DISSERTATION

Tensile Properties Prediction of Polypropylene Reinforced Woven Kenaf Composite using Micromechanical Models

by

Daniel Affendy Amri bin Khairul Anuar

22714

Dissertation submitted in partial fulfilment of

the requirements for the Bachelor of Mechanical Engineering (Hons)

JANUARY 2020

Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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(DR MOHAMAD ZAKI BIN ABDULLAH)

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

January 2020

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 people.

Daniel Affendy Amri

(DANIEL AFFENDY AMRI)

ABSTRACT

Natural fibre reinforced composites are increasingly used in various commercial applications but there has been little theoretical modelling done related to polypropylene (PP) reinforced woven kenaf composite. The objectives of this project were to predict the tensile properties of PP-Kenaf composite by applying Rule of Mixture (ROM) equations and to validate the results of tensile properties with existing experimental data from previous study. The reinforcing fibre was woven before undergoing compression molding process with the matrix. PP was used as the matrix and kenaf fibre as reinforcement. The composition used was 70:30 wt.% (PP-Kenaf). Since the kenaf fibre was woven, 15 wt.% would be in longitudinal direction and another 15 wt.% in transverse direction. With new weaving pattern, the 30 wt.% of kenaf fibre were divided equally in three directions which were longitudinal, transverse and 45°. Mathematical model using micromechanical theory such as ROM was used. Tensile strength predicted through calculations had shown higher values compared to experimental data for both plain weave and new weave and the difference were 60.9% and 54.5% respectively. Tensile modulus calculated using micromechanical theory equations were also higher compared to experimental data with the difference of only 2.7%.

ACKNOWLEDGEMENT

First, all praises to Allah for His guidance, blessings and grace in allowing me to begin and finish this Final Year Project Report. The main goal of writing this report is to document the project that I have been assigned during my final year in university. It was an honour for me to be able to be under the guidance of my supervisor, Dr Mohamad Zaki bin Abdullah. The completion of this project and the writing of this report would have not been possible without the help of multiple individuals and organizations. I am grateful to have all of them.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The usage of natural fiber as an environmentally sustainable alternative is growing in demand due to climate change. The combination of these properties from different components results in a better material. Natural fibers have an advantage over artificially made fibers mainly because of its biodegradability, low cost to manufacture and renewability.

Rule of Mixture (ROM) is a micromechanical model which can give us the homogenous property from two heterogeneous materials. This quantification of homogenous property comes from the parameters of quantity and arrangement of its individual constituents. When applying ROM as the method of analysis of composite, the equation assumes that the components are non-interacting during straining and also that they have the same properties as those of the isolated fibres and isolated matrix.

There are various advantages of using ROM as a method of predicting the tensile properties of polypropylene (PP) reinforced woven kenaf composite. The greatest advantage of implementing this method is that it can reduce the overall cost of a particular study. Moreover, mathematical approach is much simpler in application when compared to the implementation of numerical methods which requires a lot of iterations and the use of software to facilitate the process of reaching a converged value. On top of that, the usage of micromechanical model also reduces time taken to complete a study.

However, there are also certain disadvantages of the mathematical approach. For instance, the accuracy of the calculated tensile properties might not be that accurate due to the assumptions made during calculations. Although the value might not reach perfect accuracy, the method can still be considered acceptable as concluded in previous studies. Additionally, modification to the already existing micromechanical model can be made to further improve the accuracy of calculations.

1.2 Problem Statement

Limited effort has been done by previous studies to develop a micromechanical model for continuous long fibre composites especially for PP-Kenaf composite. Moreover, full understanding of the accuracy and advantages in implementing mathematical model to predict tensile properties of PP-Kenaf composite must be developed. Additionally, the applicability of existing mathematical model in predicting tensile properties such as the Rule of Mixture must be explored.

1.3 Objectives

The objectives of conducting this study are:

i. To predict the tensile properties of PP-Kenaf composite by applying Rule of Mixture and Modified Rule of Mixture equations.
ii. To validate the results of tensile properties obtained through micromechanical modelling approach with existing experimental data from previous studies.

1.4 Scope of Study

PP was used as the matrix and kenaf fibre as reinforcement. The composition used was 70:30 wt.% (PP-Kenaf). Since the kenaf fibre was woven, 15 wt.% would be in longitudinal direction and another 15 wt.% in transverse direction. With new weaving pattern, the 30 wt.% of kenaf fibre were divided equally in three directions which were longitudinal, transverse and 45°. Mathematical model using micromechanical theory such as ROM and MROM was used.

CHAPTER 2

LITERATURE REVIEW

2.1 Polypropylene (PP)

Polypropylene can be classified as a thermoplastic that is used for various usage. The advantage of using PP for applications is high cost to performance ratio and low processing temperature [1]. PP are manufactured catalytically from a by-product of petroleum refinery process called propylene, under carefully controlled heat and pressure [2]. This polymer is well known for its outstanding properties such as good surface hardness, resistance to abrasions, good mechanical properties and barrier properties to water [3]. It is also understood to be low cost, globally produced and can be burned without releasing toxic emissions which accounts for its recyclability and ease of processing. Chemically, PP also has excellent resistance thus making it possible to be processed through various converting methods such as extrusion and injection molding. However, PP does have a few disadvantages such as having poor low temperature impact strength, can be degraded by ultraviolet and flammable [2]. Figure 2.1 shows the stress-strain relationship of PP/Calcium Carbonate nanocomposites when mechanically tested [4].

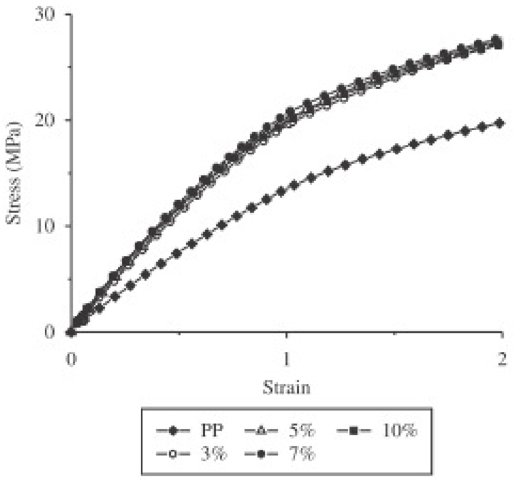


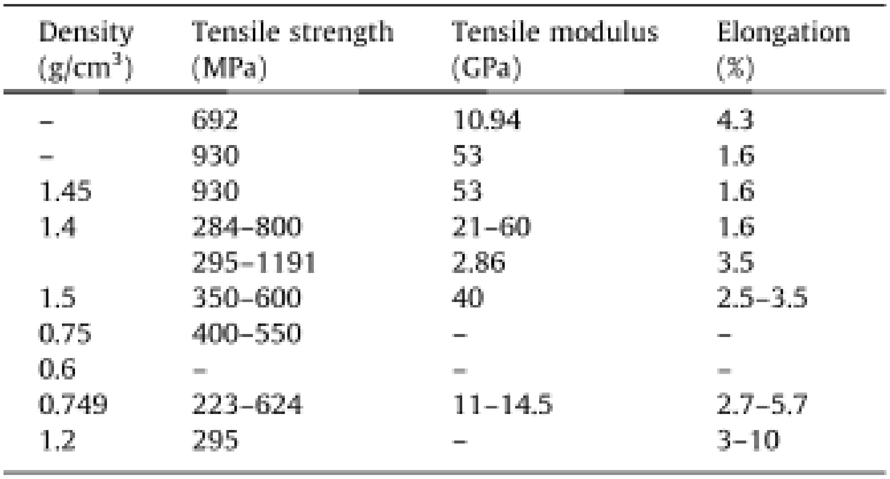
Figure 2.1: Stress-Strain Curve of PP/Calcium Carbonate Composites [4].

2.2 Kenaf

An option for natural fibre to be used as reinforcement in a composite is kenaf fibre. Kenaf (Hibiscus cannabinus L.) is related to jute or cotton and thrives in warm weather season. Kenaf fibre has been successfully integrated in various industrial applications [5]. When kenaf fibre is compared to other natural fibres, it has various advantages especially from an ecological point of view. Not only that kenaf is able to withstand a wide range of weather conditions (22°C to 30°C), it can also grow rapidly to an average height of 3 m in just 3 months after sowing seeds [6], [7]. From an economical point of view, kenaf fibre is also a viable option when it is compared to other fibres such as glass fibres because it is significantly cheaper. Furthermore, glass fibre is known to cause irritation to the eyes, skin and respiratory tract which can eventually to cancer.

Conventionally, kenaf has been used to produce twine, rope and sackcloth. However, in these modern times kenaf is utilized in paper products, animal feeds, absorbents and materials for building. A lot of studies has been made in determining the mechanical properties of Kenaf. In Table 2.1, the properties of kenaf fibre from various sources are compiled [8].

Table 2.1: Kenaf Fibre Mechanical Properties [8].

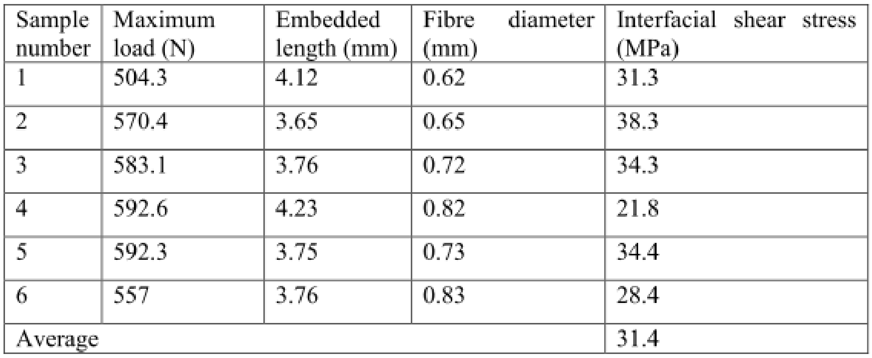


Density (g/cm^3)	Tensile strength (MPa)	Tensile modulus (GPa)	Elongation (%)
–	692	10.94	4.3
–	930	53	1.6
1.45	930	53	1.6
1.4	284–800	21–60	1.6
	295–1191	2.86	3.5
1.5	350–600	40	2.5–3.5
0.75	400–550	–	–
0.6	–	–	–
0.749	223–624	11–14.5	2.7–5.7
1.2	295	–	3–10

2.3 Natural Fiber Composite

The usage of natural fiber as an environmentally sustainable alternative is growing in demand due to climate change [9]. Composite can be defined as materials with multiple phases that still retains a significant proportion of the properties of its components [10]. The combination of these properties from different components results in a better material. The presence of alternatives has sparked the need to incorporate natural fibers as reinforcements to polymers which results in better mechanical properties and light weight such as in the automotive industry [11]. Some of the natural fibers are already being utilized in polymer composites such as kenaf, hemp, jute and banana leaf fiber [12]. Natural fibers have an advantage over artificially made fibers mainly because of its biodegradability, low cost to manufacture and renewability. One of the properties that can studied in natural fibre composites are the interfacial shear stress between matrix and reinforcement. In a study, the value of interfacial shear stress between POM-Kenaf was tabulated as shown in Table 2.2 [13]. In another study, PP-Kenaf composite study was conducted to determine the tensile strength and tensile modulus. It was found that the tensile properties vary with different compositions of kenaf fibre. Figure 2.2 shows the variation of tensile modulus with different composition of PP-Kenaf. [14].

Table 2.2: Interfacial Shear Stress in POM/Kenaf [13].



Sample number	Maximum load (N)	Embedded length (mm)	Fibre diameter (mm)	Interfacial shear stress (MPa)
1	504.3	4.12	0.62	31.3
2	570.4	3.65	0.65	38.3
3	583.1	3.76	0.72	34.3
4	592.6	4.23	0.82	21.8
5	592.3	3.75	0.73	34.4
6	557	3.76	0.83	28.4
Average				31.4

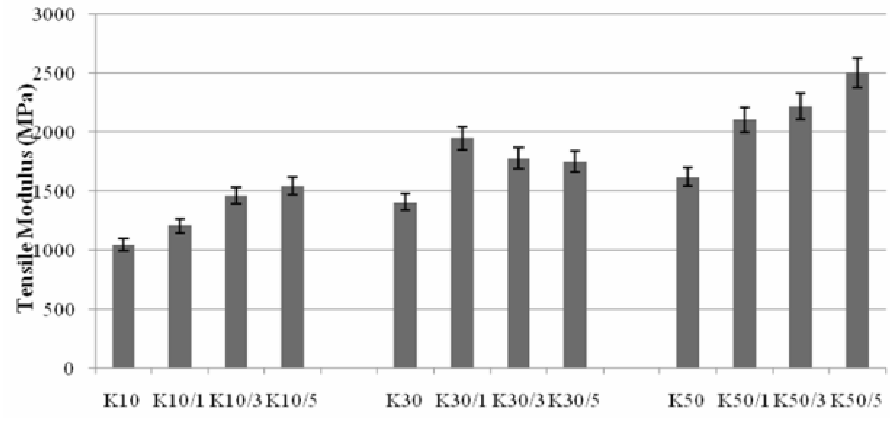


Figure 2.2: Effect of Different Composition on Tensile Modulus [14].

2.4 Weave Pattern

There are different types of woven pattern that can be made out of kenaf fibre. In one study, four different patterns of weave with reinforced composite were mechanically tested [15]. The interlacement technique used on the fabric weave were Basket 4/4, Twill 4/4, Stain 8/3 and Plain 1/1 as can be seen in Figure 2.3.

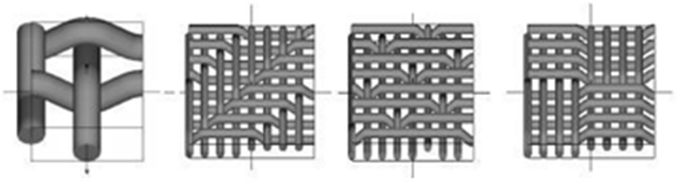


Figure 2.3: (left-right) Plain 1/1, Twill 4/4, Satin 8/3 & Basket 4/4 [15].

Three of the most basic types of weave pattern are the plain weave, basket weave and twill weave. Plain pattern of weave has the weft and warp interlacing at a right angle with respect to each other, effectively producing a crisscross pattern. The advantage of this arrangement is that it has good porosity and symmetrical fabric stability. The downside of this pattern is that it produces relatively low mechanical properties when compared to other weave pattern due to fibre compression. On the other hand, a basket style weave can be used to interlace the fibres together. This will provide better mechanical properties when compared to plain weave though basket weave is known to have less stability. The usage of fibres that are thick can prevent excessive compression that affects tensile properties. Moreover, twill weave is also an alternative way to weave fibres. In this weave configuration, one or more warp fibres weave over and under two or more weft fibres in a regular repeated manner alternately. Twill weave is known for its ability to hang around its own weight. This ability is called drapability. Unlike the previous two types of weave, twill pattern has noticeably lower chances of being affected by fibres edge compression because of smoother surface [16]. In a study previously done, plain weave pattern and new weave pattern for PP-Kenaf composite were studied for its tensile properties. It was found that the plain weave pattern has better tensile strength than the new weave pattern as seen in Figure 2.4 [17]. In a similar study, tensile strength of PP/Kenaf had shown similar characteristic for different type of weaves as shown in Figure 2.5 [18].

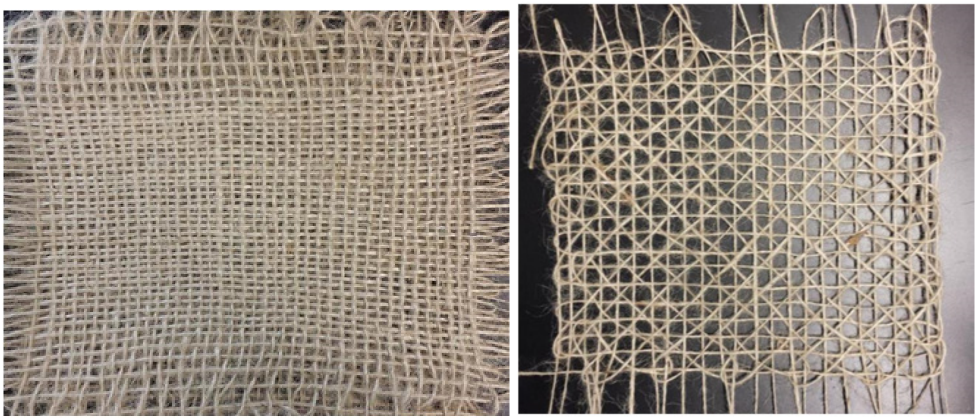


Figure 2.4: (left-right) Plain weave & New weave [17].

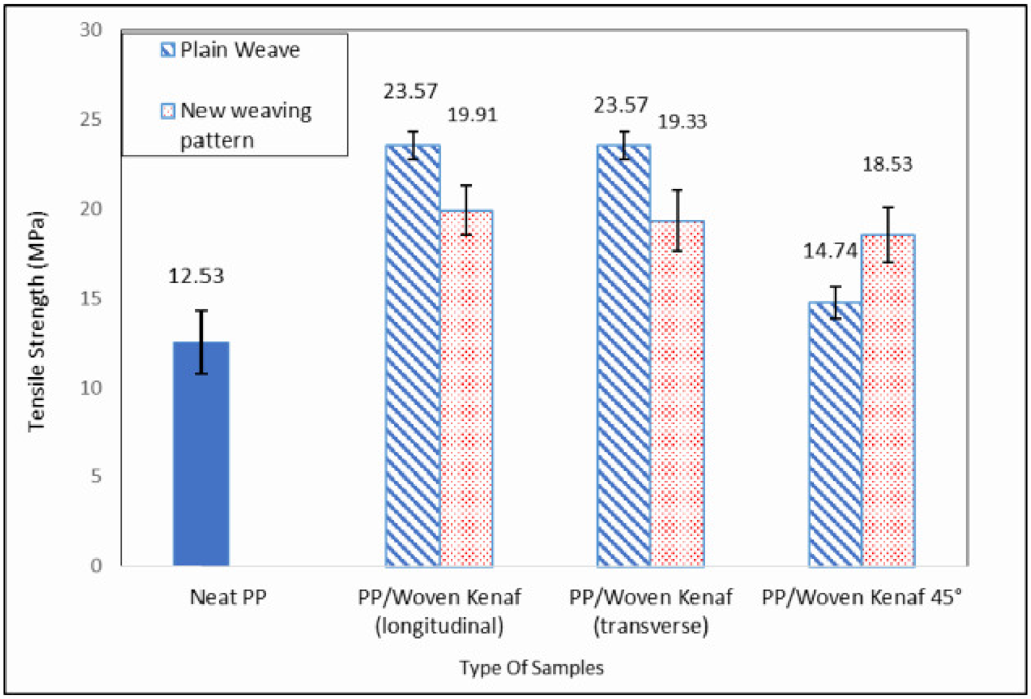
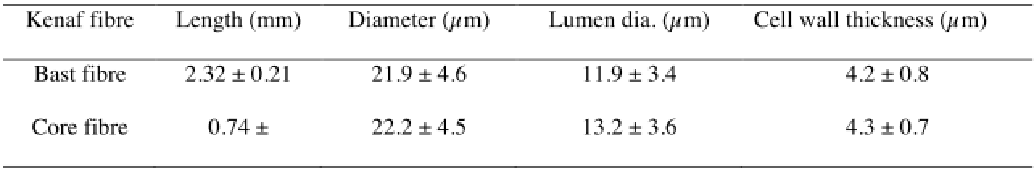


Figure 2.5: Tensile Strength of PP/Kenaf [18].

2.5 Rule of Mixture (ROM)

Rule of Mixture concept is a micromechanical model which can give us the homogenous property from two heterogeneous materials. This quantification of homogenous property comes from the parameters of quantity and arrangement of its individual constituents [19]. When applying ROM as the method of analysis of composite, the equation assumes that the components are non-interacting during straining and also that they have the same properties as those of the isolated fibres and isolated matrix [20]. There are two variants of ROM, the first one was developed by Voigt in 1889 called ROM parallel and the second one developed by Reuss in 1929 called ROM series [21]. Some of the factors that affects calculation of ROM are fibre content, fibre length, fibre diameter, fibre orientation, interfacial shear strength, yarn twist angle and the presence of void. Table 2.3 shows some of the parameters needed to calculate the critical length of PP-Kenaf composite [22].

Table 2.3: Fibre Dimensions of Kenaf Fibre [22].



Kenaf fibre	Length (mm)	Diameter (μm)	Lumen dia. (μm)	Cell wall thickness (μm)
Bast fibre	2.32 ± 0.21	21.9 ± 4.6	11.9 ± 3.4	4.2 ± 0.8
Core fibre	0.74 ±	22.2 ± 4.5	13.2 ± 3.6	4.3 ± 0.7

The equations used for Rule of Mixture calculations can be taken from 'Materials Science and Engineering: An Introduction' text book [23]. Fibre type determination is an important step before utilising ROM equations. By determining critical length of fibre, type of fibre can be identified. Equation 2.1 can be used for this purpose. This critical length l_c is dependent on the fibre diameter d and its tensile strength σ^*_f and on the fibre–matrix bond strength τ_c.

$$l_c = \frac{\sigma_f^* d}{2\tau_c} \qquad \text{(Equation 2.1)}$$

Next, the longitudinal tensile strength for long fibres of PP-Kenaf composite can be calculated using Equation 2.2. Here σ'_m is the stress in the matrix at fibre failure, V_f is volume fraction of fibre and, as previously, σ^*_f is the fibre tensile strength.

$$\sigma_{cl}^* = \sigma'_m(1-V_f) + \sigma_f^* V_f \qquad \text{(Equation 2.2)}$$

For the tensile modulus, Equation 2.3 and Equation 2.4 can be used for longitudinal and transverse loadings respectively. In these equations, E_m is modulus of elasticity at matrix phase, E_f is modulus of elasticity at fibre phase and V_f is volume fraction of fibre phase.

$$E_{cl} = E_m(1 - V_f) + E_f V_f \qquad \text{(Equation 2.3)}$$

$$E_{ct} = \frac{E_m E_f}{V_m E_f + V_f E_m} = \frac{E_m E_f}{(1 - V_f)E_f + V_f E_m} \qquad \text{(Equation 2.4)}$$

Furthermore, a modified ROM equation can be developed to account for the parameters that could help improve the calculation accuracy as can be seen in Equation 2.5 and Equation 2.6 [24].

$$\propto = 1 - \frac{V_f}{V_{f,MAX}} \qquad \text{(Equation 2.5)}$$

$$\sigma'_{cl} = \sigma'_m\left(1 - V_f\right) + \propto \sigma_f^* V_f \qquad \text{(Equation 2.6)}$$

CHAPTER 3

METHODOLOGY

This section constitutes of equations used, required parameters for this project & calculations. The overall flow and Gantt chart are also presented in this section.

3.1 Process Flow

The study was done by first finding the proper way to do prediction of PP-Kenaf composite through literature review. Then, a calculation method was identified and was set as the main tool to mathematically predict tensile properties of the composite. After that, parameters required for the equations were identified. Subsequently, data regarding matrix and fibre were gathered to be used in the calculation. Next, the calculations were performed and were compared to experimental value. Data gathered was analyzed and discussed. The overall visualization of the process flow can be seen in Figure 3.1.

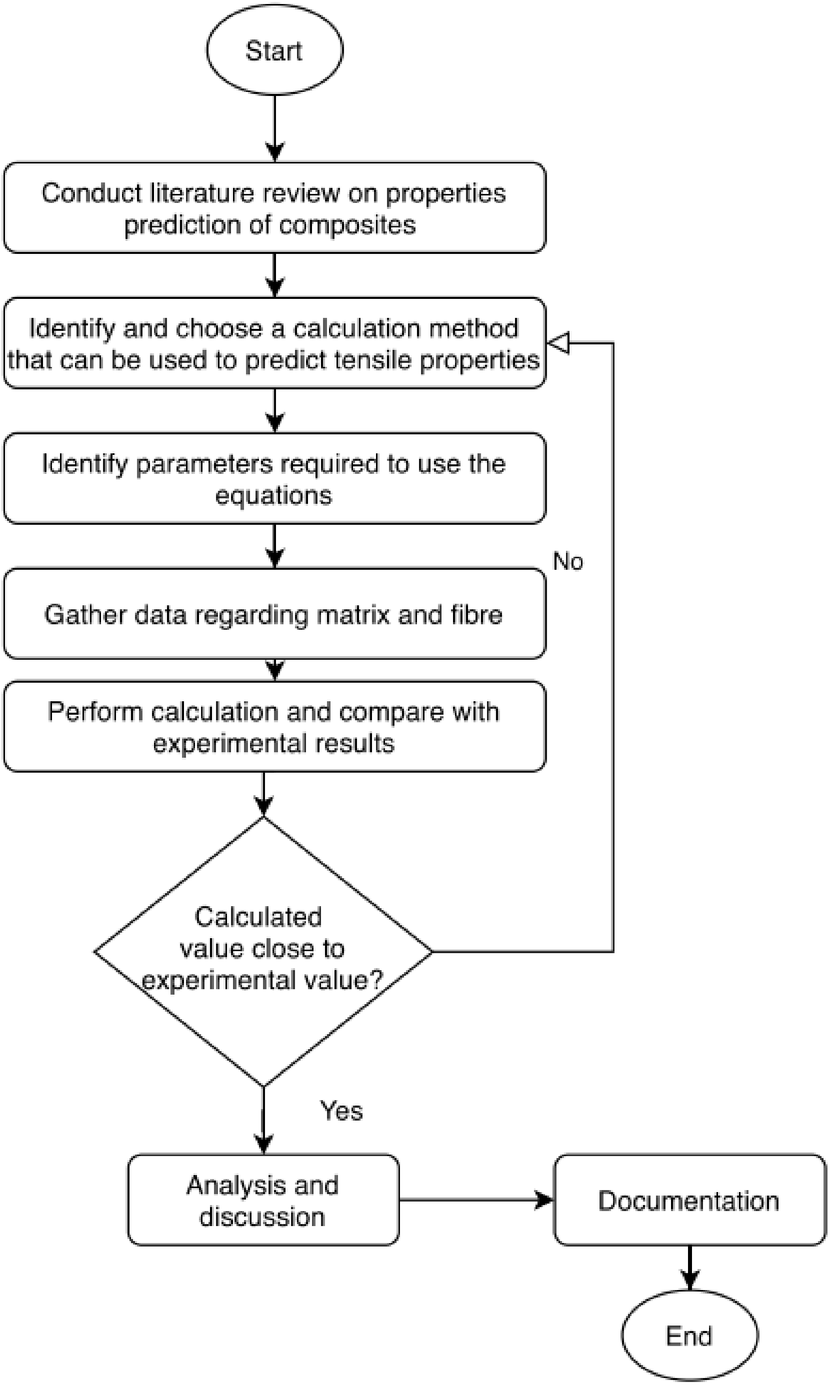


Figure 3.1: Process Flow.

3.2 Summary of Equations

a) Longitudinal Tensile Strength, σ^*_{cl}

$$\sigma^*_{cl} = \sigma'_m(1-V_f) + \sigma^*_f V_f \qquad \text{(Equation 2.2)}$$

Symbol	Meaning
σ'_m	Stress in matrix at fibre failure
V_f	Volume fraction of fibre phase
σ^*_f	Fibre tensile strength

b) Longitudinal Elastic Modulus, E_{cl}

$$E_{cl} = E_m(1 - V_f) + E_f V_f \qquad \text{(Equation 2.3)}$$

Symbol	Meaning
E_m	Modulus of elasticity at matrix phase
E_f	Modulus of elasticity at fibre phase
V_f	Volume fraction of fibre phase

c) Transverse Elastic Modulus, E_{ct}

$$E_{ct} = \frac{E_m E_f}{V_m E_f + V_f E_m} = \frac{E_m E_f}{(1 - V_f)E_f + V_f E_m} \qquad \text{(Equation 2.4)}$$

Symbol	Meaning
E_m	Modulus of elasticity at matrix phase
E_f	Modulus of elasticity at fibre phase
V_f	Volume fraction of fibre phase

d) Modified Rule of Mixture (MROM)

$$\propto = 1 - \frac{V_f}{V_{f,MAX}} \quad \text{(Equation 2.5)}$$

$$\sigma'_{cl} = \sigma'_m(1 - V_f) + \propto \sigma^*_f V_f \quad \text{(Equation 2.6)}$$

Symbol	Meaning
α	Clustering parameter
$V_{f,max}$	Maximum composite volumetric fibre packing

3.3 Parameters

A few parameters were needed in order to utilize the equations of ROM. The value of specific parameters was obtained by referencing and making comparisons to previously established studies.

a) Estimating fibre-matrix bond strength, τ_c

The value of τ_c was determined by comparing the study done for POM-Kenaf composite [13] with Technical Data Sheet for TITANPRO 6331 polypropylene homopolymer. Table 3.1 shows the summary of the values.

Table 3.1: Basis for Comparison in PP-Kenaf Bond Strength.

Composite	Matrix tensile strength (MPa)	Fibre-matrix bond strength (MPa)
POM-Kenaf	69	31.4
PP-Kenaf	35	x

Ratio between tensile strength,

$$Ratio = \frac{35\,MPa}{69\,MPa} \times 100 = 50.72\%$$

Applying ratio to fibre-matrix bond strength,

$$\tau_c = 0.5072 \times 31.4\ MPa = 15.93\ MPa$$

b) Critical length and continuous long fibre validation

The critical length was crucial in performing ROM calculations because it was used to determine whether it was continuous fibre or discontinuous fibre. The length of fibre will dictate which set of ROM equations to be used. The general rule stated that if fibre length during testing was longer than 15 times of critical length, it can be considered as continuous fibres as shown in Figure 3.2.

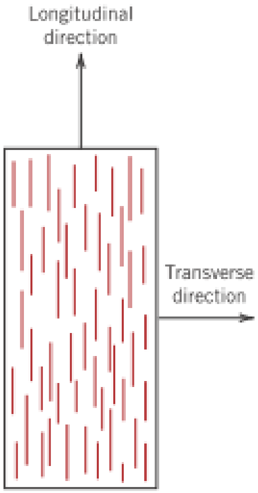


Figure 3.2: Continuous & Aligned Fibre Orientation.

By substituting values from [8], [22] and τ_c into Eqn.1,

$$l_c = \frac{\sigma_f^* d}{2\tau_c} \qquad \text{(Equation 2.1)}$$

$$l_c = \frac{284\ MPa\ \times 21.9\ \mu m}{2 \times 15.93\ MPa} = 0.195\ mm$$

By adhering to the definition, l >15l_c and since fibre was in the form of yarn thus continuous long fibre was confirmed and long fibre equations were used.

c) Finding stress in matrix at fibre failure, σ'_m

Using the stress-strain diagram of PP [4] and elongation at break of kenaf fibre [8], the stress in matrix at fibre failure can be plotted as seen in Figure 3.3.

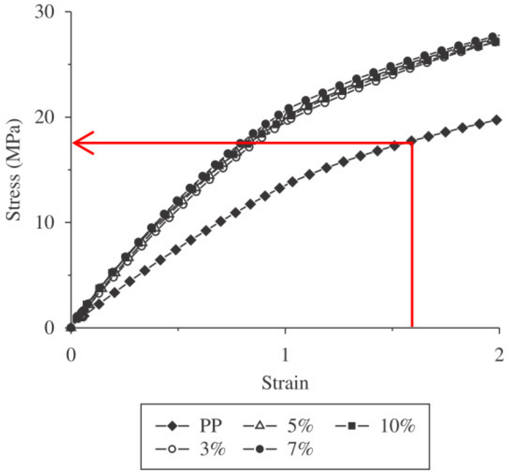


Figure 3.3: Stress at Fibre Failure Plot.

The elongation at break for kenaf fibre was 1.6% and the stress at fibre failure was found to be 17 MPa.

d) Conversion from wt.% to vol.%

The composition of PP-kenaf composite that was previously studied used 70/30 by wt.% [17]. However, due to the pattern of the weave, the kenaf fibre composition that had been involved in the tensile testing varies. The summary of fibre composition in different type of weaves can be seen in Table 3.2.

Table 3.2: Distribution of Fibre Composition in Different Weaves.

Pattern	Longitudinal	Transverse	45°
Plain weave	15%	15%	0%
New weave	10%	10%	10%

For plain weave,

$$V_m = \frac{0.85\ kg}{0.9\ g/cm^3} = 944.44\ cm^3$$

$$V_f = \frac{0.15\ kg}{1.4\ g/cm^3} = 107.14\ cm^3$$

$$V_f\% = \frac{107.14\ cm^3}{944.44\ cm^3 + 107.14\ cm^3} \times 100 = 10.19\%$$

$$V_m\% = 100\% - 10.19\% = 89.91\%$$

For new weave,

$$V_m = \frac{0.90\ kg}{0.9\ g/cm^3} = 1000\ cm^3$$

$$V_f = \frac{0.10\ kg}{1.4\ g/cm^3} = 71.43\ cm^3$$

$$V_f\% = \frac{71.43\ cm^3}{1000\ cm^3 + 71.43\ cm^3} \times 100 = 6.67\%$$

$$V_m\% = 100\% - 6.67\% = 93.33\%$$

3.4 Calculations

Having established all the parameters needed, the values found was plugged into the ROM and MROM equations for long continuous fibres.

a) Longitudinal Tensile Strength

$$\sigma_{cl}^{*} = \sigma_{m}'(1-V_f) + \sigma_f^{*}V_f \qquad \text{(Equation 2.2)}$$

For plain weave,

$$\sigma_{cl}^{*} = 17MPa\,(0.8981) + 284\ MPa\,(0.1019) = 44.2\ MPa$$

For new weave,

$$\sigma_{cl}^{*} = 17MPa\,(0.9333) + 284\ MPa\,(0.0667) = 34.81\ MPa$$

b) Longitudinal Elastic Modulus

$$E_{cl} = E_m(1 - V_f) + E_fV_f \qquad \text{(Equation 2.3)}$$

For plain weave,

$$\mathrm{E}_{cl} = 1.7GPa\,(0.8981) + 21\ GPa\,(0.1019) = 3.67\ GPa$$

For new weave,

$$\mathrm{E}_{cl} = 1.7GPa\,(0.9333) + 21\ GPa\,(0.0667) = 2.99\ GPa$$

c) Transverse Elastic Modulus

$$E_{ct} = \frac{E_mE_f}{V_mE_f + V_fE_m} = \frac{E_mE_f}{(1 - V_f)E_f + V_fE_m} \qquad \text{(Equation 2.4)}$$

For plain weave,

$$E_{ct} = \frac{1.7\ GPa\ \times 21\ GPa}{(0.8981)(21\ GPa) + (0.1019)(1.7\ GPa)} = 1.87\ GPa$$

For new weave,

$$E_{ct} = \frac{1.7\ GPa\ \times 21\ GPa}{(0.9333)(21\ GPa) + (0.0667)(1.7\ GPa)} = 1.81\ GPa$$

d) <u>MROM Longitudinal Tensile Strength</u>

For plain weave,

$$\sigma_{cl}^{*} = 17\ MPa\ (0.8981) + \left(1 - \frac{0.1019}{0.68}\right) 284\ MPa\ (0.1019) = 39.87\ MPa$$

For new weave,

$$\sigma_{cl}^{*} = 17\ MPa\ (0.9333) + \left(1 - \frac{0.0667}{0.68}\right) 284\ MPa\ (0.0667) = 32.95\ MPa$$

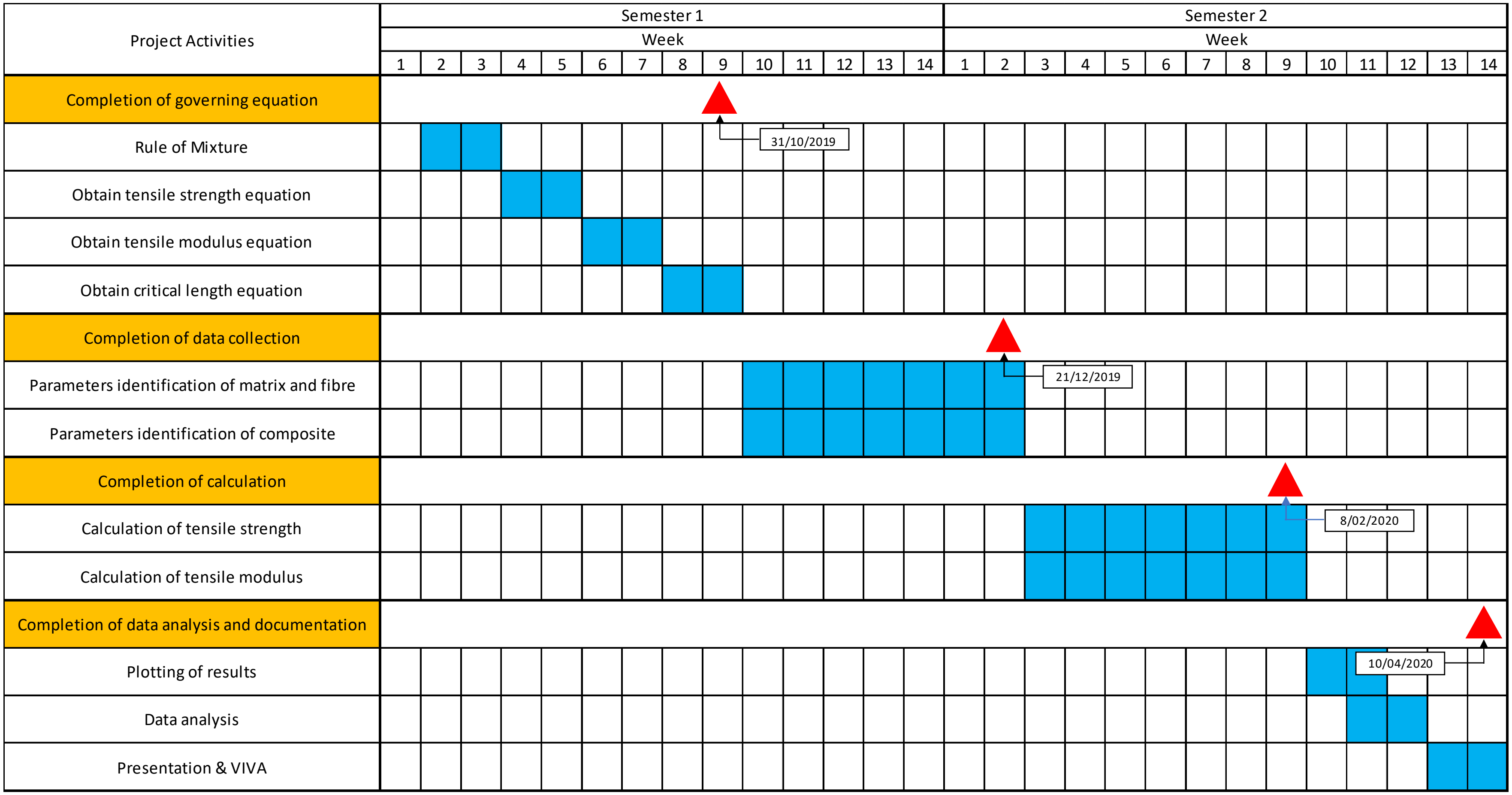
3.5 Milestone and Gantt Chart

Table 3.3 shows the project planning with key milestone of this final year project while Table 3.4 is the Gantt chart of this project.

Table 3.3: Project Milestone.

No.	Activity	Completion Date
1	Completion of governing equations	31/10/2019
2	Completion of data collection	21/12/2019
3	Completion of calculation	8/02/2020
4	Completion of data analysis and documentation	10/04/2020

Table 3.4: Gantt Chart.



Project Activities	Semester 1														Semester 2													
	Week														Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Completion of governing equation									▲ 31/10/2019																			
Rule of Mixture		🟦	🟦																									
Obtain tensile strength equation				🟦	🟦																							
Obtain tensile modulus equation						🟦	🟦																					
Obtain critical length equation								🟦	🟦																			
Completion of data collection																▲ 21/12/2019												
Parameters identification of matrix and fibre										🟦	🟦	🟦	🟦	🟦	🟦	🟦												
Parameters identification of composite										🟦	🟦	🟦	🟦	🟦	🟦	🟦												
Completion of calculation																							▲ 8/02/2020					
Calculation of tensile strength																	🟦	🟦	🟦	🟦	🟦	🟦	🟦					
Calculation of tensile modulus																	🟦	🟦	🟦	🟦	🟦	🟦	🟦					
Completion of data analysis and documentation																												▲ 10/04/2020
Plotting of results																								🟦	🟦			
Data analysis																									🟦	🟦		
Presentation & VIVA																											🟦	🟦

CHAPTER 4

RESULTS & DISCUSSIONS

4.1 Tensile Strength

Table 4.1 shows the values of tensile strength obtained for different types of weave pattern using experimental data and micromechanical model equations. Figure 4.1 shows that the value of longitudinal tensile strength obtained through micromechanical model calculations differ from the value obtained experimentally.

Table 4.1: Tensile Strength Values for Different Types of Weave Comparison.

Type	Experimental	ROM	Modified ROM
Plain Weave	23.57	44.2	39.87
New Weave	19.91	34.81	32.95

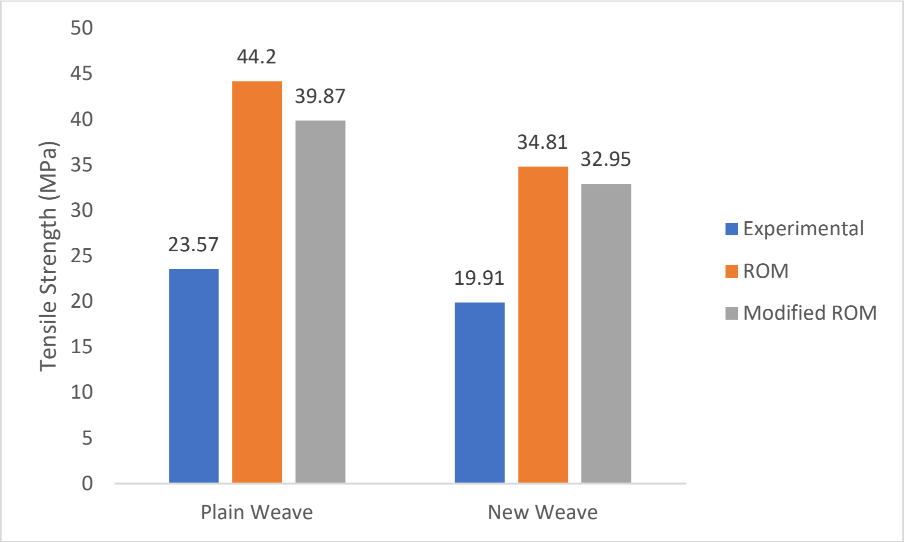


Figure 4.1: Longitudinal Tensile Strength (MPa) by Method of Calculation and Pattern.

For plain weave, the value obtained through calculation was 44.2 MPa while the experimental value was 23.57 MPa which translates to 60.9% difference. Moreover, for the new weave, by using ROM, the value of tensile strength was 34.81 MPa while the experimentally recorded value was just 19.91 MPa which is 54.5% difference.

When using MROM equations, the tensile strength had shown minor improvement in accuracy which is closer to the experimental value. The percentage difference between calculated value and experimental data were 51.4% for plain weave and 49.3% for new weave.

However, it can be said that the trend remained consistent between both methods of obtaining tensile strength. Additionally, the difference between values of MROM and experimental data for both plain weave and new weave are similar to each other, 16.3 MPa difference for plain weave and 13.04 MPa difference for new weave.

The difference between calculated values and experimental data might be due to the assumptions made when using the ROM equations. For instance, the fibre and matrix were assumed to have perfect interfacial bonding between them. Through previous studies, it was made known that the interfacial bonding of matrix and reinforcement were not always perfect thus tensile strength may deviate from the calculated value.

4.2 Longitudinal and Transverse Elastic Modulus

Table 4.2 shows the values of elastic modulus obtained for different types of weave pattern using micromechanical model calculations. Figure 4.2 shows the prediction of elastic modulus for PP-Kenaf composite by using ROM equations.

Table 4.2: Elastic Modulus Prediction.

Type	Longitudinal Elastic Modulus (GPa)	Transverse Elastic Modulus (GPa)
ROM Plain	3.67	1.87
ROM New	2.99	1.81

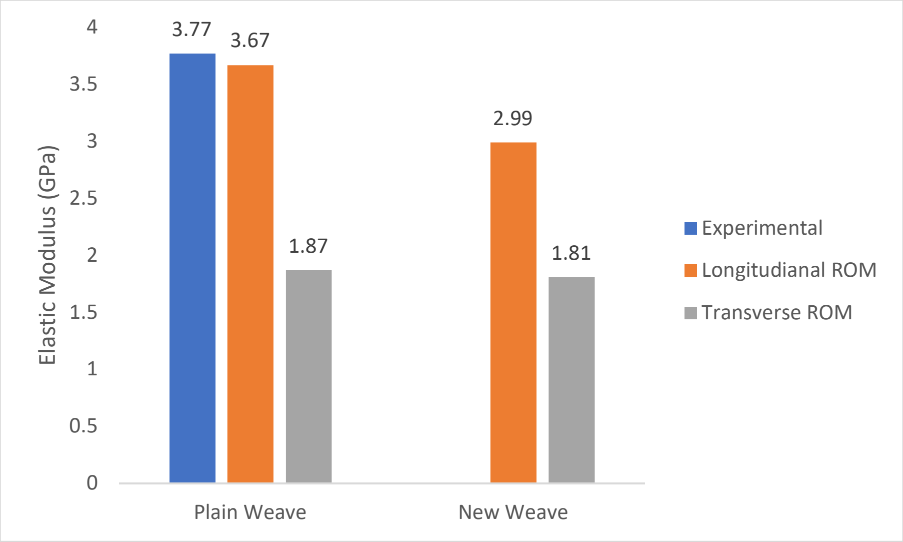


Figure 4.2: Elastic Modulus Prediction for PP-Kenaf Composite Using ROM.

The value of the calculated longitudinal tensile modulus was compared to a previous study [18]. The calculated tensile modulus which is 3.67 GPa is very similar to the experimental value, 3.77 GPa with the percentage difference of 2.7%. Therefore, it can be said that the ROM equation for longitudinal tensile modulus is accurate. Even though there were no reference for the new weave, the value was expected to be reliable based on the previously made conclusion. Generally, the values obtained for longitudinal elastic modulus are higher than the transverse elastic modulus for both plain weave and new weave.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

The objectives that were set out at the beginning stage of this project which were to predict the tensile properties of PP-Kenaf composite by applying Rule-of-mixture equations and to validate the results of tensile properties obtained through micromechanical model equations approach with existing experimental data from previous studies had been achieved. Tensile strength predicted through calculations had shown higher values compared to experimental data for both plain weave and new weave and the difference were 60.9% and 54.5% respectively. Tensile modulus calculated using micromechanical theory equations were also higher compared to experimental data with the difference of only 2.7%. From the comparison of the results obtained, it could be said that the Rule of Mixture can be used to evaluate the trends between pattern of weave. However, the formula used were not concise enough to give accurate values of the tensile strength due to the assumption of perfect interfacial bonding between fibre and reinforcement but can be used for tensile modulus prediction.

5.2 Recommendation

To evaluate the full capability of Rule of Mixture equations, calculation performed should be carried out along with real experimental testing of composites rather than basing it on previous studies. This can improve the accuracy of the study since all of the variables will be known such as the presence of voids, fibre orientation, fibre length, interfacial shear strength and twist angle of the fibre yarn. Moreover, different equations such as Hermans' Equation or modified version of ROM can be explored and utilized to obtain a more accurate micromechanical model of natural fibre composites.

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