Tensile Strength of Polyoxymethylene/Carbon Fiber/Glass Fiber Hybrid Composite

By

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CERTIFICATION OF APPROVAL

Of Research Project

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SEPTEMBER 2013

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 of persons.

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ABSTRACT

Fiber Reinforced Polymer (FRP) is one of the advanced technologies developed in the engineering material industry. These FRP are widely used in material industries to produce several products such as interior parts of car, aerospace, marine and construction industries. The hybrid composite is defined as the reinforcements which have two or more materials to bond with the matrix. This composite is offering better mechanical properties than the common composites. Currently, studies on POM/carbon fiber composite and POM/glass fiber composite have been done. However, there is limited research on POM/carbon fiber/glass fiber hybrid composite. Potentially, this hybrid composite can be used in high performance car and can replace carbon fiber reinforced polymer (CFRP). In this project, it objective is to study the tensile strength of polyoxymethylene/carbon fiber/glass fiber hybrid composite. Woven carbon fiber and woven glass fiber were used as reinforcement, while POM as matrix. The glass and carbon fibers were prepared in equal weight proportions and positioned wisely to ensure the weight distribution is good. These fibers and polyoxymethylene (POM) were fabricated using compression molding technique at 200 ^{o}C and 12 tan forces. These samples were tested for tensile strength test (ASTM D638) and data recorded. Based on result, about 222% increment of tensile strength for 70/15/15 wt. % while 200% increment of tensile strength for 80/10/10 wt. % when compared with neat POM. Therefore, overall results showed the tensile strength of hybrid composites have better improvement than neat POM.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Composite material is a structural material that consists of two or more combined constituent materials which have different mechanical properties. When they are combined, the materials will produce and form a material with different mechanical properties. Advantages of composite include high mechanical properties, corrosion resistance, and low density. Nowadays, the composite materials have been widely used. Market growth for composites has been very good since the 1960's, averaging of 15% increment per year. Besides, the composite materials are applied in engineering application because of ease of combination with other materials and adaptability to different situations to serve specific purposes and exhibit desirable properties [1]. For instance, composites are used in component parts of heavy transport vehicles due to its cost effectiveness and reinforced plastic is used in surface transportation due to its huge size [2].

In this project, woven glass fiber and woven carbon fiber were used as reinforcement for polyoxymethylene (POM) which acted as a matrix and these materials formed a hybrid composite. The glass fiber and carbon fiber have high mechanical properties which are suitable to produce high strength product such as parts of car and aircraft. One the other hand, POM has good creep resistance, high crystallinity and low smoke emission which are good for automotive, plumbing and industrial applications.

1.2 PROBLEM STATEMENT

Currently, studies on POM/carbon fiber composite and POM/glass fiber composite have been done by many researchers, [3-6]. However, very limited studies have been done on POM/carbon fiber/glass fiber hybrid composite. Potentially, this hybrid composite can be used in high performance car. For example, side mirror and gear wheel of F1 car can replace carbon fiber reinforced polymer (CFRP) with POM/carbon fiber/glass fiber hybrid composite.

1.3 OBJECTIVES

The objective of this project is to study the tensile strength of POM/glass fiber/carbon fiber hybrid composites.

1.4 SCOPE OF STUDY

Woven glass fiber (E-glass) and woven carbon fiber were used as reinforcement while POM was employed as matrix. These fibers were supplied by Castmech Tech Sdn. Bhd. Compositions of specimen were 80/10/10 wt. % and 70/15/15 wt.%. Several specimens were prepared and produced by compression molding method. These specimens underwent tensile test according to ASTM D638 standard.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW

Years ago, epoxy resin composite material was used to develop light weight and crash-worthy car chassis structures in Formula 1. In order to ensure the safety features of the car are retained, epoxy resin composite materials were reinforced with carbon and glass fiber due to its excellent mechanical properties [7]. Epoxy as a matrix in composite material is chosen in automotive industry due to its best overall strength performance and affordable cost as well as lightweight.

However, epoxy is a thermoset polymer which cannot be remolded, reshaped or recycled [8]. To improve the possibility of recycling, poloxymethylene (POM) which is a thermoplastic polymer was used in this project.

POM is used in automotive industry for body trim clips, bearings, cams, fuel system components, fasteners, and gears. Typical properties of POM include wear resistance, low moisture absorption, high stiffness, stress cracking resistance and impact resistance.

Table 2.1 shows the comparison of mechanical properties between epoxy polymer and POM polymer. Table 2.2 shows the type of materials which used as reinforcements for composites which have excellent strength and stiffness.

Table 2.1 Comparison of mechanical properties of epoxy and POM [9].

Mechanical Properties	Epoxy	POM
Density (g/cm^3)	1.3	1.41-1.62
Elastic Modulus (GPa)	2.4	2.8 - 9.7
Elongation at Break (%)	4.5	3 – 75
Tensile Strength	67	60 - 110

Table 2.2 Properties of composite reinforcing fibers.

Material	E (GPa)	σ_b (GPa)	ρ (kg/m3)	E/ρ (MJ/kg)	σ_b/ρ (MJ/kg)
E-glass	72.4	2.4	2540	28.5	0.95
S-glass	85.5	4.5	2490	34.3	1.8
Aramid	124	3.6	1440	86	2.5
Boron	400	3.5	2450	163	1.43
HS graphite	253	4.5	1800	140	2.5
HM Graphite	520	2.4	1850	281	1.3

The matrix is also important in composite because it transfer loads to the fibers. Besides, the matrix is able to protects the fibers from environmental and abrasion attack [10].

To determine the tensile strength of hybrid composite, stress in matrix is taken at composite failure where the first fibers begin to break. Once fibers begin to break, the load is transferred to the matrix [11]. Figure 2.1, shows the graph of stress versus strain curve of composite.

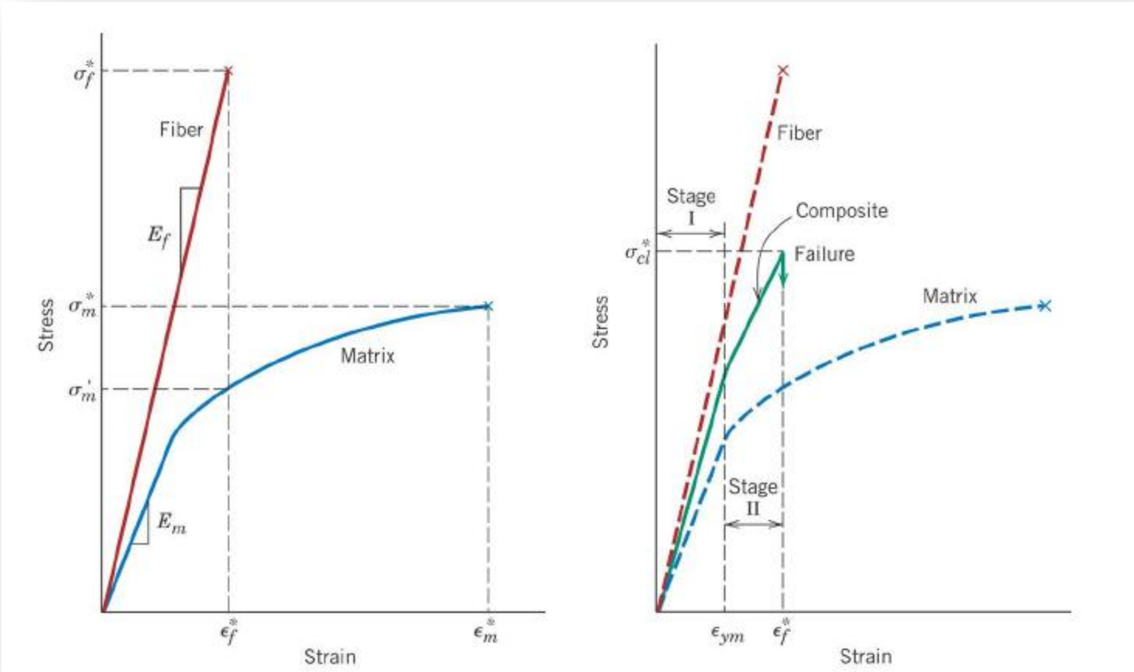


Figure 2.1 Stress versus strain curve [11]

To calculate the longitudinal tensile strength for continuous and aligned fibrous composite, Equation 2.1 is used.

$\sigma^*_{cl} = \sigma'_m V_m + \sigma^*_{f1} V_{f1} + \sigma^*_{f2} V_{f2}$ Equation 2.1

Where:

σ^*_{cl} - The longitudinal tensile strength for continuous and aligned fibrous composite

σ'_m – Stress in matrix at composite failure

σ^*_{f1} – The ultimate tensile strength of first fiber

σ^*_{f2} – The ultimate tensile strength of second fiber

V_{f1} – Volume fraction of first fiber

V_{f2}– Volume fraction of second fiber

V_m – Volume fraction of matrix

2.2 POM/CARBON FIBER COMPOSITES

Polyoxymethylene (POM) has excellent mechanical strength and stiffness, also frictional wear resistance. Thus, it has been widely used as the components of automobile devices, electrical or electrical appliances, and other various machines [3]. For further improve, the POM resin will be added with fiber reinforcements such as glass fiber, carbon fiber or order filler to improve the stiffness, strength and frictional wear resistance.

While choose carbon fiber to mixture with POM, the shorter fibers are liable to scatter while longer is tend to get intertwined to form a pill and knot. So, it is difficult to mixture carbon fiber with POM resin homogeneously and carbon fiber adhesive with the resin due to reinforcing effect is not high. Besides, carbon fiber can produce acidity which causes the POM resin experience degradation. Therefore, coupling agent (polyurethane resin) is carried out to solve these problems.

The composite consists of a POM resin, 1 to 60% by weight of carbon fiber based on the composition, 0.1 to 15% by weight of a polyurethane resin based on carbon fiber, and 0 to 50% by weight of an inorganic filler other than carbon fiber based on total amount of composition. The total amount of filler must not more than 70 % by weight based on the composition. The polyurethane resin is to enhance the bonding between carbon fiber and POM resin. Diameter of carbon fiber is 5 to 15 um while the length of carbon fiber is 1 to 10 mm (long fiber chopped strand) [4].

Table 2.3 shows the mechanical properties of POM reinforced carbon fiber (thermoplastic polyurethane as additive) with 80/20 composition.

Table 2.3 Mechanical properties of POM/carbon fiber.

Mechanical Properties (MPa)	POM/Carbon Fiber
Tensile Strength	147.6
Flexural Strength	184.4

The process of the carbon fiber/POM composite can be prepared by mixing, kneading and extrude the material with a single or twin screw extruder to produce a pellet. Component parts may be mixed to produce a master batch and followed by molded the specimens by using injection molding machine [5].

2.3 POM/GLASS FIBER COMPOSITES

Glass fiber reinforced POM composites were produced by the compositions which comprise of POM, glass reinforced fiber, and polyisocyanates. The POM has melt volume rater of less than 50 cm^3/ 10 min while the polyisocyanates acts as coupling agent which improves the compatibility of the reinforcing fibers with the polymer matrix. The glass fiber was in the form of continuous-filament fibers impregnated with POM molding composition and wound up in the form of a continuous strand. The process of molding was the pultrusion process which suitable for continuous reinforced fiber [6].

The composition of composite and the mechanical properties of the composites are shown in the Table 2.4 and 2.5, respectively:

Table 2.4: Composition of composite.

Samples	POM (wt.%)	Glass fiber (wt.%)	Coupling agent (wt%)
1	71.99	26	0.7
2	82.99	15	0.7
3	55.99	42	0.7

Table 2.5: The mechanical properties of composites.

Samples	Tensile Modulus [MPa]	Stress at break [MPa]	Elongation at break [%]	Notched Charpy [kJ/m^2]
1	9610	161.0	3.7	12.9
2	6340	120.5	4.0	9.9
3	10150	158.9	3.5	13.7

Based on the tables above, the highest mechanical properties were sample 3 followed by sample 2 and sample 1. These samples were added by melamine with 11 wt% and additives of antioxidants and nucleating agents with 1.2 wt%. These additives may affect the bonding between glass fiber and POM, which increase the mechanical properties as the weight percentage of reinforced fiber is higher.

2.4 COMPRESSION MOLDING

Figure 2.2 shows the compression molding, it is a method of molding compound in granular of powder form by filling the mold and compress under certain temperature. The pressure of compression molding will constantly increase during compression molding; it's to make sure all trapped air is pressed out of the materials [12]. The time range of compression molding depends on the thickness of materials which from 0.5 h for 10 mm thickness to 15 h for 80 mm thickness [13].

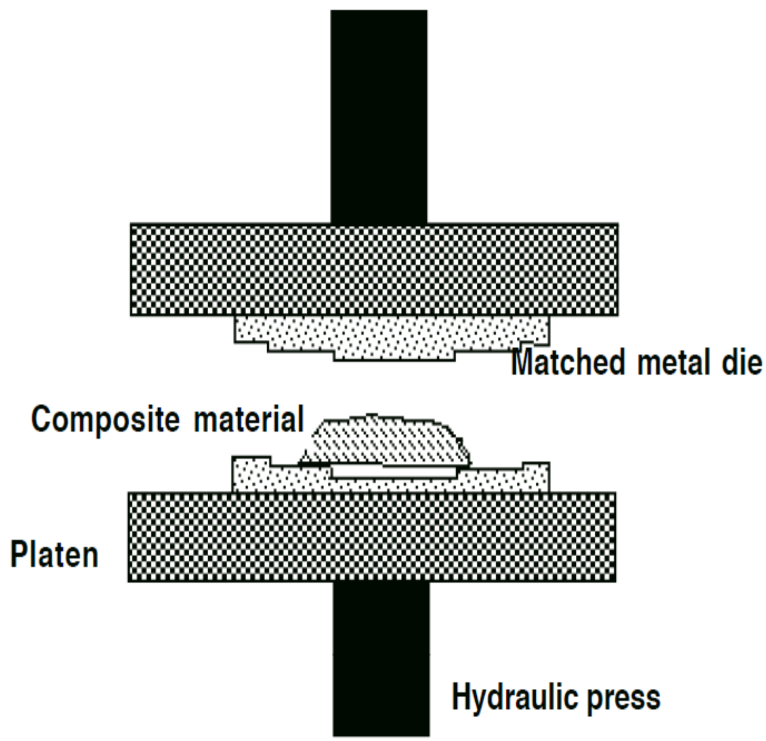


Figure 2.2 Schematic of compression molding

The advantages of compression molding are it can produce the very low shrinkage and isotropic properties which can be achieved when using optimized parameters [13].

2.5 WOVEN FIBERS

Woven fibers is one of reinforcement types which provides reinforcement in non-crimp fabrics or two orthogonal directions, where it's comprise of fibers layers at various orientation held together with through-thickness stitches. The stitches can improve the properties of strength and toughness through-thickness reinforcement. Besides, woven fabric reinforcement provides greater flexibility in processing and maintaining adequate mechanical properties, while it's suitable to be used in compression molding [14]. Figure 2.3 shows the structure of woven fibers.

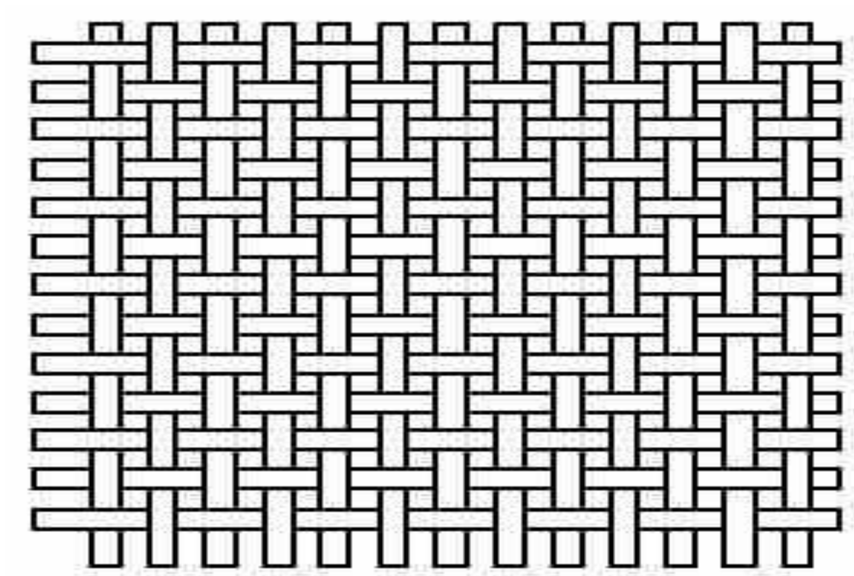


Figure 2.3 Woven fibers

CHAPTER 3

METHODOLOGY

3.1 PROJECT FLOW CHART

Figure 3.1 shows the flow activity process of the project.

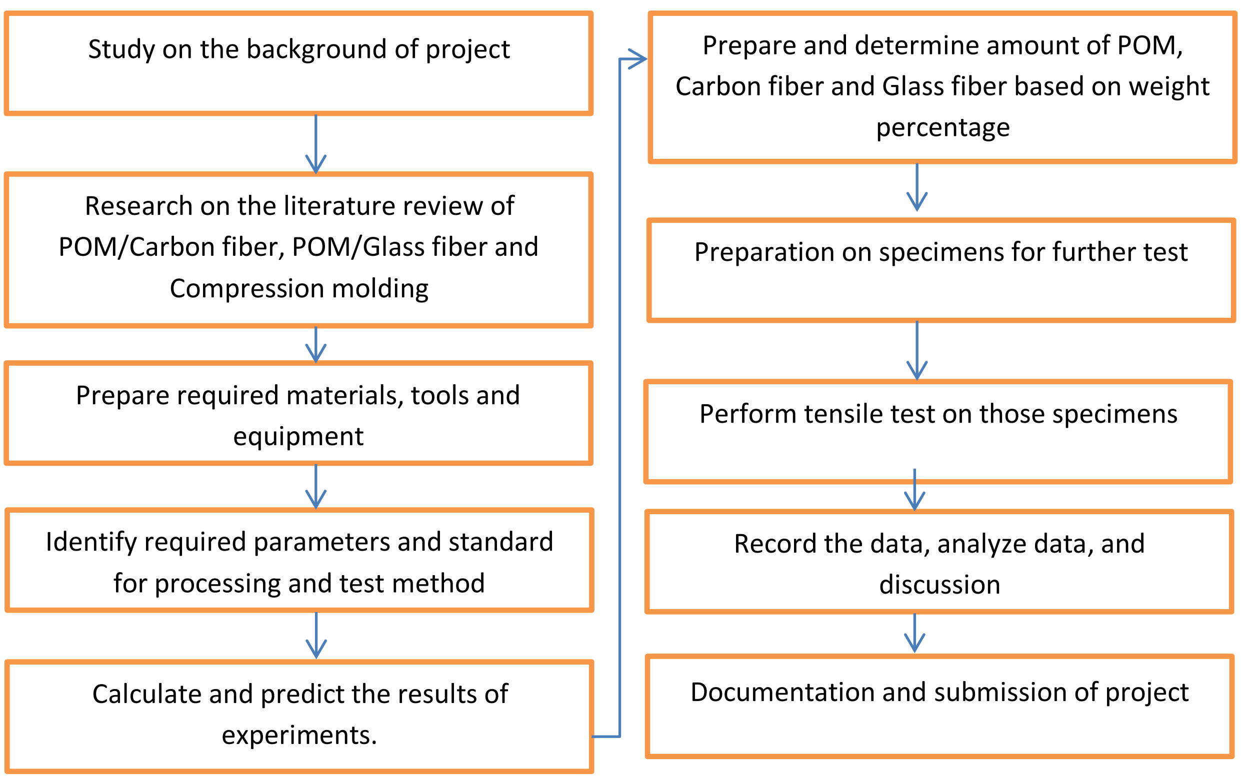
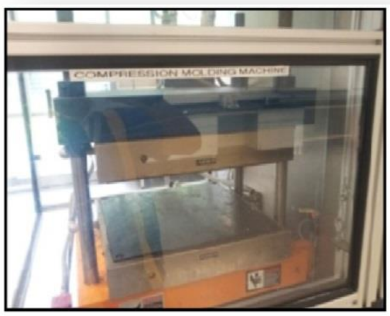


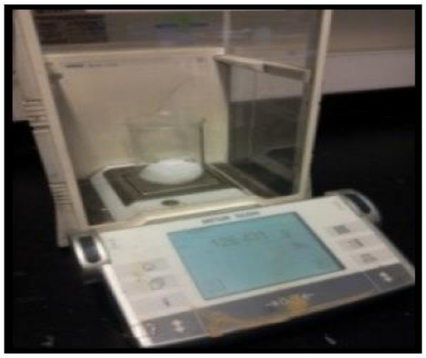
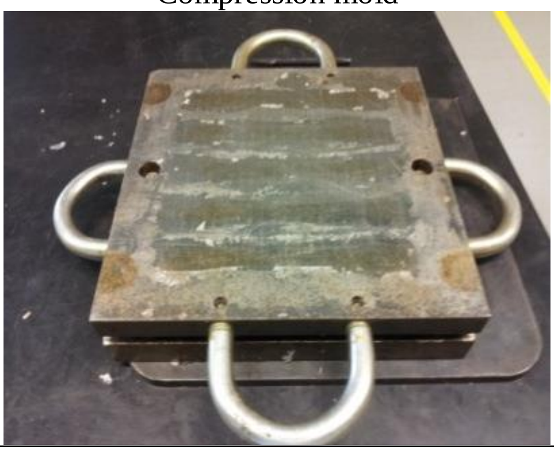
Figure 3.1 Activity process flow of the project

3.2 TOOLS AND EQUIPMENT

Tools and equipment are required to carry out these experiments. Table 3.1 below shows the tools and equipment used.

Table 3.1 Tools and equipment used.

Equipment	Function
Compression Molding Machine 	This machine is to compress the specimens of tensile, flexural and impact.
Tensile Test Machine (100kN) 	This machine is to carry out tensile test on specimens. The maximum test can be carried out is 100kN. The results of tensile strength and Young's modulus will be displayed

Electronic Mass Balance 	The weights of POM, glass fiber and carbon fiber are weighted on this machine. It can give accurate data.
Compression mold 	This mold is to compress the composite such as tensile specimen, flexural specimen and impact specimen.

3.3 MATERIAL

3.3.1 POM MATERIAL

The material for POM pellets were obtained from FORMOCON (Taiwan). The properties of POM pellets are listed on the Table 3.2. The POM pellets are grade FM090 and it is suitable for automotive parts, electronic arts, household appliances and gears [15].

Table 3.2 Properties of POM [15].

Properties	Value
Melting temperature	165.00 ^{o}C
Density	1.41 g/cm^3
Tensile strength	60.80 MPa
Elongation at break	0.60 %
Izod Impact Strength	6.40 kJ/m^2
Flexural Modulus	2550.00 MPa
Flexural strength	93.20 MPa

3.3.2 WOVEN CARBON FIBER

The woven carbon fibers have excellent mechanical properties and suitable for high performance production. The properties of woven carbon fibers are listed at Table 3.3 [16].

Table 3.3 Properties of woven carbon fiber [16].

Properties	Value
Density	1.51 g/cm^3
Tensile strength	3.80 GPa
Tensile Modulus	60.00 GPa
Elongation at break	2.00 %
Flexural Modulus	48.30 GPa
Flexural Strength	827.00 MPa

3.3.3 WOVEN GLASS FIBER

Next material that wants to be used as reinforcement is woven glass fiber, where its mechanical properties are slightly lower than woven carbon fiber. Table 3.4 shows the mechanical properties of woven glass fiber [16].

Table 3.4 Properties of woven glass fiber [16].

Properties	Value
Density	2.46 g/cm^3
Tensile strength	3.45 GPa
Tensile Modulus	86.80 GPa
Elongation at break	4.30 %

3.4 SPECIMEN PREPARATION

In these experiments, there were three specimens which are neat POM, POM/carbon fiber/glass fiber which consist of 70% POM, 15% woven carbon fiber and 15% woven glass fiber. While the other specimen is POM/Carbon fiber/Glass fiber which consist of 80% POM, 10% carbon fiber and 10% glass fiber. The measure on the composition of matrix and reinforcements are based on weight fraction. Neat POM was produced to see the mechanical properties without reinforcement. Table 3.5 shows weight fraction of matrix and reinforcement to be produced.

Table 3.5 Weight fraction of matrix and reinforcements.

Specimens	Matrix (wt. %)	Woven carbon fiber (wt. %)	Woven glass fiber (wt. %)	Number of samples	Samples code
Neat POM	100	0	0	5	POM
POM/Carbon fiber/Glass fiber	80	10	10	5	80/10/10
	70	15	15	5	70/15/15

The procedures of preparing neat POM are as follow below:

1. The reinforcements of woven carbon fiber and glass carbon fiber were cut into required shapes and dimensions.
2. The POM, woven carbon fiber and glass carbon fiber were weighted based on weight fraction decided. All materials were weighted on electronic mass balance.
3. Wax was applied on the surface of mold for easiness composites removing.
4. POM pellets after weighted were put inside the mold cavity.

5. The mold was closed by top cover of the mold and the mold was inserted into the compression molding machine.
6. The compression molding machine was setup at temperature of 210^{o}C and 10 ton force pressure.
7. The compression molding underwent preheating process for about 10 minutes before the mold was inserted and compressed for another 15 minutes.
8. After 15 minutes, the mold underwent cooling process until temperature of 80^{0}C. The cooling process was supported by outside fan to decrease the duration of cooling process.
9. The mold was taken out from compression molding and the POM layers were removed from the mold. Then, the POM layers are weighted. Figure 3.2 shows the POM layers after production process.

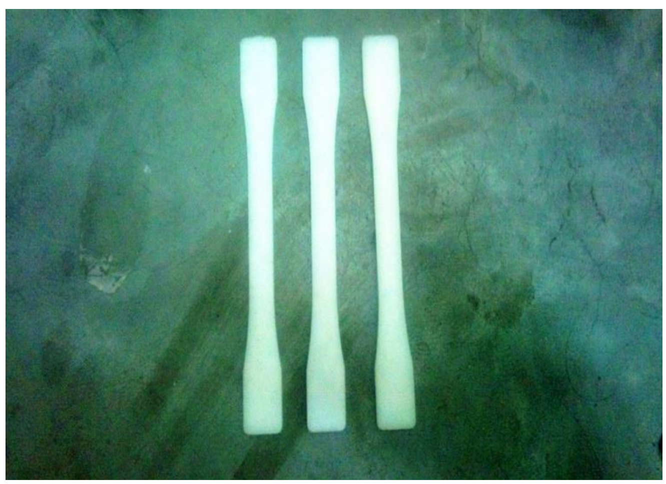


Figure 3.2 POM layers of tensile specimen

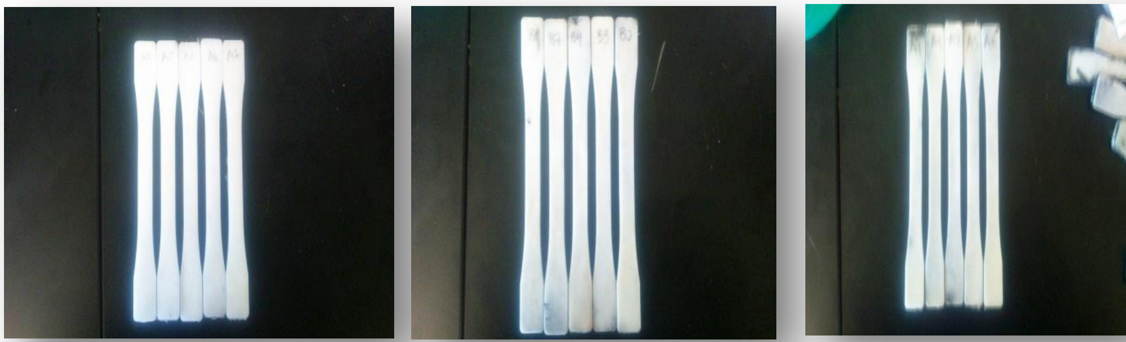
The preparation for composition of woven carbon fiber and woven glass fiber were done before the compression of composites. The woven carbon fiber and glass carbon fiber were weighed based on the weight obtained from the calculation. Both woven carbon fiber and woven glass fiber weight were taken and recorded. Figure 3.3 shows the reinforcements were cut and prepared.

Figure 3.3 Layers of carbon fiber and glass fiber

After the preparation of required woven carbon fiber and woven glass fiber, the compression process for composites was started. The procedures of producing POM/Carbon fiber/Glass fiber composites are as follows:

1. Wax was applied on the surface of mold for easiness composites removing.
2. A neat layer of POM was put inside of the mold.
3. 15wt. % of woven carbon fiber and 15wt. % of woven glass fiber were put together and arranged it based on composite arrangement.
4. Then, another POM layer was put on top of reinforcement, so the reinforcements are in the middle of POM layers.
5. The set up for compression molding was 200^{o}C and 12 ton force pressure.
6. Before proceed for the compression process, the compression molding machine underwent preheat process for 10 minutes.
7. After that, the mold was closed by the top cover and the mold was inserted inside of the compression molding. The duration of compression process was around 2-3 hours.
8. After the compression process, the mold underwent cooling process until temperature of 60^{0}C. The cooling process was supported by outside fan to decrease the duration of cooling process.
9. The mold was removed from the machine.
10. Then, the composites were removed from the mold and weighed by using electronic mass balance. Figure 3.4 shows the production of composites based on compositions decided.

11. The procedures for another different composition of fibers are repeated from steps 1 to 10.



a) Neat POM b) 70/15/15 wt.% c) 80/10/10 wt.%

Figure 3.4 Composition of Hybrid Composite

3.5 SPECIMENS TEST

3.5.1 Tensile Test

The tensile test is conducted on five specimens by using Tensile Test machine. The maximum tensile can be applied on specimens is 100kN. The specimens are produced based on ASTM D638 where the speed applied is 5 mm/min. Thickness and width of gauge length are taking by using micrometer, 5 measurements will be taken and averages will be calculated. The dimensions of specimen are shown as Figure 3.5 [18].

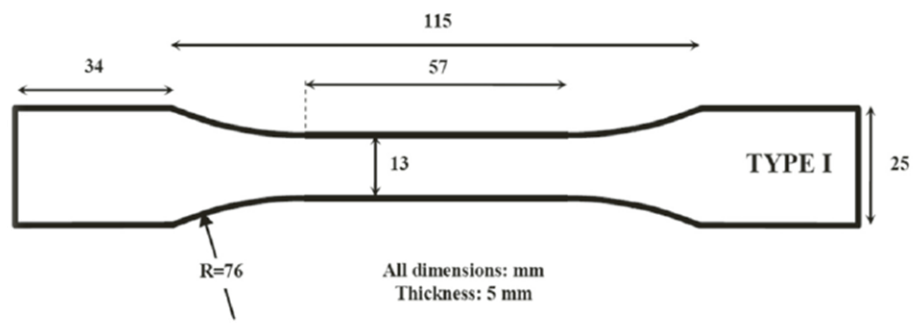


Figure 3.5 Dimensions of specimen

Table 3.6 Specimen dimensions for tensile specimen [18].

Dimensions	Length (mm)
W – Width of narrow section	13 ± 0.5
L – Length of narrow section	57 ± 0.5
WO – Width overall	19 ± 6.4
LO – Length overall	165
G – Gage length	50 ± 0.25
D – Distance between grips	115 ± 5
R – Radius of fillet	76 ± 1
T – Thickness	7 or under

3.6 KEY MILESTONES

Figure 3.6 shows the timeline of the project key milestones, this chart is the relationship between work and time. Besides, it's show the time allocated when the work is finish. The project key milestones are covering from Final Year 1 until Final Year 2.

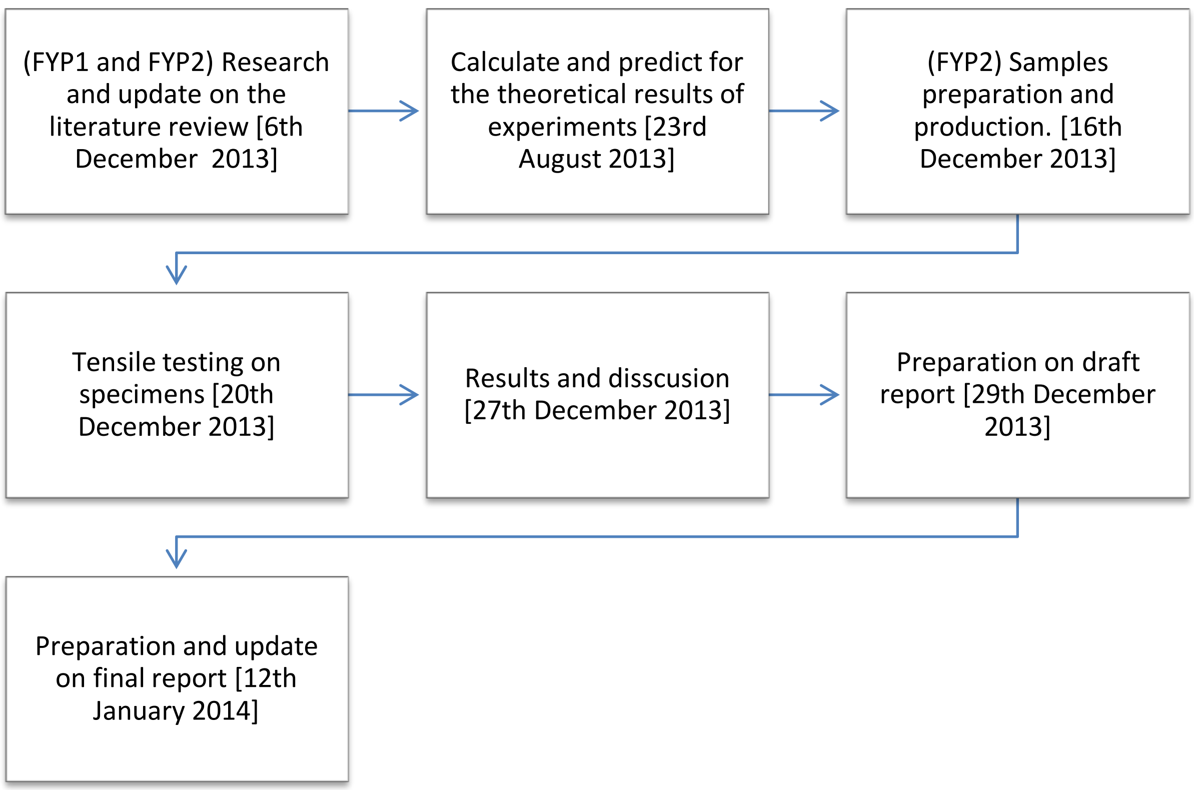


Figure 3.6 Key milestones of project

3.7 GANTT CHART

Figure 3.7 shows the Gantt chart of the project, it shows that the project activities that undergo from Final Year Project 1 until Final Year Project 2.

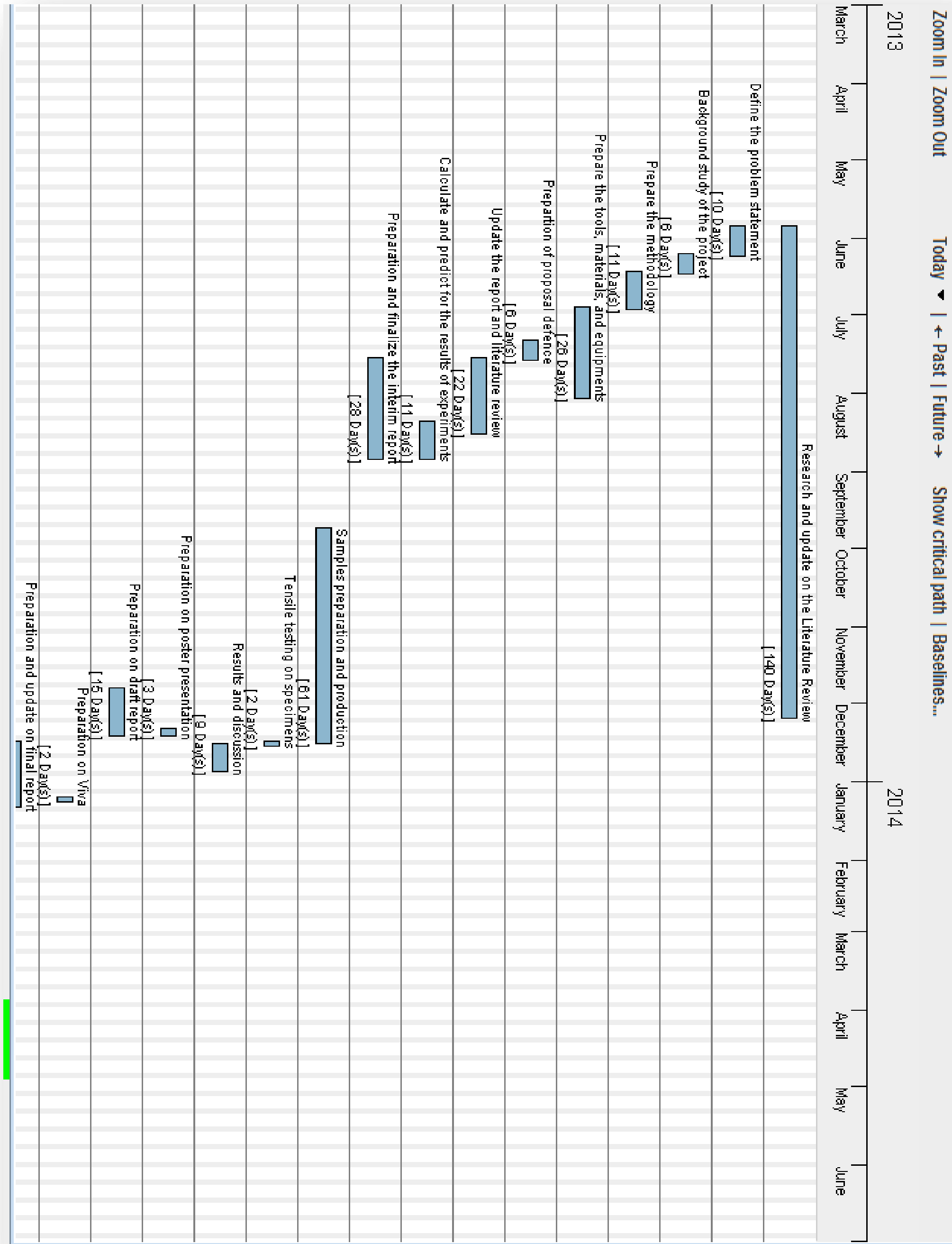


Figure 3.7 The Gantt chart

CHAPTER 4

RESULTS & DISCUSSION

In this chapter, analytical tensile strength of POM/carbon fiber/glass fiber hybrid composite 80/10/10 and 70/15/15 were calculated using rule of mixture. The analytical results were compared with the experimental results.

4.1 THEORETICAL RESULTS

The theoretical tensile strength and tensile modulus were calculated by rule of mixture, below is the formula for tensile strength and tensile modulus of hybrid composites.

$$\sigma^*_{cl} = \sigma'_m V_m + \sigma^*_{f1} V_{f1} + \sigma^*_{f2} V_{f2} \qquad \text{Equation 2.1}$$

Based on data given at Table 3.1, Table 3.3 and Table 3.4, the tensile strength of matrix at break was assumed less than 5% of tensile strength of matrix. From the formula above, the theoretical results of tensile strength for each of different composites are tabulated in Table 4.1.

Stress in matrix at composite failure, σ'_m = 57.00 MPa

The ultimate tensile strength of first fiber, σ^*_{f1} = 2000 MPa

The ultimate tensile strength of second fiber, σ^*_{f2} = 2900 MPa

Table 4.1 Theoretical results.

Samples	POM (Vol. %)	Woven glass fiber (Vol. %)	Woven carbon fiber (Vol. %)	Tensile strength (MPa)
Neat POM	100	0	0	60.8
80/10/10	80	10	10	535.6
70/15/15	70	15	15	774.9

The theoretical results of tensile strength has shown that as the volume ratio of reinforcement is higher, the tensile strength of composite also higher. Figure 4.1 show the graph generated from tensile strength value.

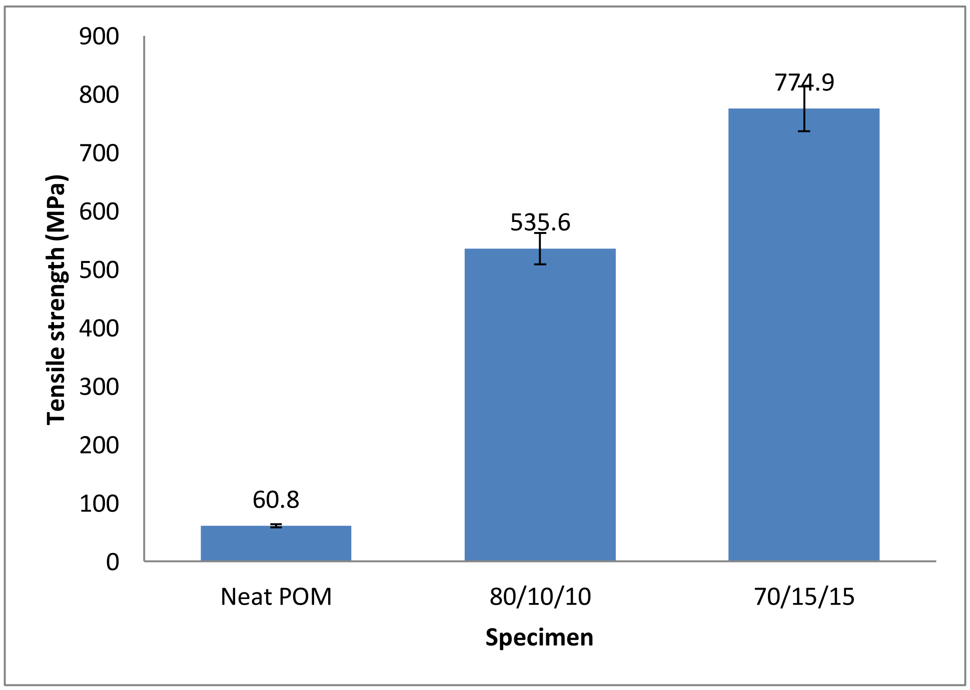


Figure 4.1 The theoretical results of tensile strength.

4.2 TENSILE STRENGTH PROPERTIES

Tensile test have been done on specimens of POM/carbon fiber/glass fiber which comprises of neat POM, 80/10/10, and 70/15/15 compositions. Five best samples were tested and recorded for each composition. Experimental results are tabulated and summarized in Table 4.2 and Figure 4.2 respectively.

Table 4.2 Tensile strength of neat POM, 80/10/10 and 70/15/15.

Sample	Tensile Strength (MPa)		
	Neat POM	80/10/10 wt.%	70/15/15 wt.%
1	47.44	131.67	150.02
2	37.31	135.58	140.17
3	39.63	134.46	140.17
4	48.04	125.67	135.20
5	44.87	124.09	136.94
Average	43.46	130.30	140.50

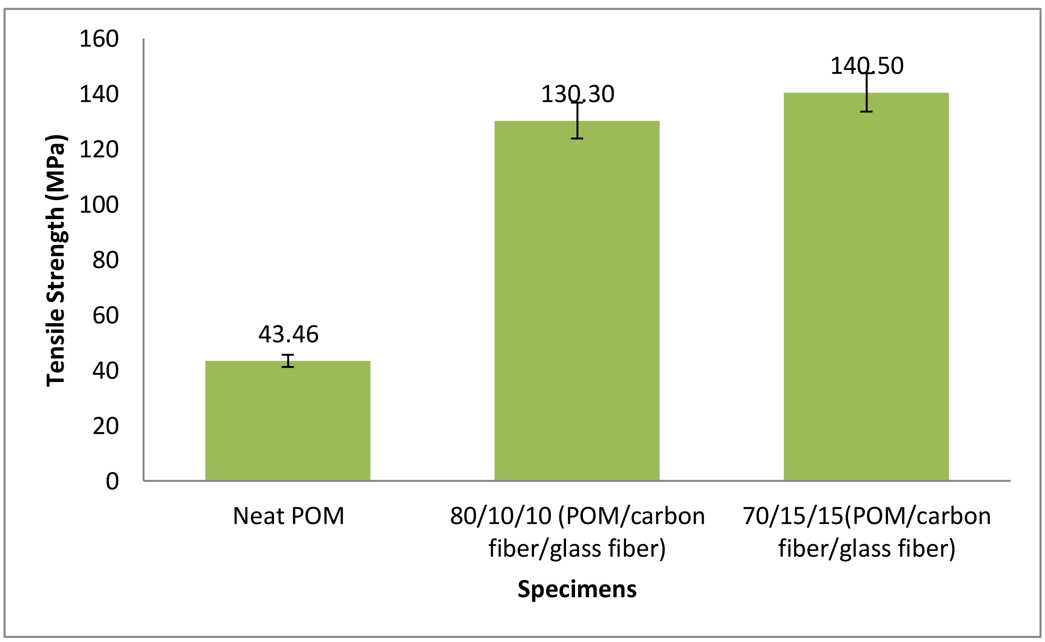


Figure 4.2 Tensile strength of POM/carbon fiber/glass fiber.

Results above show the tensile strength for three compositions, it has proved that the tensile strength for both compositions of hybrid composites have great results than neat POM. These significant increase of results is due to the reinforced fibers are able to increase the tensile strength of the hybrid composite than neat POM. Based on the graph, the composition of 80/10/10 wt.% of hybrid composite improved for approximately about 200% while 70/15/15 wt. % increase about 223% when compare with neat POM. Different of tensile strength between 80/10/10 wt.% and 70/15/15 wt. % show only approximately 10MPa or about 23%. Thus, 70/15/15 wt. % composition has high tensile strength compare with 80/10/10 wt % and neat POM.

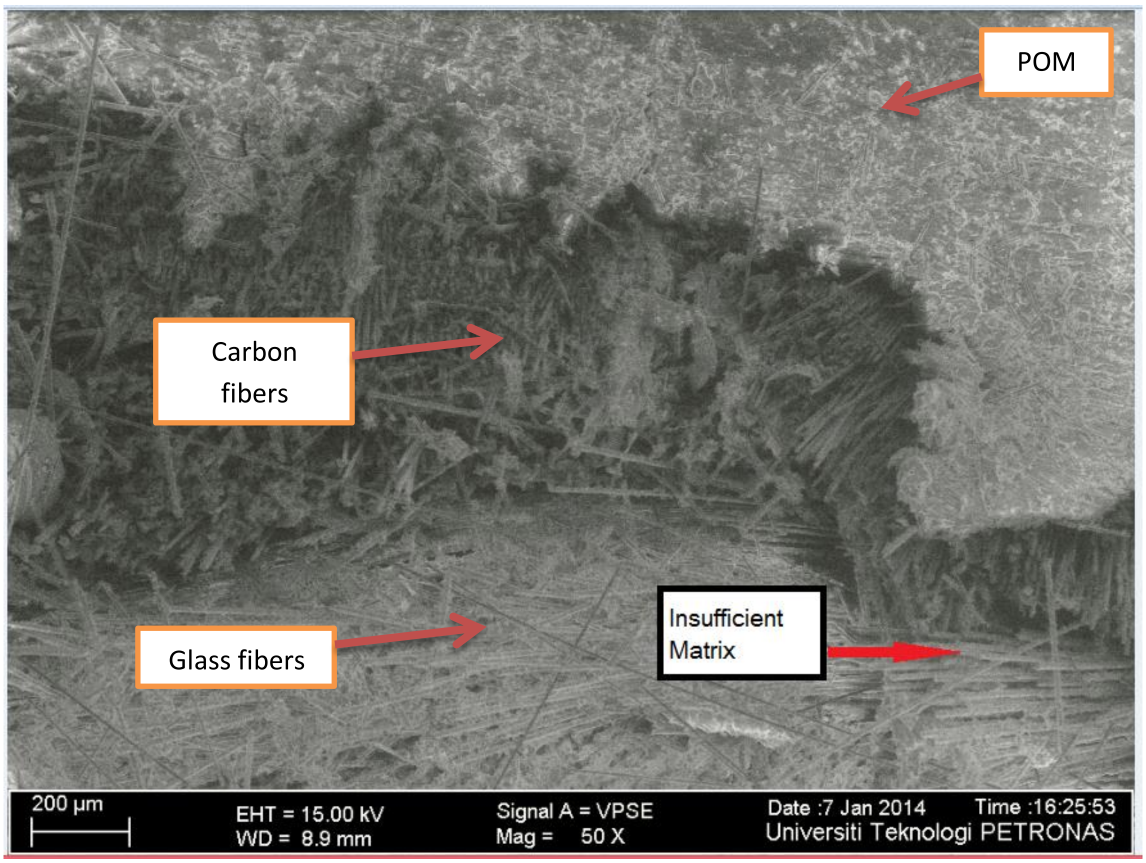


Figure 4.3 FESEM on POM/carbon fiber/glass fiber hybrid composite

Morphological characteristics of POM/carbon fiber/glass fiber hybrid composites are studied by using Field Emission Scanning Electron Microscope (FESEM) as shown in Figures 4.3. Based on Figures 4.3 above, the black fibers represent as carbon fiber while the white fiber represent as glass fiber. It is clearly shows only carbon fibers have good interfacial bonding with POM while glass fibers have poor interfacial bonding with POM. The glass fibers are not bonded well due to insufficient matrix and POM hard to penetrate the fibers. These factors cause the POM slide off from the fibers after tensile test was ongoing on the hybrid composites.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Tensile strength of POM/carbon fiber/glass fiber hybrid composite was studied. Improvement of tensile strength of 223% and 200% were achieved for 70/15/15 wt.% and 80/10/10 wt.% POM/carbon fiber/glass fiber hybrid composites compared to neat POM, respectively. Based on FESEM micrographs, the glass fibers were poor bonded with POM due to insufficient matrix and hard to penetrate fibers. Only carbon fibers have good bonded with POM matrix. These problems cause the POM slide off from reinforcements when undergo tensile strength test.

5.2 Recommendation

For future work, flexural and impact properties of POM/carbon fiber/glass fiber hybrid composite should be studied. To have better penetration of POM inside the fibers, a thin sheet of POM should be including in between the woven fiber layers.

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