STUDY ON MECHANICAL PROPERTIES OF ECO-FRIENDLY KENAF FIBRE REINFORCED METAL LAMINATE STRUCTURE

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SUPERVISOR'S DECLARATION

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DECLARATION

"I hereby declare that this research is my own except for summaries and quotations which have been duly acknowledged."

Signature :……………………..

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Date :……………………..

Specially dedicated to my beloved father, my late mother, brother, sister, to all my family members, lecturers and friends.

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ABSTRACT

During the past decades, the increasing demand of high performance and lightweight materials has stimulated the development of alternative materials, namely Fibre Metal Laminate (FML) structures. FML is a sandwich structure which is formed by bonding the metallic layers with composite as core constituent by means of adhesive agent. In this study, the mechanical behaviour of FMLs with the core constituents of environmental friendly kenaf fibre reinforced polypropylene composites was studied. The FMLs were manufactured through the hot press moulding compression method where the adhesives were incorporated between metallic layers and composite. The effects of fibre compositions (50, 60, and 70 wt%), fibre lengths (30, 60, 90 mm) and chemical treatment on the mechanical responses of FML were investigated. Results revealed that the increase of fibre composition and fibre length reduces the mechanical strength of FML. Highest tensile strength of FMLs is 46.70MPa which is 50wt% with 60mm fibre length while highest flexural strength of FMLs is 86.36MPa which is 50wt% with 90mm fibre length. However, the chemical treated kenaf fibre reinforced FML showed a significant enhancement of 10% to 20% on the mechanical properties in comparison to the non-treated fibre reinforced FML.

ABSTRAK

Sepanjang dekad yang lalu, permintaan yang semakin meningkat dalam bahan yang prestasi tinggi dan lebih ringan telah merangsang pembangunan bahan-bahan alternatif iaitu logam serat lamina(FML) struktur. FML adalah struktur sandwich yang dibentuk oleh ikatan lapisan logam dengan komposit sebagai bahan teras melalui ejen pelekat. Dalam kajian ini, sifat-sifat mekanikal FMLs yang menggunakan bahan-bahan mesra alam iaitu komposit kenaf gentian bertetulang polipropilena telah dikaji. FMLs telah dihasilkan melalui kaedah "hot press" dan pelekat digabungkan antara lapisan logam dan komposit. Kesan komposisi serat (50, 60, dan 70wt%), panjang serat (30, 60, 90 mm) dan rawatan kimia ke atas reaksi mekanikal FML telah dikajikan. Hasil kajian menunjukkan bahawa peningkatan komposisi serat dan panjang gentian mengurangkan kekuatan mekanikal FML. Kekuatan tegangan tertinggi FMLs adalah 46.70MPa yang 50wt% dengan panjang gentian 60mm manakala kekuatan lenturan tertinggi FMLs adalah 86.36MPa yang 50wt% dengan panjang gentian 90mm. Walau bagaimanapun, gentian kenaf bertetulang FML yang telah dirawat oleh kaedah kimia menunjukkan peningkatan yang besar sebanyak 10% sehingga ke 20% ke atas sifat-sifat mekanikal berbanding dengan gentian yang tidak dirawat gentian kenaf bertetulang FML.

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LIST OF ABBREVIATIONS

FML	Fibre metal laminate
LKTN	National Kenaf and Tobacco Board
ASTM	American Society for Testing and Materials
SEM	Scanning Electron Microscope
CMCs	Ceramic Matrix Composites
MMCs	Metal Matrix Composites
PMCs	Polymer Matrix Composites
PP	Polypropylene
NaOH	Sodium Hydroxide
EDM	Electrical discharge machining

CHAPTER 1

INTRODUCTION

1.1 Background of study

Throughout the 20^{th} century, laser technology to locate oil and gas deposits has been improved drastically, which causes a strong global demand on oil production. Technology in automobiles, spacecraft, electronic gadget, and power plant create a lot of pollutions from oil usage where involve air and water pollution, greenhouse effect, and ozone layer depletion.

Combustion of vehicle fuel has been identified as one of the major source of pollution. Fortunately, greenhouse effect can be controlled by reducing the gases emitted from automobiles. There are several ways to reduce the fuel consumption of automobiles, which include designing the automobile to be more aerodynamics, increasing the engine efficiency, and decreasing the weight of the automobiles. Vehicle weight reduction is an adequate idea which can be achieved by utilizing a lightweight material as the body structure of vehicle. Towards the aim of reducing the vehicle weight, sandwich structure of Fibre Metal Laminate (FML) is being proposed in automotive field. Previous study has shown 30% of weight reduction can be achieved when monolithic aluminium is replaced by glass fibre reinforced polypropylene FML (DharMalingam et al. 2014). Cheah (2010) demonstrated 10% of vehicle weight reduction can lead to 7% less fuel consumption.

Fibre metal laminates (FML) as shown in Figure 1.1 is a class of hybrid structure which is formed by bonding metallic layers to composite material using adhesive agents. In 1950, Fokker Aerostructures of Netherlands found that laminated structures can prevent rapid growth of the fatigue crack compared to the monolithic materials (Chai and Manikandan, 2014).

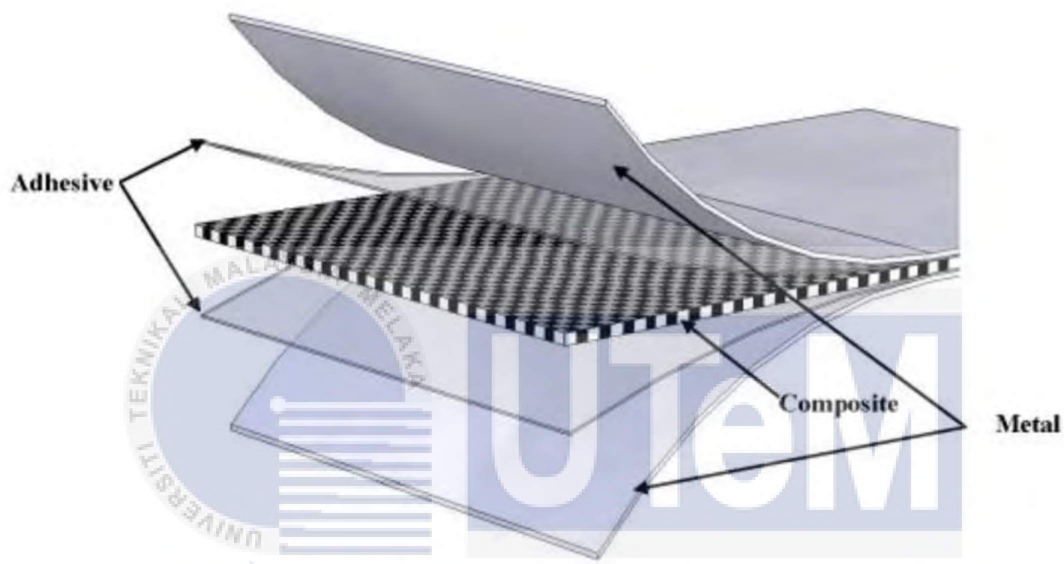


Figure 1.1: FML sandwich structure (DharMalingam and Kalyanasundaram, 2013)

The combination of composites and metals in laminated bond structures can produce a magnificent fatigue strength, impact resistance and damage tolerance. Fibre in the composite structure acts as a crack propagation retarder and increase the damping and insulation properties, while the metal layers improve ductility and impact resistance and damage tolerance (Cortes and Cantwell, 2006; Alderliesten, 2005).

Natural fibre reinforced thermoplastic composites is better than thermoset composites in terms of recyclability and processability. Thermoset matrix bring negative impacts on environmment since it is not biodegradable and recyclable whereas thermoplastic can be recycled by just heating to the melting temperature. Natural fibres such as flax, hemp, jute and kenaf fibres have been widely utilized recently due to its high availability and environmental friendly characteristic.

Kenaf fibre is from the bast and core of the kenaf plant (hibiscus cannabis L.) which constitutes 40% of the plant. Kenaf plant contains cellulose (44-575), hemi-cellulose (22-23%), lignin (15-19%), ash (2-5%), and other elements (~6%) (Kozlowski & Wladyka-Przybylak, 2008). In Malaysia, kenaf has the potential to replace local tobacco due to its high availability and ease of cultivation. The establishment of National Kenaf and Tobacco Board (LKTN) has promoted and developed the kenaf industry. To date, mechanical properties of thermoset based synthetic fibre reinforced metal laminate have been studied but there is a limited literature on the thermoplastic based natural fibre reinforced metal laminate. The mechanical performance of lightweight thermoplastic based kenaf fibre reinforced metal laminate was investigated in this study.

1.2 Problem statement

The increasing usage of fuel brought burden to environment. The fuel combustion emit harmful output that pollute the air. Since the weight of the automobiles directly affect the fuel consumption, decreasing the car body weight is crucial in order to optimise the consumption. The increasing demand in automotive and aircraft industry for lightweight structures with superior performance had stimulated the development of lightweight material such as composite structure. Current material used in automotive industries normally is steel for car bodies. The disadvantages of steel has a high expansion rate in varying temperature which causes it to crack and become deformed. FML structure of the mechanical properties will improve as the good bonding composite layer with metal skin by means of adhesive agents.

1.3 Objectives

The objectives of this research are:

i. To provide a through comparison on the tensile properties of FML with different fibre length, compositions and fibre treatment.

ii. To provide a through comparison on the flexural properties of FML with different fibre length, compositions and fibre treatment.

1.4 Scopes

The scopes of this research are:

i. To study the background literature review

ii. To fabricate and prepare the FML specimens.

iii. To conduct tensile test according to ASTM D3039.

iv. To conduct flexural test according to ASTM D790.

v. To observe and evaluate the failure mechanism of FML using Scanning Electron Microscope (SEM).

CHAPTER TWO

LITERATURE REVIEW

Literature review is a detailed and supportive information of the previous research. It is a combination of works that are related to this relevant field of the research. It proves and gives the reason to support this research theoretically. Literature review plays an important role as the future researcher able to use the provided detail and related information to support and improve the new research.

2.1 Fibre metal laminate

Fibre metal laminate is considered to be popular in recent days as many industry sectors like automotive, construction, and even aerospace are using FML to improve the material performance and reduce the cost and weight as well to reduce the unwanted greenhouse gases that can lead to air pollution. Therefore, automobiles weight reduction is the way that can be tackled down in order to improve engine efficiency. A study shows that reduction in 100kg of automobile weight can save approximate 300L to 800L fuel over the lifetime of the vehicle and this can also reduce the carbon dioxide emission to about 9g per kilometer (Helms & Lambrecht 2003).

Weight of the vehicle and usage of petroleum reduction is important indeed, however the safety of the passenger cannot be ignored. There are many years of research done to prove the advantages of FML which include high energy absorption characteristic, corrosion resistance, fire containment capacity, impact resistance and less maintenance. On top of that, duration of manufacturing of FML is simply reduced because it only need to heat up the thermoplastic composite before it is cooled down to room temperature (Carrillo & Cantwell 2009) compared to thermoset composite. This characteristic is vital as the productivity will increase if the manufacturing process time is reduced.

Fibre metal laminate (FML) is hybrid material consists of alternating layers of metal and natural fibre reinforced polymers as seen in Figure 2.1. This all began during the study to improve the crack growth properties of structural material in 1940s (C. Rans, 2007). However, the usage of the advanced aluminum alloy and fibre reinforced composite has its own advantage and disadvantage. Even both of the materials have its own weaknesses like poor fatigue strength of the aluminum alloy and the poor impact and residual strength properties of carbon fibre reinforced composites. Eventually, the thought of combining the two of the material in 1980s is to create a hybrid composite structural material to compensate weaknesses of other material (J. Laliberte, 2002). The fatigue crack growth rates can be reduced by bonding layers of material to form laminate using adhesive agent. If crack has started to grow in one of the sheet layer, the adhesive layer will act as crack divider to restrain the crack tip opening until the crack is initiate to the neighbouring layer of fibre reinforced composite too.

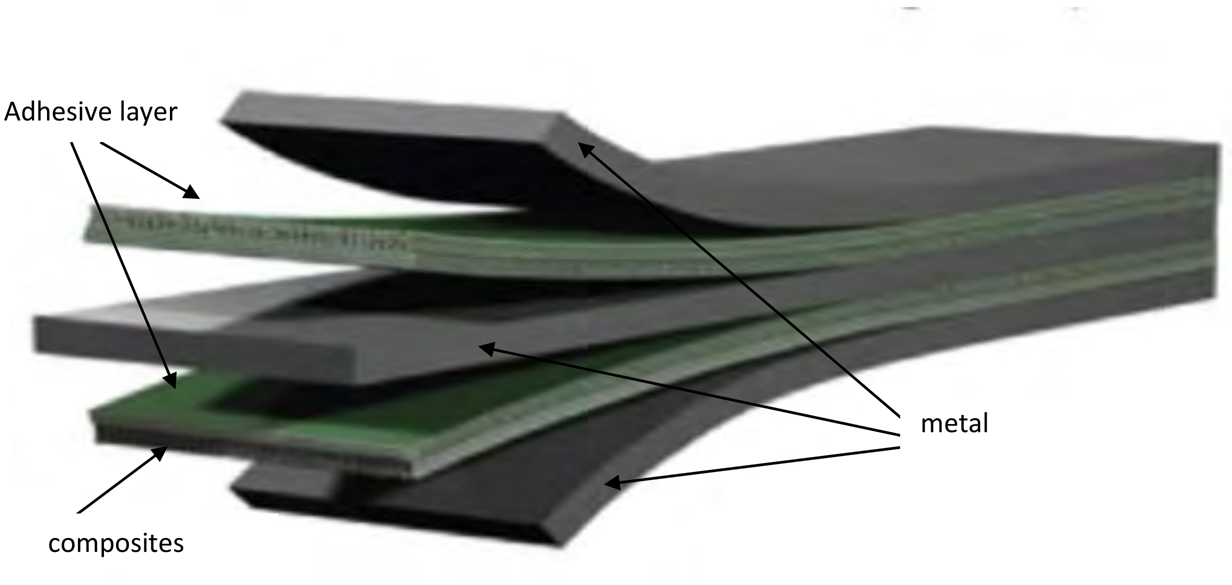


Figure 2.1: Example of fibre metal laminate (Sadighi et al, 2012)

2.2 Composite

Composite possess many mechanical advantages compared to monolithic metal. The advantages are high tensile strength and flexural strength. Composite material are defined as two or more materials combined together as a result to improve the mechanical properties compared to the original individual component (Materials & Campbell 2010).

2.2.1 Types of Composites

There are many types of composites such as Ceramic Matrix Composite (CMCs), Metal Matrix Composites (MMCs), and Polymer Matrix Composites (PMCs) (S.Kindo, 2010). Ceramic Matrix Composites are made up of ceramic matrix and fibre. Ceramic are made into fibre because it can increase the elongation resistance, thermal shock resistance and crack resistance that are normally absent in ceramic material such as glass. Ceramic fibre for CMCs normally are carbon, silicon carbide, and alumina. CMCs has the properties of light weight, high load resistance and high life cycle. Common applications used involved heat system for space vehicles, gas turbines, burners, brake disks and flame holder.

MMCs has decent properties such as high specific strength, specific stiffness, wear resistance, low density, and corrosion resistance. Since with all these good properties, MMCs composite always used in space application due to its high stiffness and almost near zero coefficient thermal expansion (Suraj Rawal, 2001).

Polymer matrix composites (PMCs) contain certain amount of fibre such as natural and synthetic fibre bonded together with matrix where polypropylene is one of the widely used matrix. PMC provides high strength, light weight, and high stiffness properties.

2.2.2 Matrix

Matrix is one of the crucial needs for composite manufacturing. Basically, the purpose of using matrix is to protect the fibres and act as bond to hold the fibre inside the composites. It allows stress transfer between the fibres in the fibre reinforced composite (Taj et al. 2007). Mechanical abrasion on the fibres surface can be avoided by using a stiffer matrix (El-Shekeil et al, 2012).

Generally, there are two types of polymer matrix which are thermoplastics and thermosets. Thermoset polymer is a network polymer which is unable to reform and reprocessed after curing. This is because the thermoset polymer form a strong covalent crosslinks between adjacent molecular chains after processing. Examples of thermoset polymer are polyester resins, epoxy and phenolic (Callister, 2007).

In contrast, thermoplastic melts when heated and harden when cooled, hence it is recyclable. This process is reversible. Common types of thermoplastic polymer are polypropylene, polyethylene, polystyrene, and polyvinyl chloride (Callister, 2007). The advantages and disadvantages of thermoset and thermoplastic are shown in the Table 2.1.

Table 2.1: Advantages and disadvantages on thermoset and thermoplastic (Rassiah & Ahmad, 2013)

Matrix	Thermoset	Thermoplastic
Advantages	1. Low viscosity 2. High adhesive with fibre 3. Excellent heat stability primal 4. Creep resistance	1. High life cycle 2. Easy to handle 3. Easy to repair 4. Recyclable
Disadvantages	1. Brittle 2. Non-recyclable 3. Unable to reform	1. Poor melt flow 2. Need to heat more than the melting point for better binding between fibre.

2.2.2.1 Polypropylene

Polypropylene (PP) is a type of thermoplastic polymer resin which is widely used in average household, commercial, and industrial application. Thermoplastic is always given a top priority than the thermoset because thermoplastic can be recycled and reused. The chemical designation is $(C_3H_6)_n$. Polypropylene is also an economical material as it offers outstanding physical, chemical, thermal and electrical properties.

PP has the properties like high rigidity and high melting point at about 157°C. Since 1957, PP became popular due to its variety of good mechanical properties and low cost. From 3rd place PP has move to 1st place by mid of 1990s (Mecharaoui, 2010). It can be reused and recycled ironically, the PP may not degrade easily inside the soil because it takes a long period for microorganism in the soil to break down the PP chemical structures. (Ammala et al. 2011). Since the PP is hydrophobic and microorganism will only attach to PP if the surface is hydrophilic. In order to increase the rate of degradation some prodegradants such as metal salts and ferrocene are added to the polymer so as to increase the rate of oxidation of polymer consequently, PP can degrade better in the soil.

2.2.3 Reinforcement

Reinforcement is one of the important materials required to produce composites. Many materials had been chosen as reinforcement such as fibre, whiskers, and fabrics. Types of reinforcement used depend on the application and situation for industry requirements. Reinforcement enhances the strength, toughness and corrosion resistance of the composite.

Fibre as the reinforcement satisfies all the condition needed to produce the composites with the most optimum performance.

2.2.3.1 Natural Fibre

In the composite industry, natural fibres are abundant resources that are in low cost, low density, high stiffness and better replacement for metals (Maya et al, 2003). There are few different types of natural fibres such as flax, hemp, jute straw, wood, rice husk, wheat, barley, oats, rye, cane, grass, reeds, kenaf and pineapple leaf (BLedzki et .al, 1999). Natural fibres are normally cheap and environmentally friendly where they are also abundant with large quantity.

2.2.3.2 Kenaf fibre

Kenaf grows in large quantities in United States of America, India, Indonesia, Bangladesh, Malaysia and majority parts of Africa (Taylor. C.S, 2014). Kenaf produces 6 to 10 tons of dry fiber per acre per year. It is estimated that the annual output of the kenaf fibre is 330 thousand tons worldwide (Chen & Liu, 2010). Kenaf fiber is quite similar with the jute fiber however, kenaf fiber is much stronger, whiter and shinier (AAA. Rashdi, 2009). Kenaf field is shown in Figure 2.2

Figure 2.2 : Kenaf field

It is important to understand the mechanical properties of kenaf fibre when designing a composite. Since natural fibres have very complex crystalline and amorphous structure, there are ways to improve the fibre strength and wettability. Mechanical properties of kenaf fibre are shown in Table 2.2.

Table 2.2: Mechanical properties of kenaf fibres

Ultimate strength (MPa)	Young's Modulus (GPa)	Modulus (GPa)	Test method	Source
930	53	-	-	Ku et al, 2013
275-450	-	-	D3039	Anandjiwala, 2007
101.3	5.5	-	-	Jeyanthi, 2012
65	8.3	7.3	-	Akil et al, 2011
350-600	40	9-10	D3039/DMA	Fiore, 2014

2.3 Mercerization

Mercerization is the most common chemical treatment technique to treat natural fibres. This is conducted to enhance the compatibility and bonding between natural fibres and thermoplastics. Mercerization also known as alkali treatment not only improves the adhesion properties between reinforcement and matrix it can also eliminates the natural impurities, oil and unwanted particles on the surface of the fibre. However, alkali treatment will deteriorate the fibre strength if the concentration of sodium hydroxide (NaOH) exceed the critical limits. Recent studies have shown that coupling agent and composite additive has the least effect to increase the adhesion ability between natural fibre and thermoplastic (Puglia et al. 2008). Thus, mercerization or alkali treatment is far more suitable technique to be used to upgrade the adhesion level of the composite.

Chemical treatment will increase the surface roughness (Onuegby et al, 2013) and to enhance the reactivity between fibre and matrix (Li et al. 2007). As a result, the mechanical properties are significantly improved as the adhesion bonding is better and the stress is able to be distributed evenly within the composite. Besides, alkali treatment is able to reduce the high moisture absorption characteristic in the natural fibre effectively. Rama devi et al. (2012) has studied the effect of alkali treatment on the water treatment on the water absorption of single cellulosic abaca fibre and the results showed that alkali treated abaca fibre has less moisture absorption. Mechanical properties of treated natural fibre reinforced composite are better than untreated natural fibre reinforced composite (Srinivasa & Bharath, 2011). All of the findings show that high mechanical strength of a composite and FML required a strong fibre-matrix adhesion through chemical treatment.

2.4 Annealing

Annealing is a heat treatment process that used to change the properties like rigidity and strength by heating the metal to a specified temperature for a period of time and then cooling down it slowly. It is also used to increase the ductility of metallic alloy through recrystallization, remove the accumulated internal stress, homogenous the metallic fine grains and improving cold forming properties (Khairia Salman Hassan et al., 2012). After recrystallization, the tensile strength, yield strength and hardness are decreased but the elongation property is increased (Rao et al. 2014).

Annealing normally has three stages, the first stage called recovering which is the removing of linear crystal defects and internal stress. The second stage is recrystallization where the new crystal created to take place of deformed crystals by internal stresses resulted from forming process. Third stage is resulted from higher temperature than recrystallizing temperature degree and run out time where the grains grows to coarse grains which affect the microscopic instruction of which decrease the mechanical properties (Khairia Salman Hassan et al., 2012). Annealing is important because it is a treatment for metal such as aluminium to soften it so it is more workable and make it more homogenous but it is also depends on certain applications. Annealing can eliminate the rolling direction effect on the aluminium sheet. Annealing normally can be done by using furnace.

2.5 Metal Surface Treatment

Surface treatment can be categorized into mechanical treatment, chemical treatment, electrochemical treatment, coupling agent and dry surface treatment (Sinmazcelik et al. 2011). Surface treatment is needed for FML fabrication as it can remove the contamination from the surface of the metal as well as to increase the surface roughness in order to increase the adhesion properties. Therefore, the mechanical interlocking between aluminium and composite can be improved. In this research, sandpaper grit 80 will be used for metal surface treatment.

2.6 Abrasive Waterjet Cutting

Abrasive water jet cutting is getting popular among researcher and industry due to its high quality cutting process. It is easy to control and able to cut any material with different thickness. There are quite a lot of different types of cutting machine that can be used such as electrical discharge machining (EDM), wire cutting, laser cutting and milling. However, abrasive water jet cutting is the most suitable method to be used for FML sandwich structure.

Abrasive water jet ultilizes a high pressure water stream together with abrasive along the cutting tool. Moreover, it is able to cut the material with the exact dimension according the system program and thus, wastage of material will be reduced (Ansar et al. 2013). Apart from that, traditional milling machine, laser cut machine and EDM wire cut are unable to cut FML system accurately. EDM wire cutting is unable to cut the FML because the of the electric resistance characteristic of composite materials. It had been showed that traditional milling process for FML had cause the fibre pull out and tool wear while laser cutting led to the damage of composite between the metals layers. Consequently, it cause a low quality cutting surface due to large difference in the thermal properties of metal and composite (Graaf & Meijer 2000).

2.7 Mechanical Properties

FML is considered a new type of material used in building structure, aircraft and automobiles. FML offers a significant improvement such as tensile and flexural strength, low crack growth rate and low density over both the composite and monolithic metallic alloy. However, the mechanical properties are still affected by several factors such as type of fibre, fibre orientation, size of fibre, length of the fibre, and types of matrix used during the fabrication process.

Mechanical strength is also affected by the aspect ratio of fibre where it is characterized by the length to diameter ratio. Therefore, the longer the length, the higher the aspect ratio and thus, the stronger the fibre. Higher aspect ratio is defined as the interfacial strength between area of matrix and reinforcement. Generally, tips of fibre will possess high stress concentration which will lead to crack (Amuthakkanna et al, 2013). This is why short fibre composite will be weaker as it has more fibre ends. Optimum length can be determined by using shear-lag analysis according to to Equation (2.1) (Dai et al, 2006).

$$\frac{l_c}{d} = \frac{\sigma}{2\tau_y} \qquad (2.1)$$

Where l_c is the critical length, d is fibre diameter, σ is ultimate strength of fibre and τ_y is interfacial shear stress.

In order to ensure the optimum stress transfer between matrix and reinforcement, length must be higher than the critical length. This increases a proper load transfer and increase the efficiency of fibre bridging system. Critical length can be lowered down by improving the fibre-matrix adhesion in order to have better interfacial shear strength (Brahmakumar et al. 2005).

2.7.1 Tensile properties

Tensile test is conducted to identify the strength of the materials through load-displacement curve. Carillo (2009), used self reinforced polypropylene (SRPP) as the composite. FML were manufactured by stacking the composite, the interlayer material and aluminium alloy 2024-0. In Meyer pneumatic press, the stack is heated at temperature of 165°C and pressure of 7 bars and slowing cooled to room temperature. The size of specimen used is 300x300mm. Instron 4204 universal test machine was used and test according to the ASTM D3039.

Sia (2014) has studied the effect utilisation of Weibul analysis on the tensile strength of natural fibres increase the predictive accuracy of the fibre strengths. As a result, researchers focus on the large scattered tensile strengths of natural fibres by using statistical approaches.

Ewulonu and Igwe (2012) have done research on the effect of oil palm empty fruit bunch (OPEFB) fibre content and particle sizes on the tensile strength of high density polyethylene. They showed that tensile strength of high density of polyethylene composite decreased as the filler loading is increased. The tensile strength is decreased because of poor bonding between filler matrix and irregular size of the OPEFB fibres.

Maleque et al. (2007) used the virgin epoxy and pseudo-stem banana reinforced epoxy composite and the ultimate tensile strength of the banana reinforced epoxy is higher in strength. This is due to the epoxy matrix transmits and distributes the applied stress to the banana fibre.

Wambua et al. (2003) studied on natural fibres reinforced polypropylene composites using film stacking method and compared with glass mat reinforced polypropylene composites from the open literature. Hemp fibre composites displayed the highest tensile strength while coir showed the lowest tensile strength. The low strength of coir may due to its low cellulose content and reasonably high microfibrillar angle.

Osman (2013) did a research on mechanical properties of natural fibre and compare with synthetic fibre. Natural fibres exhibits superior advantages over the synthetic fibres. However, natural fibre got its drawbacks like low shear interface strength, water absorption and biodegradation but it can partially overcome by introducing chemical treatment.

2.7.2 Flexural properties

Flexural strength is also known as modulus of rupture, bend strength, or transverse rupture strength which is a material properties that are defined as the stress in a material just before it yields in a flexural test. There are standards that can be conducted to find out the flexural strength such as ASTM D790, D6272 and D618. ASTM D790 is chosen because it is suitable for reinforced composite specimen. ASTM D790 is used to determine the flexural properties of a specimen. ASTM D790 has two method which is three point bend and four point bend. The differences are the location of load applied. Figure 2.3 shows the illustration of bending location.

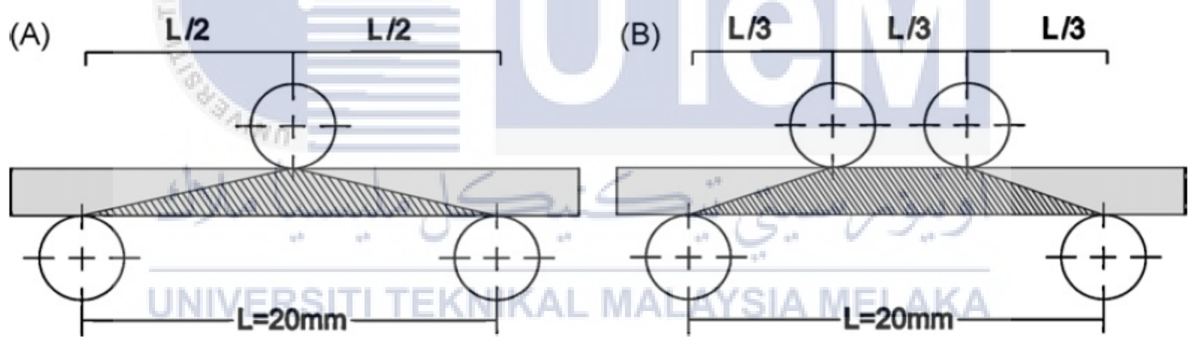


Figure 2.3: Schematic diagram of 3-point (A) and 4-point bending (B) bending tests (Rodrigues Junior, 2008).

Maleque et al. (2007) studied the flexural properties of virgin epoxy resin and pseudo-stem banana woven fabric reinforced epoxy composite. It shown that the banana woven fabric was used with the epoxy material. It shows that specimen with banana fabric has higher flexural strength and modulus as the indication of material stiffness in static bending condition.

Wambua et al. (2003) used natural fibres (sisal, kenaf, hemp, jute, and coir) reinforced polypropylene composites were processed by compression moulding using a film stacking method. Flexural strength of hemp composites shown the highest peak and compares well with glass mat composites.

Sinval et al. (2008) studied the flexural strength of microhybrid and a nanofill composite using 3 point and 4 point bending test. The test is using a universal testing machine DL2000 (EMIC) with crosshead speed of 1mm/min. 3 point bending show higher flexural strength compare to 4 point bending test.

Li et al. (1988) studied the flexural strength of passive smart-healing cementitious composite that demonstrated in the laboratory. The basic elements using in smart material are sensors and actuators in the form of controlled microcracks and hollow glass fibres carrying the air-curing chemicals.

Carillo (2009) studied the self-reinforced polypropylene(SRPP) composite mechanical behaviour. Flexural test on two types fibre orientation of FML at a strain rate of 0.01/min. [Al, 0°/90°] has higher flexural strength compare to [Al, 45°].

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This section includes all the methods from beginning till ending of tensile and flexural test. It is crucial in this research due to it may help future researcher to understand more on about tensile and flexural.

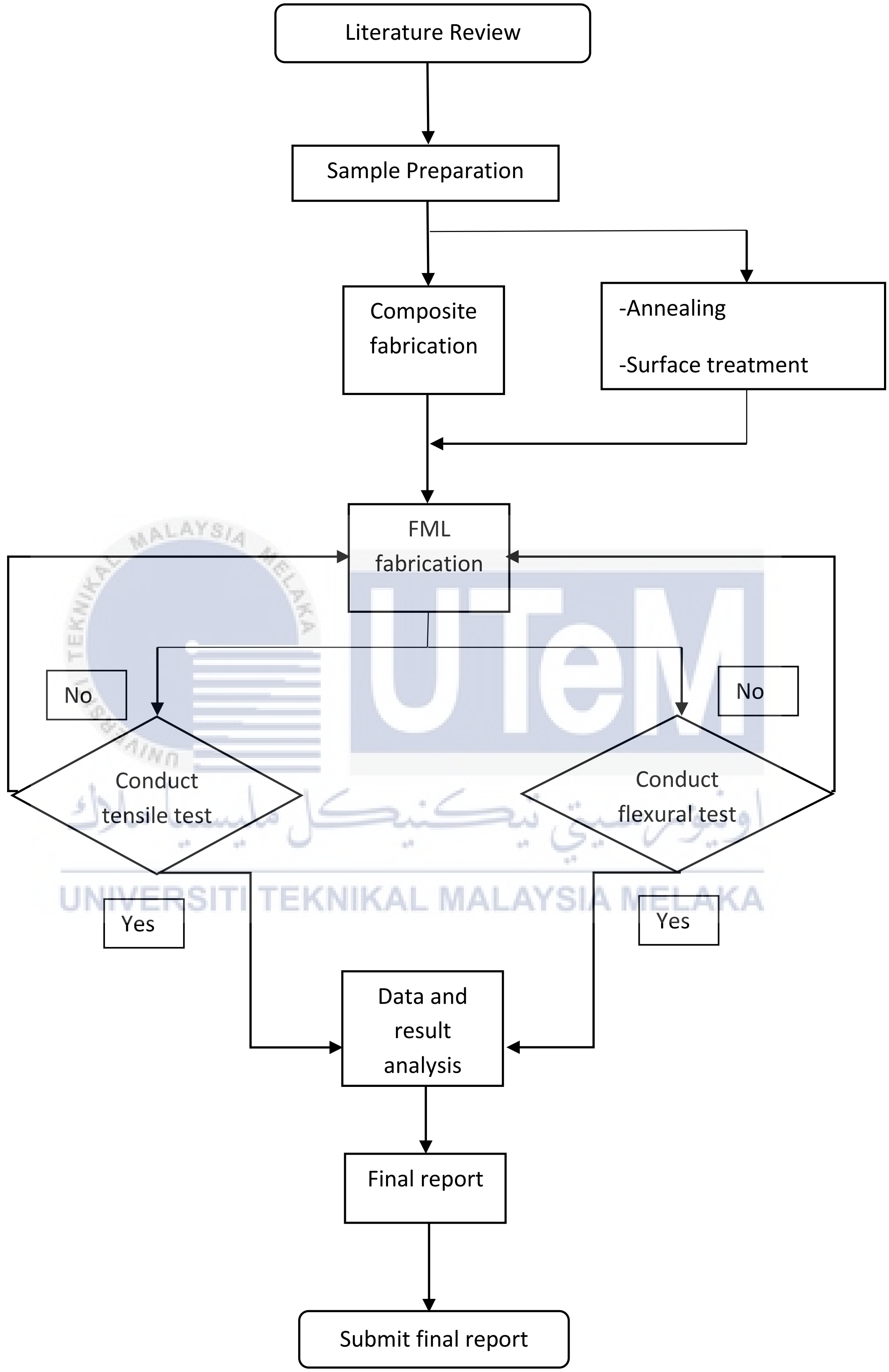


Figure 3.1: Flowchart for overall process

3.2 Material preparation

FML which is formed by stacking metals to composite. The composite was formed using hot press moulding compression method. The method used in this project is aluminium alloy 5052-0 with a thickness of 0.5mm metal. The kenaf was used as the reinforcement while the PP acted as a matrix. The adhesive agent for aluminium and composite was PP adhesive. Besides, there are other machines required such as hot press machine, abrasive waterjet cut machine, and oven.

3.2.1 Matrix

The composite is fabricated using matrix and reinforcement. The matrix used is PP which is a thermoplastic polymer and the molecular formula is $(C_3H_6)_n$. PP was picked as a matrix because it is renewable and low cost when it is used to manufacture the composite.

3.2.2 Reinforcement

In this research, there are three different parameters of fibre that are used in this study, which are fibre length, fibre treatment, and fibre composition. NaOH was used in chemical treatment to ensure a better interfacial adhesion between fibres and matrix. In this research, fibre were soaked in 5% of sodium hydroxide solution for four hours at room temperature as shown in Figure 3.2. Then, kenaf fibres were cleaned eight times by washing it until all unwanted products were removed. Finally, kenaf fibres were dried naturally and put inside oven at 40°C for 24 hours to remove excess moisture.

Figure 3.2: Fibre treatment in NaOH

3.2.3 Processing of aluminium alloy 5052

Aluminium alloy 5052 needs to undergo variety of processes before FML fabrication. Firstly, aluminium was cut into proper shape which is (250x250)mm^2 square plate. After cut into required shape, the aluminium was annealed at 345°C for 2 hours and lastly surface treatment was conducted by using 80 grit dry sandpaper to increase the adhesive bonding. Mechanical abrasion was carried out using sandpaper to produce a macro-roughened surface, different levels of roughness and textures and remove the oxidation layer (Sinmazcelik,2011).

3.3 Specimen preparation

In order to fabricate the FML specimens, several processes such as hot press moulding compression and cutting process were carried out. Therefore, hot press machine and water jet machine are required in specimen preparation process. FML can only be completed after composite fabrication process.

3.3.1 Composite Fabrication

First of all, kenaf fibre mass was measured according to the fibre composition. Kenaf fibre was randomly aligned and compressed at a pressure of 0.5MPa and temperature of 180°C for 2 minutes. PP sheets with 0.5mm were incorporated in between layers kenaf fibres. The whole stack was placed in picture frame mould with a dimension of (250x250x3)mm. It required 180°C preheat for 2 minutes before fully compressed at 0.5MPa. Preheat is required because it provides a uniform heat transfer in the matrix and avoid air bubble trap inside the composite (Abilash & Sivapragash, 2013). Then, composite was allowed to melt and fully compressed for around 8 minutes. Finally, the composites were allowed to cool down for another 6 minutes and removed from the mould frame.

Table 3.1: Weight of untreated fibre and PP

Fibre wt%	Fibre length(cm)	Fibre weight(g)	PP weight (g)	Composite weight(g)
50	3	120	28.57/27.82/62.47	204.67
	6	120	26.98/29.00/75.39	196.97
	9	120	39.75/36.85/62.76	244.05
60	3	145	27.39/32.22/62.09	241.31
	6	145	27.20/21.76/61.14	241.38
	9	145	22.23/22.18/59.02	236.98
70	3	175	27.31/27.09/63.48	272.34
	6	175	27.73/27.86/64.11	271.56
	9	175	23.05/22.47/78.22	269.67

Table 3.2: Weight of treated fibre and PP

Fibre wt%	Fibre length(cm)	Fibre weight(g)	PP weight (g)	Composite weight(g)
50	3	105	62.47/61.69/58.48	220.67
	6	105	63.97/56.21/60.36	218.36
	9	105	63.25/59.00/59.71	215.16
60	3	120	57.76/63.91/61.00	193.31
	6	120	62.51/61.95/56.22	203.35
	9	120	62.57/59.54/62.97	212.32
70	3	145	63.89/53.30/60.47	240.16
	6	145	60.95/62.31/68.78	220.34
	9	145	61.95/59.82/62.14	240.86

3.3.2 Surface Treatment

Aluminium is a famous material that has been widely used in many sectors and industries due to its high strength to weight ratio properties. Aluminium has a lot of advantages but the surface of the aluminium need to be improved by using sandpaper grit 80 for better bonding, thereby avoiding any delamination when high stress is applied.

3.3.3 FML Fabrication

FML is formed by combining composite with layers of metallic alloy using PP adhesive. Annealed aluminiums with thickness of 0.5mm were used as the metallic skin 0.4MPa layers. FML fabrication required hot press at temperature of 170°C and pressure of 1.5MPa. 170°C is the adhesive processing temperature for bonding. Besides, ethanol was used as solvent to clean all the materials like PP adhesive, aluminium sheet and composite in order to remove grease, impurities and other unwanted particles.

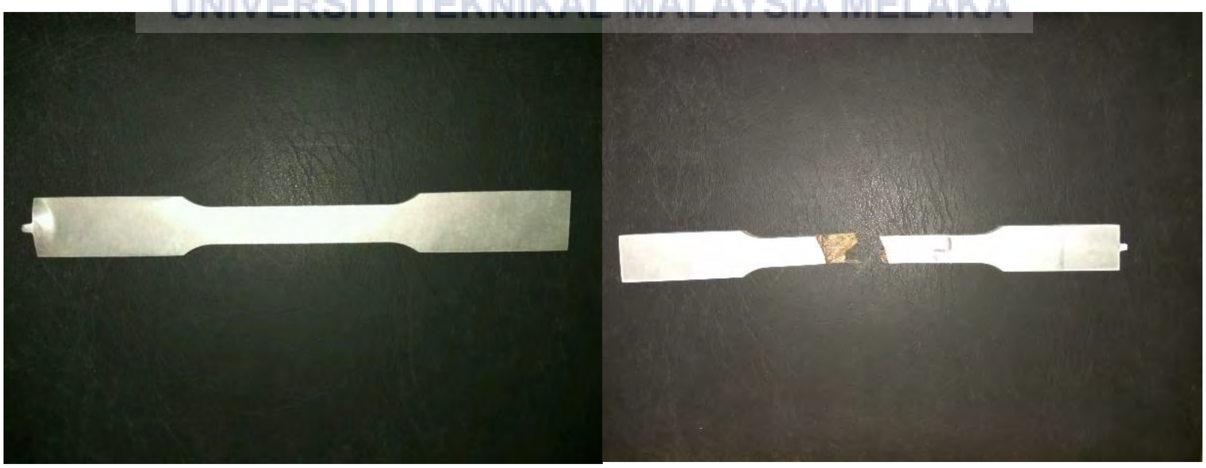
Next, the aluminium sheets were stacked with composite in picture frame mould where PP adhesives were incorporated at the interface between aluminium and composite. The mold need to be carefully placed into the hot press machine to avoid the material displaced from its original position. Initially, preheat is required to generate uniform heat distribution on the FML for 2 minutes. Then, the FML is totally compressed for 8 minutes. Finally, FML was rapid cooled until 70°C and take it out and left it cool naturally. At 70°C the adhesive and FML are considered firm and steady.

3.3.4 Cutting Process

FML panel was cut using water jet cutting machine to cut the panel according to the 2-D drawing. It had been drawn using SOLIDWORKS software and converted into DXF format to allow the water jet machine to cut according to the standard procedure.

3.4 Tensile test

Tensile test was carried out using Instron Universal Mechanical Tester 8872 with 25kN load cells. Tensile properties were determined and recorded such as modulus elasticity, elastic limit, and reduction in area, tensile strength, yield point, yield strength, and others. Moreover, the relationship of tensile stress and tensile strain can be determined from FML. This test was conducted by testing the specimens at cross-head displacement rate of 2mm/min. The size of the specimens are 160mm x 25mm x 4mm. The tensile test was carried out according to ASTM D3039.



(a) (b)

Figure 3.3: Specimen of before(a) and after(b) tensile test.

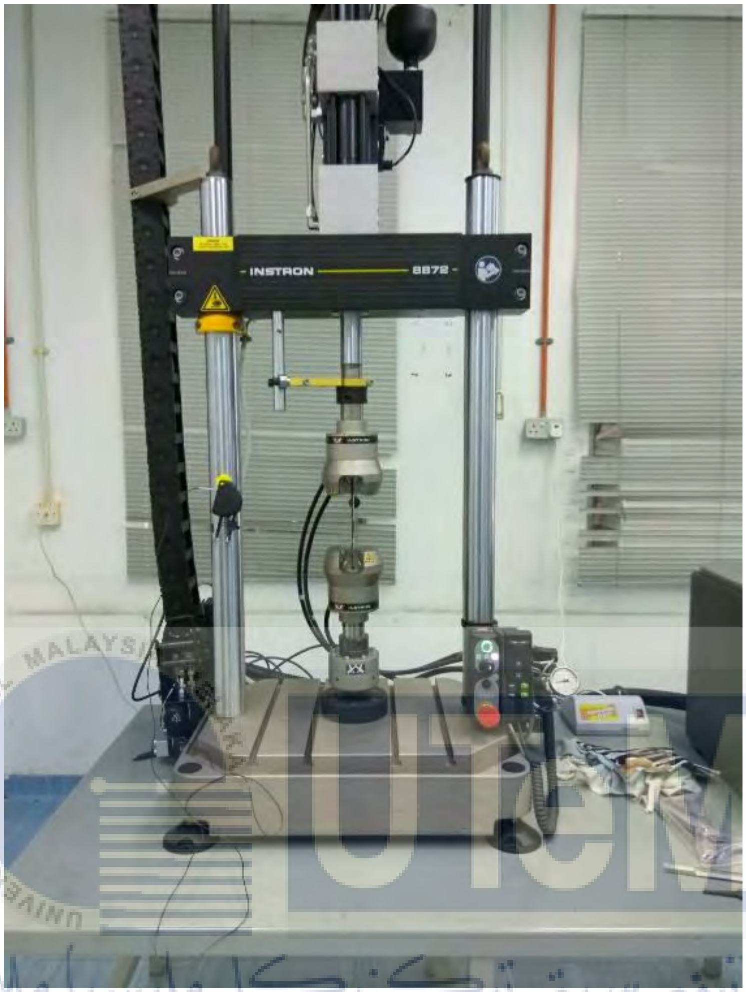


Figure 3.4: Tensile test is conducted.

3.5 Flexural test

Flexural test was carried out to study the flexural properties of the FML. By using the Instron Universal Testing Machine 8872, flexural strength, flexural yield strength, and Young's Modulus can be calculated. The size of specimens are 125mm x 12.7mm x 4mm. The flexural test was conducted according to ASTM D790.

1. Measure the width and thickness of the specimen to the nearest 0.03mm at the center of the support span. For specimens less than 2.54 mm in depth, measure the depth to the nearest 0.003mm.
2. Determine the support span to be used. Set the support span to within 1 percent of the determined value. The support span to depth ratio should be 16:1. The depth of the specimen is 4mm thus the support span is 64mm in length.
3. For flexural fixtures that have continuously adjustable spans, measure the span accurately to nearest 0.1mm.
4. Calculate the rate of crosshead motion as follows and set the machine for the rate of crosshead:

$$R = ZL^2/6d$$

R= rate of crosshead motion, mm/min

L= support span, mm

d= depth of beam, mm

Z= rate of straining of the outer fibre, mm

Z shall be equal to 0.01.

Thus,

R= 2.13mm/min

5. Place the specimen on the supports and adjust the specimen so that its center is perpendicular to the nose loading.
6. Slowly bring down the nose loading until it slightly touches the specimen. At this point, make sure that the displacement and force of the nose loading is set to zero.

7. Apply load to the specimen by using the rate of crosshead motion as calculated. At the same time take the load-extension data.

In order to avoid the human error, a 3 point bending jig is installed to the Instron machine during testing period.

(a) (b)

Figure 3.5: Specimen before(a) and after(b) flexural test.

Figure 3.6: Flexural test is being conducted.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

In this chapter, the results of tensile test and flexural test will be shown. The tensile test and flexural test was conducted by using Instron Machine Model 8872 and with parameter suggested by ASTM D3039 and ASTM D790 respectively.

4.1 Tensile test

4.1.1 Fibre length

Figure 4.1 shows the ultimate tensile trength of FML with 50wt% and different fibre length. It shows that fibre length of 90mm has the lowest tensile strength which is 37.08MPa. Fibre length of 30mm has 9.54% higher tensile strength which is 40.99MPa compared to 90mm fibre length. Fibre length of 60mm has the highest tensile strength which is 46.70MPa.

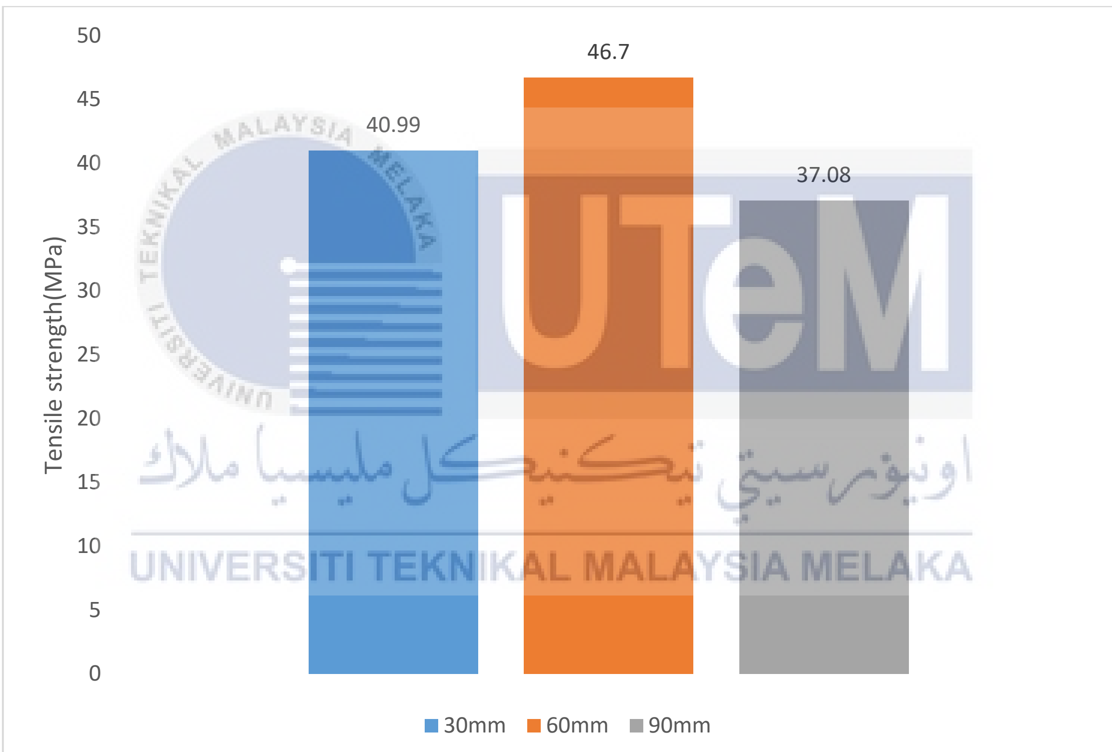


Figure 4.1: Ultimate tensile strength of FML with 50wt% and different fibre length.

Figure 4.2 and Figure 4.3 show the ultimate tensile strength of FML that have similar trend. The tensile strength is decreasing as the fibre length is increasing. In Figure 4.2, the tensile strength is 36.57MPa, 33.15MPa, and 31.05MPa for FMLs with fibre length of 30mm, 60mm, and 90mm respectively. Tensile strength of FMLs with 30mm fibre length is 15.09% higher than FMLs with 90mm fibre length. However, FMLs with 90mm fibre length has the highest tensile strain before it fails. The trend is same as in Figure 4.3 where the tensile strength is decreasing orderly in 34.48MPa, 24.21MPa, and 19.18MPa as the fibre length is 30mm, 60mm, and 90mm respectively. For FMLs with weight composition of 70wt%, tensile strength of FMLs with 30mm fibre length is 29.79% more than 60mm fibre length tensile strength and 44.37% more than 90mm tensile strength.

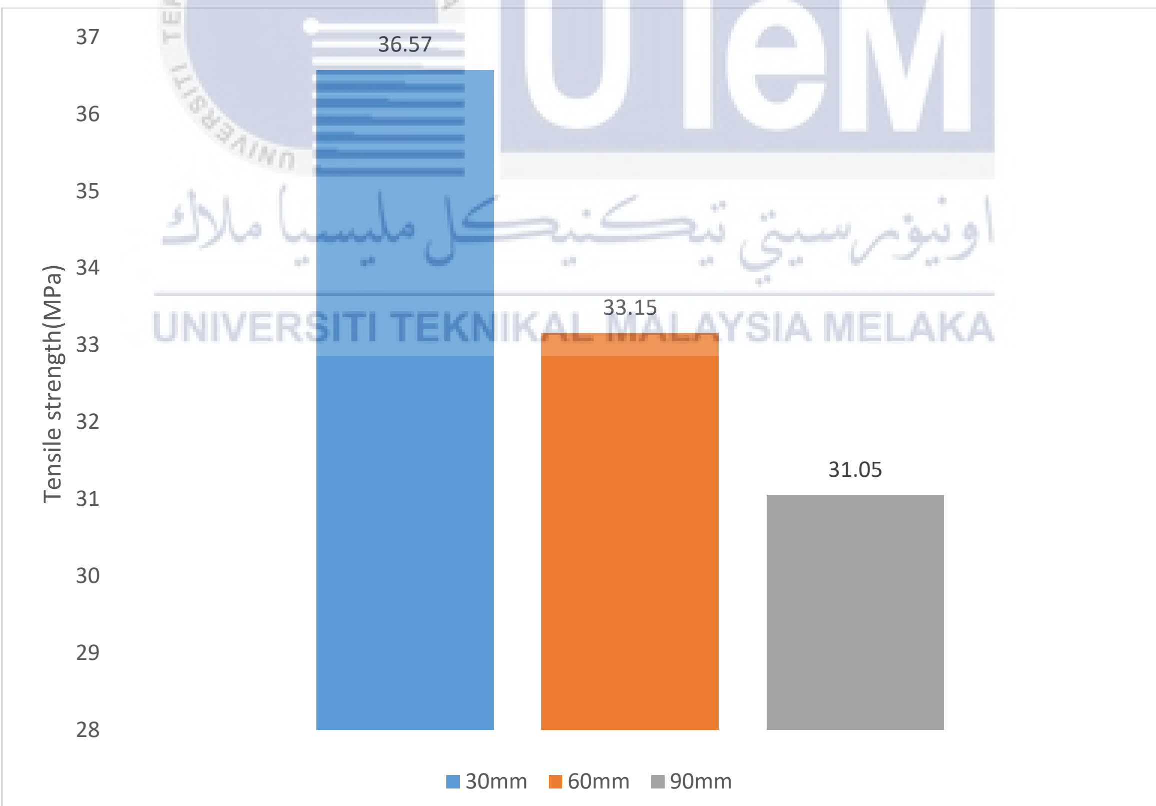


Figure 4.2: Ultimate tensile strength of FML with 60wt% and different fibre length.

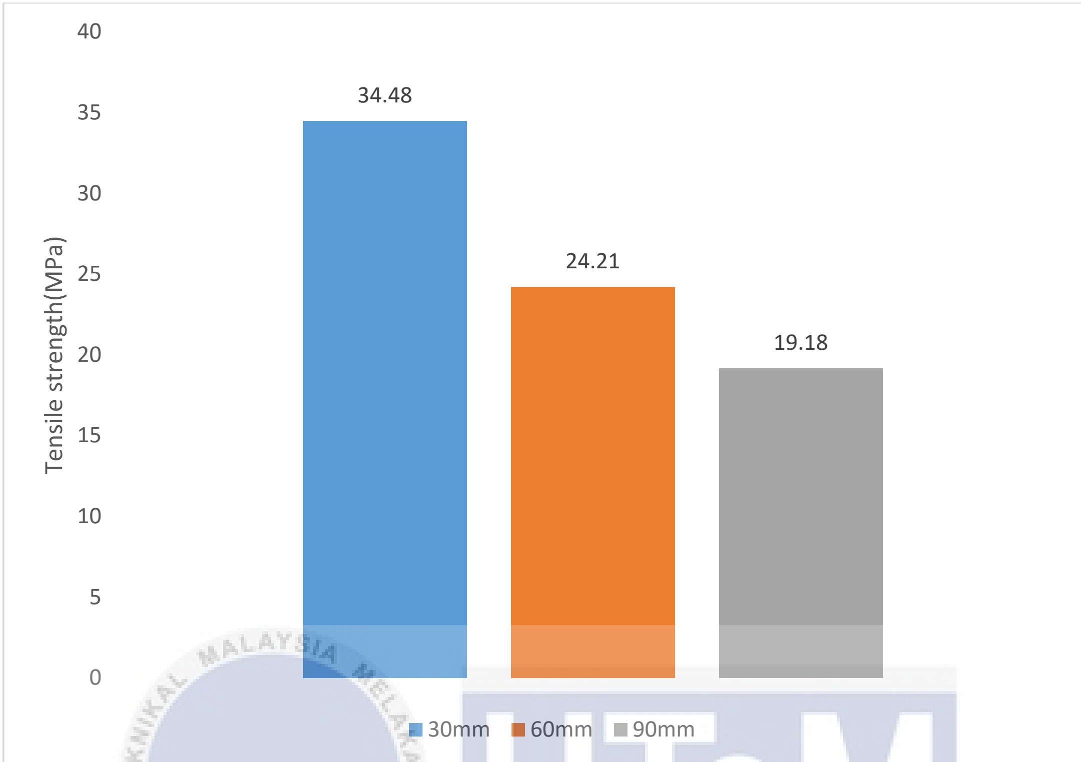


Figure 4.3: Ultimate tensile strength of FML with 70wt% and different fibre length.

Fibre length is an important factor that influences the mechanical properties of composites. When a load is applied to the matrix, stress transfer occurs by shear at the interface along the fibre length and ends of the fibre. The extent of load transfer is a function of the critical fibre length. Tensile strength of short fibre composites increase for small fibre length which also higher aspect ratio of critical fibre length per diameter of fibre will brings higher composite strength (Fu & Lauke, 1996). Critical fibre length is to allow for efficient reinforcement of a composite such that the majority of the fibre could be loaded as it was a continuous fibre. Nevertheless, when fibre length is too long that fibres may get tangles during mixing resulting in poor fibre dispersion which can reduce the overall reinforcement efficiency.

4.1.2 Fibre composition

Figure 4.4 shows that all the fibre length of 30mm, 60mm, and 90mm have the same trend in which the tensile strength decreases as the fibre composition increases. In overall, the highest tensile strength was observed in FMLs with 50wt % fibre composition and the lowest are FMLs with 70wt%. The highest tensile strength in FMLs with 50wt% of fibre composition and 60mm fibre length is 46.70MPa which is 58.93% higher compared to the lowest tensile strength of FMLs with 70wt% of fibre composition with 90mm fibre length. For FMLs with 30mm fibre length, there is only 5.72% slight difference between tensile strength of FMLs with 60wt% and 70wt%.

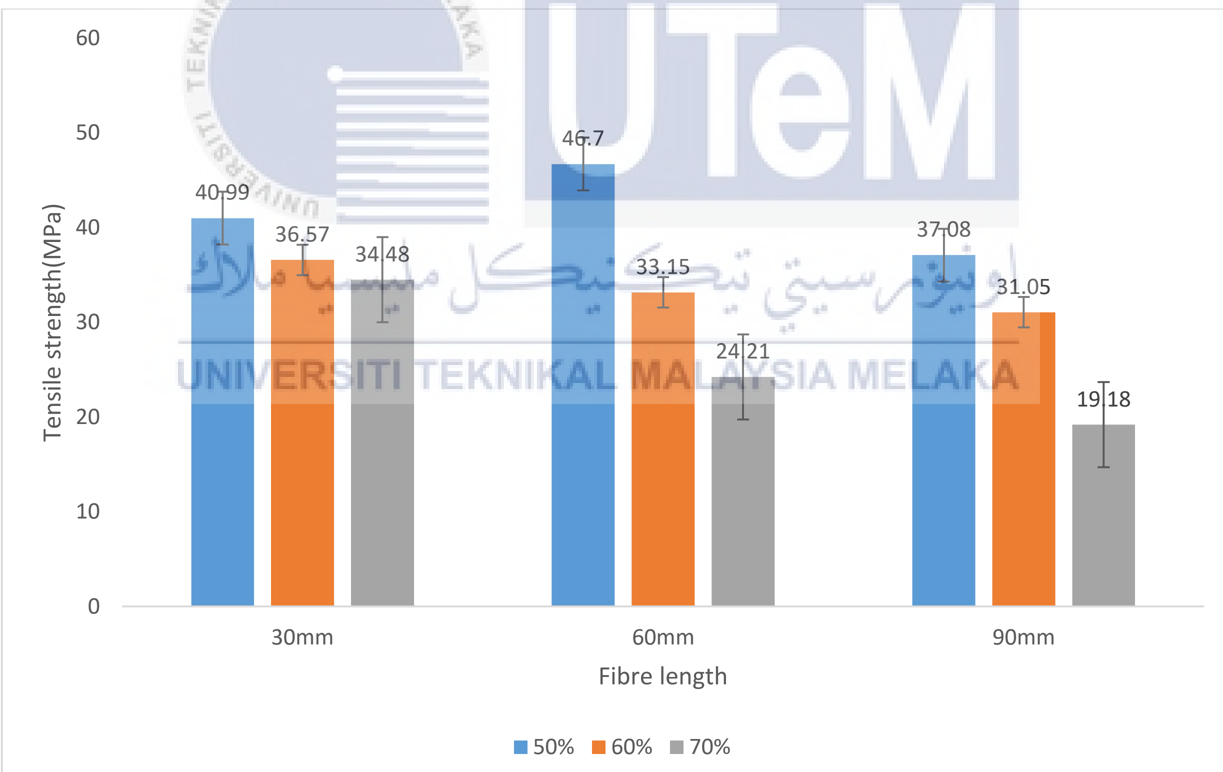


Figure 4.4: Bar chart of ultimate tensile strength of untreated FML with different fibre composition and fibre length.

Strength of composite commonly high when the fibre contents is 40-55wt%. It is due to poor wetting leading to reduced stress transfer across the fibre-matrix interface and increasing porosity (Le et al, 2015). Madsen and Lilholt (2003) investigated the influence of fibre content in terms of weight fraction on porosity of fibre. This has shown that maximum volume fractions of fibre occur around fibre contents of 50wt%-60wt% with further addiction of fibre resulting in higher porosity rather than increased fibre volume fraction, the influence of which has been incorporated into rule of mixtures models and shown to improve accuracy of prediction of strength.

4.1.3 Treatment/Non-treatment

Figure 4.5, Figure 4.6 and Figure 4.7 have similar results where the tensile strength of the FMLs with treated fibre is better than FMLs with non-treated fibre. Figure 4.5, at fibre composition of 50wt% the highest tensile strength in FMLs with treated fibre is 11.37% higher than FMLs with untreated fibre. However, in Figure 4.6 the FMLS with untreated fibre of 50wt% is 46.70MPa which is 16.30% higher than FMLS with treated fibre of 50wt%. Treated fibre and untreated fibre of 70wt% in Figure 4.7 has the highest difference of 32.69% in tensile strength.

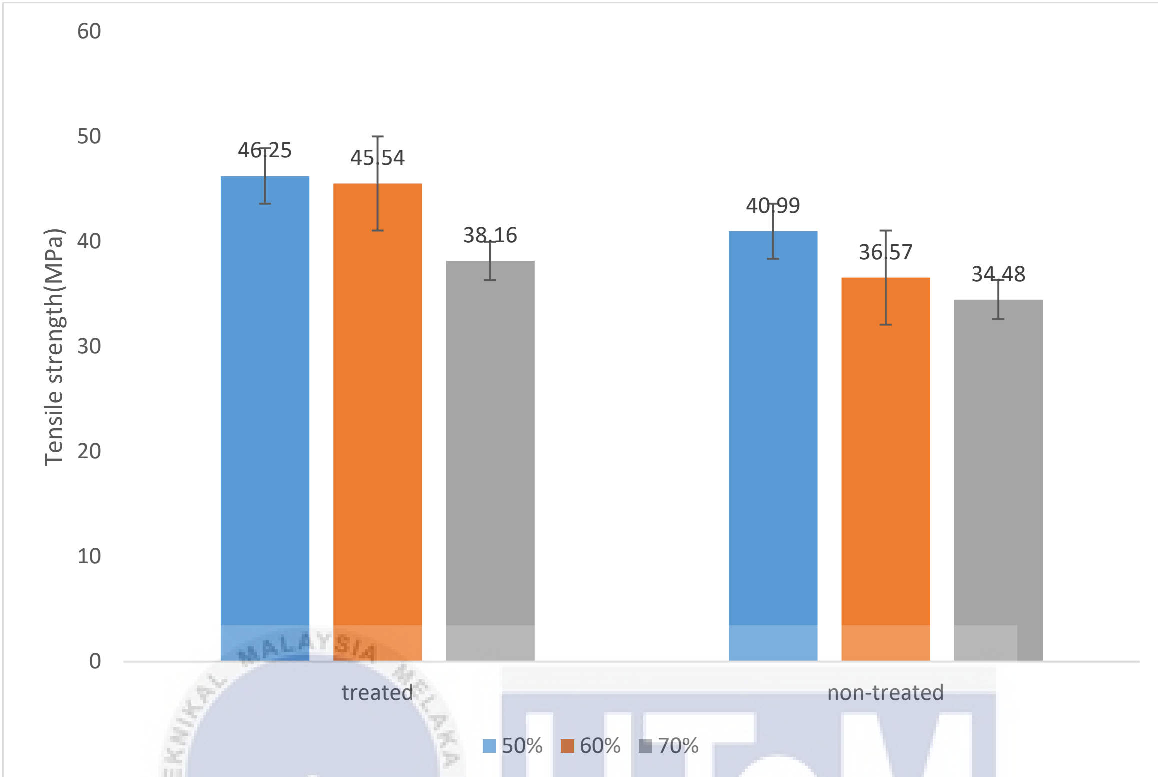


Figure 4.5: Bar graph of tensile strength of treatment and non-treatment of 30mm fibre length.

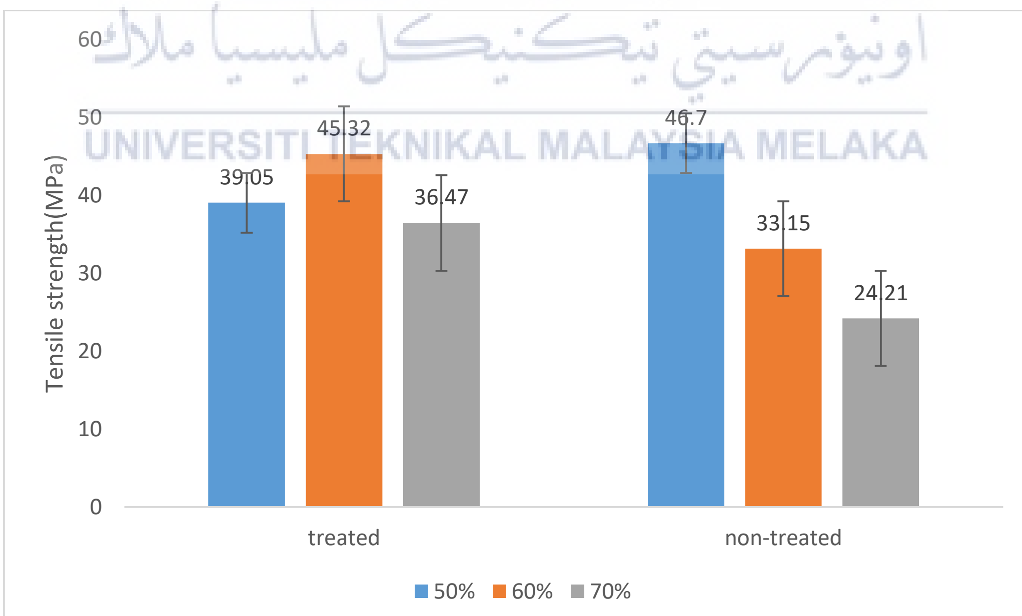


Figure 4.6: Bar graph of tensile strength of treatment and non-treatment of 60mm fibre length.

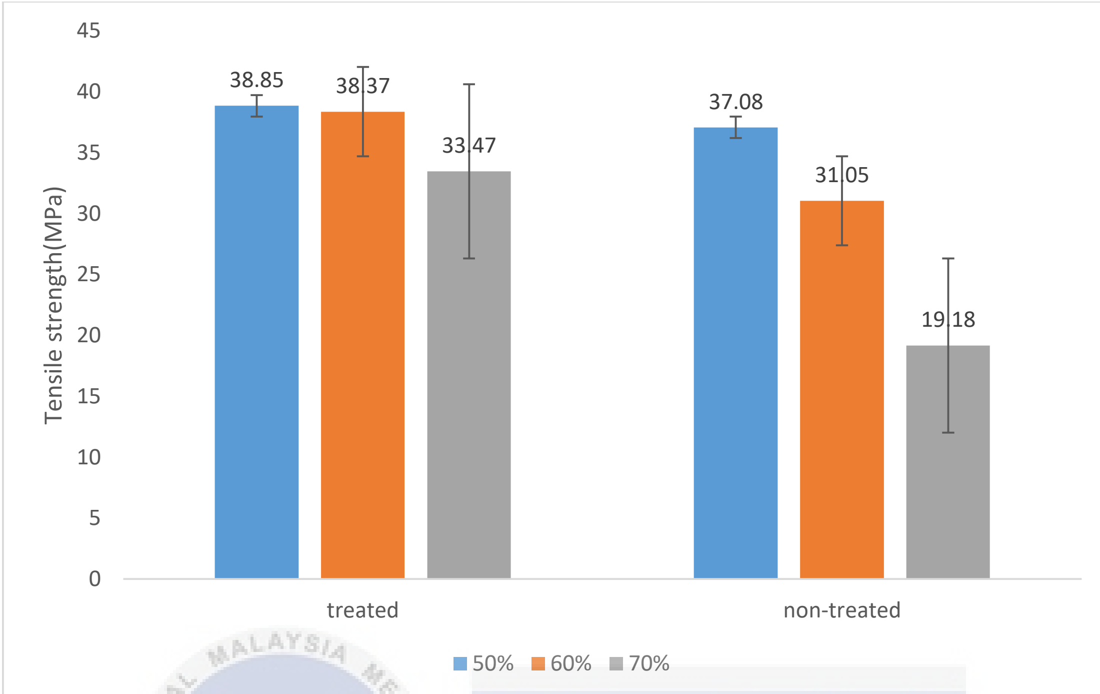


Figure 4.7: Bar graph of tensile strength of treatment and non-treatment of 90mm fibre length.

Ku H and Wang H (2011) revealed that interfacial adhesion between fibres and matrix directly affects the tensile properties of natural fibre reinforced composites. Chemical treatment of kenaf fibres using NaOH (alkalization) improved the mechanical properties because of permeability of the treated kenaf fibres (Thiruchitrambalam M, 2009). It also showed that mechanical properties of treated kenaf fibre knowingly improved compared to the untreated fibre kenaf. Chemical treatment splits the kenaf fibre bundles into fine fibres resulting fibres bundles causing to high intertwining of the fibres in the matrix thus leads to greater interfacial adhesion.

4.2 Flexural test

4.2.1 Fibre length

Figure 4.8 shows the ultimate flexural strength of 50wt% untreated FML. The curve shows that the flexural strength increases when the fibre length is increasing. From the results the flexural strength is 78.20MPa for 30mm, 71.38MPa for 60mm, and 86.36MPa for 90mm.

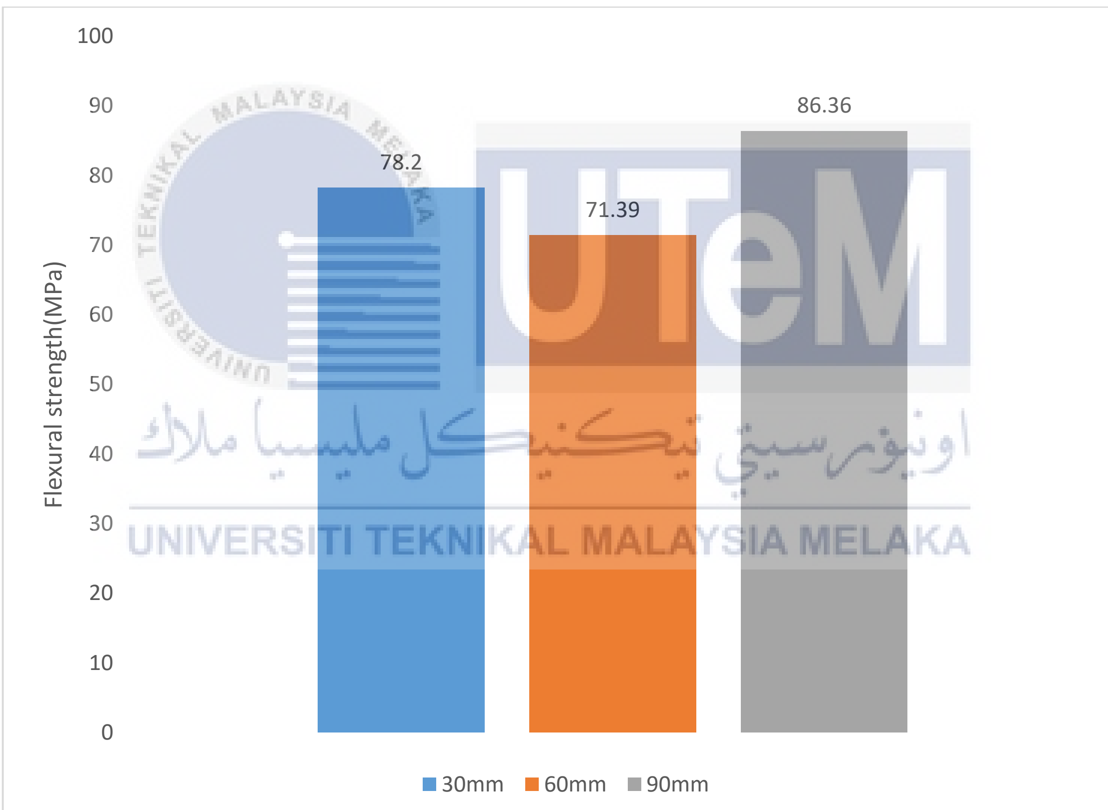


Figure 4.8: Ultimate flexural strength of FML with 50wt% and different fibre length.

Figure 4.9 and Figure 4.10 show the same trend of decreasing flexural strength as the fibre length increases. Figure 4.9, fibre length 30mm shows the highest flexural strength of 77.75MPa followed by 65.02MPa in fibre length 60mm and 56.82MPa in fibre length 90mm. Meanwhile, in Figure 4.10 the lowest flexural strength is 31.22MPa in FMLs with 90mm fibre length and increase to 36.40MPa in FMLs with 60mm fibre length and 56.72MPa in 30mm fibre length.

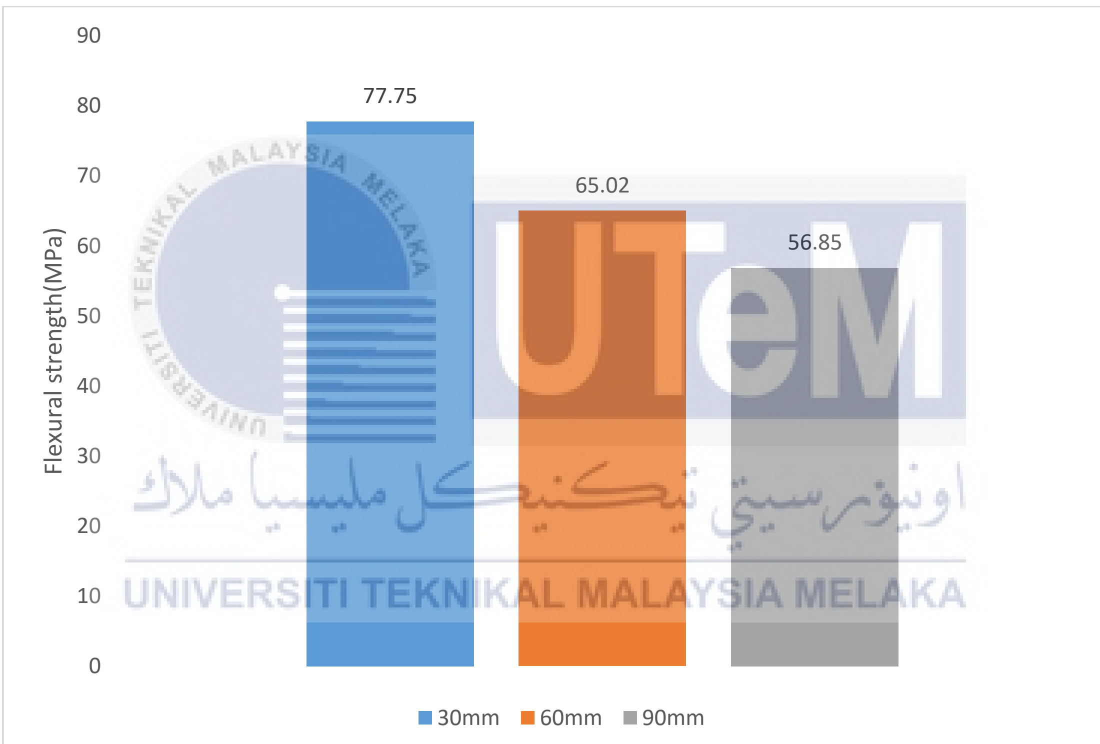


Figure 4.9: Ultimate flexural strength of FML with 60wt% and different fibre length.

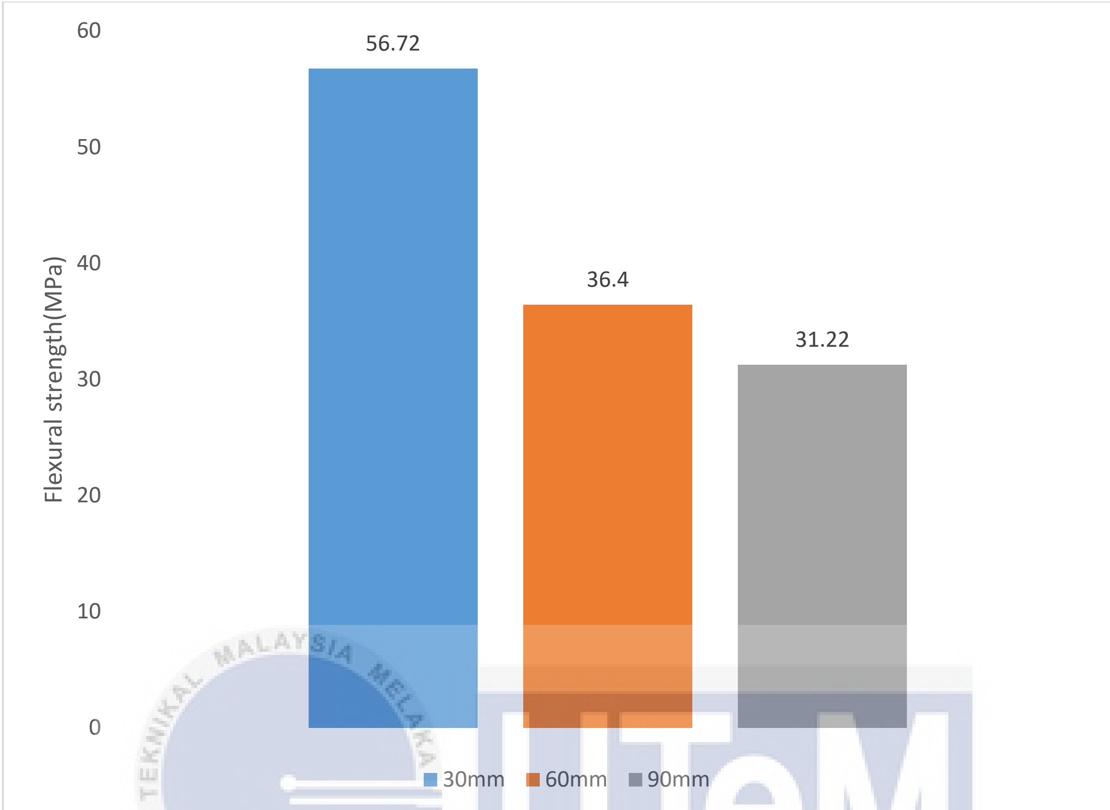


Figure 4.10: Ultimate flexural strength of FML with 70wt% and different fibre length.

Azis and Ansell (2014) reported that the flexural strength is highly depended on fibre alignment and the location of resin-rich areas. Flexural strength of short fibre reinforced composites strongly depend on the fibre length, fibre dispersion, fibre orientation and fibre/matrix interfacial length. Further increment of length showed a decline in the properties because of formation of agglomerates which block stress transfer. The declining trend is because of fibre-fibre interactions and problem with the dispersion of fibres in matrix phase (Nunna et al, 2012).

4.2.2 Fibre composition

Figure 4.11 shows that the FMLs with fibre length of 30mm, 60mm, and 90mm demonstrate the same trend among fibre composition where the flexural strength decreases as the fibre composition increases. On average highest flexural strength was observed is the FMLs with 50wt % fibre composition and the lowest are FMLs with 70wt%. However, in 30mm fibre length category, there is only 0.57% slight difference between flexural strength of FMLs with 50wt% and 60wt%.

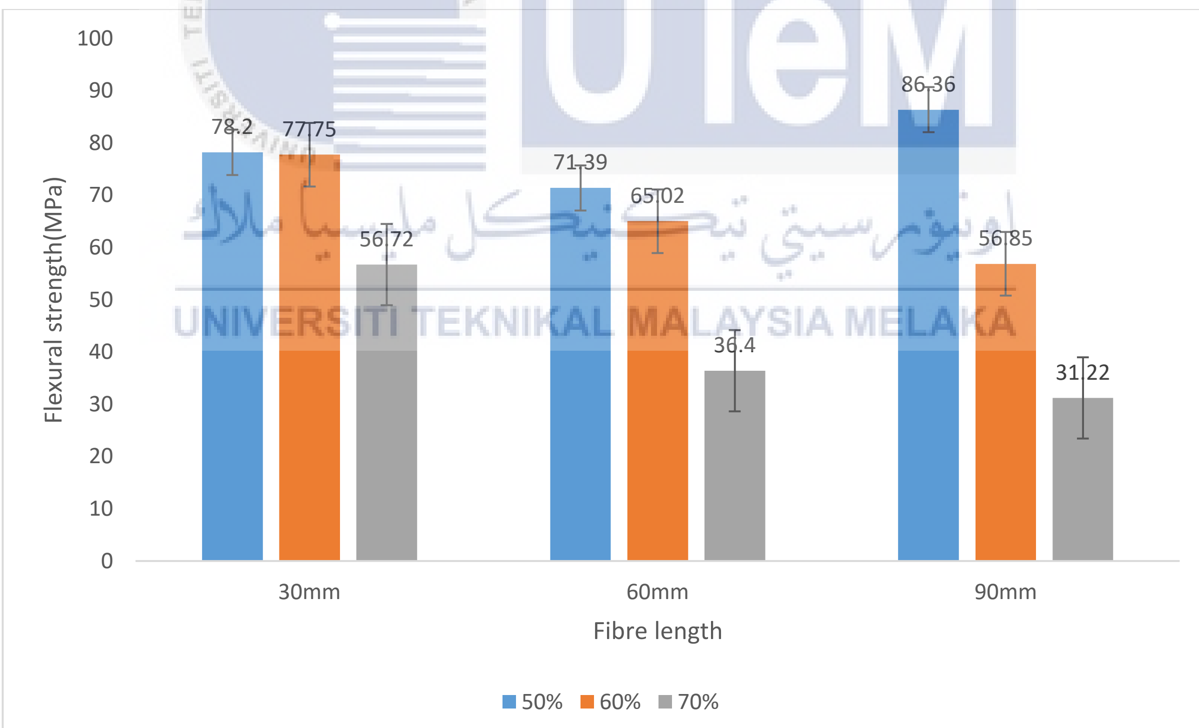


Figure 4.11: Bar chart of ultimate flexural strength of untreated FML with different fibre composition and fibre length.

The high fibre content in a FML causes low flexural strength because of the porosity. High fibre content causes the poor dispersion of fibres due to strong inter fibre hydrogen bonding which bind the fibres together. Davies G (1983) conducted an experiment on high porosity metal and stated that the decreasing flexural strength of material with high porosity is due to the voids reduce the valid area enduring load. Fibre reinforcement composite is strong in term of mechanical properties due to the force transmit to the fibre. However, this is only true when the interfacial bonding is strong between the interfaces (Quazi, 2011). As the fibre composition increases, the poorer the wettability properties of the fibre.

4.2.3 Treatment/Non-treatment

Figure 4.12 and Figure 4.13 show exactly the same trend where the treated FML is higher than non-treated fibre in terms of flexural strength.

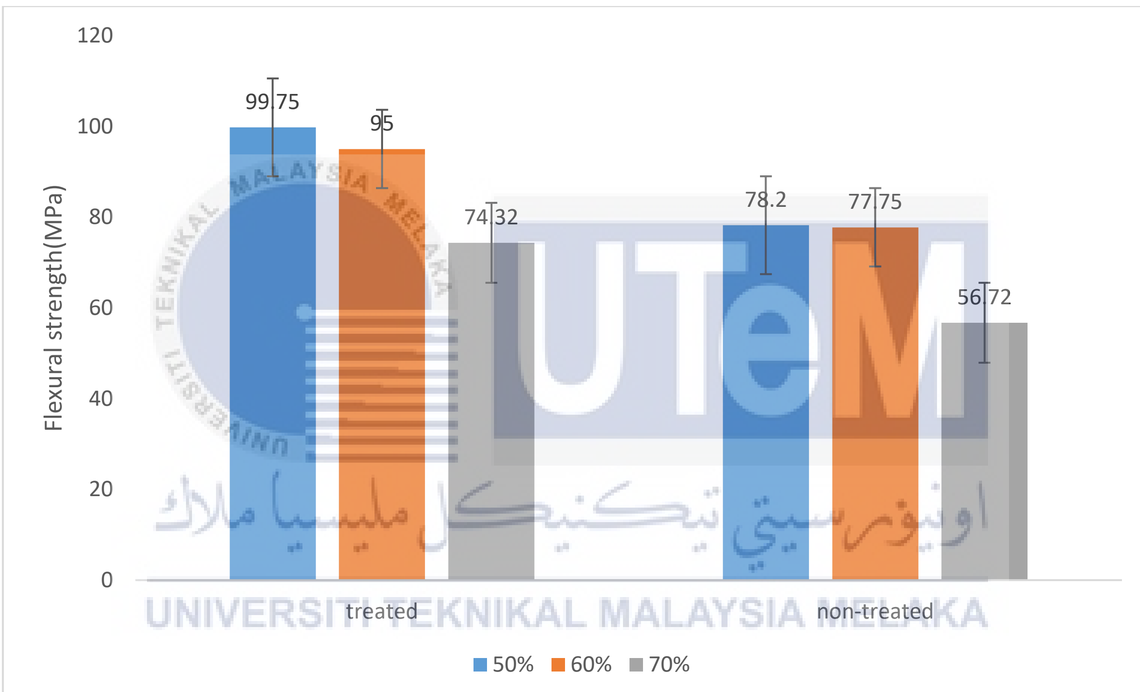


Figure 4.12: Bar graph of flexural strength of treatment and non-treatment of 30mm fibre length.

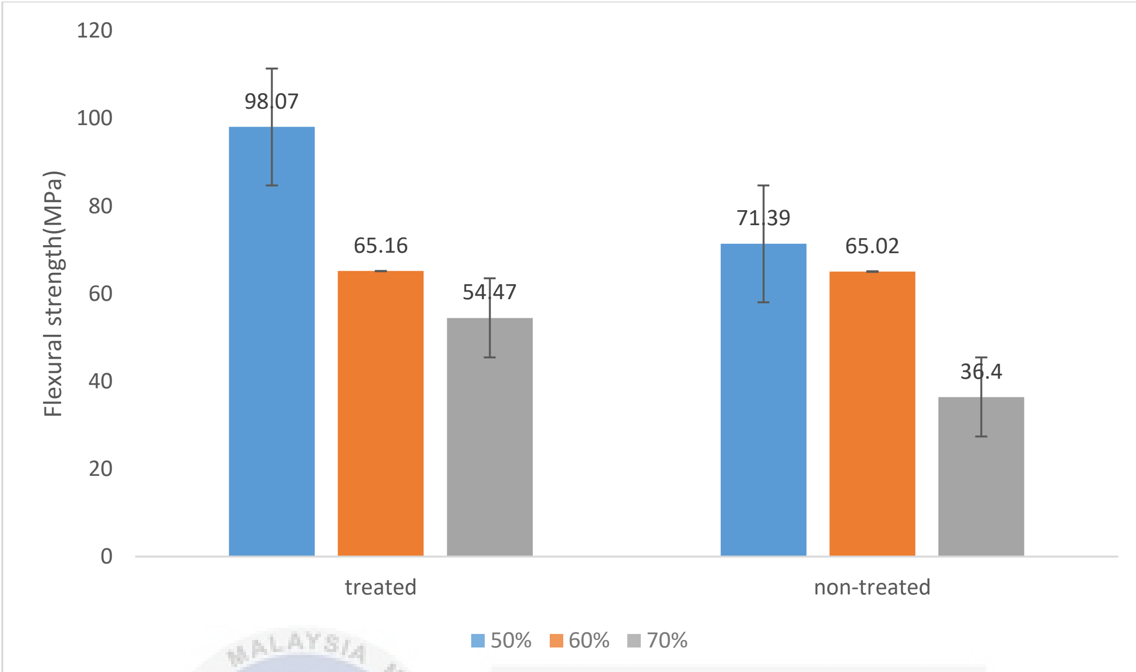


Figure 4.13: Bar graph of flexural strength of treatment and non-treatment of 60mm fibre length.

In Figure 4.14 the FMLs with treated fibre has higher flexural strength compared to FMLs with non-treated fibre but in 50wt% fibre composition treated fibre flexural strength is 1.59% less compared to non-treated fibre.

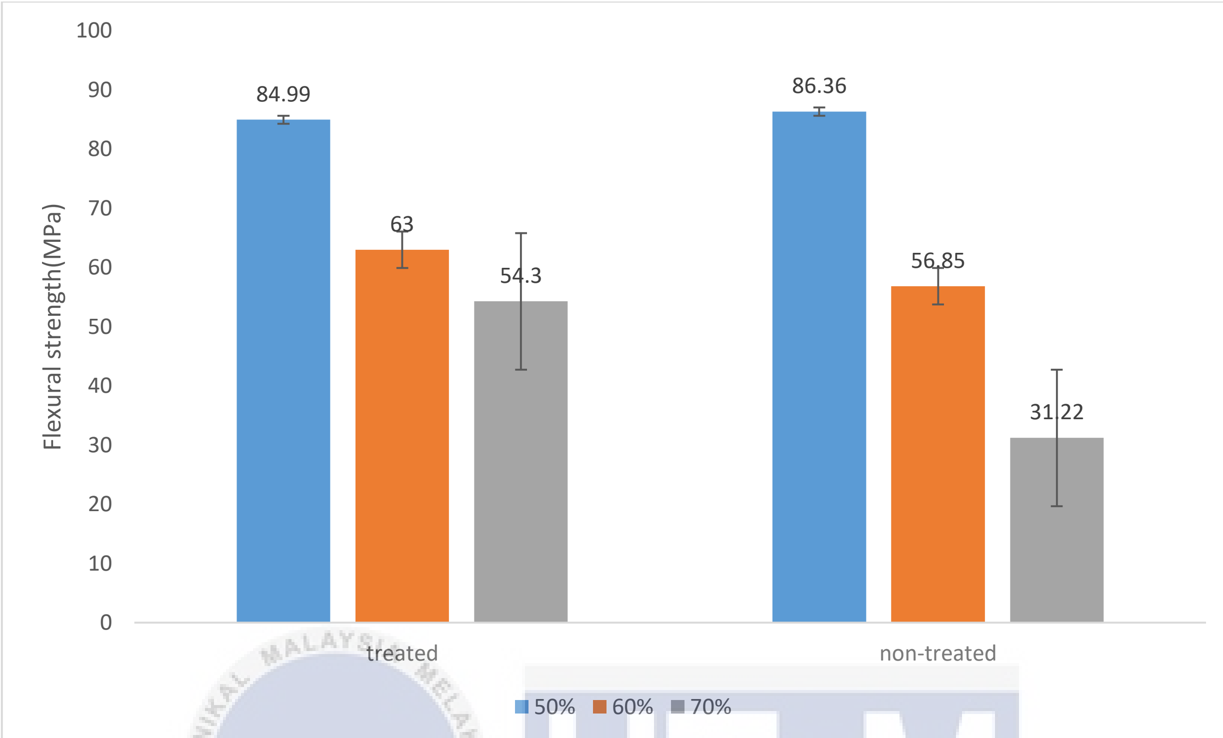


Figure 4.14: Bar graph of flexural strength of treatment and non-treatment of 90mm fibre length.

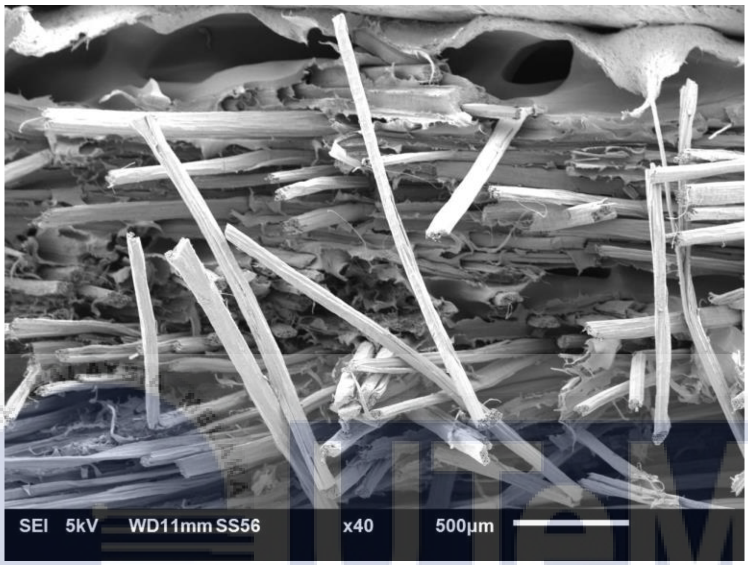
Tensile and flexural properties of the composite are improved when kenaf fibres were subjected to chemical treatment. De et al (2007) found that alkali treated could improve mechanical properties of natural fibres reinforced composites by as much as 50%. Flexural test conducted by Van de Weyenberg et al (2006) showed that longitudinal strength and stiffness experienced some increases, while transverse strength, and stiffness experienced sharp increment. This shows that the interface, rather than the fibre properties was improved. This improvement is due to fibre interlocking resulted from rougher topography and larger number of individual fibrils, and better chemical bonding. Hu and Lim (2007) showed that the alkali treatment not only enhances the fibre surface and bonding but also improves the structural content by removing all the non-structural parts of the fibres. Although composite strength will increase due to alkali treatment, strong alkali treatment in high concentration may damage the fibre which cause lower strength of fibre beyond its usability (Mohanty, 2001).

Table 4.1: Mechanical Properties of samples

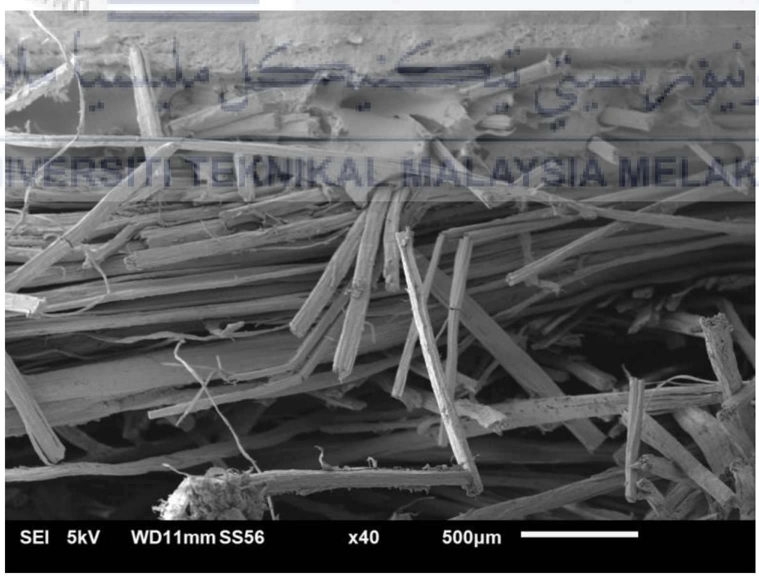
Treatment	Fibre parameters	Tensile strength (MPa)	Tensile modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)
Untreated	**30mm**				
	50 wt%	40.99	13.82	78.20	5.21
	60 wt%	36.57	13.28	77.75	6.51
	70 wt%	34.48	11.94	56.72	5.22
	60mm				
	50 wt%	46.70	12.45	71.39	6.93
	60 wt%	33.15	12.04	65.02	6.46
	70 wt%	24.21	9.58	36.40	6.21
	90mm				
	50 wt%	37.08	11.15	86.36	5.03
	60 wt%	31.05	9.36	56.85	4.73
	70 wt%	19.18	8.06	31.22	4.45
Treated	**30mm**				
	50 wt%	46.25	17.51	99.75	10.00
	60 wt%	45.54	17.77	95.00	9.90
	70 wt%	38.06	14.82	74.33	7.63
	60mm				
	50 wt%	39.04	17.05	98.07	8.60
	60 wt%	45.32	15.18	65.16	8.53
	70 wt%	36.47	14.70	54.42	7.45
	90mm				
	50 wt%	38.85	16.17	84.99	7.24
	60 wt%	38.37	17.82	63.00	6.55
	70 wt%	33.47	13.12	54.30	6.55

4.3 Failure mechanism by SEM

Figure 4.15 (a) shows the bonding of reinforcement and matrixes and delamination at the side of aluminium plate. Figure 4.15 (b) does not have a proper bonding between PP and kenaf fibre.



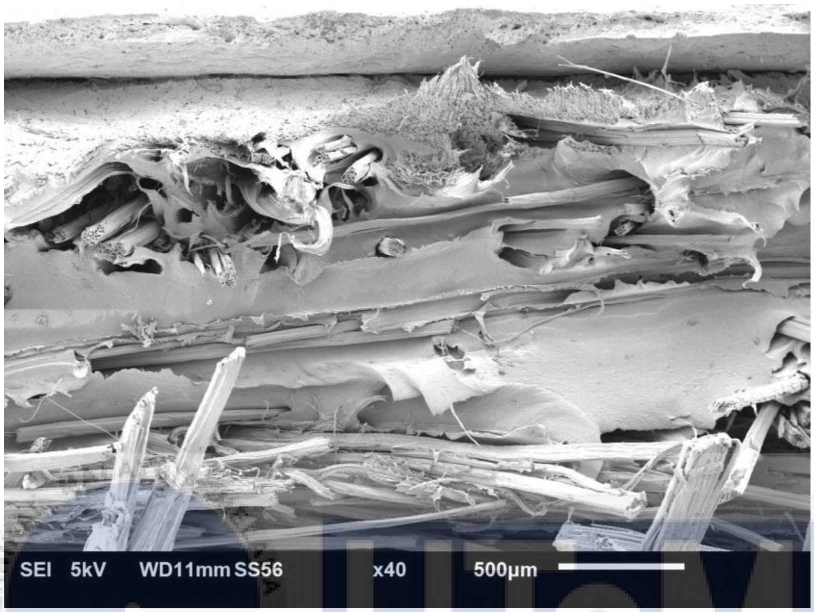
(a)



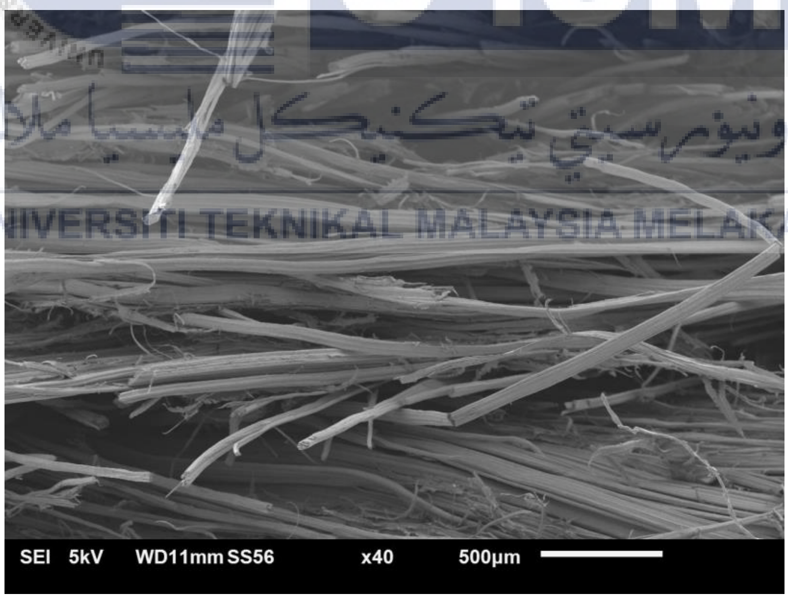
(b)

Figure 4.15: Scanning electron micrograph showing the untreated 50wt% 60mm kenaf fibre after tensile test.

Figure 4.16 (a) shows that PP is mostly bonded with treated kenaf fibre. Figure 4.16 (b) shows the effect of treatment of fibre which lead to fibre dispersion and more rough to bond with PP.



(a)



(b)

Figure 4.16: Scanning electron micrograph showing the treated kenaf fibre after tensile test.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

This chapter concluded the analysis from the results and findings from this experiment. Some recommendations are included in this chapter.

5.1 Conclusion

This research is mainly focused on investigating the mechanical behavior of fibre metal laminates under tensile test and flexural test. Each of the test specimens consists 50wt%, 60wt%, and 70wt% fibre composition with different fibre length of 30mm, 60mm, and 90mm. Another batch specimen with same parameters but with treated fibre.

Based on the results, it can be concluded that fibre content increased from FMLs with 50wt% to 70wt%, the ultimate tensile strength and modulus decreases. When fibre length was increased, tensile properties of FMLs reduced same trend was observed for the flexural properties of FMLs.

Comparison of tensile strength of FMLs with 50wt%, 60mm fibre length is the highest which is 46.70MPa while for FMLs with 60wt% and 70wt% are 30mm fibre length are the highest, 36.57MPa and 34.48MPa respectively. Among the fibre composition overall FMLs with 50wt% has the peak of tensile strength and the highest is FMLs with 50wt% and 60mm fibre length, 46.7MPa. Tensile strength of treated fibre is better than non-treated fibre at the most of 19.70%.

Flexural strength of FMLs with 50wt%, 90mm fibre length is the highest which is 86.36MPa while the FMLs with 60wt% and 70wt% are 30mm fibre length are the highest, 77.75MPa and 56.72MPa respectively. Fibre composition of 50wt% has the highest flexural strength and FMLs with 50wt% and 90mm fibre length is the highest flexural strength, 86.36MPa. Treated fibre has higher flexural strength of 21.6% compare to non-treated fibre.

Results of flexural test of FMLs with composite of different fibre length and fibre composition show that the bending has its limit and the maximum transverse shear load occurred in the FML. The transverse shear stress should be equal at both sides at each interface to prevent the specimen from delaminate, however it is difficult because the materials properties are different.

The major limitations of using natural fibres as reinforcements in thermoplastics matrix include poor interfacial adhesion between polar-hydrophilic fibres and non-polar hydrophobic matrix. However, if a FML is made from a good composite that has good interfacial adhesion, it may bring the benefits such as small crack opening, high flexural modulus and light weight.

5.2 Recommendation

This work can be further extended to study other aspects of composites and FMLs such as changing the type of fibre, fibre composition, fibre length, and types of metals. The fibre length should be optimized and the critical length of the fibre should be determine. Good fibre orientation can improve the FML strength such as the orientation should point to the direction parallel to the force applied. This may prevent the reinforcement is pulled out from the composites. Besides, more experimental testing findings such as impact test and quasi-static test can be conducted in order to determine mechanical properties of these FMLs.

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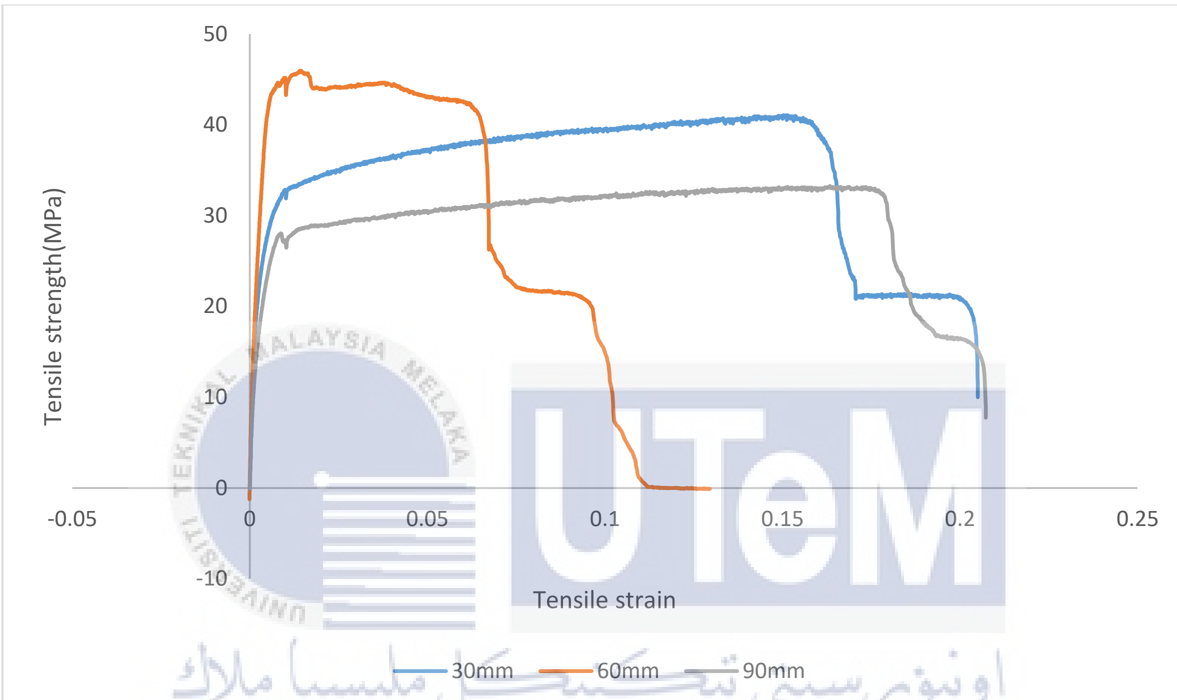
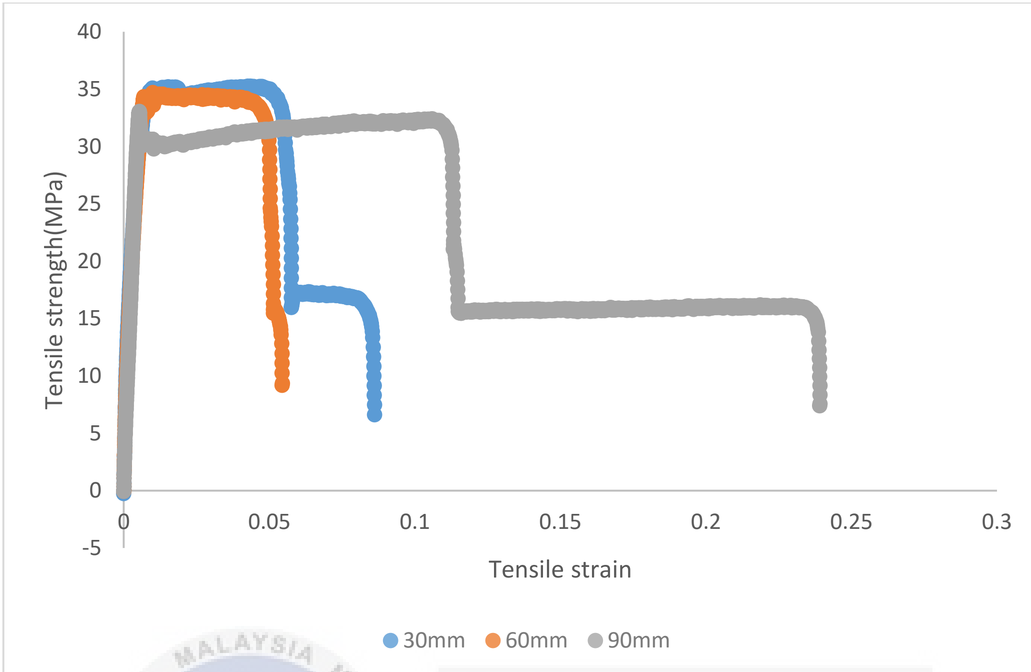
APPENDIXES

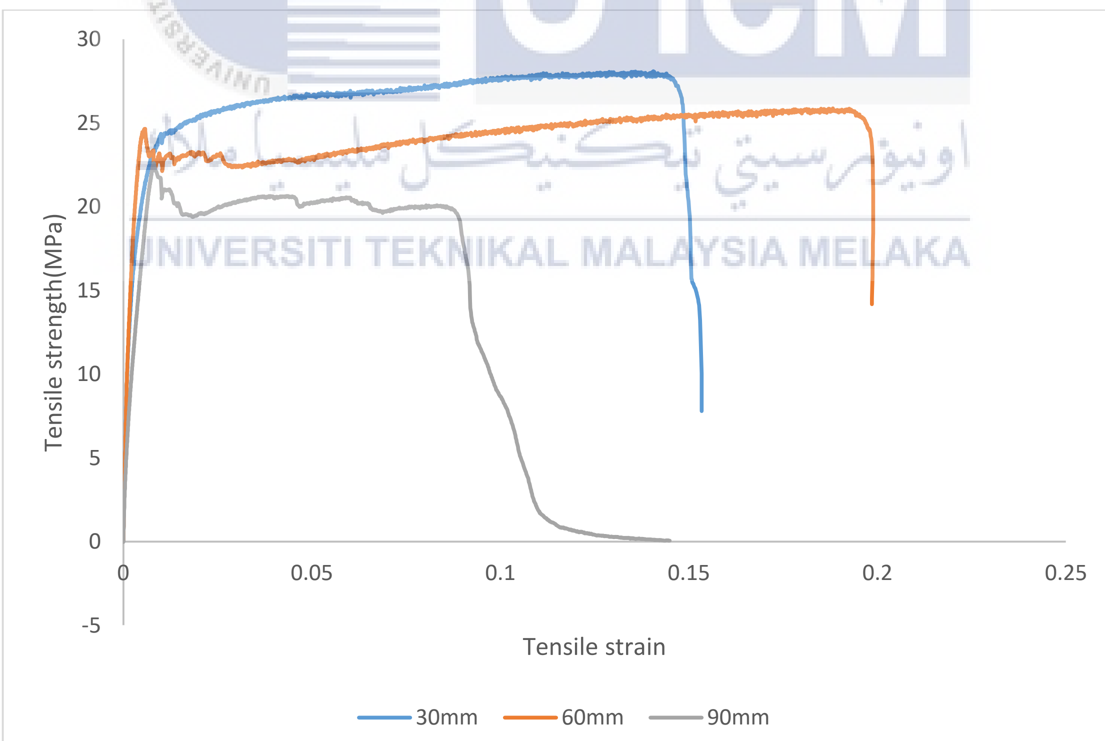
Appendix A



Appendix A1: Stress-strain curves of FML with 50wt% and different fibre length.

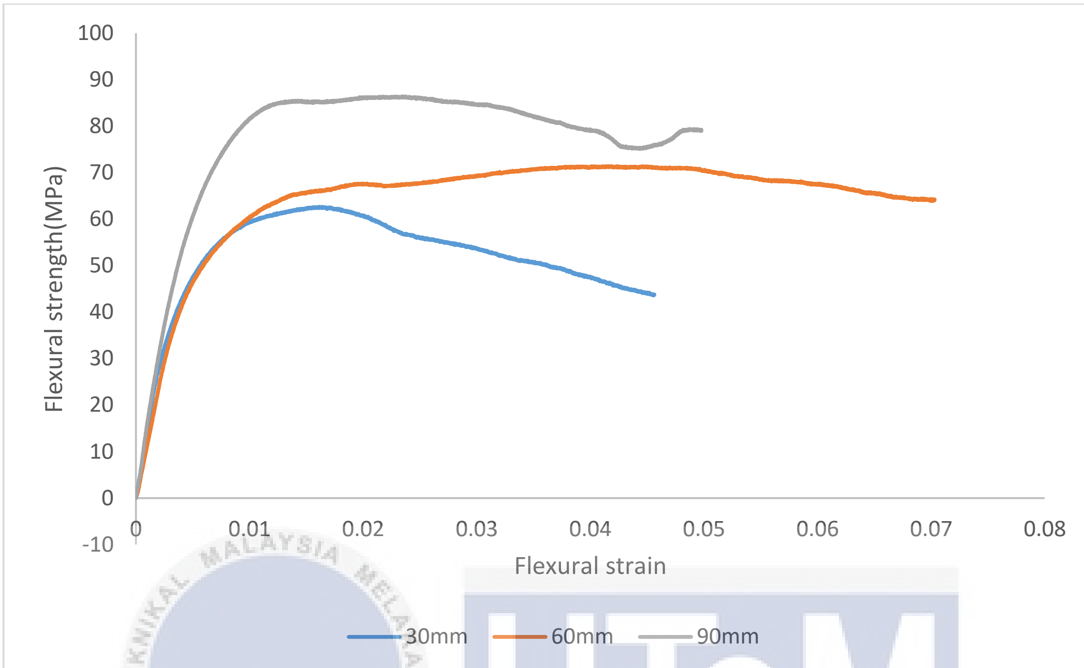


Appendix A2: Stress-strain curves of FML with 60wt% and different fibre length.

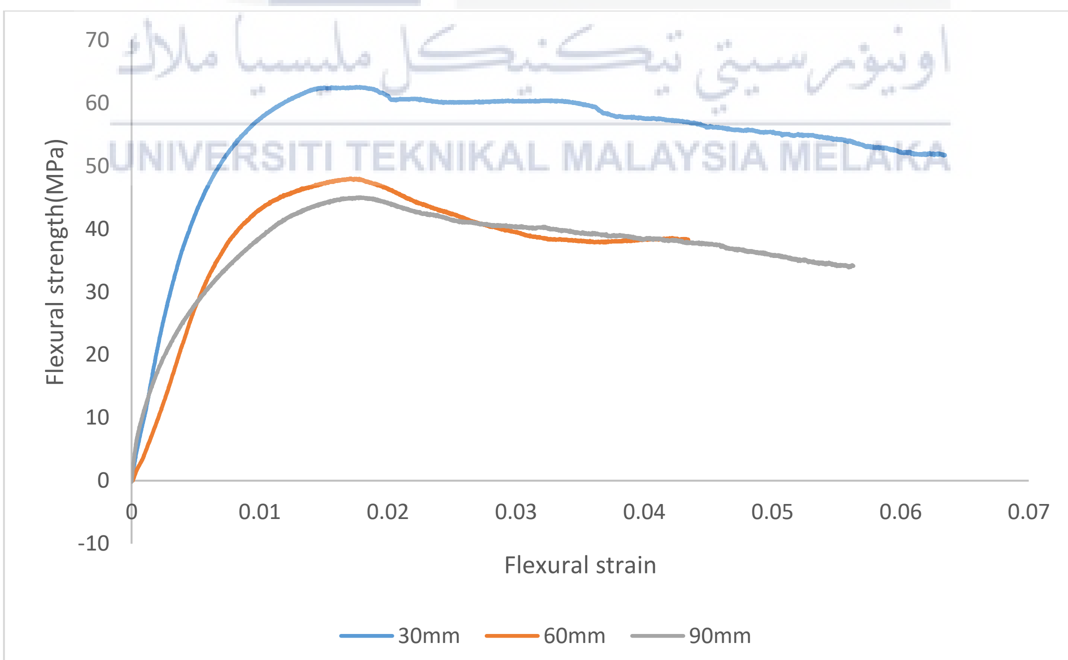


Appendix A3: Stress-strain curves of FML with 70wt% and different fibre length.

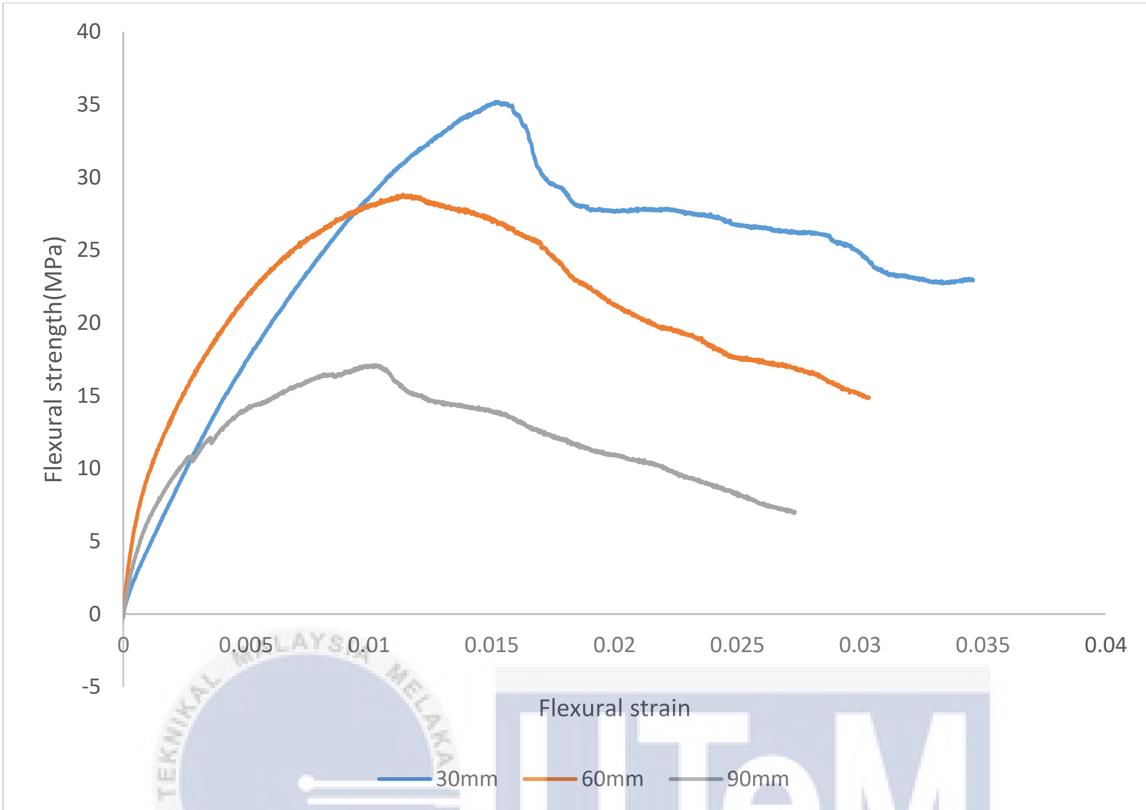
Appendix B



Appendix B1: Flexural stress-strain curves of FML with 50wt% and different fibre length.



Appendix B2: Flexural stress-strain curves of FML with 60wt% and different fibre length.



Appendix B3: Flexural stress-strain curves of FML with 70wt% and different fibre length.