Predicting the Tensile Properties of Recycled Polypropylene (r-PP)/Mengkuang Leaf Fibre (MLF) Composite using Mathematical Modelling

by

Shamni Karthegesu
23078

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

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Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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Approved by,

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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 persons.

Shamni

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SHAMNI KARTHEGESU

ABSTRACT

Mathematical modelling has long been applied to predict the tensile properties of fibre-reinforced composites due to its ability to save time and cost when compared to experimental work. In this research, the natural fibres that were studied were obtained from mengkuang leaves due to its abundance and promising properties shown in previous research. It is also necessary to conduct a study regarding the application of mathematical modelling for natural fibres since it is not widely researched upon. Hence, the aims of this study were to predict the tensile properties of r-PP/MLF composites using mathematical models and to validate the results obtained from the calculations with previous experimental results. The material used in this study were r-PP and MLF with a composition of 60 wt.% and 40 wt.% respectively, while the results were compared to results obtained experimentally from a study published by M. Z. Abdullah and N. H. Che Aslan, titled 'Performance Evaluation of Composite from Recycled Polypropylene Reinforced with Mengkuang Leaf Fiber'. The tensile strength and modulus of the composites were determined. The composite tensile strength of the 60/40 composition was found to be 55.57 MPa and 21.28 MPa and the percentage increase was 256.9% and 36.67% when compared to the experimental value (15.57 MPa) when the ROM and modified ROM equations were used respectively. For composites of 70/30 and 80/20 compositions, they were determined to be 45.02 MPa and 34.48 MPa using the ROM equation and 27.01 MPa and 25.86 MPa when the modified ROM equation was used respectively. The composite tensile modulus of the 60/40 composition were 9.49 GPa and 5.38 GPa while the percentage increase was 182.4% and 60.12% when compared to the experimental value (3.36 GPa) when the ROM and Halpin-Tsai equations were used respectively. For composites of 70/30 and 80/20 compositions, the composite tensile modulus was determined to be 7.37 GPa and 5.25 GPa using the original ROM equation and 6.08 GPa and 2.96 GPa when the Halpin-Tsai equation was used respectively. It can be concluded that the modified ROM equation and the Halpin-Tsai equation were more accurate in predicting the composite tensile properties of the 60/40 composition and displayed a more reliable trend when estimating the tensile strength and modulus values of the 70/30 and 80/20 compositions.

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CHAPTER 1

INTRODUCTION

This chapter discusses the background of study, problem statement, objectives and the scope of this project.

1.1 Background of Study

Micromechanical modelling has long been used to analyse the behaviour of composite materials from a micromechanical aspect. The rule of mixture equations have been used to predict the tensile values of fibre-reinforced composites. Though the values obtained from these equations are not as accurate as the ones obtained experimentally, these equations help in studies since they greatly reduce cost and time. In addition, these equations make several assumptions such as perfect bonding between the matrix and fibre interfaces. However, this assumption does not reflect reality since the fibre could be non-homogeneous or misaligned.

Therefore, to ensure that the predicted values do not deviate too far from experimental values, these equations have been modified to take into account various factors that were not considered in the original rule of mixture equation. In the past years, a great increase in researches and publications can be observed that address the aforementioned issue.

Natural fibre composites have been gaining more recognition as of late due to the growing economic and environmental awareness [1]. Natural composites are being used in multiple industries and for various applications and purposes. The natural fibres used in these composites are typically obtained from various plants such as kenaf, jute, pineapple and banana leaves.

Environmental problems that include reduction of crude oil, animals consuming plastic and the high price of manufacturing have made it essential to study natural fibres to ultimately replace synthetic fibres. Natural fibres are generally flexible during the manufacturing process, are low on price (referring to volume), low density, less abrasive towards tools and possess a moderately high specific stiffness and strength which is useful in making structural composites and greatly preferred by manufacturers [2,3].

Some of the most popular thermoplastics that are used as matrices in natural fibre composites include polypropylene (PP), polyethylene (PE) and polyvinyl chloride (PVC) [5]. By definition, thermoplastics are polymers that comprise of chain molecules that are linear. The strength of the bond within the chain is high but low between chains. When heated, thermoplastics soften and will eventually liquefy but will still harden when cooled after. Therefore, they can be altered in terms of shape and recycled which is a property that brings additional benefits [4].

Natural fibre reinforced composites (NFC) are composites that use fibres obtained from natural sources as reinforcement. During recent years, NFC has gained worldwide attention due to its many merits. A great number of manufacturers lean towards NFC because natural fibres are low in density, able to biodegrade, abundant in availability and is non-toxic. These characteristic have been proven to be optimal when using them as filler in polymer composites [5].

1.2 Problem Statement

As a consequence of the growing environmental concerns regarding the overuse of plastic, an increasing amount of manufacturing industries are leaning towards the usage of biopolymers instead of plastic composites. The use of mengkuang leaf fibres (MLF) to reinforce these composites have not been widely researched upon but has the potential to be used as a natural reinforcement and also grows in abundance in Malaysia. In addition, the rule of mixture method is usually applied when predicting tensile properties of composites reinforced with synthetic fibres. Therefore, it is necessary to implement the rule of mixture models for natural fibre reinforced composite and modify them to enhance prediction accuracy of these tensile properties.

1.3 Objectives

The objectives of this project are:

i. To predict the tensile properties of r-PP/MLF composites using mathematical models.

ii. To validate the results obtained from the calculations with previous experimental results.

1.4 Scope of Project

The material used as the matrix was recycled polypropylene (r-PP) while Mengkuang leaf fibres (MLF) were employed as the reinforcement in the composites. In this study, a composition of 60 wt.% r-PP and 40 wt.% (MLF) were evaluated. The length and diameter of fibres used have been determined to be 7.5 mm and 1 mm respectively. The prediction of the tensile properties of the neat r-PP as well as the r-PP/MLF composite were done using the rule of mixture model and were validated against previous experimental results. The prediction results were compared to the experimental results obtained from the study published by M. Z. Abdullah and N. H. Che Aslan, titled 'Performance Evaluation of Composite from Recycled Polypropylene Reinforced with Mengkuang Leaf Fiber'.

CHAPTER 2

LITERATURE REVIEW

In this chapter, polypropylene, natural fibres, rule of mixture method and the factors affecting natural fibres and polymer composite tensile properties are reviewed.

2.1 Polypropylene

Polypropylene is polymer of thermoplastic nature which can be made when polypropylene molecules undergo the polymerisation process [6]. PP is one of the most vastly used thermoplastics used as a matrix in polymer composites. The reasons why PP is highly sought after, is because it is low in cost and density and high heat distortion temperature [7]. As shown in Figure 2.1, it can be noticed that the demand of PP has greatly increased from 1999 to 2004.

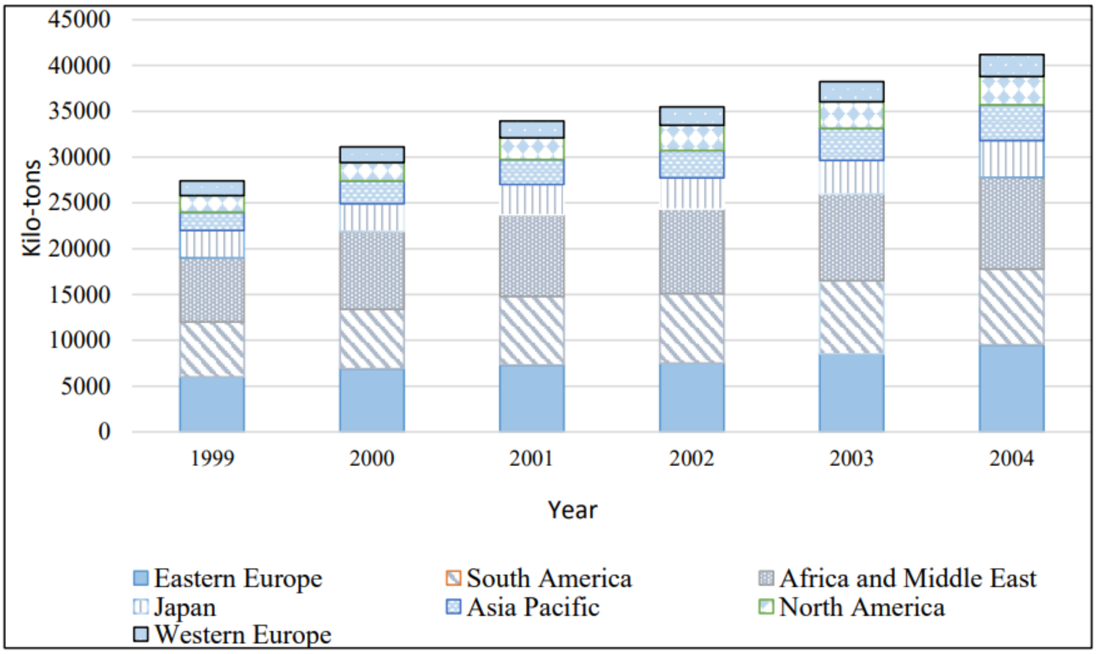

Figure 2.1: Polypropylene consumption by region from 1999 to 2004 [7].

Even though similar, there are some slight differences between neat PP (PP) and recycled PP (r-PP) in terms of mechanical properties. Based on a study done by Homkhiew et al. [8] the tensile properties of PP and wood flour composite is compared to that of r-PP and wood flour. It was observed that with the same plastic to wood flour ratio, the composite comprised of PP exhibited a higher tensile strength than those based on r-PP.

2.2 Natural Fibre

According to the source, natural fibres can be categorised into five major types which include wood, fruit, leaf, bast and leaf. Natural fibres consist of mainly three components which are lignin, cellulose and hemicellulose. These natural polymers contain hydroxyl and are dispersed all through the cell wall. Natural fibres are also comprised of ranging quantities of wax, pectin and other compounds of low molecular weight.

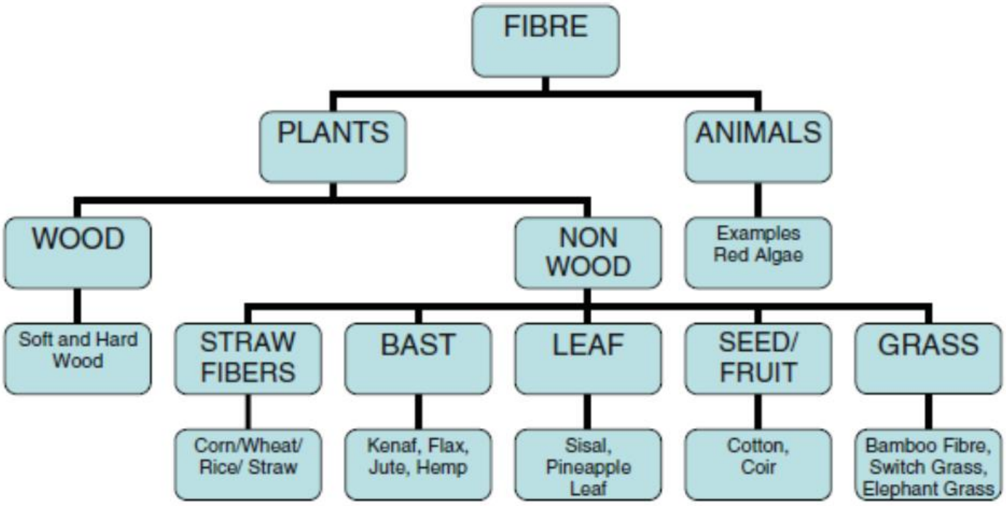

Figure 2.2: Classification of natural fibres [9].

Natural fibres have been gaining popularity in recent decades due to the merits they bring compared to traditional fibres. They have been known to be cheap, have less dense, high specific properties, are biodegradable and not abrasive [10]. Nevertheless, composites reinforced with natural fibres still have some drawbacks that hinder their expansion in the market. These problems mainly include problems during processing due to restrictive processing temperature range, hydrophilic nature of the fibre, bacterial degradation, poor dimensional stability due to water absorption, varying mechanical properties and other difficulties during processing [11].

The main purpose of the matrix is to transfer loads onto the fibre. Determining the most suitable composition is essential to enable the composition to support great forces without affecting other mechanical properties [12]. Based on research conducted by T. Quynh Truong Hoang et al. [13], the tensile behaviours of PP and r-PP with spruce fibres composites were evaluated. It was found that the tensile modulus and yield stress of r-PP was lowered by 8.5% and 7% respectively when compared to PP.

However, when 30 wt.% and 40 wt.% of spruce fibres were included, it improved the tensile stiffness of composites with r-PP even further than that of neat PP. Nevertheless, it was noticed that the addition of spruce fibres contributed to the brittleness of the material because of the agglomeration and concentration of stress transfer which lead to a distinct drop in elongation at break and a reduction in yield stress.

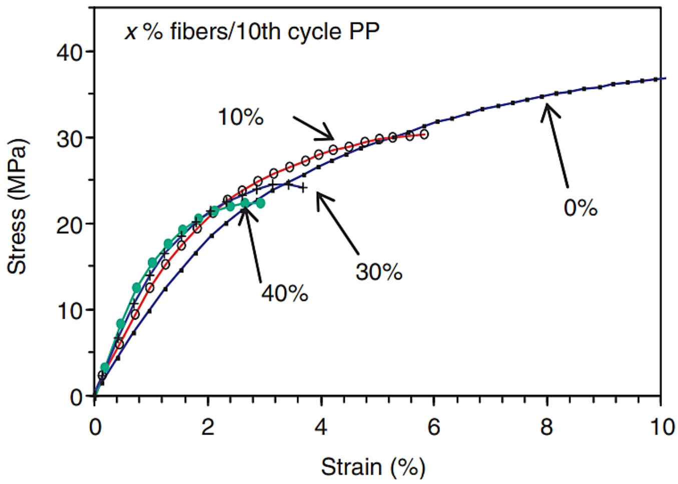

Figure 2.3: Tensile behaviour of various spruce fibre/recycled PP composites [13].

Table 2.1: Comparison of mechanical characteristics for the studied materials [13].

Test Specimen	Young's modulus (MPa)	Elongation at break (%)	Yield stress (MPa)	Toughness (MPa$\sqrt{m}$)
PP	1880 $^{\pm51}$	120	41.5 $^{\pm0.1}$	2.2 $^{\pm0.1}$
r-PP	1720 $^{\pm03}$	63 $^{\pm14}$	38.6 $^{\pm0.6}$	2.5 $^{\pm0.1}$
r-PP/10% spruce fibres	1864 $^{\pm24}$	6.1 $^{\pm0.3}$	30.0 $^{\pm0.1}$	-
r-PP/30% spruce fibres	2315 $^{\pm42}$	3.6 $^{\pm0.3}$	24.0 $^{\pm0.1}$	2.7 $^{\pm0.1}$
r-PP/40% spruce fibres	2575 $^{\pm26}$	3.2 $^{\pm0.3}$	22.5 $^{\pm0.3}$	-

2.3 Rule of Mixture

Tensile properties of composites are usually determined by experimental means. However, extra experimental work is needed if one or more fabrication parameters are changed and will ultimately result in unnecessary additional time and money being spent. This can be prevented if the tensile properties with various fabrication parameters can be predicted by applying a micromechanical model whereby the experimental work required is minimal. The rule of mixture (ROM) models are frequently used as a fairly easy method and it generates acceptable values that are comparable to values obtained experimentally [14].

The ROM method predicts the tensile performance of fibre reinforced polymers (FRP) based on the following assumptions [15]:

1. One ply is homogeneous on a microscopic level, linearly elastic, orthotropic and is originally in a non-stressed state.

2. The fibres in the composite is linearly elastic, homogeneous and is well-arranged.

3. The matrix is linear elastic, homogeneous and isotropic

4. There are no empty spaces present, and the fibre and matrix are completely linked.

Equations 2.1 and 2.2 are the ROM equations commonly used to predict the tensile values of fibre-reinforced composites. The appropriate equation is dependent on the fibre length, l and the critical length of the fibre, l_c, Meanwhile, Equation 2.3, is applied to find the tensile modulus of a fibre-reinforced composite.

If $l \geq l_c$,

$$\sigma_{1U} = \sigma_{FU}\left(1 - \frac{l_c}{2l}\right)V_f + \sigma'_m(1 - V_F) \quad (2.1)$$

If $l \leq l_c$,

$$\sigma_{1u} = \tau V_F\left(\frac{l}{2}\right)\left(\frac{W+T}{WT}\right) + \sigma'_m(1 - V_F) \quad (2.2)$$

$$E_{cd} = E_m V_m + E_f V_f \quad (2.3)$$

There are, however, some shortcomings of using this method. ROM presumes that the fibres are aligned in one direction, and when stress is equally spread. In actual fact, the fibres in a composite may not be uniformly spread and homogeneous [16]. As shown in Figure 2.5, equal deformation of the fibre and the matrix is also a factor considered in ROM, but both of these materials possess different tensile properties, leading to shear-lag that can result in rupture to occur in the composite.

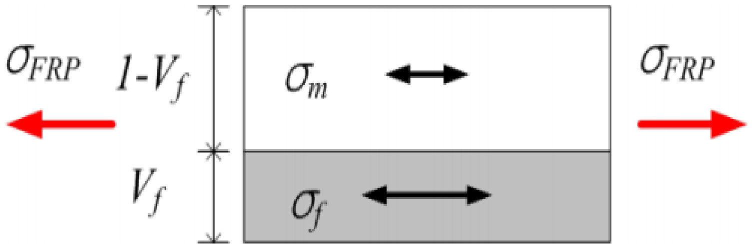

Figure 2.4: Schematic diagram of deformation of FRP under stress [17].

2.4 Modified Rule of Mixture Equation

In the original ROM equation, there are many assumptions that are made regarding the composite. These assumptions propose that the conditions in these composites are perfect, when in reality there are many instances and factors that many produce a multitude of variations in them. Therefore, the ROM tends to overestimate the composite tensile strength. This is why it is essential to modify the rule of mixture equation to estimate the tensile properties more accurately [18].

Past studies have shown that the ROM prediction is accurate for fibres that are short in length or for composites that consist of low content of fibre. Unfortunately, as the fibre levels increase, the greater the deviation of the predicted values are from the experimental values. This could be attributed to the tendency for fibres to agglomerate that could lead to uneven dispersion of stress between the fibres that are agglomerated and the ones that are not. Following that, many modification have been integrated which included Hirsch combined the parallel and series ROM models [19]. Meanwhile Cox created a model for shear lag to evaluate the efficiency factor for the length of fibre which was later combined into the parallel ROM [14].

The following equation is the modified version of the original ROM equation to predict the composite tensile strength.

$$\sigma_{1u} = \alpha\tau V_F \left(\frac{l}{2}\right)\left(\frac{W+T}{WT}\right) + \sigma'_m(1 - V_F) \qquad (2.4)$$

2.5 Halpin-Tsai Equation

As can be told by the name, this equation was generated by Halpin and Tsai to predict the properties of elasticity for short fibre reinforced thermoplastics. In this equation, the value of ξ plays a significant role in the calculations because it accounts for the packing arrangement and the fibre geometry. This parameter also plays an essential role in fitting the shape of the data determined from the equation to the ones obtained from the experiment.

There are many variations of ξ have been found in past studies and they are dependent on the particle shape and the modulus predicted [20].

The Halpin-Tsai equation is displayed below:

$$E_1 = E_M \frac{1+\xi\eta V_F}{1-\eta V_F} \qquad (2.5)$$

2.6 Factors Affecting Natural Fibre/Polymer Composites Tensile Properties

2.6.1 Fibre Content

With the incorporation of natural fibres in polymer composites, an observable increase can be noticed in the tensile properties. This increment in tensile strength can be attributed to the exceptional tensile strength exhibited by natural fibres in contrast to the polymer matrix [21]. This is depicted when kenaf fibres possess a tensile strength of 500-1500 MPa and a tensile modulus of 53 GPa. When compared to thermosets and thermoplastics, they only have a tensile strength of 14.5-100 MPa and a tensile modulus of 0.055-6GPa [22].

When the optimum fibre content is reached, the tensile strength in polymer composites begins to decrease. The reduction is due to the fact of the increase in porosity content [23] and the tendency of fibre agglomeration [24] which limits the area of fibre stress transfer.

2.6.2 Fibre Length

The length of a fibre is an essential factor in the tensile properties of a fibre/polymer composite and is usually affiliated with the aspect ratio of the fibre (length/diameter). This is accurate for fibres that are short in nature. When axial stress is supplied to the composite it is transferred from the matrix to the fibres by way of shear stress at the interface between the fibre and matrix. When the stress that is transferred, surpasses the tensile strength of the fibre, failure will be experienced.

The last fragment length that remains is defined as the critical fibre length (L_c). The critical fibre length represents the ability of the interface between the matrix and fibre to distribute load. Some of the elements that can affect critical length include fibre diameter, matrix, treatment of fibre and content of fibre. When the fibre length exceeds L_c, it is known as supercritical length while fibre lengths that are shorter than L_c are called subcritical length.

A theoretical study was conducted by Beckermann and Pickering [24] with hemp fibre/polypropylene composites where the fibres were assumed to be aligned perfectly. It was found that 50.4% of supercritical and 49.6% of subcritical length fibres led to 68.1% and 31.95% to the tensile strength of the composite, respectively. The reduction in tensile strength associated with the subcritical length of fibre is due to its inability to be completely stressed, unlike supercritical fibre lengths that possess a larger proportion in the centre of the fibre that enables it to be fully stressed.

2.6.3 Fibre Diameter

The cross-sectional area (CSA) of the fibre is directly influenced by the diameter of the fibre. Meanwhile, both of these properties affect the tensile properties, strength and modulus of the fibre. This can be confirmed by the results obtained from the study conducted by Panigrahi et al. [25] where the flax fibre/high density polyethylene composites experienced an increase in the tensile strength and modulus when the fibre diameter is reduced from 31.6µm, 26.1µm to 19.3µm.

Teles et al. [26] revealed that the relationship between the pineapple leaf fibres tensile strength and the diameter of the fibre is inversed. For a fibre length of 10 cm, the tensile strength of the fibres was 289.4 MPa at a diameter range of 0.10 mm < d < 0.13 mm and is 44.4 MPa when the range of the diameter is 0.25 mm < d < 0.28 mm. The increment on tensile strength with the reduction of the fibre diameter is affiliated with the presence of lesser number of defects and porosity of the fibre microstructure when observed in the Scanning Electron Microscopy.

2.6.4 Fibre Orientation

NFC are anisotropic because of the orientation of the fibres within the composite whereby the ideal tensile values are obtained when the angle of the fibre orientation is 0˚. In reality, however, this is impossible to be achieved with especially by short fibres due to it being unable to distribute stress close to the ends of the fibres. As the fibre orientation angle to loading direction increases up until 90˚, the composite tensile strength progressively declines.

This is because the natural fibres contribute the least to the overall strength of the composite while the majority of the stress is experienced by the polymer matrix, unlike when the fibre orientation angle is 0˚ to the loading direction. Baghaei et al. [27] noticed a downhill trend for PLA/hemp composites in their tensile strength (from 72.75, 34.75 to 22.01 MPa) and tensile modulus (from 8.77, 4.62 to 3.70 GPa) with an increase in fibre orientation angle (from 0˚, 45˚ to 90˚).

2.6.5 Interfacial Shear Strength

The area in between the natural fibres and the polymer matrix in a NFC is called an interface. Though this region is small, it plays an important role when determining the tensile properties of the composite since it helps in stress transfer between the matrix and the fibre. Therefore, it is essential for NFC to have a secure interface to attain ideal tensile values [23] but it is vital to first characterise the strength at the interface of NFC before attempting to improve it by means of treatment.

Therefore, several studies have been done to develop experimental methods to evaluate the interfacial strength by determining the interfacial shear strength (IFSS) using several micromechanical tests which consist of the single fibre pull out test, single fibre fragmentation test, single fibre compression test and microdebonding test [28].

There have also been studies where different types of treatments were attempted to improve the IFSS of the NFC which can be caused as a result of the how incompatible the hydrophilic fibres and hydrophobic polymer are between each other. Some of the ways to enhance the IFSS, can be achieved by physical or chemical treatment or both. By introducing physical and chemical treatment onto the fibres, causes physical changes on the fibre which involve fibre surface roughness while chemical treatment alters fibre surface polarity, hydrophobicity and crystallinity [23].

CHAPTER 3

METHODOLOGY

This chapter will comprise of the process flow, list down the key milestones and activities as well as the Gantt Chart of this whole project. The definition of parameters, Rule of Mixture equations, the modified Rule of Mixture equations and the Halpin-Tsai equation are discussed in detail in this chapter.

3.1 Process Flow

The flow of this project that was executed from the identification of the proper prediction method, until the obtainment and analyzation of data is shown in Figure 3.1.

3.2 Definition of Parameters

3.2.1 Dimensions of Fibre

According to the scope of the project as stated before, the length of the fibre is 7.5 mm. These dimensions are based from the values used in the study done by M. Z. Abdullah and N. H. Che Aslan [1]

However, it must be taken into account the reduction in length of the fibre after going through the compounding and extrusion process. A study has shown that after the extrusion process at a 180˚C, that 30% of the fibres in a PP/kenaf composite were reduced, from a length of 7.5 mm to 0.6 mm [29]. Hence, the length of the fibre determined to be 0.6 mm.

The width (W) and thickness (T) of the fibre were measured using SEM images of previous experiments. The width and thickness of the fibre were determined to be 0.07143 mm and 0.02857 mm respectively.

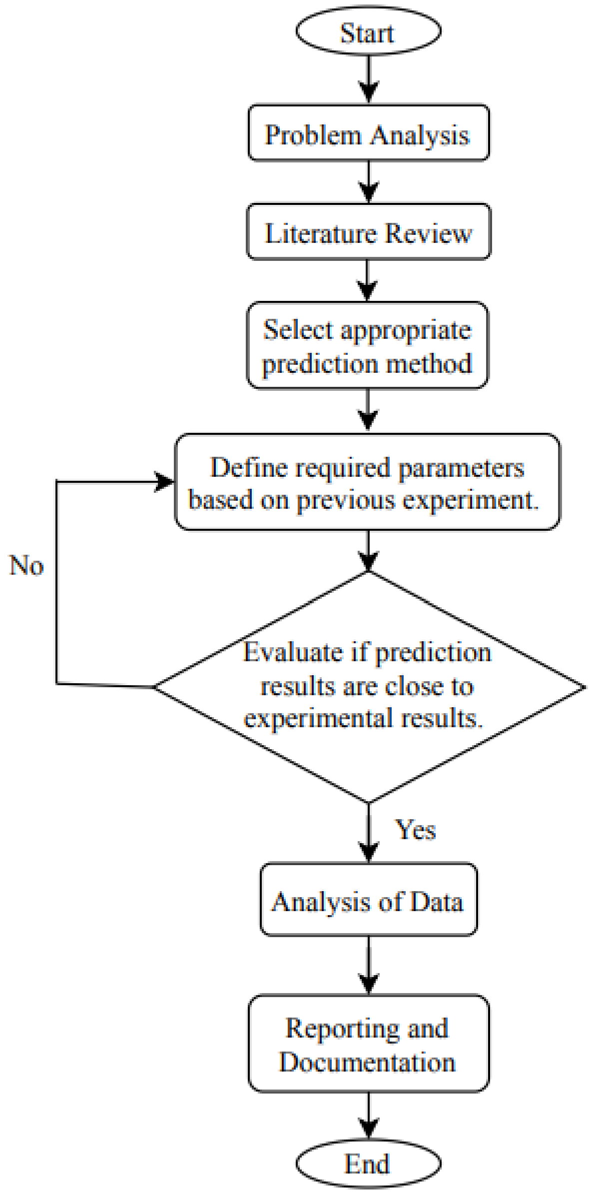

Figure 3.1: Process Flow of Project.

3.2.2 Tensile Strength (σ_f) and Modulus of Elasticity of Fibre (E_f)

Since the amount of cellulose in both kenaf and mengkuang leaves are within the same range, the necessary values needed about mengkuang leaves were assumed based from kenaf leaves' properties. The density, tensile strength and tensile modulus of kenaf fibres are 1.2 g/cm^3, 374.5 MPa and 25.07 GPa respectively [27].

3.2.3 Fibre-Matrix Bond Strength (τ_c)

The τ_c value was obtained from the following formula [28]:

$$\tau_c = \frac{\sigma_{MY}}{2} \qquad (3.1)$$

Where the σ_{MY}, is the matrix yield strength. However, since the yield strength of r-PP cannot be found, it was assumed to be 18.08 MPa which is its tensile strength based on previous research [1]. Using the formula above, the τ_c was found to be 9.04 MPa. This τ_c value is only applicable to the original ROM equation.

For the modified ROM, however, the τ_c is different from the value shown above. The theoretical and experimental values of the peak fibre stress was made sure to be in agreement by altering the interfacial shear strength. Once they are, the τ_c value that is associated with it is determined as the interfacial shear strength. Therefore, the value was found to be 4.74 MPa.

3.2.4 Modulus of Elasticity of r-PP (E_m) and Stress in Matrix at Composite Failure (σ'_m)

The value of the modulus of elasticity of neat r-PP is determined experimentally to be 1.6 GPa [1] while the stress in matrix at composite failure was found to be 15.73 MPa according to the stress-strain curve.

3.3 Rule of Mixture Equations

3.3.1 Composite Tensile Strength (σ^*_{cd})

To determine the most suitable composite strength equation to use, the critical length, l_c of the rectangular fibre must be evaluated. To do so, the following equation is used:

$$\frac{l_c}{T} = \frac{\sigma_{FU}}{\tau_i} \qquad (3.2)$$

Where σ_{FU} is the fibre tensile strength, T is the fibre thickness and τ_i is the fibre-matrix bond strength (18.08 MPa). Inserting the values stated when defining the parameters, the critical length was calculated to be 1.18 mm.

In this study, the fibres in the composite are discontinuous in nature. There are two equations that could be used to calculate the composite tensile strength, depending on the value obtained for the critical length, l_c and the length of the fibre, l.

Referring to the critical length that was found, Eqn, 2.2 is used to find the composite strength since the $l < l_c$.

3.3.2 Composite Elastic Modulus (E_{cd})

Equation 2.3 was used to evaluate the tensile modulus value of the r-PP/MLF composite.

3.4 Modified Rule of Mixture

3.4.1 Composite Tensile Strength (σ_{1u})

The modified equation used to find the composite strength (σ_{1u}), that are reinforced with rectangular fibres is Equation 2.4, where the clustering parameter (α) is found using the formula [28]:

$$\alpha = \frac{V_F}{V_{F,MAX}} \qquad (3.3)$$

Inputting values found from before, it was found that α is 0.506. Hence, the composite strength using the modified rule of mixture equation was found to have a value of 30.85 MPa.

3.4.2 Composite Elastic Modulus (E_1) using Halpin-Tsai Equation

First, the shape fitting parameter, ξ to fit the experimental results to the Halpin-Tsai equation needs to be taken into account.

$$\xi = 2\frac{L}{T} \tag{3.4}$$

Next, the η should be calculated by using the following formula [28]:

$$\eta = \frac{(E_F/E_M)-1}{(E_F/E_M)+\xi} \tag{3.5}$$

And when the η value is obtained, it is inserted into the Haplin-Tsai equation as shown in Equation 2.5 previously.

3.5 Milestones and Gantt Chart

The dates listed down in Table 3.1 shows the planning of the project with key milestones for the duration of the Final Year Project. It is essential to ensure that each progress milestone is achieved by the due dates that have been pre-determined during the planning phase. In Table 3.2, the Gantt Chart of this project show the activities carried out and key milestones achieved throughout the two semesters of executing this project.

Table 3.1: Key Milestones and Activities throughout Final Year Project.

Key Milestones/ Activities	Week
Completion of problem analysis	6
Completion of Rule of Mixture Analysis	12
Completion of calculation	14
Completion of data analysis	21
Completion of report documentation and dissertation submission	28

Table 3.2: Project Gantt Chart.

Description of Activities & Key Milestones	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 Problem Analysis						▲ 11/10/19																						
Preliminary research work	■	■	■																									
Collect and study past research papers				■	■	■																						
Completion of Rule of Mixture Analysis												▲ 22/11/19																
Study Rule of Mixture method						■	■	■																				
Identify appropriate calculation method								■	■																			
Determine appropriate parameters to set during calculation									■	■																		
Find values needed for calculation work based on past experimental research										■	■	■																
Completion of Calculation														▲ 6/12/19														
Input parameters and values found into Rule of Mixture equation													■	■														
Completion of Data Analysis																					▲ 24/2/20							
Validate results obtained with past experimental data.															■	■	■											
Tabulate and generate graphs from data obtained																		■	■	■	■							
Completion of Report Documentation and Dissertation Submission																												▲ 13/04/20
Report documentation																						■	■	■	■			
Final presentation and dissertation submission																										■	■	■

CHAPTER 4

RESULT AND DISCUSSION

This chapter describes the calculation results obtained from this research. The graphs shown below present the values obtained for the tensile strength and tensile modulus experimentally from past research. It also includes the values that were determined through the ROM and modified ROM equations.

4.1 Tensile Strength

4.1.1 Predicting Composite Tensile Strength of 60/40 Composition

The tensile strengths of neat PP, neat r-PP, r-PP/MLF (experimental value), r-PP/MLF (using ROM) and r-PP/MLF (using modified ROM) are documented in Table A1 in the Appendix.

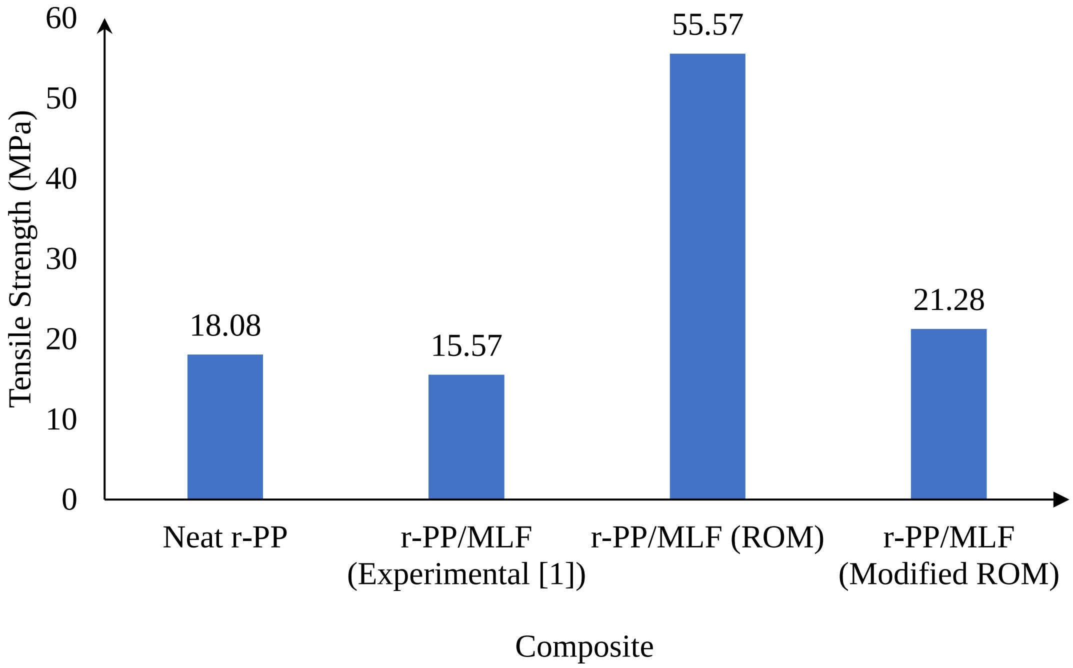

Figure 4.1: Tensile strength of neat PP, neat r-PP, r-PP/MLF (experimental [1]) and r-PP/MLF (using ROM and modified ROM).

Based on Figure 4.1 as shown in page 19, the tensile strength value calculated using the original ROM equation (55.57 MPa), it is much greater compared to when modified ROM is used. In addition, the value acquired by implementing the modified ROM, which was 21.28 MPa, was much more accurate in predicting the experimental composite tensile strength (15.57 MPa).

This can be narrowed down to the fact that the original ROM equation assumes a variety of condition in the composite which are not necessarily true in reality. The original ROM assumes that the matrix and fibre phases are perfectly bonded together and that the fibres are properly aligned. The fibre curvature is also neglected.

The major difference in both equations that were used was that the modified ROM incorporated the clustering parameter, α. This parameter is known as the ratio of total fibre surface area to the area that is accessible to load transfer. Composites are highly susceptible to a variety of microstructural changes when they undergo manufacturing processes. Since these processes are unable to be perfectly controlled, a phenomenon known as fibre clustering has a tendency to occur. When this takes place, the distribution of the composite microstructure is no longer consistent and can ultimately affect the performance and the properties of the composite.

4.1.2 Predicting the Composite Tensile Strength of 70/30 and 80/20 Compositions

The tensile strength of the r-PP/MLF composite was also predicted for compositions of 70/30 and 80/20 as shown in Figure 4.2 in the next page. According to the figure as well, the trend of the composite tensile strength can be seen. The data associated with graph is presented in Table A2 in the Appendix.

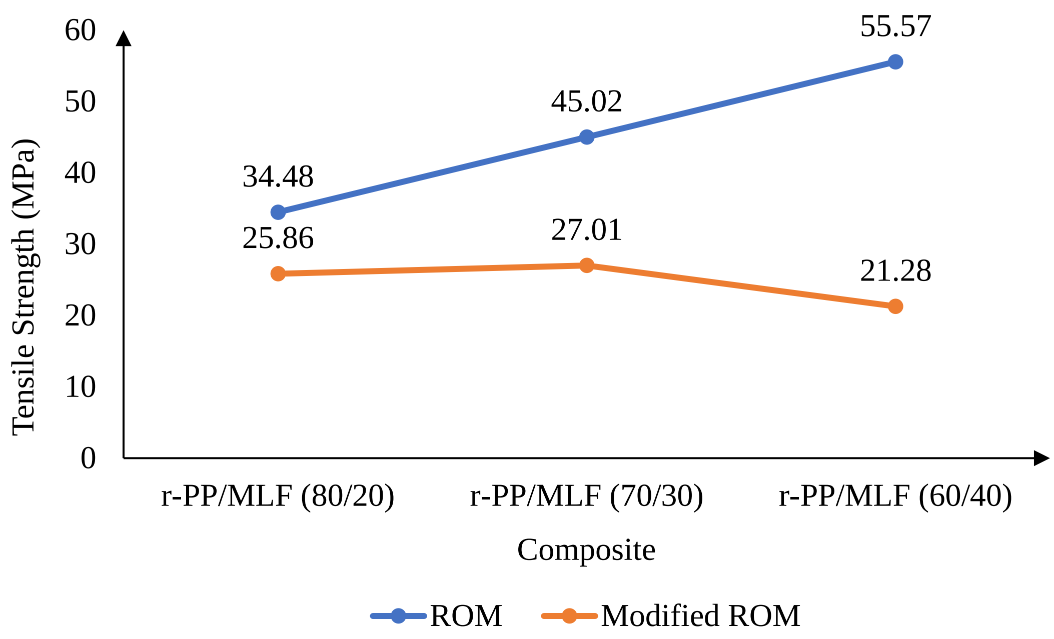

Figure 4.2: Composite tensile strength prediction of 60/40, 70/30 and 80/20 r-PP/MLF compositions.

The graph in Figure 4.2 in the previous page validates the accuracy when the modified ROM is used to predict the tensile strength of the composite. Using the original ROM equation, a linear increase can be seen in the tensile strength values which are 34.48 MPa, 45.02 MPa and 55.57 MPa for compositions of 80/20, 70/30 and 60/40 respectively. This trend is can be attributed to the fact that the tensile strength increases as fibre content increases.

Using the modified ROM equation, however, shows that the tensile value is predicted to increase from 25.86 MPa to 27.01 MPa and decrease to 21.28 MPa for compositions of 80/20, 70/30 and 60/40 respectively. The increase in the tensile strength could mean that the 70/30 composition is the ideal composition where the distribution of fibre is expected to be more even. The 60/40 composition showed a decrease in tensile strength value since the wettability of fibres by the matrix as the fibre loading increases. Therefore, it could be said that the modified ROM is far more accurate for prediction purposes since it takes into consideration the fibre wettability phenomenon.

4.2 Tensile Modulus

4.2.1 Predicting Composite Tensile Modulus of 60/40 Composition

The tensile modulus values of neat PP, neat r-PP, r-PP/MLF (experimental value), r-PP/MLF (using ROM) and r-PP/MLF (using modified ROM) are shown in Table A3 in the Appendix.

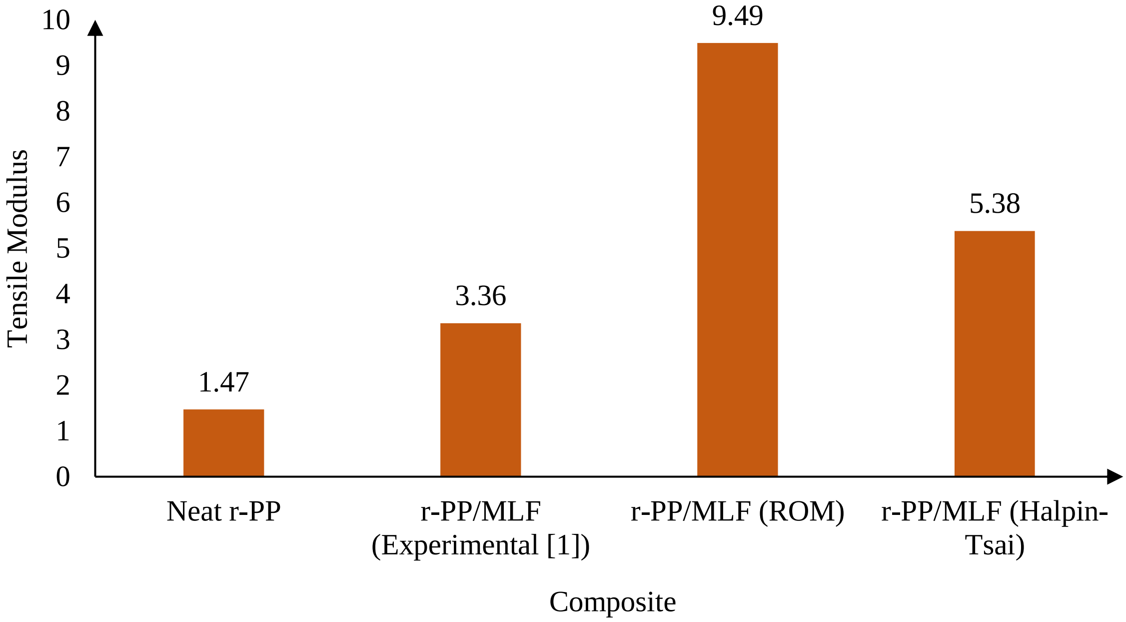

Figure 4.3: Tensile modulus of neat PP, neat r-PP, r-PP/MLF (experimental [1]) and r-PP/MLF (using ROM and Halpin-Tsai).

Based on Figure 4.3, it clearly can be seen that the tensile modulus value determined when the original ROM equation is applied (9.49 GPa) has a greater deviation from the experimental value (3.36 GPa) when compared to the value obtained when the Halpin-Tsai equation was used (5.38 GPa). It can be said that the Halpin-Tsai equation is far more capable of predicting the tensile modulus of the composite.

The accuracy of the Halpin-Tsai equation considers imperfect conditions between the fibre and matrix phases interface. This better represents real-life situations where these manufactured composites are more likely to lack proper interfacial bonding between these two phases. As discussed in the previous chapter in this paper, the Halpin-Tsai equation includes a shape-fitting variable that fits it to the data obtained from experimental work and is influenced by the fibre geometry and packing arrangement.

4.2.2 Predicting the Composite Tensile Modulus of 70/30 and 80/20 Compositions

The tensile modulus of the r-PP/MLF composite was also predicted for compositions of 70/30 and 80/20 as shown in Figure 4.4 below. The data obtained from the graph is presented in Table A4 in the Appendix.

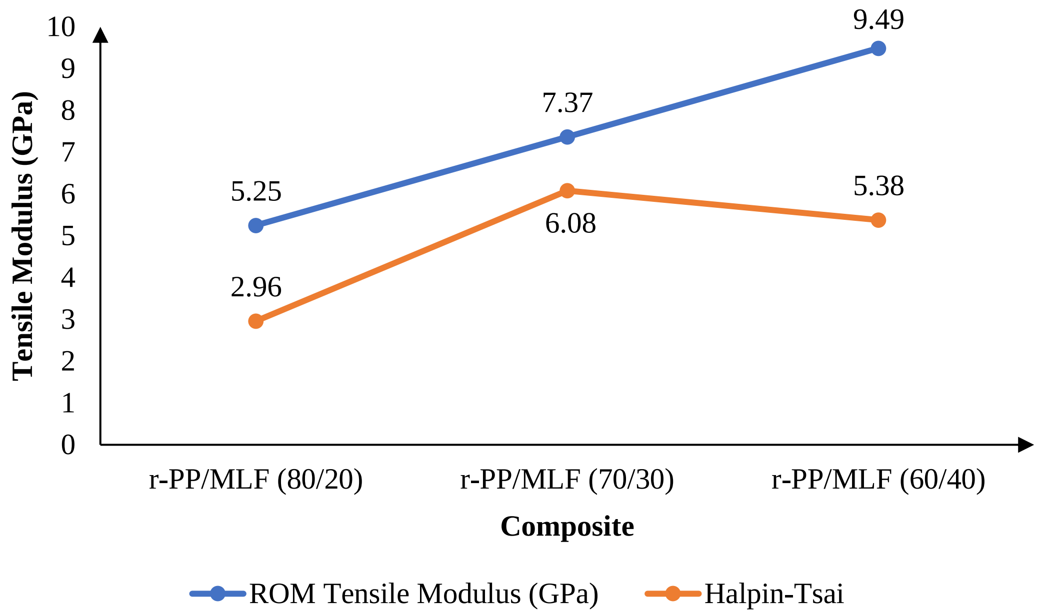

Figure 4.4: Composite tensile modulus prediction of 60/40, 70/20 and 80/20 r-PP/MLF compositions.

Figure 4.4 above, shows that when the ROM equation is used, the graph shows that as fibre content increases, the tensile modulus of the composite also shows an increase in value from 5.25 GPa to 7.37 GPa and finally 9.49 GPa for a composition of 80/20, 70/20 and 60/40 respectively. Theoretically, this trend is correct since the increase in fibre content will produce a greater stiffness in the composite.

However, in the Halpin-Tsai equation, the tensile value was seen to increase from 2.96 GPa to 6.08 GPa and then decline to a value of 5.38 GPa for compositions of 80/20, 70/30 and 60/40 respectively. The increase in the tensile modulus could mean that the 70/30 composition would be the most ideal. The decline in the tensile modulus that is anticipated from the 60/40 composition could be due to the poor interfacial bonding or the lack of proper fibre distribution. When the fibre is not evenly dispersed throughout the composite, the transfer of stress between the fibre and matrix phases cannot take place in the proper manner.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

To conclude, the objectives of this study were achieved where the tensile properties of the r-PP/MLF composites of 60/40 composition were predicted and validated with previous experimental work. The tensile strength value was predicted to be 55.57 MPa using the original ROM equation and was 21.28 MPa using the modified ROM equation. It was observed that the value obtained when the modified ROM equation was applied was closer to the experimental value of the r-PP/MLF composite which was 15.57 MPa.

For composites of 70/30 and 80/20 compositions, it was determined to be 45.02 MPa and 34.48 MPa using the ROM equation and 27.01 MPa and 25.86 MPa when the modified ROM equation was used respectively.

Meanwhile, the composite tensile modulus of the 60/40 composition was 9.49 GPa, using the ROM equation and 5.38 GPa using the Halpin-Tsai method. It was noticed that the value obtained from the Halpin-Tsai method was far more accurate in predicting the experimental tensile modulus value which was 3.36 GPa.

For composites of 70/30 and 80/20 compositions, the composite tensile modulus was determined to be 7.37 GPa and 5.25 GPa using the original ROM equation and 6.08 GPa and 2.96 GPa when the Halpin-Tsai equation was used respectively.

5.2 Recommendations

Past research has shown an increase in tensile properties when the natural fibres were subjected to alkaline treatment and when coupling agent is added to the mixture. Hence, the Rule of Mixture equations should be modified to include calculations that take into consideration the effects of surface treatments and coupling agents in the changes of tensile values. This way, the values can be predicted without having to determine it by experimental means which can prove to be costly and time-consuming.

The modified Rule of Mixture equations could be further improved in the future by taking into consideration several factors such as the fibre angles and the corrections for the distribution of length. In the present calculations, the fibres were assumed to possess consistent lengths and aspect ratios. These assumptions are incorrect since these factors can undergo changes during the manufacturing process in reality.

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APPENDIX

Table A1: Tensile strength of neat PP, neat r-PP, r-PP/MLF (experimental) and r-PP/MLF (using ROM and modified ROM)

Composite	Tensile Strength (MPa)
Neat r-PP	18.08
r-PP/MLF (Experimental)	15.57
r-PP/MLF (ROM)	55.57
r-PP/MLF (Modified ROM)	21.28

Table A2: Composite tensile strength prediction of 60/40, 70/20 and 80/20 r-PP/MLF compositions

	ROM	Modified ROM
Composite	Tensile Strength (MPa)	
r-PP/MLF (80/20)	34.48	25.86
r-PP/MLF (70/30)	45.02	27.01
r-PP/MLF (60/40)	55.57	21.28

Table A3: Tensile strength of neat PP, neat r-PP, r-PP/MLF (experimental) and r-PP/MLF (using ROM and Halpin-Tsai)

Composite	Tensile Modulus (GPa)
Neat r-PP	1.47
r-PP/MLF (Experimental)	3.36
r-PP/MLF (ROM)	9.49
r-PP/MLF (Halpin-Tsai)	5.38

Table A4: Composite tensile modulus prediction of 60/40, 70/20 and 80/20 of r-PP/MLF compositions

	ROM	Halpin-Tsai
Composite	Tensile Modulus (GPa)	
r-PP/MLF (80/20)	5.25	2.96
r-PP/MLF (70/30)	7.37	6.08
r-PP/MLF (60/40)	9.49	5.38