**Predicting Tensile Properties of Lalang Grass Fiber (LGF) Reinforced Polypropylene (PP) using Mathematical Modelling**

by

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23057

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Mechanical Engineering
With Honours

January 2020

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## CERTIFICATION OF APPROVAL

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Approved by,

mohamadzakiabdullah

(DR. MOHAMAD ZAKI BIN ABDULLAH)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, 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 acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

INTAN FAZREENNA BT MOHAMAD REDZUAN

## ABSTRACT

Fiber reinforced-polymer composite is commonly used in many fields due to its advantages such as low cost, renewability and biodegradable factors. Very limited efforts have been done on theoretical modelling of short fiber reinforced polymer. Moreover, the use of mathematical modelling for predicting the tensile properties of lalang grass fiber (LGF) reinforced with polypropylene (PP) is almost non-existence. Therefore, the objectives of this project were to predict the tensile properties of PP/LGF composite using mathematical modelling and to validate the theoretical values with the previous experimental results. The composition of the PP/LFG that was used to validate the prediction is 70/30 wt.%. Mathematical models using micromechanical theories such as the rule of mixture, modified rule of mixture and Halpin-Tsai were used. Mathematical modelling allows for fast and efficient data estimation and prediction that is useful in enhancing the process of composite development. In order to calculate the theoretical value, all the parameters needed can be found from literature reviews. Modified rule of mixture can produce good mathematical data for predicting the tensile strength of the composite. The tensile strength from the analytical data using modified ROM method produced the closest value to the experimental data with the percentage difference of approximately 13%. However, for predicting the tensile modulus of the composite, Halpin-Tsai method produce good mathematical data. This method predicted the closest data to the experimental data in predicting the tensile modulus with the percentage difference of 68%.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

The mechanical properties of the composites can be obtained by using mathematical modelling, where it enables fast and efficient data prediction and estimation before proceeding with the development of the composite. Based on literature reviews, the accuracy of using mathematical modelling in predicting the mechanical properties is adequate. Other than that, it can reduce the costs by using mathematical models, since the mechanical properties can be predicted before continuing with experimental research. Rule of mixture is one of the methods that can be used to predict the mechanical properties of the composite. It is known as a simple formula for predicting the properties such as tensile strength, elastic modulus, density and specific heat of the composite [1]. In order to validate the prediction made using the rule of mixture method, it is therefore important to compare it with previous experimental results.

However, there are some disadvantages of using mathematical models in predicting the mechanical properties of the composite. One of the limitations is the accuracy of the obtained results may vary, depending on the assumptions made. Other than that, due to limited work being done in the development of the models, the mathematical model is quite limited. Therefore, in order to predict the mechanical properties of the composite, it is important to find the best mathematical model from the existing study.

Composite is composed of two or more components, each with different physical or chemical properties. There are two important phases in the composite which are matrix and reinforcing phase. Matrix in the composite is to hold the fibers together in place as well as transfer the load to the fibers. Meanwhile, reinforcement provides strength to the composite.

Throughout the years, these composites made of non-degradable, non-renewable petroleum-based polymers deplete in nature as time goes by. Most of the environmental issues come from these such polymer-based products. Hence, due to environmental concerns, biodegradable materials have been used in the industry and become high in demand. Therefore, natural fibers were used in the composites as alternative reinforcement [2].

This century has seen remarkable advances in green technology in the field of materials science through the creation of biocomposites due to environmental and sustainability problems. Biocomposites are composite materials consisting of petroleum derived nonbiodegradable polymers (PP, PE) or biodegradable polymer (PLA, PHA) and natural fiber [3]. When natural fiber is used as the reinforcement, Polypropylene (PP) is commonly selected as the polymer matrix for the composite due to its advantages. One of the advantages is PP has low processing temperature and it is important because natural fibers are known to have relatively low thermal stability [4]. Higher fiber content in the composites has shown to increase the stiffness and strength of the composites. However, PP is known as a hydrophobic matrix where it does not quickly interact with molecules of water. Natural fiber, however, has high water content and is known as hydrophilic. Therefore, it is advisable to use coupling agent or compatibilizer to have stronger interfacial shear strength between matrix and fiber [5].

Natural fibers are also used in the composites due to their ability to degrade and eco-friendly. The different natural fibers such as bamboo, flax, jute, kenaf, and sisal were used in numerous studies. Lalang grass is one of the new candidates that act similar to other natural fibers to be used as reinforcement in the composites. Lalang grass (*Imperata cylindrica*) is chosen as the fillers due to its low cost since it does not have much economic value and often regarded as a major problem to agricultural farms. This can give advantage to the farmers as they can get extra income by selling the Lalang grass to companies [6].

## 1.2 Problem statement

Due to both environmental concerns and the lack of oil-derived products in the future, biocomposites have become the main subject in the activity research. Furthermore, the main purpose for using natural fiber in the composites is because they are low in cost. One of the choices is the study of PP composites reinforced with lalang grass fiber. However, very little effort has been made to model short fiber-reinforced polymer theoretically. In addition, the use of mathematical modelling for predicting the tensile properties of lalang grass fiber (LGF) reinforced with polypropylene (PP) is almost non-existence.  This is because, majority of the mechanical properties of the composites are obtained through experimental research. Therefore, mathematical models may be used to predict the tensile properties of the PP/LGF composite due to the limited time and cost.

## 1.3 Objectives

The objectives of this project were:

i. To predict the tensile properties of PP/LGF composite using ROM and modified ROM for tensile strength and ROM and Halpin-Tsai for tensile modulus.
ii. To validate the prediction values of the tensile properties of PP/LGF composite for the 70/30 composition with the previous experimental results.

## 1.4 Scope of project

The project was carried out to predict the tensile properties of the polymer composites that are made from PP and LGF as well as to verify the predictive values with the previous experimental results. The composition that was used to compare the result is 70 wt.% of PP and 30 wt.% of LGF. The length and diameter of the fiber used in the composite are 7.5 mm and 1 mm, respectively. The rule of mixture, the modified rule of mixture and Halpin-Tsai were used to predict the tensile properties of the composite. Validation of the predictive value was made by comparing it with the previous experimental result.

# CHAPTER 2

# LITERATURE REVIEW

This chapter starts with general information on natural fiber. The focus then changes to polypropylene and lalang grass fiber as well as the mathematical models.

## 2.1 Natural fiber

Natural fibers are usually obtained from plants and animal sources and geological processes. They are known for their biodegradability and non-abrasive. Therefore, they can be used to make composite materials, where it changed the orientation of fibers to improve the properties. Such natural fibers are low-cost, lightweight and have high specific properties and are able to replace the majority of glass and mineral fillers [7]. The main purpose of natural fibers is the same as other reinforcement where they are used in composites to enhance the matrix's rigidity and stiffness. Matrix in the composite acts as a medium to distribute the load on the material onto the fibers.

Wool and dyed flax are among the earliest natural fibers found in the Republic of Georgia back in 36,000 BP. Through years, composite industry began to improve its product where better plastic resins and enhanced reinforcing fibers were developed. They found a lot of new plants that can be used as natural fibers in the composites. As shown in Table 2.1, plants that produce cellulose fibers can be divided into several types of fibers [8]. Table 2.2 shows the world's most popular natural fiber and their its production [8].

Table 2.1: The types of fiber that have been used as natural fibers in composites [8].

| **Types of fibers** | **Example** |
|---|---|
| Bast fibers | Jute, flax, ramie, hemp, and kenaf. |
| Seed fibers | Cotton, coir, and kapok. |
| Leaf fibers | Sisal, pineapple, and abaca. |
| Grass and reed fibers | Rice, corn, and wheat. |
| Core fibers | Hemp, kenaf, and jute. |
| Other kinds | Wood and roots. |

Table 2.2: Natural fibers in the world and their world production [8].

| **Fiber source** | **World production ($10^3$ ton)** |
|---|---|
| Bamboo | 30 |
| Sugar cane bagasse | 75 |
| Jute | 2300 |
| Kenaf | 970 |
| Flax | 830 |
| Grass | 700 |
| Sisal | 375 |
| Hemp | 214 |
| Coir | 100 |
| Ramie | 100 |
| Abaca | 70 |

In addition to the biodegradability and non-abrasivity of natural fibers, they are also believed to have environmental benefits. It will allow for a lower reliance on non-renewable energy, a decline in pollutant emissions, lesser greenhouse gas emissions and increased recovery in energy [9]. This shows that the usage of natural fibers in the future will be increased due to the demand for environment-friendly composites for the industry.

According to Saheb and Jog [10], glass fibers have higher tensile strength with 3400 MPa than that of natural fibers (jute) with 393 MPa. However, specific modulus needs to be considered to compare the strength of glass fibers and natural fibers and it showed natural fiber's values are better than glass fibers [10]. The mechanical properties for some of the commercially used natural fibers are shown in Table 2.3.

Table 2.3: Mechanical properties of natural fibers [10].

| Fiber | Specific Gravity | Tensile Strength (MPa) | Modulus (GPa) | Specific Modulus |
|---|---|---|---|---|
| Jute | 1.3 | 393 | 55 | 38 |
| Sisal | 1.3 | 510 | 28 | 22 |
| Flax | 1.5 | 344 | 27 | 50 |
| Sunhemp | 1.07 | 389 | 35 | 32 |
| Pineapple | 1.56 | 170 | 62 | 40 |
| Glass Fiber-E | 2.5 | 3400 | 72 | 28 |

## 2.2 Mechanical properties of natural fiber-reinforced composites.

The literatures selected were focused on the study context which is the study of the effect of natural fiber on the tensile properties in the composites. This is done to study the pattern of the tensile properties of these composites to predict the results of PP/LGF composite.

In this study, Shalwan and Yousif [11] had used several types of fibers from natural sources flax, hemp, jute, kenaf and cotton as the reinforcement. The matrix chosen were PLA, PP, epoxy and polyester. There were seven different composites used in this study as shown in Table 2.4. Based on the study, some cases showed that the uses of natural fiber in the composites had improvement in the tensile strength compared to the neat polymer.

Table 2.4: Type of polymer and natural fiber in the composite [11].

| **Polymer** | **Natural fiber** |
|---|---|
| PLA | Jute |
| PLA | Flax |
| PP | Kenaf |
| PP | Hemp |
| PP | Cotton |
| Epoxy | Jute |
| Polyester | Jute |

Tensile strength and modulus were tested according to the respective ASTM. Based on Figures 2.1, the results show that the addition of jute fibers in PLA had significantly increased by 75.8% in the tensile strength of the composite compare to the neat PLA. However, there were some cases that showed the reduction in tensile strength when the natural fiber is added. For example, it can be observed that the addition of flax fibers in PLA had a reduction by 16% in the tensile strength of the composite. The tensile modulus of epoxy/jute is significantly higher than the tensile modulus of neat epoxy. From all this, it shows that, the addition of fiber in the composite gives better tensile properties compared to the neat matrix.

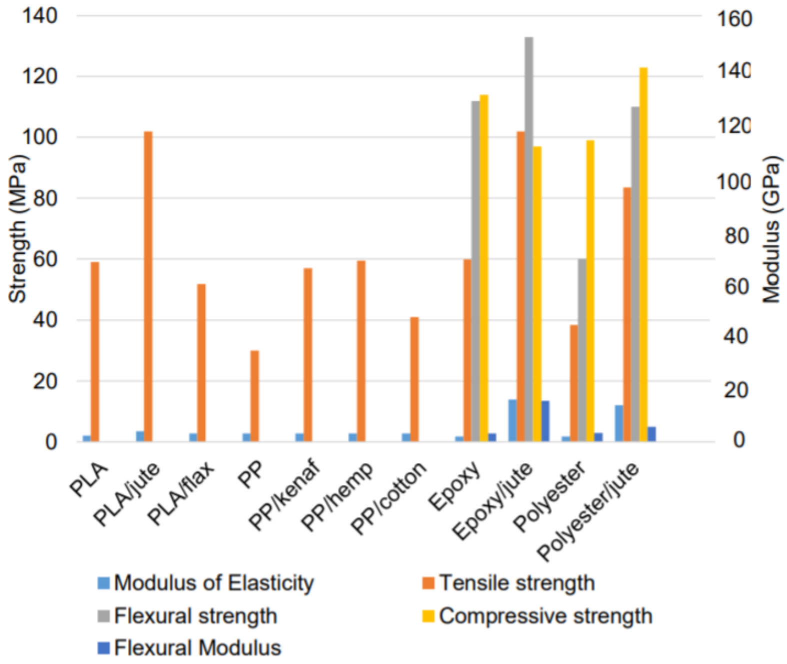


Figure 2.1: Tensile strength and modulus of several fiber/matrix composite [11].

Meanwhile, the configuration of fiber had an impact towards the mechanical properties of PP/banana fiber composite was studied in another study [12]. Injection molding was used to fabricate the composites in this study. According to their respective ASTM standards, the mechanical properties such as the tensile and flexural strengths were tested for.

When raw fibers from bananas were added in PP, the tensile strength showed a significant increase compared to the neat PP.  From the Figure 2.2, it was shown that when banana yarn was added in PP, it showed the greatest improvement in tensile strength when compared to the neat PP. This also proves that, fiber reinforced composites exhibit better mechanical properties then in neat polymer.

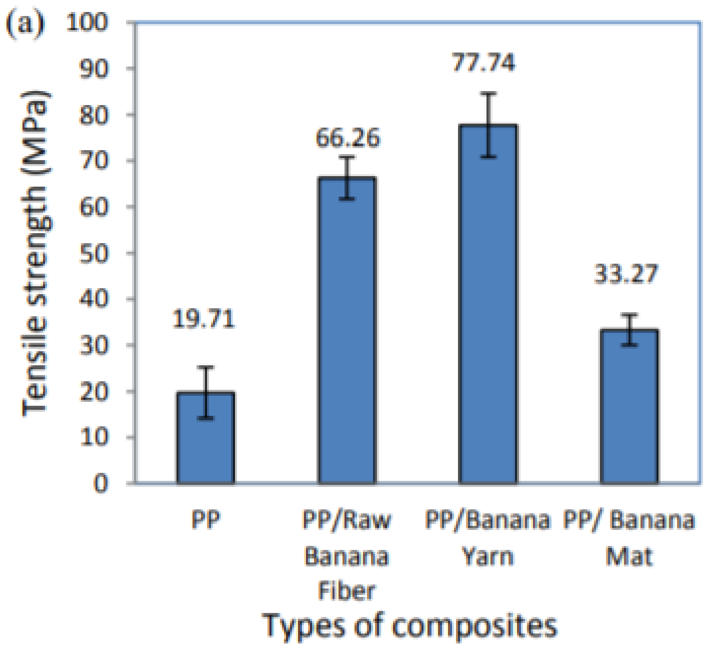


Figure 1.2: Tensile strength of PP/banana fiber composites [12].

Furthermore, the flexural strength of PP/banana fiber composites are higher when compared to the neat PP. For these composites, the highest flexural strength was when banana yarn were added to the composite. Figure 2.3 shows the flexural strength of PP/banana fiber.

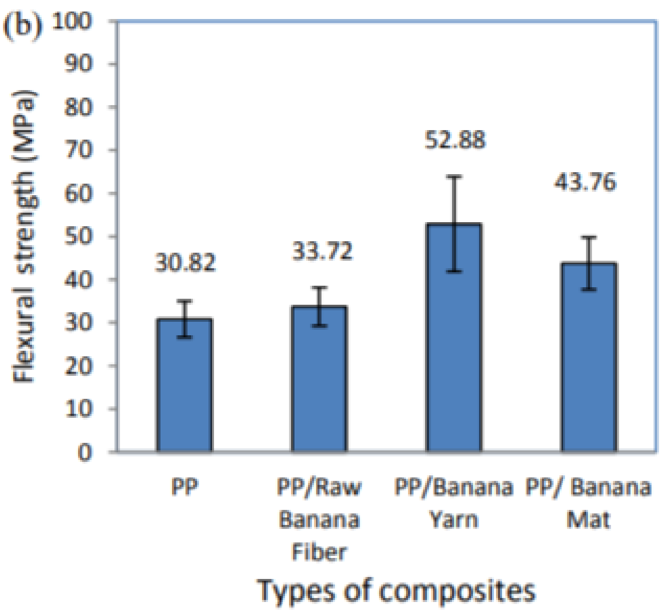


Figure 2.2: Flexural strength of PP/banana fiber composites [12].

## 2.3 Polypropylene

There are many studies have been carried out that use thermoplastics as the matrix to be reinforced with natural fibers [13]. The thermoplastics analyzed polypropylene (PP), polyethylene (PE), polystyrene (PS) and polyamides (Nylon6 and 6, 6) [13]. PP is an unsaturated hydrocarbon composed of only the atoms of carbon and hydrogen and it is known to be prepared while carefully controlling the heat and pressure by polymerizing propylene, a gaseous by-product of petroleum refining with the presence of catalyst [14]. In addition, PP is commonly used for production purposes because of it is less dense, is high processible, exhibits good mechanical properties, has good temperature, possesses excellent electrical properties, is dimensionally stable and has good impact strength [15]. Since it is known to has the lowest density among other plastics, it gained the popularity very quickly.

However, according to Maddah [16], PP also have several disadvantages such as easily degraded by Ultraviolet (UV), flammable, poor low temperature impact strength and difficult to bond. Therefore, PP is combined with additives such as mineral fillers and rubbers or elastomers to increase the mechanical and thermal properties [17]. Moreover, fiber-reinforcing is one way to enhance the mechanical and thermal properties.

## 2.4 Lalang grass fiber (LGF)

Lalang Grass (*Imperata Arundinacae*) or commonly known as cogon grass is a green plant that grows abundantly in Malaysia and has no use in any industry. This has led to several studies on the use of lalang grass as a composite reinforcement. One of the studies is on the effect of lalang grass with several different compositions as reinforcing filler and natural rubber (NR) as the matrix. Based on the results, the use of ICCF as a reinforcing filler had a positive effect on tensile strength and modulus compared with neat NR [18]. Then, there was another study on the effect of the composition of the fiber-matrix on the mechanical properties. In this study, 10 and 20 wt% of fiber was used to find the experimental results [19]. Based on the results, the tensile strength, modulus yield strength show an increasing pattern with increasing fiber content. This shows that the mechanical properties of the composites are improved with increasing lalang grass fiber content.

## 2.5 Mathematical models

Many theoretical models have been developed over the previous decade to predict the mechanical properties of fiber reinforced composites [22]. One of the main methods used for the mathematical calculation is by using rule of mixture [22]. According to Bakhori et al. [23], the relationship between the experimental and predicted value from the composite used showed that there is relatively good agreement between the tensile strength and Young's Modulus obtained experimentally with those of the rules of mixture results. However, Ku et al. [24] stated that the Halpin-Tsai equation was noticed to be the most effective equation for the prediction of the Young's modulus of the composite. The length of the fibers, fiber loading and orientation and fiber to matrix bonding plays an important role in order to obtain the desired properties. The properties of the composites can be predicted by the rule of mixture, where $P_c$ is the property to be found, $P_m$ is the corresponding property of the matrix and $P_f$ corresponding to the property of the fiber. $V_m$ and $V_f$ are the relative composite volume fractions of the matrix and fiber, respectively as shown in Eqn. 2.1. The rules of mixture for predicting tensile stress of the composite can be seen in Eqn. 2.2.

$$P_c = P_m V_m + P_f V_f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn. 2.1}$$

$$\sigma_c = \sigma_m V_m + \sigma_f V_v \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn. 2.2}$$

The equations to be used in the rule of mixture method can be found from Callister and Rethwisch [25]. The length of fiber plays a pivotal role in deciding the suitable equation to be used for predicting the tensile properties. Critical length of the fiber is calculated using Eqn. 2.3. When the length of fiber is smaller than the critical length, the equations for the composite tensile strength and modulus are displayed in the Eqns. 2.4 and 2.5, respectively. however, when the length of fiber is bigger than the critical length, the equation to predict the tensile strength of the composite is shown in Eqn. 2.6.

$$l_c = \frac{\sigma f\, d}{2\tau} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn. 2.3}$$

$$\sigma^*_{cd} = \frac{l\,\tau}{d}\, V_f + \sigma'_m\,(1\text{-}V_f) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn. 2.4}$$

$$E_{cd} = E_m V_m + E_f V_f = E_m V_m + E_f\,(1\text{-}V_m) \quad \ldots\ldots.. \text{Eqn. 2.5}$$

$$\sigma^*_{cd} = (1\text{-}\,\frac{lc}{2l})\sigma_f\, V_f + \sigma'_m\,(1\text{-}V_f) \quad \ldots\ldots\ldots\ldots\ldots... \text{Eqn. 2.6}$$

where, σf is the fiber tensile strength

τ is the interfacial shear strength

$\sigma'_m$ is the stress of matrix at fiber fracture

$E_m$, $E_f$ are the modulus of elasticity of matrix and fiber

However, the study of Angelo et al. [26], it was found that the modified rule of mixture strength model adequately predicts the tensile strength of the different composite specimens. According to them, interfacial shear strength is an important parameter in Eqn. 2.4, which the composite is assumed to have a perfect matrix/fiber adhesion. However, this is not possible in real composites due to the weak chemical bonding and mechanical attachments which reduces the transfer of load via the interface [27]. Fiber-fiber interactions can also occur, which will decrease the ability to bear stress though the composite has a perfect matrix/fiber bonding. Therefore, it can be said that, the fiber-fiber interactions are important to the composites and a clustering parameter, α can be incorporated to the rule of mixture equation, which modifies Eqn. 2.4 as shown in Eqn. 2.7.

$$\sigma^*_{cd} = \alpha\frac{l\,\tau}{d}\, V_f + \sigma'_m\,(1\text{-}V_f) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \text{Eqn. 2.7}$$

in Eqn. 2.7 the parameter α is given as [26]:

$$\alpha = 1 - \frac{V_f}{V_{f,maz}} \quad \text{.......................................... Eqn. 2.8}$$

According to the study of Angelo et. al [28], Halpin-Tsai equation has been found to be the best method for predicting the composite tensile modulus compared to other methods. The equation for the Halpin-Tsai method is as shown in Eqn. 2.9. The parameter η and $\mathcal{E}$ are as shown in Eqn. 2.10 and 2.11, respectively. $\mathcal{E}$ is a shape fitting parameter that is used to fit the Halpin-Tsai equation to the results obtained experimentally.

$$E_c = E_m \left( \frac{1+\mathcal{E}\eta V_f}{1-\eta V_f} \right) \quad \text{.................................... Eqn. 2.9}$$

$$\eta = \frac{(E_m/E_f) - 1}{(E_m/E_f) + \mathcal{E}} \quad \text{..................................... Eqn. 2.10}$$

$$\mathcal{E} = 2\ (L/D) \quad \text{............................................. Eqn. 2.11}$$

# CHAPTER 3

# METHODOLOGY

In this chapter, process flow, formulation, morphological analysis and Gantt chart of key milestones and project activities are discussed.

## 3.1 Process flow of the project

The project process flow, as shown in Figure 3.1, was a theoretical base project. In particular, it was a study of the mathematical modelling to predict the tensile strength and modulus of the composite. Firstly, the selection of natural fiber and matrix were done. Lalang grass fiber and PP were selected as the reinforcement and matrix, respectively. Then, the identification of calculation method was made and rule of mixture, modified rule of mixture and Halpin-Tsai were selected to calculate the composite tensile strength and modulus.

After the selection of calculation method was done, identification process for the parameters needed for the calculation were made. There are several parameters that are important to be considered in order to calculate the tensile property values by using the proposed method. The parameters are as follows:

- Fibre length and diameter
- Volume fraction of the fiber and matrix
- Ultimate tensile strength of the fiber and matrix
- Modulus of elasticity of the fiber and matrix
- Interfacial shear strength of the composite

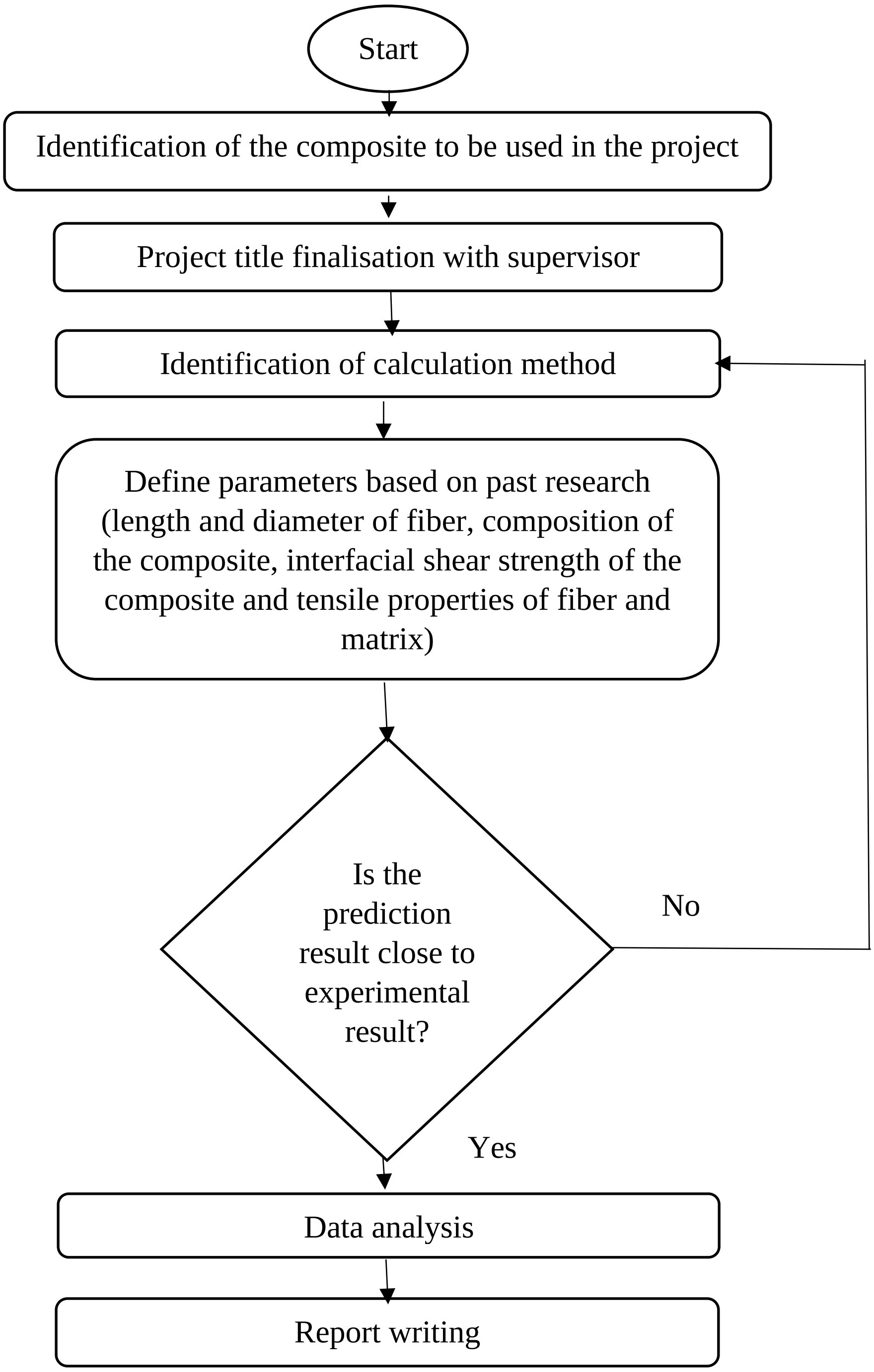


Figure 3.1: Project workflow diagram.

The calculation for the tensile strength of the composite was performed after all the parameters were collected. The result obtained from the calculation was then compared to the previous experimental result to validate the accuracy of the calculation.

### 3.2 Equations used in the project

In this study, the orientation of fiber is to be assumed as unidirectional. For predicting and validating the tensile strength of the composite, two different mathematical models, ROM and modified ROM were used. For both models, the fiber length is assumed to be smaller than the critical length. Hence, when using ROM for predicting the tensile strength of PP/LGF composite, Eqn. 2.4 was used. Meanwhile, Eqn. 2.7 was used to predict the tensile strength of the composite using modified ROM. The obtained data were then compared with the previous experimental study for the tensile strength of PP/LGF. Other than that, with using both methods, the tensile strength for different compositions of the composites were predicted.

ROM and Halpin-Tsai models were used to predict the tensile modulus of PP/LGF composite. Therefore, Eqn. 2.5 was used to calculate the tensile modulus using ROM method. Meanwhile, when using Halpin-Tsai method to predict the tensile modulus of the composite, Eqn. 2.9 was used. The validation of the obtained data was done by comparing it with the previous experimental data for the tensile modulus of PP/vetiver. Then, using both methods, the tensile modulus for different compositions of the composites were predicted.

### 3.3 Design parameters

The materials data used in this project are shown in Table 3.1. As mentioned in the scope of project, the length of the fiber is 7.5 mm. However, the fiber length after extrusion and injection molding was taken into considerations. According to the study of Subasinghe et al. [29], the average fiber length after injection molding was

0.6 mm due to high shear action. The fiber tensile strength and modulus were obtained from the study of Ruksakulpiwat et al. [30], where vetiver fiber was used as the reinforcement. Due to the absence of LGF data in literature review, the properties of vetiver fiber were used instead of LGF. This is because the percentage of cellulose in vetiver fiber is in the same range as lalang grass fiber. The prediction for the tensile properties of the composites were done for four different compositions which are 80 wt.% of PP and 20 wt.% of LGF, 70 wt.% of PP and 30 wt.% of LGF, 60 wt.% of PP and 40 wt.% of LGF and 50 wt.% of PP and 50 wt.% of LGF. However, the fiber and matrix volume fractions are needed to calculate the tensile properties. Therefore, the volume fractions of the matrix and fiber are calculated and shown in Table 3.2.

Table 3.1: Materials data for determining tensile strength and modulus of the composite.

| Category | Parameter |
|---|---|
| **Length of fiber** | 0.6mm [29] |
| **Diameter of fiber** | 0.12mm [31] |
| **Interfacial shear strength** | 3.2 MPa |
| **Tensile strength of fiber** | 247 MPa [30] |
| **Tensile strength of matrix** | 30 MPa [31] |
| **Modulus of elasticity of fiber** | 12 GPa [30] |
| **Modulus of elasticity of matrix** | 1.3 GPa |
| **Stress of matrix at fiber failure** | 26.1 MPa |

Table 3.2: Volume fraction of PP and LGF in the composites.

| Composition | PP, $V_m$ | LGF, $V_f$ |
|---|---|---|
| **80/20** | 0.87 | 0.13 |
| **70/30** | 0.80 | 0.20 |
| **60/40** | 0.71 | 0.29 |
| **50/50** | 0.63 | 0.38 |

### 3.4 Key milestone

Table 3.3: Shows the key milestone for this project.

| **Key Milestone Activities** | **Date** |
|---|---|
| Selection of topic | 20 August 2019 |
| Proposal defense presentation | 14 October 2019 |
| Completion of equation | 25 October 2019 |
| Completion of data collection | 28 February 2020 |
| Completion of calculation | 13 March 2020 |
| Completion of data analysis, documentation and VIVA | 10 April 2020 |

### 3.5 Gantt chart

Table 3.4: Gantt chart of the project.

| KEY MILESTONES AND PROJECT ACTIVITIES | WEEK | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| Completion of Equation | | | | | | | | 25/10 | | | | | | | | | | | | | | | | | | | | |
| Selection of matrix and …..reinforcement | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Selection on the composition ratio | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Selection of calculation method | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Completion of Data Collection | | | | | | | | | | | | | 29/11 | | | | | | | | | | | | | | | |
| Selection of parameters | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Finding references | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Completion of Calculation | | | | | | | | | | | | | | | | | | | | 17/2 | | | | | | | | |
| Calculation of critical fiber length | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Calculation of tensile strength of …..composite | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Completion of Data Analysis | | | | | | | | | | | | | | | | | | | | | | | | 13/3 | | | | |
| Validate with previous experimental …...results | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Evaluate the predictive values | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Completion of Report Writing and VIVA | | | | | | | | | | | | | | | | | | | | | | | | | | | | 10/4 |
| Report writing | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| VIVA | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Mathematical model results

The composite was assumed to have perfect interfacial bonding with no void. The results were calculated using the rule of mixture, modified rule of mixture and Halpin-Tsai. After the critical length was calculated, it was found that the fiber length is smaller than the critical length as to be assumed. The tensile strength and modulus data of the composites were tabulated in Tables 4.1 and 4.2, respectively. As expected, most of the analytical results showed better performance compared to the experimental.

Table 4.1: Tensile strength of the PP/LGF composite.

| Composition | ROM (MPa) | Modified ROM (MPa) |
|---|---|---|
| **80/20** | 32.48 | 24.35 |
| **70/30** | 36.10 | 22.97 |
| **60/40** | 40.07 | 21.14 |
| **50/50** | 44.44 | 18.74 |

Table 4.2: Tensile modulus of the PP/LGF composite.

| Composition | ROM (GPa) | Halpin-Tsai (GPa) |
|---|---|---|
| **80/20** | 2.69 | 2.14 |
| **70/30** | 3.44 | 2.64 |
| **60/40** | 4.40 | 3.33 |
| **50/50** | 5.26 | 3.99 |

## 4.2 Tensile strength

Figure 4.1 shows the tensile strength of the 70/30 PP/LGF composite for both analytical and experimental results. The analytical results were compared with the results that were acquired from the study of PP/LGF by Asokan [31]. As expected, the tensile strength from analytical result using ROM method is significantly higher than the experimental result by 36%. Meanwhile, the tensile strength from the analytical result using modified ROM has a lower value when compared to experimental value. It was noticed that the percentage difference between the modified ROM and experimental value was found to be approximately 13%. This may be due to the presence of clustering parameter in the modified ROM equation, where it takes into consideration of the available fiber stress transfer area.

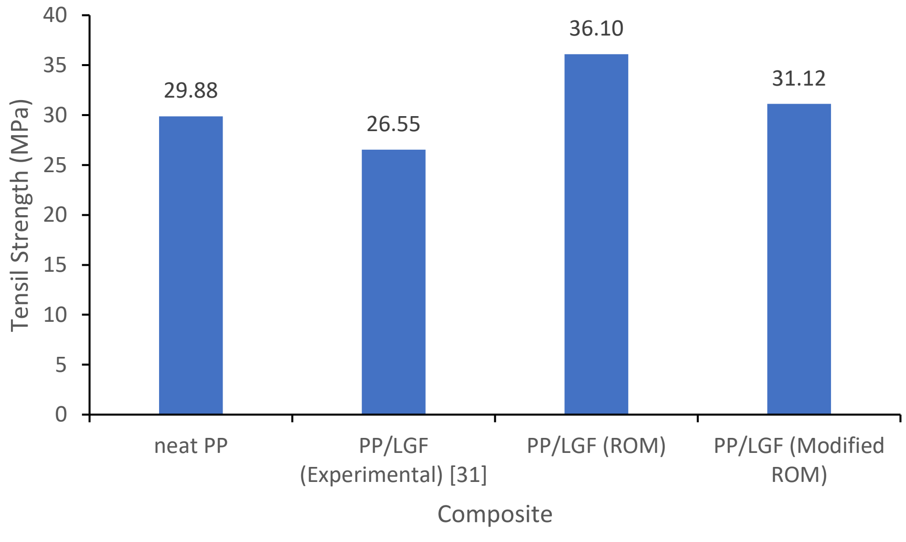


Figure 4.1: Tensile strength of the 70/30 PP/LGF composite for analytical and experimental results.

The predicted tensile strength of LGF reinforced PP composites at various volume fraction of the fiber was shown in Figure 4.2. It was noticed that, modified ROM method produced lower values than ROM method in predicting the tensile strength of the composites. Based on the ROM result, the tensile strength of the LGF reinforced PP composites increased with increasing fiber content. This may be happening because, when using the ROM equation to predict the tensile strength, the composite is assumed to have a perfect matrix/fiber adhesion. Meanwhile, for the modified ROM, the highest tensile strength was observed when the fiber loading is at 20 wt.% and the lowest value was when the fiber loading is at 50 wt.%. This may be due to the amount of fibers present in the composite that influences the fiber-matrix interfacial bonding. In addition, when the fiber volume fraction in the composite is high, the matrix was not able to completely coat the fibers, which may affect the transferability of stresses between the fibers. Therefore, the modified ROM method produced better results because it takes into account the fiber stress transfer area. Hence the higher the fiber content in the composite, the lower the available fiber stress transfer area, which resulting in low tensile strength.

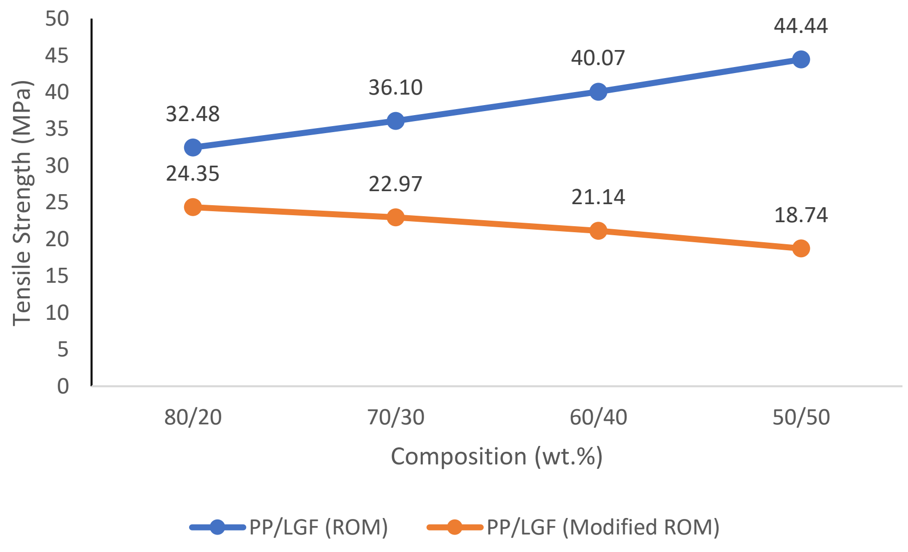


Figure 4.2: Tensile strength of the composite for different composition using ROM and modified ROM method.

## 4.3 Tensile modulus

The predictive values of the tensile modulus for the ROM and Halpin-Tsai method were compared with the experimental value from the study of PP/vetiver by Ruksakulpiwat et al. [30]. The results for the tensile modulus of the 70/30 PP/LGF composite for both analytical and experimental finding was shown in Figure 4.3. Based on the results obtained, the analytical results of the tensile modulus of the composite for both ROM and Halpin-Tsai method showed higher values then the experimental value. The tensile modulus for Halpin-Tsai method and the experimental were recorded at 2.64 GPa and 1.57 GPA, respectively. Meanwhile, the tensile modulus of the composite using ROM method was recorded at 3.44 GPa, which is much higher than that of experimental value. The recorded analytical values were higher than the experimental value may be due to the different mechanical properties that was taken as a replacement for LGF. Based on calculation, Halpin-Tsai equation showed better predictions for the tensile modulus of the LGF reinforced composite. This may be due to the presence of $\mathcal{E}$ in the Halpin-Tsai equation, where the parameter is used to fit the equation with the experimental data. Packing arrangement and fiber-reinforcing geometry were taken into account in calculating the parameter. . It was also found that, the recorded percentage difference between experimental and Halpin-Tsai values is 68%. This percentage is quite high may be due to the assumptions made while collecting the parameters to be used in the equations.

Figure 4.4 shows the tensile modulus of PP/LGF composites at various fiber loading. It showed that the tensile modulus of PP/LGF composites for ROM and Halpin-Tsai methods increased with increasing fiber contents. However, ROM method was found to produce higher values than Halpin-Tsai method. The highest tensile modulus for the ROM method was recorded at 5.26 GPa when the fiber content is 50 wt.%. Meanwhile, the highest tensile modulus for Halpin-Tsai method was recorded at 3.99 GPa when the fiber content is 50 wt.%.

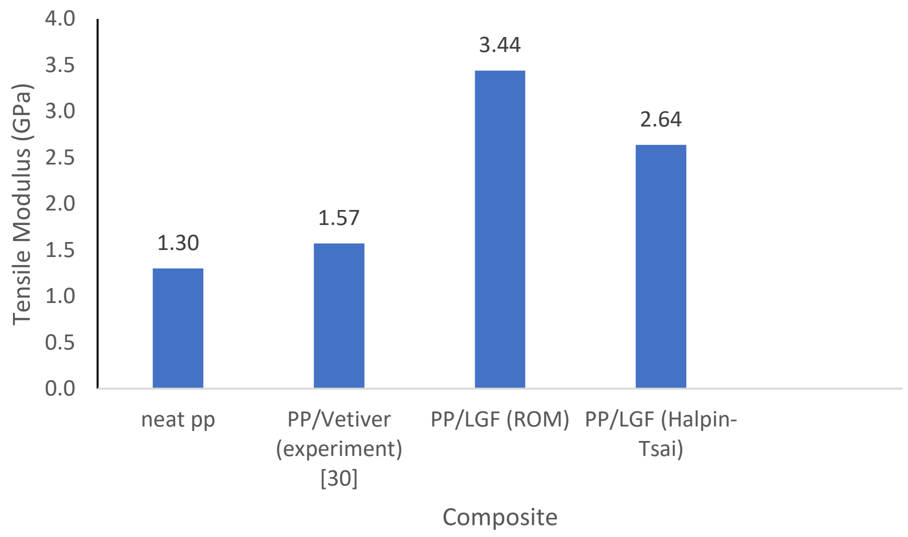


Figure 4.3: Tensile modulus of the 70/30 PP/LGF composite for analytical and experimental results.

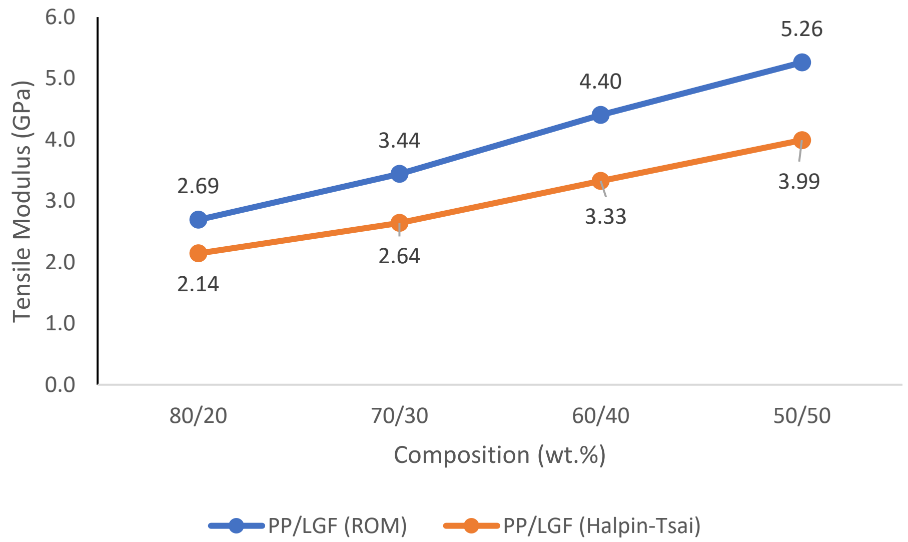


Figure 4.4: Tensile modulus of the composite at different fiber loading using ROM and Halpin-Tsai method.

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

As a conclusion, the objectives of this project were successfully achieved. Tensile strength and modulus of PP/LGF composites were successfully predicted and validated using the proposed method which are ROM, modified ROM and Halpin-Tsai with previous experimental results. Modified ROM method predicts better result for the composite tensile strength when compared to the experimental value with percentage difference of 13%. When using ROM method to predict the composites' tensile strength, the values increased with increasing fiber content. Meanwhile, the highest tensile strength for modified ROM method was achieved at 24.35 MPa when the fiber content is 20 wt.% and it decreased with increasing fiber content. Halpin-Tsai method produced good prediction value for the tensile modulus of the composite where the value is closer to the experimental value compared to the value from ROM method. However, the composite tensile modulus for ROM and Halpin-Tsai method at different fiber loading increased with increasing volume fraction of fiber. The highest tensile modulus for ROM and Halpin-Tsai method. Hence, modified ROM was proven to be the best method to predict the tensile strength of PP/LGF composite, while Halpin-Tsai is the best method to accurately predict the tensile modulus of PP/LGF composite.

## 5.2 Recommendations

The data for the parameters should have been taken from the same materials used in the project to have higher accuracy in predicting the mechanical properties. Other literature reviews, where the composite tensile strengths were studied for different fiber loadings should have been taken to be the comparison data. It would ensure that the comparison can be made for different fiber volume fractions and the best method to predict the tensile properties is clearly visible. Other than that, different other mathematical modelling methods such as inverse rule of mixture, Nairn shear-lag and Mendels et al [32]. should have been used to predict the tensile properties of the PP/LGF composites. This will ensure better comparison can be done and the best mathematical modelling can be chosen from the project.

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