Tensile and Flexural Properties of Grass/Epoxy Composites

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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SEPTEMBER 2012

CERTIFICATION OF ORIGINALITY

With this Iclarify that this report wasoriginally produced except the specified references and acknowledgement and the original work contained herein have not beenundertaken or done by unspecified sources or persons.

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ABSTRACT

The applications of synthetic fibrecomposites in industry are very significant especially in aerospace and automotive sector due to their excellent properties and low density. However, concern for environment has caused people to start looking forward to use natural fibre as reinforcement in composite. One of the natural fibres that need to be extracted its competency as the reinforcing component is grass (*ImperataCylindrica*). Grass is an invasive plant that grows at a disturbed area. The inexpensiveness and the abundance source of grass in this country has made is the potential candidate to be studied. In this research, the effects of length of5 %wt. discontinuous reinforcements (10, 15 and 20 mm)on tensile and flexural properties of grass/epoxy composites are investigated. The plates were produced manually by using hand stirring technique. The curing process was done at room temperature of 25°C for 24 hours without compression pressure. Then, tensile and flexural test was conducted with the crosshead speed on 20 mm/min. From the test, the mechanical properties of the composites are increasing with the fibre length. Besides, it is found out that the optimum fibre length of grass to reinforce the epoxy is 20 mm with the tensile strength, Young’s modulus, flexural strength and flexural modulus of 22.03 MPa, 1.38 GPa, 51.68 MPa and 4.77 GPa respectively. Besides, the addition of grass reinforcement in epoxy (GE_{20}) shows the most significant effect in the flexural modulus of the composites where it increases approximately by 39 %.

ACKNOWLEDGEMENT

Firstly, I would like to express my greatest gratitude to *Allah SubhanahuWataala* for His blessings during my strenuous times and for His gift of the health and the ability for me to complete this research. In these two semesters, I have been fortunate to receive generous support from several persons who contributed in different ways to the process of completion of this research. I could not finish my research without the supports from them.

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CHAPTER 1
INTRODUCTION

1.1. Background of Study

The use of fibre composites in industrial application is really important nowadays. High strength and low density are the major advantages that make the composite significant especially in automotive and aerospace sector. During late 1940s, the first synthetic fibre reinforcement which is glass fibre was developed and became a pioneer in the development of other types of non-renewable sources such as carbon and aramid. However, the environmental impact due to the composite processing is worrying. Besides, it is also of the main reason for the drastically increment of today's carbon dioxide emission. However, number of researchers claim that natural fibres are a potential source as a composite's reinforcement.*Wambua et al.* [1] claimed that some natural fibrescomposites exhibit comparable specific mechanical properties with glass fibre composites. For the sake of environment, researches are carried out throughout the world in order to unleash the capability of cellulose-based fibre.

In this study, the influence of reinforcement length on the property of grass/epoxy composites is focused. Grass (*ImperataCylindrica*) which belongs to Poaceae(Gramineae) family is used as the reinforcement in the form offibre. Common names of *ImperataCylindrica* are cogon grass, spear grass, blady grass satintail or in Malaysia,lalang. *I. Cylindrica* is a perennial grass which produces loose to compact tufts with erect culms (10 to 280 cm long) arising from tough, branched, whitish, creeping rhizomes. Most rhizomes are found in the upper 40 cm of the soil profile but they can grow to depths of more than one metre. The inflorescence is a cylindrical, spike-like panicle, 3-60 cm long and 0.5-2.5 cm wide, consisting of many spikes surrounded by hairs, which give the inflorescence a silky, while appearance [2].

Grass is one of the most dominant and difficult weeds to control in tropical Asia, Latin America and West Africa where it grows in areas disturbed by human activities. Apart from being used in agricultural sector, grass has a high potential as a natural component in composite material because the source is abundant, inexpensive and biodegradable. In this work, a scientific attempt to study the viability of grass fibre as the reinforcement is made in order to justify its usability.

On the other hand, an epoxy is used as the matrix in the composite. It is formed by polymerize the mixture of resin (epoxide) and hardener (polyamide). Categorized as a thermosetting polymer, epoxy has a rigid structure due to crosslink that connect one polymer chain to another. It is one of the most important groups due to its wide range of properties whereby the mechanical and chemical properties are dependent on amount and type of resin and hardener, temperature and curing time [3]. The epoxy functions as binder that holds the reinforcement in orderly pattern. Besides, it plays an important role in distributing force evenly to the reinforcement as the composite structure is subjected under compressive and tension loading.

1.2. Problem Statement

The demand of the natural fibre as alternative to synthetic fibre such as glass fibre in reinforcing polymer is increasing nowadays. The abundance of grass in tropical countries had made it as the potential candidate for natural fibre. Therefore, this research paper is to establish the mechanicalproperties of grass reinforced epoxy composite.

1.3. Objective

The objective of this research is to investigate the effect of the reinforcement's length on tensile and flexural properties of grass/epoxy composite.

1.4. Significance of Study

The significant of the study is to utilize the abundance source of natural fibre. Although some of natural fibres such as hemp and flax are being studiedthoroughly to adapt the requirement in automotive sector,still there are numerous species of plants that need to be studied their fibre's suitability as the reinforcement of plastic. Besides, this is one of the efforts in providing an alternative material for replacing synthetic fibre which is natural, biodegradable and environmental friendly.

1.5. Scope of Study

In this study, afibre reinforcement of grass/epoxy composites is fabricated. After that, several numbers of specimens were prepared from the plates and tested to extract their tensile and flexural properties. The details of the experiment are listed as follows:

- Reinforcement: 5 wt% grass fibre in the form offibrewith the length of 10 mm, 15 mm and 20 mm.
- Matrix: Epoxy
- Fabrication Method:Hand stirring technique
- Mechanical Test:
    - I. Tensile Test
    - II. 3-Point Bending Test
- Mechanical properties studied:
    - I. Elastic modulus and ultimate tensile strength
    - II. Flexural modulus and flexural strength.

CHAPTER 2
LITERATURE REVIEW

Concern for environment and the depleting sources of fossil fuel have driven the researchers to find ways to replaces the petrochemical products with bio-based material. One of the efforts is to use natural fibre instead of synthetic fibre as the reinforcing component in composite materials.

2.1. Environment Superiority of Natural Fibre

According to *Joshi et al.* [4], it is undeniable that natural fibre is environmentally better than the existing synthetic fibre where the hemp, China reed and flaxfibrecomposites are compared with glass fibre composite through life cycle assessment (LCA) studies. The cultivation of natural fibre is mainly dependent on solar energy and the fibre extraction and production only requires small portion of fossil fuel. As the result, the pollutant emission due to the processing is lower compared to that of synthetic fibre.

Besides, the density of natural fibre is lower resulting in lighter final component which will enhance fuel efficiency in automotive applications. In the same research paper, a comparison of LCA of a side panel for Audi A3 car made form ABS co-polymer and an alternative design made from hemp/epoxy composite with fibre volume fraction of 66 %. It is proved that the natural fibre components uses 45% less energy compared to that of the ABS co-polymer components as shown in Table 1.Nevertheless, the environmental superiority of natural fibre over synthetic fibre is still not enough to convince the world its practicability in industrial applications.

Table 1: Life cycle environmental impact of production of a side panel [4]

Component material → environmental indicator ↓	ABS copolymer	Hemp-Epoxy
Total energy (MJ)	132	73
CO_2 emissions (kg)	4.97	4.19
Methane (g)	17.43	16.96
SO_2 (g)	17.54	10.70
NO_x (g)	14.14	18.64
CO (g)	4.44	2.14
Phosphate emissions to water (g)	0	0.09
Nitrate emissions to water (g)	0.08	12.05

2.2. Composite Characteristic

By definition, natural fibrecomposite is material comprises of two or more constituent elements which are basically reinforcement and matrix. The behaviour of the composite is strongly manipulated by several factors which are fibre properties, matrix properties,interface properties, and textile architecture.In composite, fibre acts as the reinforcement to support the structure whereas the matrix is to hold the reinforcement together in orderly pattern. Nevertheless, the fibre is not the only component that determines the stiffnessof a composite. Matrix also plays the role in determining the characteristic of a composite. Based on "rules of mixture"[5] as shown in Eqn. 1, the stiffness of composite is influenced by the elastic modulus of the fibre, matrix and their volume fractions. The equation is very beneficial in anticipating the elasticity of the composite based on type and amount of reinforcement and matrix used before the real fabrication is proceed.

$$E_c = E_m v_m + E_f v_f \qquad \text{.........Equation. 1}$$

where:

E_c = Elastic modulus of composite

E_m = Elastic modulus of matrix

E_f = Elastic modulus of fibre

v_m = Volume fraction of matrix

v_f = Volume fraction of fibre

The reinforcement has a higher modulus compared to the modulus of the matrix as shown in Figure 1. Therefore, the higher volume fraction of reinforcement, the stronger the composite would be. However, there is a limit where the fibre volume fraction could not exceed certain value as told by *Ochi* [6]. In his research, the tensile and flexural strength of unidirectional kenaf/PLA composites increases with the fibre volume fraction. After it reach 70 % of fibre volume fraction, the properties decreases. On the other hand, particulate reinforced composite contains lesser reinforcement to achieve optimum properties which is 40 to 50 % volume percent [7].

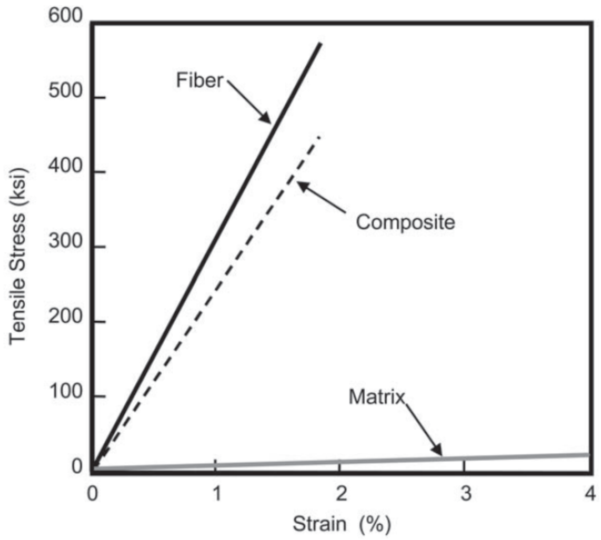
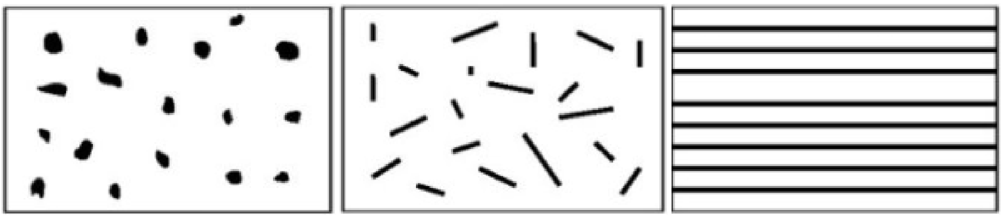


Figure 1: Comparison of tensile properties of fibre, composite and matrix [7]

Initially, the extracted fibre is used straight away for the composite fabrication. Later on, it is found that fibre treatment is necessary to improve the quality of the fibre/matrix adhesion. *Liu et al.* [8] stated that the impact strength of Indian grass fibre reinforced soy based bio-composites was improved 40 % compared to the untreated fibre soy based bio-composites after the alkali treatment due to the improved dispersion of fibre in matrix.In the same paper, it said that the tensile and flexural properties of the composite are increased with the alkali concentration and treatment time. However, the effectiveness of the fibre treatment also depends on the nature of the fibre. Different types of fibre shows a different improvement in properties. It is proved by *Gomes et al.* [9] that the tensile strength of 10 wt% alkali-treatedCurauafibres composite is almost the same as the untreated fibre composite.

2.3. Types of Reinforcement

Besides, type of reinforcement is a great affecting factor in composite's properties. According to *Campbell* [7], the reinforcements present in two categories which are continuous and discontinuous reinforcement. Continuous reinforcement has a higher aspect ratio which is ratio of fibre length over its diameter (*l*/*d*). On the other hand, discontinuous reinforcement has lower aspect ratio. The example of continuous reinforcement is unidirectional fibre, while the examples of discontinuous reinforcement are short fibre and particulate as shown in Figure 2.



(a) (b) (c)

Figure 2: Schematics and not-to-scale diagrams showing the various formats available for the reinforcing phase: (a) particulate, (b) short fibres and (c) unidirectional continuous fibre [10].

According to Smith et al. [10], the physical and mechanical behaviour of particulate system is uniform in all direction. In short fibre system, the behaviour is usually planar isotropic where the properties are uniform in planar direction. On the other hand, the long fibre system is anisotropy where the properties are dependent on the direction of the fibre. Among the three systems, the one which reinforced with long fibre exhibits the best mechanical properties when the load applied is parallel with the fibredirection.

2.4. Weakness of Natural Fibre

Despite of the interesting properties, weaknesses are highlighted by the researchers such as moisture absorption and high scattering of the properties. Moisture absorption ability which dependent on the fibre volume fraction makes the composite becomes weaker in terms of mechanical properties. As shown in Figure 3, the Young's modulus and tensile strength of the jute/epoxy composite decreases with the moisture content. This is because the water on the surface of the fibre acts like a separating agent to the fibre-matrix interface. Wherebyduring the curing of the matrix, the water evaporates and void is created [11]. Besides, the lumen that present in fibre also creates void. Based on an investigated done by *Placet et al.*[12], the elastic modulus of elementary hemp fibre is influenced by the lumen surface area and the fibre diameter, where the bigger surface area of lumen results a lower elastic modulus. From that, one can concluded that high void content in a composite will weaken its structure.Besides, the scattering of mechanical properties is also higher than that of synthetic fibres.*Charletet al.*[13] has found out the scattering is due to the variation of cellulose content in a single fibre and the variation of defects.The author added that small difference in the cellulose amount in one flax fibre to another could be the reason for a large difference in the tensile properties.Besides, the defects are said to be formed during the stem growth and fibre extraction process. The random sizes and location of the defects are the most likely the reason for the scattering of its properties.

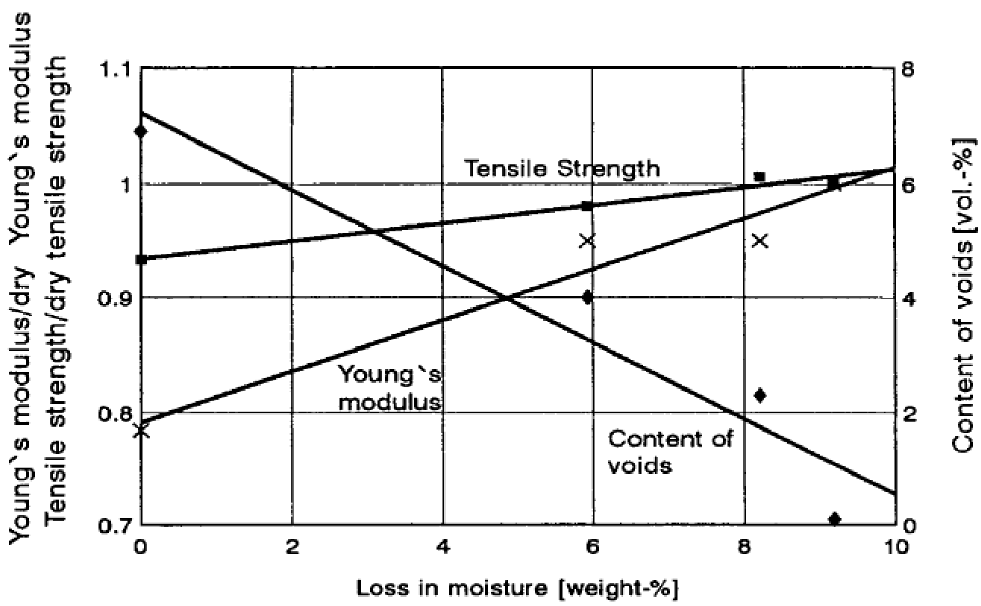


Figure 3: Influence of loss in moisture on Young's modulus, Tensile strength and void content of jute reinforced epoxy composite [11]

CHAPTER 3

METHODOLOGY

3.1. Project Activities

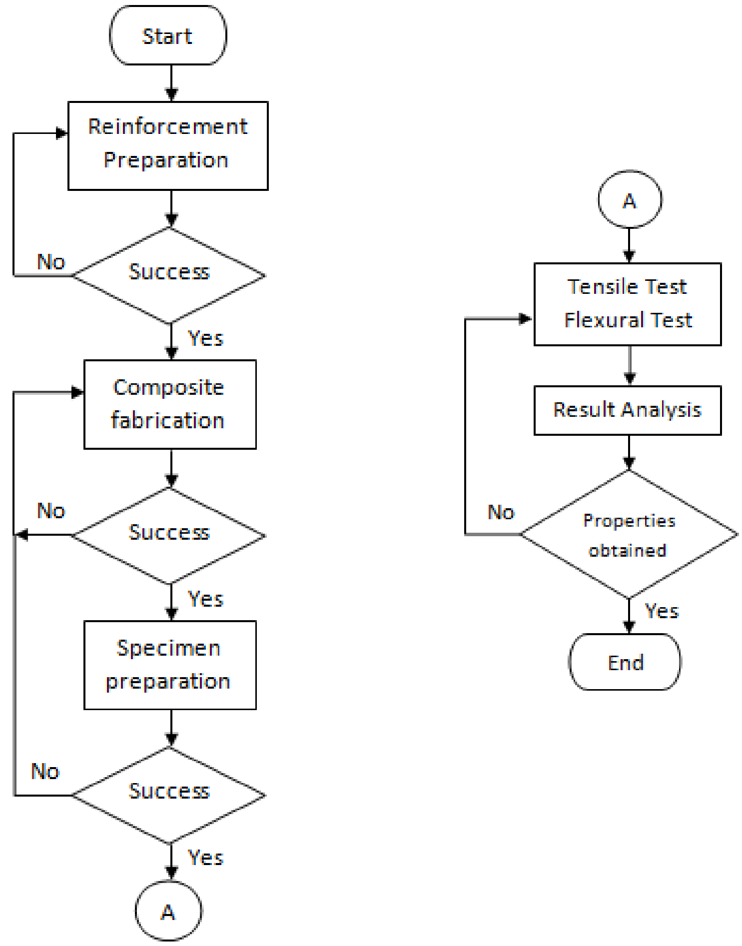
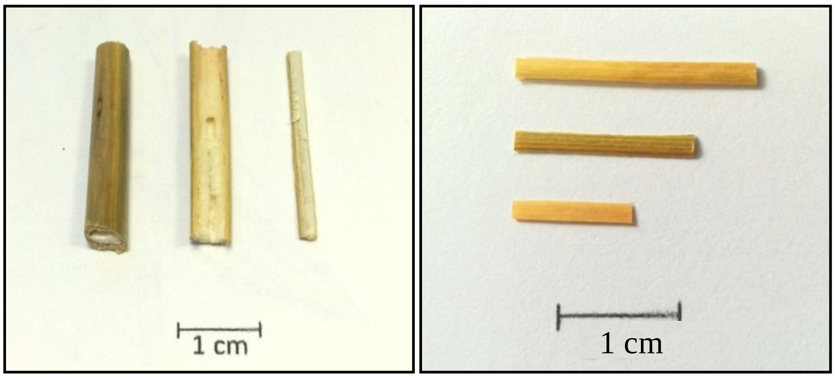


Figure 4: Flow chart of the study

The research started with the collection of dried grass stems. Then, the stem is processed into two shapes; particulate (for density determination) and rectangular shape (for mechanical properties determination). The procedure of processing the stems into particulate form is as shown in Figure 6 by using Low Speed Granulator SG 16-21 and ROCKLABS Grinder as shown in Figure 7 (b) and (c) respectively. On the other hand, the reinforcement which is grass fibre is producedwith the varying in length of 10, 15and 20 mm. Then, the research is continued with the fabrication of plates; Neat Epoxy, GE_{10}, GE_{15} and GE_{20}. The fabrication for the four plates is done carefully in order to maintain the thickness and flatness. After that, tensile and flexural specimens are produced from the fabricated plates by cutting them with the use of laser cutter. Next, mechanical test comprises of tensile and flexural test are conducted. Data obtained from the test was treated and analyzed in order to determine the properties of each composition. Finally, comparison of properties is made in order to see their relationship with the fibre length as well as the effectiveness of the fabrication technique of thecomposites.

Figure 5: Process of machining the dried grass stem into particulate form for the fibre density measurement

3.2. Reinforcement



(a) (b)

Figure 6: Various stages where the stem is cut (a) and the final form of the grass; 10 mm, 15 mm and 20 mm (b)

In this research, three types of composites were studied.The purpose of having three different lengths of reinforcement in this study is to obtain the numerical proof of the superiority in mechanical properties between them in reinforcing epoxy. The surrounding area near Simpang Pulai, Perak was the location where the naturally dried grass stems werecollected.The first step in order to process them into reinforcement is they werecarefully divided into equal parts by cutting them in longitudinal direction by using knife. Then, the soft structure at the internal wall of the stems is removed. Finally, they were cut in transverse direction into 10, 15 and 20 mm in length (Figure 5).

(a) (b) (c)

Figure 7: Cutter (a), Low Speed Granulator SG 16-21 (b) and ROCKLABS Grinder (c)

3.3. Matrix

The matrix used for binding the grass reinforcement together is a thermosetting polymer provided by Wee Tee Tong Chemicals. The mixing of the resin and hardener is based on weight ratio of10:6 as provided by the manufacturer as shown in Equation2 and Equation3.The density of the epoxy is 1.126 g/cm^3. Based on the ratio, the mass of resin and hardener are measured by using an electronic balance carefully to ensure both chemicalsare prepared based on the specified value. Fail to do so would cause a defect in fabricated plate where the excess of resin results in soft spots which acts like a void in the polymer structure [2].

$$m_{resin} = \frac{10}{16} m_{matrix} \qquad \text{.......Equation 2}$$

$$m_{hardener} = \frac{6}{16} m_{matrix} \qquad \text{.......Equation 3}$$

The matrix is prepared based on the following steps:

1. A plastic container is placed on the electronic mass balance before the value was set to zero.
2. Then, the specified amount of resin (m_{resin}) is poured into the container.
3. The reading was taken and the amount of hardener ($m_{hardener}$) is calculated based on Equation. 2 and Equation. 3. The value is recorded.
4. The specified amount of hardener is poured into the same plastic container.
5. The mixture is then stirred by using plastic tea spoon for a minute so ensure the homogeneity.

3.4. Plate fabrication

5 wt% grass reinforcement is used with the epoxy to produce the plates. Hand stirring technique is used as the fabrication method.The mould used for the fabrication is an aluminium food container with dimension of 30 cm by 20 cm by 6 cm. Firstly, pre-fabrications of neat epoxyand 5 wt% particulate grass/epoxy composites was carried out to determine the density of cured matrix and the grassfibre.

Table 2: Designation of composites

Composite	Composition
GE_{10}	Epoxy (95 wt%) + grass fibre (fibre length 10 mm) (5 wt%)
GE_{15}	Epoxy (95 wt%) + grass fibre (fibre length 15 mm) (5 wt%)
GE_{20}	Epoxy (95 wt%) + grass fibre (fibre length 20 mm) (5 wt%)

After that, the real fabrication of composite plates with reinforcement of 10 mm, 15 mm and 20 mm grass fibre are fabricated. Three composites plates are produced; GE_{10}, GE_{15} andGE_{20} (Table 2).The procedure of fabrication is based on the following steps; pictures are in Figure 9:

1. The cavity of the aluminiummould is spread with wax (Kiwi Shoe Polish) to ensure the matrix is not stick with the mould surface.
2. The specified amount of matrix is prepared based on procedure in Section 3.2.
3. Based on the mass of the matrix, 5 wt% of grass fibre is added into the solution
4. The mixture of fibres and the matrix is stirred for one minute to ensure the wetting of the fibre.
5. Then, the mixture is poured into the mould.
6. The fibres are distributed by using spoon as uniform as possible.
7. Finally, the mixture is left for curing process.

(Note: Steps 3 and 4 are not applicable for fabricating neat epoxy plate).

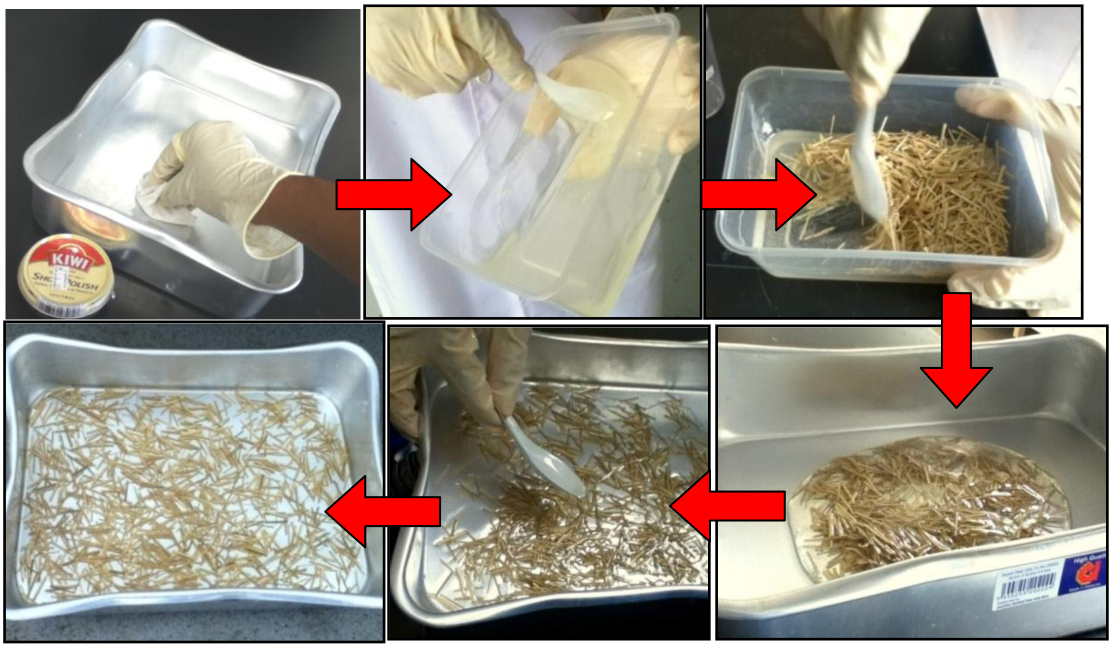


Figure 8: Process of fabricating the composite plate by using hand stirring technique

After 24 hours of curing process at room temperature without compression pressure, the plates are ejected from the moulds. Figure 8 shows a cured GE_{10}, GE15and GE_{20} composite plates. From the figure, it could be seen that the fibres are randomly oriented. However, the distributions of fibres are not consistent throughout the plates where there are fibre agglomerations at some points.

(a) (b) (c)

Figure 9: The cured GE_{10} (a), GE_{15} (b) and GE_{20} composite plates (c)

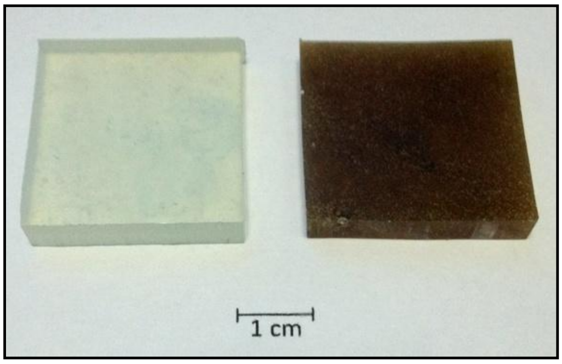


Figure 10: Density determination sample of neat epoxy and 5 wt% grass particulate/epoxy composite

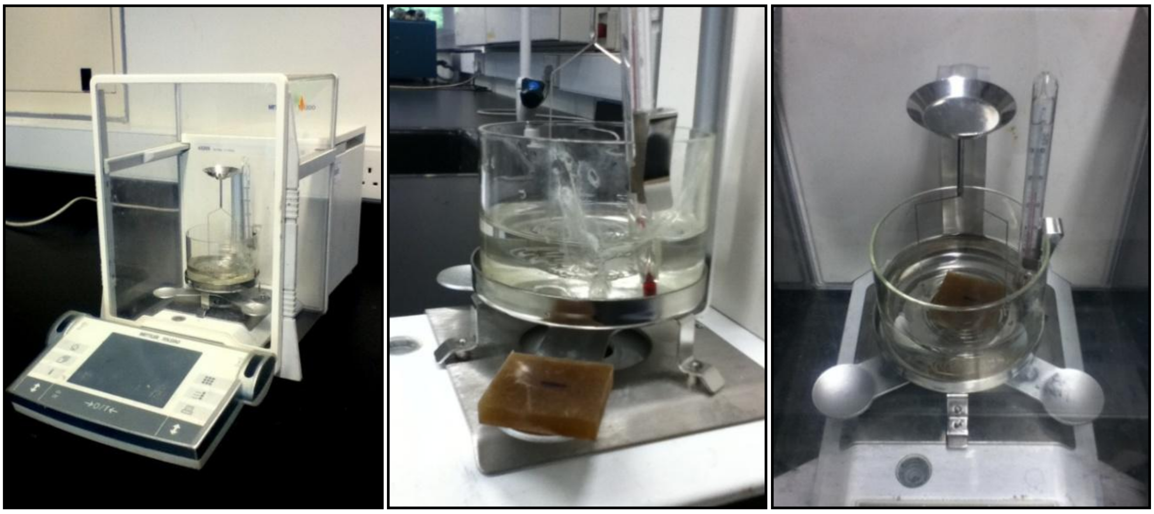
From the pre-fabrication, the two plates fabricated were cut into three specimens with dimension of 3 cm by 3 cm (Figure 10) by using jigsaw. Then, density of the specimen is measure by using METTLER TOLEDO density measuring device. The procedure of determining the density of specimen is based on the following steps [14]:

1. The density of the sample in the air is measured by putting the sample on the weighing spoon as shown in Figure 11 (b). The measurement is recorded as A.
2. Then, the density of the sample in water is measure by putting the sample on the carrier and immersed into the water as displayed in Figure 11 (c). The measurement is recorded as B.
3. The obtained parameters are computed into Equation 4 to calculate the density of sample.
   (The density of fibre is calculated based in rule of mixture [5])

$$\rho = \frac{A}{A-B}(\rho_0 - \rho_L) + \rho_L \qquad \text{.......Equation 4}$$

Where:

ρ = Density of sample *(gcm^{-3})*
ρ_o = Density of water *(gcm^{-3})*
ρ_L = Density of air *(gcm^{-3})*
A = Mass of sample in air *(g)*
B = Mass of sample in water *(g)*



(a) (b) (c)

Figure 11: The use of METTLER TOLEDO Density Measuring device (a) for measuring density of sample in the air (b) and in the water (c)

3.5. Specimen Preparation

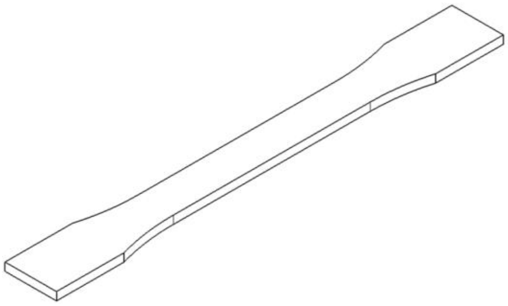
The fabricated plates are processed into two types of specimen; tensile specimen and flexural specimen. Basically, both types of specimens are cut by using a laser cutter as shown in Figure 12. Firstly, the profiles of the “dog bone” and rectangular shape specimen as shown in Figure 13 and 14 respectively are produced by using CATIA software. Then, the drawing is transferred into CorelDraw software which is integrated with the laser cutter.

Figure 12: Laser Cutter

The procedure of cutting the specimen is shown below:

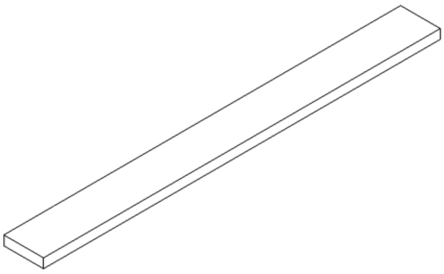
1. Power supply is switched on.
2. The water pump is switched on.
3. The composite plate is put into the machine as shown in Figure 12. Masking tape is used to fix the plate.
4. An 8 mm gauge is used to set a gap is set between nozzle and the plate.
5. Origin is set and the machine is pre-run.
6. Laser is switched on and "start" button is pushed. The laser will cut the plate based on the profile set in CorelDraw software.
7. The laser is switched off when the cutting is completed.

   (The cutting of the plate produces a strong smell. Wearing a face mask is recommended)



Dimensions	Length (mm)
Width of narrow section	13 ± 0.5
Width overall	19 ± 6.4
Length overall	165
Gage length	50 ± 0.25
Distance between grips	115 ± 5
Radius of fillet	76 ± 1
Thickness	7 or under

Figure 13: Geometry and dimension of "dog bone" tensile specimen [15]



Dimensions	Length (mm)
Width	12.7
Length	127
Thickness	3.2

Figure 14: Geometry and dimension of the flexural specimen [16]

3.6. Mechanical Test

3.6.1 Tensile Test

In order to obtain the tensile properties of the fabricated plates, tensile test is conducted on five specimens in room temperature of 25°C for the fourplates by using a Universal Testing Machine LLOYD as shown in Figure 15. The speed of the crosshead is 20 mm/min. The specimens are prepared based on ASTM standard D 638 by referring the dimension of Type 1 specimen [15]. Before proceed with the test, the region where the specimens would be gripped are scratched by using cutter in order to provide rough surface for the enhancement of the grip. Besides, two pieces of special tape separated with approximately 10 cm length were attached within the gauge length of the specimen.

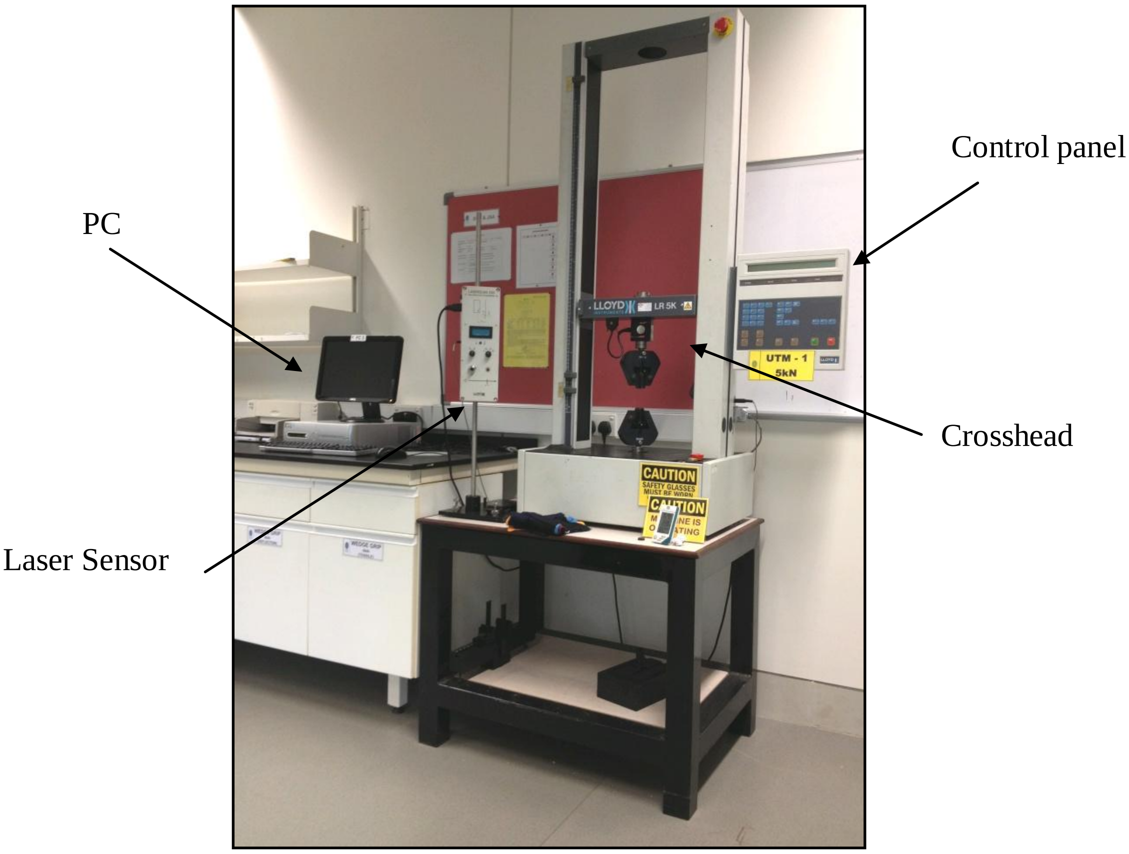


Figure 15: Universal Testing Machine LLYOD

In this test, the specimens are gripped at both ends and followed with an exertion of tension until the specimen fails. The data are recorded and saved into Microsoft Excel. The procedure of conducting the tensile test is as shown as follows:

1. Firstly, software “Nexygen” and “LRX Console” are run.
2. After that, grip(Figure 16) which is equipment for tensile test was attached at the Universal Testing Machine LLOYD before the machineis switched on. An appropriate height of the grip is adjusted so that the specimen could be placed.
3. Specimen is placed inside the grips.
4. Then, laser sensor is switched on followed by an adjustment of the tape so that the gap between the two tapes is exactly “10.00” as displayed at the sensor.
5. Next, file for the particular specimen is created in Nexygen software followed by the insertion of the specimen’s details; thickness and width.
6. The position of the grips is set to zero.
7. “Play” button is clicked to start the test.
8. The machine will automatically stop when the specimen fails.

Figure 16: Setup for tensile test

3.6.2. Flexural Test

For obtaining the flexural properties of the plates, a 3-point bending test is conducted on three specimens for every composition by using the same machine. The speed of the crosshead is 20 mm/min.Meanwhile, the support span length is 90 mm. The specimens are prepared based on ASTM standard D 790 [16].The data are recorded and saved into Microsoft Excel. The procedure of conducting the test is as shown as follows:

1. Firstly, equipment (Figure 17) for conducting 3-point bending test is equipped at the machine.
2. Then, software “Nexygen” and “LRX Console” are run.
3. After that, the machine is switched on.
4. Specimen is placed right on the middle of the supports.
5. Next, file for the particular specimen is created in Nexygen software followed by the insertion of the specimen’s details; thickness and width.
6. The position of the grips is set to zero.
7. “Play” button is clicked to start the test.
8. The machine will automatically stop when the specimen fails.

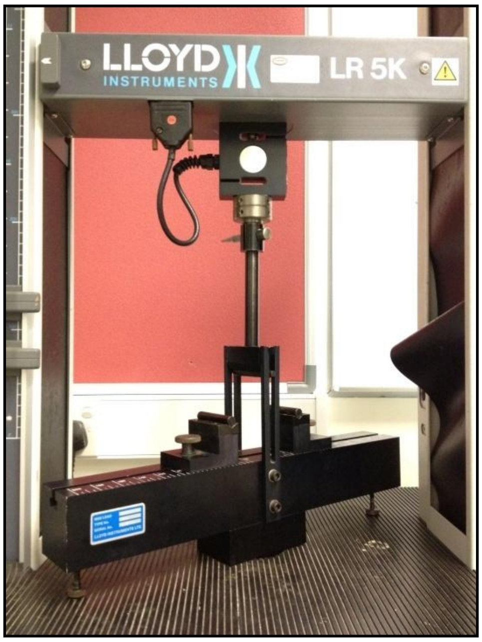


Figure 17: Setup for 3-point bending test

3.7. Gantt Chart and Key Milestones

Table 3: Project Activities and Key Milestones for FYP I

Detail	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Topic Selection	■	■												
Literature Review		■	■	■	■	■	■	■	■	■	■	■	■	
Submission of Extended Proposal						❖								
Laboratory equipment familiarization and experiments							■	■	■					
Proposal Defence										❖				
Interim Report Preparation										■	■	■	■	
Grass Reinforcement preparation													■	■
Interim Report Draft Submission													❖	
Interim Report Submission														❖

Legends:

■ Process

❖ Key Milestone

Table 4: Project Activities and Key Milestones for FYP II

Detail	**Week**														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Fibre Preparation	■	■	■												
Plate& Specimen Fabrication				■	■	■	■	■							
Tensile and Flexural Testing								■	■						
Data Treatment								■	■	■					
Submission of Progress Report								❖							
Pre-SEDEX											❖				
Submission of Draft Report												❖			
Submission of Dissertation (soft bound)													❖		
Submission of Technical Paper													❖		
Oral Presentation														❖	
Submission of Project Dissertation (hard bound)															❖

Legends:

■ Process

❖ Key Milestone

CHAPTER 4
RESULTS& DISCUSSION

In this chapter, results from all the works that have been done as explained in the previous chapter are discussed. Basically, the physical, tensile and flexural properties of the materials obtained were tabulated. Besides, the data are transformed into graphs such as bar charts and scattering charts. The values used are the average value accompanied with the coefficient of variations (CV) to indicate inconsistency of the result obtained.

4.1.Physical Properties

The dried grass stems that were cut by using a sharp cutter into rectangular form are having thickness and width maintained about 0.4 mm and 1.4 mm respectively. The measurement was done by using digital verniercalliper. For the density of fibre, the value was obtained from calculation based on rules of mixture. In order to do that, densities of three samples of composite of epoxy with 5 %wt. grass particulate were measured. Three measurements were taken for each sample and the average values are calculated and tabulated in Table 5 with CV in the brackets.

Table 5: Average density of 5 wt% particulate grass/epoxy composite, cured epoxy and grass fibre; CV (%) in brackets

Composite (g/cm^3)	Epoxy (g/cm^3)	Grass fibre (g/cm^3)
1.155 (0.21%)	1.152 (0.02%)	1.219 (4.68%)

Based on Table 5, the density of composite, epoxy and grass fibre are 1.155 g/cm^3, 1.152 g/cm^3 and 1.219 g/cm^3 respectively. The coefficient of variationof density of composite and grass fibre is quite higher than that of the epoxy. From the table, one can see that the density of composite is in the middle between the epoxy and the grass. If the weight percent of grass is increased, the composite's density would be greater than the fibre. Besides, there is slightly different in the density of epoxy sample and the typical densityof cast epoxies resins at room temperature (1.25 g/cm^3) [17]. The different is due to the fabrication of the samples. In this research, the mixing and the curing process of the epoxy was done manually in room temperature with no compression pressure. Apart from gravitational force, there are no other forces that act on the epoxy during curing which caused the air bubbles to be trapped inside. As a result, the density of the epoxy sample reduced by approximately 8%.

4.2. Tensile Properties

The specimens were successfully tested on five specimens for every composition. The fractures occurred within the range of gauge length. Figure 18 shows the typical breakage experienced by the composite specimens. From the observation, most of the fractures occurred at thefibre-matrix interfacial region.

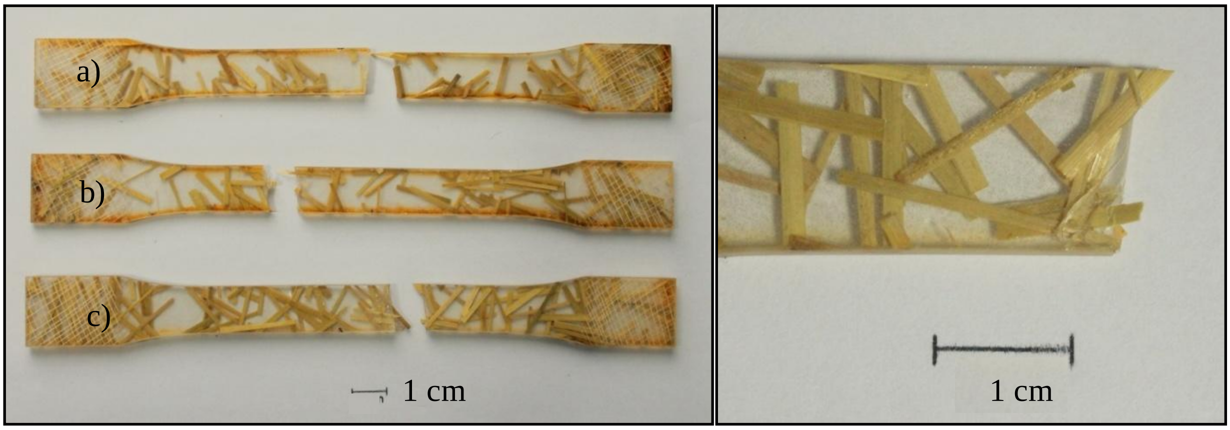
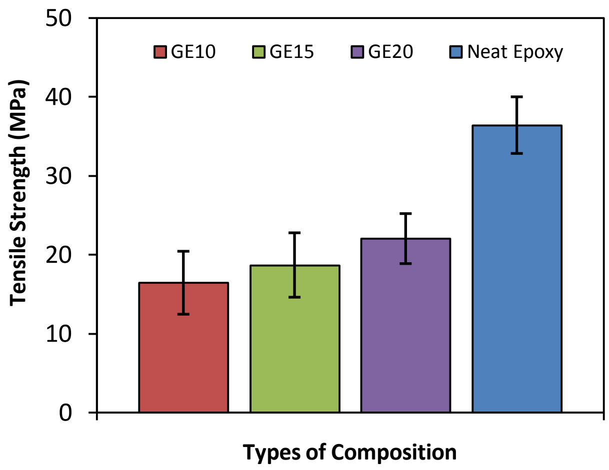


Figure 18: Typical breakage experienced by GE_{10} (a), GE_{15} (b),GE_{20}tensile specimen (c) and magnified view of fractured region.

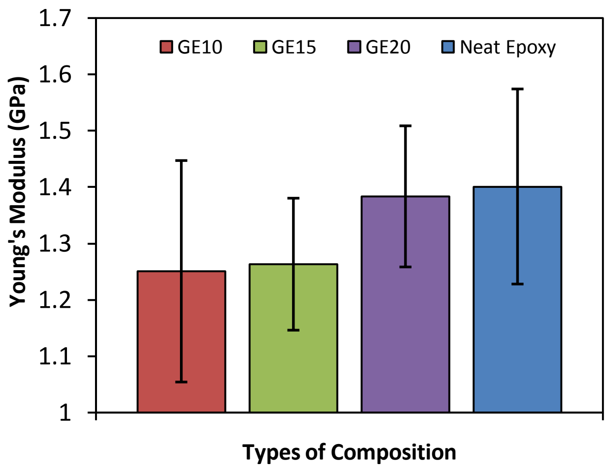
From the tensile tests, several properties are extracted. However, only Young's modulus and Ultimate Tensile Strength (UTS) are discussed. Generally, the addition of 5 %wt. grass fibre does not give a significant change to the brittle behaviour of epoxy, where the composites break when it reaches UTS. Therefore, the yield strength and fracture strength are the same as the UTS. Besides, the information about strain is not successfully extracted from the tests because most of the specimens experienced slippage at the beginning of the test although the specimen preparation was already done by following the guideline. Nevertheless, the Young's modulus and UTS of each composition are tabulated in Table 6 with CV in brackets.

Table 6: Tensile properties of all compositions; CV (%) in brackets

	GE_{10}	GE_{15}	GE_{20}	Neat Epoxy
σ_{UTS} (MPa)	16.43 (24.28 %)	18.68 (21.85 %)	22.03 (14.39 %)	36.4 (9.85 %)
E(GPa)	1.25 (15.71 %)	1.26 (9.27 %)	1.38 (9.05 %)	1.4 (12.35 %)



(a)



(b)

Figure 19: Tensile strength (a) and Young's modulus (b) of each type of specimens

UTS and Young's modulus of each composition are tabulated in Table 6 and plotted in from or bar chart in Figure 19; the vertical lines on the top of the bar charts indicate the CVs. From that, one could see that the UTS and Young's modulus of composites are increasing with the fibre length. However, the all the composites are having lower strength and stiffness compared to the neat epoxy. The reductions are quite significant in the UTS where GE_{10}, GE_{15} and GE_{20} specimens experience about 55 %, 47 % and 30 % reduction respectively.

The properties of composites are significantly affected by the fibre volume fraction. *Agarwal et al. s*tated that having a volume fraction lower than the critical value will cause the properties of composite to fall below the pure matrix where the fibre will not give any contribution in supporting the load [17]. Therefore, having 5%wt. fibre for this experiment could be the reason for the weakening effect. Besides, there are other reasons that lead to the decrement of composite's properties. According to *Yusoff et al.*, the tensile properties of the composites are strongly influenced by interfacial adhesion between the fibre and matrix where it affects the efficiency of load transferring from the matrix to the fibre[18]. Besides,*Arib et al.* the orientations of the fibre and presence of voidsmay also be the factors that contribute to the lower values [19]. In this experiment, the fibres are randomly distributed. Therefore, the fibres could not hold the load effectively when it was transferred by the matrix when load is subjected to the composite.Besides, there was no chemical treatment conducted on the grass where they were used at it is. This may be the reason for the weak interfacial bond between the fibre and the matrix. Plus, the moisture absorption of the composite is one of the factors that bring down the composites' properties as described by *Bledzki et al.* [11]

The comparison between the three composites can be seen in Figure 20 (d). The curve of typical neat epoxy is excluded from the plot in order to only highlight the difference between the three compositions of composites. From that, it can be observed that GE_{20} composite is having the highest average UTS with the value of 20.03 MPa followed by GE_{15} and GE_{10} composites accordingly. On the other hand, the highest value of Young's modulus achieved by the composite is also through GE_{20} specimens with the value of 1.38 MPa. However, the gradient of the curves could barely be distinguished visually in the plot due to small difference between them. All in all, both trends; UTS and the Young's modulus, of randomly-oriented grass/epoxy composites are increases with the fibre length as highlighted by *Biswas et al.* in the research on the effect of fibre length on coir fibre reinforced epoxy composites [20].

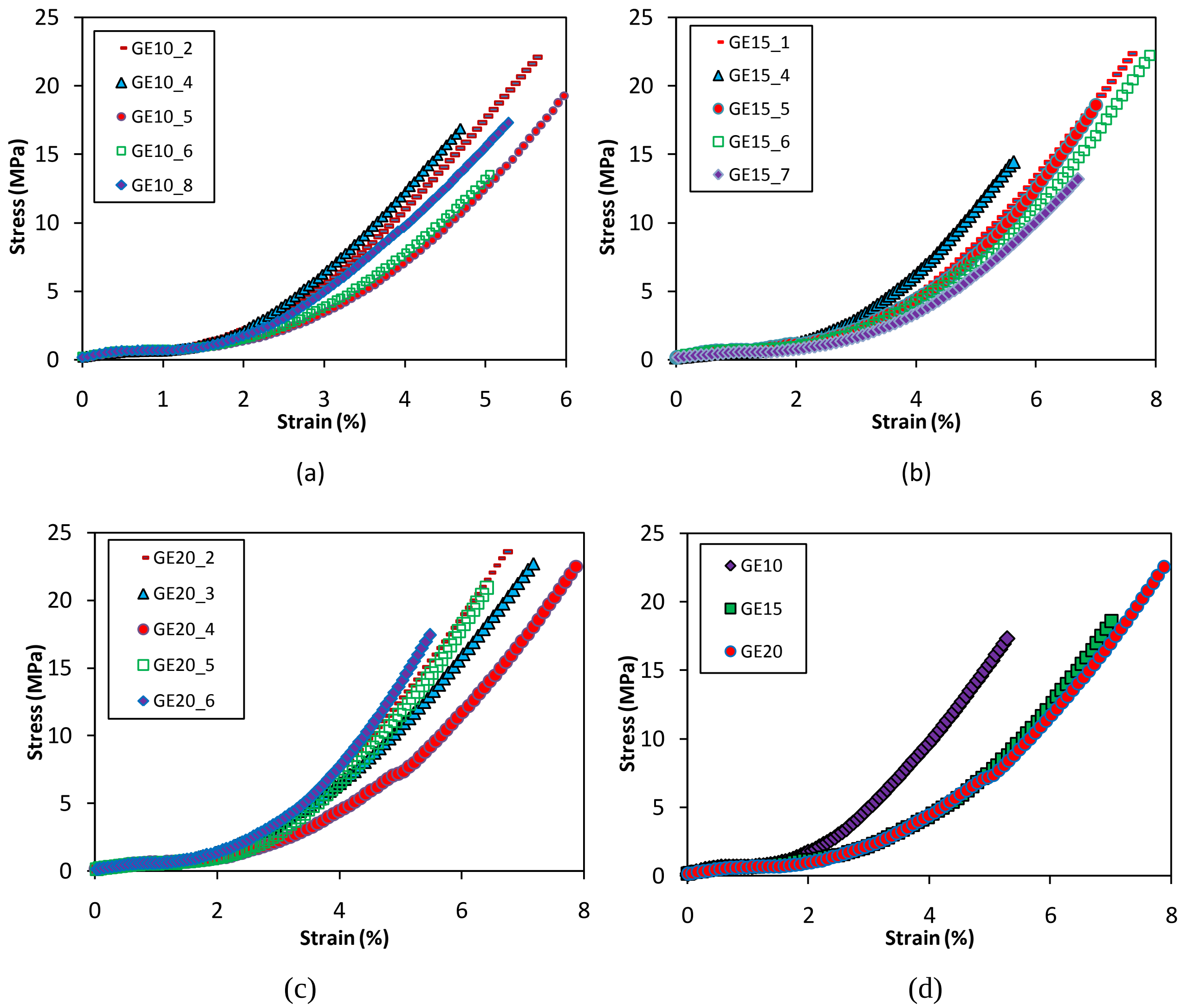


Figure 20: Typical behaviour towards tensile loading of GE_{10} (a), GE_{15} (b) and GE_{20} (c) and the representative curves from all composites (d)

Based on the Figure 20 (a), (b) and (c), it can be observed that the specimens from every composite's composition seemed to experience increasing rate of elongation at the early stage of the tensile test. However, the information at the beginning of the applied stress is not reliable because the specimen experienced slippage which causes the curve not to be in linear form. Apart from that, the breakage of each of the specimens also were not so consistent which lead to higher coefficient of variation of the UTS compared to that of the Young's modulus.

4.3 Flexural Properties

The specimens were successfully tested on three specimens for every composition. The fractures occurred in the middle of the specimen where the force is applied. Figure 21 shows the typical breakage experienced by the composite's flexural specimens.

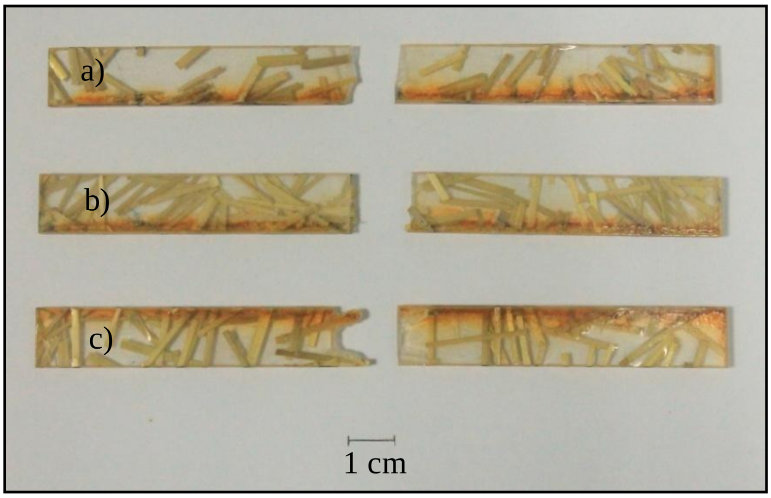
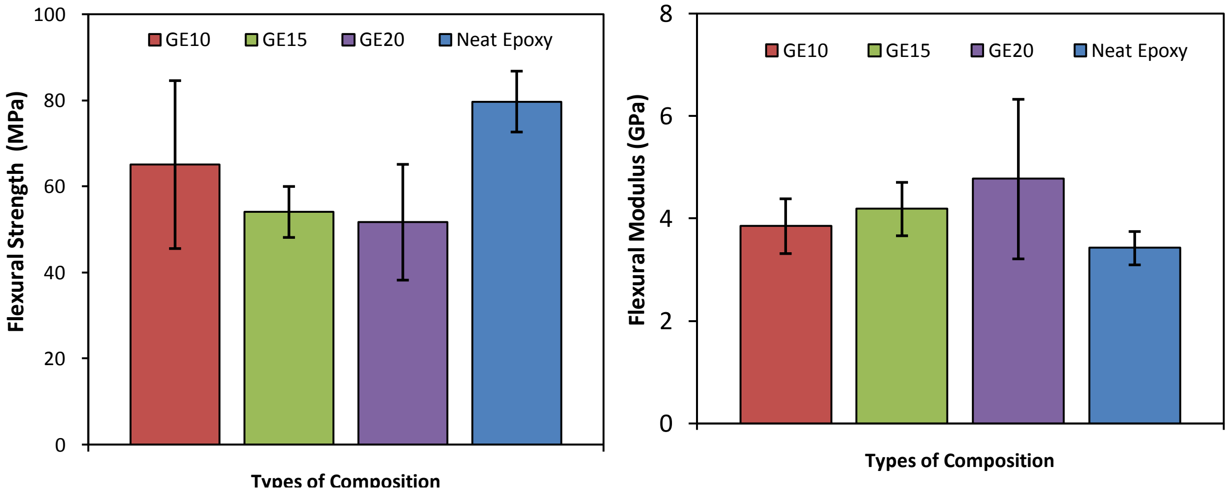


Figure 21: Typical breakage experienced by GE_{10} (a), GE_{15} (b) and GE_{20} (c) flexural specimen

From the flexural tests that were conducted on three specimens from every composition, several properties are extracted. However, only flexural strength and modulus are discussed. The flexural properties of all compositions are tabulated in Table 7 and plotted in the form of bar chart in Figure 22; with CVs of each data are expressed as vertical lines on top of the bar charts. From that, it could be seen that the flexural modulus of the composites are higher than that of the neat epoxy and the values are increasing with the fibre length. The GE_{20} specimens exhibit the highest flexural modulus with the value of 4.77 GPa. Meanwhile, the neat epoxy is having the value of 3.42 GPa. The addition of 5 %wt. of grass fibre with the optimum length of 20 mm results in the increment of flexural modulus by approximately 40%.

Table 7: Flexural properties of GE_{10}, GE_{15} and GE_{20} composites; CV (%) in brackets

	GE_{10}	GE_{15}	GE_{20}	Neat Epoxy
σ_f(Mpa)	65.07 (29.97 %)	54.07 (10.95 %)	51.68 (26.02 %)	79.71 (8.87 %)
E_f (GPa)	3.85 (13.88 %)	4.19 (12.45 %)	4.77 (32.64 %)	3.42 (9.81 %)



(a) (b)

Figure 22: Flexural strength (a) and modulus (b) of each type of specimens

Unfortunately, the flexural strengths of the composites are following the trend of tensile properties where the values are lower than the neat epoxy. The GE_{10}, GE_{15} and GE_{20} composites are having a reduction in flexural strength of 18, 32 and 36 % respectively compared to that of the neat epoxy. Apart from that, the flexural strengths of the composites are portraying a bizarre trend where the values are decreasing with the increment of the fibre, contrary to the research conducted by *Biswas et al.*, where the flexural strength is increasing with the fibre length [20]. The highest average flexural strength is achieved through GE_{10} specimens with the value of 65.07 MPa. Meanwhile, the flexural strength of GE_{15} and GE_{20} specimens are 54.07 and 51.68 MPa respectively.The coefficient of variation of flexural strength of GE_{10} and GE_{20} are quite significant compared to the others. This is due to the big difference in the strength recorded from one specimen to another during the tests. From Figure 22 (a), it could be seen that there is a possibility to get the opposite trend based on the big scattering of the result. However, the hypothesis could only be confirmed by conducting more tests on the specimen. Besides, having more number of tests would make the result become more reliable.

The behaviour of each specimen of GE_{10}, GE_{15} and GE_{20} toward bending stress is plotted in Figure 23 (a), (b) and (c) respectively. The typical curves of the three composites are plotted together in Figure 23 (d). The curve of typical neat epoxy is excluded from the plot in order to only highlight the difference between the three compositions of composites. From the plot, it could be seen that GE_{10} is having the highest flexural strength followed by GE_{15} and GE_{20} accordingly. However, the differences in slop are too small to be noticed in the plot.

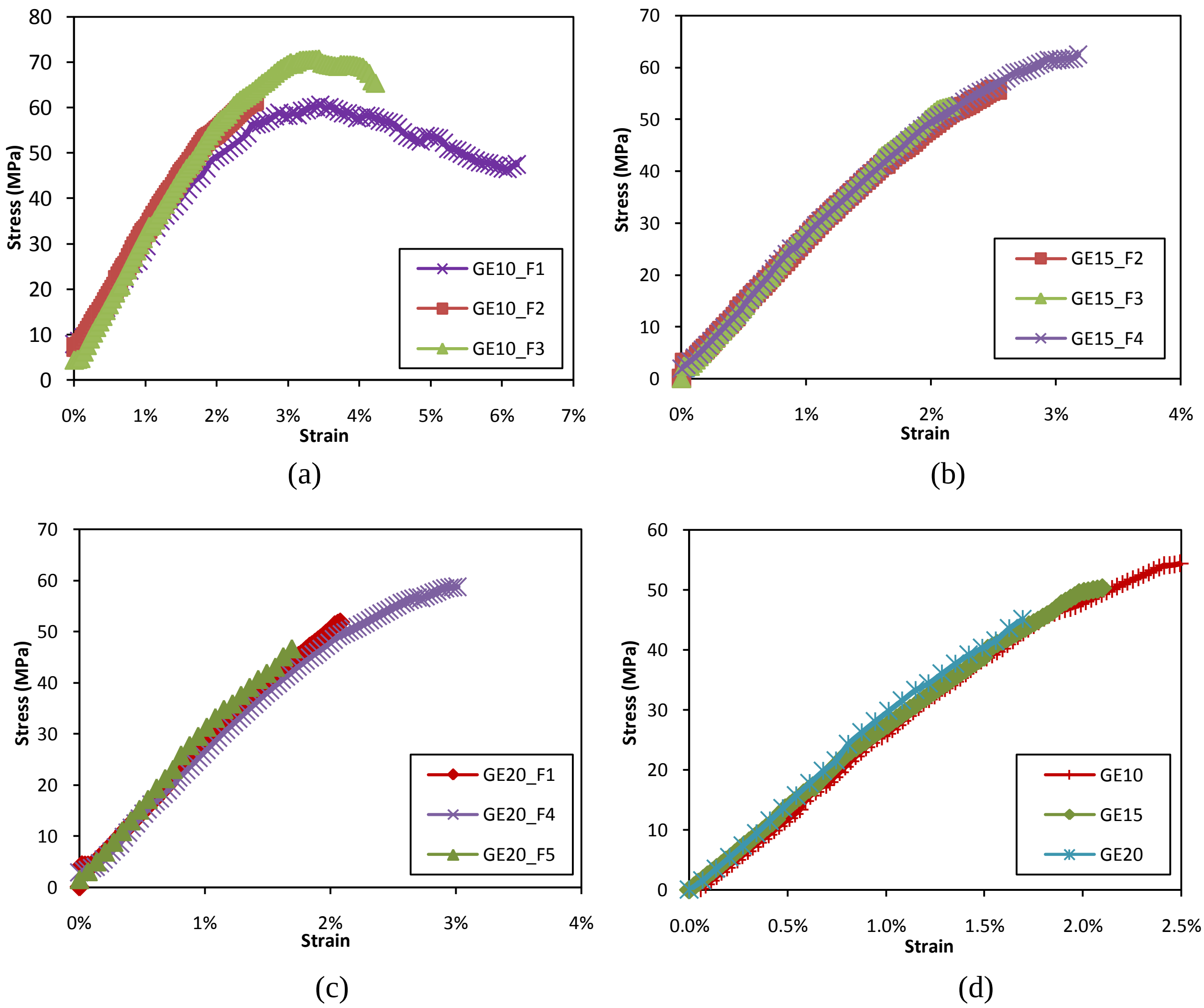


Figure 23: Behaviour towards flexural loading of GE_{10} (a), GE_{15} (b) and GE_{20} (c) and the representative curves from all composites (d)

*Khalil et al.*highlighted that the poor flexural properties showed by the composites were attributed to the weak fibre/matrix bonding. The weak interfacial regions reduce the efficiency of stress transferred between resin and fibre, thus poor strength properties can be anticipated. There are several factors that affect the quality of interfacial bonding such as nature of the fibre and the binder, types of mixing procedures, processing conditions employed and the fibre treatment [21].

In this research, the composites were fabricated manually through hand-stirring technique. The manual stirring of fibres in the resin might be factor that lead to poor fibre wetting and eventually negatively affects the fibre-matrix adhesion due to presence of voids at the surface of the fibres. Besides, the curing also was done with no compression pressure. So, there was no external force act on the mixture during curing to eject the trapped air. As a consequence, the composite suffers reduction in flexural properties.

CHAPTER 5

CONCLUSIONS& RECOMMENDATIONS

5.1. Conclusions

The objectives of the study were achieved. The 5%wt. grass fibre reinforced epoxy composites are successfully fabricated by using hand-stirring technique and the curing was taken place at room temperature of 25^{o}C with no compression pressure. The fabricated plates were nicely cut into specimen by using laser cutter and tested through tensile test and flexural based on experimental methods provided by ASTM. From the experiment, it can be concluded that the tensile strength, modulus and flexural modulus of grass/epoxy composite is increasing with the fibre length. Besides, it is found out that the optimum fibre length of grass for reinforcing the epoxy is 20 mm with the tensile strength, Young's modulus, flexural strength and flexural modulus of 22.03 MPa, 1.38 GPa, 51.68 MPa and 4.77 GPa respectively. Besides, the addition of grass reinforcement in epoxy (GE_{20}) shows the most significant effect in the flexural modulus of the composites where it increases approximately by 39 %.

5.2 Recommendations

Based on the findings, the grass/epoxy composites is recommended to be in applications subjected to bending stresses as it portraying better flexural properties compared to the tensile properties. As for the future works, it is recommended to varythe volume fraction in order to get the optimum properties. Besides, it is very interesting to study the effect of fibre treatment on the properties. Apart from that, the moisture absorption analysis of the composite is also important in order to get more information about the potential of grass as reinforcing component in plastic materials.

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