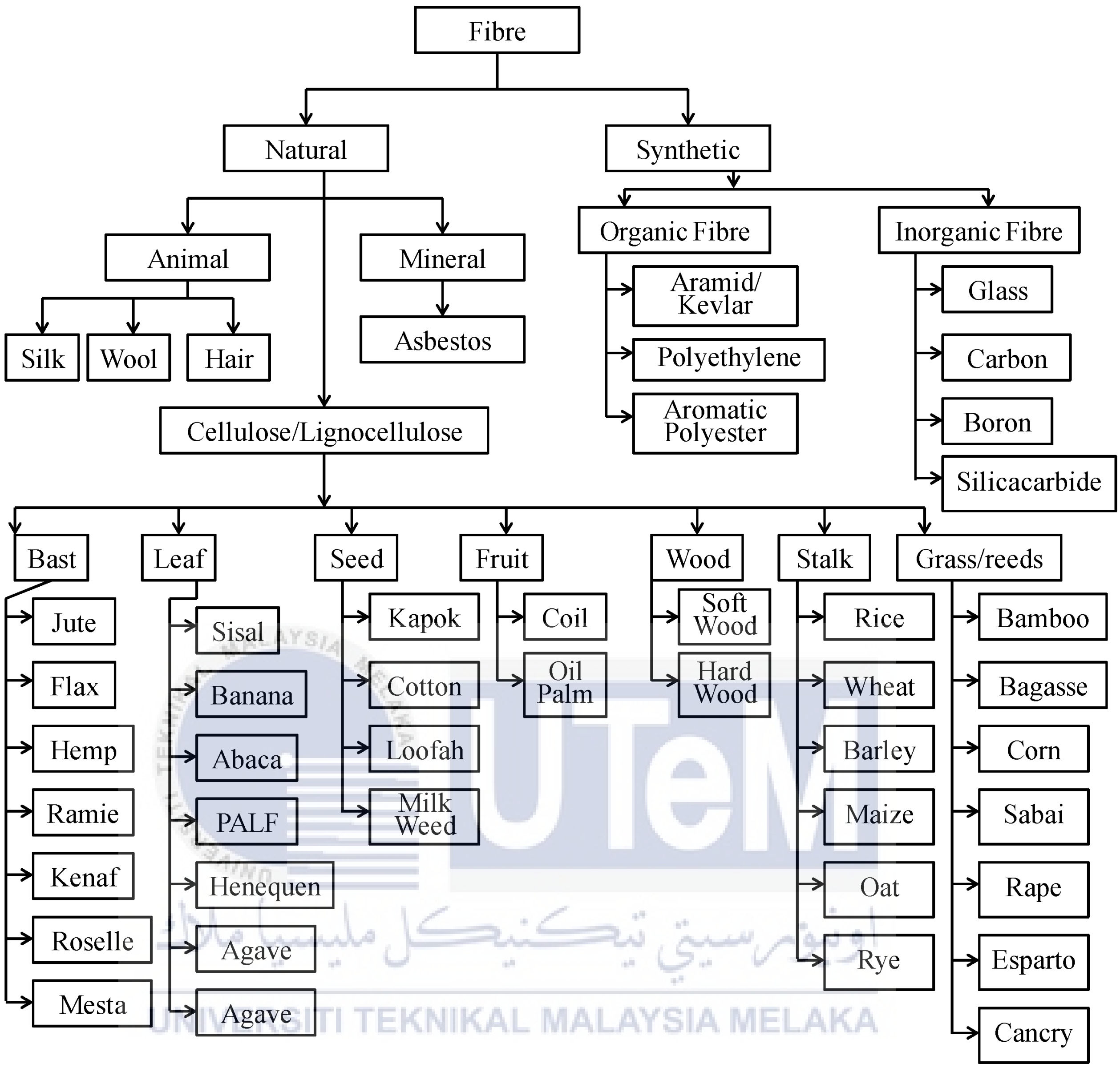


Figure 2.1: Classification of natural and synthetic fibres (Jawaid, M., 2011a).

2.3.2.1 Natural Fibres

In the recent decades, sustainable development of environmental friendly products is the huge factor in the selection of material for engineering applications. Natural fibres which have a great capability of recycling successfully attract the attention of researchers and scientists over conventional glass and carbon fibres. Natural fibres act as an alternative reinforcement in polymer composites. (Malkapuram et al., 2008).

Natural fibres also known as lignocellulosic fibres can be drawn from plants, animal or minerals. For the plant fibres, they are composed of cellulose, hemicellulose, lignin and pectin whereas animal fibres are extracted from protein for example hair, silk and wool. (John et al., 2008). The plant fibres can be further classified into several groups which depend on the extraction sources. Theoretically, there are three main groups of lignocellulosic fibres: the bast, leaf and seed fibres (Ku et al., 2011). The types of natural fibres and their respective origins are summarized in Table 2.1.

Table 2.1: Types of natural fibres and their respective origins (John et al., 2008).

Parts of Plant	Fibres extracted
Bast/stem	Flax, jute, hemp, jute, kenaf, ramie
Leaf/hard	Abaca, banana, cantala, Caros, Cuarua, Pineapple, sisal
Seed	Cotton
Fruit	Coir, oil palm, sponge guard
Grass	Bamboo, bagasse

The most promising advantages of natural/lignocellulosic fibres over synthetic fibres are that they are renewable, biodegradable and consuming less energy. Furthermore, natural fibre reinforced composites have shown the potential to be reprocessed and recycled without prominently deteriorate the mechanical properties. Another attractive characteristic of natural fibres is that the price of natural fibres is about 70% lower than that of glass fibres. For example, pineapple leaf fibre is considered as the waste biomass fibres and hence available at minimal cost. Moreover, natural fibres are lightweight and thus they can be a replacement for metallic material in many applications (Jawaid et al., 2011). Other than that, lignocellulosic fibre leaves limited amount of residue if they are subjected to incineration, turning less carbon dioxide (CO_2) to the atmosphere. Carbon dioxide is greenhouse gases which can deplete the ozone layer causing global warming. The strength and stiffness of natural fibres, for example, hemp, kenaf and jute are becoming increasingly important consideration in composite production.

Moreover, natural fibres possess excellent mechanical characteristics in comparison to the glass fibres, for examples flexibility, stiffness and modulus. Natural fibres are safe to use by a human as it is naturally non-irritation to the skin and non-abrasive to the equipment. Natural fibres also play an important role in achieving the zerowaste strategy in which the natural fibres can be used to generate electricity at the end of their life cycle. The application of composites made of natural fibres is in two categories, extensive application and common application. In the extensive application, for example, consumer goods, low-cost housing and civil structure. The application of traditional lightweight reinforced plastics is constrained by the repressive cost of reinforcements (Sanjay et al., 2017).

One of the main drawbacks of natural fibres is that the mechanical properties of natural fibres especially their strength and young modulus are much lower as compared to the glass fibres. Also, the intrinsic hydrophilicity of natural fibres results in the weak moisture resistance. Due to the hydrophilicity of natural fibres, the fibre-matrix interfacial adhesion in natural fibre based composites is weak, which in turn reduces the mechanical properties. Hence, to solve this problem, several treatments need to be done on natural fibres to improve the moisture resistance and also the adhesion strength.

To improve the properties of fibre reinforced polymer, the orientation of fibres in the composites plays important roles. The mechanical characteristics of fibre reinforced composites are affected by the orientation, length and size of the fibre, which define the ability of the composites to deliver stress to the fibres via the matrix in an effective way (Fuqua et al., 2012**).** The reason behind the great thickness of natural fibres is due to the random orientations of the natural fibres, which are non-continuous, except the natural fibres are spun into yarn. Fibres can be arranged in several orientations such as unidirectional fibres, chopped fibres and woven fibres. However, woven fibre mats are currently among the most attractive orientation due to the high dimensional stability of such orientation. There are several weaving patterns which are uniaxial, biaxial, plain, twill and satin. Table 2.2 shows the comparison of mechanical properties of natural fibres and E-glass fibres (Sanjay et al., 2017).

Table 2.2: Comparison of mechanical properties of some natural fibres and E-glass fibres based on previous studies (Sanjay et al., 2017).

Fibres	Tensile Strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Density (g/cm^3)
Abaca	400	12	3-10	1.5
Bagasse	350	22	5-8	0.89
Bamboo	290	17	-	1.25
Banana	529-914	27-32	5-9	1.35
Coir	220	6	15-25	1.25
Cotton	400	12	3-10	1.51
Curaua	500-1150	11.8	3.7-4.3	1.4
Flax	800-1500	60-80	1.2-1.6	1.4
Hemp	550-900	70	1.6	1.48
Jute	410-780	26.5	1.9	1.48
Kenaf	930	53	1.6	-
Pineapple	413-1627	60-82	14.5	1.44
Ramie	500	44	2	1.5
Sisal	610-720	9-24	2-3	1.34
E-glass	2400	73	3	2.55

Lignocellulosic fibres have been used as reinforcing materials for over 3000 years. Over the centuries, the natural fibres have been widely used by the researcher in the fabrication of fibre reinforced polymer matrix composite (Ku et al., 2011). The study of fibre reinforced polymer began in 1908 and lately advance it step to glass fibre reinforced plastics. The first fibre reinforced plastic used in the history is cotton polymer composite which functions as radar aircraft by the military (Jawaid et al., 2011)

2.3.2.2 Kenaf Fibres

Over decades, kenaf has served multiple functions as it diversity mechanical properties. In past, kenaf has been used as cordage crop to produce rope and sackcloth. Kenaf fibres have superior mechanical properties such as high flexural strength and relatively lightweight that make it an excellent choice to replace many metallic materials. Kenaf fibres could be utilized as a reinforcing material for polymeric composites as an alternative to the glass fibres (Quazi et al., 2011).

Today, the application of kenaf has expanded broadly into a variety of fields such as paper products, building material, absorbent and animal feeds (Edeerozey et al., 2007). The main reason for the demand of kenaf is because of kenaf accumulates carbon dioxide at a significantly high rate and kenaf absorb nitrogen and phosphorus from the soil.

The plantation of kenaf is easy because of kenaf is able to withstand a wide range of weather condition. The average height of the kenaf is above 3 meters with a diameter of 3-5 cm in three months, this indicates that the sources of kenaf fibres can be obtained easily compared to the glass fibres. Figure 2.2 shows the kenaf plant and the product kenaf fibres. Generally, the tensile strength and modulus of kenaf are 11.9GPa and 60GPa. Table 2.3 shows the properties of filled/reinforced polypropylene composite.

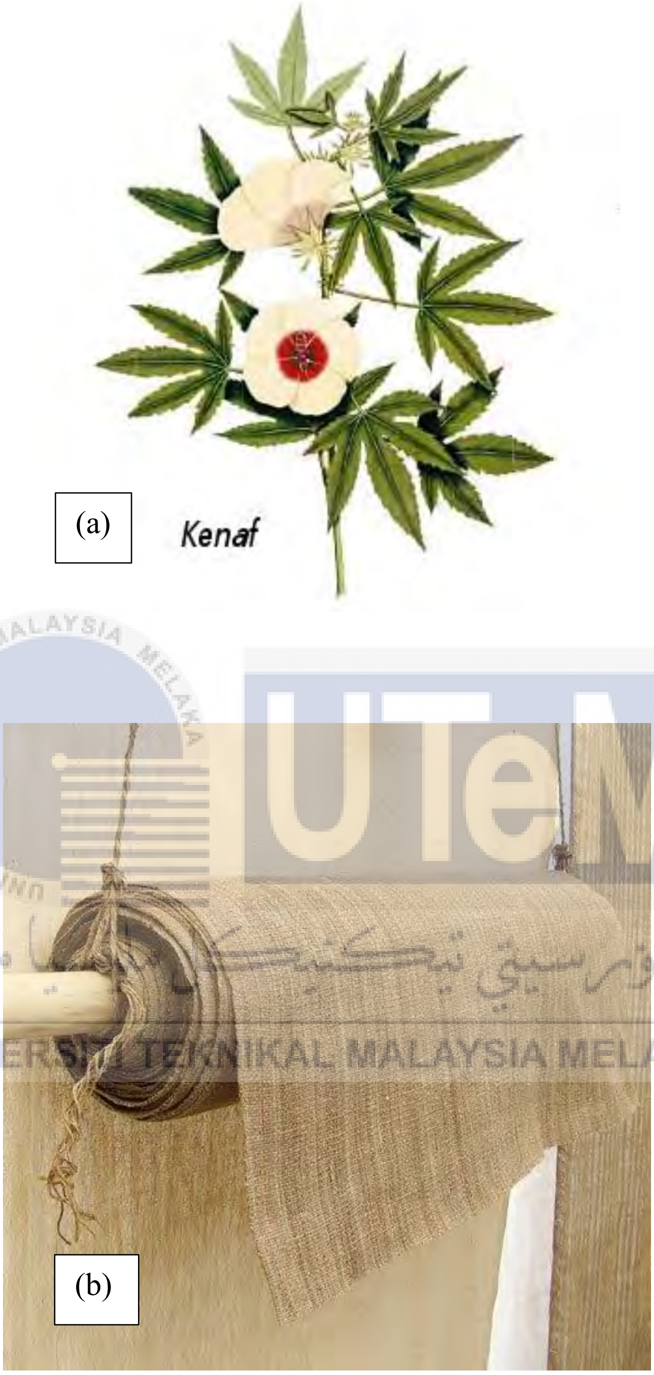


Figure 2.2: (a) Kenaf plant (adapted from https://goo.gl/dRSfwW) and (b) woven kenaf fibre (adapted from https://goo.gl/ikd5zc).

Table 2.3: Properties of filled/reinforced polypropylene composite (Akil et al.,2011).

Filler/Reinforcement in PP	Units	Neat PP	Kenaf	Glass	Talc	Mica
Filler by weight	%	0	50	40	40	40
Filler by volume	%	0	39	19	18	18
Specific gravity	-	0.9	10.7	1.23	1.27	1.26
Tensile modulus	GPa	1.7	8.3	9	4	7.6
Specific tensile modulus	GPa	1.9	7.8	7.3	3.1	6.0
Tensile strength	MPa	33	65	110	35	39
Specific tensile strength	MPa	37	61	89	28	31
Elongation at break	%	>10	2.2	2.5	-	2.3
Water absorption (24h)	%	0.02	1.05	0.06	0.02	0.03

2.3.2.3 Synthetic Fibres

Synthetic fibres are known as man-made fibres, which can be a fabrication from synthesized polymers or other small inorganic molecules. Typically, synthetic fibres have better mechanical properties than natural fibres especially they have advantages to be selected as a replacement material for metallic material. Synthetic fibres have been widely used in many applications, because of the designability of synthetic fibres. The requirement from a customer on the fibres can be custom-made. Although synthetic fibres come along with many advantages, the critical issue that slows down the demand for synthetic fibres is because of their reusability. Sustainable development has been concerned when coming to the selection of material or structure. After the end of the lifespan, synthetic fibres are hard to be recycled and to be decomposed biologically (Srinivas et al., 2012). Hence, the application of synthetic fibres has gradually been replaced by other sustainable and eco-friendly material.

Glass fibres are the most famous synthetic fibres among all. Carbon and aramid are also grouped in synthetic fibres in which carbon fibres show great flexural strength. The reason of synthetic fibres not being fully replaced by the natural fibres is because of their excellent moisture resistance. Figure 2.3 shows a detail classification of synthetic fibres. Generally, a man-made fibre breaks into two main groups, organic and inorganic.

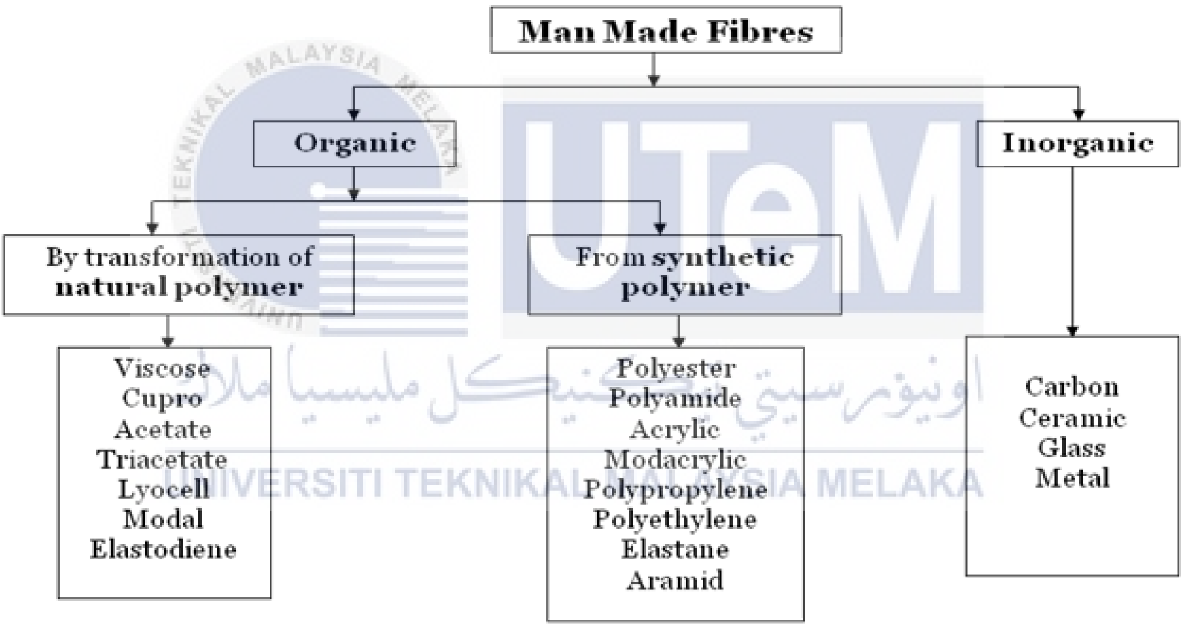


Figure 2.3: Classification of man-made Fibres (adapted from https://goo.gl/pUqixR).

2.3.2.4 Glass Fibres

The raw material of Glass fibre is glass. Glass is put into a furnace and heated up to a very high temperature. The furnace temperature is controlled precisely to ensure the steady flow of glass. The glass then will melt and form a molten glass which than extruded to fabricate into glass fibre (Masuelli et al., 2013).

Among all synthetic fibres, glass fibres are the most commonly used in the fabrication of composite due to their low cost as compared to aramid and carbon. Glass fibres typically have better mechanical properties than natural fibres (Sanjay et al., 2017). Glass fibres are lightweight, high strength and robust material. Even though carbon has better properties in stiffness, the raw material price for glass is less expensive and the structure of glass fibres is far less brittle. Glass fibres can be easily fabricated by using moulding because of their build strength and weight properties (Quazi et al., 2011). The applications of glass fibres are wide such as automobile, roofing, pipes, external door barrier and etc.

Previous studies have been reported that glass fibre reinforced polypropylene polymers are very attractive due to their potential for impressive strength to weight ratios and impact energy absorption. The excellent behaviour forms the increasing popularity of the glass fibre reinforced polypropylene in the applications of automotive and energy (Fitoussi et al., 2013). Table 2.4 compared the properties of natural fibres and glass fibres in terms of density, cost, renewability, recyclability, energy consumption, CO_2 neutral, abrasion to the machine, inhalation health risk and disposal.

Table 2.4: Comparison of properties of Natural Fibre and Glass Fibre (Sreenivasan et al., 2013).

Properties	Natural fibres	Glass fibres
Density	Low	Twice that of NF
Cost	Low	Low, but higher than NF
Renewability	Yes	No
Recyclability	Yes	No
Energy consumption	Low	High
Carbon Dioxide, CO_2	Yes	No
Abrasion to machines	No	Yes
Inhalation health risk	No	Yes
Disposal	Biodegradable	Not biodegradable

2.4 Mechanical Properties

The nature of fibre and the matrix used determine the mechanical properties of the composite (Vinay et al., 2016) The mechanical properties of fibre being tested are tensile strength, young modulus, impact behaviour and flexural properties. Venkateshwaran (2012) stated that the mechanical properties are influenced by fibre orientation, fibre length, weight ratio and interfacial adhesion between fibre and matrix. The previous study showed that hybrid composites that composed of natural and synthetic fibres are able to improve the mechanical properties of the composite in term of better impact strength, increased fatigue life and high stiffness (Srinivas et al., 2012).

2.4.1 Density

The density of the fibre reinforced polymers influences the stiffness and strength of the composite. Also, higher density results in the heavy composite which is not favoured to sustainable development. Equation (2.2) stated that the calculate the density of the material,

$$\rho(g/cm^3) = m/v \tag{2.2}$$

Where ρ is the density of the material, m is the mass of material and v is the volume of material.

For Hybrid composites which consist of more than one type of fibre, the density of the composite can be calculated by using Eq. (2.3).

$$\rho_c = \rho_m . V_m + \rho_f . V_f \tag{2.3}$$

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

2.4.2 Tensile Strength

Li et al. (2013) studied the mechanical behaviours of unidirectional flax and glass fibre reinforced hybrid composites. The purpose of the study is to investigate the effect of hybridization on hybrid flax/glass fibre reinforced composites. The result showed that the tensile properties of the flax/glass fibre hybrid composite have been improved with the increasing of glass fibre content in the composites. Also, the tensile strength and tensile failure strain showed much influence on the stacking sequence of the fibre, but not the tensile modulus. Rule of Mixture (ROM) was used to predict and calculate the tensile strength of the components. Figure 2.4 and 2.5 showed the graphically how the Glass fibre volume content (%) influenced the tensile modulus (GPa) of the composite.

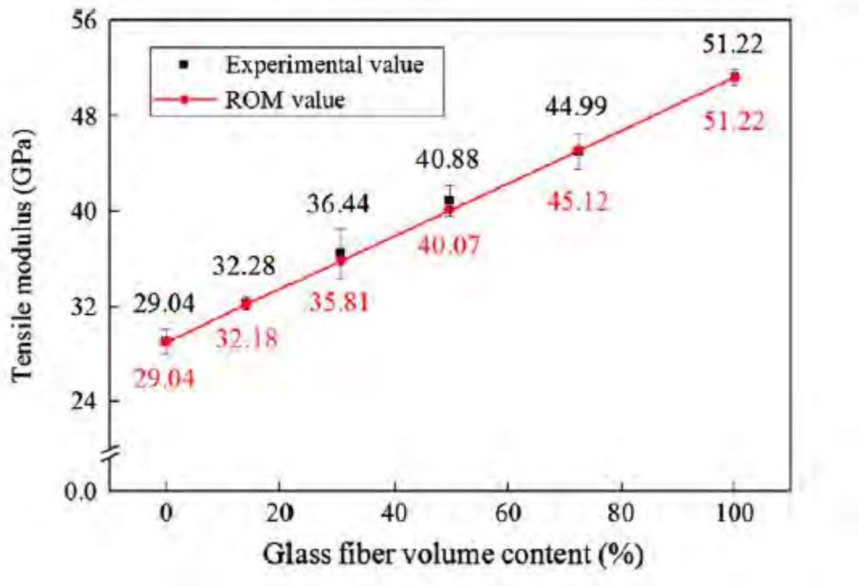


Figure 2.4: Glass fibre volume content (%) versus tensile modulus (GPa) for experimental value and ROM value.

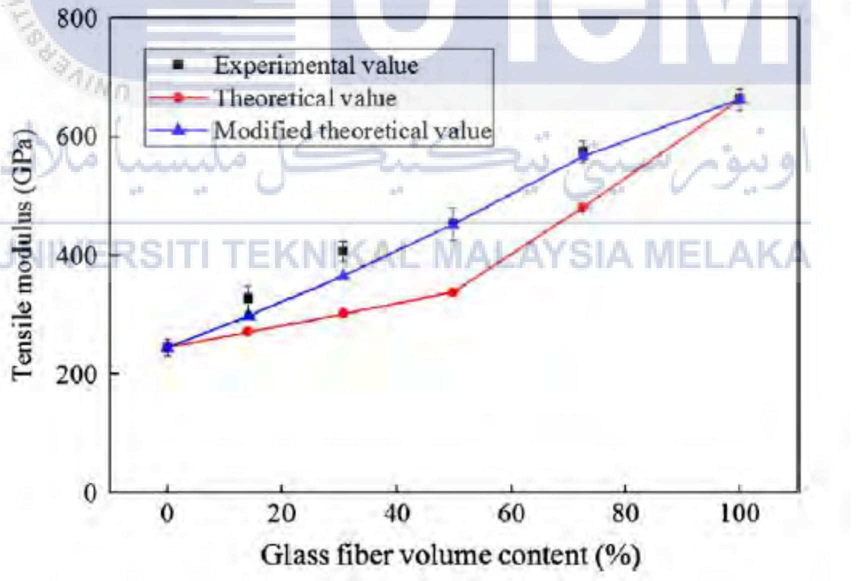


Figure 2.5: Glass fibre volume content (%) versus the Tensile modulus (GPa) for Experimental value, Theoretical value and Modified theoretical value.

Vinay et al. (2016) studied the mechanical properties of Kevlar/carbon fibre reinforced vinyl ester resin and glass/carbon fibre reinforced vinyl ester resin hybrids. The hybrid composites were fabricated using hand layup methods. The result of the study indicated that the mechanical properties of hybrid composites improved advance compared with individual pure fibre. Overall, glass/carbon fibre reinforced composites showed the highest mechanical properties.

Venkata and Ramprasad (2016) studied the tensile properties of hybrid jute/carbon fibre reinforced epoxy composites and further compared the tensile properties with pure jute-epoxy and carbon-epoxy composites so to establish the development of hybrid composites. From the result, the hybridization of jute/carbon fibre reinforced epoxy showed thirty times more tensile strength that pure jute-epoxy composites. The result also showed that the tensile strength can be improved to 16 times by mixing half jute and carbon fibres in the epoxy composites. For the percentage of elongation, jute/epoxy hybrid composites showed the highest result thus indicating that hybrid composites have good toughness value.

Pandya et al. (2011) studied the mechanical properties of pineapple leaf/sisal fibre reinforced polyester composites. The result showed a great improvement in tensile strength of hybrid composite. Moreover, the water absorption tendency of composite decreased in hybrid composites, indicating the improvement of moisture resistance. Basiji et al. (2010) also reported that the tensile strength of hybridized composite has better value as compared to single natural fibres based composites.

Naresh et al. (2016) studied the tensile strength of GFRP, CFRP and hybrid composites with statistical analysis (Weibull statistical analysis). From the result obtained, it indicated that there is a significant strain-rate effect on the tensile strength of GFRP and hybrid composites.

Adhikari and Gowda (2016) investigated the banana/jute hybrid polyester composites in terms of their tensile strength. They revealed that the tensile strength is increased when the volume fraction of fibre is increased until it reaches 15% due to better load carrying capacity of fibre. The further increment of fibre content decreased the tensile strength due to poor interfacial adhesion between fibres and matrix. Figure 2.6 showed the tensile strength of various volume fraction of fibre for 3mm and 5mm thickness specimen.

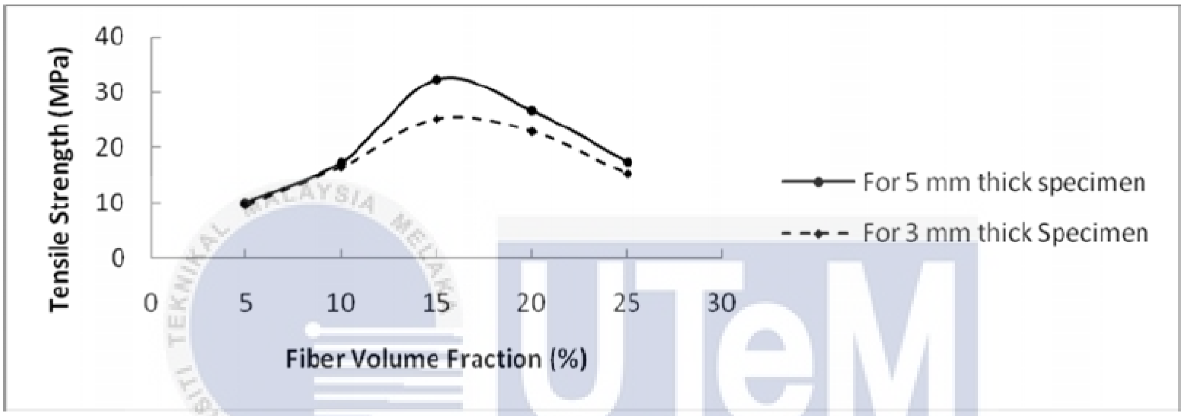


Figure 2.6: Tensile strength of composite.

Navjot et al. (2015) studied the effect of reinforcing sisal and hemp fibres, either alone or simultaneous into polymer matrix containing 50-50 mixture of fresh and recycled high density polyethylene (HDPE) on the tensile behaviour. The tensile strength of the sisal-hemp fibres/HDPE hybrid composites is superior to single fibre (hemp/sisal) reinforced HDPE composite. Mirbaghere et al. (2007) reported that the enhancement in tensile properties of the wood flour reinforced polypropylene composite when the composite was further reinforced with kenaf fibres.

2.4.3 Impact Properties

Hung et al. (2017) investigated the impact response of hybrid carbon/glass fibre reinforced polymer composite. It was found that the damage size and defection due to impact can be reduced by incorporating the carbon fibres at the top and bottom layers of composites. This is due to carbon fibres have higher flexural strength and the flexural strength of the composite is controlled by the strength of the bottom layer.

Yan et al. (2015) have used recycled Kevlar fibres hybridized with glass fibres to fabricate a new type of hybrid composite which was then subjected to low-velocity impact to study its impact properties. The stacking sequence was arranged where the kevlar fibres were placed as top and bottom layers while the glass fibres were located in the middle of the composites. The result showed that areal density of fibres significantly influences impact behaviour which in most of the time, increasing in areal density of fibres able to increase the impact performance of hybrid composite.

Sarasini et al. (2016) have carried out a research on the low-velocity impact damage behaviour of carbon/flax hybrid composites. In the research, the results showed that the stacking sequence greatly influenced the flexural strength of the hybrid composites. This is due to the increment of the volume fraction of carbon fibres that have a higher strength to resist the damage. The damage and defects were recorded and discussed. The images of damage are shown in figure 2.7. The study concluded that hybrid composites based on carbon fibre layer will have better flexural strength compared to other natural fibre layers.

Figure 2.7: The scanned image of damage of different configuration hybrid composite after subjected a 10J impact.

Zhu et al. (2015) have investigated the impact behaviour and damage characteristics of hybrid composite Ti/M40 fibre reinforced polymer composites. They reported that the fracture behaviour of hybrid composites was predominated by their poor bonding interface. The size of the projectile would affect the type of damage induced, with larger diameter projectile, much more energy is transmitted to the hybrid composite which induced more damage.

Bulut and Erklig (2017) investigated the quasi-static indentation effect on laminated hybrid composite plates. They studied the energy absorption and load carrying capacity of the hybrid composite laminates for two different cases (double and triple fibre configurations). The results showed that the hybridization of two or three different fibres significantly affects the indentation responses (force and absorbed energy) with respect to non-hybrid composites.

Sayer et al. (2010) performed an experimental investigation of the impact behaviour of hybrid composite plates made from carbon and glass fibres. The hybrid composites were subjected to an impact loading and the results showed that the hybrid composites which have the highest impact resistance are carbon/glass hybrid composites and the sequence of the test is carbon at tension side and glass at impacted side. It can be seen clearly in Figure 2.8 and Figure 2.9, the damage on carbon/glass hybrid composites is relatively small as compared to glass/carbon hybrid composites.

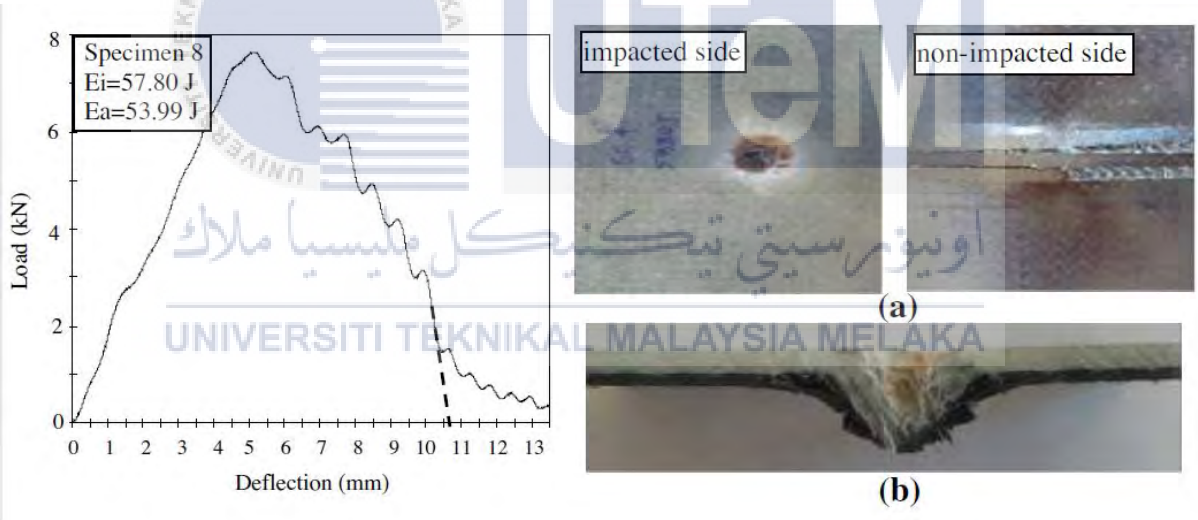


Figure 2.8: The load–deflection curve of specimen 8 for GC and image of damaged specimen (a) impacted side and non-impacted side, (b) cross-section.

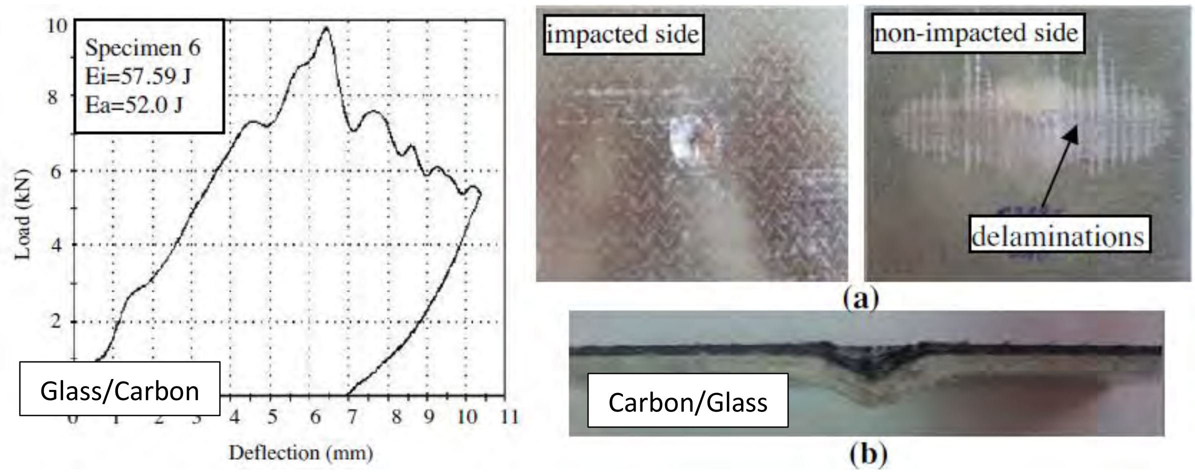


Figure 2.9: The load–deflection curve of specimen 6 for CG and image of damaged specimen: (a) impacted side and non-impacted side, (b) cross-section.

Gustin et al. (2005) investigated the low-velocity impact on a sandwich composite of Kevlar/carbon fibres. The results showed that the stiffness of the laminates decreased when the Kevlar fibres were introduced into the system. However, the Kevlar fibres increase the energy absorption capacity of the laminates.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the methods on how to carry the investigation and experiment of the hybrid fibre reinforced polymer. The detail of each step and precautions will be discussed in each section to provide a clear guideline when carried out the experiment. The test which will be conducted is tensile test, quasi-indentation impact test and low-velocity impact test.

All the testing is conducted based on specific standards from ASTM. The flow chart of the methodology is shown in Figure 3.1.

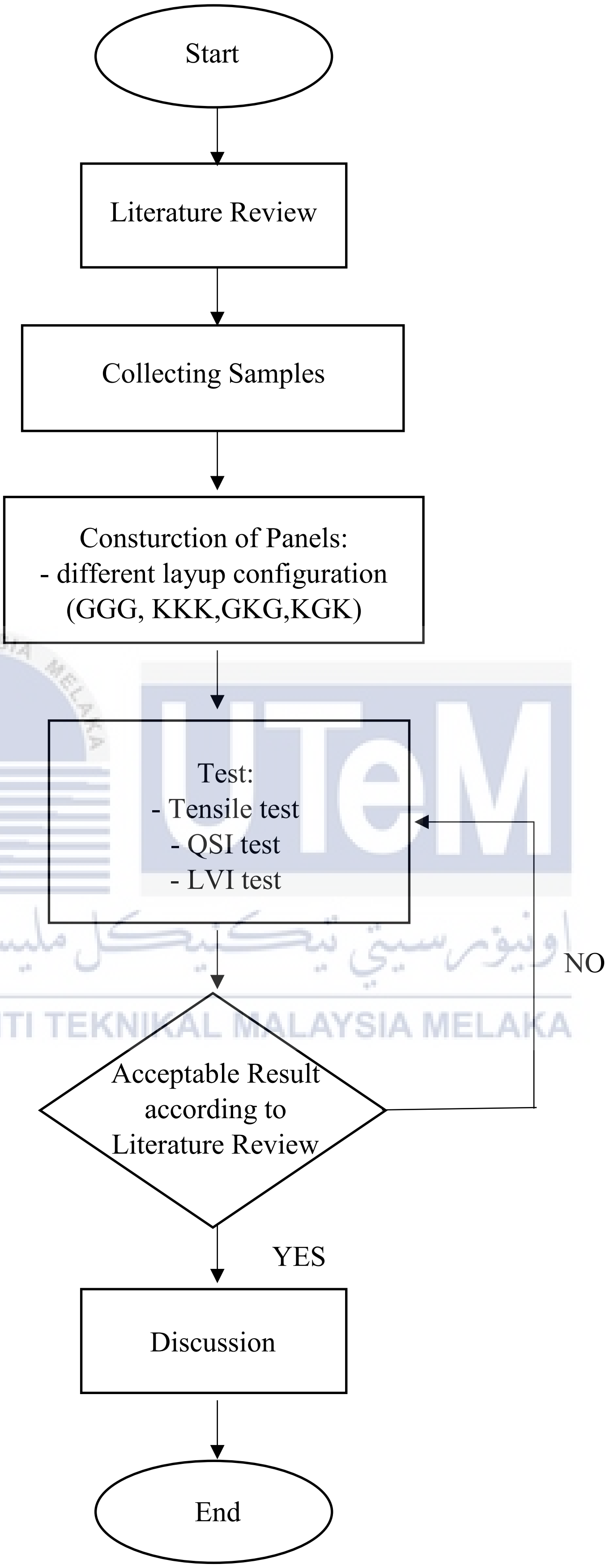


Figure 3.1: Flow chart of the methodology.

3.2 Materials

The materials investigated in this study is hybrid kenaf/glass fibre reinforced polypropylene composites. The glass fibre layers were partially substituted with kenaf fibre layers in the hybrid composite laminates. The thermoplastic based polymer matrix that binds the hybrid composite is, polypropylene (PP). The hybrid composites consist of a total number of three fibre layers. Hybrid composite laminates with four stacking sequences of fibre layers were fabricated. The different stacking sequences of fibre layers are non-hybrid glass fibre reinforced composites (GGG), non-hybrid kenaf fibre reinforced composites (KKK), hybrid glass/kenaf/glass composites (GKG)and hybrid kenaf/glass/kenaf composite (KGK). The stacking sequences of the hybrid composite are shown in Figure 3.2.

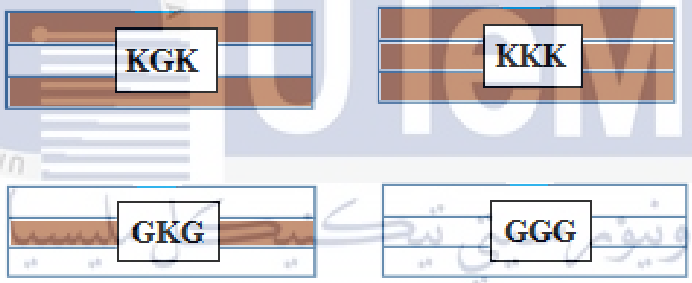


Figure 3.2: Stacking sequence of the hybrid composites.

3.2.1 Polypropylene Matrix

Polypropylene matrix is of categories of the thermoplastic polymer. The advantages of using the thermoplastic polymer as a matrix in the fabrication of hybrid composites are that they are eco-friendly, can be recycled from the waste product and the excess can be re-melted and reused. Also, the temperature for PP sheet to be melted is 175 °C which can be melt with the natural fibres without affecting the thermal stability.

The PP sheet used for this study is fabricated from a raw material, spherical pellets. A portion of spherical pellets was poured into a mould and being compressed using motorize hydraulic moulding test press machine. The temperature was set at 175 °C for spherical pellets to melt. The dimension of the PP sheet formed was 250mm x 250mm. All these PP sheets will be used in the fabrication of hybrid composite as matrix layer. Figure 3.3 showed the image of spherical pellets, motorize hydraulic moulding test press machine and PP sheet fabricated.

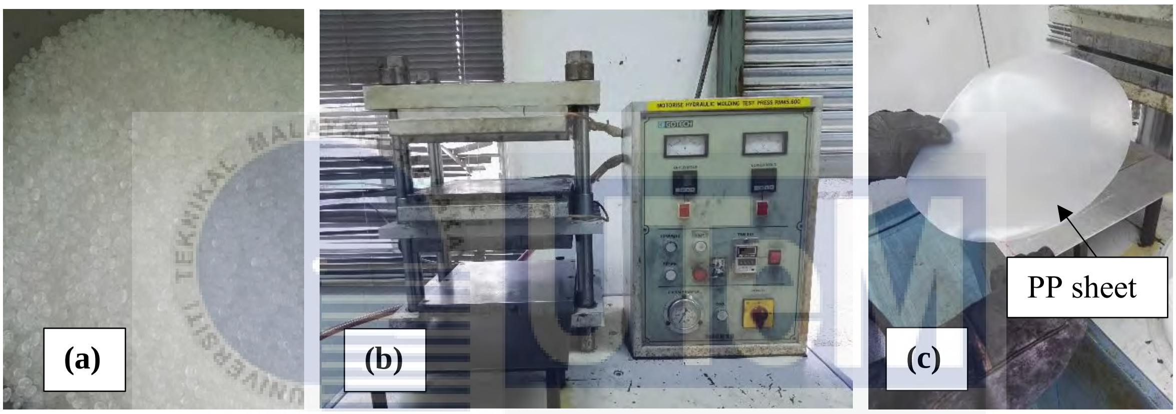


Figure 3.3 : (a) spherical pellets, (b) motorize hydraulic moulding test press machine and (c) PP sheet fabricated.

3.2.2 Fibres

The fibres used in this study come from two classes, natural and synthetic fibres. The fibres were cut into a dimension of 250mm x 250mm. Figure 3.4 depicts the woven glass and kenaf fabrics respectively.

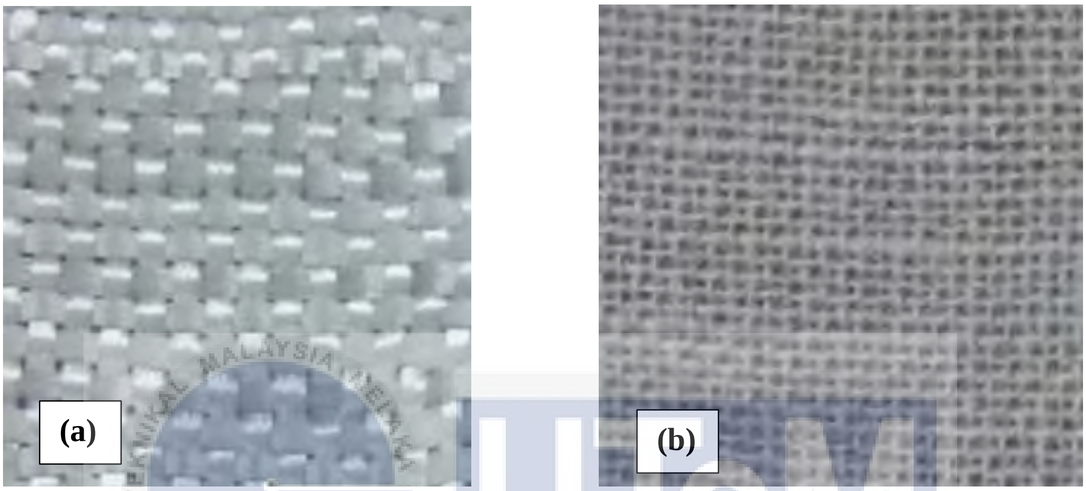


Figure 3.4: (a)Woven Glass Fibre and (b)Woven Kenaf Fibre.

3.3 Hybrid Composite Fabrication

The fabrication process of hybrid composites is through the film stacking method. This method was carried out by stacking matrix polymer film and reinforcing fibre alternatively. The stacked piece was then compressed using motorize hydraulic moulding test press machine under a certain temperature. This method is suitable for fabricating a low viscous polymer with reinforcing fibres (Mudhukrishnan et al., 2015).

First, the motorize hydraulic moulding test press machine was set to 175 °C and the pressure was fixed at 3.5 MPa The fibres and PP sheets were placed in a mould with dimension of 250mm x 250mm with thickness 3mm between the plates and the press. The hybrid composite was then pre-heated under 175 °C for two minutes, to ensure all the PP sheets have been melted to ensure fluent flow when compression process. The orientation of the fibres were in same direction to minimize the variable which may affect the result of this study. The stacking sequence for example KGK, kenaf/glass/kenaf fibre, was PP/K/PP/G/PP/PP/K/PP (refer figure for all stacking sequence. 5 layers of PP was used to make sure that the composition of matrix was able to bind all the reinforcement together. The hybrid composites were subjected to the compression process for 8 minutes to ensure the interfacial adhesion of the fibres was stable. The hybrid composite was cooled for another 8 minutes before taken out from the mold.

3.4 Specimen Preparation

The 250mm x 250 mm hybrid composites fabricated from the film stacking process were cut into specific dimension according to the corresponding ASTM standard for each test. The tests are tensile test, quasi-static indentation test and low-velocity impact test. The hybrid composites were cut into the requirement dimension with the use of Proxxon table saw machine. All the detail data for the test is tabulated in Table 3.1

Table 3.1: The detail data of the specimen for respective tests according to ASTM.

Properties	Standards	Specimen shape	Specimen dimension (Length x width)	Thickness
Tensile	ASTM D3039	Rectangular	200mm x 25mm	3 mm
QSI	ASTM D6264	Square	100mm x 100mm	3 mm
LVI	ASTM D7136	Square	100mm x 100mm	3 mm

3.5 Tensile Test

The machine used for the tensile test was INSTRON 5969 universal testing machine (UTM) as shown in Figure 3.5. The tensile test was conducted with reference to ASTM D3039 standard procedure. The specimen with a dimension of 200mm x 25mm was clamp top and bottom, and quasi-static cross-head displacement rate was set up as 2mm/min. The test was ended as the specimen fracture. The stress-strain curves were drawn in a graph and the results were tabulated in a table for further discussion. The tensile test for each specimen was repeated 3 times to ensure the accuracy of the data by taking the average value.

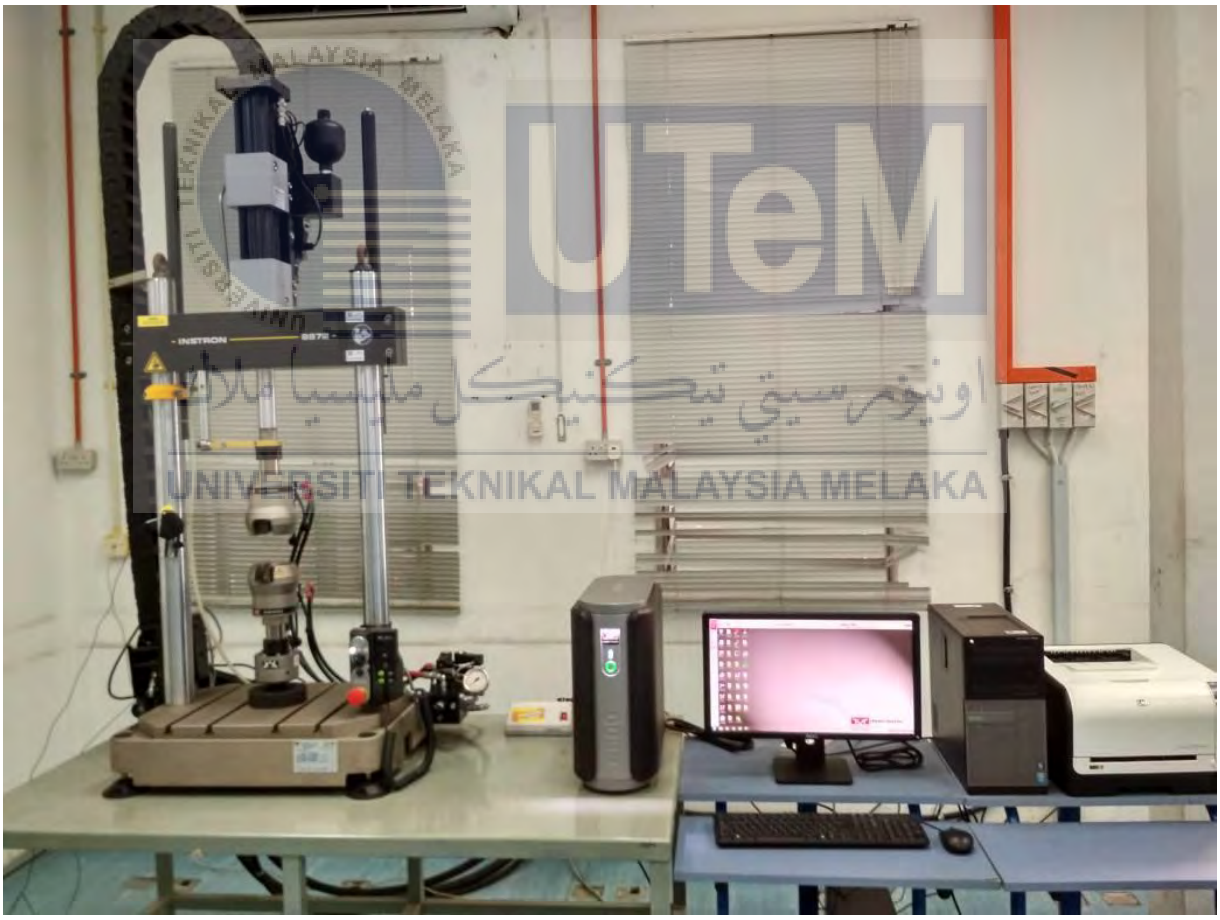


Figure 3.5: INSTRON 5969 universal testing machine (UTM).

3.6 Quasi-static Indentation Test

The quasi-static indentation test was conducted according to the ASTM D6264 to measure the impact behaviour of the hybrid composites by investigating the damage size and shape on the surface that was impacted by the indenter. The Indentation test was carried out using INSTRON 5585 Universal Testing Machine which has 150kN capacity. The specimen was clamped with 4 screws on all four edges on the UTM test board with an open hole in the middle. The screw locked up by using torque wrench diagonally to prevent extra tension on the specimen when conducting the testing. The crosshead displacement rate was fixed at 1.25 mm/min. The actual and schematic diagram of the UTM machine was shown in Figure 3.6.

Figure 3.6: INSTRON 5585 Universal Testing Machine.

3.7 Low-velocity Impact Test

The low-velocity impact tests were performed based on ASTM 7136 standard using INSTRON 9250 machine. A hemispherical impactor with 12.7mm diameter and 6.5 mass was dropped on the specimen to evaluate the impact force over time. There is an optical sensor which recorded the incident velocity. Hence, graph can be generated simultaneously with the testing process. Figure 3.7 showed the actual view of the Low-velocity impact machine.

Figure 3.7: INSTRON 9250 Impact testing machine.

CHAPTER 4

DATA AND RESULTS

4.1 Volume Fraction

Volume fraction is the ratio of the volume of the fibre to the total volume of the composite. Volume fraction can be used to determine the mechanical properties of the composite, for example, the composites density, mass, and void content can be calculated using rule of hybrid. Composites can have different combination of matrix and reinforcement. The density of glass fibre is 2.55g/cm^3, kenaf fibre is 1.4g/cm^3 and the thermoplastic polypropylene is 0.90g/cm.

To calculate the volume fraction of the composite, it is necessary to obtain the mass, volume and density of the fibre and polypropylene in the composite. The mass of the pure kenaf fibre, glass fibre, polypropylene sheet and composites panels are measured using electronic balance. The equation to calculate the volume fraction is expressed by the Eq (4.1).

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

where V_f is the volume fraction of fibre, v_f is the volume of fibre and v_c is the volume of composite.

The equation can be rewritten in the form of Eq (4.2).

$$V_{kenaf} = \frac{\frac{m_{kenaf}}{\rho_{kenaf}}}{\frac{m_{glass}}{\rho_{glass}} + \frac{m_{kenaf}}{\rho_{kenaf}} + \frac{m_{polypropylene}}{\rho_{polypropylene}}} \tag{4.2}$$

The volume fraction of composite samples was calculated and tabulated in a table. Table 4.1 shows the volume fraction for each material in the composite.

Table 4.1: Volume fraction of each material in the composite.

Sample of Composite	Volume fraction of glass fiber	Volume fraction of kenaf fiber	Volume fraction of polypropylene
GGG	23.53	0	76.47
KKK	0	21.07	78.93
GKG	15.69	7.03	77.28
KGK	7.84	14.05	78.11

4.2 Void content

Void is a pore that remains unoccupied in a composite material. Significant amount of void can affect mechanical properties of the composites. Hence, void might alter the validity of the result. The void content can be calculated by finding the difference between the theoretical density of composite to the measured density of the composite. The formula for determining the theoretical density of the composite and void content is expressed by the Eq (4.3) and (4.4).

$$\rho_c = \rho_{glass}.V_{glass} + \rho_{kenaf}.V_{kenaf} + \rho_{polypropylene}.V_{polypropylene} \tag{4.3}$$

where ρ_c is the theoretical density of the composite, ρ_{glass} is the density of the glass fibre, V_{glass} is the volume fraction of glass fibre, ρ_{kenaf} is the density of kenaf fibre, V_{kenaf} is the volume fraction of kenaf fibre, $\rho_{polypropylene}$ is the density of polypropylene, $V_{polypropylene}$ is the volume fraction of polypropylene.

$$V_v = \frac{\rho_{ct} - \rho_{cm}}{\rho_{ct}} \tag{4.4}$$

Where V_v is the void content (volume fraction), ρ_{ct} is the theoretical density of the composite, ρ_{cm} is the measured density of the composite.

Table 4.2 shows the theoretical density, measured density and void content of the composite, GGG, GKG, KGK and KKK composites.

Table 4.2: Measured and theoretical density and void content of each composite.

Sample of composites	Measured density (g/cm^3)	Theoretical density (g/cm^3)	Void content (%)
GGG	1.235	1.289	4.189
KKK	1.001	1.045	4.211
GKG	1.166	1.194	2.356
KGK	1.053	1.100	4.272

4.3 Tensile Test

The ultimate tensile strength and young modulus of the composite laminates are shown as in Figure 4.1. Significantly, the ultimate tensile strength is increased with the incorporation of glass fibre in the composite. This is due to that glass fibre has much better mechanical properties than kenaf fibre. As the volume of glass fibre increases, the mechanical properties increase. It could be observed that the GGG composite exhibited the highest tensile strength at 85.795MPa, followed by GKG hybrid composite at 72.039MPa. The ultimate tensile strength of GKG is 12.99% lower than GGG, while KKK non-hybrid composite is 16.03% lower than KGK. This is due to the middle layer of the fibre only act as the interphase for the composite which not much alter the mechanical properties. A similar trend is observed for the young modulus**.** Table 4.3 shows the tensile properties of composite laminates.

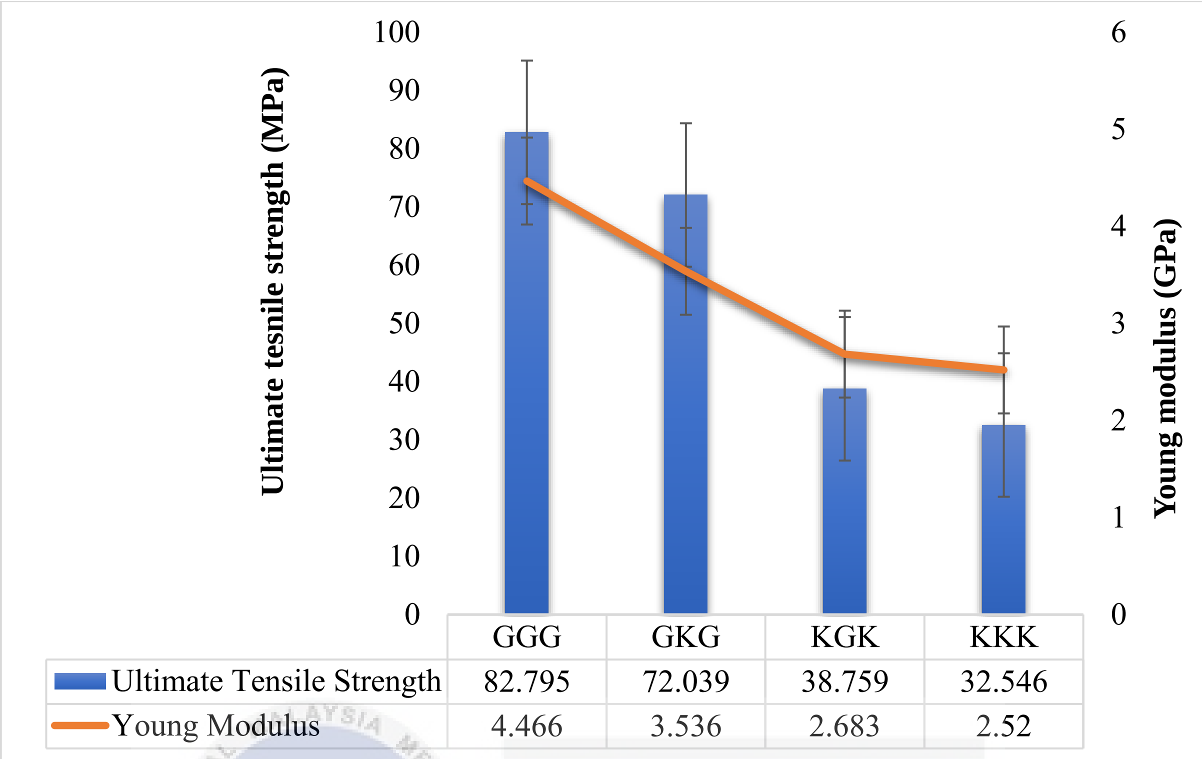


Figure 4.1: Ultimate tensile strength and Young Modulus of composite laminates.

Table 4.3: Tensile properties of composite laminates.

Sample of composites	Ultimate tensile strength (MPa)	Maximum load (kN)	Young modulus (GPa)
GGG	82.795 ± 0.918	6.14 ± 0.534	4.466 ± 0.252
GKG	72.039 ± 1.994	5.21 ± 0.203	3.564 ± 0.131
KGK	38.759 ± 1.276	2.68 ± 0.434	2.683 ± 0.243
KKK	32.546 ± 2.055	2.16 ± 0.384	2.520 ± 0.415

4.4 Quasi-static Indentation

Quasi-static indentation test was conducted to study the composite impact resistance when subject to a load. The result of the test is analysed in term of force-displacement curves, total energy absorption, peak load, and the damage mechanisms. The typical quasi-static indentation force-displacement curve is shown in Figure 4.2. The curve increases linearly with displacement up to knee point, where delamination occurred. Beyond this point, the curve started to increase non-linearly until it reached the maximum load which is the peak load that the specimen can withstand. Beyond the maximum load, the specimen was fully failed and the rest of the load was caused by the frictional force.

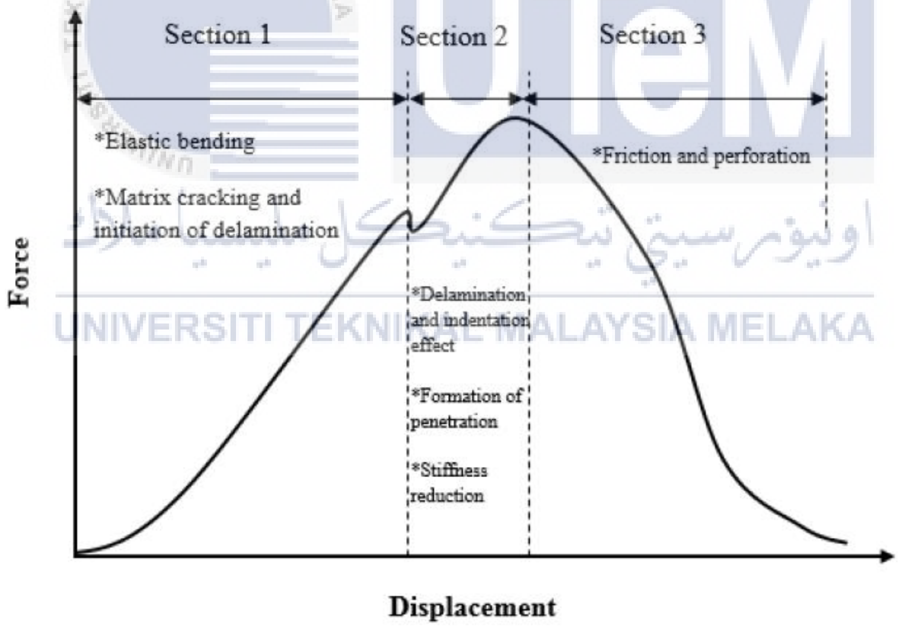


Figure 4.2: Typical force-displacement curve of quasi-static indentation (Bulut, M & Erkig, A, 2017).

Figure 4.3 shows the penetration force-displacement curve for glass and kenaf fibre hybrid and non-hybrid composites. As shown in the Figure 4.3, it can be observed that GGG composite has a better penetration resistance compared to other composites, as it retained the load applied up to 1.40221 kN. This might be due to the strength of the outer layer which resists the formation of shear plug. However, the peak load of hybrid composite GKG was only 5.82% lower than GGG. This could be due to the middle section fibre of a GKG not much affecting the penetration resistance as it only provided interphase for both face sheet fibre. For the curve of GGG and GKG composites, both show a similar trend where the knee point occurs when the indenter was approximately 5mm down. The knee point was most probably due to the fibre and matrix breakage. For the KGK and KKK composites, both showed similarities in the form of the curve.

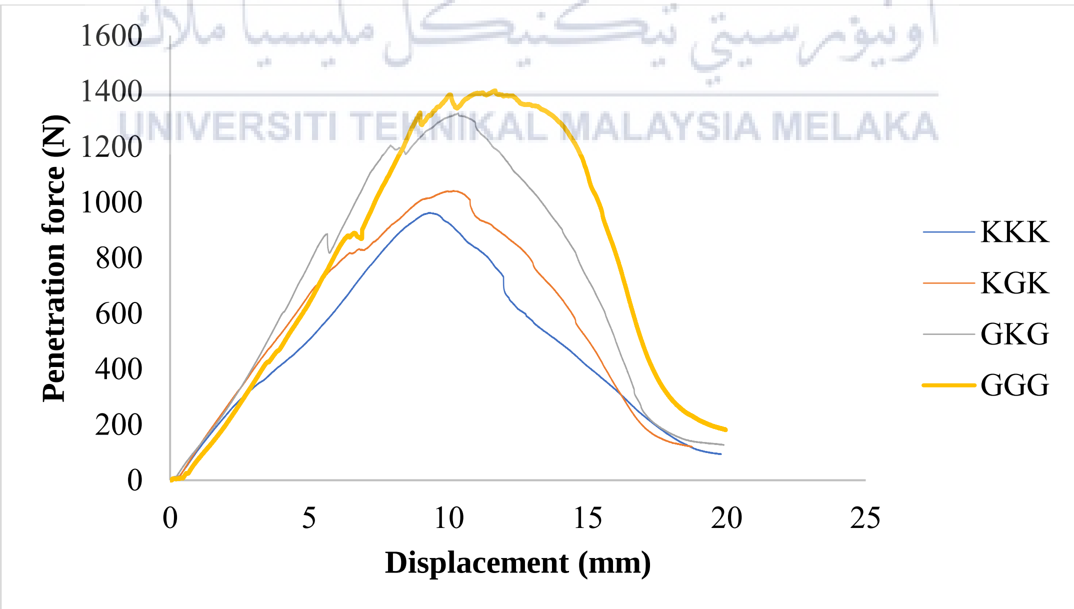


Figure 4.3: Penetration force-displacement curves of composite laminates.

From Table 4.4 and Figure 4.4, it is clear to observe that the energy absorption and maximum force increase as the content of glass fibre increase in the composite. The energy absorption and maximum penetration of GGG composites are the highest among other composites. This is due to glass fibre has significantly better mechanical properties and penetration resistance than natural fibre. However, the energy absorption and maximum force of GKG composite only 7.08% and 5.82% lower than GGG composite respectively. The penetration resistance of the materials is mainly dominated by the outermost layers and thus GKG composite has a comparable energy absorption and maximum load to the non-hybrid GGG composites. As reported by Subramaniam et al. (2017), the placement of high strength fibres as the outermost layers of the composites results in the extension of the force-displacement curve, resulting in higher energy absorption capacity. GKG composite has lower density and mass than GGG composites, leading such material as a better selection towards lightweight and higher performance materials. A similar trend was also noticed for the KGK and KKK composite, as the energy absorption and maximum force of KGK only 13.33% and 7.59% higher than KKK composite.

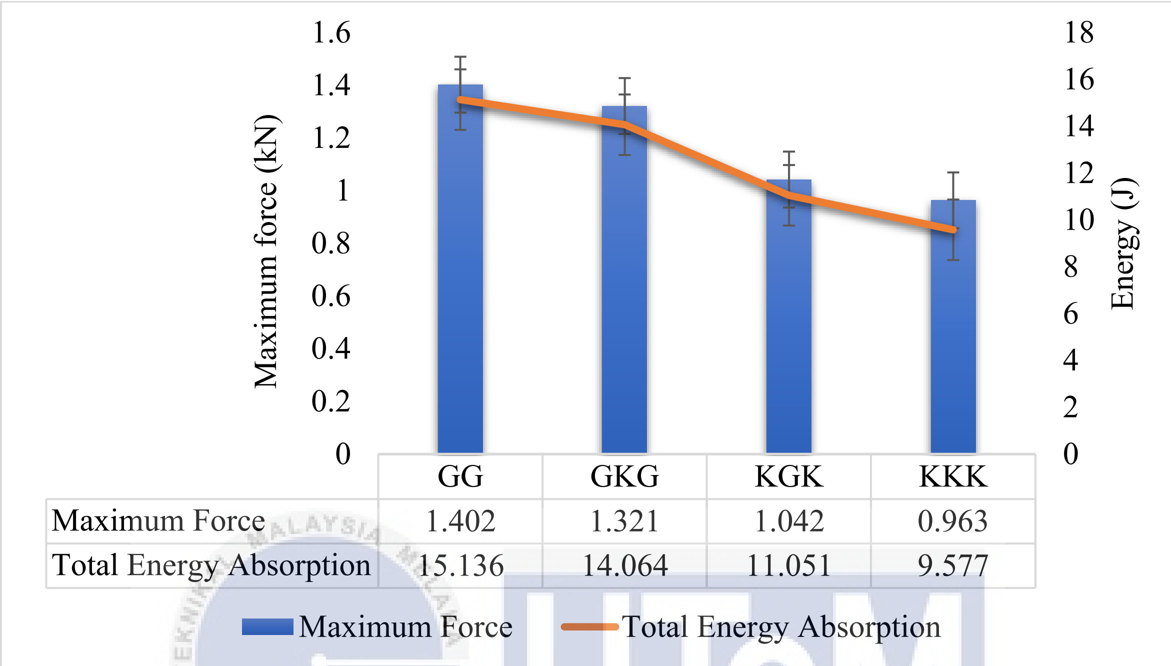


Figure 4.4: Maximum force and penetration energy of composite laminates.

Table 4.4: Total energy absorption and maximum force of composite laminates.

Sample	Total Energy absorption (J)	Maximum force (kN)
GGG	15.136	1.402
GKG	14.064	1.321
KGK	11.051	1.042
KKK	9.577	0.963

The specific energy absorption is calculated by dividing the total energy absorption by the mass of each composite while energy density was calculated by multiplying specific energy with density of each composite. Figure 4.5 shows the specific energy and energy density for each composite. Among the specimen, GKG hybrid composite recorded the highest specific energy absorption at 392.68 J/kg, that is 0.26% higher than GGG non-hybrid composite. This may be due to that the middle layer of kenaf fibre did not contribute much on the energy absorption of the composite. Meanwhile, the weight of kenaf fibre is less than glass fibre, resulting in higher specific energy absorption compared to GGG non-hybrid composite. A similar trend also could be seen for the KGK and KKK composite. The specific energy of KKK was only 5.20% lower than KGK. In accordance with the result, it may be observed that the middle layers of the fibre in the composite laminates do not have the significant effect on the energy absorption. However, the middle layer plays a significant role in reducing the overall weight of the composite laminates without compromising the energy absorption capacity through the appropriate hybridisation. As can be noticed in Figure 4.5, the energy density shows the similar trend for KKK and KGK composites. However, different trend was discerned for GGG and GKG composite owing to the higher density of GGG composite in comparison with GKG composite.

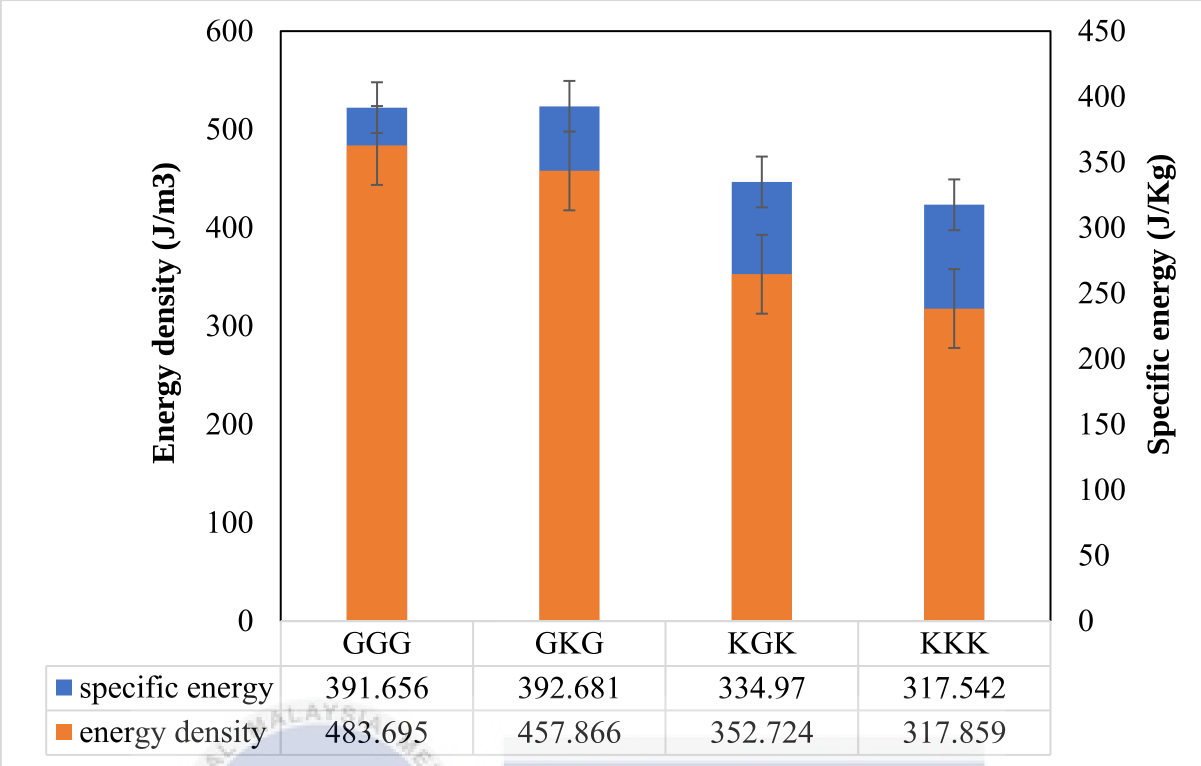


Figure 4.5: Specific energy and energy density of composite laminates.

4.5 Low-Velocity Impact

The low-velocity impact was conducted to study the impact behaviour of a material when subjected to a drop weight impact under different energy levels. The most important experimental finding from the low- velocity impact is the force-displacement curve of the material. This curve illustrates the impact behaviour of a material when subjected to low-velocity impact. There are two types of force-displacement curve patterns which are open type and close type curves (Farzin et al, 2016).

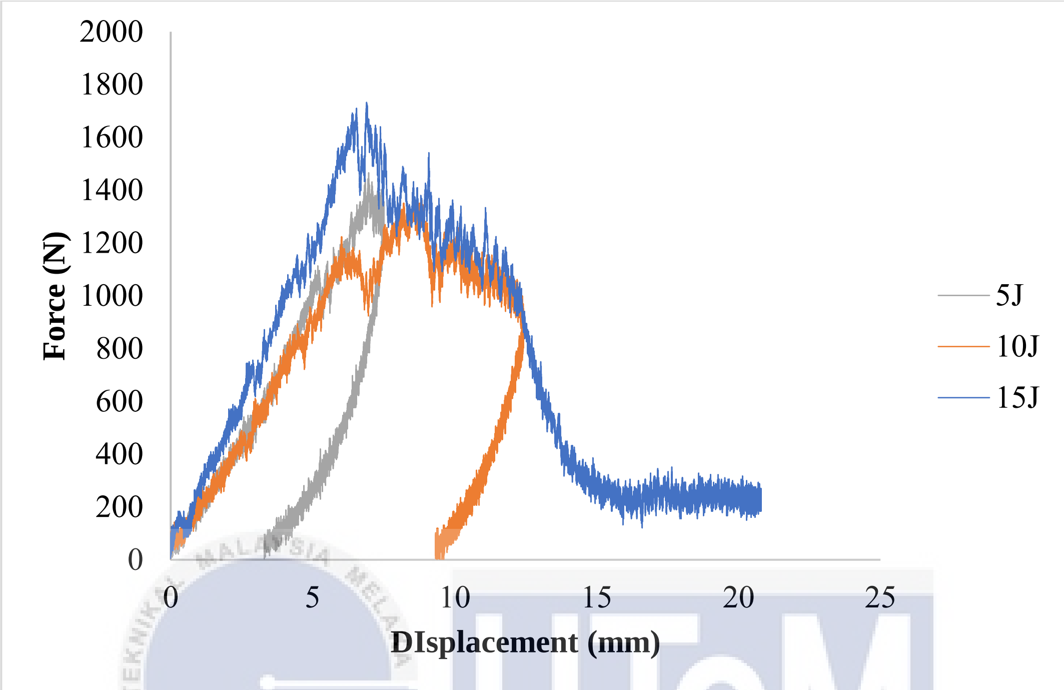
The force-displacement curve with a close type illustrates that rebounding happens when surface of the material is subjected impact loading. As in this case, the surface of the material usually has minimum or no damage. The close type curve also represents the elastic response of composite specimen under impact loading. The force-displacement curve will change as the impact energy change. As the impact energy is going higher, the close type curve changed to open type curve.

The open type curve on force-displacement curve illustrates that excessive damage on the composite surface or complete failure in the composite structure. Figure 4.6 and 4.7 show the force-displacement curves of composite laminates to attest their impact behaviour.

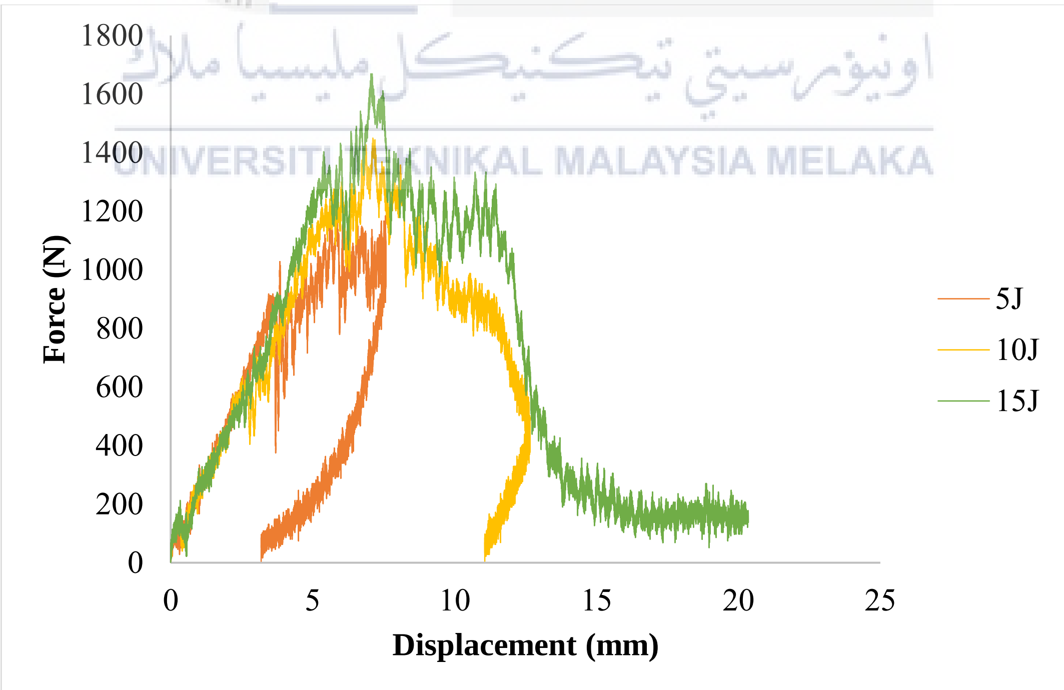
As for the force-displacement curve, the end tail is very important as it shows how the material behaves during the impact test. The curve can be divided into two sections, ascending section and descending section. The ascending section is started from the origin up to the peak force where in this section the impact loading process happening. For the descending section are the loading and unloading process. This descending section illustrates the impact response of a material.

For rebounding case, the response of the curve is close type. As for penetration, the curve is open type same as rebounding. The descending section is parallel to the displacement axis and curve remains open for perforation.

Figure 4.6 shows the force-displacement curve of GGG and its hybrid GKG composites. The impact energy was fixed at 5J, 10J and 15J for each of the composite. As obviously shown in Figure 4.6, the curves for all energy level showed an almost similar trend. As the impact energy is 5J, both the GGG and GKG composites demonstrated close type curve and had peak force when the composite was indented to around 6mm. The close type curves were also observed when the impact energy level of 10J was applied. However the maximum displacement of GGG and GKG composite laminates for energy level of 10J was higher than 5J. For impact energy of 15J, the curve belongs to open type in which the perforation occurred for both GGG composite and hybrid GKG composite. When compared the force-displacement curves of non-hybrid GGG and hybrid GKG composite laminates, it can be concluded that GKG hybrid composite exhibited comparable impact characteristic.



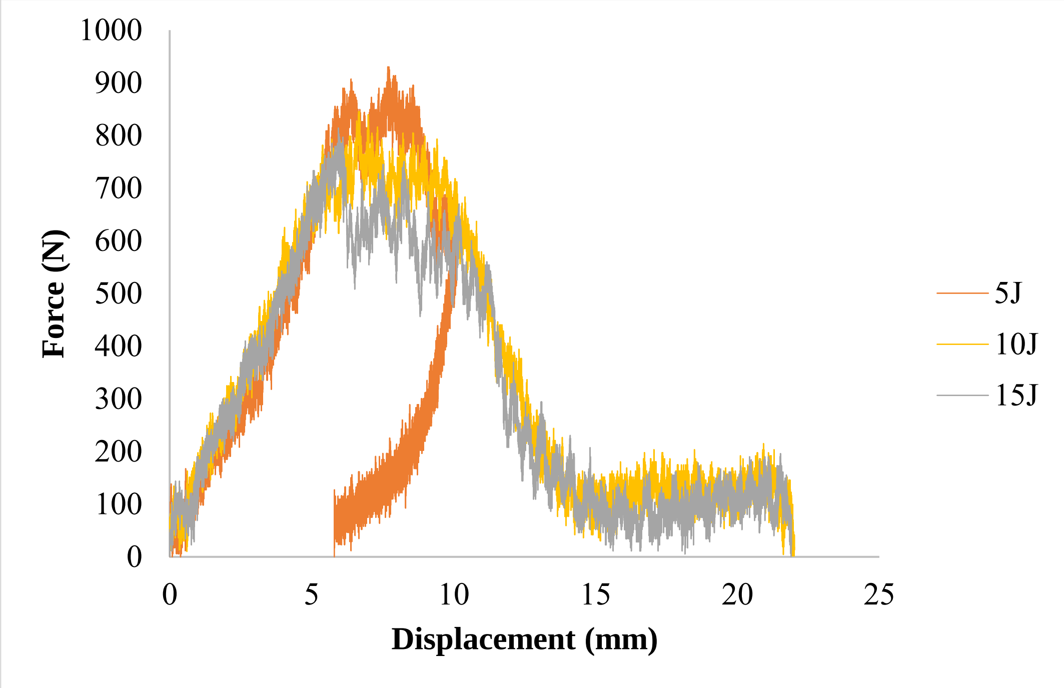
(a)



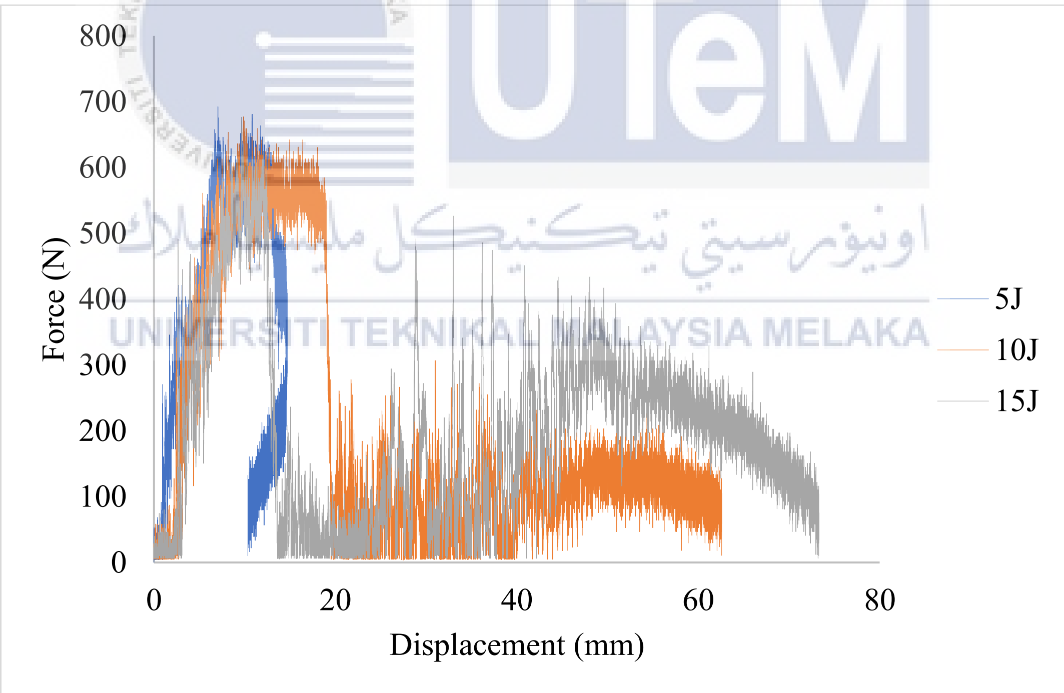
(b)

Figure 4.6: Force-displacement curve of composite laminates (a) GGG and (b) GKG.

Figure 4.7 shows the force-displacement curves of KGK hybrid composite and KKK composites as subjected to low- velocity impact test under 5J, 10J and 15J energy levels. The force-displacement curves of KGK hybrid composite and KKK composites showed a similar trend. However, the noise occurred for KKK composite is more obvious. The substitution of kenaf fibre with glass fibre in the middle section improve the impact properties of the composite as the force-displacement curve showed a smoother curve on KGK rather than KKK when composite laminate was subjected to 5J impact energy. The open curve was shown when higher impact energy 10J and 15J was applied, as penetration happened on the surface of the KGK composite. In overall, penetration occurs with the increase of energy level, leading to the open type curve.



(a)



(b)

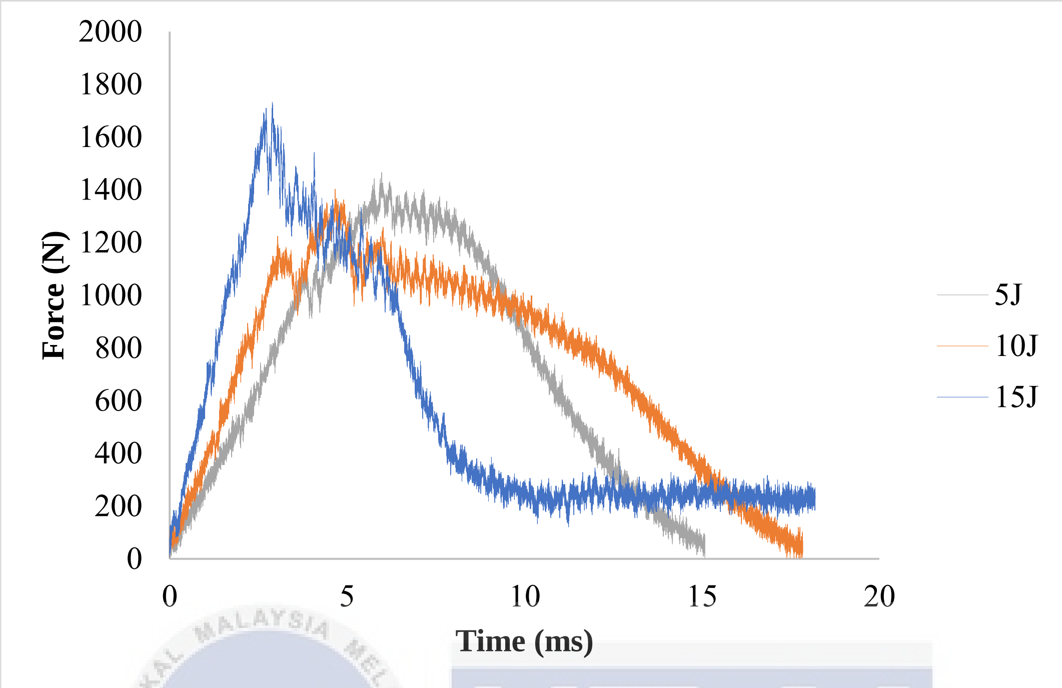
Figure 4.7: Force-displacement curve of composite laminates (a) KGK and (b) KKK.

For low-velocity impact test, peak load and absorbed energy capacity are important properties that demonstrate the impact performance of the composite. The absorbed energy capacity of the composite is obtained by determining the area under the force-displacement curve. Table 4.5 tabulates all the absorbed impact energy in the specimens for each composite. GGG composite showed the highest energy absorption for all impact energy as compared to the other hybrid and non-hybrid composites. For impact energy of 10J, GGG composite reached maximum absorbed energy up to 6.197J, where GKG composite only reaches 5.240J at the same impact energy. This is because GGG composite has a higher composition of glass fibre where glass fibre has relative good energy absorbing characteristic. However, the difference is not very prominent, as for 10J impact energy, energy absorption of GKG composite is only 15.44% lower as compared to GGG composite. For KGK hybrid composite, the absorbed energy was relatively low where the absorbed energy was 28.44% lower than the total energy applied at 5J. For higher impact energy, the difference becomes more significant. This showed that kenaf fibre has relatively weak impact resistance compared to glass fibre.

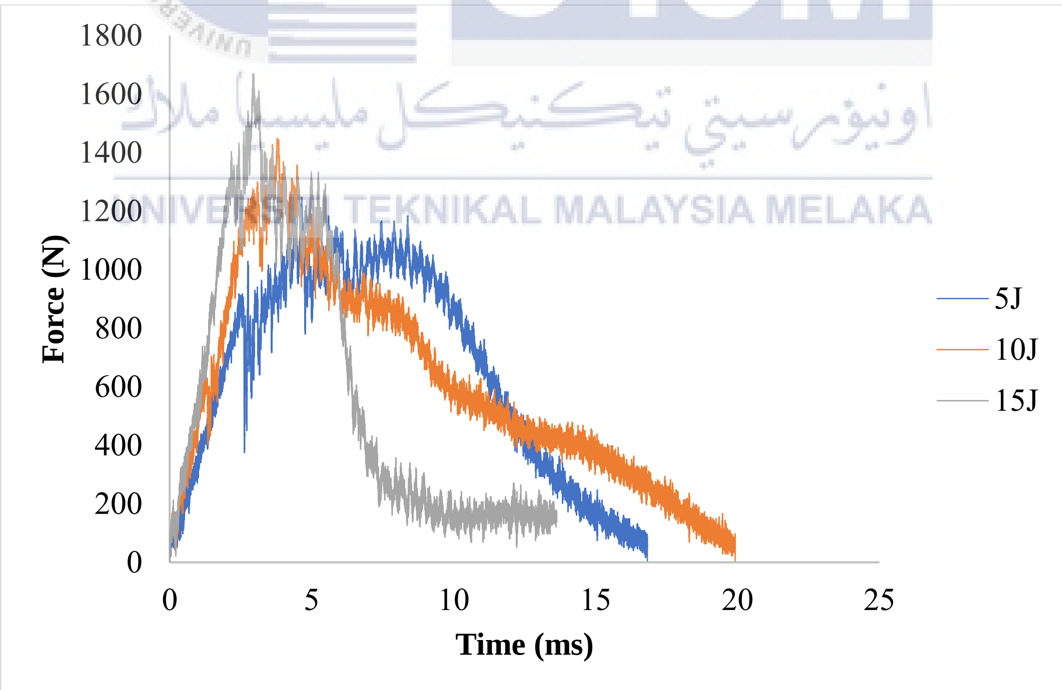
Table 4.5: Peak energy for each of the composite under low-velocity impact test.

Sample of composites	**Peak Impact energy**		
	5J	**10J**	**15J**
GGG	4.612J	6.197J	5.785J
GKG	3.567J	5.240J	5.578J
KGK	3.578J	3.847	3.538J
KKK	2.150J	3.030J	2.617J

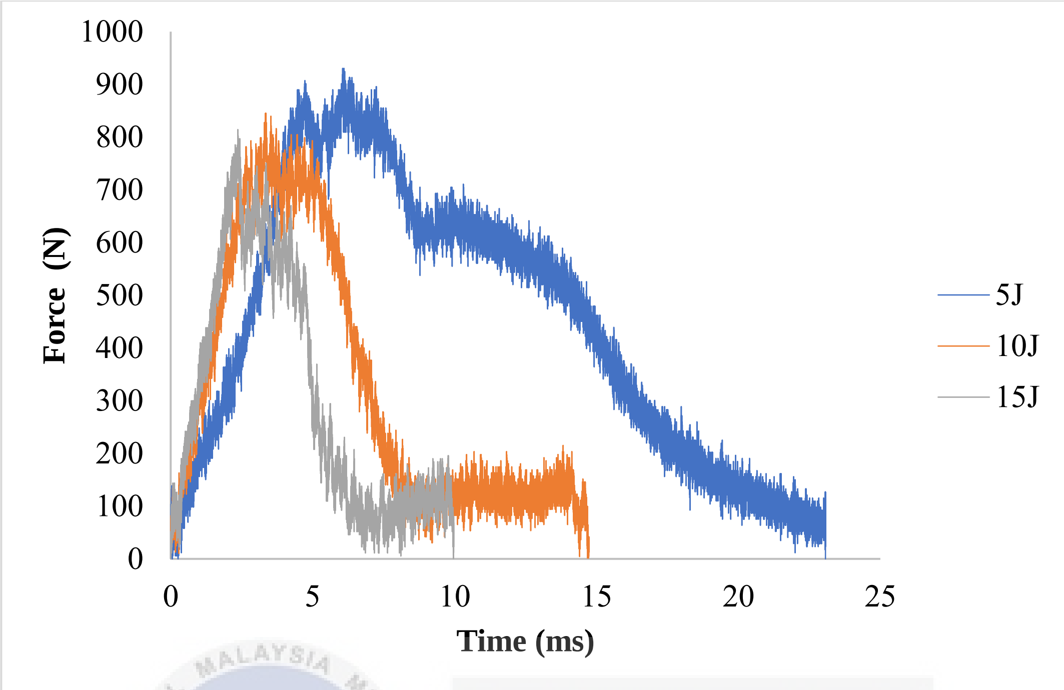
The contact force-time curve indicates the duration of time for the impact to happen. Figure 4.8 shows the contact force-time curve for all sample composites. For rebounding condition, the contact force-time curve is parabolic shape. This shape of the curve changes when different impact energy values are applied to the composite. As the energy value increases, the force increases before the penetration occurred. The penetration occurred when the contact force reached peak force. At this point, the force decreases as penetration happens. The force-time curve of low-velocity impact is symmetrical and loading time is equal to the unloading time. However, this situation only happened for low energy value where the composite able to withstand. For high energy impact curves, the loading time is shorter than the unloading time, where penetration or perforation occurs on the composite surface. When GGG and GKG composite were subjected to impact loading with 5J energy value, the force-time curve was symmetrical, this implied that rebounding occurred. As for 10J and 15J energy level, the oscillation of the force-time curve becomes larger, where in this case, penetration or perforation occurred. A similar trend was shown for both GGG and GKG composites.


2000
1800
1600
1400
1200
1000
800
600
400
200
0
Force (N)
0
5
10
15
20
Time (ms)
5J
10J
15J

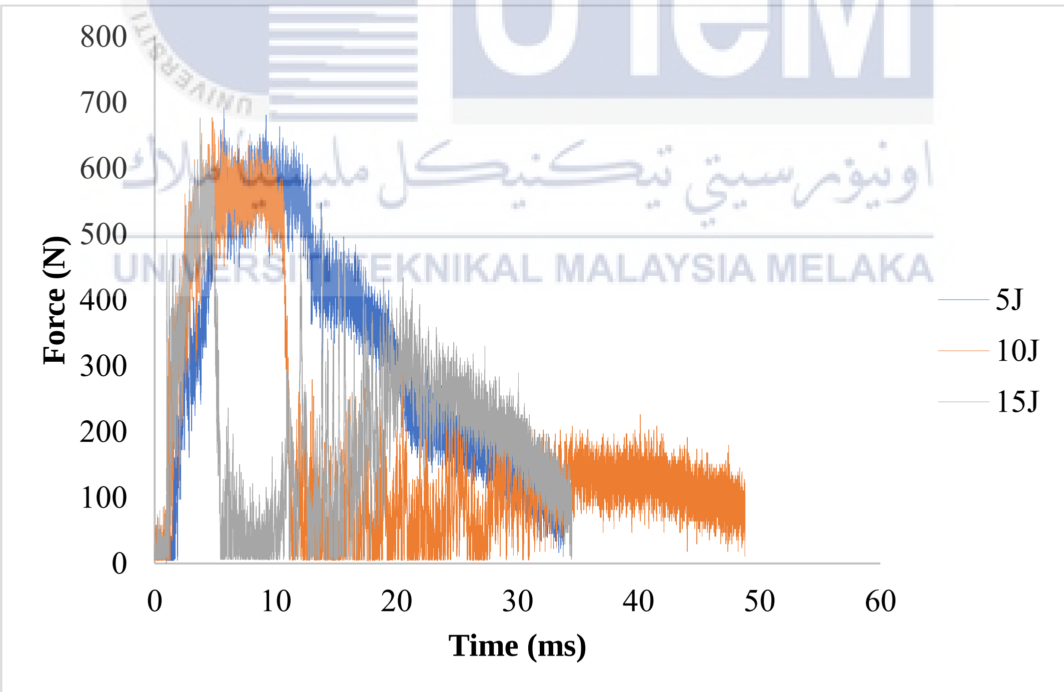
(a)


1800
1600
1400
1200
1000
800
600
400
200
0
Force (N)
0
5
10
15
20
25
Time (ms)
5J
10J
15J

(b)



(c)



(d)

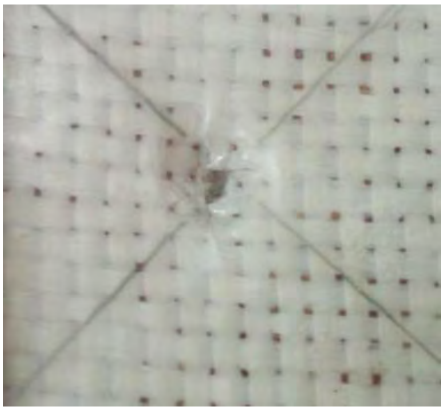
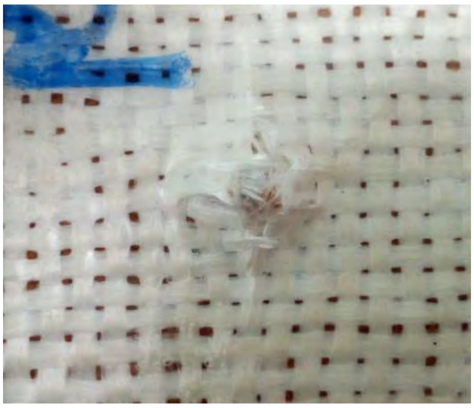
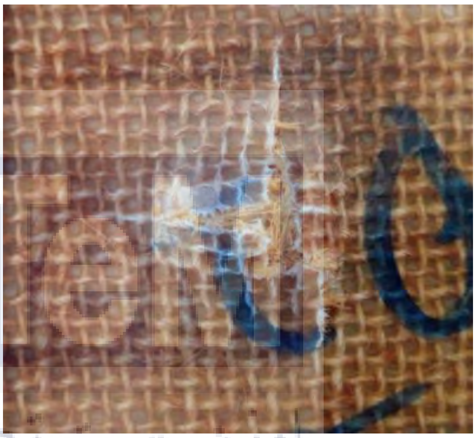
Figure 4.8: Force-time curves of composite laminates (a) GGG (b) KGK (c) KGK and (d) KKK.

4.6 Damage Mechanism

The damage mechanism of the composite was studied after the quasi-static indentation test. The damage modes for this test are usually correlated to fibre shear by compression-shear on the impact surface and fibre shear by tension-shear on the rear surface (Suhad et al, 2017). Generally, perforation occurred by tension-shear. Table 4.6 depicts the optical image of damaged composites for front and rear surfaces. As shown in Table 4.6, the crack propagated all along the impact surface and rear surface of the composite. The damage behaviour of GGG and GKG composite was more likely similar. This situation is due to the middle fibre layer has not significantly affected the impact properties. Similar damage behaviour was observed for KGK composite. However, the cavity becomes larger. The rear surface of KGK has matrix crack and severe fibre breakage. A cross shape failure was shown on the rear surface, showing that energy started to dissipate all over the composite. For KKK composite, the cavity created by the indenter more obvious in the impact point compared to other composite laminates.

Table 4.6: Optical image of all damaged composite for front and rear surface.

Composite	Front	Rear
GGG		

Composite	Front	Rear
GKG		
KGK		
KKK		

The post-damage assessment on the front and rear surfaces of composite laminates was conducted to examine the damage pattern after the low- velocity impact test. The damages of the composites are shown in Table 4.7, Table 4.8, Table 4.9 and Table 4.10. Generally, the damage modes of materials under low-velocity impact test are microcracks, fiber pull out, fiber breakage, fiber bridging, debonding, and delamination at the interface. The damage behaviours are dependent on the impact energy applied to the composite. However, the damage behavior of the composite materials is highly dependent on each of the constituents in the composite as well.

As shown in Table 4.7 and Table 4.8, GGG and GKG composites showed almost no damage as the indenter rebounded from the front surface of the composites when the energy level of 5J was applied. The energy transfer to the rear of the composite, resulting in a matrix crack. With the increase of the energy value, the composites start to be dented by the indenter and perforation happen for higher energy level. It could be seen that on 10J energy value, matrix fracture was noticed on the front surface of GGG composite whereas fiber breakage was observed on the rear surface. A similar observation was noticed for GKG composite. Perforation occurred when the impact energy value is 15J regardless of the fiber configurations. As shown in Table 4.7 and Table 4.8, the indenter penetrated the composite, created a hole in the impact point.

Table 4.7: Failure surface of the GGG composites after the impact tests.

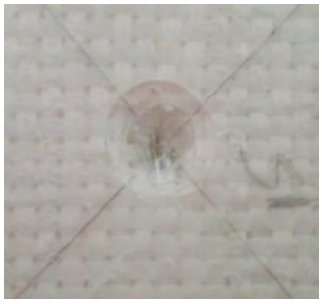
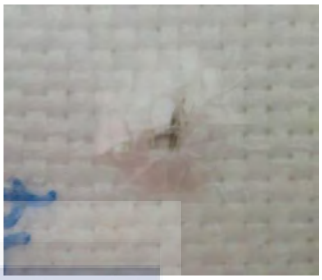
	5J	10J	15J
Front			
Rear			

Table 4.8: Failure surface of the GKG composites after the impact test.

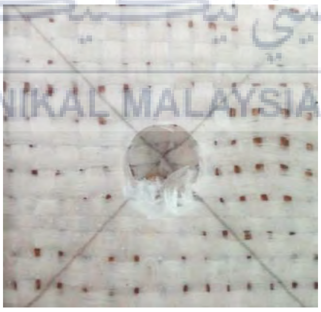
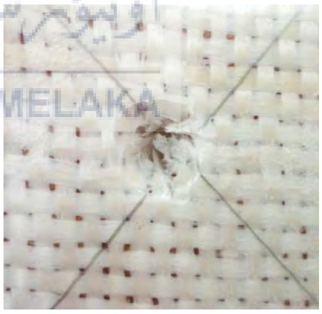
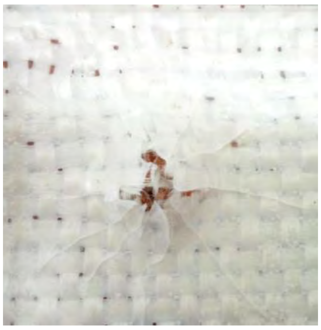
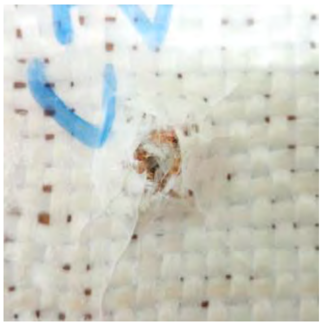
	5J	10J	15J
Front			
Rear			

Table 4.9 and Table 4.10 elucidate the post-impact failure surface of KKK and KGK composites. The failure mechanism of KKK and KGK composites as shown in the Table 4.9 and 4.10 shows the similar behavior. When energy level of 5J was applied, the KKK and KGK composites showed some cracks on the front and rear surfaces. KKK have more severe damage compared to KGK on the rear surface. This is due to the extra glass fiber increase the impact resistance of KGK composite. As the energy value reached 10J, the damage pattern became more obvious, the effect of the extra glass fiber added in kenaf composite. For KKK composite, the front surface is completely failed as the energy applied exceed the limit. The indenter penetrated through the KKK composite, breaking apart the fiber and matrix. For KGK composite, failure mechanism of fully perforated was noticed instead of penetration. This indicated that the impact energy did not propagate throughout the surface of the specimen. The force-displacement curves of KGK and KKK composites showed a close pattern which is closely matched with these damage morphologies.

Table 4.9: Failure surface of the KGK composites after the impact tests.

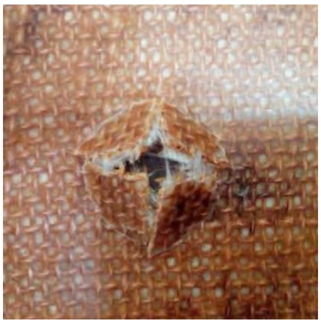
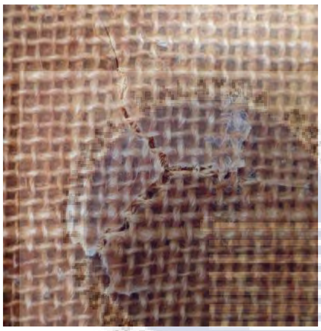
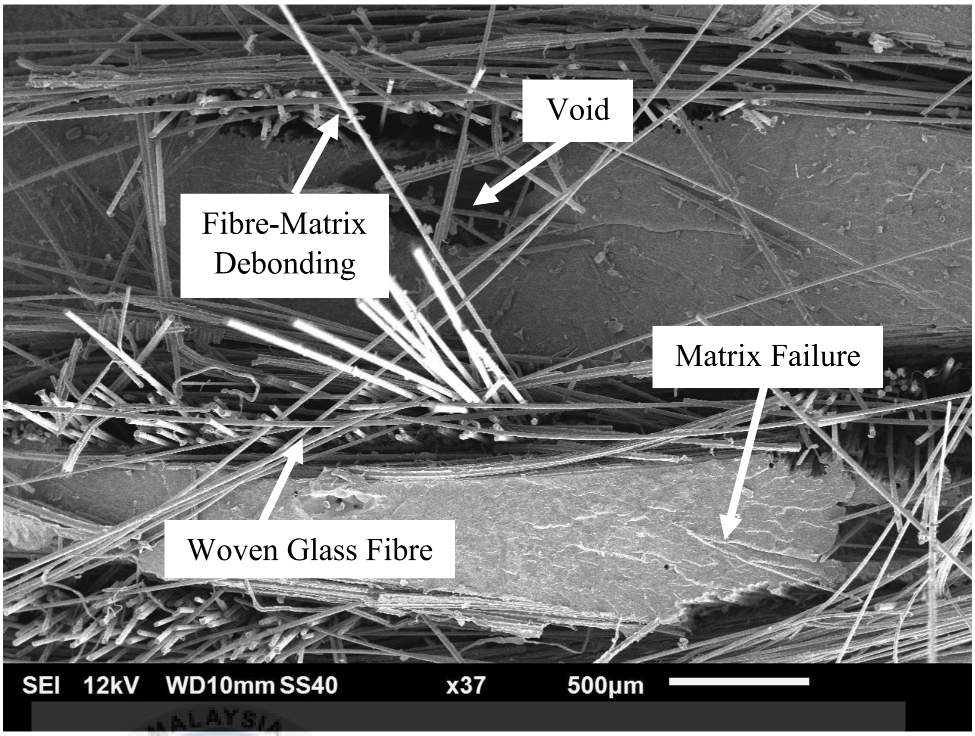
	5J	10J	15J
Front			
Rear			

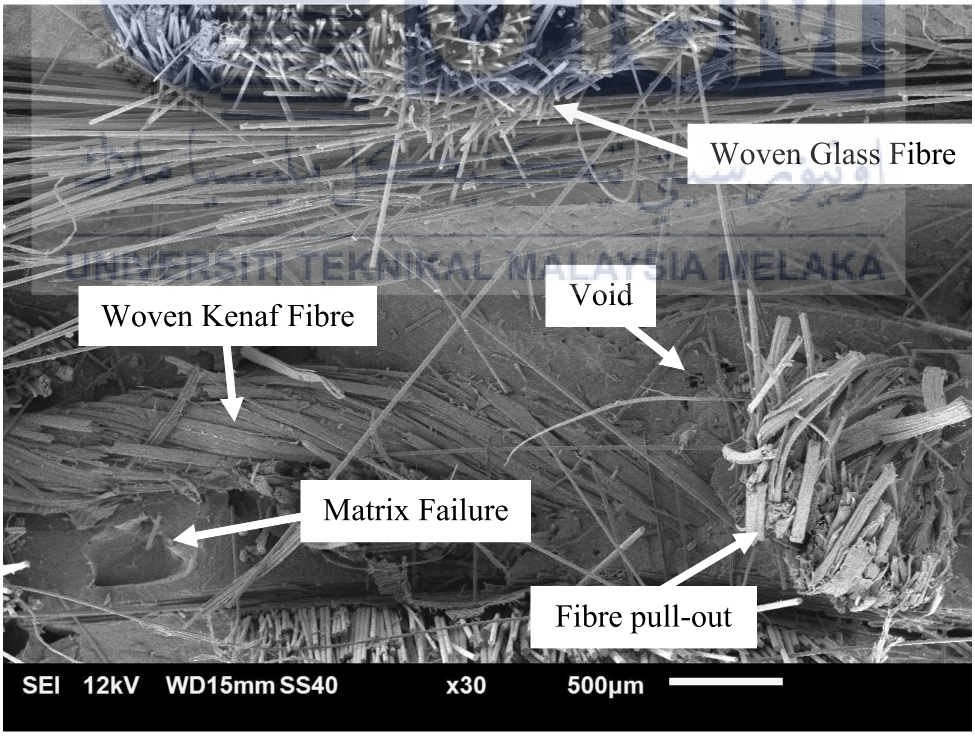
Table 4.10: Failure surface of the KKK composites after the impact tests.

	5J	10J	15J
Front			
Rear			

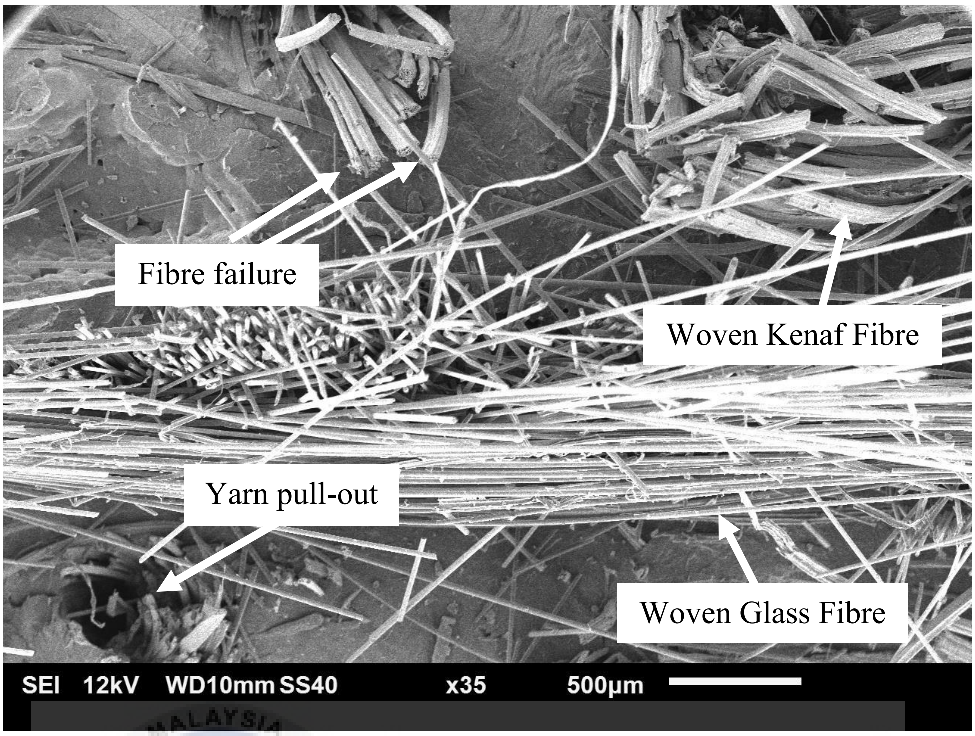
The fractured surface of the composite after tensile loading was examined using Scanning Electron Microscope (SEM) to study the damage mechanism. Figure 4.9 showed all the composite laminates SEM diagram. The general damage modes include fiber pull-out, debonding and fiber fracture as illustrated in the figure. It could be seen that the glass fiber reinforced composite has more apparent fiber pull-out and fiber-matrix debonding. This can be explained by the reason of poor interfacial bonding of the matrix with glass fiber. Fiber fracture was found in the micrograph for kenaf fiber, as kenaf fiber has relatively poor extension ability under tensile loading.


Void
Fibre-Matrix Debonding
Matrix Failure
Woven Glass Fibre
SEI 12kV WD10mm SS40 x37 500µm

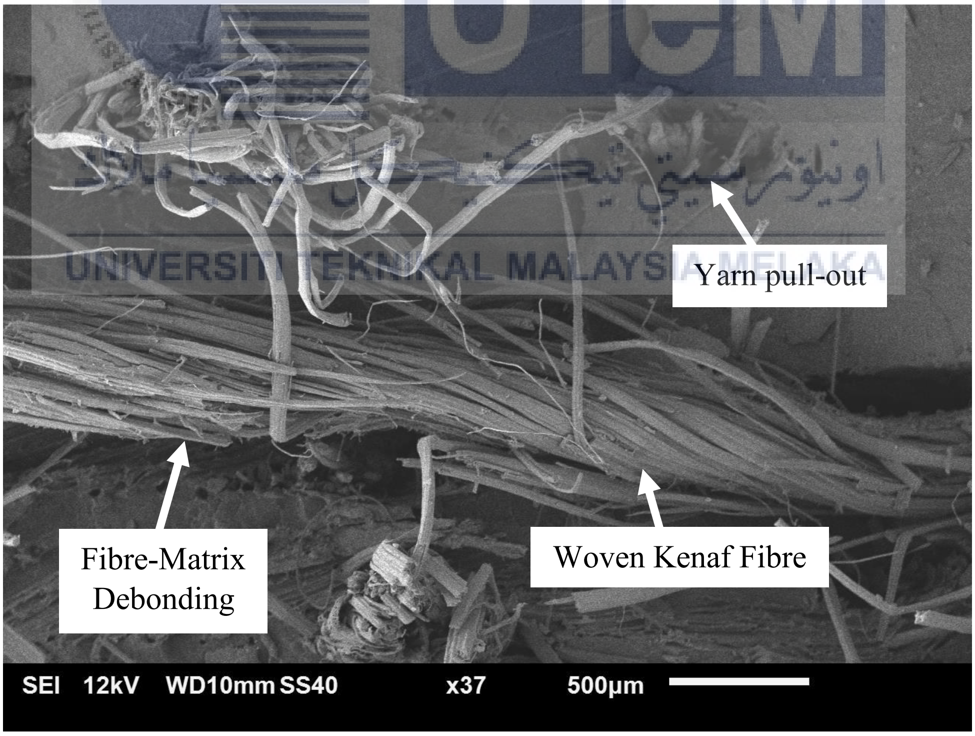
(a)


Woven Glass Fibre
Woven Kenaf Fibre
Void
Matrix Failure
Fibre pull-out
SEI 12kV WD15mm SS40 x30 500µm

(b)



(c)



(d)

Figure 4.9: SEM images of composite laminates (a) GGG (b) GKG (c) KGK and (d) KKK.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study, the quasi-static indentation, low-velocity impact and tensile axial loading test were carried out for the hybridized glass/kenaf fibre reinforced composites. For the tensile properties of composite laminates, the results showed that GGG composite reached the highest ultimate tensile strength at 82.795Mpa which was followed by GKG hybrid composite at 72.039MPa. The KKK composite demonstrated the lowest ultimate tensile strength. Overall, the partially substitution of kenaf fiber with glass fiber results in the positive hybrid effect where the tensile properties were improved with the incorporation of glass fiber in the composite laminates.

For the quasi-static indentation, the hybridization effect of the composite was investigated and the results were represented as the force-displacement curves. The area under the graph which indicates the total energy absorption by the composite was studied. Based on the results, it showed that GGG composite has the highest total energy absorption. However, the hybrid GKG composite only 7.08% lower in term of total energy absorption compared to GGG composite. When the mass of each composite laminate was considered, GKG hybrid composite attested the highest specific energy absorption due to the advantage of its lightweight characteristic and comparable energy absorption in comparison with GGG non-hybrid composite. This result showed that the hybridization improved the impact strength of the composite. For KGK and KKK composite, similar trend was observed where the partially incorporation of glass fiber improved the energy absorbing characteristic. The damage mechanism was also studied for all composite specimens. It was found that the delamination was more significant over the indented point for glass fiber dominated composites. This is due to the weak interfacial bonding of glass fiber with matrix.

For the low-velocity impact test, the impact resistance of composite was investigated. Also, the penetration and perforation threshold of the composite were determined by plotting the graph of contact force-displacement, contact force-time and peak energy absorption of peak contact force. The impact energies were fixed at 5J, 10J and 15J. According to the result, GGG composite was slightly better than GKG hybrid composite in term of energy absorption regardless of different impact energies. However, the difference in the energy absorption of GGG and GKG composites was not significant. This is due to the impact behavior of composite laminates is predominantly governed by the outermost layers in the composite and thus the middle layer of fiber has less contribution to the impact properties. Therefore, it is concluded that kenaf/glass fiber reinforced hybrid composites have the potential to replace non-hybrid glass fiber reinforced composites in impact critical applications. The damage mechanism of low-velocity impact composite is highly dependent on the impact energy levels. As the impact energy increases, several failure modes could be observed and spreading of damage can be identified on the front and rear surface of composite, which mainly consists of delamination, fiber pull out ad fiber debonding.

5.2 Recommendation

Material selection is a very important process where choosing the appropriate type of material is able to reduce the weight, cost and increases the performance in an engineering application. The test carried out for the composites samples (materials) can be varied. As in this study, low-velocity impact, Quasi-static indentation and tensile tests were carried out. The tests such as compression test, three-point bending test and the fatigue test can be carried out for the composite samples to explore the mechanical properties of the composite samples. As for the best of the study of hybridization effect, a different type of natural and synthetic fibres can be explored where a new fibre combination in hybrid composite with better mechanical properties might be found out.

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