Study of SAWDUST: Methyl Methacrylate Polymer Composite Properties

by

NurFarah Nabilah binti Ismail

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Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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Chemical Engineering Programme
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(CHEMICAL ENGINEERING)

Approved by.

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(Dr. Maziyar Sabet)

UNIVERSITI TEKNOLOGI PETRONAS

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MALAYSIA

May 2014

CERTIFICATE 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.

(NURFARAH NABILAH BINTI ISMAIL)

ABSTRACT

In recent years, there are concerns for the production of sawdust polymer composites as there is huge amount of sawdust can be found easily and they can easily incorporated with polymers to improve the properties. However, problem arises when the properties of sawdust are influenced by many other factors such as amount of the polymer loading and size of sawdust. Furthermore, the increase demand in using sawdust composites results in a need for a better understanding of the effect of polymer loading and particle size on the characteristics of sawdust composites. So, from this study we will identify the influence of the chemically treated sawdust with polymethyl methacrylate at various particle sizes of sawdust and polymer loading. Apart of that, the research also would like to find out the mechanical and morphological properties which include moisture content, density, flexural, tensile and thickness swelling. These are vital, because we want the composite structure to be durable and to have better properties.

In this work, composite materials were prepared from polymethyl methacrylate with four different size of sawdust (1.99mm $\leq$ x $\leq$ 1.18mm, 1.17mm $\leq$ x $\leq$ 0.425mm, 0.424mm $\leq$ x $\leq$ 0.212 mm and 0.211mm $\leq$ x $\leq$ 0.063mm) with three different ratio of fillers (10%, 25% and 75%).

The molding method is used to prepare the specimens of sawdust composite. The mechanical properties studied include tensile and flexural strength where the dimensional stability studied includes water absorption, thickness swelling and density.

The results show that the composite material had lower water absorption compared with raw sawdust. Also for the effect of filler loadings on the composite, increases amount of filler loading gives better mechanical properties to the composite but the percentage of water absorption and thickness swelling are also increases.

Lastly for the effect of particle sizes on the composite, large particle size are found to give better mechanical properties, however the percentage of water absorption and thickness swelling will also increase with an increase in particle size.

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LIST OF ABBREVIATIONS AND NOMENCLATURE

Symbol	**Meaning**
PMMA	Polymethyl methacrylate
-OH	Hydroxyl group
TS	Thickness Swelling
SEM	Scanning Electron Microscopy

CHAPTER 1: INTRODUCTION

1.1 Background of Study

The rapidly expanding use of composites components has influenced the focus of present day researchers on sustainable and renewable natural fiber reinforce composites. And for decades, the development of wood-panels has attributed to the economic advantage of low cost wood and inexpensive processing with various types of binders (Ashori & Nourbakhsh, 2008) .

Demand for composites wood products such as particle board, plywood and hardboard has recently increases substantially throughout the world. The increased demand in using wood composites and due to huge amount of wood sawdust can be found easily and low cost of the sawdust, have encourage manufacturers to research alternative sources of fibers. Through various studies, composite panels made of plant biomass in the form of wood have been shown to serve as a cost-effective source of fiber. Most of these potentials are found in wood processing byproducts known as sawdust **(**Charoenwong & Pisuchpen)**.**

Over the past decades, natural plant fibers have been receiving considerable attention as a substitute for synthetic fiber reinforcement such as plastic and there are environmental and economic reasons for replacing part of the plastics with wood. The environmental awareness of people forced the industries to choose natural materials as substitutes for non-renewable materials. Wood has been used as building and engineering material since early times and offers many advantages such as renewable, recyclable ad biodegradable(Al-Omairi, 2011).

In wood industries such as timber and furniture, large amounts of sawdust are always found as a waste. Basically, sawdust is used as a source of fuel or used to make other furniture product such as plywood. Although the use of sawdust is not very popular for polymer composite, but basically this material is light, cheap and it can be added to commodity matrix in certain loading level hence offering one of the best solutions for the utilization of waste wood and cheap product (Idrus, 2011).

Due to the high availability and low cost of the sawdust, it can be a more useful and valuable by mixing sawdust with polymer in order to improve the properties of the composites (Idrus, 2011). In addition, wood composite processing minimizes abrasion of the equipment due to the low hardness of wood compared to inorganic fillers (J. Prachayawarakorn, Khamsri, Chaochanchaikul, & Sombatsompop, 2006).

Various chemical can be used to treat raw sawdust to form a polymer composite. Based on recent studies, mechanical testing for treated sawdust is better than raw sawdust and supported by Scanning Electron Microscopy (SEM) images showing a better filler-matrix adhesion compared to the raw ones. As there is better interaction between the matrix and an increase in fiber, the density of the treated sawdust also increases. Chemically treated sawdust composites also showed low water absorption and thickness swelling compared to the raw composites. This indicates that the chemical treatment reduces the hydrophilic nature of sawdust (Idrus, 2011).

Since sawdust can be found easily and inexpensive, so the treatment of sawdust to improve the properties of the composites can be useful and valuable. In this study, raw sawdust will be chemically treated with polymethyl methacrylate (PMMA). Polymethyl methacrylate is one of the most common vinyl monomers used to make wood polymer composites (WPC) and inexpensive(Ashori & Nourbakhsh, 2008). Thus the aim of this study is to produce a composite of raw and treated sawdust at different particle size and amount of polymer loading and then characterize the properties.

1.2 Problem Statement

In recent years, there are concerns for the production of sawdust polymer composites as there is huge amount of sawdust can be found easily and they can easily incorporated with polymers to improve the properties. Besides that, the presence of sawdust in large quantity primarily creates disposal challenges for the wood processing industries. However, sawdust residue can be converted into useful and valuable product by adding polymer to increase the physical and morphological properties. Therefore it has encouraged researchers to find ways to improve the properties of sawdust composite.

The properties of sawdust composites are influenced by many factors, therefore, in this project, sawdust composites were prepared by varying the amount of polymer loadings and the particle size of sawdust in order to seek better properties of the composites.

1.3 Objective

The objective of this study is to:

i. To study the properties of the raw sawdust and chemically treated sawdust.
ii. To investigate the influence of sawdust particle size on the properties of sawdust composites.
iii. To investigate the influence of the amount of polymer loadings on the properties of sawdust composites.

1.4 Scope of Study

The scope of study is to recognize the field of research in this final year project as below:

i. Investigating the properties of the raw sawdust and chemically treated sawdust.
ii. Examining the influence of sawdust particle size on the properties of sawdust composites.
iii. Examining the influence of the amount of polymer loadings on the properties of sawdust composites.

CHAPTER 2: LITERATURE REVIEW

Sawdust or wood dust is a by-product of cutting, grinding, sanding or otherwise pulverizing wood with a saw or other tool. It is composed of fine particles of wood. It is also the byproduct of certain animals, birds and insects which live in wood, such as the woodpecker and carpenter ant (Wiki, 2013).

Sawdust is a waste product which usually thrown away and which therefore, is obtainable free or at nominal cost and has many practical uses. Materials such as sawdust can replace and reduce the utilization of plastic which relate with the environmental issue and also offer other advantage. An interesting use of sawdust in construction is demonstrated by the wall form units made of low-density cement-bonded wood fiber composite. It is composed of sawdust that is neutralized and mineralized and then bonded together with cement. This material is lightweight with an adequate carrying capacity, porous, thermal insulation and very durable. It does not rot or nor decay. It is also insect proof and does not support fungus growth. It is accepted as environmental friendly and does not contain nor emit any toxic elements (Militz).

Sawdust has many practical uses in the garden. When used it properly, it can actually support the growth of plants by helping to improve the soil. Sawdust can also be used to store crops, repel pests, deter weeds and is handy for cleaning up accidental spills (Brown).

Sawdust also can be used as wood filler. Combining sawdust and glue is one of the most common ways of filling an imperfection by filing the wood into the void (Heather, 2008). Besides that, sawdust also can be used as a fuel for cooking and for heating the house (Dr. Qui).

One of the major uses of sawdust is to make a particle board. Particle board was first developed in Germany by Max Himmelheber after World War II. Before that time sawdust and wood shavings were used only as fuel, but the invention of particle boards gave wood byproducts a new purpose. Particle boards are produces in many thicknesses, and are commonly used for furniture parts and insulation for walls and floors (Wiki, 2014).

Sawdust is often mixed with other remnant pieces of wood to create a sheet of particle board. They have applications in composite wood products, as fillers in plastics and adhesives, and for a number of other industrial and consumer products (Burden, 2012). The most common particles are wood chips, shavings and flakes, which are often gathered from lumber mills, and brought in their raw state to the particle board manufacturer. The sawdust is then sifted, and each particle is housed separately in accordance with its size (Maté, 2012).

Nowadays, sawdust polymer composites are chosen as material in engineering products for a variety of reasons, including lightweight, high stiffness, high strength, low thermal expansion, corrosion resistance, and long fatigue life. In furniture and paper industries, huge amount of wood sawdust are always found as a wastes. Because of the high accessibility and low cost of the chip wood and sawdust, they can easily be incorporated with polymers by compounding process in order to improve the properties of reinforced polymers such as high strength and ease of processing compared to wood (Puvanasvaran, Hisham, & Kamil Sued, 2011).

Increasing demand in using sawdust composites has attributed to the economic advantage of low cost composites ad inexpensive processing with various types of binders. Through various studies, composites panels made from sawdust have been demonstrated capable serving as a cost-effective ad generally very prone to expansion and discoloration due to moisture (Charoenwong & Pisuchpen, 2012).

Composite materials are defined as any physical combination of two or more dissimilar materials used to produce a new material which is that cannot be obtained by each component individually. The two materials work together to give the composites unique and better properties. Composites have become more important as it can help to improve the quality of life. Composites typically use as a thermoset resins which, begin as liquid polymer and are converted to solids during the molding process (Al-Omairi, 2011).

Polymer is called as giant molecules in which atoms are linked together by covalent bonds along the molecules. The polymer chain consists of a large number of small molecules called monomers or repeated units which are linked together chemically. Polymers are prepared by a process called polymerization where monomers react together chemically to form linear or branched chains network (Balasubramanian, 2011).

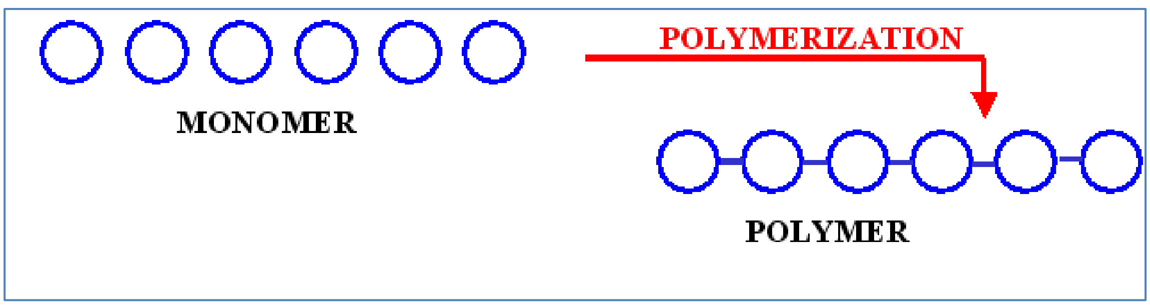


Figure 1: Polymer Formation

Polymer matrix composites is the material consisting of a polymer matrix combine with a fibrous reinforcing dispersed phase and are very popular due to their low cost and simple fabrication methods. The polymer matrix composite will provide a medium for binding and holding the reinforcements together into a solid and provides better properties. Sawdust polymer composites are normally produces by mixing wood sawdust with polymer or by adding wood sawdust as a filler in a polymer matrix, and pressing or molding under high pressure and temperature (Al-Omairi, 2011).

The properties of sawdust composites are strongly influenced by the properties of their constituent materials, their distribution and the interaction between them. Size of sawdust and volume fraction will also affect the mechanical and physical properties of sawdust composites products (Rahman., Islam., & Huque., 2010).

The rapidly expanding use of composite components in automotive, construction, sports and other mass production industries, has influenced the focus of present day researchers on sustainable and renewable natural fiber reinforces composites. Recently various researchers have been carried out on different natural fiber reinforces composites with the intention to produce material of desired properties (Fakhrul, Mahbub, & Islam, 2013).

In 2011, Idrus et al studied treated tropical wood sawdust by using polypropylene polymer composite. The wood sawdust composites exhibited better mechanical and morphological properties. The values of the Young’s modulus and hardness are found to be higher for treated sawdust polypropylene composites than the raw ones. Also, the scanning electron micrograph (SEM) showed a better filler-matrix adhesion compared to raw ones. A major factor contribution to this difference is that the treated sawdust attributed to better dispersion of the filler in the matrix and filler-matrix interfacial adhesion.

Prachayawarakorn et al reported the tensile and flexural moduli of the composites, increased with increasing sawdust content. This could be of economic benefit to industries as one could add greater amounts of wood sawdust particles to replace the polymer phase without significant changes in mechanical properties, therefore leading to cost savings.

Miguez Suarez et al, 2003 investigated the SEM studies of tensile fracture surfaces of polypropylene sawdust composites. In polypropylene sawdust composites, adhesion between the two materials is expected to be rather poor because sawdust has a polar nature and polypropylene is characterizes by non-polar groups. The use of a compatibilizer such as maleated polypropylene (MAPP) can improve adhesion, and thus, improve the mechanical properties of the composites. SEM examination of the polypropylene sawdust composite shows good adhesion between the polypropylene matrix and sawdust fibers however, for the composite sample with MAPP content give a better improvement in the adhesion of sawdust filler.

Idrus, 2011 examined the water absorption characteristic for the raw and treated sawdust polypropylene composites against filler loading. The water absorption of composites increased gradually with an increase in filler loading. This is due to higher contents of filler loading in the composites that can absorb more water. However, the treated sawdust polypropylene composites exhibits the lowest water absorption compare to raw one at all filler loading.

Charoenwong & Pisuchpen, who studied the effect of adhesive and particle size of composite found out that the course particle improved the mechanical properties however the water resistance properties were adversely affected. The reason for this behavior is attributed to the strength of course particle size and high adhesion between course particle sizes. The course particle sizes are tightly interlocked which cause an increase in the strength of the boards. Fine particle has better resistance to water and water absorption due to the denser packing, more uniform grain sizes and easier adhesive penetration compared to the course particle.

Puvanasvaran et al., 2011 carried out a study on the composites for different particle sizes in the case of sawdust and chip wood. The comparison between the tensile strength of rough sawdust is higher than rough chip wood. On the other hand, for soft chip wood the tensile strength is higher than the soft sawdust. In term of flexural properties, the stress compression load (MPa) is found decreased with the increments of the particles sizes for sawdust but a vise versa behavior is shown by the chip wood composite.

Jutarat Prachayawarakorn & Anggulalat, 2003 investigated on the influence of Meranti sawdust aspect ratios and amount of loadings on the properties of composites, found that Young’s modulus and flexural modulus of the sawdust-polypropylene composites were increased prominently with the increasing of not only the sawdust aspect ratio but also the percentage, % sawdust content.

Rezaur Rahman et al, 2010 investigated the influence of benzene diazonium salt fiber treatment on the mechanical and morphological properties of sawdust reinforce polypropylene composites. The impact strength of fiber reinforces polymer composites depends on the nature of the fiber, polymer matrix and the filler-matrix interfacial wetting. High fiber content increase the probability of fiber concentration that causes stress concentration regions require less energy to extend the crack propagation.

Based on previous study, it was found that sawdust has many applications in industrial and consumer products, so, to make the product more valuable and better properties, chemical treatment can be one of the solutions. From all the above, the author concludes that chemically treated sawdust will improve the properties of sawdust. However, the physical and mechanical properties of a polymer composite strongly depend on the nature of the polymer.

In this study, polymethyl methacrylate (PMMA) will be used for the treatment of sawdust in order to improve the properties of sawdust composites. Polymethyl methacrylate is a transparent thermoplastic often used as a lightweight or shatter-resistant alternative to glass. Chemically, it is the synthetic polymer of methyl methacrylate (Wiki, 2014).

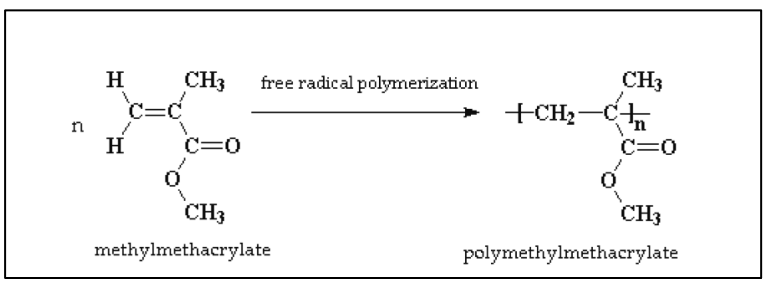


Figure 2: Free-radical Polymerization of Methyl Methacrylate

PMMA in its unmodified are not a tough material in a comparison with engineering plastics. However, when modified, these properties can be significantly improved(Plascams, 2014).

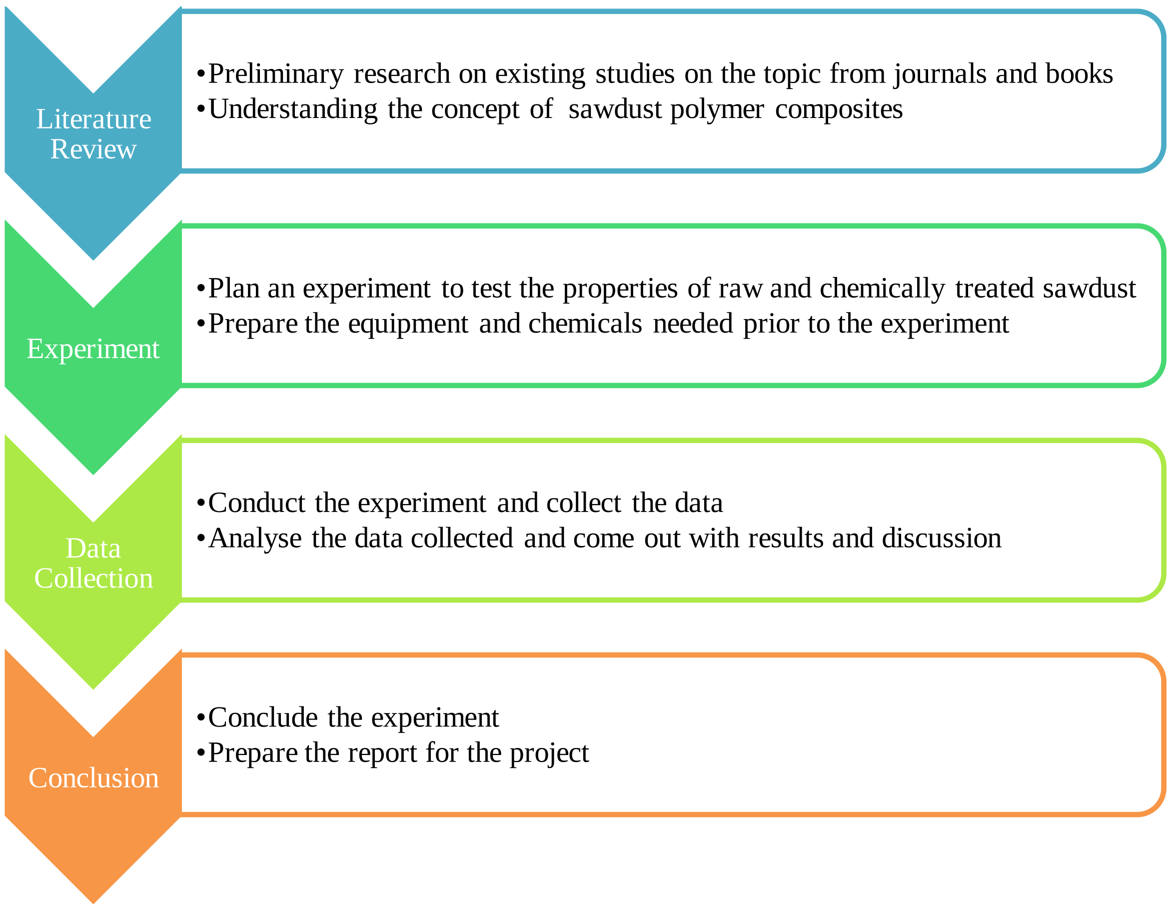
PMMA also offers significant advantages and an additive in a wide range of copolymer-based products and is used in molding. Below are the uses and advantages of PMMA (Plascams, 2014).

Table 1: Uses and Advantages of PMMA

Used in	Advantages
• Plastic sheet • Molded and extruded products • Optics • Vehicles • Office equipment	• Hardness • Flexibility • Clarity • Color compatibility • Toughness • Internal plasticization • Weather ability

CHAPTER 3: METHODOLOGY

3.1 Project Flow Chart



3.2 Gantt Chart

Project activities	Week No																												
	JAN			FEBRUARY				MARCH				APRIL			MAY		JUNE				JULY				AUGUST				
	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	15
Selection of project topic																													
Preliminary research work																													
Submission of extended proposal						•																							
Proposal defense																													
Fine-tuning research methodology																													
Submission of interim draft report													•																
Submission of interim report														•															
Project work continues																													
Submission of progress report																						•							
Data analysis and documentation																													
Pre-SEDX																									•				
Submission of draft report																										•			
Submission of dissertation																											•		
Submission of technical paper																											•		
Oral presentation																												•	
Submission of project dissertation																													•

Process

• Milestone

3.3 Experiment Methodology

3.3.1 Materials Used

The sawdust was obtained from a tree species called 'Meranti' and purchased from a local sawmill industry located at Kampar, Perak and stored in polyethylene bag until needed. Sawdust mixture was analyzed using sieve analysis and screened using a series of sieves: 2.36mm, 2.0mm, 1.18mm, 0.60mm, 0.425mm, 0.3mm, 0.212mm, 0.15mm and 0.063. Four different particle size of sawdust was chosen in this project and below is the range of sawdust particle according to sieve size.

Table 2: Range of sawdust particle size according to sieve size

Sample	Range of sawdust particle size
A	1.99mm$\leq$ x $\leq$ 1.18mm
B	1.17mm$\leq$ x $\leq$ 0.425mm
C	0.424mm$\leq$ x $\leq$ 0.212mm
D	0.211mm$\leq$ x $\leq$ 0.063mm

3.3.2 Mixing and Manufacturing of Sawdust-PMMA Composites

Four different particle size of sawdust (A,B,C,D) will be mixed with polymethyl methacrylate (PMMA) at different loading. The mixture, according to Table 2 was compression molded into a composite at the temperature of 160 ^{o}C. The molding time and pressure of forming procedure were 5 min and 5000 psi. Below are the percentage mixtures by weight for the composite materials:

Table 3: Percentage Mixture of the Composite

Sawdust Content (%)	Methyl Methacrylate Content (%)
10	90
25	75
40	60

.

3.3.3 Cast Mould

The cast mould used for casting the polymeric specimens and composites, which was shown in Figure (3-5) made of iron which consists of two plates. The first one acts as a base where the second plate used as a cover putting on the first plate to make sample thickness uniform. Before casting, the iron plates were cleaned to remove the dirt and dust that were presented on the surfaces. Then, the plates were coated with wax so that the sample was easy to remove from casting after compression molding.

Figure 3: Cast mould for water absorption and thickness swelling testing

Figure 4: Cast mould for tensile testing

Figure 5: Cast mould for flexural testing

3.3.4 Testing

In order to determine the properties sawdust composite, the experimental test to be performed as per below:

Table 4: Experiment and List of Equipment

Experiment	Equipment
Mechanical Testing - Tensile Test - Flexural Test	• Tensile Machine • Flexural Test
Dimensional Stability - Water absorption - Thickness swelling - Density	• Weighing Scale • Oven • Distilled Water • Beaker

3.3.5 Water Absorption of Raw Sawdust

The test sample of 10g of raw sawdust with sieve size of 1.18mm, 0.425mm, 0.212mm and 0.063mm were prepared for the measurement of water absorption. The samples were dried at 100 ^{o}C in an oven until a constant weight was reached. After constant weights have reached, each specimen of sawdust is soaked with water for 2 hour in a beaker. Then, the sawdust is filtered until there is no free water content and reweight. Water absorption was calculated according to the formula:

$$\text{Water absorption (\%)} = [(W_f - W_i)/W_f] \times 100\%$$

Where W_f is the sample weight after soaking and W_i is the weight of sample after oven dried.

3.3.5 Dimensional Stability for Sawdust-PMMA Composites

Sawdust-PMMA Composites of dimensions 63 mm x 10 mm x 4 mm were prepared for the measurement of water absorption and thickness swelling. The samples were air dried at 70 ^{o}C until a constant weight was reached. Then, weigh all the composites immediately to get the initial weight, w_i and measure the initial thickness, T_1 for each sample. Then composites is immersed in the beaker containing 250 mL with water for 24 hours in a beaker and were periodically take out of the water, wiped with tissue paper to removed surface water, reweighed and dimension re-measured to get the final weigh, w_f and final thickness swelling T_2 . Lastly measure the volume of water displaced. Finally the percentage of water absorption, thickness swelling and density was calculated according to the formula:

a. **Water Absorption (%)** = $[(W_f\text{-}W_i)/W_f] \times 100\%$

Where W_f is the sample weight after soaking and W_i is the weight of sample after oven dried. The thickness swelling coefficient (TS) is calculated as follows:

b. **Thickness Swelling (%)** = $[(T_2\text{-}T_1)/T_2] \times 100\%$

Where TS is the percent of thickness swelling and $T_{1 \text{ and }} T_2$ is the thickness of the specimen before and after the test respectively.

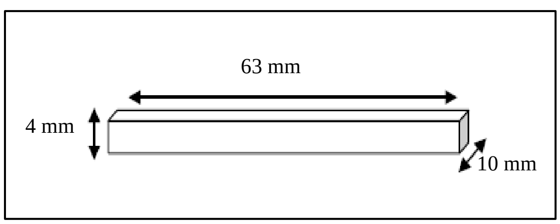


Figure 6: Dimensions of Water Absorption and Thickness Swelling Test Specimens.

c. **Density Determination**

$$\rho = \frac{Mass\ of\ composite\ polymer}{Volume\ of\ water\ displace}$$

3.3.7 Mechanical Testing for Sawdust-PMMA Composites

Flexural and dimensional stability test were conducted to observe the physical and mechanical properties of the sawdust-PMMA composites.

a. Flexural Test

The flexural tests were carried out according to ASTM D790-Procedure A. For the flexural testing, a three point of bending with a span of 96 mm was used and the crosshead speed was set at 2.560 mm/min. In this method, the specimen is placed on two supports and a load is applied in center. The loading at failure is the flexural strength.

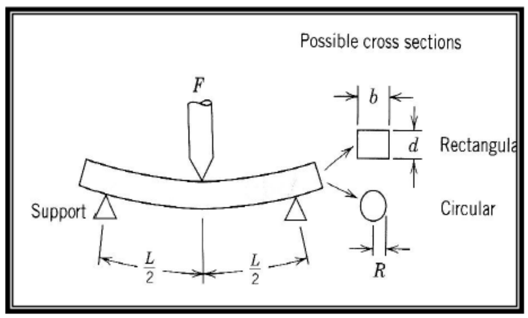


Figure 7 : A three-point bending scheme for measuring the flexural strength

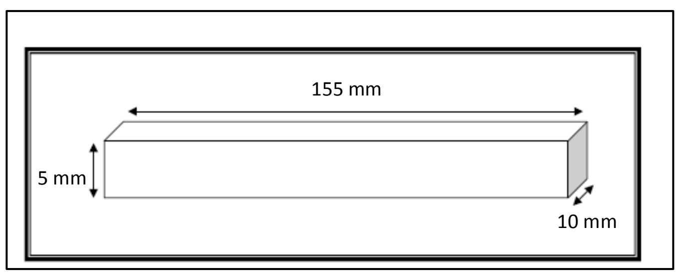


Figure 8: Dimension of Flexural Test Specimens.

b. Tensile test

The tensile tests were carried out according to the ASTM D 638-89. In this method, the specimen is placed into tensile grips and attached the extensometer to the sample. The test begins by separating the tensile grips at a constant rate of 50.00 mm/min. Then by using the machine, the amount of force and stress increase until the sample breaks. The stress needed to break the sample is the tensile strength of the specimen.

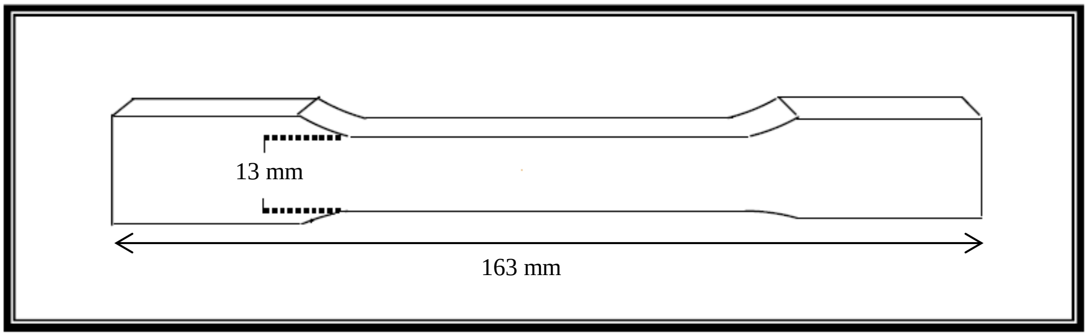


Figure 9: Dimension of Tensile Test Specimens

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Water absorption of Raw Sawdust

4.1.1 Result

Table 5: Percentage of Water Absorption

Particle Size (mm)	Wi (g)	Wf (g)	Water absorption (%)
A	9.441	18.566	49.149
B	8.955	36.639	75.559
C	8.86	37.681	76.487
D	8.946	40.644	77.989

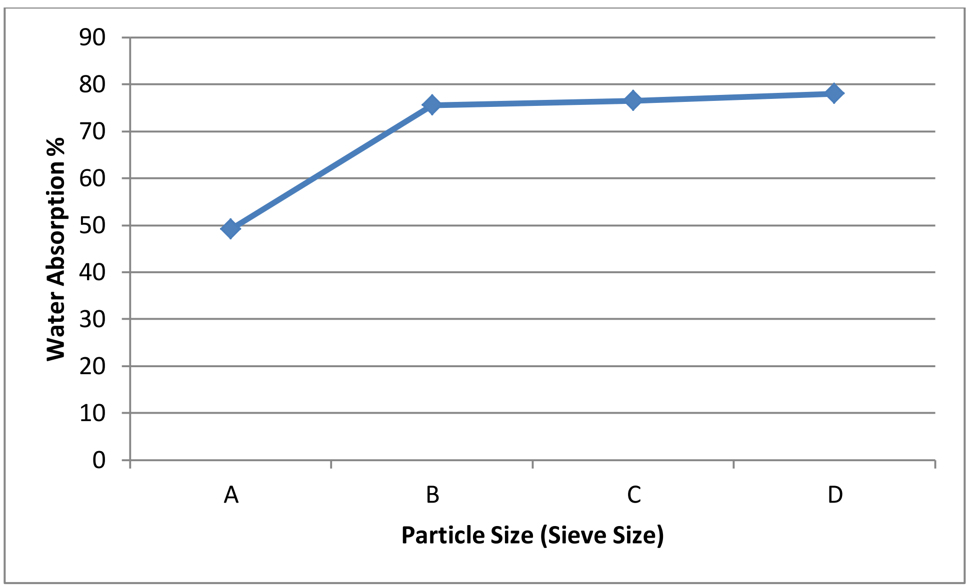


Figure 10: Water absorption of sawdust at different particle size after 2 hours soaking in water

4.1.2 Discussion

Figure 10 shows the water absorption by sawdust with different particle sizes. From the results, water absorption of sawdust reduced with an increase in particle size. This is because smaller particle size has more grain and a smaller surface area for the same amount of weight. Therefore, smaller particle size has more contact and easily penetrated by water to form hydrogen bonds, which results in weight gain in sawdust.

For large particle size, water cannot be absorbed completely into sawdust particles in two hours, causing low water absorption.

4.2 Water absorption for Sawdust-PMMA Composites

4.2.1 Result

Table 6 : Water absorption for 90% PMMA, 10% Sawdust

Particle Size (mm)	Wi (g)	Wf (g)	Water absorption (%)
A	3.91	4.11	4.78
B	3.81	3.98	4.32
C	3.71	3.85	3.56
D	4.02	4.15	3.20

Table 7: Water absorption for 75% PMMA, 25% Sawdust

Particle Size (mm)	Wi (g)	Wf (g)	Water absorption (%)
A	3.9	4.14	5.79
B	3.8	3.99	4.76
C	3.6	3.77	4.51
D	4	4.15	3.61

Table 8: Water absorption for 60% PMMA, 40% Sawdust

Particle Size (mm)	Wi (g)	Wf (g)	Water absorption (%)
A	3.95	4.25	7.01
B	3.84	4.10	6.40
C	3.77	4.00	5.87
D	3.79	4.00	5.38

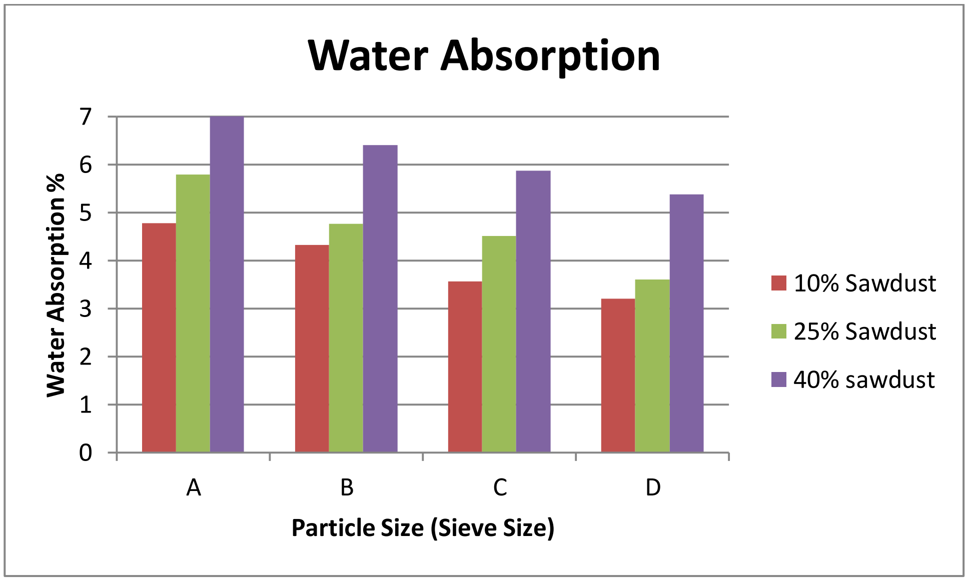


Figure 11: Percentage of water absorption versus size of sawdust

4.2.2 Discussion

From figure 11, we can see that at the same size of sawdust, the water absorption of composites decreased gradually with less amount of sawdust. 10 % of sawdust mixture showed lower water absorption compared to 40 % sawdust mixture. This is due to the lower content of filler loading in the composites that can absorb water. When the content of wood sawdust increase in the composite, the number of free –OH groups is contain more from the cellulose and hemicellulose inside the fiber responsible for increase in the water absorption. These free hydroxyl groups come in contact with water and form hydrogen bonding, which result in weight gain in the composites (Yang, Kim, Park, Lee, & Hwang). Therefore, high amount of sawdust exhibits the highest water absorption compare to less amount of sawdust

For the sizes of sawdust, at same amount of polymer loading, the highest water absorption was observed for larger particle size which is 1.18 mm. This is because larger particle sizes are tightly interlocked and oriented randomly where small particle sizes offer denser packing, more uniform grain sizes and easier adhesive penetration compared to the larger particle sizes (Ahmad & Mei, 2009). On the other hand, it can be observed that the void area for the biggest sawdust particles in the composites can be seen clearly compared to the others (Charoenwong & Pisuchpen, 2012). Therefore, larger particle size has more contact and easily penetrated by water to form hydrogen bonds, which results in weight gain in sawdust.

4.3 Thickness Swelling (TS) for Sawdust-PMMA Composites

4.3.1 Result

Table 9 : Thickness swelling for 90% PMMA, 10% Sawdust

Particle Size (mm)	T_1 (mm)	T_2 (mm)	TS (%)
A	4.00	4.45	10.05
B	4.02	4.43	9.24
C	3.82	4.11	7.4
D	4.04	4.25	4.99

Table 10: Thickness swelling for 75% PMMA, 25% Sawdust

Particle Size (mm)	T_1 (mm)	T_2 (mm)	TS (%)
A	3.93	4.47	12.05
B	3.89	4.35	10.63
C	4.06	4.40	7.73
D	4.07	4.30	5.43

Table 11: Thickness swelling for 60% PMMA, 40% Sawdust

Particle Size (mm)	T_1 (mm)	T_2 (mm)	TS (%)
A	3.91	4.63	15.65
B	3.97	4.46	11.06
C	4.16	4.55	8.56
D	4.07	4.32	5.79

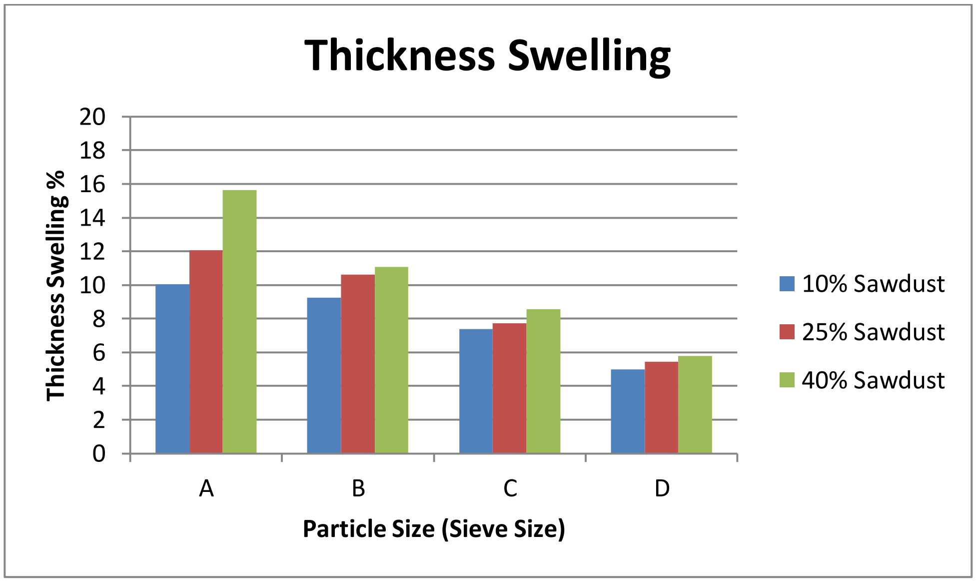


Figure 12: Percentage of thickness swelling versus size of sawdust

4.3.2 Discussion

The result for thickness swelling was shown in Figure 12, it was observed that the thickness swelling for all composites with same particle size increase as the sawdust content increased inside the composites. The result showed that the thickness swelling was the highest for the 40 % sawdust content which corresponded to the highest water absorption. Therefore, in a similar manner to the water absorption, the thickness swelling increased with sawdust content.

For the sizes of sawdust, it was observed that the result for thickness swelling is the highest for larger particle size. Even though the larger particle size improved the mechanical properties, the water resistance properties were adversely affected. Because larger particle sizes are tightly interlocked and oriented randomly, therefore the void areas or pore size are larger than smaller size particle causing the composites to easily penetrate by water (Khalil-Abdul, Issam, Ahmad-Shakri, & Awang, 2007)

4.4 Density for Sawdust-PMMA Composites

4.4.1 Result

Table 12: Density for 90% PMMA, 10% Sawdust

Particle Size (mm)	Initial volume of water in the beaker, V_o (ml)	Final volume of water in the beaker, V_f (mL)	W_i (g)	Density (kg/m^3)
A	250	244.74	3.91	743.89
B	250	244.14	3.81	651.28
C	250	244.13	3.71	632.28
D	250	242.57	4.02	541.3

Table 13: Density for 75% PMMA, 25% Sawdust

Particle Size (mm)	Initial volume of water in the beaker, V_o (ml)	Final volume of water in the beaker, V_f (mL)	W_i (g)	Density (kg/m^3)
A	250	245.87	3.9	945.3
B	250	245.53	3.8	851.3
C	250	245.05	3.6	728.2
D	250	244.39	4	713.9

Table 14: Density for 60% PMMA, 40% Sawdust

Particle Size (mm)	Initial volume of water in the beaker, V_o (ml)	Final volume of water in the beaker, V_f (mL)	W_i (g)	Density (kg/m^3)
A	250	245.84	3.95	951.8
B	250	245.97	3.84	936.6
C	250	245.92	3.77	919.5
D	250	245.73	3.79	881.4

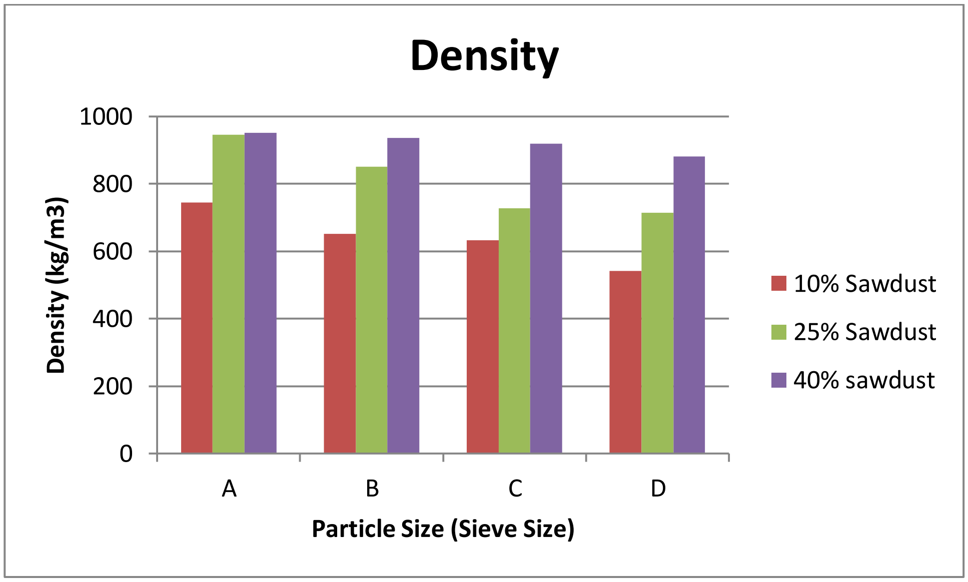


Figure 13: Density versus size of sawdust

4.4.2 Discussion

From the figure 13, it was observed that the density of composites increased as the sawdust loading increased. The highest was at sawdust 40 % for A particle size which is 951.8 kg/m^3. This is expected as sawdust particles have higher density as compared to PMMA itself.

For the sizes of sawdust, the density of the sample increase with the increase in sawdust particle size in the composite. This is due to the fact that for smaller particles sizes, they have higher compressibility because they had more porosity (Shehu, Aponbiede, Ause, & Obiodunukwe, 2014).

4.5 Flexural Test for Sawdust-PMMA Composites

4.5.1 Result

Table 15: Flexural properties for 90 % PMMA, 10 % Sawdust

Particle Size (mm)	Stress Compression Load (MPa)
A	12.45
B	8.01
C	5.15
D	1.50

Table 16: Flexural properties for 75 % PMMA, 25 % Sawdust

Particle Size (mm)	Stress Compression Load (MPa)
A	15.33
B	12.25
C	7.19
D	2.56

Table 17: Flexural properties for 60 % PMMA, 40 % Sawdust

Particle Size (mm)	Stress Compression Load (MPa)
A	20.70
B	16.18
C	10.01
D	7.25

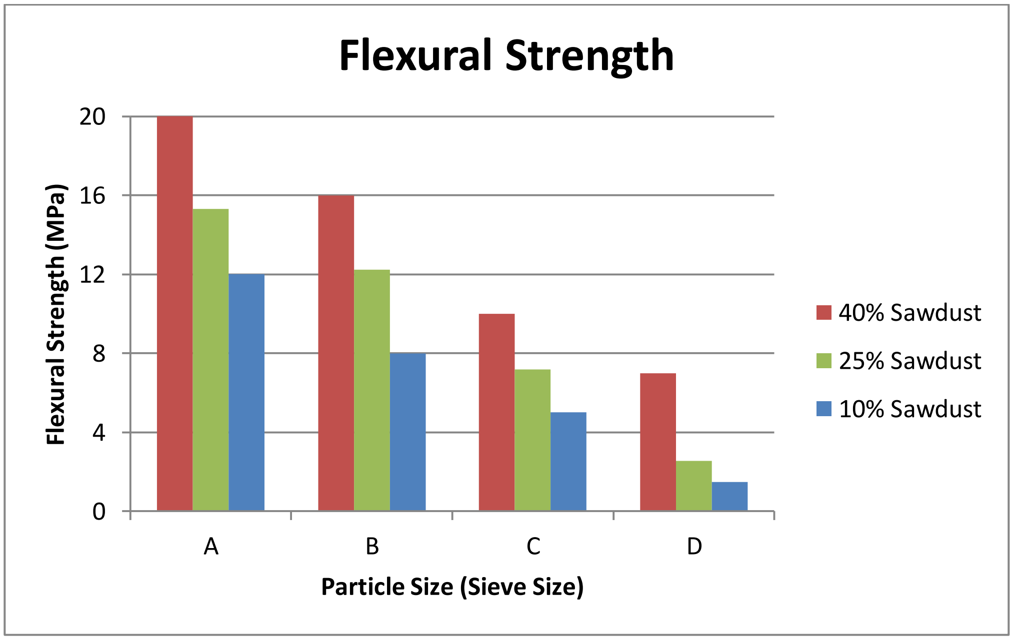


Figure 14: Flexural strength versus size of sawdust

4.5.2 Discussion

Flexural strength of sawdust composites at different particle size are shown in Figure 14. Flexural strength (MPa) is found increased with the increments of filler loading (sawdust) increased. It is found that at 10 % sawdust content, the flexural strength of the composites was the lowest compared to the others. Therefore, when the sawdust loadings increased, the flexural strength gradually increased which is due to the increased in resistance to shearing in the composites structure probably because the presence of the fibers (Rahman. et al., 2010) .

Meanwhile, for the particle sizes, flexural strength is increased with increasing sizes of the sawdust. This showed that, with bigger size of sawdust which is for A particle, the flexural strength of the composite is the highest than the smaller sizes of sawdust. Meaning that larger particles size of sawdust attributed to a better dispersion of the filler in the matrix and stronger filler-matrix adhesion (Idrus, 2011). Based on the results it shows that by varying the amount of polymer loadings (PMMA) and the particle size of sawdust, the flexural strength of the composite can be improved.

4.6 Tensile Test for Sawdust-PMMA Composites

4.6.1 Result

Table 18: Tensile properties for 90 % PMMA, 10 % Sawdust

Particle Size (mm)	Tensile Strength (MPa)
A	5.65
B	5.01
C	4.78
D	4.39

Table 19: Tensile properties for 75 % PMMA, 25 % Sawdust

Particle Size (mm)	Tensile Strength (MPa)
A	4.55
B	4.3
C	3.38
D	3.13

Table 20: Tensile properties for 60 % PMMA, 40 % Sawdust

Particle Size (mm)	Tensile Strength (MPa)
A	3.42
B	2.95
C	2.35
D	2.01

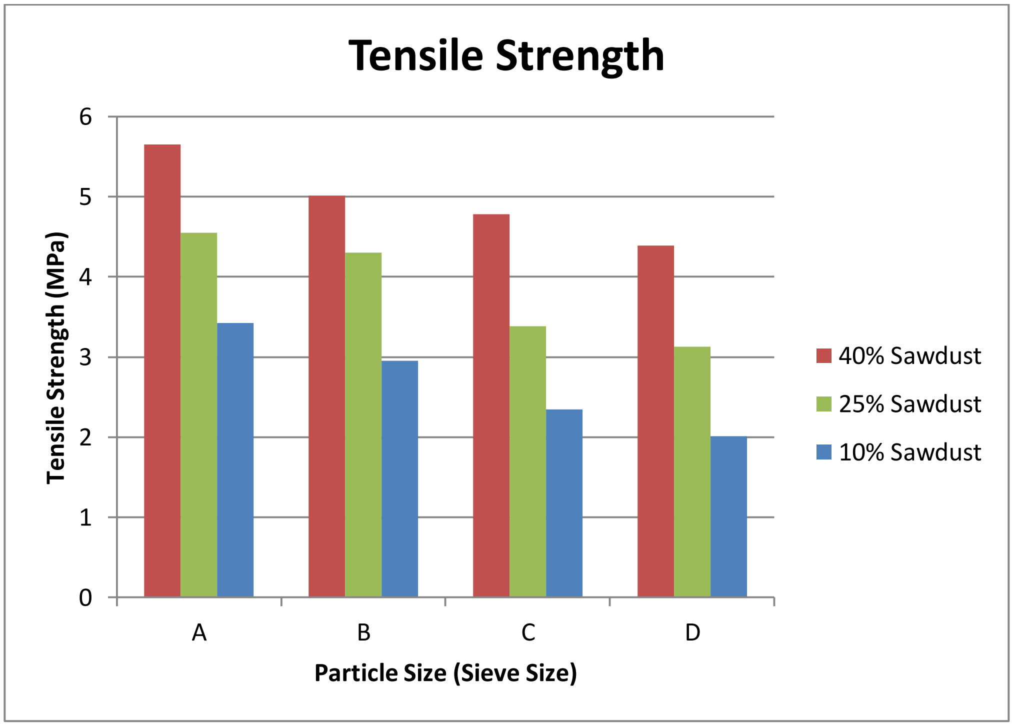


Figure 15: Tensile strength versus size of sawdust

4.6.2 Discussion

From figure 15, for the different ratio of sawdust and PMMA, the tensile strength will increase with the increases in filler loading from 10 %, 25 % to 40 %. The tensile strength increased due to the increasing filler content in the composites was effected the interfacial strength and become stronger between the filler and matrix. Therefore, the highest sawdust content had improved the tensile strength of the composites.

Meanwhile for the size of sawdust, tensile strength is increased with an increasing size of the sawdust. This showed that, with smaller size of sawdust which is D particle, the tensile strength of the composite is weak than the larger sizes of sawdust.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

In this project, raw sawdust was mixed with polymethyl methacrylate with different ratio and different particle size of sawdust. It is found that the sawdust polymer composite showed the lowest water absorption when compared with the percentage of water absorption of raw sawdust.

For the effect of filler loadings on the composite, it is observed that the tensile strength and flexural strength is increase with an increase in filler loading. Hence, meaning that high amount of sawdust content attributed to the better dispersion of the filler in the matrix and stronger filler-matrix interfacial adhesion. Meanwhile the water absorption and thickness swelling increased with filler loading, however, sawdust polymer composite showed huge difference on the percentage of water absorption compared to raw composites, showing that adding the polymethyl methacrylate has an effect to reduce the hydrophilic nature of the sawdust.

For the effect of particle sizes on the composite, larger particle sizes are found to give better mechanical properties, however the water absorption and thickness swelling increased with an increase in particle size. Since PMMA in its unmodified are not tough materials in a comparison with engineering plastics. However, based on the results it shows that by varying the amount of polymer loadings (PMMA) and the particle size of sawdust, mechanical properties of these composite can be significantly improved.

As a recommendation, more research about sawdust polymer composites need to be conducted because it will be beneficial to the manufacturer and environment. Besides, we can reduce the use of wood material to prevent deforestation and forest degradation.

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APPENDICES

1. Sieving Analysis

Figure 16: Sieving machine used to sieve the sawdust particle according to the size

2. Water absorption for raw sawdust

1.18mm

0.425mm

0.212mm

0.063mm

3. Manufacturing of sawdust-PMMA composites

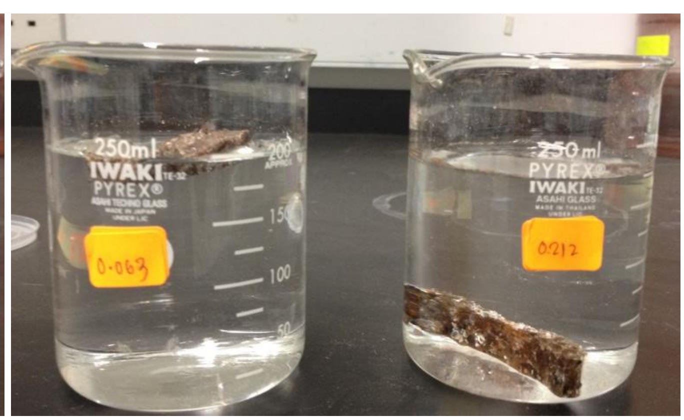
Figure 18: Example of sample preparation using mold

Figure 17: Compression molding machine used to mold the samples

4. Sawdust-PMMA composites for water absorption and thickness swelling testing

1.18 mm 0.425 mm 0.212 mm 0.063 mm

5. Water absorption test



6. Tensile strength test

Figure 20: Tensile machine used to test the tensile strength

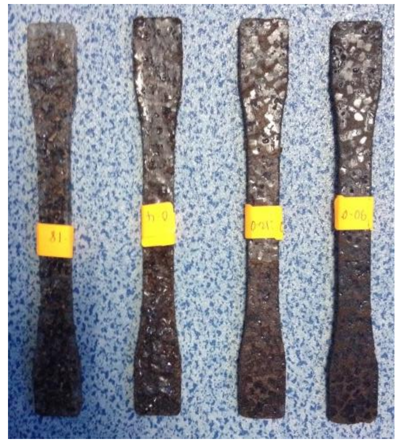


Figure 19: Some of the samples for tensile strength testing

7. Flexural strength test

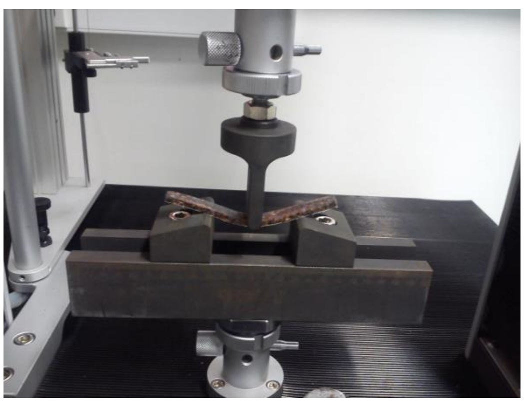


Figure 21: Flexural machine used to test the flexural strength

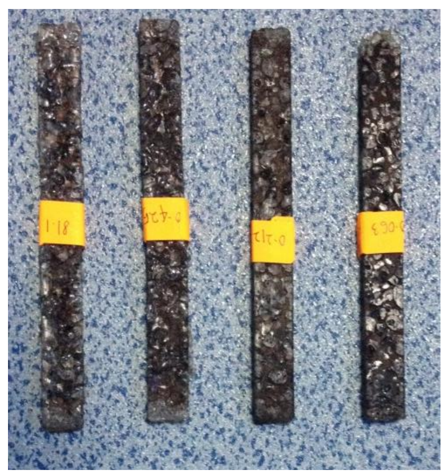


Figure 22: Some of the samples for flexural strength testing