UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Mechanical Engineering

ANALYSIS OF WOVEN FABRIC CHARACTERISTICS FOR COMPOSITE REINFORCEMENT

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Bachelor of Science in Mechanical Engineering

2018

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**A thesis submitted
in fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Honours**

FACULTY OF MECHANICAL ENGINEERING

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that this thesis entitled "Analysis of Woven Kenaf Fabric Characteristics for Composite Reinforcement" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : ....

Date : ....

APPROVAL

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

Signature :……………………………

Supervisor Name :……………………………

Date :…………………………............

ABSTRACT

Nowadays, the decrease of landfill site has become a concern in Malaysia with the ever-increasing amount of trash fully occupying limited available landfill area. Such concern has causes the industry to consider develop their product using cheap, renewable and biodegradable source. This leads to the research in usage of natural plant-based fabric in reinforcing composites. This research aims to investigate the effect of ageing, loading direction and moisture on the tensile properties of kenaf fabric. Two batch of plain woven kenaf fabric is purchased at a different time is used throughout this research. ASTM: D5035 is employed when conducting the tensile test of kenaf fabric in both the warp and weft direction. In the case of moisture condition, the kenaf fabric is tested and compared in dry and fully saturated moisture condition only. The results collected indicated that kenaf fabric exhibit better tensile properties in the weft direction in overall while age and moisture condition cause a change in strain and tensile properties.

ABSTRAK

Marcapada ini, peningkatan dalam kadar pembuangan sampah ke tapak pelupusan sampah yang terhad telah menyebabkan masalah kekurangan tapak peluspusan sampah di Malaysia. Hal ini telah menyebabkan industri bertindak untuk menghasilkan produk menggunakan bahan yang lebih murah, boleh diperbaharui dan dibiodegradasi. Oleh itu, pelbagai pengajian mengenai penggunaan kain berdasarkan serat tumbuhan sebagai bahan penguat untuk komposit telah dijalankan. Kajian ini bertujuan untuk mengenalpasti kesan lokasi penempatan beban, masa penyimpanan dan kelembapan terhadap kekuatan tegangan kain kanabis. Kajian ini secara keseluruhannya dijalankan menggunakan dua bidang kain kanabis yang dibeli daripada masa yang berbeza. Kekuatan tegangan kain tersebut telah dikaji berdasarkan ASTM: D5035 melalui penempatan beban pada arah pakan dan lungsin kain tersebut. Kesan kelembapan kain pula dijalankan dengan membandingkan kekuatan tegangan kain dalam keadaan yang kering dan basah sahaja. Hasil kajian menunjukkan bahawa kain kanabis mempunyai kekuatan tegangan yang lebih besar dalam arah lungsin berbanding dengan arah pakan manakala jangka masa penyimpanan dan kelembapan kain telah menyebabkan perubahan kekuatan dari segi kekentalan dan tegangan kain kanabis.

ACKNOWLEDGEMENT

First and foremost, I would like to thank my supervisor, Assoc. Prof. Dr. Sivakumar Dhar Malingam, from Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka for his helpful advice and encouragement throughout the completion of my undergraduate project. Secondly, I would like to express my utmost gratitude to Mr. Ng Lin Feng, my respectable senior in providing unconditional support and guidance in attempting various phase during the research.

Thirdly, sincere thanks are given to the lab assistant and technician of the lab notably Mr. Wan Saharizal Bin Wan Harun, assistant engineer for Mechanical Structure Lab for his invaluable assistance in operating and conducting the tensile test accurately and precisely according to relevant standards. Fourthly, I would like to express my thanks to the examiners for my project, Assoc. Prof. Ahmad Rivai and Dr. Khairi Bin Mohamed Nor for providing suggestion and remarks on my progress to improve the quality of my work. Fifthly, I also would like to thank the Committee of Undergraduate Project of Faculty of Mechanical Engineering for their constant reminder and helpful guidance in facilitating me throughout the completion of this project.

Last but not least, I would like to say thank you to my family, friends and fellow course mate in making the process of completing this project a fun, educative and enjoyable one.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Lately, the issue of environmental pollution is highlighted by the public due to the increase of global temperature, decreased land and the effect of the pollution towards the sustainability of endangered wildlife and plants. In Malaysia, the problem of decrease in landfill area for solid waste disposal has increased public awareness in environment sustainability issues. To overcome these environmental challenge, researchers have been proactively looking for solution to overcome these adverse effects for the sake of sustainability of natural resources and mankind. Various approaches have been taken to allow biodegradation of daily used products such as plastic bags and fabrics to further reduce the landfill and treatment needed from disposal of such items. The introduction of using biodegradable materials to manufacture human daily used products will significantly reduce the landfills caused by disposal of these products while providing a better and cleaner environment. Biodegradable materials like hemp, sisal, cotton and bamboo fibres are thoroughly researched in manufacture of various product and bio-composites, but not much research has been done on kenaf (*Hibiscus Cannabinus L*) fabric and its uses in manufacturing industry.

6000 years ago, kenaf had been cultivated by Afrika farmers as cordage crop and livestock feed for various husbandry purpose (Dempsey, 1975). Since then, little technology and research regarding the usefulness of kenaf has been done throughout these centuries where most of the research were focused in textile industry. With the global mind attempts to perform sustainable development, manufacturing industries are encouraged to adopt new, biodegradable materials in the place of non-renewable resources in manufacturing products. This can be seen in the Mediterranean paper and textile industry where kenaf has been used in pulp production to replace wood in the manufacturing process (Ardente et al., 2008). Kenaf bast fibres have also been extracted to be used in reinforcement of thermoplastic composites. The advancement of technology and research allow kenaf plant to be one of the primary economy crops for farmers with its wide uses by the various industry.

Despite all the uses that can be provided by kenaf plant, the fabric produced has been mainly used as is without considering its possibility in composite reinforcement. The property of kenaf fabric allow it to be used as food safe package for fruits and vegetables. However, the mechanical properties of this material under different conditions are not researched by most researchers worldwide. The relationship of moisture, age, temperature and orientation of fibres with its mechanical properties can provide insight in discovering new application for this material.

The application of kenaf in production of papers and textiles generally means that it will be exposed to water during its working condition whether as a bag or straps. The changes in its mechanical properties should be identified to ensure that the product will be safe to use while having a longer lifespan. Most natural fibre might swell when exposed to moisture which could affect its mechanical properties. Such phenomenon should be investigated to determine its effect on the appearance, chemical properties and mechanical properties to further prolong its lifespan to prevent waste.

Just in time production concept suggest that some of the produced product need to be stored as surplus stock to meet the demand of customer at any time. The extra product produced needs to be stored properly for unknown duration until a requested from customer has been received. The effect of storage duration or time on the fabric also needs to be investigated to ensure the quality of the fabric. The fabric might be undergone decomposition or bug infestation throughout its storage time. This could impact the quality of the fabric in terms of tensile properties and general appearance. The results from this investigation could help the manufacturer to determine the quality of the fabric to protect its company reputation. Manufacturer could also ensure the quality of their product that uses kenaf fabric as base material.

1.2 Problem Statement

The mechanical properties of kenaf as reinforcement fibre in bio composite have been widely researched for its reinforcement effect on the composite. However, the research about the properties of kenaf fabric itself is still lacking in a lot of aspects. Kenaf fabric has a lot of potential as the base material for biodegradable composite or simply as the reinforcement layer for metal or plastic composite. Kenaf fabric has some other uses besides its role in composite such the manufacture of biodegradable bags and low-cost packaging for fresh crops and plants. The basic mechanical properties of kenaf fabric is usually provided in the datasheet by the manufacturer which includes the weight and density of the fabric in overall, tensile strength of the fabric and the amount of yarn in the fabric. The absence of its mechanical properties under different condition limit its uses in developing and designing new product.

For fabric, its most common application lies in packaging of products and as base material for clothes which is usually susceptible to tension and moisture. Most research today mainly focus on the reinforcement capability of the material in its bio composite. The effect of moisture content in kenaf fabric towards its tensile properties remains unknown by many which cause the material not to be considered when deciding material to be use in product development.

The effect of age or time of the fabric towards its mechanical properties is one interesting topic not considered in most other research. The packaging of the product is generally needed to be long lasting and durable to protect the packaged product from any external damage. External interference to the packaging can comes in physical and chemical form such as bug bites, damage from pest such as mice, moisture absorption from exposure to rain and chemical exposure from leakage in other products such as detergents, juices or ink for marking purpose. Such research provides us an insight regarding the quality of the stored fabric whether it can still be used for its decided purpose.

Thus, the main problem statement to be solved by this research is:

- What is the effect of moisture to the tensile properties of kenaf fabric?
- What is the effect of time or age of the fabric in its tensile properties?

1.3 Objective

Based on the problem statement mentioned in the last section of this proposal, this research aims at discovering the effect of moisture content in the tensile properties of kenaf fabric. The objectives for this research are:

- To investigate the tensile properties of kenaf fabric with different moisture content
- To research the tensile properties of kenaf fabric with different age or storage time

1.4 Scope of Project

The scopes of this project are:

1. This research focuses on the fabric properties and the changes in tensile properties based on selected criteria of kenaf fabric only.
2. Only plain woven weave structure fabric is used in this research.

3. The research aims to identify the effect of age and moisture on the tensile properties of kenaf fabric.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The reinforcement of composite using woven fabric is widely practiced nowadays by manufacturers to reduce production cost and sustainability of the product. Reinforcement of composite using kenaf is especially cheaper compared to synthetic fibres such as glass fibres considering the amount of energy and additional cost required to produce and process the synthetic fibres. As an evidence, 1kg of kenaf only required 15MJ of energy in production while glass fibres require a total of 54MJ of energy to be consumed for each kilogram produced (Nishino, T. 2004). Being a fast-growing crop, kenaf only takes 3 months to mature and having an annual yield up to 10000kg/ha, kenaf has been proven to have a constant supply throughout the years (S. K. Ramamoorthy et. al., 2015). Kenaf generally requires a hot and humid environment to cultivate successfully. Such environmental condition is nicely inclined with the environmental condition in Malaysia, which only have sunny and rainy weather. Such environmental condition coupled with easy cultivation of kenaf plant, Malaysia farmer are generally encouraged to cultivate this economy crop in their field. Composite reinforced using natural fibres such as kenaf and hemp has improved sustainability due to its biodegradable property. However, the incorporation of natural fibres into composite is not without its flaw. Some of the limitation of using natural fibres in reinforcing composite includes decreased mechanical and thermal properties due to low thermal resistance and hydrophilic properties of natural fibres, anisotropic properties and poor adhesion between the natural fibre and composite matrix (Celino et. al., 2014). Thus, researchers have been investigating various properties of natural fibres that could contribute or impair the overall performance of the resulted bio-composite using natural fibres.

2.2 Chemical Composition and Structural Organization of Kenaf

The structural and chemical composition of kenaf contribute to its mechanical and thermal advantages over other natural fibres. Kenaf fibres are characterised as a bast fibres which are fibres collected from the stem or phloem of the plant. Being a plant based fibre, the major chemical component of kenaf is lignocellulose (cellulose, hemicellulose and lignin) where these component is different from one plant to another plant (Ramamoorthy et. al., 2015). Lignocellulose is a linkage of cellulose and hemicellulose that are joint together by lignin. Such component coupled with pectin and protein provide the mechanical support for most plant cell. Cellulose provides the strength and stiffness of a plant fibre which is made up from linear 1,4-β-glucan polymer consisting D-anhydroglucose ($C_6H_{11}O_5$) that contain the hydrophilic hydroxy groups (OH). Such chemical structure causes most plant fiber to be hydrophilic in nature. Figure 2.1 shows the chemical structure of a cellulose. A summary of chemical component present in kenaf fibres from various parts is shown in Table 2.1

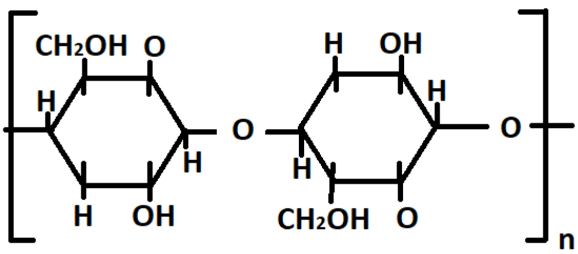

Figure 2.1: Chemical structure of cellulose

Table 2.1: Chemical composition of different fractions of kenaf fibre (Abdul Khalil et. al., 2010)

	Kenaf whole (core + bast)	Kenaf core	Kenaf bast
Extractive (%)	6.4	4.7	5.5
Hemicellulose (%)	87.7	87.2	86.8
α-Cellulose (%)	53.8	49.0	55.0

Lignin (%)	21.2	19.2	14.7
Ash (%)	4.0	1.9	5.4

In the table, hemicellulose is the collection of cellulose and hemicellulose without any other extractives, lignin and ash in a plant fibre. α-cellulose on the other hand is the major component found in wood and paper pulp. This component provides the high strength in most fibre-based product (Ayadi et al., 2016). As can be seen in Table 2.1, the kenaf bast has the highest α-cellulose compared to fibres extracted from other region of the plant. This result indicates that kenaf bast fibres are the most suitable fibres to be used in textiles and reinforcement of bio-composites due to their higher strength. The chemical composition of kenaf is also susceptible to change in regional environment condition such as regional temperature, soil condition and air humidity. Thus, it is logical to think that the chemical composition of kenaf originated from Afrika to be different with ones cultivated locally in Malaysia. According to Ashori et al. (2016), the Malaysia cultivated kenaf bast fibres have lower lignocellulose material compared to the core fibres. Results from Ashori et al. (2016) also showed that the chemical composition of kenaf is different in amount when compared to research data collected by other party from another country. A summary of Malaysia cultivated kenaf chemical composition is shown below:

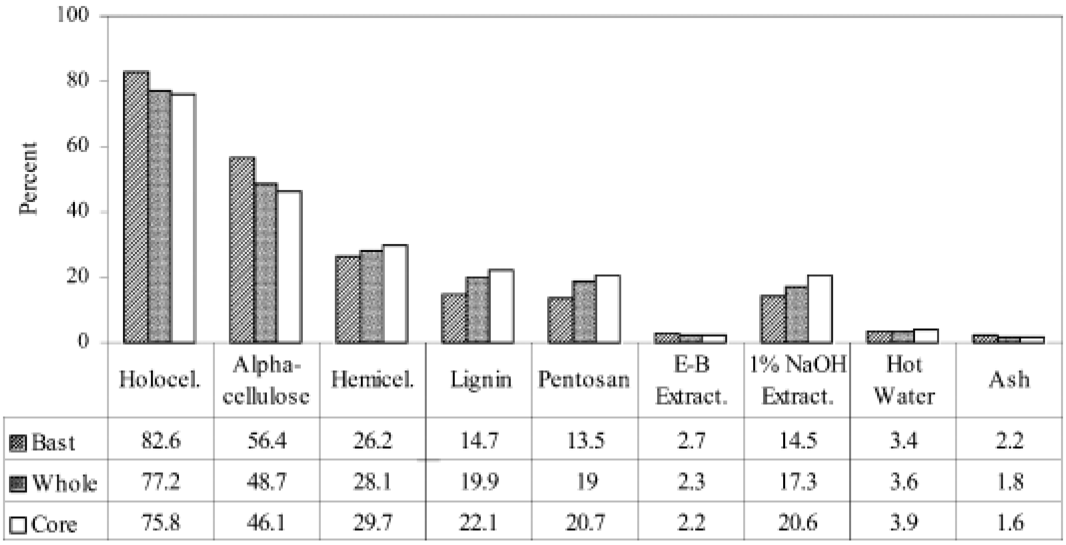

Figure 2.2: Chemical composition of Malaysia cultivated kenaf in different fraction (Ashori et al., 2006)

When comparing kenaf fibres with other bast fibres, Ramamoorthy, Skrifvars & Persson (2015) reported that kenaf has the lowest cellulose content (31-39%) and the highest lignin content (15-19%) among the other bast fibres such as hemp, jute and ramie. Such characteristic of kenaf indicates its potential as reinforcement material in composite manufacturing. The chemical composition of some bast fibres are shown in Table 2.2.

Table 2.2: Chemical composition of some bast natural fibres (Ramamoorthy et al., 2015)

Fibre	Cellulose (wt%)	Lignin (wt%)	Hemicellulose (wt%)	Wax (wt%)
Flax	71.0	2.2	18.6-20.6	1.7
Hemp	70.2-74.4	3.7-5.7	17.9-22.4	0.8
Jute	61.0-71.5	12.0-13.0	13.6-20.4	0.5
Kenaf	31.0-39.0	15.0-19.0	21.5	-
Ramie	68.6-76.2	0.6-0.7	13.1-16.7	0.3

In terms of structural organization, plant fibres generally have a multi-scale structure which can be used at various scales for composite reinforcement. The construction of plant fibre yarn contains a large number of short fibres that are twisted together at an angle to provide substantial strength to the yarn (Madsen et al., 2007). Thus, the strength of yarn can be traced back to a single unit fibre. Past research has shown that unit fiber has multiple cell wall and a polygonal cross-section which is normally assumed to be circular to simplify calculation of stress in plant fibres. The unit fibre has a lumen which gives a hollow structure, a thin external cell wall which made up of pectin, low crystalline cellulose, hemicellulose and low amount of wax and a thick secondary cell wall which have microfibrils oriented parallel to each other. The secondary cell wall can be divided into three layers which has different thicknesses, microfibril twist angle and chemical composition. The mechanical properties of unit fiber are largely dependent on the second layer which made up about 80% of the secondary cell wall thickness (Celino et al., 2014). Figure 2.3 below shows the structure and chemical composition of a single fiber or unit fiber cell.

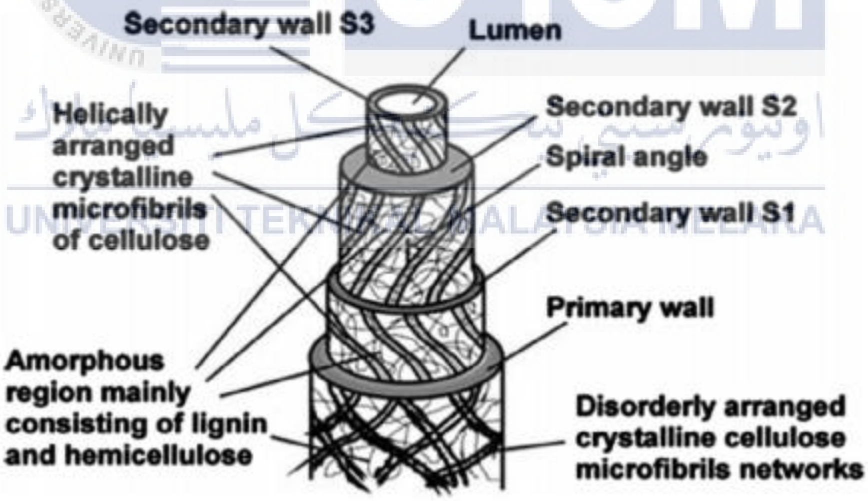

Figure 2.3: Structure of a single fiber cell (M.Ramesh, 2016)

2.3 Effect of Woven Fabric Properties in Fabric Reinforced Composite

The properties of woven fabrics depend on fabric crimp, tensile property of fabric and weaving structure of fabric. Fabric behaves differently when subjected to load compared to rigid material like wood and metal due to the woven structure used in arranging or weaving the yarns into textiles. Research has been done over the decades to identify the strength and weakness of each factor in enhancing the performance and usage of natural fibre fabric.

2.3.1 Tensile properties of fabric

The tensile properties of fabric can be seen from several factors which are the tensile strength of yarn, fabric density or linear density of yarn and the effect of crimp percentage on fabric. The strength of yarn originated from the chemical composition of fibre. When a plant fibre is subjected to a load, the applied stress starts to disturb the amorphous part of the molecular structure of the fibre by stretching the primary and secondary bond (Annis, 2012). If the loading is removed from the fibre at this stage, the fibre will show elastic behaviour by recover from its achieved extension due to loading (E.M. Abou-Taleb, 2014). As the loading continue to increase, plastic deformation occurs as the long chain of cellulose molecule rearrange reciprocally as a consequence of missing secondary bonding. However, further increasing the load will then increase the elongation of these bond and subsequently break the chemical bond and causes rupture to the yarn.

In the case of fabric density, fabric density is defined as the amount of yarn present per unit length in the fabric. This factor is also known as fabric compactness and yarn spacing. Due to anisotropy property of fabric, fabric density is determined based in the direction of the fabric in weft and warp direction. The warp can be identified as the yarns that are I parallel with the selvages on the fabric while weft or filling is the yarns perpendicular to the selvages or warp yarn. According to ASTM: D3776, Standard Test Method for Warp End Count and Filling Pick Count of Woven Fabric, the fabric density of a fabric is normally determined by counting the number of yarn in warp and weft direction in 1cm. Based on M.M. Islam et al. (2014), the distribution of fibre per unit area in a plate is not easy to control when using short fibre as this could result in inconsistency in density and fibre volume fraction of composite. Such concern can be overcome when manufacturing composite using natural fibre by using woven fabric with constant fibre density where the fabric density can be easily determined. S.F. Eryuruk and F. Kalaoglu (2015) reported that the tearing strength value of weft is higher than warp in their research. The densities of warp and weft also plays a role in deciding the tensile strength of fabric. The tensile strength of fabric will be reduced if the tension of warp and weft increases during weaving which limits the extensibility of fabric (Hossain, Datta & Rahman, 2016). Tensile test in fabric can be determined using two main method, the grab test and strip test. Both tensile test specifically recommended the test to be done on both the warp and weft direction as the property and stress distribution is different in warp and weft.

Figure 2.4 shows the stress strain graph of a typical fabric. As seen in the graph, the stress strain graph of fabric can be divided into three parts. The first part is the nonlinear portion at the beginning of the graph where the decrimping and crimp interchange occurs when the fabric is in tension. In this state, the yarns in the fabric will be straightened as the decrimping and crimp interchange occurs. In the second part which is the linear portion of the graph, the yarns in the fabric have become fully straightened and will be subjected to direct loading as the tension force increases in the fabric. The yarns in the fabric will continue to extend until fracture as seen in the serrated portion in the graph. The third part in the graph lies after the peak of the stress strain graph. This portion shows irregular behaviour as the yarns in the fabric begins to fracture with increasing strength applied one by one. An increment in tensile strength is expected in this portion as the fractured yarn might entangle the adjacent yarn that obstruct the movement of the yarn. A higher force is required to fracture the yarn if it becomes entangled with the surrounding yarns as the friction between the entangled yarns reduces the effective force that put the yarn in tension.

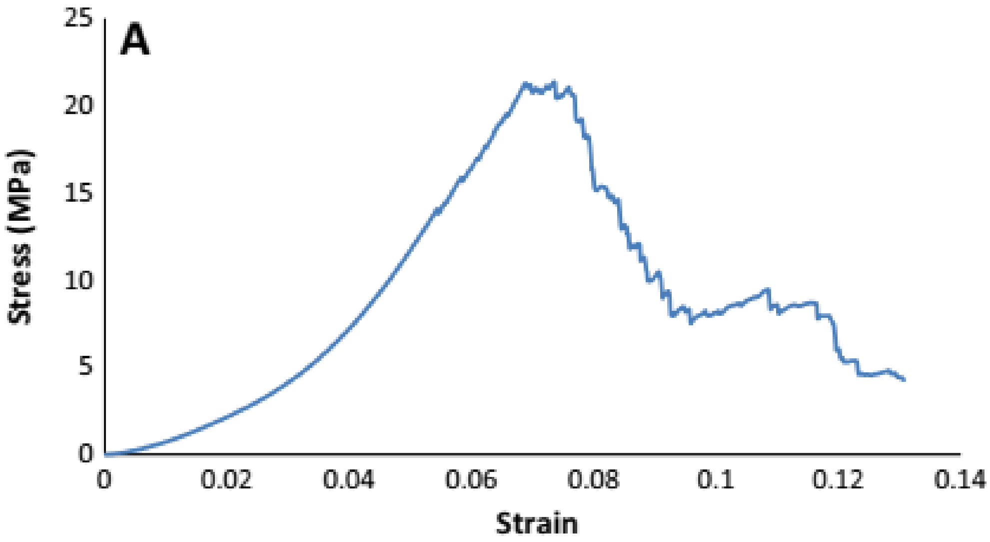

Figure 2.4: Stress strain graph of fabric (Misnon et al., 2015)

2.3.2 Crimp percentage in fabric

Crimp in fabric refers to the interlacing of yarn in warp and weft that causes the yarn to appear in a zig-zag pattern when viewed at one side. Thus, crimp is expected to increase with increasing fabric density where there are more yarn present in the fabric allowing more interlacing to occur between yarn. When loading the fabric, the yarn of the fabric will undergo a de-crimping process at internal interchange where the yarn will be pulled from loosely arranged zig-zag pattern to become straight and round (Misnon, et al. 2015). The extension or yarn tension due to crimp which causes crimp interchange helps to extend the fabric more, giving it more elasticity (Hossain, Datta & Rahman, 2016). The faces that is in contact that will experience the burnt from abrasion during the daily use of the fabric. When the fabric has been worn out completely, the other faces in the yarn will then only experience the abrasion force between other yarn in the weave structure (Annis, 2012). The reduction in yarn is mainly due to the differential loading occurred. Figure 2.5 illustrate the structure of crimp in fabric.

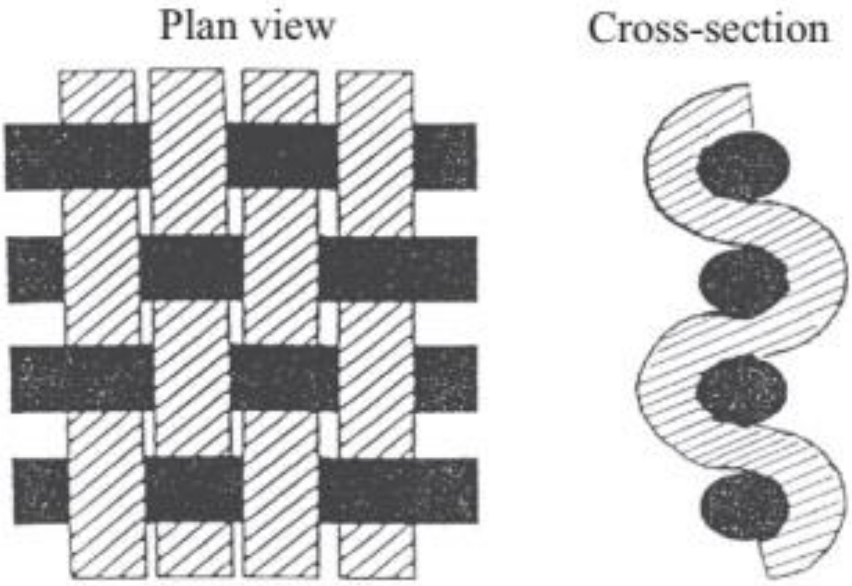

Figure 2.5: Plain weave structure fabric crimp in plain and cross-section view (Misnon et al. 2015)

In practice, fabric crimp is generally determined using ASTM: D3883, Standard Test Methods for Yarn Crimp and Yarn Take-up in Woven Fabric. The yarn crimp of fabric is measured based on the percentage difference between the length of yarn on fabric and the extended length of yarn after unravelled from fabric. The formula used to calculate the crimp percentage in fabric as proposed by ASTM: D3883 is given in equation 2.1:

$$\text{Yarn Crimp}(\%), \mathrm{C} = \frac{\text{Extended yarn length}, \mathrm{Y_2} - \text{Original Yarn Length}, \mathrm{Y_1}}{\text{Original Yarn Length}, \mathrm{Y_1}} \times 100\% \qquad (2.1)$$

2.3.3 Weaving structure of fabric

Textile is made by weaving yarns together using various technique to improve its mechanical properties, appearance and aesthetic design. In the olden days, textile is generally weaved using basic weaving technique such as plain, twill and satin. The advancement of technology and industrial revolution introduced more complex weaving structure like Matt weave and Diamond weave. Weaving the yarns together produced crimp in fabric which generally reduce the tensile property of the fabric. The improvement in tensile property are different for every weaving structure due to the different way the yarns are interlaced with each other. Figures 2.6, Figure 2.7 and Figure 2.8 shows some of the common weave structure in fabric:

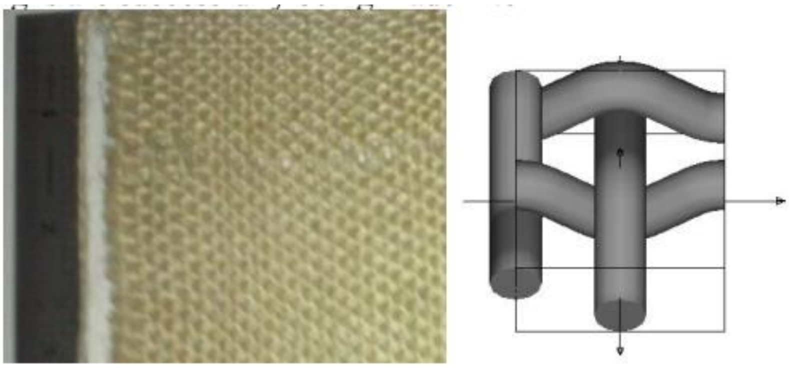

Figure 2.6: Photograph and 3D image from WiseTex software of Plain 1/1 woven fabric (Saiman, Wahab & Wahit, 2014)

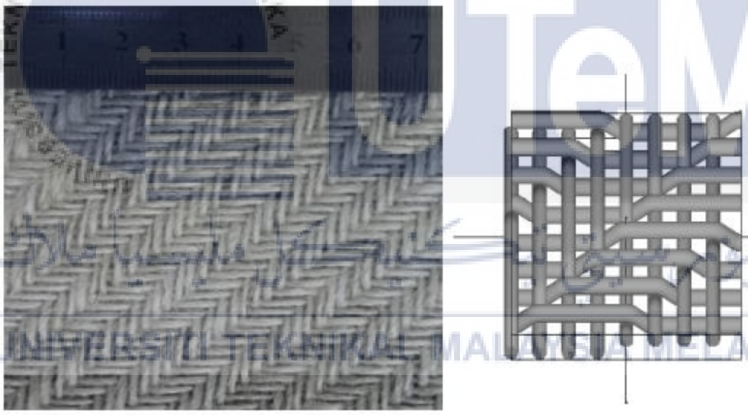

Figure 2.7: Photograph and 3D image from WiseTex software of Twill 4/4 weaving structure (Saiman, Wahab & Wahit, 2014)

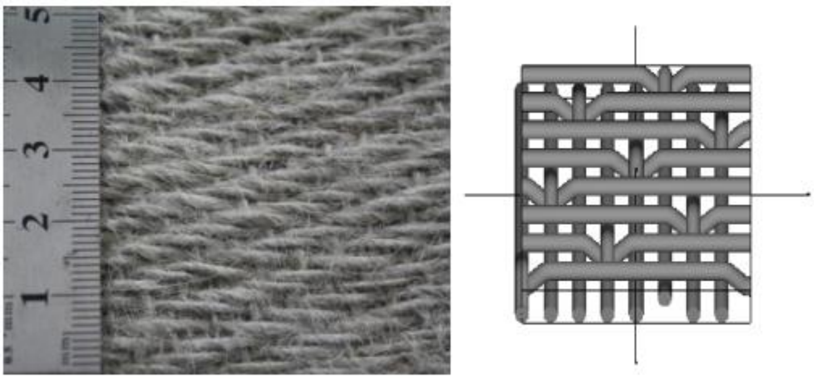

Figure 2.8: Photograph and 3D image from WiseTex software of Satin 8/3 weaving structure (Saiman, Wahab & Wahit, 2014)

Different weave structure provides different degree of improvement to the fabric when subjected to loading. Ferdous et al. (2014) reported that the twill structure is the strongest structure followed by plain woven and satin. Such result is mainly due to the little amount of slippage of yarn occur in plain woven fabric weave structure which causes the strength of fabric to decrease as the crimp in fabric increases. The findings by Ferdous et al. (2014) is further supported by Saiman, Wahab & Wahit (2014) research which concluded that a weave design that provide lower crimp percentage will produce a stronger fabric because the fibre strength can be fully utilized. However, Saiman, Wahab & Wahit (2014) also noted that when introducing woven fabric into composites, Plain 1/1, Twill 4/4 and Satin 8/3 showed almost similar breaking strength as compared to their dry fabric form with the exception of Basket 4/4 weave structure. Basket 4/4 weave structure showed a decrement in breaking strength when incorporated into composite when compared to its dry fabric form. This can be explained where the lower crimp percentage weave structure has higher number of floating yarn between each interlacing point. These floating yarns form a jammed structure while the interlacing end point generate a big space which does not provide any reinforcement property. This increases the porosity of fabric and the area of resin-rich region that are weaker since the reinforcement material only cover the surface of fabric. From the viewpoint of bending strength, Alavudeen et al. (2014) discovered that the hybrid effect of using two different fibre yarns could create an interlocking structure. This structure restricts the extension of yarn along the longitudinal and transverse direction which results in higher bending strength of the fibres. Besides that, kenaf and banana fibre hybrid weave structure also reported to have increased the capability of withstanding compressive force and improved resistance to shearing. According to Salman et al. (2015), plain weave woven fabric exhibits better reinforcement to composite in increasing the tensile strength of composite compared to twill type fabric. These researches have proven to be successful in improving composite using natural fibre fabric as reinforcement material. Plain woven fabric which might be weaker in terms of mechanical properties when used as is but exhibit excellent reinforcement potential when used in the manufacture of composite. The overall mechanical properties of the composite such as tensile strength, flexural strength and ability to withstand compressive force improves by reinforcing the composite with correct proportion of woven fabric.

2.4 Effect of Moisture Concentration in Fabric to Fabric Reinforced Composite

Most plant fibre-based fabric is hydrophilic in nature. Such property comes from the chemical composition of plant fibres which have the hydrophilic hydroxyl group (OH). In plant fibres the major component responsible for water absorption have polar group which are cellulose, hemicellulose, pectin and lignin (Celino et al., 2014a). The other factor which determine the level of moisture absorption is the fibre particular structure. Plant fibres are highly porous which allow them to store water in them with their high surface exchange rate (Celino et al., 2014). According to Bessadok et al. (2007), when the moisture in air exceed a certain threshold, a relaxation of the existing void in fibre structure will appear that leads to swelling effect of fibre. In terms of effect of moisture on the mechanical properties of natural fibres, an increase in stress at failure is observed with the relative humidity up to RH = 70%. If the relative humidity exceeds this threshold value, the tensile strength of the fibre will decrease (Celino et al., 2014). This is due to the absorption of water lead to rupture of hydrogen bond between the matrix of amorphous phase and the crystalline fraction of the fibres.

When natural fibres or fabrics are introduced into composite, the composite usually obtains or enhances its ability to biodegrade and absorb moisture. In composite, there are three major mechanism of moisture absorption. The first method is the diffusion of water into micro gaps present in fibre molecule. The second mechanism involves with the capillary transportation of water into gaps and flaws at the interface between fiber and composite matrix. The third way occurs when water is transported into micro cracks in composite matrix produced from the swelling effect of fibres (Zamri et al., 2011). Past research has indicated that the absorption of moisture of natural fabrics or fibres usually affect the mechanical properties of bio-composite negatively (Salman et al., 2015). The presence of moisture in bio-composite has been known to reduce the flexural strength and tensile strength of the composite. To compensate such negative influence, hybridization or reinforcement of composite using two types of natural fibre is done. Yahaya et al. (2016) have reported that the hybridization of kenaf-Kevlar hybrid composite has lower impact strength the more of kenaf is used in the composite. Besides that, Sanjay & Yogesha (2016) also reported that the hybridization of hydrophilic natural fibre with hydrophobic E-glass decreases the moisture absorption of natural fibre composite. This result is further supported by Zamri et al. (2011) where the hybridization of jute and glass fibre also exhibit a lower moisture absorption compared to natural fibre composite.

In the case of effect of presence of impurities in water to water absorption rate of composite, Zamri et al. (2011) reported that the absorption rate of water in natural fibre composite is the highest in distilled water followed by acidic solution and seawater. Similar trend is also discovered by Sanjay & Yogesha (2016) where the absorption rate of composite is the highest in distilled water and followed by normal water and salt water. This is mainly due to the hydrolysis of cellulose is more efficient in hypotonic solution such as distilled water and weaker in hypertonic solution like salt water.

2.5 Effect of Biodegradation of Fabric to Fabric Reinforced Composite

Biodegradation is an advantages and disadvantages of a composite at the same time based on different situation. If biodegradation occurs after the end of life cycle of the fabric, such property is considered to be an advantage due to improved sustainability of the fabric. However, if biodegradation occurs during the fabric service life, such property can only be seen as a major disadvantage as its intended function might not be fulfilled properly. The mechanism of biodegradation of natural fibre fabric can occur photochemically or biologically. The photodegradation of fibre occurs when the natural fibre is exposed to sunlight. The UV rays present in sunlight will breakdown the cellulose, hemicellulose and lignin component in the fibre (Abdullah, Dan-mallam & Yusoff 2013). Lignocellulose material is the main component in providing mechanical strength and rigidity to the natural fibre. A decrease in these materials will impact the mechanical properties such as tensile strength, flexural strength and impact strength of the fibres.

Regardless of environmental condition, fabric is always susceptible to the microbial attack at all times. This mechanism of biodegradation relies on the hydrolytic and oxidative microorganism such as bacteria and fungi (Sohel Rana et al, 2014). The growth of bacteria and fungi is ideal on fabric surface due to the porous, hydrophilic structure that could easily provide water, oxygen and nutrient from decomposition of fibre. Cellulose is one of the main component presents in plant fibre. The amount of cellulose varies from plant to plant which suggest different biodegradation rate for each plant. The microbial obtain nutrient from cellulose in fibre which is a polysaccharide consist of β-glucose linked by 1,4-β-glycoside bonds (Beata Gutarowska & Andrzej Michalski, 2012). This component exists as long chain molecule which can undergo enzymatic hydrolysis by microorganism to produce nutrient for other bacteria and fungi. The enzymatic hydrolysis of microbial using cellulase can be seen in Figure 2.9 (Paul, 1997):

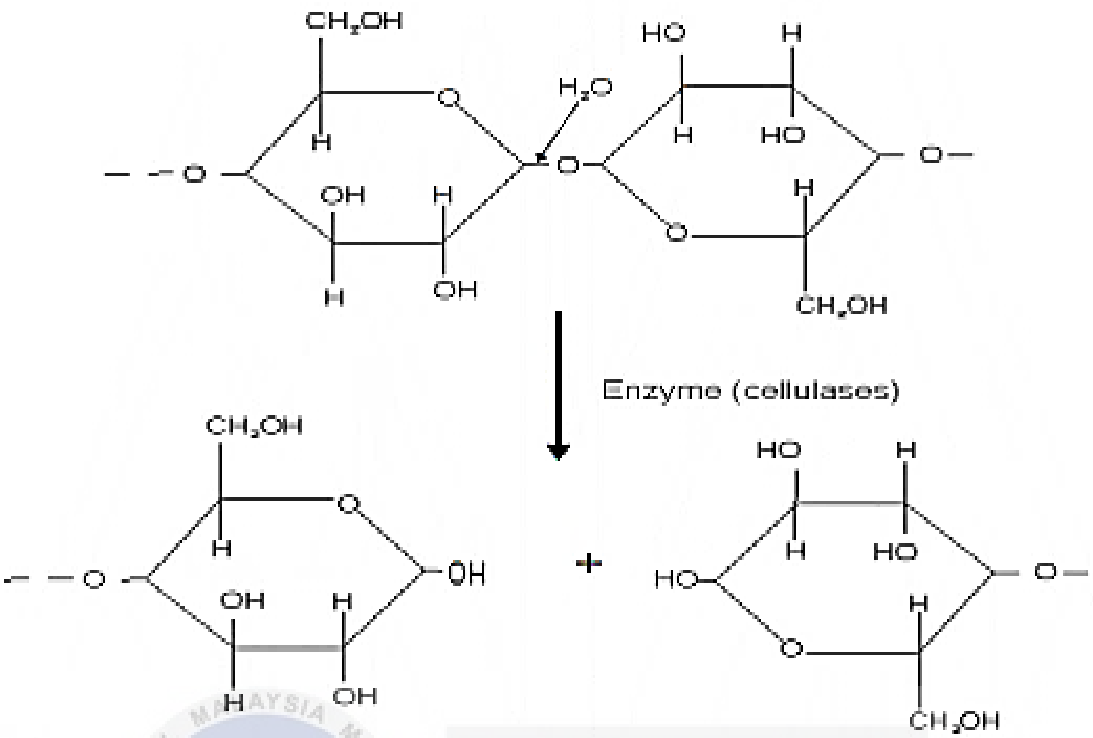

Figure 2.9: Enzymatic hydrolysis of cellulose using cellulase (F. H. Paul, 1997)

The hydrolysis of cellulose using cellulase convert the polysaccharide molecule of cellulose into simple, soluble sugar that can be readily metabolized inside bacterial and fungi cells (Boryo, D.E.A, 2013). The breakdown of cellulose component in fibre will then be reflected to its mechanical properties.

Researchers have also investigated the impact of biodegradation properties to the mechanical properties and structure of bio-composite. Abdullah, Dan-mallam & Yusoff (2013) reported that the environment degradation of POM/kenaf composite causes a significant drop in tensile strength. The environment degradation of tested composite is conducted by exposing the composite under moisture water spray and UV penetration for 672 hours. This result shows that the presence of moisture could further increase the degradation rate of natural fibre and more reduction in its mechanical strength. The same research also reported that POM/kenaf composite is more susceptible to environmental degradation compared to hybrid composite. Besides that, S. Rana et al. also reported that the biodegradation of natural fibre could severely impact the tensile strength of fibre where the mean braking load prior biodegradation by burial is 297 g-force has been reduced to only 2 g-force after burial. The decrement in tensile properties is explained by the effect of hydrolysis of chemical bond during microbial polymerization of molecule weaken the fibres.

CHAPTER 3

METHODOLOGY

3.1 Determination of Fabric Properties

Various fabric properties such as fabric thickness, fabric density and fabric weight are normally provided in the data sheet from the manufacturer. Validation of these data will be done by using appropriate standard tests to verify the proper value the properties of kenaf fabric.

3.1.1 Fabric weight

The fabric weight of kenaf fabric used in this research is determined using ASTM: D3776, Standard Test Procedure for Mass Per Unit Area (Weight) of Fabric. Five specimens are required in this testing which are cut from random location from the fabric. Each specimen is weighed three times to its nearest 0.1% of its mass in grams to get an average reading for each specimen. The fabric weight is determined from the average from all the specimen weight in grams per cubic meter, g/m^2.

3.1.2 Fabric thickness

ASTM: D1777, Standard Test Method for Thickness of Textile Materials is used to determine the fabric thickness of kenaf fabric. The thickness of the fabric is measured at 20 locations chosen at random to obtain an average value. The thickness of fabric is measured in millimetres, mm.

3.1.3 Fabric density/ yarn spacing

Yarn spacing or more commonly known as fabric thickness is related to the compactness of the fabric. This property shows the amount of yarn present per length in the fabric. Yarn spacing is measured in compliance with ASTM: D3775, Standard Test Method for Warp End Count and Filling Pick Count of Woven Fabric. The amount of yarn is counted in a 20mm length at randomly chosen location on the fabric. The data collected is recorded in the form of:

Yarn Spacing = Number of Warp Yarn x Number of Filling or Weft Yarn, per 20mm

Care to be taken that for fabric width less than 1000mm or 1m, no count should be made 150mm from the selvages and 0.5m from the end of roll or piece. For fabric less than 1m and more than 125mm, no count should be made one tenth from the width of the fabric and 0.5 m from the roll or piece. For fabric width less than 125mm, count all the warp yarns in the width, including the yarn in selvages, then divide the width of the fabric. For filling yarn, count randomly space along the length where practical.

3.2 Determination of Yarn Properties

Fabric is a structure made from a collection of yarns. The properties of yarn will directly impact the performance of the fabric. In this research, the yarn size and yarn crimp will be measured by employing suitable standard procedure.

3.2.1 Yarn size

The yarn size of kenaf fabric used is measured according to ASTM: D1907, Standard Test Method for Linear Density of Yarn (Yarn Number) by the Skein Method. Individual yarn is unravelled from the kenaf fabric and cut into length of 50cm. The cut yarn is then weighed using a balance. 3 yarns of 50cm is unravelled and weighed to obtain an average reading. The yarn size is calculated using the formula given in equation 3.1:

$$\text{Yarn Size, N} = \frac{\text{Average weight of yarn,w(g)}}{\text{Length of yarn,l (m)}} \times \text{constant for tex system, k} \tag{3.1}$$

For metric system, constant k is given as 1000m/g and the yarn size is measured in the unit of tex.

3.2.2 Yarn crimp

The yarn crimp of kenaf fabric used in this research is determined by employing ASTM: D3883, Standard Test Methods for Yarn Crimp and Yarn Take-up in Woven Fabric. In this standard procedure, two parallel lines are marked in warp direction with 20cm apart from each parallel line. Next, cut the fabric 30cm along the weft or filling direction while crossing the parallel lines. Several yarns are then unravelled from the fabric from one edge and carefully unravel the next 5 yarns for measurement. Precaution should be taken not to unravel the yarn with excessive force which could disturb the twist or strain of the yarn. The unravelled yarn is then pull taut from both sides to measure the length of the yarn. The yarn crimp can then be calculated using the formula in equation 3.2:

$$\text{Yarn Crimp(\%), C} = \frac{\text{Extended yarn length,}Y_2 - \text{Original Yarn Length,}Y_1}{\text{Original Yarn Length,}Y_1} \times 100\% \tag{3.2}$$

3.3 Experimental Method

In this research, the tensile strength of kenaf fabric will be conducted in dry and wet condition. The following section will discuss about the steps required to prepare the specimens and conduct the tensile test.

3.3.1 Preparation of specimen

A specimen of kenaf fabric with dimension of 25mm width and gauge length of 200mm will be used to conduct the tensile test in all condition. A 30mm width, 250mm long strip of fabric will be cut from the kenaf fabric. Then, carefully unravel yarn from each side until the width of specimen become 25mm. The extra 50 mm length from the strip will serve as the clamping region of the tensile test machine. By using resin adhesive solution, stick two pieces of cardboard at the end of each specimen on each side to provide a firm grip to the clamp of universal tensile test machine. Note that the carboard applied should not cover more than 25mm of each end of the specimen. For specimen to be immersed in water, wrap the cardboard with a layer of adhesive tape to provide water resistance to the cardboard region.

3.3.2 Moisture absorption of the specimen

The moisture condition of the specimen is crucial in determining the dry and wet condition for the specimen. Weigh the specimen in room condition and record its weight in a table. Then, immerse the specimen in water for ten minutes. After 10 minutes, wipe the specimen using dry paper to remove excess water and weigh the specimen again. Then, immerse the specimen for another 10 minutes. Repeat the procedure until the change in weight of the specimen is within 1% from the previous weight. A graph of weight of the specimen against immersion time should be done to determine the time needed to immerse the specimen to reach its saturation point in moisture. This procedure will determine the minimum time needed to immerse the specimen to obtain a wet specimen for the tensile test. The moisture uptake of the kenaf fabric can also be calculated using equation 3.3 as shown:

$$\text{Moisture uptake of fabric (\%)} = \frac{\text{Weight of saturated wet fabric (g)} - \text{Initial weight of dry fabric (g)}}{\text{Initial weight of dry fabric (g)}} \times 100\% \qquad (3.3)$$

3.3.3 Tensile test of specimen

The tensile test for this research will follow ASTM: D5035. In this method, the clamp of tensile test machine needs to be 10mm wider than the width of the specimen. Based on the specimen prepared, a specimen of 25mm width and gauge length of 200mm will be used throughout all the test. The tensile test will be conducted using Universal Tensile Test Machine Instron 8872 with Bluehill 3 software as shown in Figure 3.1 and a crosshead speed of 2mm/min until the specimen break apart totally. The cross-sectional area used to convert applied force to stress is determined by using the thickness of the fabric multiplied by its specimen width.

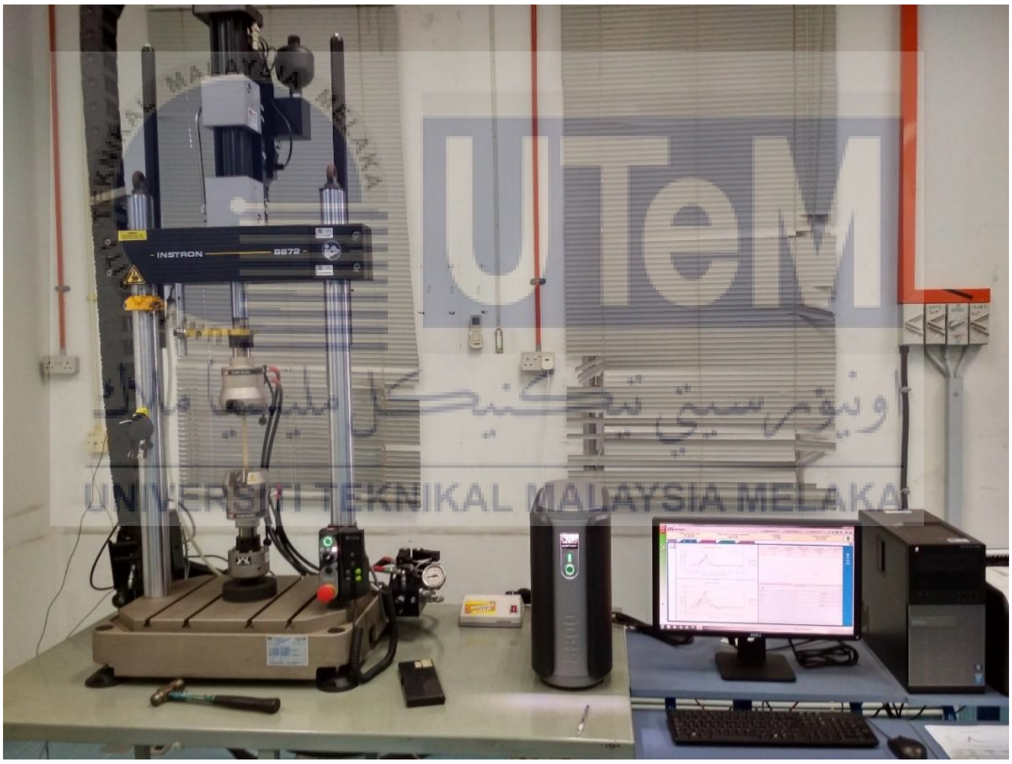

Figure 3.1: Universal Tensile Test Machine Instron 8872

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Physical Properties of Kenaf Fabric

The physical properties of both batch of kenaf fabric will be determined accordingly for its weight, thickness, yarn spacing, yarn size and yarn crimp. The obtained results will then be analysed and discussed between the kenaf fabrics themselves based on the difference in their tensile properties. Based on the observation on the fabric condition, both the old and new fabric does not have any obvious fabric faults and missing picks in its weave structure at the span of 1m in length. Missing picks is one of the common fabric defect which are represented by missing yarn or out of sequence yarn identified in the fabric weave structure. Such defect is usually caused by loom (weaving machine) faults during the insertion of weft yarn. A fabric with missing picks is expected to have inconsistent tensile properties typically in the weft direction. Both the old and new fabrics are observed to be free from this defect and are considered to be good-quality fabrics. Difference found between the old and new kenaf fabric can be seen immediately by the colour difference of the two fabrics. The new fabric appears to be lighter in colour compared to the old fabric. The old fabric has a darker colour tone in overall and emanating a smoky smell. When touching the fabric, the new fabric is smooth and soft while the old fabric feels rigid when stretched with a spiky surface sensation. This is mainly due to the kenaf fiber in the old kenaf fabric starts to deteriorate and separated from the fabric weave structure, as the fiber hardens throughout the storage process. The smoky smell emanating from the old fabric comes from ageing of the fabric from sunlight and any contaminant present on the fabric prior the storage period. Figure 4.1 and Figure 4.2 depict the new and old batch of kenaf fabrics respectively.

Figure 4.1: New kenaf fabric

Figure 4.2: Old kenaf fabric

A 10cm width and 10cm length square fabric is used in measuring its weight. The weight of the fabric is tabulated in Table 4.1. In terms of fabric weight, the old kenaf fabric is calculated to be 294g/m^2 while the new kenaf fabric is weighed 295g/m^2. The fabric weight of new and old batch of kenaf fabrics is summarized in Table 4.2. The old kenaf fabric is slightly lighter by 1g/m^2 when compared to the new kenaf fabric. Both the old and new kenaf fabric is classified as heavy weight fabric in the textile industry as their fabric weight is more than 200g/m^2. Such fabric is usually used in making canvas or denim which are sewn into bags or durable equipment pouches.

Table 4.1: Weight of 10cm x 10cm kenaf fabric

	Old Kenaf Fabric Weight (±0.01g)	New Kenaf Fabric Weight (±0.01g)
1	2.92	2.78
2	2.82	2.91
3	3.09	3.07
4	2.92	3.06
5	2.95	2.95
Average	2.94	2.95

Table 4.2: Fabric weight of old and new kenaf fabric

Fabric age	Fabric weight (± 0.03g/m^2)
Old	294
New	295

In terms of thickness of the kenaf fabrics, both the old and new kenaf fabric has the same thickness which is 0.8mm. The thickness of fabric is approximately double to the thickness of the yarn present in the fabric, where the thickness of the fabric is the average measurement of its yarn at different location selected at random. Similarity in thickness found on the old and new fabric also signifies that the thickness of the two fabrics will not be a dominant factor that deviates the tensile properties of both of the fabric. The thickness of the old and new fabric is summarized in Table 4.3.

Table 4.3: Fabric thickness of old and new fabric

	Thickness (±0.1mm)
Old kenaf fabric	0.8
New kenaf fabric	0.8

Yarn spacing is the amount of yarn present in the warp or weft in fabric. Such term is also known as fabric density by others. This property is the dominant factor in the deciding the weight and tensile properties of the fabric. This is because a higher number in the yarn spacing of the fabric indicates that there are more yarn present along a fixed length in the warp or weft direction, which give the fabric a higher weight. The presence of more yarn in a fixed length also indicates that there are more yarns that could support the applied force which provide the fabric better tensile properties. The yarn spacing in this research was measured using the metric system by calculating the amount of yarn in the fabric at a span of 20mm for the warp and weft direction. Result shows that both the old and new kenaf fabric have nearly similar yarn spacing, where the new fabric has one more yarn in the warp direction when compared to the old fabric. The measured yarn spacing is tabulated in Table 4.4.

Table 4.4: Yarn spacing of old and new kenaf fabric

	Yarn spacing (warp yarn x weft yarn, per 20mm)
Old kenaf fabric	10 x 10, per 20mm
New kenaf fabric	11 x 10, per 20mm

Yarn size or linear density of fabric has direct relationship with the weight of the fabric. The yarn size of the old and new batch of kenaf fabrics is tabulated in Table 4.5. Yarn of 0.5m was used in the measurement of yarn size using tex measurement system. Based on the result obtained, new kenaf fabric had a higher yarn size compared to old kenaf fabric. The recorded old fabric was 273 tex while the yarn size of new fabric was 43.96 percent higher than the old fabric yarn at 393 tex. This result indicates that the new fabric has a heavier and thicker yarn compared to the old fabric. this is consistent with the result obtained as the new kenaf fabric is slightly heavier than the old kenaf fabric by 0.01g/m^2. Fabric with bigger yarn size are known to be heavier compared to fabric with smaller yarn size. The difference in yarn size between the two kenaf fabric is much smaller than expectation considering the new kenaf fabric is only heavier than the old fabric by 0.01g/m^2 but have a difference of 43.96% in yarn size. Upon close observation, the yarn thickness is inconsistent throughout the fabric. Such difference might be due to the measured yarn are thinner than the average value in the old fabric.

Table 4.5: Yarn size of kenaf fabric

	Weight of Old Yarn (±0.01g)	Weight of New Yarn (±0.01g)	Yarn Size of Old Fabric (tex)	Yarn Size of New Fabric (tex)
1	0.13	0.20	260	400
2	0.14	0.18	280	360
3	0.14	0.21	280	420
Average	0.14	0.20	273	393

Yarn crimp is the waviness of the yarn formed due to the warp and weft yarn interlacing with each other during weaving process. Yarn crimp is a crucial parameter in fabric because such parameter could affect the tensile properties, weight and thickness of the fabric. The initial length of yarn on fabric used in this research is 20cm. The results of the yarn crimp for both the old kenaf fabric and new kenaf fabric are shown in Table 4.6 and Table 4.7. The old kenaf fabric was measured to have 3.35% of crimp while the new kenaf fabric had 5.55% of crimp. The new kenaf fabric has higher crimp level than the old kenaf fabric by 65.67%. Based on the obtained result, the new kenaf fabric with higher crimp percentage should be heavier compared to the old kenaf fabric with lower crimp percentage.

The results obtained fall in line with the expectation where the new kenaf fabric is heavier than the old kenaf fabric.

Table 4.6: Crimp percentage of old kenaf fabric

	Length of Unravelled Yarn (±0.05cm)	Crimp Percentage (%)
1	20.50	2.50
2	20.70	3.50
3	20.70	3.50
4	20.70	3.50
5	20.75	3.75
Average	20.67	3.35

Table 4.7: Crimp percentage of new kenaf fabric

	Length of Unravelled Yarn (±0.05cm)	Crimp Percentage (%)
1	21.00	5.00
2	21.10	5.50
3	21.15	5.75
4	21.20	6.00
5	21.10	5.50
Average	21.11	5.55

4.2 Effect of Force Direction

Fabric generally shows anisotropy behaviour in tensile properties. Such behaviour indicates that the tensile strength of fabric depends on the direction of loading force applied. In actual practice, the tensile properties of fabric are done on the warp and weft direction. Figure 4.3 demonstrates the fabric condition during the tensile test and Figure 4.4 shows the stress-strain curves of old kenaf fabric samples. The tensile strain, tensile strength and Young modulus from the tensile test of old kenaf fabric is tabulated in Table 4.8 and Table 4.9 respectively according the warp and weft direction. From the stress-strain curves obtained, it was noted that the curve of kenaf fabric consists of three phases. The kenaf fabric first underwent nonlinear extension when force was applied to the fabric strip which is represented in the curve line at the beginning of the stress-strain curves. As the loading force increases, the fabric strip started to elongate linearly with the increase of force applied. Such property occurred in fabric is mainly due to the de-crimping process that occurs when the fabric strip experiences tensile force. The yarn that has a wavy profile from interlacing itself with the perpendicular yarn began to be straightened when pulled from each end of the yarn. This trend continued until a "tack" sound was heard from the fabric which signifies the fracture of one of the yarns in the fabric sample. After the first yarn in the fabric strip has fractured, which was continuously followed by the fracture of other yarns in the fabric, as represented by the consequent peak found on the stress-strain curves after the first peak. Waisting occurred during this phase where the fabric strips started to decrease in width at a certain region when the yarn begins to clump together with the adjacent yarn. The tensile test of fabric ends after most of the fabric yarn has fractured. Figure 4.3 shows the images of fabric strip before and after the tensile test. Note to be taken on the image on the right where the width of fabric strip became smaller in the middle portion of the fabric strip where waisting occurred.

Figure 4.3: Tensile test of fabric strip before testing (left), after test where waisting occurred (right)

In the tensile test, the tensile strength of the fabric is calculated using the maximum load that could be sustained by the fabric throughout the tensile test divided by the cross-sectional area of the fabric strip. By observing the trend of stress-strain curves for warp and weft direction, it can be seen that both the warp and weft direction has similar trend in terms of tensile properties. Figure 4.4 and Figure 4.5 show the stress-strain curves of the old fabric for weft and warp directions with its respective relevant data recorded in Table 4.8 and Table 4.9. In general, the old kenaf fabric possesses better tensile strength and Young's modulus with a shorter elongation under tensile extension. The fabric had higher maximum load when it was loaded in the weft direction. This can be proved when the old fabric was loaded in the weft direction, a total of 319.935N of force could be loaded but when loaded in the warp direction, the maximum load decreases by 22.03% with a total of 249.439N. In terms of tensile strength, the old weft fabric sample showed a higher tensile strength with a value of 15.997MPa in the weft direction in comparison with the warp direction that only demonstrated tensile strength of 12.472MPa, which is 22.04% less than weft direction. When viewed in terms of elongation and stiffness, the old kenaf fabric was observed to be more flexible in the warp direction and was capable to elongate easily when a tension force was applied. The old kenaf fabric elongated 8.611mm in the warp direction when loaded and a tensile strain of 0.043. In the weft direction, the elongation decreases by 46.02% at 4.648mm while the tensile strain decreases by 46.51% at 0.023. Thus, the overall results showed that the old kenaf fabric is stiffer in the weft direction and is proven when its Young's modulus was higher than the warp direction by 57.66% with a value of 685.063MPa.

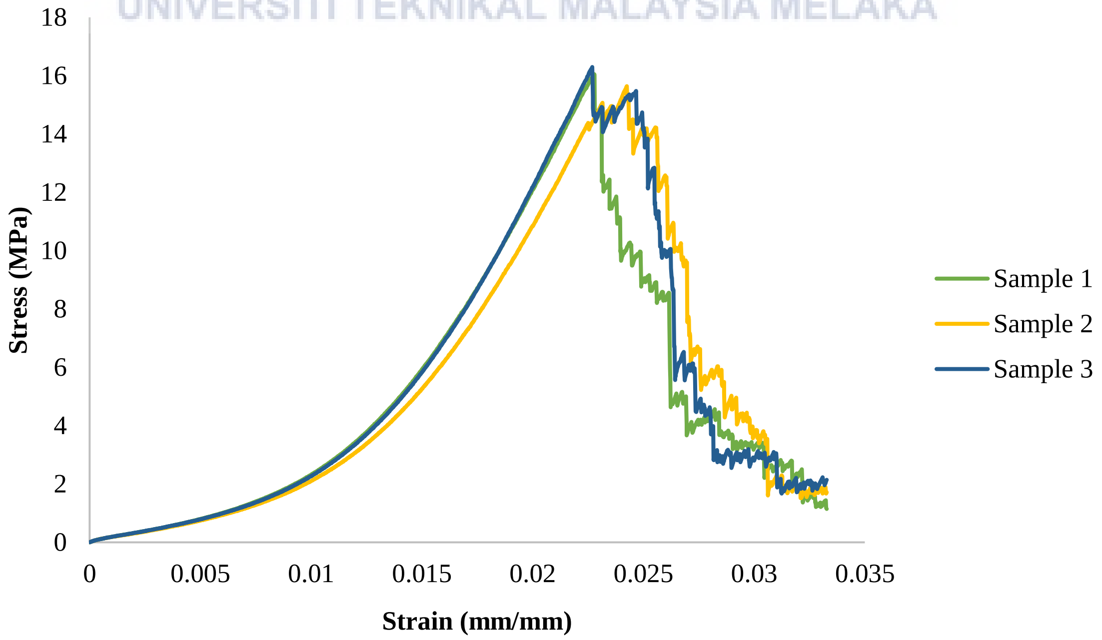

Figure 4.4: Stress-strain curves of old weft sample

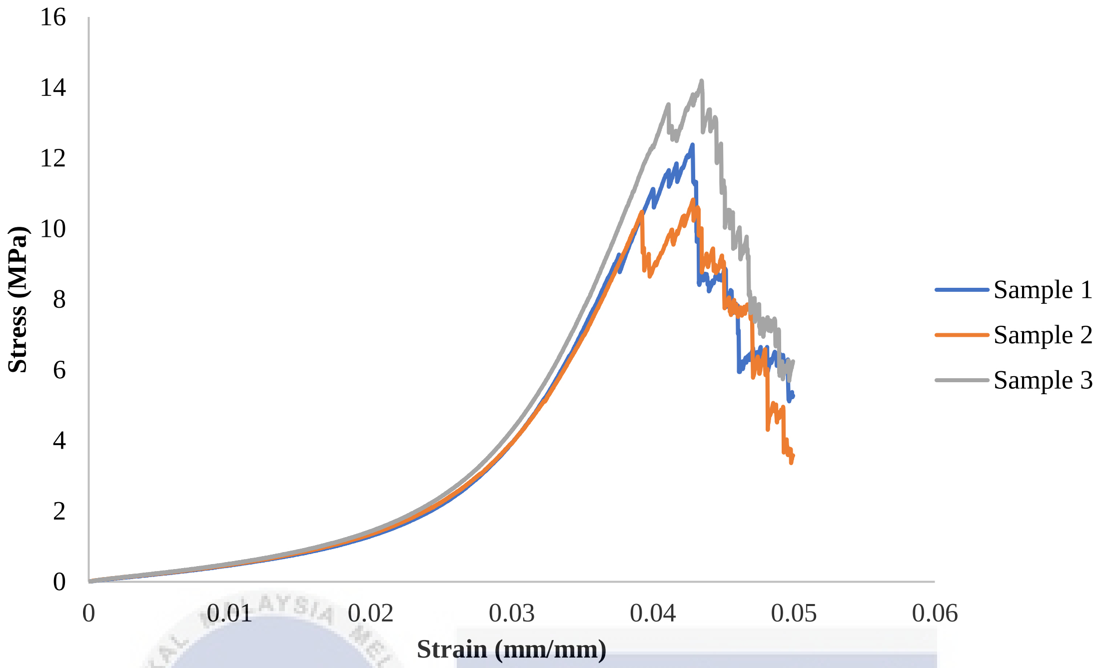

Figure 4.5: Stress-strain curves of old warp sample

Table 4.8: Tensile test result of old weft sample

Sample	Maximum load (N)	Extension at max load (mm)	Tensile Strain (mm/mm)	Tensile stress (MPa)	Young's Modulus (MPa)
1	321.068	4.555	0.023	16.053	694.957
2	312.803	4.850	0.024	15.640	651.667
3	325.934	4.540	0.023	16.297	708.565
Average	319.935	4.648	0.023	15.997	685.063

Table 4.9: Tensile test result of warp sample

Sample	Maximum load (N)	Extension at max load (mm)	Tensile strain (mm/mm)	Tensile stress (MPa)	Young's Modulus (MPa)
1	247.769	8.565	0.043	12.388	288.093
2	216.614	8.574	0.043	10.831	251.884
3	283.933	8.693	0.043	14.197	330.163
Average	249.439	8.611	0.043	12.472	290.047

The tensile test result of new fabric is represented in stress-strain curves as shown in Figure 4.7 and Figure 4.8 with their related data tabulated in Table 4.10 and Table 4.11 based on the loading direction of the new fabric sample. The same trend can be seen in the new fabric sample where the new fabric possessed a higher tensile strength and can withstand a much bigger load when loaded in the weft direction. The new fabric was able to withstand a total of 277.622N force which is higher than in warp direction for 19.89% or 55.216N in average. In terms of tensile strength, the new weft fabric sample is expected to have a higher tensile strength then the warp sample. This is evident as new fabric weft sample shows a total of 13.865MPa in average which is higher than the warp sample by 19.8%. Weft sample also exhibits better flexibility where the Young's modulus of weft sample is bigger than the warp sample by a total of 143.528MPa or 50.49%. Thus, it was proven that the new fabric warp sample has better flexibility and able to elongate longer than the weft sample under the same force. By comparing both the old and new kenaf fabric, it can be seen that the weft direction of both fabric has superior tensile properties compared to the warp direction. Such results can be explained through the non-homogeneity of the kenaf fabric property due to its varying yarn thickness throughout the fabric. After a close observation on the kenaf fabric, it is discovered that the number of thicker yarn are more in the warp direction compared to the weft direction as shown in Figure 4.6. Thicker yarn will provide a bigger cross-sectional area during tensile loading and in turn decrease the tensile strength of the fabric. The yarn size and fabric thickness measured in this research are average values taken from the thickness at randomly selected area throughout the fabric, regardless of warp or weft direction. Such inconsistency is expected from kenaf fabric since the kenaf yarn are produced from short bast kenaf fiber through the spinning process to draw out the required yarn size. Even with current technology, a perfectly even yarn thickness is a challenging feat from conventional fabric spinning process using short natural fiber. This is evident by the research done by Rajib et al. (2017) where conventional ring spun yarn reported to have 15.04% of yarn unevenness while yarn spun using compact spinning method reported to be 14.68% throughout the tested cotton fabric. Such result is also further supported by Madan et al. (2017) where ring spun yarn have an unevenness up to 11.93% while yarn spun using compact spinning method recorded an unevenness up to 11.74% based on unevenness in yarn thickness. Since this research focus on the characterisation of fabric instead of yarn, the twist angle of the yarn is not investigated, and suggestion will be made to future research regarding the effect of yarn twist to tensile strength of fabric.

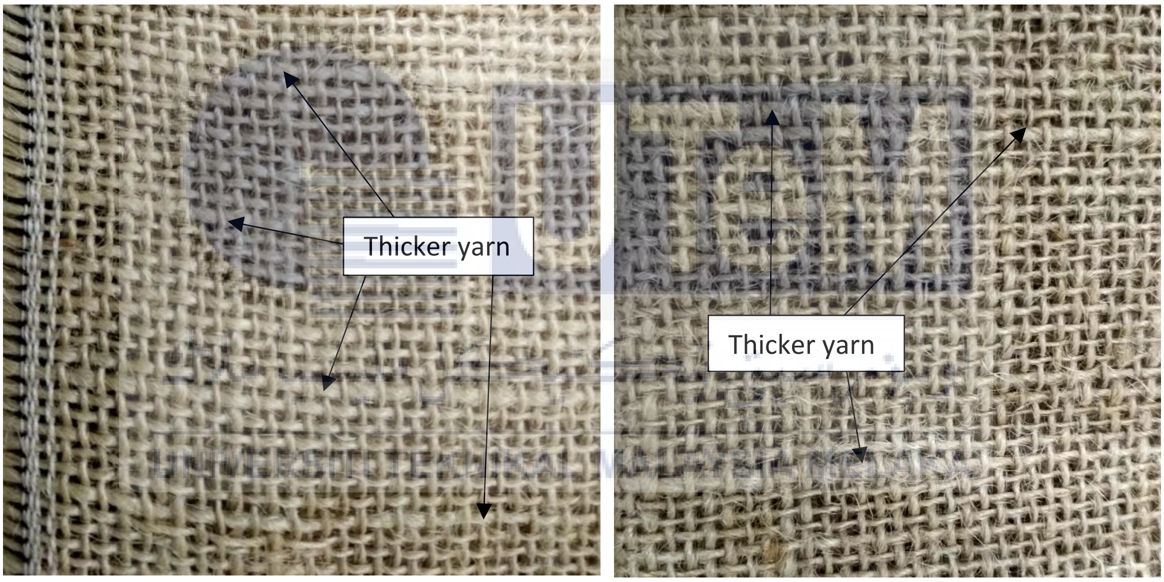

Figure 4.6: Irregularities in fabric in cross sectional area of yarn in new fabric (left) and old fabric (right)

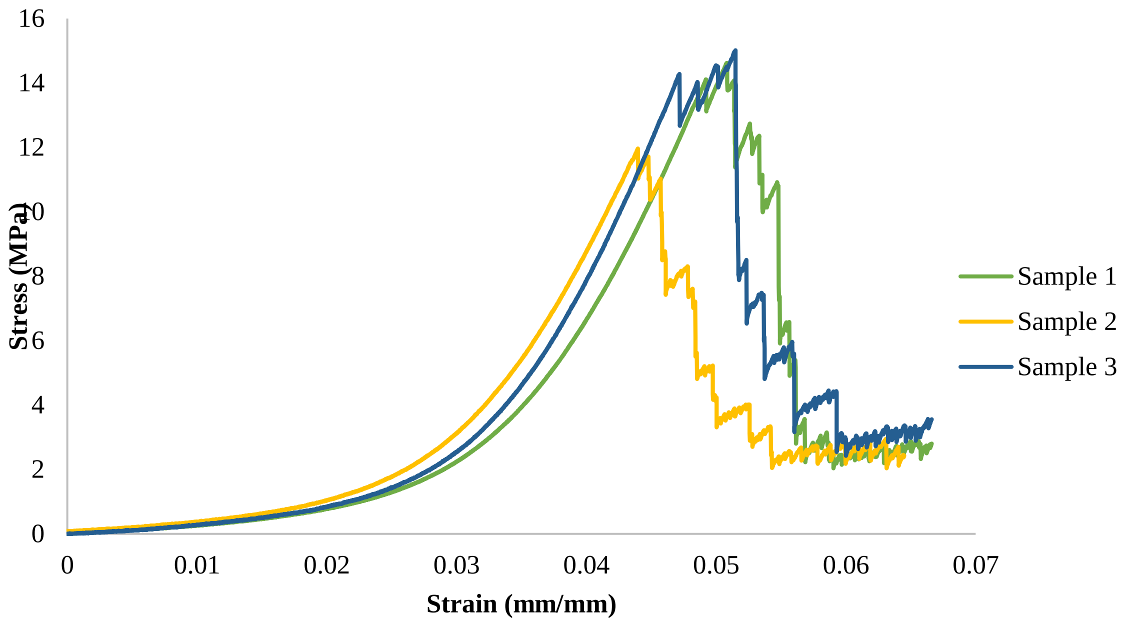

Figure 4.7: Stress-strain curves of new weft sample

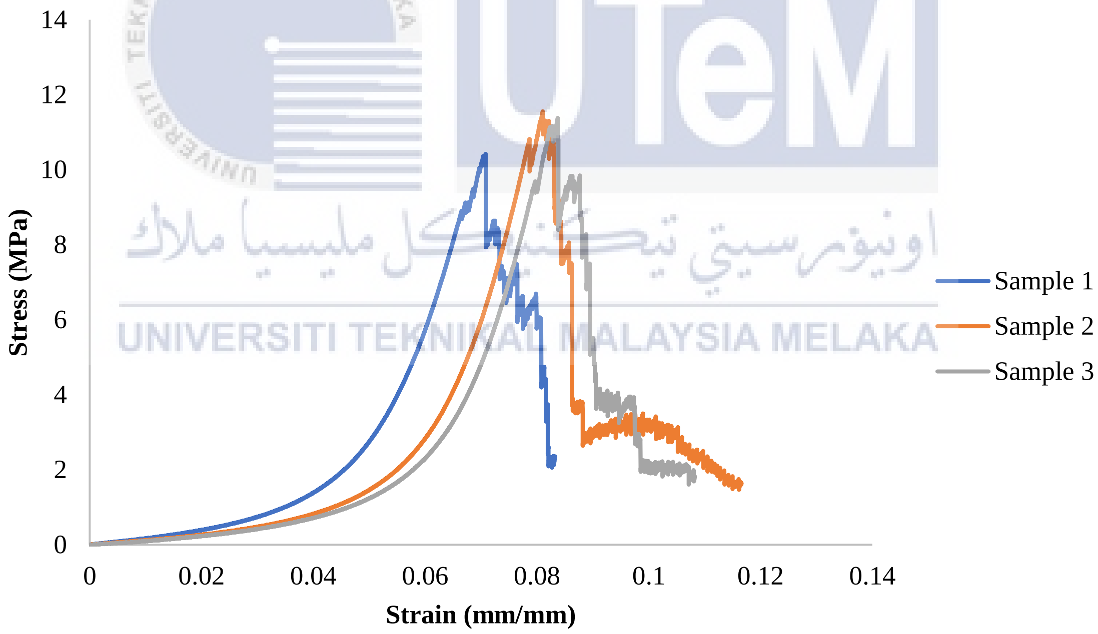

Figure 4.8: Stress strain graph of new warp sample

Table 4.10: Tensile test result of new weft sample

Sample	Maximum load (N)	Extension at max load (mm)	Tensile strain (mm/mm)	Tensile stress (MPa)	Young's Modulus (MPa)
1	292.402	10.168	0.051	14.620	286.667
2	239.226	8.797	0.044	11.961	271.841
3	300.237	10.297	0.051	15.012	294.353

Average	277.622	9.754	0.049	13.865	284.287

Table 4.11: Tensile test result of new warp sample

Sample	Maximum load (N)	Extension at max load (mm)	Tensile strain (mm/mm)	Tensile stress (MPa)	Young's modulus (MPa)
1	208.489	14.166	0.071	10.424	146.817
2	231.203	16.213	0.081	11.560	142.716
3	227.527	16.746	0.084	11.376	135.429
Average	222.406	15.873	0.079	11.120	140.759

4.3 Effect of Moisture

The moisture absorption of kenaf fabric was conducted and the results are presented in the Table 4.12 and Figure 4.9. The moisture saturation point for kenaf fabric is identified from the fabric weight against immersion time graph to determine the immersion time needed to prepare a wet sample for tensile test. Moisture saturation point is reached when the fabric weight becomes nearly constant as shown in Figure 4.9, where the maximum water uptake of kenaf fabric was reached.

Table 4.12: Results of moisture absorption of kenaf fabric

Immersion Time (min)	Weight of Old Fabric (±0.01g)	Change in Weight of Old Fabric (%)	Weight of New Fabric (±0.01g)	Change in Weight of New Fabric (%)
0	4.30	0.00	4.38	0.00
10	8.90	106.98	8.95	104.34
20	9.41	118.84	9.61	119.41
30	10.00	132.56	10.03	129.00
40	10.15	136.05	10.10	130.59
50	10.19	136.98	10.37	136.76

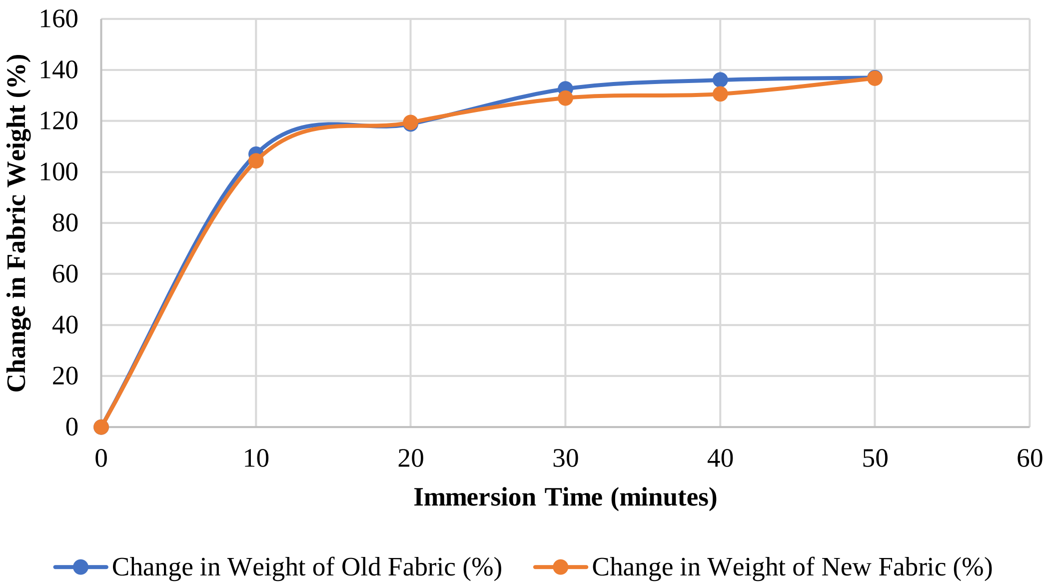

Figure 4.9: Graph of change in weight of kenaf fabric against immersion time

From the graph, both the kenaf fabric will be in their moisture saturation point when immersed in distilled water for at least 20 minutes. The kenaf fabric specimen will be immersed in distilled water for at least 20 minutes prior tensile test to determine the effect of moisture uptake on the tensile strength of kenaf fabrics. The moisture uptake of both the old and new fabric is tabulated in Table 4.13. Both the old and new kenaf fabric has nearly similar moisture uptake which is 136.98% for old fabric and 136.76% for new fabric with a difference of mere 0.22%. It can be concluded that both the fabrics have similar moisture uptake since both fabric is made from the same material with nearly similar fabric weight and yarn spacing. Based on past research on kenaf fiber, the kenaf fiber is capable of absorbing 149.19% of water (Symington et al., 2009). Such discovery is relevant to the moisture uptake of kenaf fabric since kenaf fabric is made from kenaf yarn which in turn was made from kenaf fiber. The moisture uptake of kenaf fiber will be reflected on the kenaf fabric since they both share the same moisture uptake mechanisms.

Table 4.13: Moisture uptake of kenaf fabric

	Moisture uptake of kenaf fabric (%)
Old kenaf fabric	136.98
New kenaf fabric	136.76

Figure 4.10 and Figure 4.11 show the stress-strain curves of wet old kenaf fabric sample in the weft direction and warp direction. Table 4.14 and Table 4.15 summarise the tensile properties of old batch kenaf fabric for both warp and weft directions after water immersion. Similar trend was noticed in the tensile properties of the wet kenaf fabric just like its dry form. The wet kenaf fabric had better tensile strength and Young's modulus in the weft direction compared to the warp direction for both the old and new fabric. However, the warp sample had better tensile strain compared to the weft sample, rendering the warp sample to be more elastic than the weft sample. As evidence, the weft sample exhibited higher tensile strength and Young's modulus which is 22.27% and 40.96% respectively higher than the warp sample. Nevertheless, the tensile strain and elongation of kenaf fabric in the weft direction are 32.26% and 31.68% respectively lower than in warp direction. Similar trend as in the tensile properties of dry kenaf fabric regardless of loading direction was also observed for the wet new kenaf fabric as shown in Figure 4.12 and Figure 4.13. The new wet kenaf sample has superior tensile properties in the weft direction but inferior in tensile strain compared to the warp direction. Table 4.16 and Table 4.17 recorded the tensile properties of new batch kenaf fabric for both warp and weft direction after water immersion.

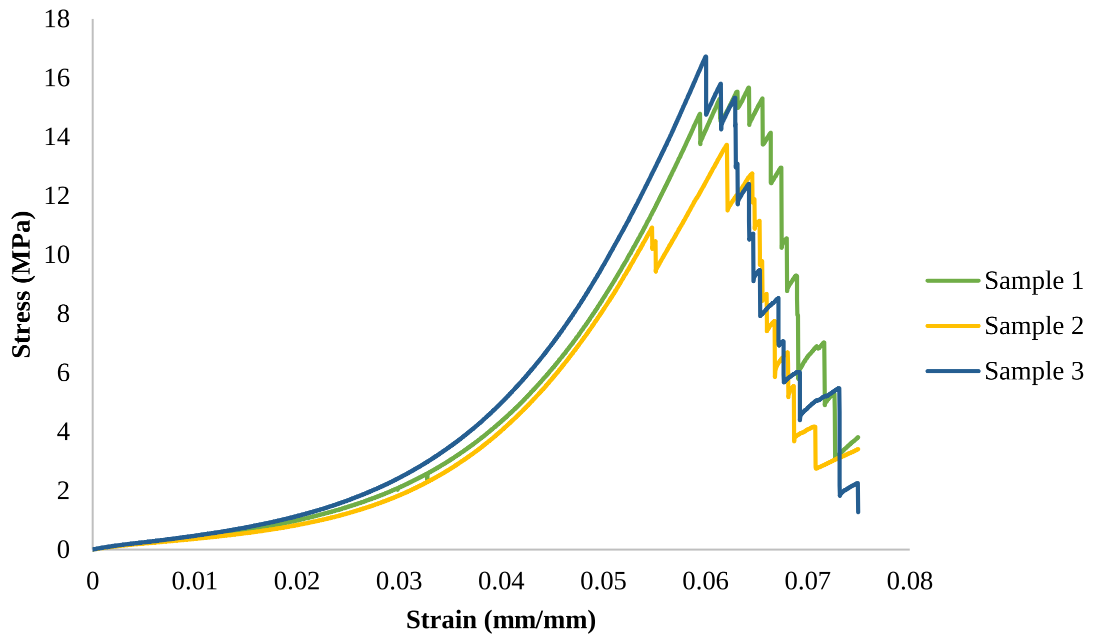

Figure 4.10: Stress strain graph of wet old weft sample

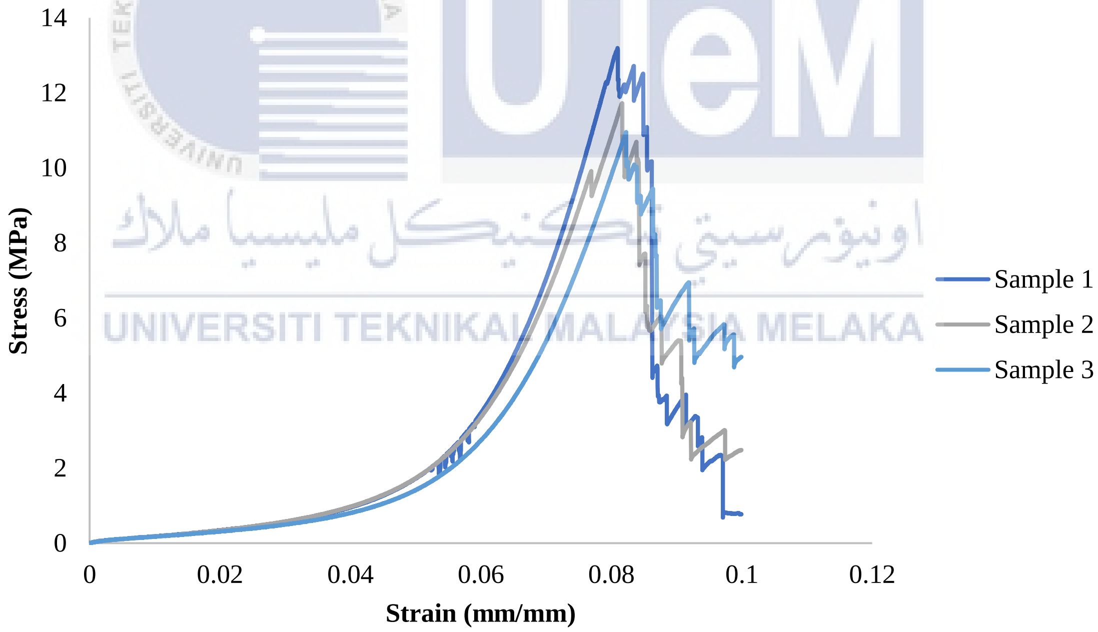

Figure 4.11: Stress strain graph of wet old warp sample

Table 4.14: Tensile test result of wet old weft sample

Sample	Maximum load (N)	Extension at max load (mm)	Tensile strain (mm/mm)	Tensile stress (MPa)	Young's modulus (MPa)
1	313.599	12.848	0.064	15.678	244.969
2	274.642	12.419	0.062	13.732	221.484

3	334.475	12.006	0.060	16.723	278.717
Average	307.572	12.424	0.062	15.378	248.032

Table 4.15: Tensile test result of wet old warp sample

Sample	Maximum load (N)	Extension at max load (mm)	Tensile strain (mm/mm)	Tensile stress (MPa)	Young modulus (MPa)
1	263.832	16.193	0.081	13.192	162.864
2	234.323	16.334	0.082	11.716	142.878
3	219.009	16.457	0.082	10.950	133.537
Average	239.055	16.328	0.082	11.953	146.426

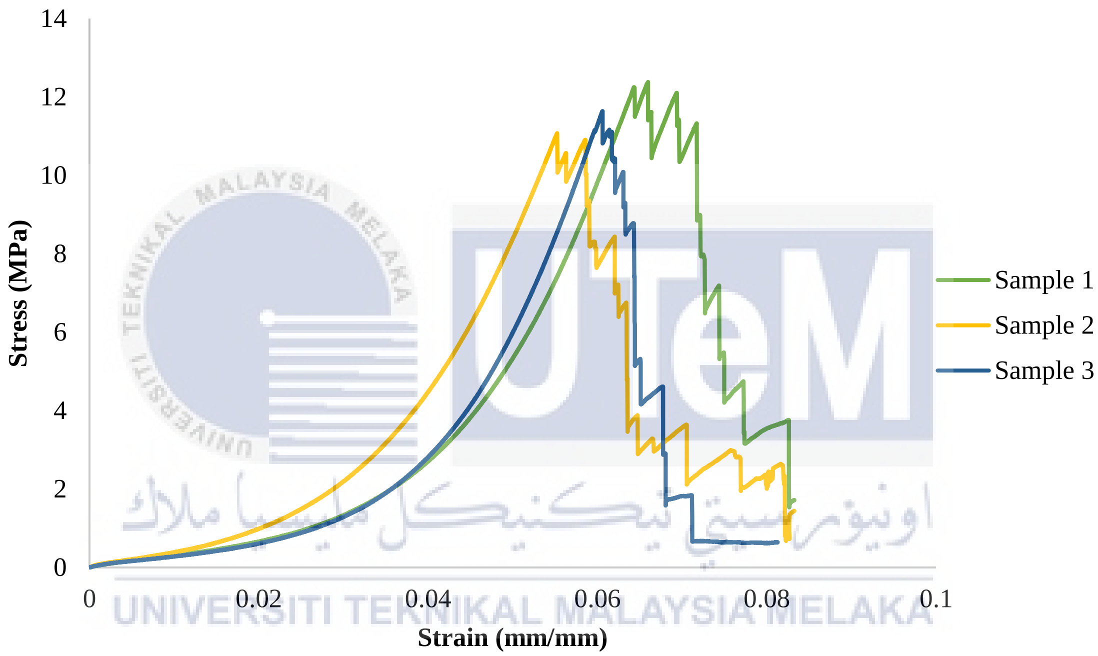

Figure 4.12: Stress strain graph of wet new weft sample

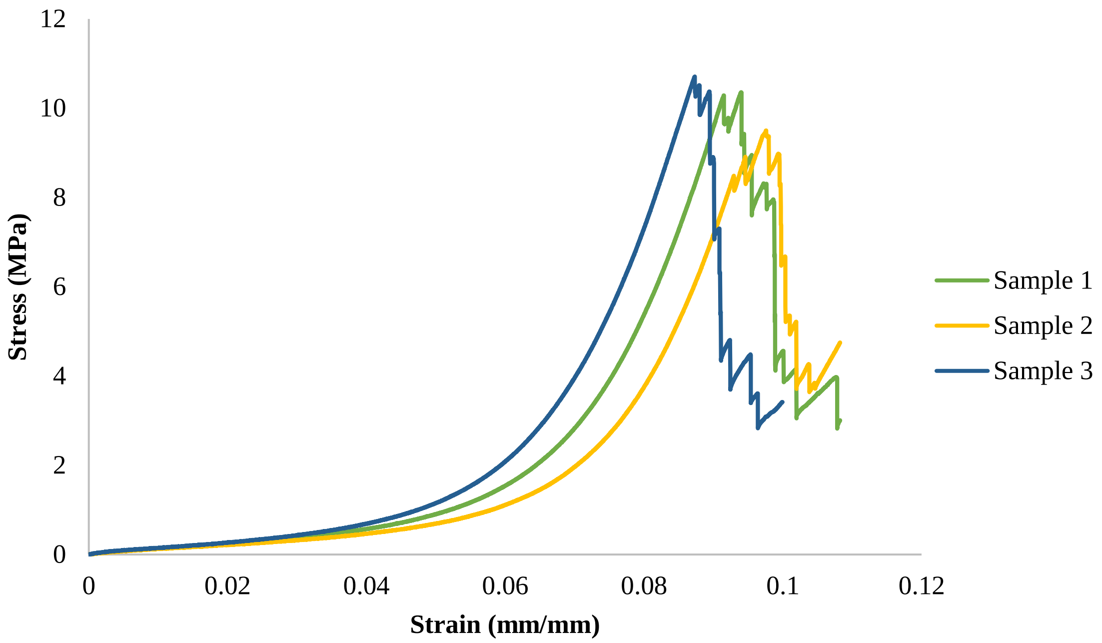

Figure 4.13: Stress strain graph of wet new warp sample

Table 4.16: Tensile test result of wet new weft sample

Sample	Maximum load (N)	Extension at max load (mm)	Tensile strain (mm/mm)	Tensile stress (MPa)	Young modulus (MPa)
1	247.631	13.196	0.066	12.382	187.606
2	221.463	11.046	0.055	11.073	201.327
3	232.785	12.120	0.061	11.639	190.803
Average	233.960	12.121	0.061	11.698	193.245

Table 4.17: Tensile test result of wet new warp sample

Sample	Maximum load (N)	Extension at max load (mm)	Tensile strain (mm/mm)	Tensile stress (MPa)	Young modulus (MPa)
1	207.186	18.805	0.094	10.359	110.202
2	189.981	19.516	0.098	9.499	96.929
3	214.173	17.463	0.087	10.709	123.092
Average	203.780	18.595	0.093	10.189	110.074

When compared to the dry kenaf fabric, it was observed that the wet kenaf fabric is weaker in terms of maximum load, tensile strength and Young's modulus but gain in extension under maximum loading and tensile strain. The same trend occurs for both the warp and weft direction for the old and new kenaf fabric. A summary of the difference of various properties between wet and dry fabrics is summarized in Figure 4.14 for the old kenaf fabric and Figure 4.15 for the new kenaf fabric. The obtained results show similar trend with research done by Davies and Bruce (1998) where the stiffness of the flax and nettle fiber decreases with increasing relative humidity or moisture uptake. This is further supported by Symington et al. (2009) where the sisal fiber tested decreases in tensile strength at 90% humidity exposure and an increase in Young's modulus as the humidity increase followed by a distinct decrease as the humidity increase after a certain point. Sisal, flax and nettle are categorised as bast fibres which is same as kenaf and therefore exhibits a similar trend in tensile stress and tensile strain. The factor which causes the sudden decrease in tensile strength as the bast fiber is still under research as stated by Symington et al. (2009). According to Celino et al. (2014), the decrease in Young's modulus at a certain level of moisture uptake of the fiber increase is due to the plasticization of fiber. Symington et al. (2009) suggest that the sudden decrease in Young's modulus of the fiber due to moisture absorption is due to the swelling effect of fiber. As the fiber absorb moisture into its structure, the fiber will begin to swell and increases its radial tension and increases its Young's modulus. As the swelling effect continues to take effect, the fiber structure will eventually become vulnerable to external force which results in the lowering of its mechanical properties. This effect becomes more effective with a higher cellulose content in the fiber. The decrease of Young's modulus is also contributed by the increment of the tensile strain of the fiber besides the lowering of its tensile strength. Celino et al. (2014) explains that the increment of tensile strain of the fiber as the moisture content increase is due to water acting as the plasticizer and softener for the fiber. Symington et al. (2009) states that the water content in fiber is suspected to relax the fiber structure slightly as the hemicellulose submatrix in the fiber accepts the water content into the fiber structure which relaxes the fiber structure against external force.

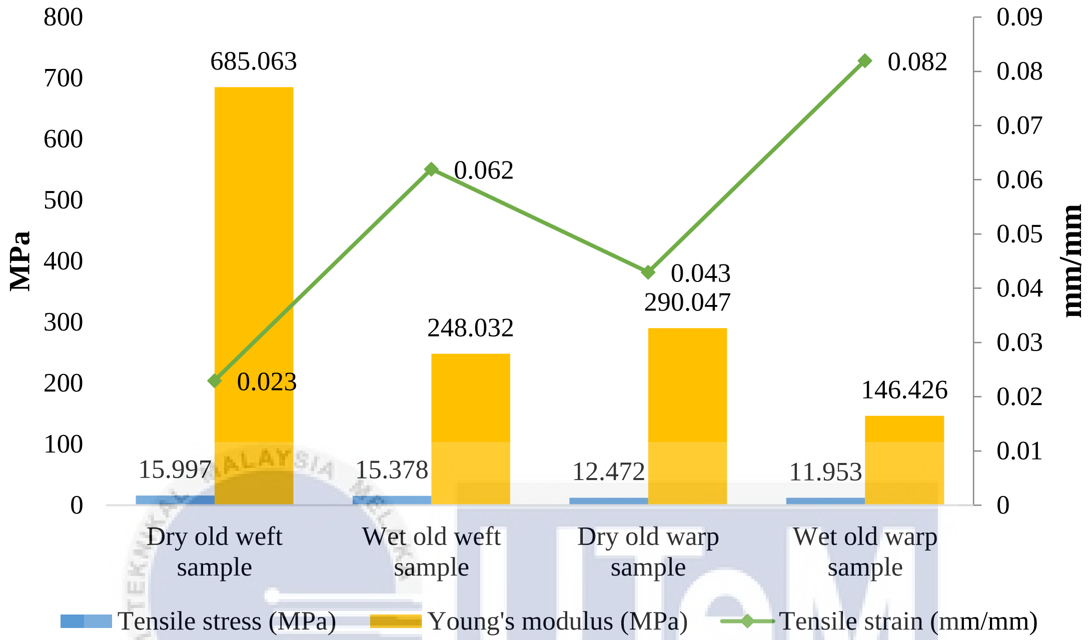

Figure 4.14: Difference in various properties between dry and wet old kenaf fabric

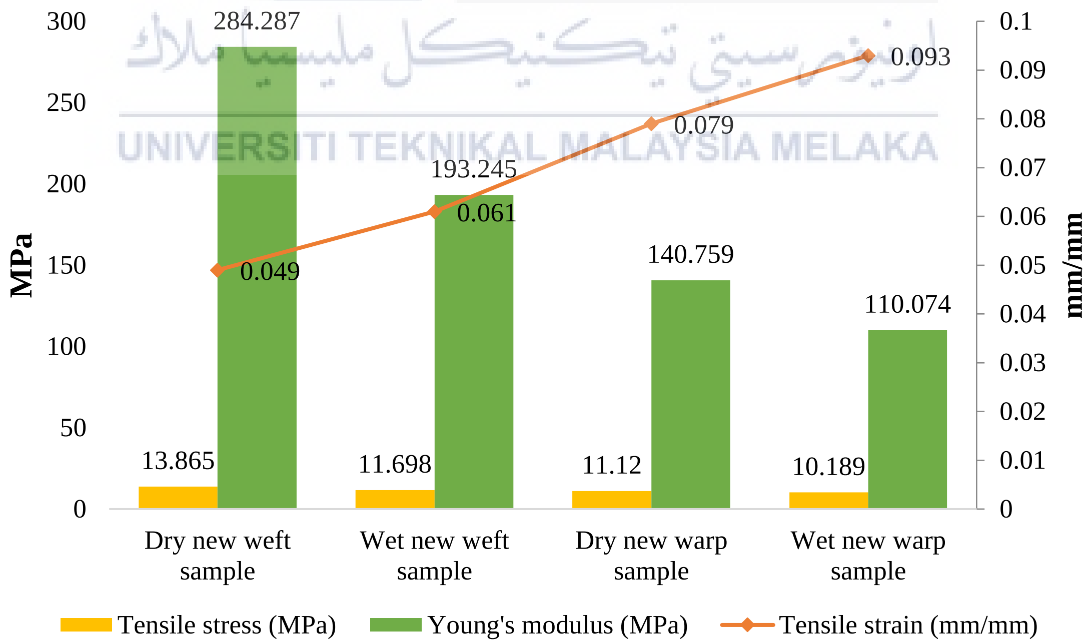

Figure 4.15: Difference in various properties between dry and wet new kenaf fabric

4.4 Effect of Age

The effect of age of the fabric is often known as degradation of the fabric where the fabric undergone photochemical or biological degradation as the time passes. The degradation of fabric is also highly associated to the storage condition of the fabric such as the air humidity and exposure to sunlight. In this research, the effect of age of the fabric is done by conducting tensile test on the old fabric which is kept in a dry room with minimal daily exposure to sunlight against the new fabric which is purchased at a later time. The comparison between the two fabrics can be seen in Figure 4.16.

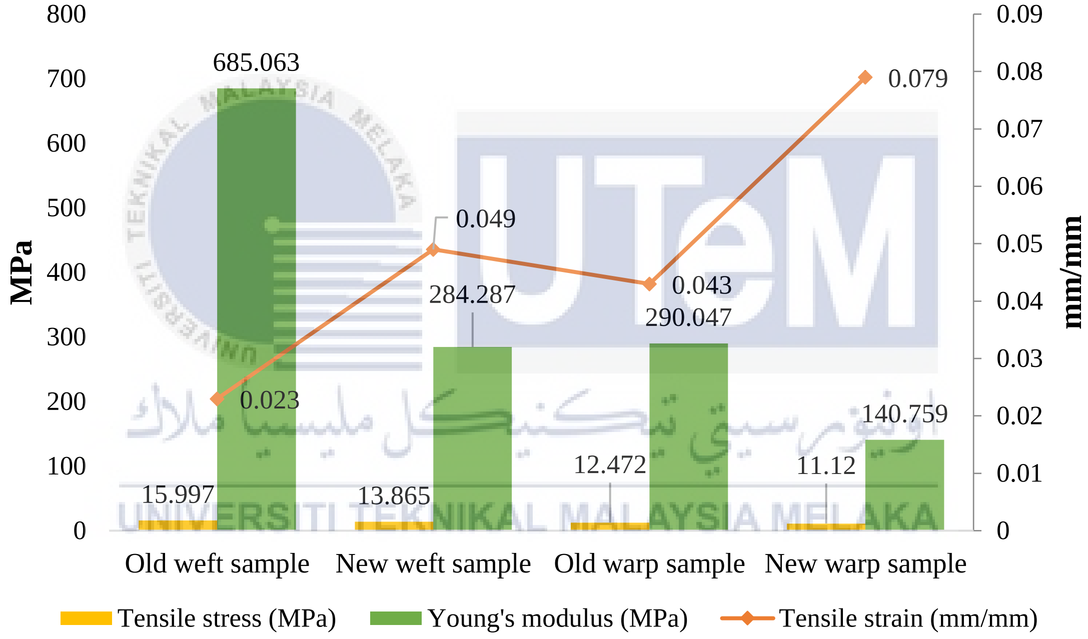

Figure 4.16: Comparison between various property of old and new kenaf fabric

As seen in Figure 4.16, the old fabric has better tensile strength and Young's modulus in both weft and warp direction compared to the new fabric. However, the new kenaf fabric appears to have better tensile strain than the old fabric. Such finding is similar to the trend depicted in the difference in moisture content between dry and wet fabric suggest that the new fabric possess excessive moisture in its structure that weakens its tensile properties. Previous research studies have shown that the presence of moisture in hydrophilic fabric would increase the tensile properties until a relative humidity of RH = 50% (Placet et al., 2012b) or when RH = 70% (Van Voorn et al., 2001). The excessive difference between the Young's modulus of old weft fabric compared to the new weft fabric is mainly due to the higher tensile strength and lower tensile strain of the old fabric.

In the case of effect of age in wet kenaf fabric, the similar trend occured as in the dry fabric where the old fabric is superior in tensile strength and Young's modulus but inferior in tensile strain. The difference between each property in soaked old and new kenaf fabric is less obvious as their dry form due to the smaller difference between the two fabrics in its tensile strain. The difference in tensile strain in the dry old and new fabric is very large where the difference is nearly double from the old fabric. However, the difference in tensile strain between the old and new fabric is within 10% from the tensile strain of new fabric. Figure 4.17 shows the comparison of tensile properties between old kenaf fabric and new kenaf fabric. In overall, the effect of age in kenaf fabric primarily affects its tensile strain and only has a little effect on its tensile strength. The difference between the old kenaf fabric and new kenaf fabric in the tensile strain highly affect the Young's modulus or stiffness of the fabric.

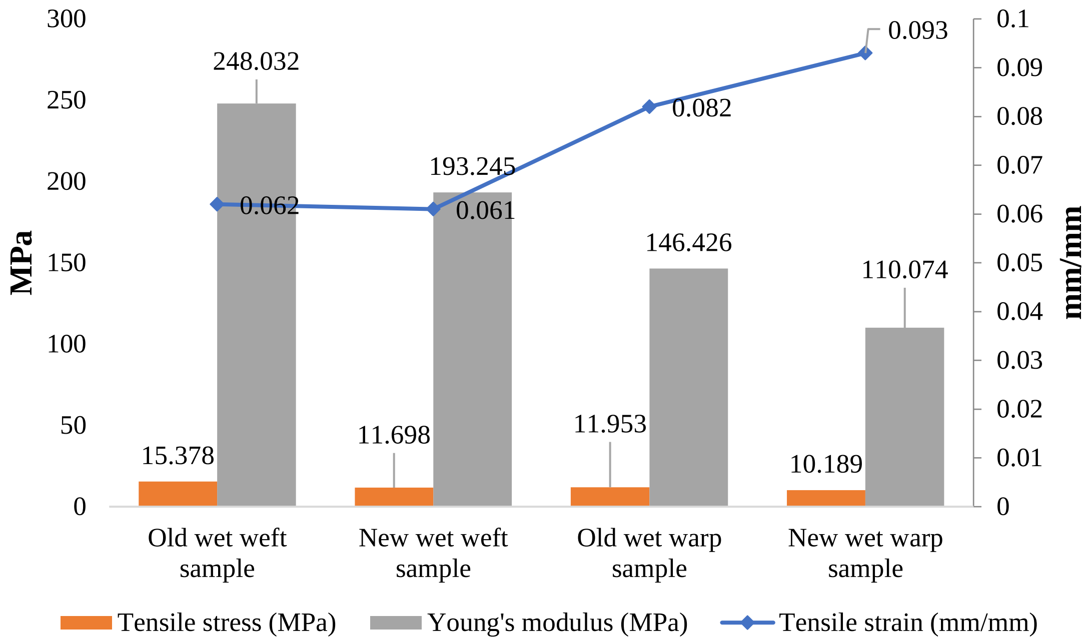

Figure 4.17: Comparison between various property of old and new wet kenaf fabric

CHAPTER 5

CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH

5.1 Conclusion

This research aims to investigate the effect of fabric directions, effect of moisture and effect of age towards the tensile properties of kenaf fabric. Prior the testing of the fabric based on the required parameters, the fabric is first measured for its fabric characteristics and observed for any manufacturing flaw. In overall, both the old and new kenaf fabric is well manufactured with minimal manufacturing flaw and missing picks. However, the relevant fabric characteristics such as fabric weight, fabric thickness, yarn size and yarn crimp suffer from non-homogeneity of the fabric property. To circumvent this situation, relevant standards are used to obtain an average measurement for each property which will be used as reference value throughout the research. The kenaf fabric obtained weighs 294g/m^2 for the old kenaf fabric and 295g/m^2 for the new fabric which are characterise as heavy fabric in the eye of textile manufacturer. Most other fabric characteristic appears to be nearly similar between the old kenaf fabric and new kenaf fabric. After the characterisation of fabric is completed, tensile testing of kenaf fabric for the required parameters could be done by preparing the necessary fabric samples.

In terms of direction of force loading on the kenaf fabric, the weft fabric sample shows superior tensile strength than the warp fabric sample. However, the warp sample exhibits a better tensile strain and are more elastic with a lower Young's modulus value. Similar trend is observed for both the old and new kenaf fabric. The main factor that causes this trend is due to the existence of thicker warp yarn in the fabric. The non-homogeneity property of natural fiber fabric contributes to this factor as current yarn manufacturing technology still prone to cause imperfection in unevenness of yarn thickness. Intensive observation reveals that there are more thick yarns in the warp direction in oppose to the weft direction. In terms of moisture effect, the wet kenaf fabric suffers a drop in tensile strength and Young’s modulus but gain a higher tensile strain for both the old and new fabric. This result coincides with the results of other researchers that works on the same parameters on bast fiber. Such action is justified as kenaf is characterised as a bast fiber and the tensile property of fiber will be reflected on the fabric made from the same material as fabric is formed from countless strains of fiber. The decrement in tensile strength coupled in increment of tensile strain is explained to be due to the swelling effect of fiber and the effect of water acting as plasticizers and softener for the fabric. Lastly, the effect of age happens to similar with the effect of moisture on kenaf fabric, where the tensile strength of the fabric decreases slightly with an increase in tensile strain. The effect of age is less prominent when the fabric is soaked until saturation.

5.2 Recommendation for Future Research

This research focuses in the change in tensile stress of kenaf fabric under different condition which are loading direction, moisture content in fabric and age of fabric. From the literature review, it is known that the tensile property of kenaf fabric is highly affected by its cellulose content and the microstructure of the kenaf fiber. Although the non-homogeneity of kenaf fabric could cause irregular trend in the fabric, this problem can be overcome by conducting the test on several different batches of kenaf fabric that are bought at the same time. Besides that, it is also highly recommended to conduct thermal analysis on the kenaf fabric to investigate the change in cellulose content due to different parameters such as ageing and moisture absorption. Information regarding the changes in cellulose content before and after the testing procedure might shed some light in the dominant factor in explaining the tensile test result obtained. Prior the tensile test of kenaf fabric, the moisture content of the fabric needs to be determined accurately using a moisture analyser to identify the relative humidity of the fabric. This is crucial because past researchers had discovered that the tensile strength of natural fiber fabric changes with the increment of moisture content until relative humidity of RH = 50%. Lastly, the significance of the tensile test can be verified using analysis of variance (ANOVA) to determine the relationship between the tensile test result of each sample. the accuracy and precision of the tensile test results could be improved if such action is taken.

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