Tensile Strength of Woven Kenaf Reinforced High Density Polyethylene (HDPE) Composites

By

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Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

Of Research Project

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Approved by,

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TRONOH, PERAK
MAY 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(NUR ZATIL ILHAM BT KAMARUDDIN)

ABSTRACT

Environmental awareness and depletion of petroleum resource issue have triggered an enormous interest in utilizing natural fiber as environmentally friendly and sustainable materials as an alternative to the existing material. Therefore, this project aims to study the tensile strength of woven kenaf fiber reinforced HDPE composites. The raw materials for this project were continuous kenaf fiber from India and HDPE pallets. The kenaf was weaved to produce a structured fiber instead of continuous or short fiber. Two composition of HDPE/woven kenaf fiber were used i.e. 90/10 and 80/20 to produce the composite materials using compression molding technique at processing temperature of 170℃. The samples were underwent tensile test according to ASTM D638 standard. It is found that the tensile strength of the composite increase with the increase of fiber content. HDPE/woven kenaf of 80/20 wt.% showed an improvement of 16.6 % in tensile strength compared to neat HDPE.

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CHAPTER 1

INTRODUCTION

1.1. Background of Study

Fiber reinforced composite materials are an important class of engineering materials. They offer an outstanding mechanical properties, unique flexibility and in design capabilities and ease of fabrication [1]. Composite using high strength fiber such as carbon and glass are commonly used in broad range of applications from aerospace structure to automotive parts and from building materials to sporting goods [2]. Hence, the use of thermoplastic composites produced from synthetic polymers reinforced with natural fiber has attracted the attention of many researchers worldwide [3,4] due to the major advantages low cost, low density, low weight, good thermal and acoustic insulating properties and higher resistance to fracture [1,3,4].

Besides, utilization of natural fiber has gained attention due to the awareness to lessen the dependence on petroleum based fuels and products. Green, environmentally friendly, sustainable, renewable, biodegradable, composites from natural fiber are among the most keenly required materials nowadays [5]. In addition, thermoplastic materials currently dominate, as matrices for bio-fiber; the most commonly used thermoplastics for this purpose are polypropylene (PP), poly vinyl chloride (PVC) and also polyethylene (PE) [1] possess a major advantage that it can be recycled.

1.2. Problem Statement

In order to reduce the cost of production and the harmful destruction in environment, the development of natural fiber reinforced composites become an attractive research lines to replace the synthetic fiber such as carbon and glass fiber. Most of the researches and studies focus on the short and discontinuous fiber reinforced composites such as Zampalomi et.al., 2007 [5], the research was on chopped kenaf fiber reinforced PP composites, Li *et al*., 2007 [6] studied on the short sisal fiber reinforced HDPE composites properties and John *et al.*, 2010 [4] studied the properties of non-woven kenaf fiber reinforced PP composites.

1.3. Objective

The objective of the project is to study the tensile strength of woven kenaf fiber reinforced HDPE composites.

1.4. Scope of Study

This project use HDPE as the matrix and woven kenaf fiber that is produced in India as the reinforcement. The weight percentage of HDPE/woven kenaf are varied 90/10 and 80/20. Compression molding with sandwich/laminate technique will be used to fabricate the composites.

CHAPTER 2

LITERATURE REVIEW

The utilization of natural fiber as a reinforced can be traced back more than 10,000 years ago [7-8]. However, it application in manufacturing industries gradually was replaced by synthetic fiber like glass, carbon and aramid fiber. These composites performance character such as strength-weight ratios and modulus-weight ratios are markedly superior to those of metallic materials and natural fiber reinforced composites. For these reason, synthetic fiber reinforced polymers have emerged as a major class of structural materials and are widely use as substitution for metals in many weights critical components in aircraft, aerospace, automotive, marine and other industries [9]. On the other hand, these advantages cause environmental problems in disposal synthetic fiber reinforced composite by incineration [10].

The element of sustainability, eco-friendly and green material had become a major requirement in new products designing [11]. As a result, composite industries are struggling in searching and evaluating more environmental friendly materials for their product development to fulfill the global market regarding sustainable material demand from raw materials to manufacturing and end up to product disposal [12]. One of the alternatives solution that gaining attention over the past two decade is via utilizing an abundantly available natural fiber as reinforced materials in polymer matrix composite [1,3,5-7].

2.1. Kenaf Fiber

Kenaf (*Hibiscus cannabinus*, L.Family *Malvaceae)* is seen as an herbaceous annually renewable crop that can be grown under a wide range of weather condition; for example, it can grows more than 3m within 3 months even in moderate ambient conditions with stem diameter of 25-51 mm [13]. Kenaf's short growing season and its minimal water, fertilizer and pesticide requirements make it among the most environmentally friendly and sustainable fiber crops on the planet [14]. The fiber is basically found in the bast (bark) of the plant. Figure 2.1 shows the exposed physical appearance of kenaf.

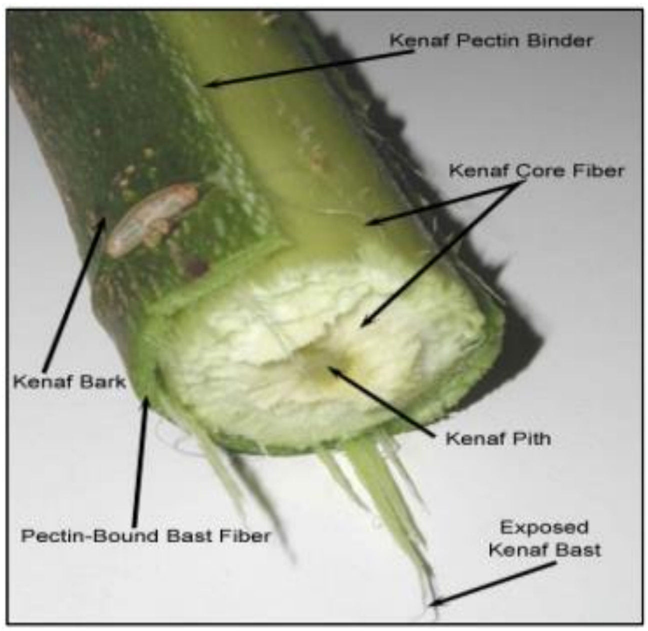


FIGURE 2. 1. Exposed physical appearance of kenaf [13].

According to Aji, I.S. *et al.* [13], very high interests in kenaf cultivation in recent years is due to two main reasons; one is kenaf's ability to absorb nitrogen and phosphorus included in the soil. Secondly is that kenaf's ability to accumulate carbon dioxide at a clearly high rate. Longer, stiffer and more tensile than many wood fiber, kenaf bast fiber make an excellent reinforcing agent for a wide range of thermoplastic based composites [14]. In addition, according to Aji. I.S. *et al.* [13] also, kenaf bast fiber has been reported to have superior flexural strength combined with its excellent tensile strength that makes it the material choice for a wide range of extruded, molded and non-woven products.

2.2. Woven Composites

Woven composites is known to be complex system which have additional features such as interlace spacing or gap, interlace point and unit cell [15]. There are very few reports on woven fiber composites reported so far. The popularity of woven composites is increasing due to simple processing and acceptable mechanical properties [16]. Woven composites provide more balanced properties in the fabric plane than unidirectional laminas. According to Khashabaa and Seif [17], the usage of woven composites has increased over the recent years due to their lower production costs, lightweight, higher fracture toughness and better control over the thermo-mechanial properties. The weaving of the fiber provides an interlocking that increases strength better than can be achieve by fiber matrix adhesion. Failure of the composite will require fiber breakage since fiber pullout is not possible with tightly woven fibers [18].

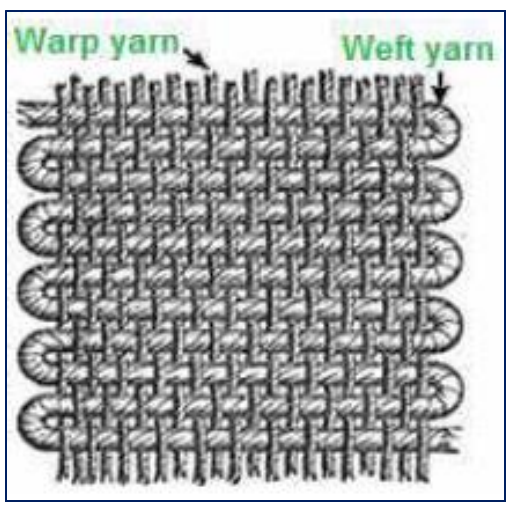


FIGURE 2. 2. Warp and weft in plain weaving [19].

The manner in which the warp and weft threads are interlaced is known as the *weave style*. The three basic weave styles or architecture are plain weave, satin weave and twill weave [19]. In this project, the kenaf will be weaved as plain weave. Plain weave is the most basic type of textile weaves. The warp and weft are aligned so they form a simple criss-cross patern. Each weft thread crosses the warp threads by going over one, then under the next, and so on.

FIGURE 2. 3. Example of plain woven kenaf yarn.

2.3. Mechanical and Physical Properties of Materials

The mechanical and physical properties of materials used in this project are shown in Table 2.1. The melting temperature of the matrix is intended to be lower than reinforcement fiber. The temperature gap between matrix and fiber should be large enough to prevent any possibility for the reinforcement to melt.

TABLE 2. 1. The properties of the materials used.

Properties/Materials	**HDPE [20]**	**Kenaf [21]**
Tensile strength, σ (MPa)	31	295-1191
Tensile modulus, E (Gpa)	1.86	22-60
Flexural strength (Mpa)	40	-
Melting Temperature (˚C)	130	-
Water absorption (%)	0.01	17
Density, ρ (kg/m³)	950	1220-1400

2.4. Rule of Mixtures

Rule of mixtures is a method of approach to approximate estimation of composite material properties, based on assumption that a composite property is the volume weighed average of the matrix properties. The properties of the composite largely depend on the length of individual fiber, fiber loading and orientation, level of mixing, fiber to matrix bonding and the arrangement of the fiber in the composite. Limitation of composite strength depending on the failure strain of the fiber [22]. The tensile properties of the composite can be estimated by the rule of mixtures as follow:

$$\sigma_c = \sigma_m V_m + \sigma_f V_f \text{ .... Equation 1}$$

$$E_{cl} = E_m V_m + E_f V_f \text{ .... Equation 2}$$

where:

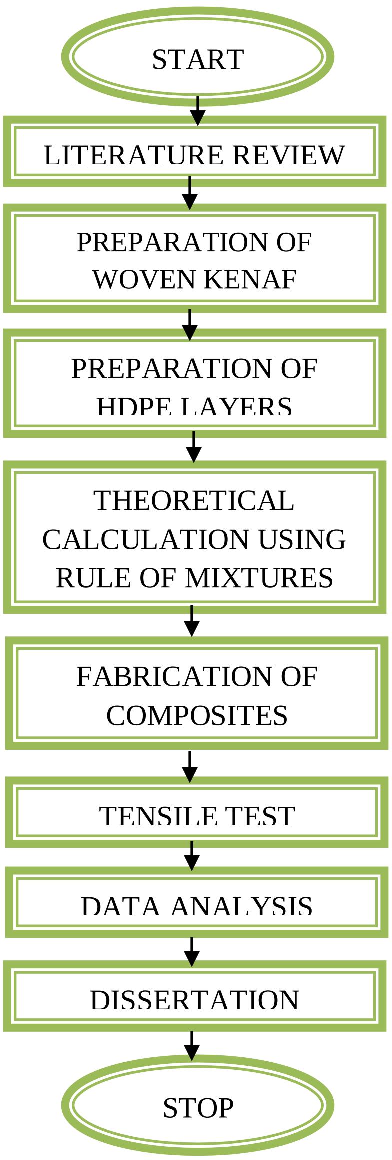
σ	= tensile strength
Ecl	= longitudinal modulus
V	= volume fraction
c	= composite
m	= matrix
f	= fiber

By definition, composite material is a material in which two or more distinct materials are combined together but remain uniquely identifiable in the mixture. In composite, fiber acts as the reinforcement to support the structure. As shown in equation 2, the fiber and matrix (binder) are the components that contribute to the stiffness of composite.

CHAPTER 3

METHODOLOGY

Figure 3.1 shows the flow chart diagram of this project.



- Preview / Analysis problem
- Fundamental studies from references and journals.
- Literature review on composite materials, kenaf fiber, thermoplastic and fabrication techniques.

- Identify required tools, equipment and materials.
- Identify the processing parameters and testing procedures.
- Design the required mold.
- Prepare the woven kenaf.
- Calculate the amount of woven kenaf, HDPE based on weight percentage.
- Weigh the kenaf and HDPE based on weight percentage.
- Fabricate the samples using compression molding.
- Cut the samples according to the dog bone shape.
- Perform tensile test according to ASTM D638.
- Data analysis, result and discussion.

- Project documentation and submission.

FIGURE 3. 1. Project Activities Flow Chart

3.1. Project Work

The project is an experimental base project. Specifically, it is a study of tensile and flexural test of woven kenaf fiber reinforced HDPE composites. First and for most, the project begin with the research on several issues which had been mentioned in the project activities above. With the collective information, the project was preceded with the literature review on the composite materials, kenaf fiber and natural fiber as reinforcement for composites.

After completing the literature review, the project moved on to the designation of the mold. A square mold was designed with the parameters according to the size of compression molding available in the university. Next, start with weaving the kenaf with the size of 24 cm X 24 cm which was according to the size of the mold cavity. After the mold was ready from the manufacturer, HDPE layers were fabricated.

Before the composites were fabricated, the amount of the kenaf and HDPE was calculated and weighed carefully. The weight percentage of HDPE/woven kenaf were varied to be 90/10 and 80/20. Then, the composites were fabricated with compression molding by using the sandwich techniques. The sample then cut according to the rectangular shape manually. In this project, the 5 samples were produced for each composite material for tensile test by following the ASTM D638 standard.

3.2. Tools/equipments Required

TABLE 3. 1. List of equipment and function to carry out the project.

Equipment	Function
CARVER Inc Compression Molding Machine 	To compress the polymer composites.
AMATEK Inc Universal Testing Machine 	To carry out the tensile test and 3 points bending test on the specimens and obtain significant mechanical properties of the composites such as tensile strength, modulus of elasticity, flexural strength and flexural modulus.
Electronic balance 	To weight the HDPE pallets and kenaf.
Compression mold 	To compress the composite into required shape and thickness.

3.3. Materials

3.3.1. Matrix (HDPE Titanvene HD5218EA)

High density polyethylene (HDPE) pellets were from PT. TITAN Petrokimia Nusantara (Banten, Indonesia). The materials have a melt flow index of 18g/10 min at 190˚C, a density of 950 kg/m³ and melting temperature of 130˚C. Table 3.2 shows the properties of the HDPE Titanvene HD5218EA [23].

TABLE 3. 2. Properties of HDPE HD5218EA [23].

Properties	Value
Tensile strength (MPa)	25
Flexural modulus (MPa)	1300
Elongation at Break (%)	250
Charpy Impact Strength (kJ/m²)	5

3.3.2. Kenaf Fiber

The kenaf fiber used was from Innovative Pultrusion Sdn. Bhd. (India). The kenaf fiber used was the long fiber was weaved to produce a 24 cm x 24 cm woven kenaf. Weaving tool was used to assist in the weaving process. It started by producing the warp first and followed by the weft yarn. It took about 3 hours to complete a 24 cm x 24 cm woven kenaf.

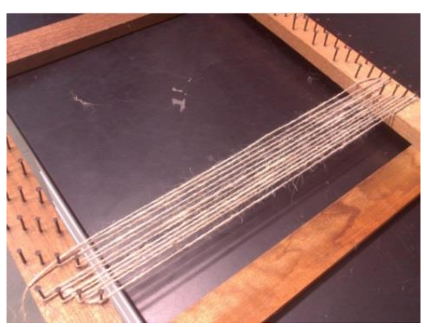


FIGURE 3. 2. Weaving tool.

3.4. Preparation of Samples

There were 3 types of specimens produced which were neat HDPE, HDPE/woven kenaf with composition of 90/10 and HDPE/woven kenaf with composition of 80/20. Neat HDPE was produced as a benchmark to compare the result with the composites. The composites were fabricated using sandwich/laminate method. Table 3.3 shows the fiber and matrix weight fraction for each type of specimen. The first step to produce the composites was to prepare the neat HDPE layer. The procedure was explained below.

TABLE 3. 3. Fiber and matrix weight fraction for each specimen.

Specimen	**Matrix (wt.%)**	**Woven kenaf (wt.%)**	**No. of samples**
Neat HDPE	100	0	5
HDPE/kenaf	80	20	5
	90	10	5

Procedures of preparing neat HDPE layers:

1. A thin layer of wax was applied on the surface of the mold for the neat HDPE layer to be easily removed.
2. 120 g of HDPE pellets were weighed using an electronic balance and then put inside the mold cavity.
3. The top cover of the mold was closed and the mold then was inserted into the CARVER Inc compression machine.
4. The compression machine was setup at 160˚C temperature and 12 ton force pressure.
5. The mold was preheated for about 10 minutes before it was compressed under pressure for 20 minutes.
6. The mold was then cooled down under pressure using air supply an external fan to help in faster cooling until the temperature drop to 80˚C.
7. Then, the compression was stopped and mold was removed from the machine.
8. HDPE layer was removed and weighed using the electronic balance.

FIGURE 3. 3. Preparation of neat HDPE layer using compression molding.

After the woven kenaf was prepared, the composite was ready to be produced. It took almost 3 hours to produce a 24 cm x 24 cm woven kenaf. The woven kenaf was weighed using the electronic balance and the weight was recorded. The procedure of producing the composite is as follow:

Procedures of preparing HDPE/woven kenaf composite:

1. A thin layer of wax was applied on the surface of the mold for the composite to be easily removed later.
2. A neat HDPE was put inside the mold cavity, followed by the woven kenaf and finally another layer of neat HDPE was put on top of the woven kenaf.
3. The top cover of mold was closed and the mold was inserted inside the compression molding.

4. The parameter of the machine was setup at 170˚C and 12 ton force pressure.
5. The mold was preheated for about 10 minutes before it was compressed under pressure for about 20 minutes.
6. Then, the mold was cooled down under pressure using air supply and external fan to help the cooling faster until 50˚C temperature is reached.
7. The mold was carefully removed from the machine and the composite was removed from the mold and weighed using the electronic balance.
8. Steps 1 to 7 were repeated for different composition of fibers.

Figure 3.4 shows the summary of the main stages involved in producing the composite using compression molding.

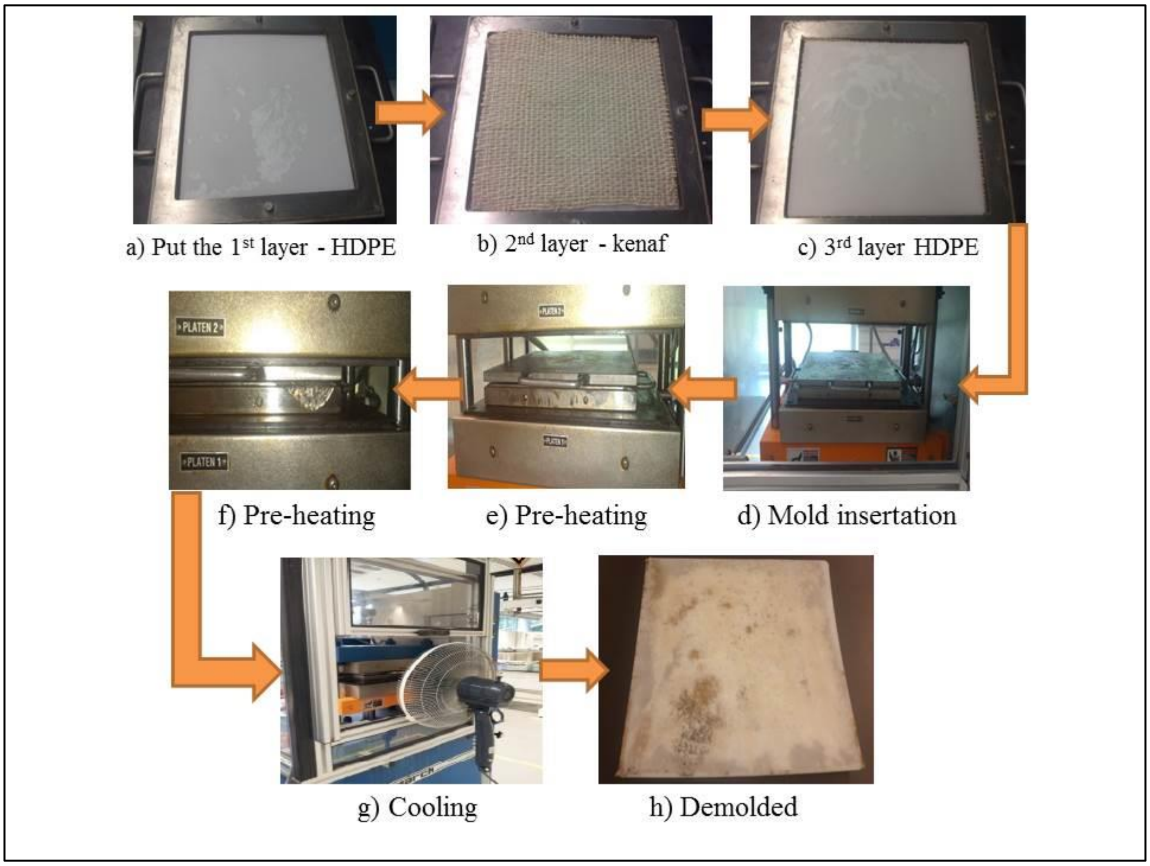


FIGURE 3. 4. Process of preparing kenaf reinforced HDPE composite.

3.5. Tensile Test

Tensile test was conducted on five specimens under the room temperature at 25 ˚ C using the Universal Tensile Machine. The specimens were tested based on ASTM D638. The loading speed was 5 mm/minutes. Figure 3.5 shows Universal Testing Machine with maximum loading 10kN.

FIGURE 3. 5. Universal Tensile Machine with maximum loading of 10kN.

Procedures of conducting tensile test were as follows:

1. Each specimen was labeled with a marker pen to indicate the material.
2. An appropriate height of the crosshead was adjusted so that the specimen could be placed.
3. Specimen was placed inside the grips.
4. The position of the grip was set to zero.
5. The parameters of the specimen were set for example the length, the width and the thickness.
6. Play button was clicked to start the test.
7. The machine was automatically stopped when the specimen fails.
8. All the data such as the force at peak and elongation at break were recorded.

3.6. Gantt Chart and Key Milestones

The Gantt chart on the next page will show the relationship between work and time. It contains key milestones and time allocated to complete each work. Table 3.4 shows the key milestones of the project.

TABLE 3. 4. Project Key milestones.

Key milestones	Completion Date
Tools/materials procurement	14th July 2013
Fabrication of composite	13th August 2013
Tensile test	22nd August 2013
Data analysis	23rd August 2013
Dissertation	28th August 2013

Table 3.5 shows the activities of the project.

TABLE 3. 5. Summary of project activities and key milestones for FYP 1 and FYP 2.

ID	Task Name	May-13 / Jun-13 / Jul-13 / Aug-13 (13 16 19 22 25 4 7 10 13 16 19 22 8 11 14 17 20 23 1 4 12 15 18 21 24 27 30)
	FYP 2	(30/8)
1	**Tool/materials procurement**	(14/7)
2	Check availability of compression molding	
3	Design mold	
4	Order required mold from manufacturer	
5	**Fabrication of composites**	(13/8)
6	Preparation of woven kenaf	
7	Fabrication of neat HDPE layers	
8	Theoretical calculation of composition	
9	Fabricate HDPE/woven kenaf (90/10) composites	
10	Fabricate HDPE/woven kenaf 80/20) composites	
11	**Tensile test**	(22/8)
12	Cut specimens into dogbone shape	
13	Run test	
14	**Data analysis**	(23/8)
15	Tensile strength graph	
16	Compare results of each composition	
17	**Dissertation**	(28/8)

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, a theoretical tensile strength for neat HDPE, HDPE/woven kenaf 90/10 wt. % and 80/20 wt. % are calculated using the rule of mixture. Experimental result from the tensile test are tabulated and discussed further. The results value used are the average value from the five specimens tested. Finally, theoretical results are compared to the experimental results.

4.1. Theoretical Results

4.1.1. Rule of Mixtures

Table 4.1 shows the calculation formula to find the theoretical tensile strength of the composite.

TABLE 4. 1. Calculation formula for tensile strength.

Properties	**Formula**
Tensile Strength	$\sigma_c = \sigma_f V_f + \sigma_m V_m$

Where: σ_c = Tensile strength of composite

σ_m = Tensile strength of matrix

σ_f = Tensile strength of fiber

V_f = Volume fracture of fiber

V_m = Volume fracture of matrix

4.1.2. Sample Calculation

Calculation for HDPE/woven kenaf of 90/10 wt.%:

1) V_f= 10 wt. % = 10 % vol. %
2) V_m = 90 vol. %
3) σ_m = 25 MPa
4) σ_f = 295 MPa

Tensile strength of composite, σ_c:

$$\sigma_c = \sigma_f V_f + \sigma_m V_m$$
$$= (295)(0.1) + (25)(0.9)$$
$$= 52 \text{ MPa}$$

From the calculation above, the theoretical tensile strength for different samples composition are tabulated in Table 4.2 as follows:

TABLE 4. 2. Theoretical results.

Samples	**Matrix (wt. %)**	**Kenaf (wt. %)**	**Tensile strength (MPa)**
Neat HDPE	100	0	25
90/10	90	10	52
80/20	80	20	79

`

Figure 4.1 shows the relationship between the volume fraction of the kenaf fiber and the composites tensile strength. Assumption is made that the composites have perfect interfacial bonding between matrix and fiber. It is obviously shown that percentage of fiber is proportional with the tensile strength of the composites. As the fiber content increase, the tensile strength is increased as well.

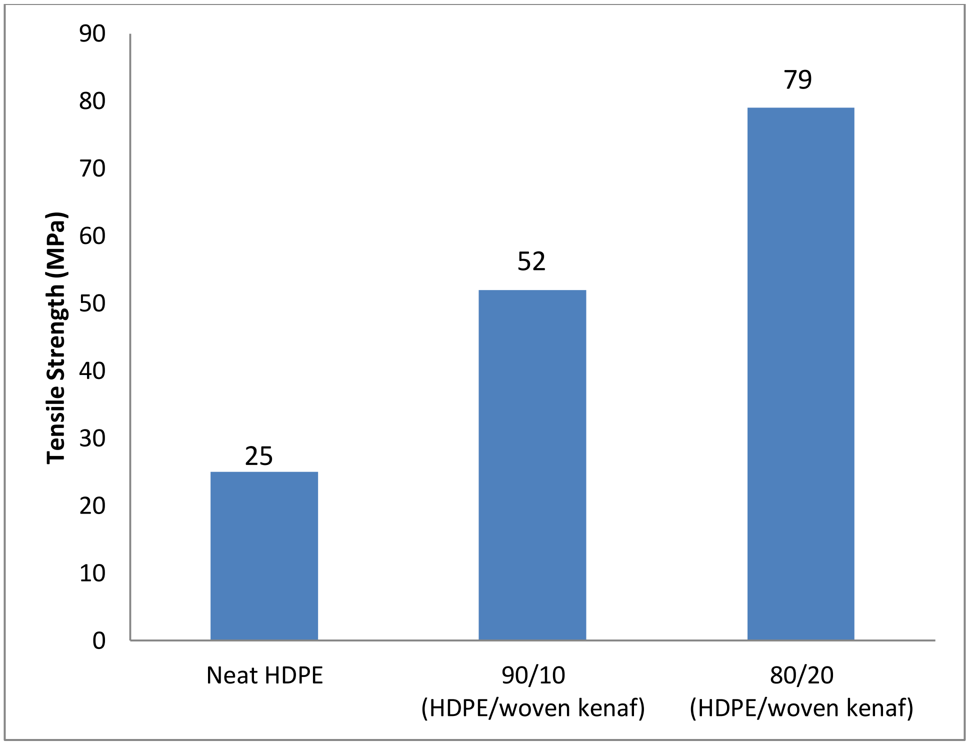


FIGURE 4. 1. Theoretical tensile strength of HDPE/woven kenaf composites.

4.2. Tensile Strength

The results from the tensile test are tabulated in Table A1 (Appendix) and Figure 4.2 shows the summarize of the results in a graph form. Generally, it is shown that the fibers loading significantly affect the tensile strength of the composites. The composites tensile strength increase with the fiber content compared to the neat HDPE. Based on the graph, the tensile strength of 90/10 wt. % of HDPE/woven kenaf improved by approximately 1.7 % compared to neat HDPE while tensile strength of 80/20 wt. % of HDPE/woven kenaf shows 16.6 % increment from the tensile strength of neat HDPE.

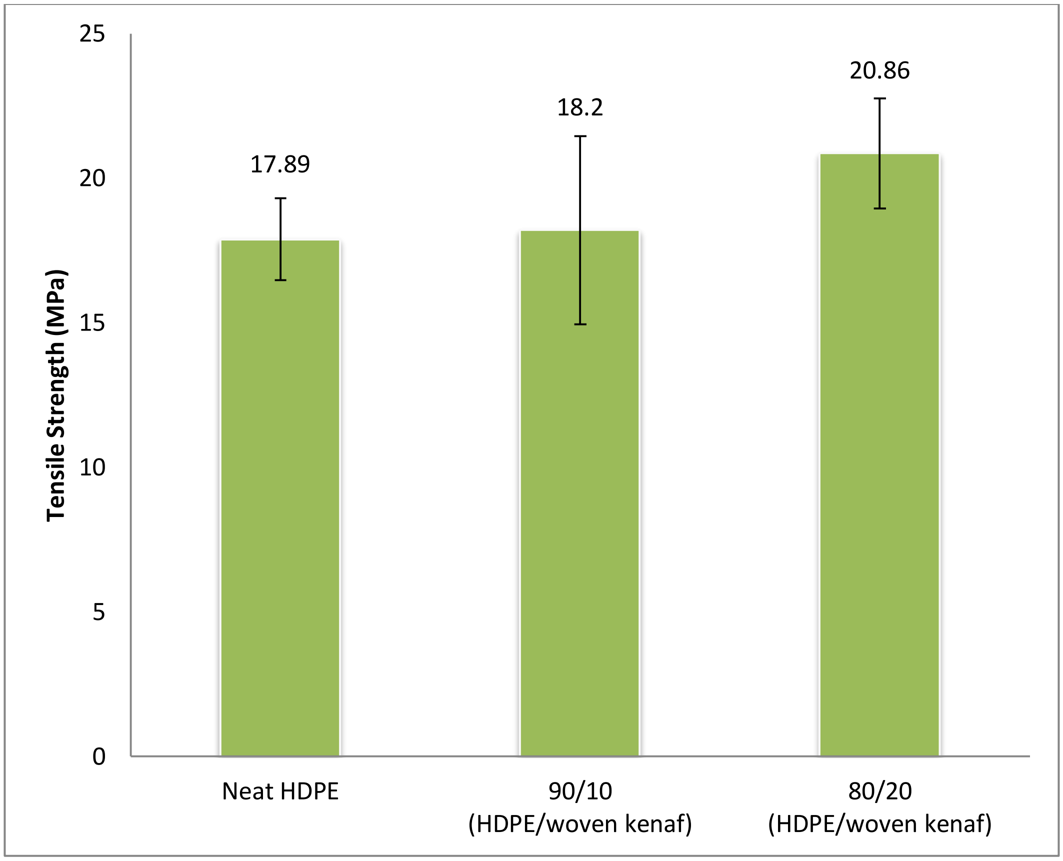


FIGURE 4. 2. Tensile strength of HDPE/woven kenaf composites.

Next, Figure 4.3 shows the comparison of the tensile strength between the experimental results and the theoretical results. Theoretical results give higher tensile strength than experimental result. For neat HDPE, it showed 28.4 % decrement, approximately 65.0 % and 73.6 % decrement in tensile strength for 90/10 wt. % and 80/20 wt. % HDPE/woven kenaf composites respectively. One possible explanation of this huge different is the poor quality of the materials produced in the experiment. The materials that are produced have defect such as cavitation or bubbles trapped inside the materials that has decreased the strength of the materials. Besides, the possible cause that cause the decreasing in tensile strength is the poor interfacial bonding between matrix and fibers.

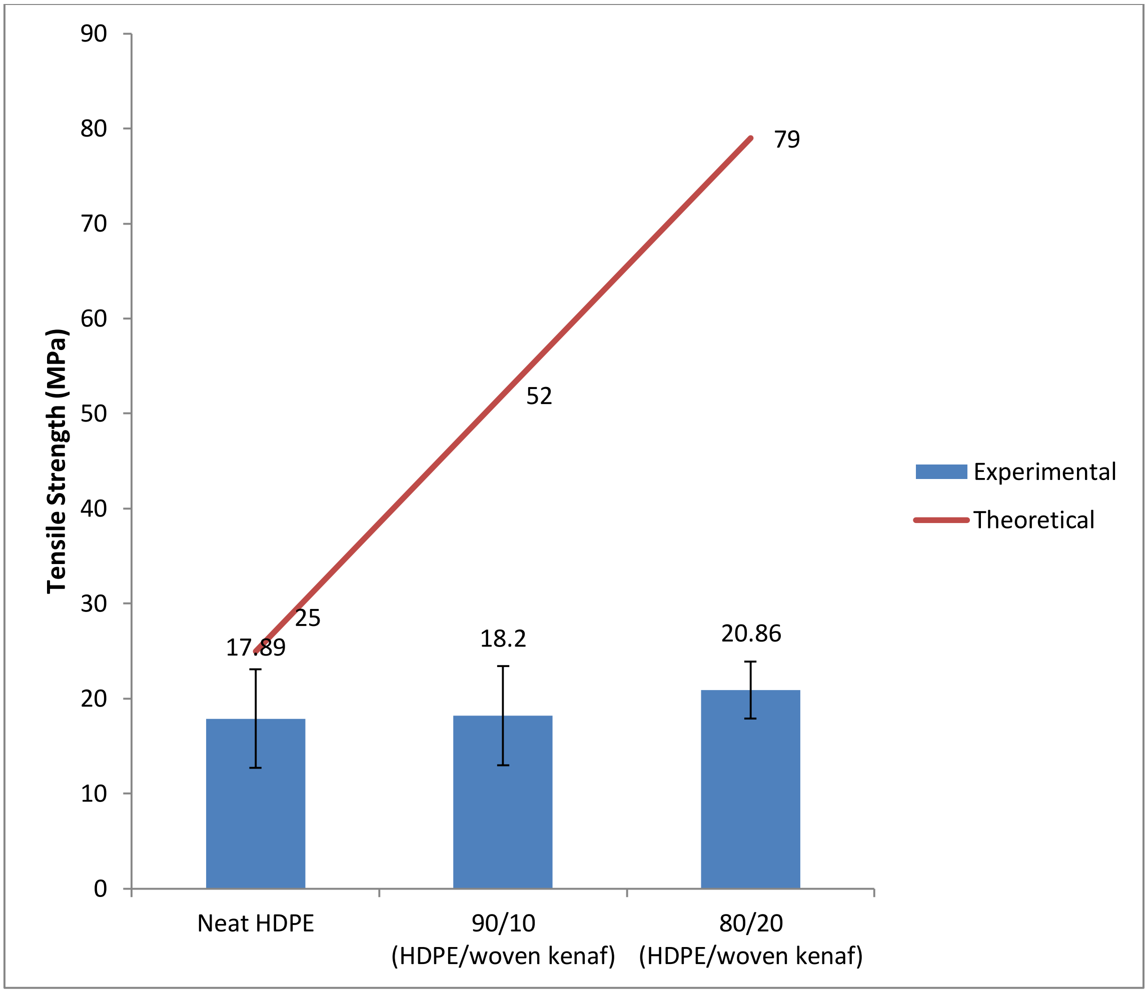


FIGURE 4. 3. Experimental and theoretical results of neat HDPE and HDPE/woven kenaf composites.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The investigation of the effect of fibers loading on the tensile properties of woven kenaf reinforced HDPE composites had been achieved and presented. It has been found that the tensile strength of the composites increase significant with fiber content. HDPE/kenaf of 80/20 wt. % improved in tensile strength by approximately 16.6 % compared to the neat HDPE. The theoretical results using the rule of mixtures were much higher than the experimental results. This may be due to the assumption made when using the rule of mixtures that there is perfect adhesion bonding between the fiber and the matrix. The difference in processing method of the composite also lead to the different. Experimentally, the composites were fabricated using the compression molding compared to injection molding where injection molding produces less voids/bubbles trap on the products. Injection molding produces better products than compression molding.

5.2. Recommendations

The recommendations of this project are as follow:

1) To produce better quality of HDPE/kenaf composites using compression molding, higher temperature should be used (suggested temperature is 190˚C) because the melt flow rate of HDPE is 18 g/10 min for temperature of 190˚C. The matrix will melt well and penetrate through the reinforcement properly and give better adhesion between the matrix and the fiber.

2) Further study should be done by increasing the fiber content to get the optimum value of fiber content in the composites i.e. using 60/40 wt. % of HDPE/woven kenaf.
3) Coupling agent should be added to the composition to get better adhesion between the fiber and the matrix.
4) Chemical treatment on the kenaf to minimize the moisture on the kenaf to produce better adhesion between fiber and matrix.

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APPENDICES

TABLE A 1. Tensile strength of HDPE/kenaf composites.

Sample	Tensile Strength (MPa)		
	Neat HDPE	90/10 wt.%	80/20 wt. %
Sample 1	18.28	18.79	19.44
Sample 2	16.32	14.56	23.56
Sample 3	19.07	17.13	19.63
Sample 4	-	22.33	20.81
Sample 5	-	-	-
Average	**17.89**	**18.20**	**20.86**
Std	**1.41**	**3.25**	**1.90**