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An Investigation into the Effects of Fibre Volume Fraction on GFRP Plate

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Abstract—This paper presents the mechanical properties of Glass Fibre Reinforce Plastic (GFRP) plates with different fibre volume fraction, V_f by considering both analytical and experimental method. The fibre used is chopped strand mat (CSM) type E-glass fibre where the matrix used is unsaturated polyester resin. The composite plates were prepared by hand lay-up technique. Rule of mixture (ROM) and modified rule of mixture (MROM) were used to predict the performance of the composite plates. Tensile test according to ASTM D 3039 was carried out to obtain ultimate strength and modulus of elasticity of the composite plate with different V_f. Three different composite systems were tested in this study. The actual V_f of the composite plates were justified by burn out test (SIRIM MS 1390:1995). MROM was found had better validity than ROM to be used to estimate the mechanical properties of specimens. The experimental results show that the mechanical properties were improved when V_f is increased. Thus, the influence of fibre volume fraction on the mechanical properties of CSM E-glass fibre/polyester composites has been evaluated.

Keywords: GFRP, fibre volume fraction effects, mechanical properties.

1. Introduction

Among many kind of composite materials, polymer composites are the most common material to be used for lightweight structures such as aircraft and automobile [1]. Fibrous polymer composite is the material that containing fibre which provide strength and stiffness to it. The used of fibre reinforced plastics (FRP) in several industries is increased and become important in this decade due to its special mechanical properties. Even though FRP still cannot totally replace the used of steel and aluminium alloy, but its significance of light weight, high specific strength and lower thermal expansion properties had successfully grab the manufacturers' attention[1].

Composite materials can combine the properties of the component of the mixtures, however, many of the mechanical properties such as strength, stiffness and toughness is weighted by the fibre volume fraction (V_f) of the composite [2]. Hence, the amount of fibre in the composite is largely governed by the manufacturing process used [3].

Fibre volume fraction was found to have significant effects on important composite properties including failure mode and ultimate strength. Mechanical properties of FRP can be improved with increasing fibre volume fraction [4].

As a general rule, the stiffness and strength of a laminate will increase in proportion to the amount of fibre present [3]. However, when the fibre volume fraction was sufficiently large, the composite ultimate strength was degraded. [4]. In addition, above about 60-70% V_f (depending on the way in which the fibres pack together) although tensile stiffness may continue to increase, the laminate's strength will reach a peak and then begin to decrease due to the lack of sufficient resin to hold the fibres together properly [3].

The significant increased of the used of FRP in industry shown that there is a need to improve the properties and quality of polymer composite. In order to maintain and produce polymer composite with greatest mechanical properties, a standard in manufacture polymer composite is very important. Therefore, a proper fibre volume fraction which plays an important role on mechanical properties of FRP should be investigated to obtain the best performance.

Hence, the aim of this project is to investigate the performance of different fibre volume fraction to the CSM E-glass fibre/polyester composite plate. Universal Testing Machine (INSTRON) was used to perform tensile test to examine the strength, modulus of elasticity and fibre failure of the specimens.

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Rule of mixture (ROM) and modified rule of mixture (MROM) were used to predict the performance of the specimens with different V_f. The validity of theoretical result was evaluated by comparing it with experimental results.

2. Materials and Methods

2.1 Materials

The studied materials will be composite which consists of polymer resins and glass fibres. The raw materials chosen to be used to fabricate the specimens of the project are unsaturated polyester with 1% of hardener and chopped strand mat (CSM) type E-glass fibres.

Chopped strand mat (CSM) is a non-woven material. The glass fibre strands from roving are chopped into 2.5 to 5 cm lengths and evenly distributed at random onto a horizontal thin plane and bound together with an appropriate chemical binder. These mats weight from 0.25 to 0.92 kg/m^2 and are available in widths from 5 cm to 1.95 m. This random arrangement results in equal but lower strength in all fibres directions (about one-third of the unidirectional mat). The properties of the glass fibre used are given in Table 1 while the properties of polyester resin are given in Table 2.

Table 1 Mechanical properties of E- Glass fibre

Density (g/cm^3)	Tensile Strength (MPa)	Elastic Modulus (GPa)
2.50	1750	73

Table 2 Mechanical properties of polyester resin

Density (g/cm^3)	Tensile Strength (MPa)	Elastic Modulus (GPa)
1.2	55	2.4

2.2 Composite Sample Preparation

The composite laminates were fabricated by using hand lay-up technique. The desired laminates were containing three layers of fibres.

The first step of the specimens' preparation process is to set the percentage of fibres content in the composite. The amount of resin needed for each category of composite laminate was calculated after that. Then the ply of CSM fibre with dimension 25cm x 30cm were cut out and ready to be used for composite laminate fabrication purpose.

Fabrication process started with cleaning the glass plate which used as the base of the laminate layers of composite materials. Release anti-adhesive agent is applied onto the glass plate surface after the glass plate is cleaned. Then, a ply of CSM fibre was put on the glass plate and resin was poured on the fibre. It is then swept and level on the fibre surface by using squeezer.

This process was carry-on until the resin was covered and adhere the whole ply of fibre. This is to make sure the resins are totally absorbed by the fibres and provide a good adhesive bonding between fibres and resins. After first layer of the composite laminate is totally wet and adhere by resins, the steps are repeated for second layer of the laminate until the third layer. It is left for 24 hours for curing purpose.

Table 3 Weight percent of fibre content for each category of specimens

Category	Weight Percent of Fibres (%)	Weight Percent of Matrix (%)
S1	20	80
S2	30	70
S3	40	60

Specimens are prepared after the composite laminates are ready. The geometry of the specimens is set by referring to ASTM standard D 3039 [5]. The proper design of specimens is mentioned in this standard. The dimension of the test specimens are 25mm x 250mm. There are total four categories of specimens prepared for testing purpose. The weight percent of fibre contained in the composite laminates was shown in Table 3.

The specimen is then cut out by using cutter machine. Grinding process was done by sand belt grinding machine as finishing purpose. Specimens are labeled according to different fibre volume fraction. Six test specimens were prepared for each category.

2.3 Burn Out Test

Burn out test is a test used to determine the weight percent contain in composite laminates. This test is based on Malaysian Standard, SIRIM MS 1390:1995 [6]. The purpose of this test is to ensure the actual percentage of the fibres content in the composite laminate. Hence, it can used to justified whether the fibre content comply with the preset fibre content or not.

First, a small piece of composite is cut out from the composite laminate for each category. Then it is labeled according to the preset category which is S1, S2 and S3. The weight of every small piece is measured and recorded.

The furnace is switched on and set to be 600^{o}C. The furnace is then let to reach the desired heat until the temperature inside the furnace is stable. After that, the small piece of composites which put on a piece of ceramic was put in the furnace and burned at 600^{o}C for one hour.

The small piece is then moved out from the furnace after burning. The weight of the small piece is measured again for second time. This test is actually burn resins out and left fibre. Thus, the actual weight percent of fibres contain in the composite is obtained.

2.4 Tensile Test

Tensile test is conducted to examine the strength and modulus of elasticity of the specimens for this project. The test is based on ASTM standard D 3039. This is the standard which is specially to be used to determine the tensile properties of polymer composite materials. The machine used to conduct tensile test is 50 kN INSTRON Universal Testing Machine, model 3369.

The ultimate tensile strength of the specimen can be determined from the stress-strain curve plot by the raw data of test results. The initial portion of the curve where stress is proportional with strain before yield occurred is used to determine the specimen modulus of elasticity.

The speed of testing or cross head speed is set at 1mm/min. The speed of testing is set at 1mm/min and remains constant for all specimens during the test, so that the test carried out is in static condition. This is to ensure the consistency and accuracy of the experiment.

2.5 Failure Mode

Specimens will fracture at different mode. It can be fail with degrees, explosive on non-explosive, fail within gage length or out of gage length and other few more typical types. The location of failure can be coded by referring to ASTM Standard D 3039. Thus, the failure mode of the specimens is can be determined based on this code.

2.6 Theoretical Results

Rule of mixture (ROM) the simplest way to estimate the mechanical properties of composite materials. It is applied to obtain the analytical result. The formula used to calculate strength and modulus of elasticity is given by:

$$\sigma_c = V_f \sigma_f + \sigma_m (1 - V_f) \tag{1}$$

$$E_c = V_f E_f + E_m (1 - V_f) \tag{2}$$

Modified rule of mixture (MROM) is often used to predict strength of short fibre composites [7]. This method considered two other factors that will affect the properties of composite materials which is fibre orientation and fibre length. Hence, it is also applied to estimate the performance of the specimens too. The formulas are given by:

$$\sigma_{cu} = \chi_1 \chi_2 V_f \sigma_f + \sigma_m (1 - V_f) \tag{3}$$

$$E_c = \eta_L \eta_0 V_f E_f + E_m (1 - V_f) \tag{4}$$

where,

σ_c, σ_{cu} = stress of composite

σ_m = matrix stress at the strain corresponding to the fibre's ultimate tensile stress

σ_f = corresponding fractions of the stress on the fibres

V_f = fibre volume fraction

E_c = Modulus of Elasticity for composite

E_f = Modulus of Elasticity for fibres

E_m = Modulus of Elasticity for matrix

χ_1, η_0 = fibre orientation factor

χ_2, η_L = fibre length factor

The product of χ_1 and χ_2 is the fibre efficiency factor for the strength of the composite. Typically, χ_2, $\eta_L \approx 1$ for fibres longer than about 10 mm. The value of χ_1, η_0 for random in-plane for CSM is 0.375.

3. Results and Discussion

3.1 Tensile Test Results

The experimental results were obtained by carried out tensile test. The results for specimens category S1 are summarized in Table 4.

Table 4 Summary of experimental result for category S1

Category	Strength (MPa)	Modulus of Elasticity (GPa)
S11	60.59	2.26
S12	51.54	2.01
S13	61.30	2.53
S14	57.03	2.11
S15	57.71	4.76
S16	51.88	4.57

According to Table 4, the modulus of elasticity of the specimens is in the range of 2GPa to 4.8GPa. Specimen S15 attained the highest modulus of elasticity among all six specimens which is 4.76GPa.

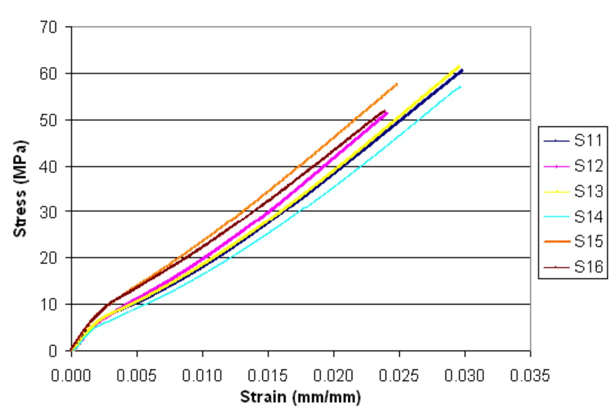

Figure 1 Stress-strain curve of specimens (V_f = 0.107)

The specimens achieved in the range of 50MPa to 62MPa for the ultimate strength. Among all six specimens from S11 to S16, specimen S13 obtained the highest ultimate strength which is 61.30MPa. Stress-strain curve for specimens category S1 ($V_f = 0.107$) is shown in Figure 1.

Table 5 Summary of experimental result for category S2

Category	Strength (MPa)	Modulus of Elasticity (GPa)
S21	90.89	6.82
S22	74.69	6.42
S23	76.31	6.31
S24	70.24	6.06
S25	81.79	6.47
S26	72.99	6.55

For category S2 (Figure 2), specimen S21 achieved the highest ultimate strength which is 90.89MPa. Specimen S24 is the specimen with lowest ultimate strength among six specimens which is 70.24MPa. The results for specimens category with $V_f = 0.171$ (S2) is summarized in Table 5.

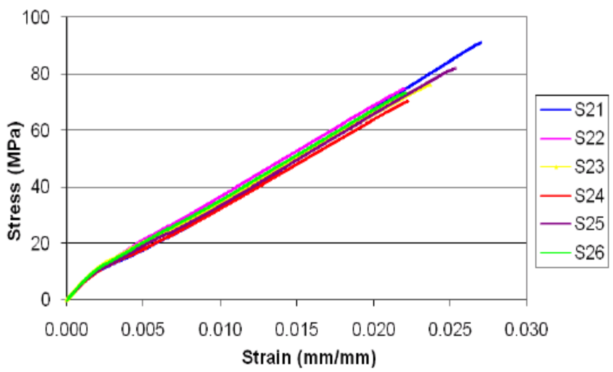

Figure 2 Stress-strain curve of specimens ($V_f = 0.171$)

Specimen S21 attained the highest modulus of elasticity which is 6.82GPa among six specimens where specimen S24 is the specimen achieved the lowest modulus of elasticity which only reached 6.06GPa. Stress-strain curve for specimens category S3 is presented in Figure 3. V_f for the specimens of this category is 0.242.

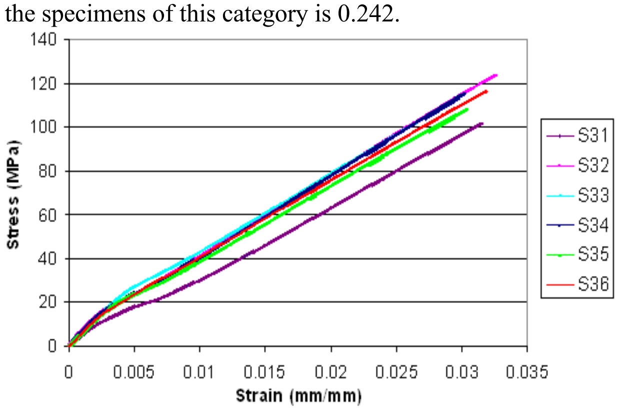

Figure 3 Stress-strain curve of specimens ($V_f = 0.242$)

Strength achieved by the specimens is in the range of 100MPa to 125MPa. Specimen S32 is the specimen that achieved the highest ultimate strength which is 123.56MPa among all six specimens.

Table 6 Summary of experimental result for category S3

Category	Strength (MPa)	Modulus of Elasticity (GPa)
S31	101.67	5.69
S32	123.56	7.83
S33	101.99	7.30
S34	114.97	7.00
S35	107.96	5.83
S36	116.21	5.18

The specimen that attained the lowest ultimate strength is S31 which only accomplished 101.67MPa. Specimen S32 attained the highest modulus of elasticity which is 7.83GPa among six specimens. Specimen S36 is the specimen achieved the lowest modulus of elasticity which only reached 5.18GPa. The mechanical properties of the specimens under category S3 are summarized in Table 6.

3.2 Failure Mode

As be observed, all of the specimens are failed explosively where majority of the specimens are broke at the middle of the gage. Therefore, the way of the specimen failed is matched one of the typical failure mode as shown in ASTM Standard D 3039. The specimens were having flat failure as observed.

The failure code of all categories of specimens is XGM where X represent explosive, G represent gage and M represent middle. This means the specimens are failure explosively at the middle of the gage length. This code is determined according to failure code stated in ASTM Standard D 3039.

3.3 Burn Out Test Result

The result obtained from burn out test shows that the fibre contents of the fabricated laminate is tally with the preset weight percent of fibre. Table 7 presented the comparison between actual and preset fibre content for each category. The differences between preset and actual weight percent of fibre is only up to 14%

Table 7 Comparison of preset and actual fibre content for each category

Specimens	Weight Percent of Fibre, W_f (%)		% of Difference
	Preset	Actual	
S1	20	21.5	7.5
S2	30	34.1	13.6
S3	40	44.3	10.8

3.4 Effects of Fibre Volume Fraction

Specimens tested in the experiment is fibrous polymer composite which containing fibre which provide strength and stiffness to it. The mechanical properties such as strength, stiffness and toughness are weighted by the fibre volume fraction (V_f) of the composite.

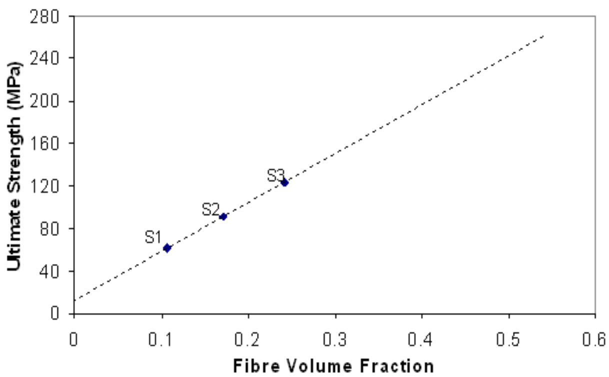

Figure 4 Highest ultimate strength of specimens with different V_f.

Figure 4 presents the highest ultimate strength of CSM E-glass fibre/polyester composite specimens for each category. The figure shows the changes in strength when V_f increased. As can be seen in the figure, ultimate strength for specimen category S3 is 123.56MPa. This is larger than ultimate strength of specimen category S2 which only achieved 90.89MPa. Meanwhile, specimen category S1 achieved the lowest strength among all three categories which is 60.30MPa.

The figure shows that increase of strength when the V_f of the composite increased obviously. The increase of strength is linear with V_f. S3 is the category where the specimens contain highest V_f. Hence, it had a larger value of strength than two other categories of specimens.

According to Figure 4, the relationship between ultimate strength and fibre volume fraction can be expressed by:

$$\sigma_{cu} = 458.33V_f + 12.603 \qquad (5)$$

However, this relationship is only valid for CSM E-glass fibre/polyester with V_f in the range $0 \leq V_f \leq 0.242$. This is because the relationship among ultimate strength and higher V_f for existed and other type of fibrous composite materials has not been evaluated yet.

The value of Modulus Young is denoted by the gradient of the graph stress versus strain before yield occurred. The comparison of Modulus Young result between every category is presents in Figure 5

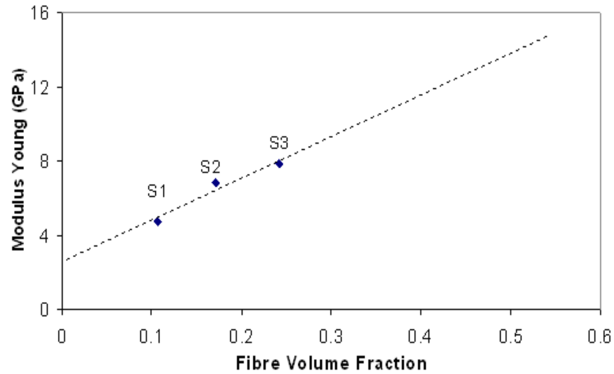

Figure 5 Highest Modulus Young of specimens with different V_f.

This comparison is made between the highest Modulus Young attained in each category which is 4.76GPa for category S1, 6.82GPa for category S2 and 7.83GPa for category S3. As can be observed from Figure 5, value of Modulus Young is increasing linearly with the increase of V_f, where the relationship between Modulus Young and fibre volume fraction can be expressed by:

$$E_c = 22.586V_f + 2.5551 \qquad (6)$$

However, (6) had the same limit of validity with (5) because the relationship among Modulus Young and higher V_f for existed and other type of fibrous composite materials also has not been evaluated yet.

According to Figure 5, an obvious increasing in value of modulus of elasticity when V_f increase from 0.107 (category S1) to 0.171(category S2). However, the increase of gradient of the graph is not that significant when V_f increase from 0.171 to 0.242 (category S3). This is because when fibre content of composite laminate increase, resin to hold the fibres together properly is decreased. Thus, the laminate's modulus of elasticity begins to reach the peak. Thus, there is a limit of increasing V_f. The limit of reinforcement is varies for different type of fibre used.

As can be seen from Figure 4 and 5, the relationship of both ultimate strength and modulus of elasticity with fibre volume fraction is linear. The increase of strength and modulus of elasticity of the specimens when V_f increased had clearly proved the effect of V_f onto mechanical properties of fibrous composite materials.

3.5 Validity of Theoretical Results

In order to evaluate the validity of theoretical result, comparison is made between theoretical value and experimental value. Table 8 shows the comparison between experimental and ROM theoretical strength. This comparison is made between the highest strength for each category of specimen with predicted strength.

Table 8 Comparison of experimental and ROM theoretical strength

Specimen	V_f	Strength (MPa)		% of
		Theory	Experiment	Error
S1	0.107	236.37	61.69	73.9
S2	0.171	344.85	90.89	73.6
S3	0.242	465.19	123.56	73.4

As can be observed from the Table 8, the value of strength for each category estimated by ROM is much larger than the experimental strength. The percentage of difference is up to 74%.

ROM is the most common method used to estimate the mechanical properties of the composite laminates. For a unidirectional composite laminates, it was found adequate to predict experimental results [8]. But, the validity of this method for all kind of composite laminates is still under investigation. ROM is being modified; non-unidirectional reinforcement correction factor and length correction factor are introduced.

Comparison is made again between the highest experimental strength for each category with MROM theoretical strength. This is in order to examine whether which method is suitable to be used to predict the performance of CSM E-glass fibre/polyester composite.

Table 9 Comparison of experimental and MROM theoretical strength

Specimen	V_f	Strength (MPa)		% of
		Theory	Experiment	Error
S1	0.107	119.33	61.69	48.3
S2	0.171	157.81	90.89	42.4
S3	0.242	200.50	123.56	38.4

Table 9 presents the result of the comparison. From the table, it shows that the percent of difference is much smaller compare to ROM method. The difference is only up to 48%. This result shows that fibre length and orientation should be counted as factors that affect mechanical properties of the specimens too.

Comparison between experimental and ROM theoretical Modulus Young is shows in Table 10. As can be seen in the table, the difference is up to 58%. The range of theoretical result is located between 9GPa to 19GPa where experimental result only in the range from 4.5GPa to 8GPa. Moreover this is the comparison between the highest experimental results for each category with ROM theoretical Modulus Young.

Table 10 Comparison of experimental and ROM theoretical Modulus Young

Specimens	V_f	Modulus of Elasticity (GPa)		% of
		Theoretical	Experimental	Error
S1	0.107	9.63	4.76	50.6
S2	0.171	13.96	6.82	51.1
S3	0.242	18.76	7.83	58.3

Table 11 presents the comparison between experimental and MROM result. This comparison shows a better result than previous comparison where the percent of difference only up to 5.2%. This shows that MROM is more suitable to be used to predict the Modulus Young of the specimens than ROM.

Table 11 Comparison of experimental and MROM theoretical Modulus Young

Specimens	V_f	Modulus of Elasticity (GPa)		% of
		Theoretical	Experimental	Error
S1	0.107	4.95	4.76	3.8
S2	0.171	6.48	6.82	5.2
S3	0.242	8.17	7.83	4.2

The fibre used in the experiment is chopped strand mat (CSM) type E-glass fibre. This is a kind of short fibre and evenly distributed randomly. Therefore, ROM is not suitable to be used to predict the mechanical properties for this type of composite. This difference between ROM and MROM result occurred is because of MROM considers about fibre length and fibre orientation too. However, the model used in ROM is a model with unidirectional aligned continuous fibres.

MROM is often used to predict strength of short fibre composites [7]. However, the percentage of difference between theoretical and experimental result is still large even MROM is applied. This result shows that it is difficult to predict the strength of a composite.

Unlike modulus of elasticity, strength on a contrary is a structure-sensitive property. Thus, synergism can occur in the composite state. There are a lot of other factors that might influence the composite properties need to be considered. For example, matrix or fibre structure may be altered during fabrication [9].

Modulus Young predictions are compared directly with result of tests on tensile test specimens. It shows that MROM predictions are much accurate than ROM. This is because the fibre used in the composite laminate is CSM. Therefore, the equation of ROM that does not consider the fibre length and orientation is not suitable to be used to make the predictions.

The increase in the longitudinal modulus of fibrous composite as a function of the reinforcement volume fraction is fairly straight forward. The modulus for discontinuous reinforcement is independent of the particle clustering [9]. Thus, theoretical predictions on Modulus Young is much accurate than predictions on strength.

4. CONCLUSION

Fibre volume fraction, V_f was found to have significant effects on mechanical properties of the composite including strength, toughness, failure mode and so on. The mechanical properties can be improved by increasing fibre volume fraction. However, the composite ultimate strength will degrade if the fibre volume fraction is too large.

This study is carried out in order to investigate the mechanical properties of chopped strand mat (CSM) E-glass fibre/polyester composite panel with different fibre volume fraction. The specimens are subjected to axial load. Tensile test is conducted to establish the strength and modulus of elasticity for the composite laminates. This test had given the basic concept of the effect of fibre volume fraction onto the mechanical properties of the fibre reinforced composites.

The results of experiment show that the mechanical properties of the specimens were increased when fibre volume fraction increased. Comparison between theoretical and experimental result shows that ROM is not appropriate for quasi-isotropic laminates such like CSM because the angle plies offer substantial stiffness and strength at failure [10].

Thus, the conclusion that can be made is the mechanical properties of the glass fibre reinforced polymer composite is depends on the fibre volume fraction. However, there is limitation to increase the fibre volume fraction, V_f of glass fibre reinforced fibre (GFRP). V_f only can increase up to the level without affected the bonding of the composite so that mechanical properties would not be degraded. In addition, the validity of theoretical predictions on the mechanical properties of GFRP can be increase by considering all the possible factors that affect the properties such like fibre length and orientation.

5. ACKNOWLEDGEMENT

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6. REFERENCES

[1] Dr. Robert, I. M. (May/June 1999) Fibre Reinforced Polymers - From Aerospace to Infrastructure. *ATSE Focus No 107*.

[2] Michael, F. A. and Dvid, R. H. J. (2006) *Engineering Materials 2 An Introduction to Microstructures, Processing and Design*. 3rd. ed. U. K.: Elsevier.

[3] David, C. Guide to Composite. *NetComposite*.

[4] Xu, H. H. K., Ostertag, C. P., Braun, L. M. and Lloyd, I. K. (1994) Effects of Fibre Volume Fraction on Mechanical Properties of SiC-fibre/Si[3]N[4]-Matrix Composites. *Journal of the American Ceramic Society (J. Am. Ceram. Soc.)* vol. 77, no7, pp. 1897-1900.

[5] American Standard and Testing Methods (ASTM) (1998). *Standard Test Method for Tensile Properties of Polymer Composite Materials*, ASTM Standard D 3039.

[6] Standard and Industrial Research Institute of Malaysia (SIRIM) (1995). *Specification for glass-reinforced polyester panels & panel water tanks*. Malaysia, MS 1390:1995.

[7] Shao, Y. F. and Bernd, L. (1996) Effects of Fibre Length and Fibre Orientation Distributions on The Tensile Strength of short-Fibre-Reinforced Polymers. *Composites Science and Technology*. Volume (56): 1179-1190.

[8] E. E. Gdoutos, K. Pilakoutas and C. A. Rodopoulos (2000) *Failure Analysis of Industrial Composite Materials*. U. S. A.: McGraw-Hill.

[9] Marc, A. M. and Krishan, K. C. (1999) *Mechanical Behavior of Materials*. International ed. U. S. A.: Prentice Hall Inc.

[10] Stephan, P. P. (1998). *Quasi-Static and Fatigue Evaluation of Pultruded Vinly Ester/E-Glass Composite*. Virginia Polytechnic Institude and State University: Master Thesis.