A STUDY ON QUASI STATIC INDENTATION BEHAVIOUR OF KENAF BAST FIBRE REINFORCED METAL LAMINATE SYSTEM

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DECLARATION

I declare that this project report entitled "A Study on Quasi Static Indentation Behaviour of Kenaf Bast Fibre Reinforced Metal Laminate System" is the result of my own work except as cited in the references.

Signature : ....

Name : Nisallini A/P Pilvamangalam

Date : ....

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 Bachelor of Mechanical Engineering (Structure & Materials).

Signature : ....

Name : Dr. Sivakumar A/L Dhar Malingam

Date : ....

DEDICATION

To my parents.

ABSTRACT

The growing concerns in reducing the usage of non-renewable sources in production of engineering materials have called for the development of FML. Fibre Metal Laminate (FML) is hybrid material that has the combined advantages of metallic materials and fibre reinforced matrix systems. It had been widely used in aircraft and automotive industry for impact prone applications due to its excellent mechanical properties. This study investigates the quasi static indentation behaviour of fibre metal laminates (FML) based on kenaf/Poypropylene. The effects of fibre length (3, 6 and 9cm) and fibre loading (50, 60 and 70 wt%) were studied. Aluminium 5052-0 has been used in this research. The specimens were prepared and tested using Instron Universal Mechanical Tester 5585H in accordance to ASTM D6264 to assess their performance. The results reveal that FML 60 wt% treated 9cm kenaf fibre exhibited the highest energy absorbing properties at 30.82J compared to other configuration tested. It also proves that FMLs with treated kenaf fibre absorbs an average of 19% more energy compared to FMLs with untreated kenaf fibre.

ABSTRAK

Kajian ini dijalankan untuk menyiasat kesan rawatan kimia, muatan serat dan penjang serat terhadap kelakuan lamina logam gentian (FML) apabila dikenakan beban quasi statik. lamina logam gentian berdasarkan serat kenaf yang dirawat dan tidak dirawat dengan muatan serat 50 wt%, 60% berat dan 70 wt% berat dan panjang serat 3cm, 6cm dan 9 cm telah disediakan untuk menjalankan kajian ini. Aluminium 5052-0 juga telah digunakan dalam kajian ini. Spesimen telah disediakan dan diuji menggunakan mesin Instron Universal Mechanical Tester 5585H berdasarkan piawai ASTM D6264 untuk menilai prestasi specimen. Hasil eksperimen menunjukkan bahawa FML T-60(9) mempunyai sifat penyerapan tenaga dan rintangan penembusan yang tertinggi berbanding dengan konfigurasi lain yang diuji. Ia juga menunjukkan bahawa FMLs dengan serat kenaf dirawat mampu menyerap lebih banyak tenaga berbanding FMLs dengan serat kenaf yang tidak dirawat.

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to my supervisor Dr. Sivakumar A/L Dhar Malingam for his continuous guidance and encouragement to successfully complete my final year project.

I am very much thankful for my seniors, Kathiravan and Ng Lin Feng for their valuable guidance at various stage of this project.

Lastly but not least, I would like to thank my parents for their continuous support and blessings throughout this project.

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LIST OF ABBEREVATIONS

FML	Fibre Metal Laminate
SEM	Scanning Electron Microscope
PP	Polyproplene
PLA	Poly(lactic acid)
NaOH	Sodium Hydroxide

CHAPTER 1

INTRODUCTION

1.1 Background

Recently, researches have shown an increased interest in replacing synthetic fibres with natural fibres as an eco-friendly and cost effective move in the production of engineering materials. Due to the potential of petroleum shortage in future, there is a growing interest in maximizing the use of renewable materials in order to reduce the dependence on petroleum based products (Ramesh, 2016). This eventually led to the development of eco-friendly natural fibre thermoplastic composites.

Kenaf is the common name for hibiscus cannabinus which is a member of the Malvaecae family (Tajeddin, Rahman & Abdulah, 2009). Although kenaf originated from Africa, it is now grown commercially in the United States of America, India, Indonesia, Bangladesh, Malaysia, South Africa, Thailand, Vietnam, and several parts of Africa. Like most natural fibres, kenaf has low density, high specific mechanical properties and is environment friendly (Avella et al. 2008). It was found that tensile modulus, impact strength and the ultimate tensile stress of kenaf reinforced polypropylene composites increases with the fibre content with a moderate increase between 30 and 40% fibre weight fraction and a sharp increase from 40 to 50% fibre weight fraction (Wambua, Ivens & Verpoest, 2003).

One of the major drawbacks of natural fibre reinforced material is the poor adhesion between the filler surface and the matrices in the composite material which affects its mechanical properties (Edeerozey et al., 2007). This issue can be handled by using coupling agents and fibre surface treatment using alkaline solution in order to strengthen the adhesion between the natural fibre and the matrix. Previous researches on kenaf natural fibre reinforced polypropylene composites have provided insights of its tensile and flexural strength when compared with other compression moulded fibre composites reinforced with coir, sisal, hemp and jute fibre (Zampaloni et al., 2007). Thus, kenaf bast reinforced composite fibre could be useful in several industries such as automotive and aerospace industry.

Fibre metal laminate (FML) can be defined as a hybrid material consisting of metal sheets sandwiching a fibre reinforced plastic layer (Alderliesten et al., 2009). Figure 1.1 shows the layup of a FML. In a fatigue test conducted by Fokker Aero on Fokker-27 centre wings showed that laminated structures have higher resistance to fatigue crack growth. It was observed that the fibres in composite layer reduce the crack growth by acting as a barrier against crack propagation while the metal layers contributes in terms of ductility and impact resistance (Cortés & Cantwell, 2004). Several experiments performed on FML with larger fatigue cracks in aluminium have proved the enhanced fatigue performance of this material (Vlot & Gunnink, 2001).

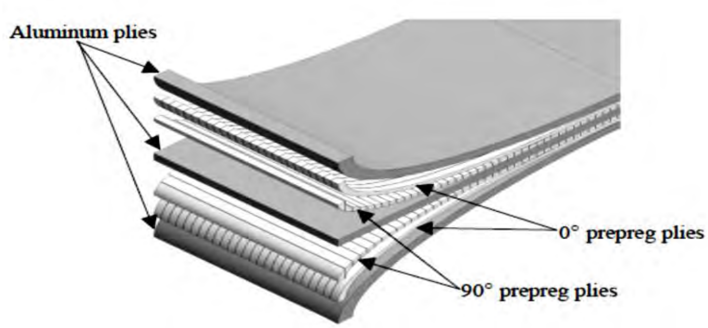

Figure 1.1: A sample of FML layup (Source: Rodi, 2012)

1.2 Problem statement

New regulations on environment and the growing concerns in reducing the usage of non-renewable sources in production of engineering materials have called for the development of FML. FML is a hybrid material consisting of alternating layers of metallic sheet and fibre reinforced composite stacked together. The FML has combined advantages of metallic materials and fibre reinforced matrix systems. Recently FML have been used widely in aircraft and automotive industry for impact prone applications due to its excellent mechanical properties. This research will study the FML under quasi static impact. FML made of Aluminium alloy 5052-0 with kenaf bast fibre reinforced polypropylene (PP) is manufactured for the test.

1.3 Objectives

The objectives of this study are:

1. To investigate the effect of fibre length of treated and untreated kenaf bast fibre – polypropylene on quasi static indentation of FML.

2. To investigate the effect of loading of treated and untreated kenaf bast fibre – polypropylene on quasi static indentation of FML.

1.4 Scope of project

The scopes of this study are:

1. To fabricate FML.
2. To conduct quasi static indentation test on FML according to ASTM D6264.

CHAPTER 2

LITERATURE REVIEW

2.1 Kenaf fibre

Originated from Africa 4000 years ago, kenaf is now actively cultivated around the globe for its fibre (Zhang, 2004). The kenaf stem consist of two types of fibres; the outer bark, known as bast and the inner core with a makeup of about 40% and 60%, respectively. Figure 2.1 shows the kenaf bast fibre used for this research.

Figure 2.1: Kenaf bast fibre

2.1.1 Kenaf bast fibre morphology

Several studies on the structure and properties of kenaf bast fibre have been conducted in the past in order to understand the pros and cons of the natural fibre by analysing its morphology and characteristics. Analysis on kenaf fibres was carried out using Scanning Electron Microscope (SEM) by several researches as shown in Figure 2.2. Figure 2.2 (a) shows the longitudinal view of kenaf fibre that highlights its longitudinal ridges and non-porous surface. Figure 2.2 (b) shows the SEM images across the cross section of kenaf fibre.

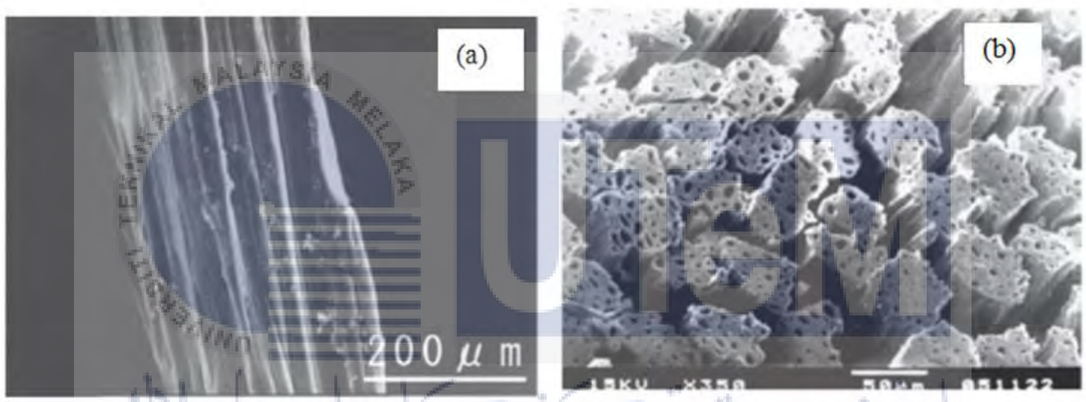

Figure 2.2: (a) Longitudinal view of the untreated kenaf fibres (Source: Shibata et al., 2008), (b) SEM images across the cross section of kenaf fibre (Source: Sharifah & Ansell, 2004)

Kenaf fibres are lignocellulose material mainly composed of cellulose, whose elementary unit, anhydro d-glucose, contains three hydroxyl (–OH) groups. These hydroxyl groups are the reasons for its hydrophilic characteristics. The hydrophilic nature of kenaf and the nonpolar characteristics of most thermoplastics result in compounding difficulties leading to non-uniform dispersion of fibres within the matrix, which weakens the properties of the resultant composite (John et al., 2010).

Previous researches show that chemical treatments can be used to improve the mechanical performance of the natural fiber. Based on a study regarding chemical modification of kenaf fibers conducted by Edeerozey et al. (2007), it was observed that the kenaf fibre that have been treated with alkali had better mechanical properties compared to untreated kenaf fiber. The study has compared various concentrations of NaOH in order to find the optimum concentration of NaOH to alkalize kenaf fibers.

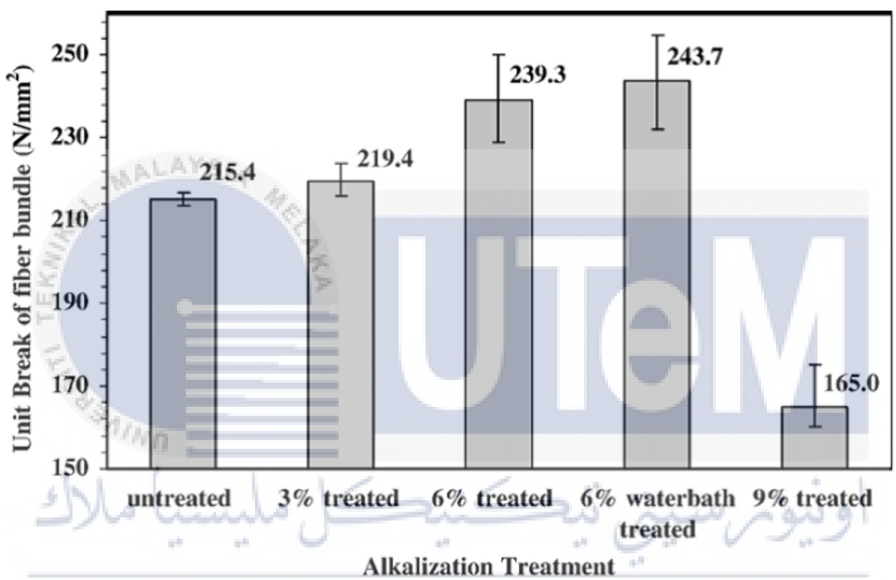

Figure 2.3: Fiber bundle tensile strength of differently treated kenaf fiber (Source: Edeerozey et al., 2007)

Figure 2.3 shows the fiber bundle tensile strength of differently treated kenaf fiber. Based on the results, fiber treated with 6% NaOH in water bath (at 95 °C) recorded the highest value of unit break (UB). However, when the NaOH concentration is increased to 9%, the average unit break decreased significantly. This may be due to the fibre damage caused by the high concentration of NaOH, thus resulting in lower tensile strength.

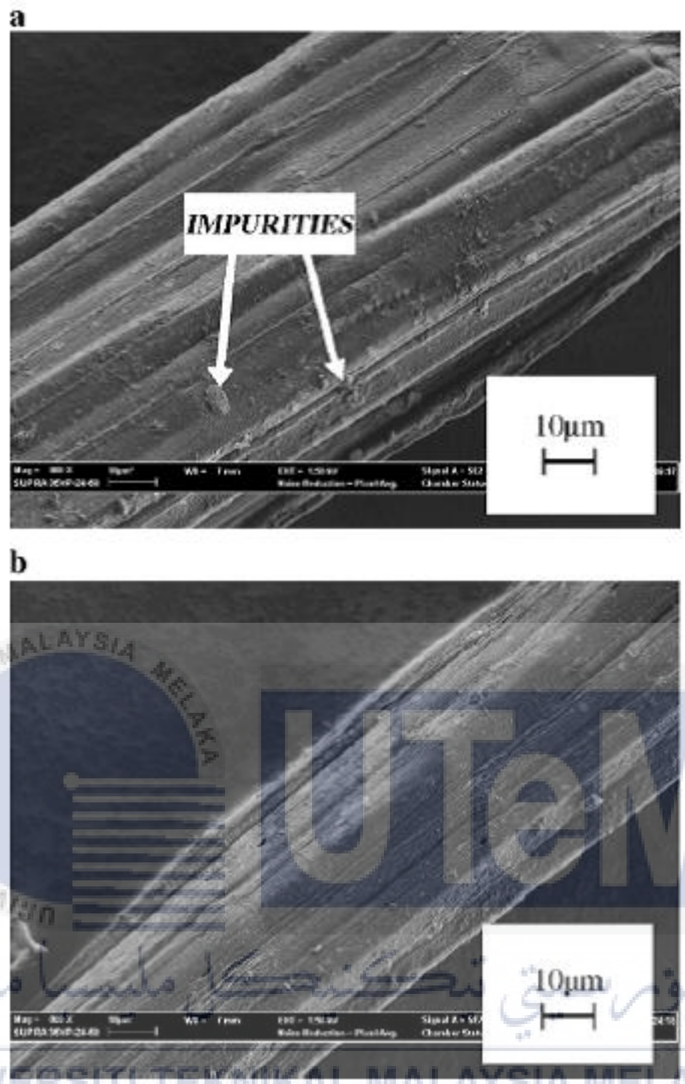

Figure 2.4: SEM micrograph of (a) an untreated kenaf fiber and (b) 3% NaOH treated kenaf fiber (Source: Edeerozey et al., 2007)

In Figure 2.4, it can be observed that the chemical surface treatment causes a clean and rough surface on the fibre which is important for interfacial bonding of polymer and kenaf fibre because it provides a better interlocking between the polymer and fibre (Mahjoub et al., 2014)

2.1.2 Mechanical properties of kenaf bast fibres

Ochi (2008) conducted a research to investigate the effect of environmental temperature on the growth of the kenaf fibre on the tensile and elastic properties of the kenaf fibre and emulsion-type PLA resin composite. The study was conducted by comparing the tensile strength of kenaf fibres grown at 22°C and 30°C. Kenaf fibre bundles with a diameter of 50–150 µm and length of 500 mm were used for this study.

The tensile specimen for kenaf fibre was prepared by gluing the fibre to the paperboard, which was then carefully gripped by the testing machine, and cut with a thin heated metal wire along the cutting line indicated in Figure 2.5. The JIS R 7601 method was used to determine tensile strength of kenaf fibre by performing the tensile test at a strain rate of 0.04 per min. Based on the results from Figure 2.6, it was observed that the tensile strength and elastic modulus of kenaf fibres grown under an average temperature of 30°C were greater than those grown under average temperature of 22°C.

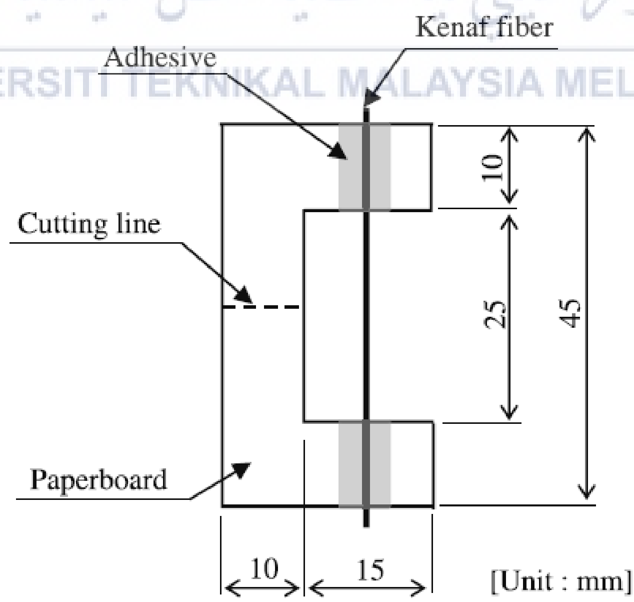

Figure 2.5: Tensile specimens for kenaf fibres (Source: Ochi, 2008)

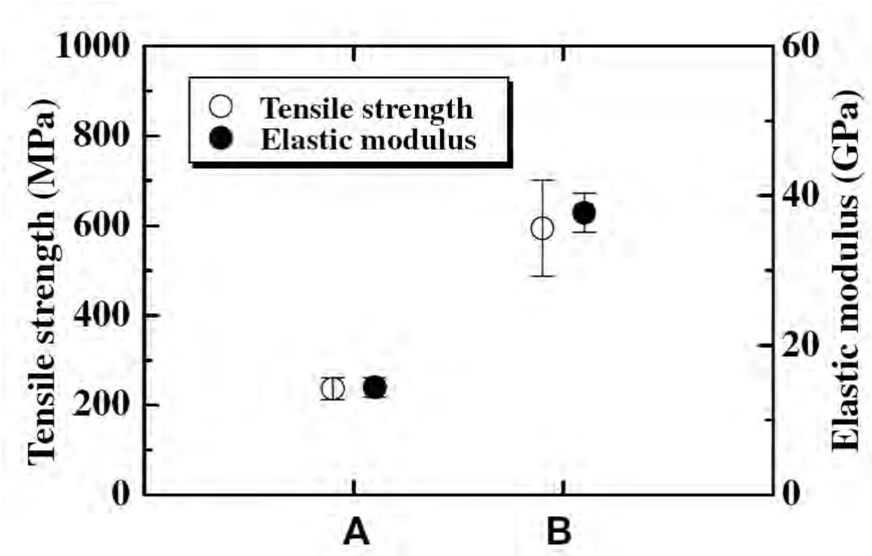

Figure 2.6: Tensile strength and elastic modulus of kenaf fibre, (A=22°C, B=30°C) (Source: Ochi, 2008)

Based on Ochi's research in 2009 regarding the tensile properties of kenaf fibre bundle, the effect of stem diameter and length on the mechanical properties of kenaf fibre of different types was investigated. The specimens for the tensile test was prepared referring to JIS R 7601: 1986 testing methods for carbon fibres and attached vertically to the testing machine. A strain rate of 0.04 per minute was applied to the fibres. At the end of the research, it was concluded that the stem diameters do not significantly affect the fibre strength based on the result shown in Figure 2.7. However, tensile strength and the elastic modulus of kenaf fibre were observed to increase with the length of the stem as shown in Figure 2.8 and 2.9.

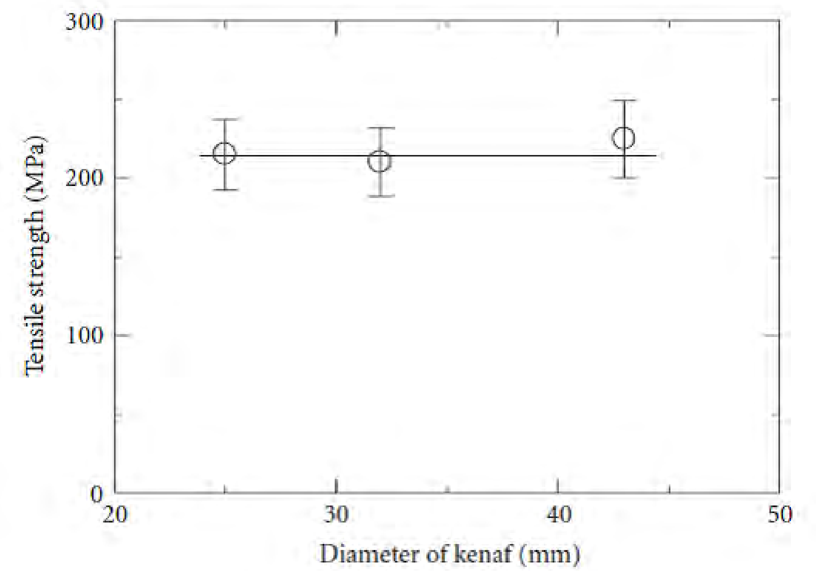

Figure 2.7: Relationship between tensile strength and diameter of kenaf (Source: Ochi, 2009)

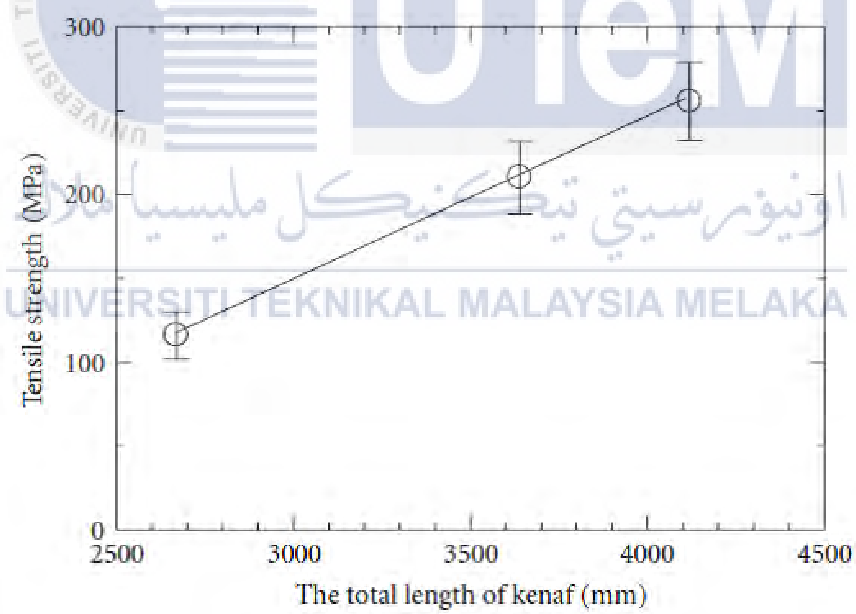

Figure 2.8: Relationship between tensile strength and length of kenaf (Source: Ochi, 2009)

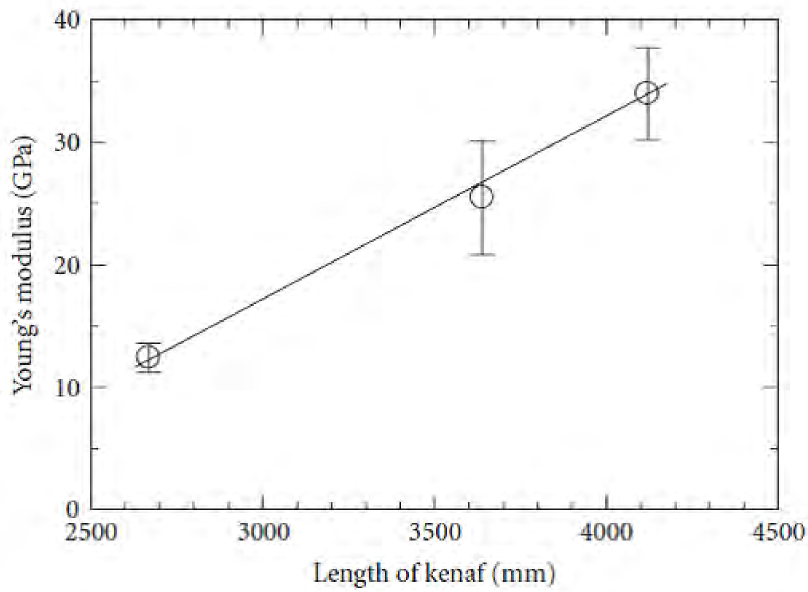

Figure 2.9: Relationship between elastic modulus and length of kenaf (Source: Ochi, 2009)

2.2 Effect of chemical treatment on mechanical properties of kenaf bast fibre composite

Sharifah & Ansell (2004) have studied the effect of alkalization and fibre alignment on the mechanical and thermal properties of kenaf and hemp bast fibre composites. In the study, the fibres were treated using 6% NaOH solution and were combined with polyester resin and hot-pressed to form natural fibre composites using stainless steel mould of dimension 240×60×40 mm. Charpy impact tests were performed using an Avery Denison impact tester in accordance to ASTM D 256. The work of fracture values were calculated by dividing the energy in kJ recorded on the tester by the cross sectional area of the specimen.

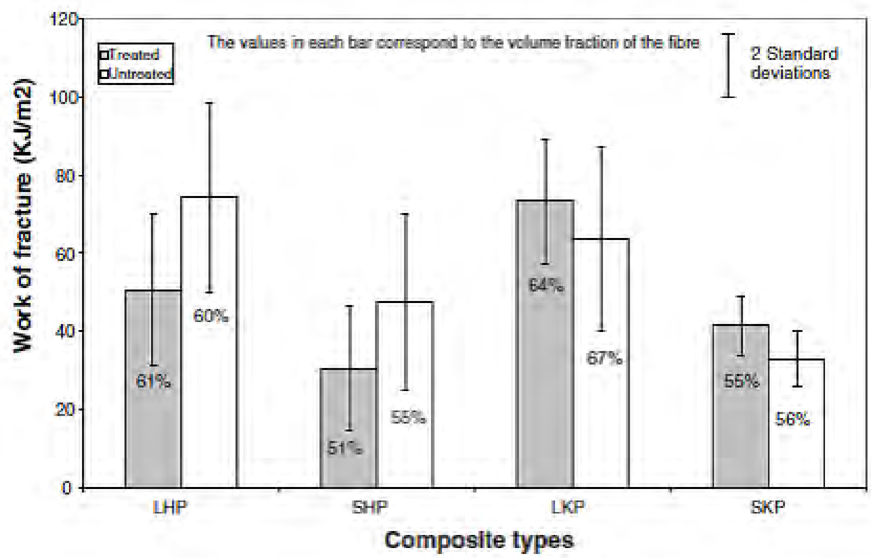

Figure 2.10: Work of fracture of treated and untreated long kenaf/polyester (LKP), short kenaf/polyester (SKP), long hemp/polyester (LHP) and short hemp/polyster (SHP) composites (Source: Sharifah & Ansell, 2004)

Based on the Charpy impact test conducted, it was observed that the toughness of the long fibre composites is higher compared to the short fibre composites in general. However, there is a large amount of variability in the results as shown in Figure 2.10. Work fracture of treated fibre in kenaf/polyester composite for both short and long fibre recorded a higher value compared to the untreated ones.

In a study conducted by Saliu et al. (2015), the effect of epoxy concentration and fibre loading on the mechanical properties of ABS/epoxy-coated kenaf fibre composites was investigated by performing tensile, flexural, impact and hardness test. The kenaf fibre used in this study were cut to 3mm length and treated using 6% NaOH solution for three hours before coating it with 30, 40 and 50 wt% epoxy resin. The dried ABS pellets and the kenaf fibre was melt-mixed using fibre loading of 12%, 30% and 50% in an internal mixer and compressed using a compression moulding machines to form the composites. The Izod impact test was performed on the samples using a Zwick Pendulum Impact Machine with pendulum energy of 7.5J according to ASTM D256. The impact strength of the specimens was then calculated by dividing the recorded absorbed impact energy by the cross-sectional area of the samples.

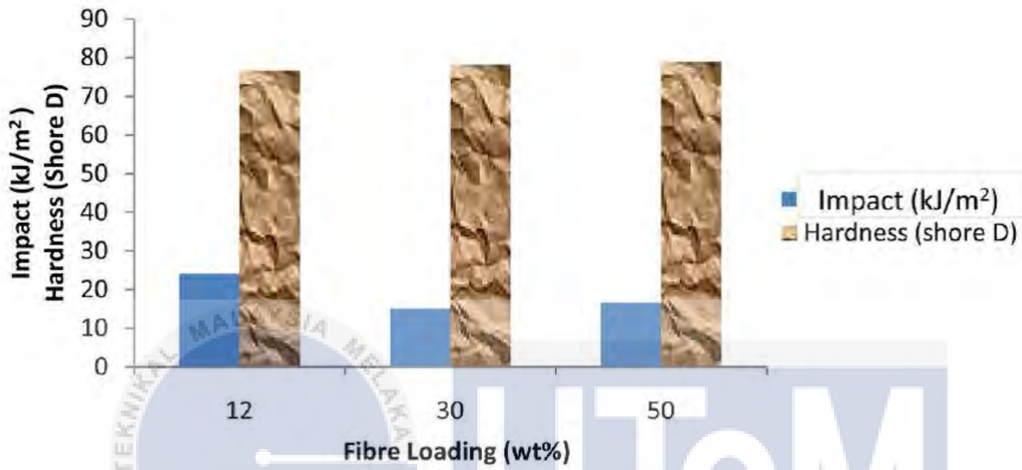

Figure 2.11: Impact and hardness values of the composites versus the fibre loading (Source: Saliu et al., 2015)

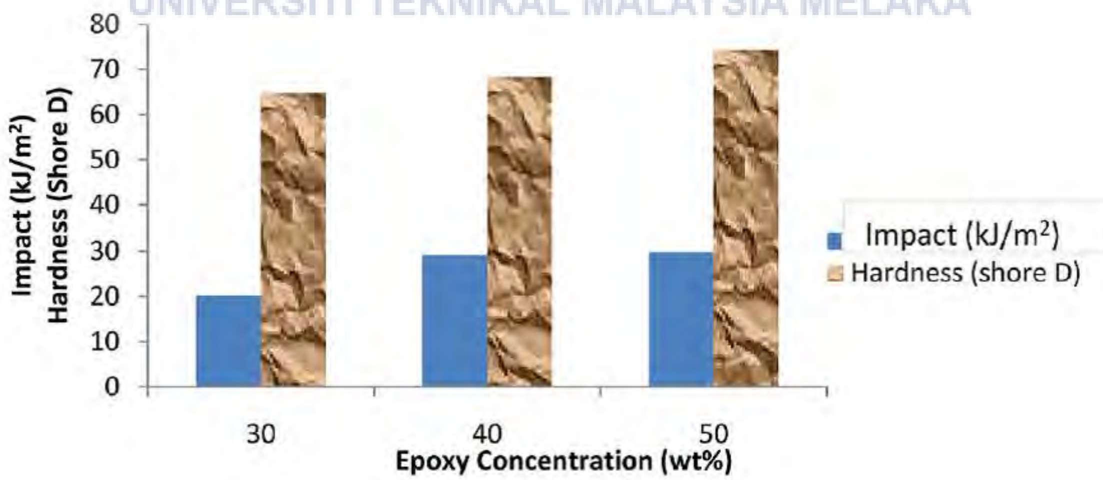

Figure 2.12: Impact and hardness values of the composites versus epoxy concentration (Source: Saliu et al., 2015)

Figure 2.11 and Figure 2.12 indicate the impact and hardness values of the composites versus fibre loading and epoxy concentration respectively. It was found that the impact values have no obvious trend for fibre loading. The highest impact value recorded is 24.14 kJ/m^2 for 12 weight% fibre loading. The value then decreased to 15.12 kJ/m^2 for 30 weight% and later increased slightly to 16.71 kJ/m^2 when at 50 weight% loading. For epoxy concentration however, the trend shows that the impact strength increases as epoxy concentration increases.

Bakar et al. (2010) conducted a study on the mechanical properties of treated and untreated kenaf fibre reinforced epoxy composite to understand the effect of alkaline treatment using 4% NaOH on flexural strength, flexural modulus and impact strength of the composite. The composites were prepared in both untreated and treated forms of fibre with varying fibre loading of 5, 10, 15, 20 and 25 weight% by using hot press method. The Izod impact test for this study was conducted using Ray Ran Pendulum Impact System in accordance to ASTM D256-88.

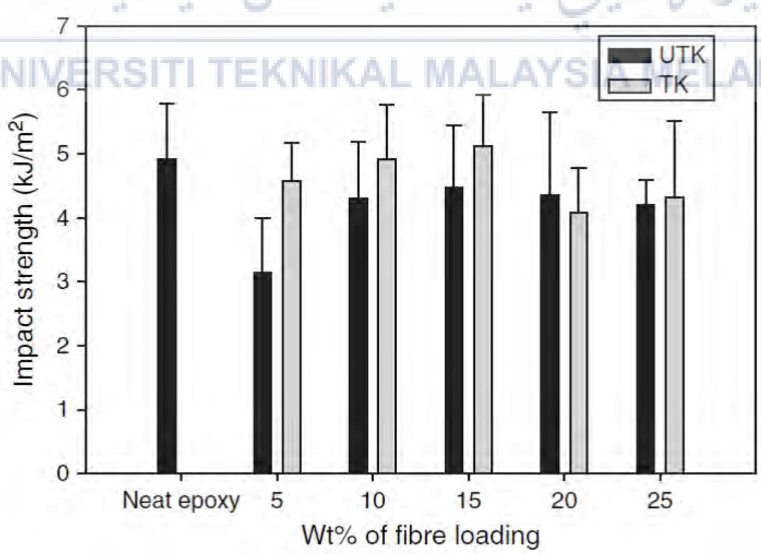

Figure 2.13: Impact strength of treated kenaf fibre (TK) and untreated kenaf fibre (UTK) reinforced epoxy composite for each fibre loading (Source: Bakar et al., 2010)

Figure 2.13 shows the comparison of impact strength recorded between treated and untreated kenaf fibre reinforced epoxy composite for each fibre loading. The impact strength seems to be higher for treated kenaf fibre compared to untreated fibre for every fibre loading except for 20 weight% loading. The impact strength for both untreated and treated kenaf composites shows an increasing trend up to 15 wt% fibre loadings. Increasing the fibre loading beyond that value caused a slight fall in the impact strength. For 15 weight% fibre loading, the impact strength for treated fibre showed an improvement of 14.7% compared to untreated fibre.

2.3 Quasi static indentation test on composite

Yahaya et al. (2014) studied the quasi-static penetration and ballistic properties of kenaf–aramid hybrid composites to understand the penetration behaviour of the kenaf–Kevlar hybrid laminated composite under quasi-static conditions by focusing on the penetration process, penetration resistance, energy absorption and the failure of hybrid laminated composites. The specimen used in this study is fabricated using hand-lay-up method to stack up alternate layers of Kevlar and kenaf as illustrated in Figure 2.14. The quasi static test was conducted using a surface-hardened steel indenter with conical tip, and a diameter of 10 mm attached to a tensile machine.

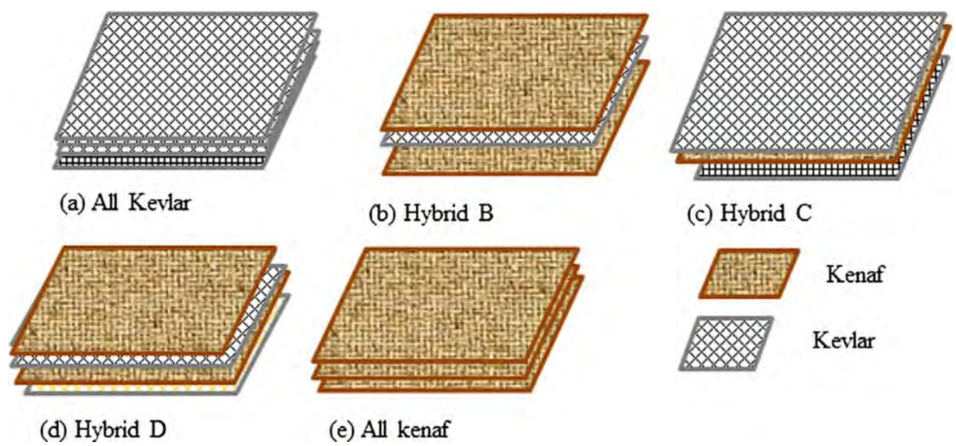

Figure 2.14: Configuration of sample prepared (Source: Yahaya et al., 2014)

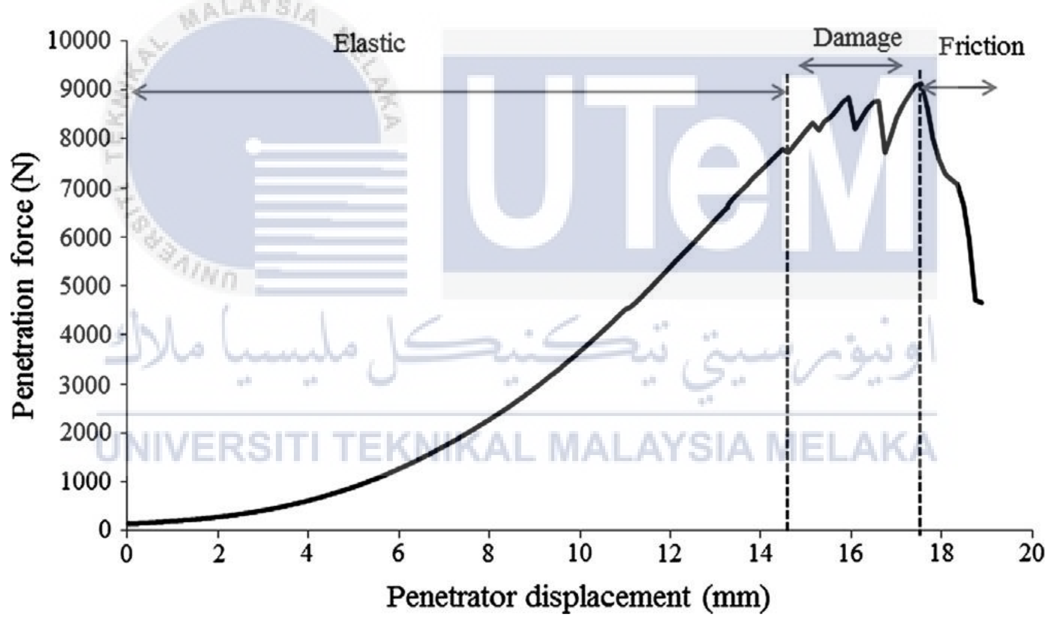

Figure 2.15: Force displacement curve for Kevlar/epoxy composites (Source: Yahaya et al., 2014)

The penetration resistance force-penetrator displacement curves for Kevlar/epoxy composites tested in the study are presented in Figure 2.15. The authors highlighted three distinct regions in the penetration force-penetrator displacement curves. The three regions represents penetration, perforation and frictional in the penetration test. The initial failure;

penetration occurred on the loaded side after initial linear segment. After the plateau region which is shown as a fall in penetration force, perforation occurs. The sudden drop in penetration is caused by fibre– matrix failure which is followed by fibre breakage. The third region was the plateau region which was related to the residual frictional force. The occasional rise in load is due to the fibre breakage as the indenter moves through the thickness of the specimens.

Table 2.1: Penetration energy and maximum load of samples tested (Source: Yahaya et al., 2014)

Sample	Energy absorption (J)	Maximum force (N)
All Kevlar	73.3	9260
Hybrid B	90.0	13275
Hybrid C	131.0	17440
Hybrid D	88.1	16440
All kenaf	4.8	790

The energy absorbed and maximum load for each sample tested is presented in Table 2.1. It is apparent from this table that the energy absorption and maximum penetration force of hybrid composites is higher than the all Kevlar composite. Hybrid C recorded the highest energy absorption at maximum force signifying that it has better resistance towards penetration compared to other hybrid sample tested.

In a research conducted by Salman et al. (2017) which investigated the quasi-static penetration behaviour of plain woven kenaf/aramid reinforced polyvinyl butyral hybrid laminates, it was found that this composite material had positive behaviour on quasi-static penetration in terms of maximum load carried, energy absorbed in impact, and damage mechanisms. The hybrid composite materials for this research was produced using a hot press technique and consist of 19 layers of plain woven kenaf and aramid with various configurations and alternation as shown in Table 2.2. The quasi-static perforation test was conducted using a Universal Testing Machine in accordance to ASTM D6264 to study the damage evolution and penetration resistance behaviour of the hybrid laminates. The authors have also assessed the effect of hybridization on the energy absorption of hybrid laminated composites under static loading.

Table 2.2: Specifications of the laminated hybrid composites prepared (Source: Salman et al., 2017)

Sample code	Specimens descriptions
KV	19 Kevlar
H1	17 Kevlar/2 Kenaf
H1A	17 Kevlar/2 Kenaf [Alternate]
H2	16 Kevlar/3 Kenaf
H2A	16 Kevlar/3 Kenaf [Alternate]
H3	15 Kevlar/4 Kenaf
H3A	15 Kevlar/4 Kenaf [Alternate]
H4	13 Kevlar/6 Kenaf
H4A	13 Kevlar/6 Kenaf [Alternate]
H5	11 Kevlar/8 Kenaf
H5A	11 Kevlar/8 Kenaf [Alternate]
H6	9 Kevlar/10 Kenaf
H6A	9 Kevlar/10 Kenaf [Alternate]
KF	19 Kenaf layers

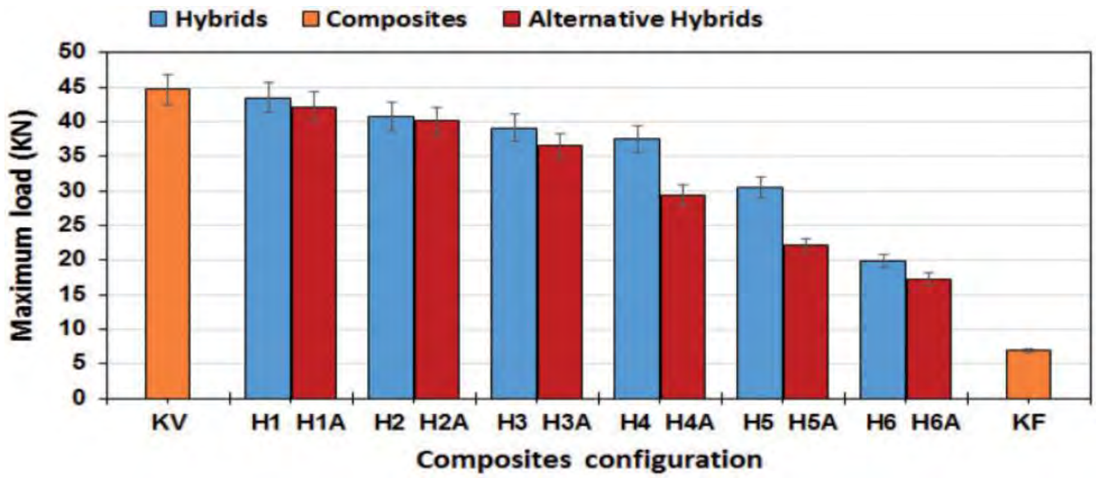

Figure 2.16: Maximum penetration load of all hybrid composites (Source: Salman et al., 2017)

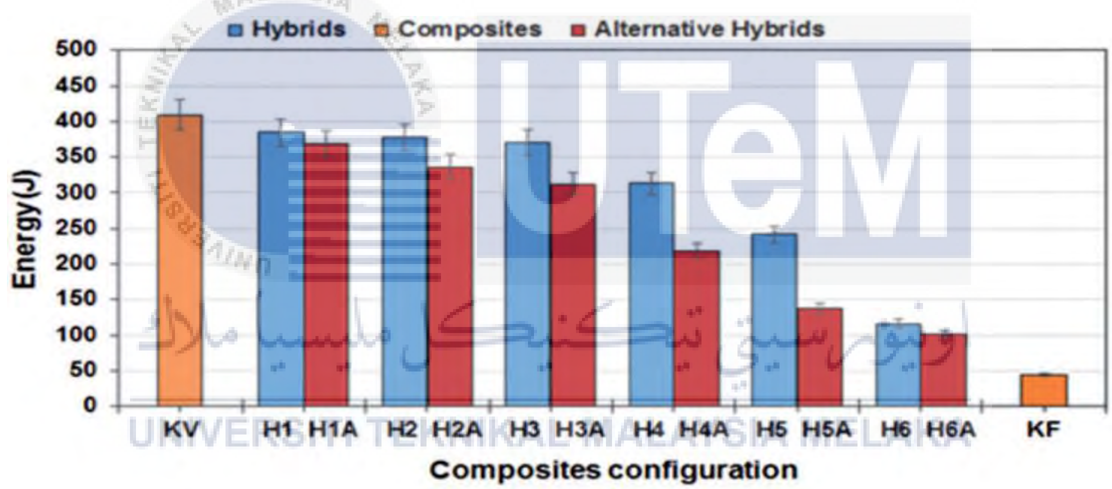

Figure 2.17: Penetration energy of all hybrid composites (Source: Salman et al., 2017)

Figure 2.16 shows that the maximum penetration load-carrying capacities of hybrid composites gradually decrease when the number of kenaf layers was increased in general. The energy absorption during the penetration process for each hybrid composite is presented in Figure 2.17. The findings highlight that the energy absorption and maximum penetration force of Kevlar composite are higher than all hybrid composites and kenaf composite. However, hybrid H1 recorded the highest energy absorption, signifying that it provides a better penetration resistance compared to other hybrid materials tested. The authors have also pointed out the hybrids with woven kenaf placed together and Kevlar 29 layers separately were able to obstruct the propagation of cracks more than hybrids with alternate layers of kenaf and Kevlar.

The authors explained the penetration process by highlighting the initial failure on the matrix which propagates as the indenter moved through the thickness of the hybrid composites by pushing the fibers away. Perforation occurs after the force-displacement curve reaches maximum force causing fiber breakage linked with the residual frictional force. Figure 2.18 presents the cross-sections of selected samples cut along the thickness direction at the impact region. The specimens were observed to have fiber shear on the impacted surface due to compression-shear and fiber shear on the rear surface due to tension-shear. Besides that, the crack propagation in all the hybrids was mainly driven through the inter-laminar regions. However, delamination happened in both inter-laminar and intra-laminar regions. The authors have also noted that the hybrid laminated composites and Kevlar composites had similar damage behavior.

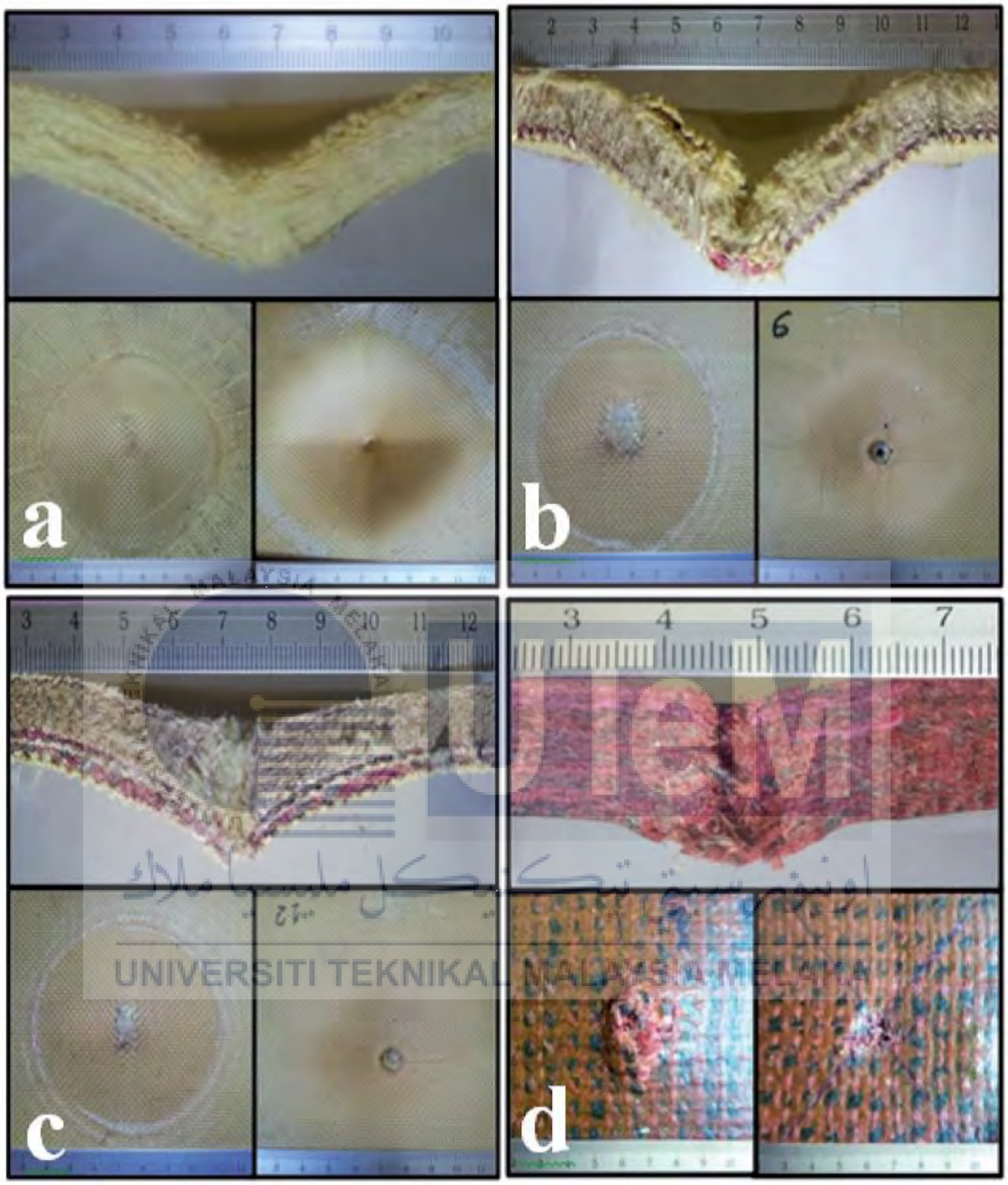

Figure 2.18: Optical pictures of damaged surface of hybrid composite laminates after quasi-static test, cross-sectional surface, rear surface, and impacted surface: (a) Kevlar composite, (b) hybrid of placing kenaf layers and Kevlar 29 layers separately, (c) hybrid of placing kenaf layers alternately with Kevlar 29 layers and (d) kenaf composite (Source: Salman et al., 2017)

2.4 Fibre metal laminate

In recent years, researches on improving the properties of existing composites had led to the development of fibre metal laminate (FML). FMLs are hybrid composites that combine the advantages of metals and fibre reinforced composite materials. FMLs consist of a sandwich structure that has alternating layers of fibre reinforced matrix and metal alloy

2.4.1 Quasi static indentation test on fibre metal laminate

Abdullah et al. (2014) did a research on indentation fracture behavior of fibre metal laminates based on kenaf/epoxy by conducting static indentation tests on FMLs with a loading rate of 10 mm/min using a Model 5982 Instron Universal Testing Machine. This research focused on two parameters; the thickness and the lay-up of FMLs. Table 2.3 provides the variations of FMLs prepared for this research.

Table 2.3: Variations of FMLs prepared (Source: Abdullah et al., 2014)

Configuration	Lay-up	Thickness of aluminium alloy sheet (mm)
Pure kenaf	-	-
2/1-0.3 FML	2/1	0.3
2/1-0.6 FML	2/1	0.6
3/2-0.6 FML	3/1	0.6

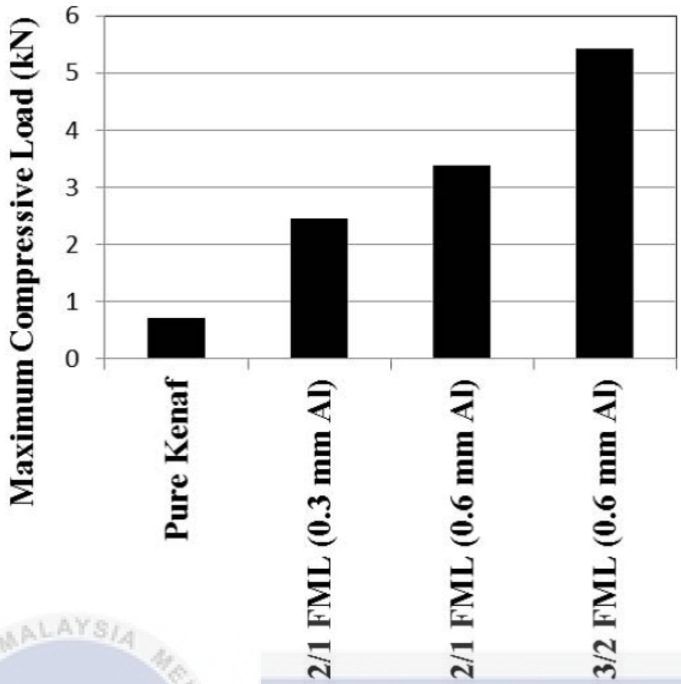

Figure 2.19: Maximum compressive load for each specimen (Source: Abdullah et al., 2014)

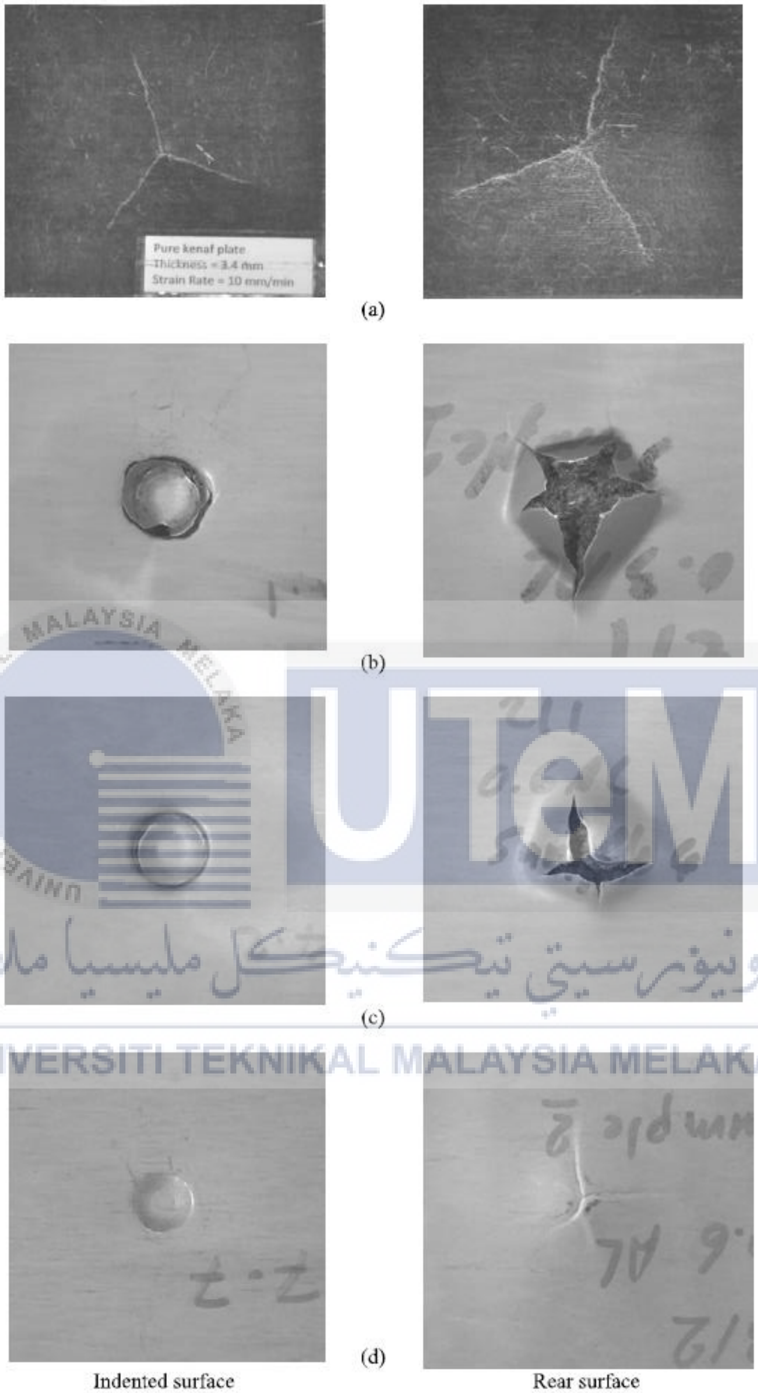

Figure 2.20: Photographs of the indented (a) pure kenaf fibre plate, (b) 2/1-0.3 FMLs, (c) 2/1-0.6 FMLs and (d) 3/2-0.6 FMLs (Source: Abdullah et al., 2014)

It is visible in Figure 2.18 that each specimen exhibits different maximum compressive load. An obvious increase in maximum compressive load was observed when the thickness of aluminium sheet was increased. A similar trend was recorded when the number of layers were increased to 3/2 from 2/1 lay-up. The research also presented photographs of indented samples to show the failure mechanism of FMLs at different configurations. It was observed that the FML specimens produced a dent before cracking due to the protection given by alluminium alloy layers and 3/2 FMLs has better resistance towards deformation compared to 2/1 FMLs. The effect of FML thickness is clearly visible in Figure 2.19 as the 2/1-0.6 FMLs has lesser deformation compared to 2/1-0.3 FMLs.

Pang et al. (2015) conducted a research on the effect of loading rate on indentation behaviour of fibre metal laminates based on kenaf/epoxy. The kenaf/epoxy based FMLs with 2/1 and 3/2 lay-up were fabricated using the vacuum infusion process and hydraulic pressing technique for this research. In this research, the indentation test was conducted using Instron Universal Testing Machine 5982 according to ASTM D6264 with loading rate of 1 mm/min, 10 mm/min and 100 mm/min. Table 2.4 shows the maximum contact force and maximum energy absorbed of each specimen.

Figure 2.21: Photographs of the indented 3/2 FMLs (Source: Pang et al., 2015)

Table 2.4: Maximum contact force and maximum energy absorbed of each specimen (Source: Pang et al., 2015)

Specimen	Loading rate (mm/min)	Maximum contact force (kN)	Maximum energy absorbed (J)
2/1 FMLs	1	3.40 (+/-0.16)	23.89 (+/-0.16)
2/1 FMLs	10	3.49 (+/-0.16)	30.12 (+/-0.16)
2/1 FMLs	100	3.68 (+/-0.16)	33.98 (+/-0.16)
3/2 FMLs	1	5.95 (+/-0.05)	39.62 (+/-0.16)
3/2 FMLs	10	5.52 (+/-0.14)	21.66 (+/-0.16)

Based on table 2.4, it can be seen clearly that kenaf/epoxy based FMLs shows a load rate reliance when subjected to static indentation contact force. For 2/1 FMLs, maximum contact force and maximum energy absorbed increased with increasing the loading rate. However for 3/2 FMLs, the maximum contact force and maximum energy absorbed decreased with increasing loading rate. Visual examinations on the front and rear surfaces of the indented specimens showed that the loading rate did not affect the static indentation failure mechanisms of 2/1 FMLs. However, delamination occurred in 3/2 FMLs when the loading rate was increased up to 10 mm/min as shown in Figure 2.20.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter covers the methodology part of this research based on the information gathered from previous researches. This chapter discusses the fabrication and testing processes such as composite preparation, FML preparation and specimen preparation for quasi static indentation test according to ASTM D6264.

3.2 FML panel manufacturing process flow chart

The FML panel manufacturing process is illustrated in the flowchart shown in Figure 3.1. The processes include the preparation of composite, aluminium, FML and quasi static indentation testing step by step in order to achieve the objectives of this research.

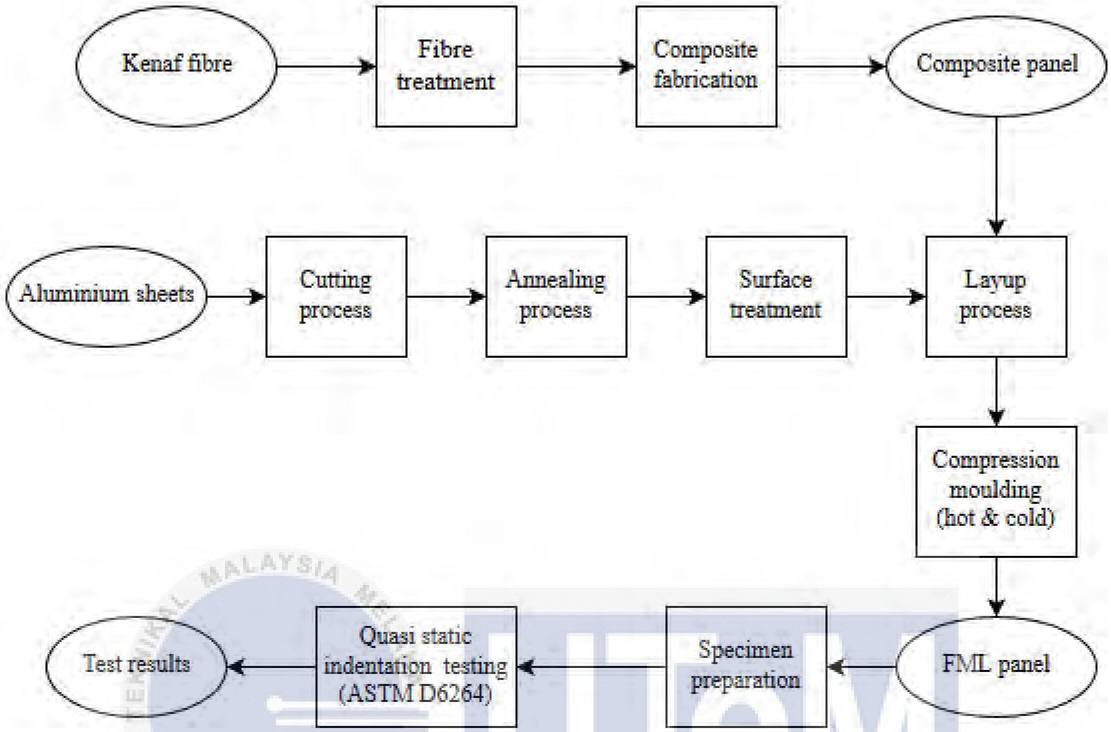

Figure 3.1: FML panel manufacturing process flowchart

3.3 Composite fabrication

In this research, kenaf bast fibres were used as the reinforcement while polypropylenes (PP) were used as the matrix. The fibre treatment applied on the kenaf bast fibers was to clean and chemically modify the fibre surface to reduce the moisture absorption process and to increase its surface roughness for better interfacial adhesion. The fibers were soaked in 5% Sodium Hydroxide (NaOH) solution at room temperature for 4 hours as shown in figure 3.2. The fibers were then filtered out and washed thoroughly with tap water to remove traces of NaOH. The treated fibres were then allowed to dry at room temperature overnight. Next, the air dried fibres were dried in an oven at 40°C for 24 hours.

Figure 3.2: NaOH treatment on kenaf fibre

The fibres were then cut into short pieces with 3 different lengths; 30mm, 60mm and 90mm. Polypropylene (PP) sheets were used as the matrix for this research. The PP sheets were prepared by compressing PP resins in a 200 mm x 200 mm frame mould with 1 mm thickness using the hot press machine for 10 minutes at 175°C by applying 50 kg/cm^2 pressure. Next, the fibres are compressed for 2 minutes at 180°C by applying 50 kg/cm^2 pressure to shape them into flat mats. The fibre mats and PP sheets are stacked alternately in a frame mould of 200 mm x 200 mm with 3 mm thickness. It is then compressed in the hot press machine to form composite panels with consistent thickness as shown in figure 3.3. The composite composition prepared for this research is presented in table 3.1.

Table 3.1: Composite composition prepared

Specimen code	Fibre weight (%)	Fibre length (cm)	Fibre treatment
UT-50(3)	50	3	Untreated
UT-60(3)	60		
UT-70(3)	70		
UT-50(6)	50	6	
UT-60(6)	60		
UT-70(6)	70		
UT-50(9)	50	9	
UT-60(9)	60		
UT-70(9)	70		
T-50(3)	50	3	Treated
T-60(3)	60		
T-70(3)	70		
T-50(6)	50	6	
T-60(6)	60		
T-70(6)	70		
T-50(9)	50	9	
T-60(9)	60		
T-70(9)	70		

Figure 3.3: Kenaf-PP composite panel

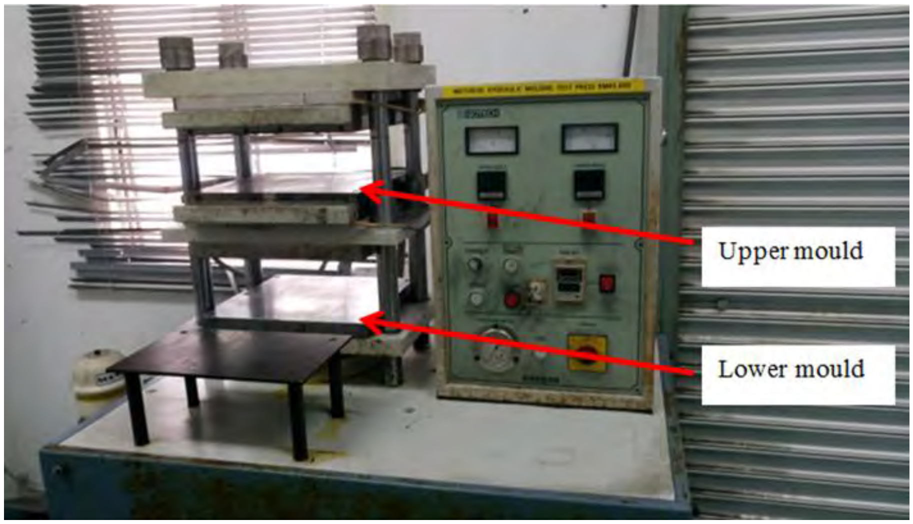

Figure 3.4: Hot press machine

The hot press machine consists of two moulds, the upper and lower mould as shown in figure 3.4. The upper mould is for heating while the lower mould is for cooling process. The kenaf-PP layup was placed in the hot press machine for 2 minutes for preheating process. Then, it was compressed for 8 minutes at of 190 ℃ by applying 50 kg/cm^2 pressure. Then, the moulds were cooled at room temperature while applying the same amount of pressure for 8 minutes. After cooled completely, the composite was removed from the mould.

3.4 Aluminium preparation

The aluminium used in this research is Aluminium alloy 5052-0. The dimension of the Aluminium sheets used for FML is 200 mm x 200 mm with 0.5 mm thickness. The aluminium was annealed before the FML fabrication. The material composition of Al 5052 is shown in table 3.2

Table 3.2: Standard chemical composition of aluminum alloy AL-5052 by (wt %) according to ASTM B209

Contents	**Minimum %**	**Maximum %**
Chromium	0.15	0.35
Copper	-	0.1
Magnesium	2.2	2.8
Manganese	-	0.1
Silicon	-	0.25
Zinc	-	0.1
Aluminium	96.3	97.65
Other elements are not more than 0.05% each with total 0.15%.		

3.4.1 Annealing of aluminium alloy 5052

The aluminium alloy 5052-H32 was annealed to get 5052-0. Annealing is a heat treatment process for aluminium that increases its ductility by relieving the internal stresses and refines the grain structure by making it homogeneous. Annealing process is done at 350°C according to ASTM B918 for 2 hours followed by controlled cooling at 10°C per hour down to 260°C then air cooled.

3.4.2 Aluminium surface treatment

Surface treatment helps in creating a rough surface on the aluminium plates in order to enhance the surface adhesion properties during FML fabrication process. In this research, mechanical treatment or abrasive treatment was opted by using 80 grit sand papers.

3.5 FML fabrication process

In this process, the composite and aluminium sheets were stacked together with polypropylene adhesive in between as shown in figure 3.5.

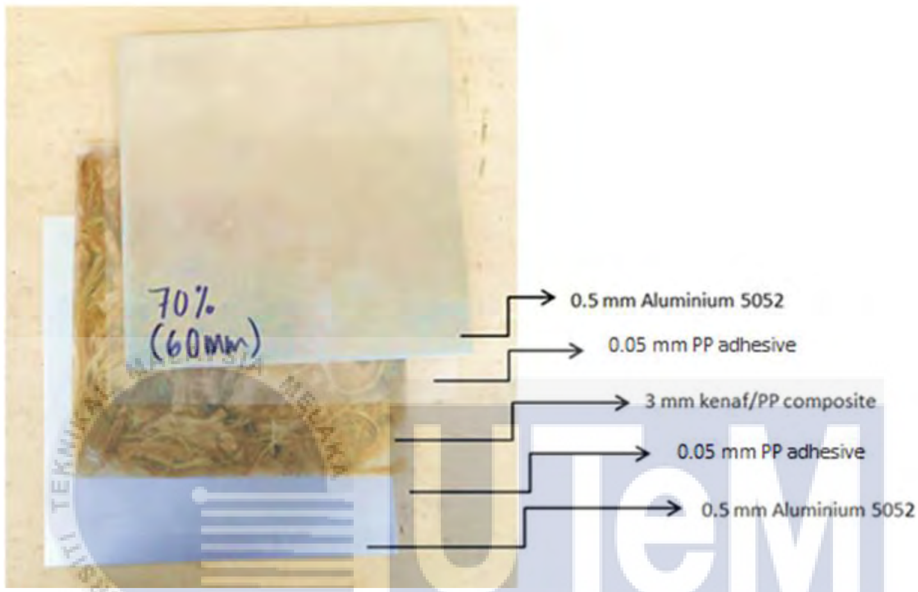

Figure 3.5: FML layup

Then, the assembly was placed in a 4 mm thick mould frame and preheated in the hot press machine at 170 °C for 2 minutes. Next, it was compressed at 0.4 MPa while maintaining the temperature for 8 minutes. Then, the FML was cooled down to 80°C while maintaining the pressure. Finally, the FML was removed from the mould.

3.6 Specimen preparation

Specimens for the impact test were prepared in accordance to the American Society for Testing and Material ASTM D5687 and cut using a shearing machine, is shown in figure 3.6.

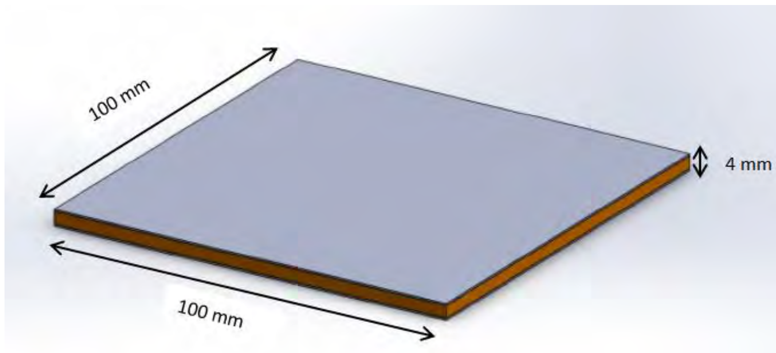

Figure 3.6: Schematic diagram of the specimen

3.7 Quasi static indentation testing

Instron universal mechanical tester 5585H was used in this research to conduct quasi static indentation test on the specimens. This equipment has the capacity up to 150 kN and is compatible with Bluehill® software to store the results of tested specimen which can be saved and printed out. The test was conducted according to ASTM D6264 in room temperature (24±3ºC) and relative humidity of 30±2%.

The specimens were tested in an edge supported configuration consisting of two parallel rigid plates with a 76 mm diameter hole in the center of each. The specimens are placed in between the parallel plates with sufficient force to prevent slippage of the specimen in the clamp during quasi static indentation test and mounted in the lower head of the testing machine. The dimension of support fixture used to conduct the test is shown in figure 3.7. The indenter used in this test has a smooth hemispherical tip with a diameter of 12.7mm. The crosshead displacement rate was set at 1.25 mm/min for the testing.

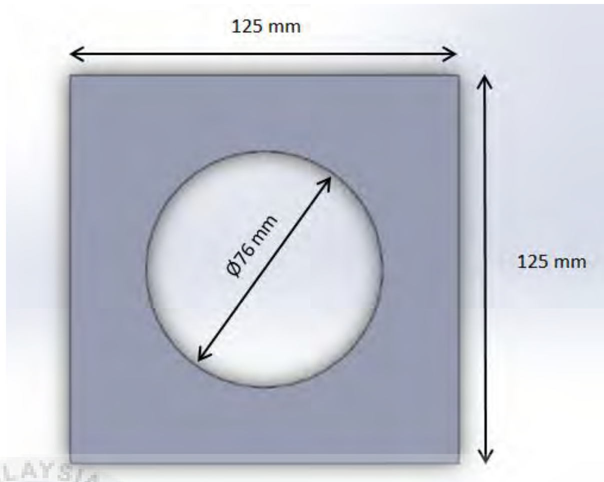

Figure 3.7: Dimension of the support fixture used

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter covers the experimental results of this research based on the quasi static indentation test conducted. The data obtained were tabulated and analysed throughout this chapter.

4.2 Quasi static indentation test

The quasi static indentation test was carried out using Instron Universal Mechanical Tester 5585H to study the effect of fibre length, loading of kenaf bast fibre – polypropylene and fibre treatment on the energy absorption of fibre metal laminate and the damage mechanisms. Three specimens for each composition of FML were tested using smooth hemispherical tip with a diameter of 12.7mm at 1.25mm/min crosshead displacement rate. The specifications of the FML used for testing is presented in Table 3.1 in previous chapter. Figure 4.1 shows the force versus displacement curves for each composition of FMLs with untreated fibre while Figure 4.2 shows the force versus displacement graph for each composition of FMLs with treated fibre.

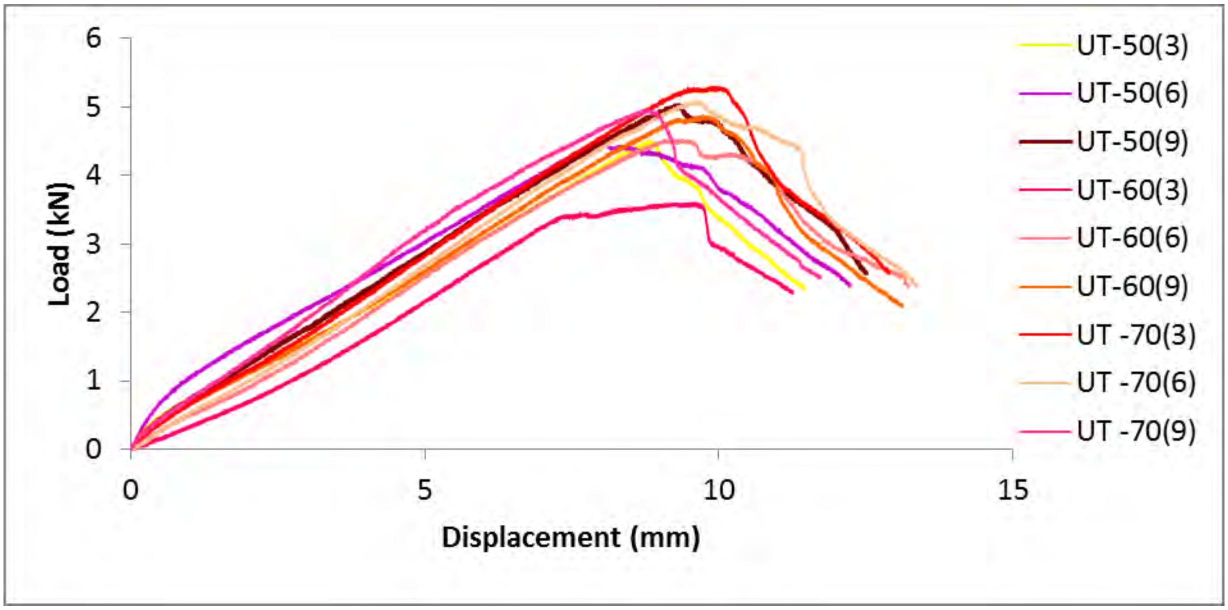

Figure 4.1: Comparison of load versus displacement graph for each composition of FML with untreated fibre

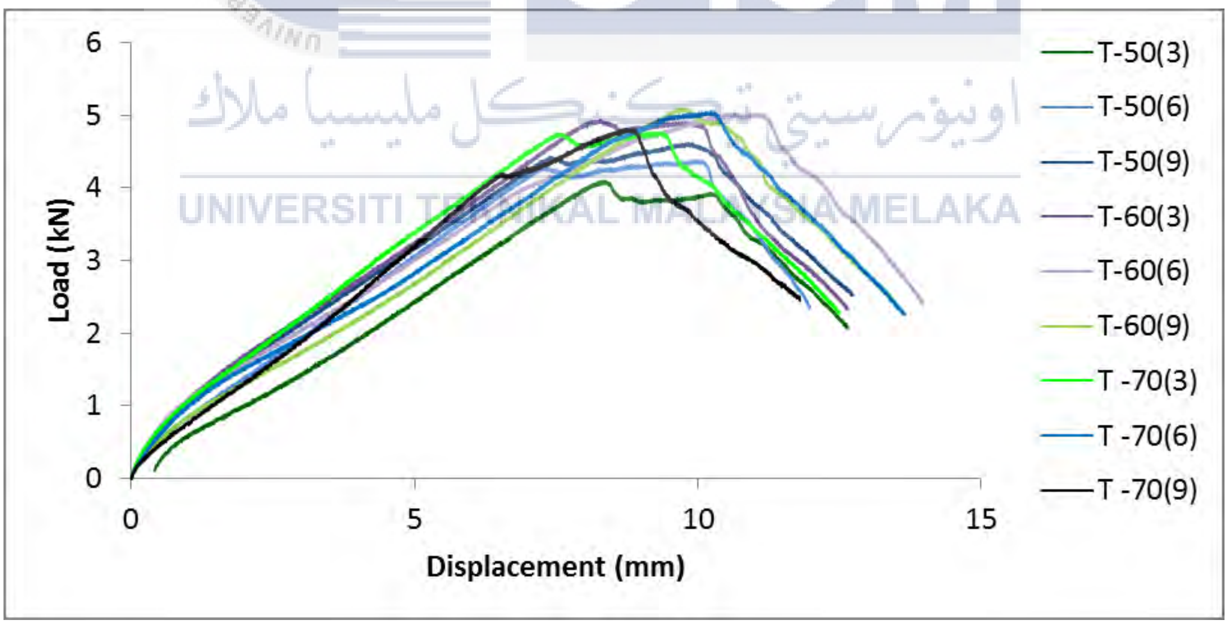

Figure 4.4: Comparison of load versus displacement graph for each composition of FML with treated fibre

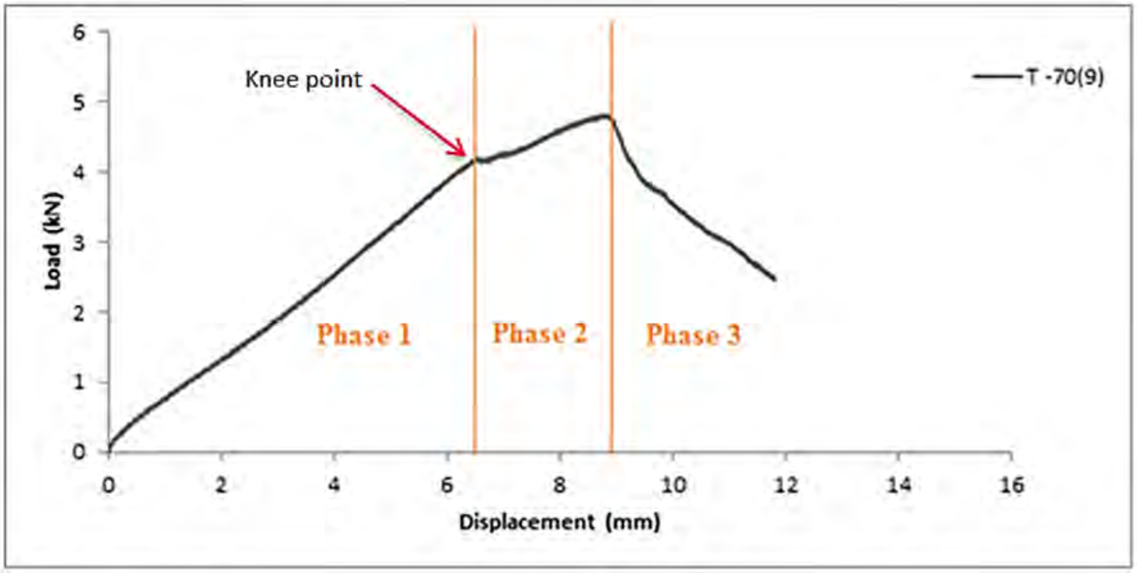

Figure 4.3: Phases of a load versus displacement graph for FML with 70% weight composition of 9mm untreated kenaf fibre

Generally, it can be observed from Figure 4.1 and 4.2 that each specimen exhibits similar curve trend but with different maximum load. The trend of the load versus displacement curve can be divided into three distinct phases as indicated in Figure 4.3. Initially, the curve showed a linear behaviour where it increased along with displacement until reaching a knee point. Beyond the knee point, the curve continued to increase non-linearly until a maximum load peak is achieved. This is due to the dent forming on the top surface of the fibre metal laminate which eventually initiated a crack. The indenter then moved through the thickness of the fibre metal laminate by pushing the top aluminium sheet along with the matrix and kenaf fibres through the rear surface. Finally, when the rear aluminium sheet was penetrated by the indenter, the curve dropped drastically which indicates that the specimen has failed (Pang et al., 2015).

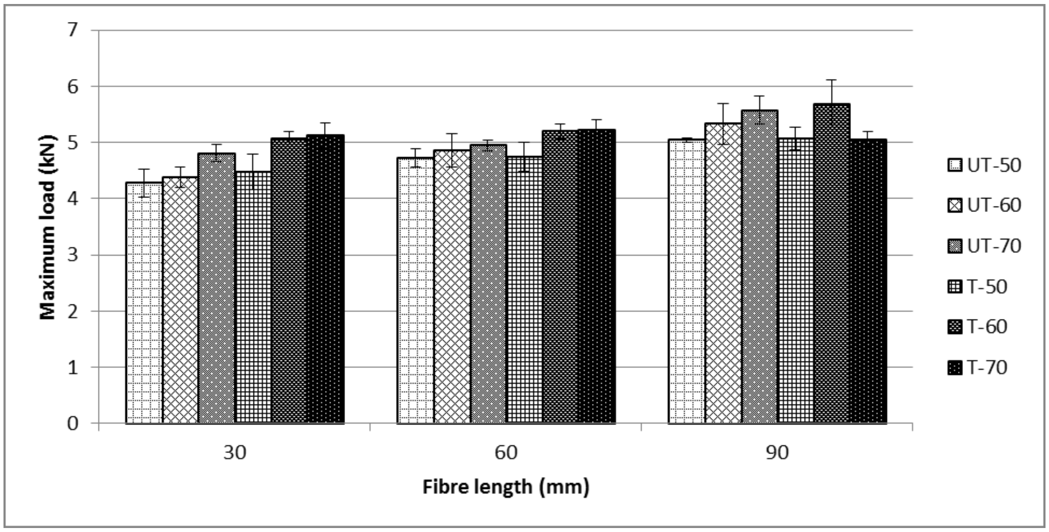

Figure 4.4: Maximum load for each specifications of the FML tested

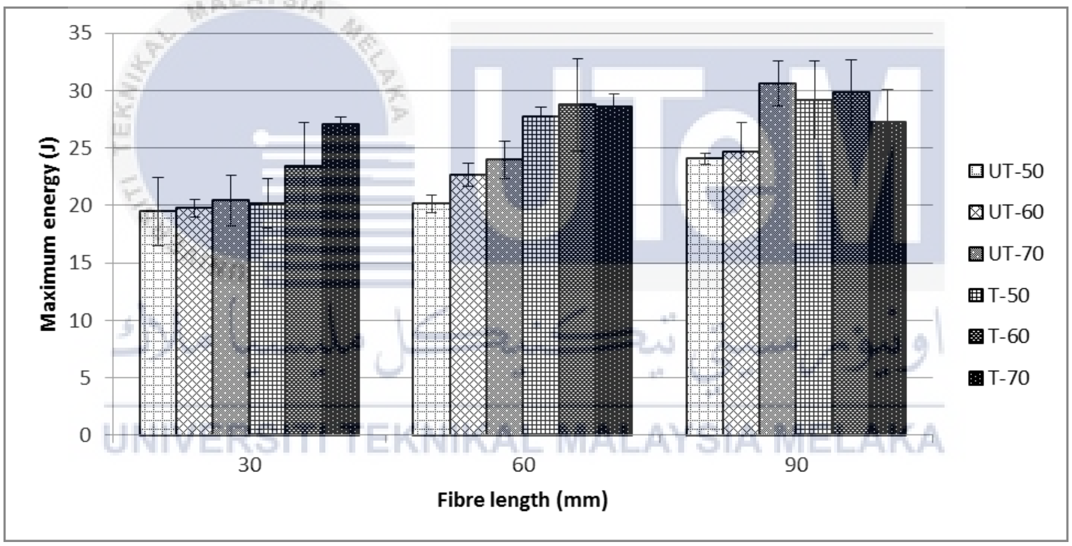

Figure 4.5: Maximum energy for each specifications of the FML tested

The results reveal that the maximum penetration load-carrying capacities of the FMLs tested vary with its configuration as shown in Figure 4.4. Figure 4.5 shows the maximum energy absorbed during the penetration process which was obtained by measuring the area under the force versus displacement curves presented in Figures 4.1 and 4.2 up till the maximum load. These values are listed in Table 4.1.

It was observed from Figure 4.4, the maximum penetration load of FML increases as the fibre length increases for both treated and untreated fibre. FML with 50 wt% untreated fibre loading (UT-50) and 50 wt% treated fibre loading (T-50) showed an increase of 4.92% and 0.60% respectively in terms of maximum load when the fibre length was increased from 3cm to 9cm. This may be due to uneven stress distribution along the fibre when shorter fibre was used. Shorter fibre will form more fibre ends that act as stress concentration points which will eventually lead to fibre breakage followed by a crack on the matrix and metal layer (Farahani et al., 2012). Thus, certain fibre length is required to ensure effective and uniform distribution of stress between fibre, matrix and metal layer in a FML.

Table 4.1: Maximum load and maximum energy recorded for each sample tested

Specimen code	Maximum load (kN)	Maximum energy (J)
UT-50(3)	4.27	19.48
UT-60(3)	4.38	19.79
UT-70(3)	4.81	20.43
UT-50(6)	4.72	20.14
UT-60(6)	4.86	22.67
UT-70(6)	4.95	23.98
UT-50(9)	5.04	24.05
UT-60(9)	5.33	24.66
UT-70(9)	5.57	30.58
T-50(3)	4.48	20.18
T-60(3)	5.07	23.42
T-70(3)	5.12	27.06
T-50(6)	4.74	27.74
T-60(6)	5.20	28.76
T-70(6)	5.21	28.61
T-50(9)	5.07	29.21
T-60(9)	5.68	30.82
T-70(9)	5.05	27.28

Generally, the maximum energy absorbed seems to be higher for FMLs with treated kenaf fibre compared FMLs with untreated fibre irrespective of fibre loading and length. The maximum energy absorption for FML with 70 wt% treated 3cm kenaf fibre, T-70(3) indicated an improvement of 32.5% compared to FML with 70 wt% untreated 3cm kenaf fibre, UT-70(3). The trend is similar for FMLs with 6cm kenaf fibre at 50 wt% loading where the maximum energy recorded for FML T-50(6) is 37.7% higher than FML UT-50(3) that has similar fibre loading and length. The result is consistent with the study conducted by Bakar et al. (2010) that noted the improvement in mechanical properties of composite reinforced with treated kenaf fibre. The increase in energy absorption properties of FML can be explained in terms of fibre-matrix interfacial bonding. Alkaline treatment performed on kenaf fibre removes lignin hemicelluloses and impurities from the fibre surface. This increases the surface area of kenaf fibre and provides better interlocking between the polymer and fibre. Thus, FMLs with treated fibre has stronger fibre-matrix interfacial bonding compared to FMLs with untreated fibre. However for FML with 9cm kenaf fibre at 70 wt% loading, the ones with treated kenaf fibre showed a decline of 10.79% in maximum energy absorbed in comparison to FMLs with untreated fibre. The slight decrease could have been caused by the high viscosity of the matrix in the liquefied state as well as insufficient amount of polypropylene for proper fibre wetting which plays a significant role in the strength of mechanical interlocking between fibre and matrix (Bakar et al., 2010).

In terms of fibre loading, it is observed from Figure 4.5 that the overall energy absorbing properties of FMLs increases as the fibre weight percentage increases for both treated and untreated kenaf fibre. For instance, the maximum energy absorbed by FMLs with treated 3cm kenaf fibre recorded an increment of 16.1% when the fibre loading is increased from 50 wt% to 60 wt%. The energy absorption increases another 15.5% when the fibre loading is further increased to 70 wt%. As the fibre content in FML increases, more energy is required to weaken the fibre-matrix interfacial bonding. Therefore, more energy will be absorbed by the fibres. However, for certain combination the value of maximum energy absorbed reduces when the fibre content is increased beyond 60 wt%. The maximum energy absorbed by FML T-70(9) was 11.5% lower than FML T-60(9). This might be due to the insufficient amount of polypropylene to wet the fibre surface. In addition to that, the increased fibre content will result in agglomeration of fibre which disrupts the distribution of stress along the fibre (Tay et al., 2012). In general, FML T-60(9) recorded the highest energy absorption at 30.82 J, indicating that this configuration provides a better penetration resistance compared to other configurations tested.

4.3 Damage Mechanism

Selected specimens were examined in the rear and indented surface to analyze the failure mechanisms during the quasi-static tests. The photographs of specimens examined are presented in Figure 4.6. Generally, all three specimens examined showed similar failure mechanism where the initial failure started from a dent on the indented surface. It is then followed by a small crack spreading along the rolling direction on the bottom aluminium sheet. As the load increases, the size of the indentation increases along with the crack length on the rear surface which results in the formation of a second crack that propagates in a perpendicular direction to the initial crack.

Cracks at the rear surface of the specimen are noticed to be longer compared to cracks on the indented surface which means the rear surface undergoes more deformation compared to the indented surface as the indenter moves through the thickness of the FML. It is also visible in Figure 4.6, the presence of petaling cracks on the rear surface of the all three specimens examined. The petaling cracks are results of crack propagating away from the centre point which was subjected to the pressure of penetrating indenter during indentation. Compared to FML T-50(3), FML T-70(3) did not produce a gaping hole. However, a circular crack that replicates the shape of the indenter which is a result of aluminium sheets and kenaf fibre being pushed through the rear surface as the load increases is visible in Figure 4.6(c). The single most striking observation to emerge from the post-test examination is that when compared among FML with different fibre loading, FML with 70 wt% fibre loading showed better resistance to deform compared to FML with 60 wt% and 50 wt% fibre loading.

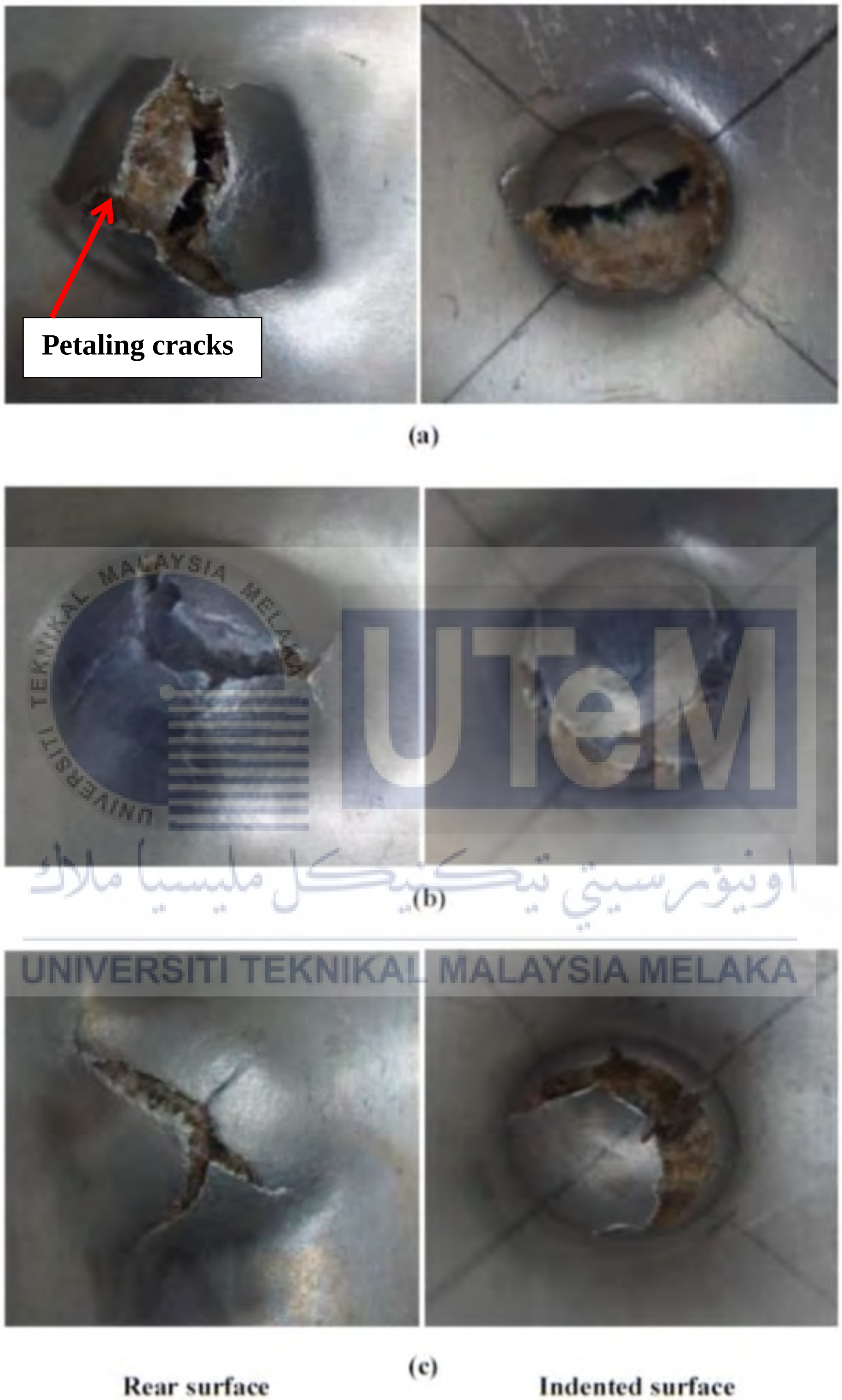

Figure 4.6: Photographs of indented FMLs (a) T-50(3) (b) T-60(3) (c) T-70(3)

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

5.1 Conclusion

This study has found that FMLs with a fibre length of 9cm showed better energy absorbing properties compared to FMLs with fibre length of 6cm and 3cm regardless of fibre treatment and loading. FML reinforced with 50 wt% untreated 9cm kenaf fibre absorbed 30.59 J of energy which is 19.4% and 23.5% higher than FML reinforced with untreated 6cm and 3cm kenaf fibre respectively at similar loading. Likewise, FML reinforced with 60% treated 9cm kenaf fibre recorded an increment of 7.16% and 31.6% in energy absorption compared to the ones with treated 6cm and 3cm fibre respectively at similar fibre loading.

The second major finding was that the energy absorption properties of FMLs increases as the fibre loading increases regardless of fibre length and treatment. The energy absorbed by FML reinforced with 60 wt% treated 3cm kenaf fibre was 16.1% higher than FML reinforced with 50 wt% treated 3cm kenaf fibre. Similarly, the energy absorption of FML reinforced with 70 wt% treated 3cm kenaf fibre was 15.5% higher than FML reinforced with 60 wt% treated 3cm kenaf fibre.

This study has also shown that alkaline treatment on kenaf fibre used to reinforce the fibre metal laminate system showed a positive effect in terms of increasing energy absorption and maximum load variations. FMLs reinforced with treated kenaf fibre recorded an average of 19% increments in energy absorption and 4% increments in maximum load compared to FML reinforced with untreated kenaf fibre

In summary, the load versus displacement curve for each specimen shows similar curve trend but with three distinct phases before failure occurs. Post-test examination reveals that FML with 70 wt% fibre loading showed the highest resistance to deformation when subjected to quasi static loading.

5.2 Recommendations

This research has thrown up many questions in need of further investigation. Further work needs to be done to establish whether the quasi static indentation behaviour of kenaf bast fibre reinforced metal laminate system will be affected if the fibre loading is increased beyond 70 wt%. In addition to that, using different types of fibre surface treatment can broaden the view on the effects of fibre surface treatment on fibre-matrix interfacial bonding. It is recommended that further research include several other testing such as tensile, fatigue and flexural test to study the mechanical properties of kenaf bast fibre reinforced metal laminate system. Furthermore, SEM (Scanning Electron Microscopy) is suggested to study the surface morphology of the fibre-matrix bonding and fractures surface of FML in future.

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APPENDIX A

Quasi static indentation raw data

Maximum load and maximum energy recorded for FML with untreated kenaf fibre

Fibre weight %	Fibre length (cm)	Maximum load (N)					Standard deviation
		1	2	3	4	Average	
50	3	4502.162	3921.349	4400.054	3766.31	4274.521693	253.1858
50	6	4490.376	4793.675	4871.833	4199.643	4718.627773	164.5222
50	9	5029.738	4995.848	5097.215		5040.933579	42.13347
60	3	3602.341	4759.806	4782.179	4384.897	4381.441953	182.2359
60	6	4523.352	5254.746	4807.487		4861.861637	301.0557
60	9	4872.277	5352.417	5760.324		5328.339403	362.9433
70	3	4956.931	4873.859	4595.843		4808.87788	154.4086
70	6	5086.66	4846.616	4903.197	4503.399	4945.490833	102.4594
70	9	5292.654	5527.792	5901.492		5573.97923	250.6937

Fibre weight %	Fibre length (cm)	Maximum energy (J)					Standard deviation
		1	2	3	4	Average	
50	3	20.256	15.56	22.628	15.167	19.48133	2.937032
50	6	20.165	21.089	28.912	19.17	20.14133	0.783607
50	9	24.664	23.56	23.928		24.05067	0.458977
60	3	19.151	30.439	20.869	19.343	19.78767	0.768625
60	6	21.668	22.246	24.087		22.667	1.031446
60	9	25.02	27.558	21.414		24.664	2.520878
70	3	23.523	18.403	19.364		20.43	2.221991
70	6	24.841	21.368	25.397	21.713	23.98367	1.621569
70	9	28.248	33.062	30.419		30.57633	1.968454

Maximum load and maximum energy recorded for FML with treated kenaf fibre

Fibre weight %	Fibre length (cm)	Maximum load (N)					Standard deviation
		1	2	3	4	Average	
50	3	4097.357	4863.188	3910.422	4476.508	4479.017767	312.6542
50	6	4983.366	3840.551	4382.372	4861.162	4742.299873	259.3512
50	9	4919.598	5342.022	4071.28	4940.314	5067.31132	194.4338
60	3	5068.63	4938.9	5212.247		5073.259	111.6414
60	6	5030.081	5213.59	5353.842		5199.17088	132.5675
60	9	5105.168	4426.718	6097.479	5849.389	5684.012053	421.6496
70	3	4964.929	4949.478	5436.465		5116.95718	226.0142
70	6	5259.764	4948.097	5427.219		5211.69347	198.5322
70	9	4988.065	4932.073	3904.091	5243.926	5054.68815	135.7496

Fibre weight %	Fibre length (cm)	Maximum energy (J)					Standard deviation
		1	2	3	4	Average	
50	3	17.109	15.038	21.609	21.814	20.17733	2.171253
50	6	28.195	17.495	28.368	26.646	27.73633	0.77421
50	9	25.131	37.632	29.018	33.471	29.20667	3.407403
60	3	28.237	22.968	19.069		23.42467	3.756724
60	6	34.307	25.152	26.813		28.75733	3.982364
60	9	28.509	32.973	14.564	30.983	30.82167	1.825987
70	3	26.634	26.611	27.927		27.05733	0.615019
70	6	29.855	28.796	27.18		28.61033	1.099927
70	9	23.618	27.66	17.936	30.55	27.276	2.842974

Note: The highlighted data in table are not included to calculate the average value due to error. Thus, it was neglected and not included in the graphs plotted.