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Research Article

Processing and Characterization of Fiber/Plastic Composite for Turbine Blade

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Abstract- In order to know the influence of fraction volume of composite (E-glass/Carbon fiber with Polyester/Epoxy matrix) for choosing the best wind turbine blade material, some objectives of this research are: 1) It is to find the best composite from tensile test to the combination ratio between E-glass and carbon fibers with polyester and epoxy matrix; 2) It is to find the best composite from density test to the combination ratio between E-glass and carbon fibers with polyester and epoxy matrix; 3) It is to find the best composite from hardness test to the combination ratio between E-glass and carbon fibers with polyester and epoxy matrix; 4) It is to find the best composite from micrograph test to the combination ratio between E-glass and carbon fibers with polyester and epoxy matrix. Thus, the significance of this study is to find the best result, as for the material used to make the composite is from E-glass and carbon fibers and polyester and epoxy matrix; the comparison of fraction volume or ratio between fiber and matrix is 1: 1, 1: 2, 2: 3; 3) and the test items mold with the hand lay-up method. So, it is hoped that the best ratio of composite can be found as the material for wind turbine blade. This study uses an experimental research, in which the methodology of this research explains several steps of testing to analyze the best composite of the specimen tested. Based on data analysis and from the testing to composite fabrication of E-glass and Carbon fibers with Polyester and Epoxy matrixes, with the variation of a fraction the volume of 1:1, 1:2, and 2:3, it can be conclude that: 1) it is found that the highest tensile strength, strain and young's modulus composite is 23,22 N/mm, 7,389% and 315 N/mm in carbon with epoxy (1: 1); 2) the lowest density of composite is 1,04 gr/cm3 found in the carbon with epoxy (1: 1); 3) the highest hardness is 77,75 VHN on E-glass with polyester (2: 3) composite; 4) from the micrograph test it is found that the best composite is Carbon-Epoxy (1:1) with 4 lines.

Keywords: fraction volume, E-glass fiber, Carbon fiber, Polyester matrix, Epoxy matrix, tensile test, density test, hardness test, micrograph test.

Introduction

People began to realize that the world's oil supplies would not last forever and that remaining supplies should be conserved for the petrochemical industry. The use of oil as a boiler fuel, for example, would have to be eliminated. Other energy sources besides oil and natural gas must be developed. The two energy sources besides petroleum which have been assumed able to supply the long term energy needs of the United States are coal and nuclear energy. Unfortunately, both coal and nuclear present serious environmental problems. Coal requires large scale mining operations, leaving land that is difficult or impossible to restore to usefulness in many cases. The combustion of coal may upset the planet's heat balance. The production of carbon dioxide and sulfur dioxide may affect the atmosphere and the ability of the planet to produce food for its people. Coal is also a valuable petrochemical feedstock and many consider the burning of it as a boiler fuel to be foolish.

Nuclear energy has several advantages over coal in that no carbon dioxide or sulfur dioxide are produced, mining operations are smaller scale, and it has no other major use besides supplying heat. The major difficulty is the problem of waste disposal, which, because of the fears of many, will probably never have a truly satisfying solution (Johnson, 2001). Recently, composite materials are extensively used to design the wind turbine blades (Babu et al, 2006). Wind turbine blades are made of lightweight materials to minimize the loads from rotating mass. Steel often used to construct the blade, but it has disadvantage like corrosion and its heavy. Meanwhile, fiber is better than steel which is non-corrosive, strong, lightweight, maintenance-free, and can be erected efficiently and economically. Besides, its exterior gel coat finish and color is molded into the laminate. The molded-in surface coat that contains the color is resistant to ultraviolet attack and airborne contamination. It also has excellent weather ability, heat resistance, and chemical resistance and fire retardancy properties. The finished shape can be curved, corrugated, ribbed or contoured. It weighs less than two pounds per square foot of surface area. Per unit of weight, it is among the strongest commercial materials available. Pound for pound, it is stronger than concrete, steel or aluminum. Moreover, it can be produced to be watertight, virtually maintenance-free.

Review of Related Literature

Wind Turbine

"Wind turbines" is now being used as a generic term for machines with rotating blades that convert the kinetic energy of wind into useful power.

Parts of Wind Turbine

Wind turbines come in many sizes and configurations and are built from wide range of materials. In simple terms, a wind turbine consists of a rotor that has wing shaped blades attached to a hub; a nacelle that houses a drive train consisting of a gearbox, connecting shafts, support bearings, the generator, plus other machinery; a tower; and ground-mounted electrical equipment. The wing shaped blades on the rotor actually harvest the energy in the wind stream.

The rotor converts the kinetic energy in the wind to rotational energy transmitted through the drive train to the generator. Generated electricity can be connected directly to the load or feed to the utility grid.(Peters, 1998).

Wind Turbine Materials

A wide range of materials are used in wind turbines. There are substantial differences between small and large machines and there are projected changes in designs that will accommodate the introduction of new material technologies and manufacturing methods. The estimated materials use in small and large turbines is shown in Table 1 (Ancona, 2001). To arrive at a total, the material usage is weighted by the estimated market share of the various manufacturers and machines types. (Peters, 1998).

Table (1) Blade material options

Material	Manufacturing method
Metal	Steel or aluminum blades may be manufactured as solid shapes or from rolled plates that are welded together on airfoil shaped support plates.
Composite	Blades of carbon or glass fiber reinforced polymer composites may be manufactured in two-part moulds
Wood	Wooden blades may be carved from a wood work-piece by mechanical means or by hand

Each of the abovementioned alternatives entails a number of relative advantages and disadvantages, some of which are listed qualitatively below.

Metal blades	1. Heavy (steel) 2. Light (aluminum) 3. Expensive 4. Widely available Demanding manufacturing processes
Composite blades	1. Lightweight 2. Strong 3. High repeatability 4. Good fatigue characteristics 5. Low material availability 6. Possibility for complex airfoil shape
Wooden blades	1. Lightweight 2. Abundant supply 3. Cheap 4. Strong 5. Flexible

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	6. Non-uniform when hand-carved 7. Simple airfoil shape required

Composite for Wind Turbine Blade

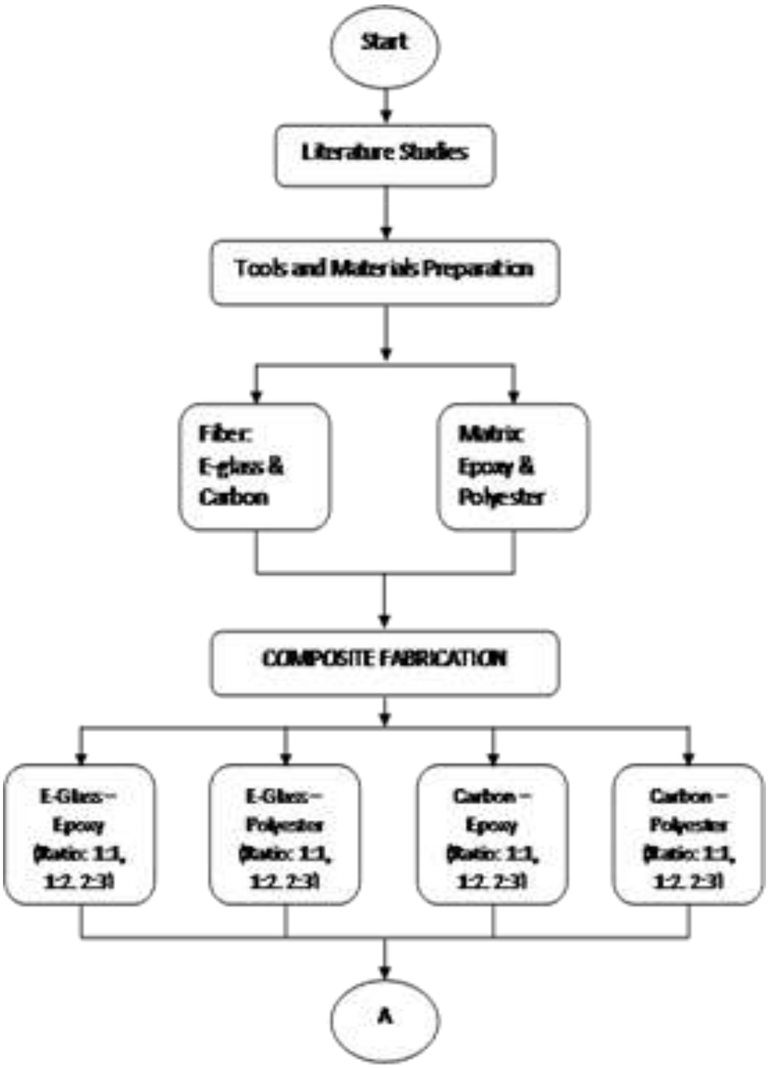
Blades represent the most important composite based part of a wind turbine, whose properties quite often determine the performances and lifetime of the wind turbine. A blade consists of two faces (on the suction side and the pressure side), joined together and stiffened either by one or several integral (shear) webs linking the upper and lower parts of the blade shell or by a box beam (box spar with shell fairings). The box beam inside the blade is adhesively joined to the shell. Wind turbines blades are subject to the external loading, which includes the flap wise and edgewise bending loads, gravitational loads, inertia forces, loads due to pitch acceleration, as well as tensional loading. The flap wise load is caused mainly by the wind pressure, while the edgewise load is caused both by gravitational forces and torque load. The biggest edgewise bending moment is at the blade root. The flap wise and edgewise bending loads cause high longitudinal, tensile and compressive stresses in the material. The upwind side of the blades is subject to tensile stresses while the downwind side is subject to compression. The flap wise and edgewise bending moments lead to the fatigue damage growth. These two moments are responsible for 97% of the damage in blades. The wind blades are also subject to cyclic loadings, caused by wind variations, turbulences, wind shear, and other effects, like pressure variations of air around the tower. During the functioning, the stability of the blade shape (aerodynamic profile), high durability and reliability should be ensured. The shape stability corresponds to the minimum deflection of the blade under the wind loads. This is achieved by increasing the moment of inertia of the blade (using the corresponding blade design) and by increasing the flexural stiffness of the wind blade material. The flap wise bending is resisted by the spar, internal webs or spar cabs inside the blade, while the edges of the profile carry the edgewise bending. Table 2 summarizes the roles of the parts of wind blades in maintaining the blade shapes.

Table 2 Wind blade parts and their functions in maintaining the blade shapes (Larsen, 2009)

Part	Function	Materials used
Blade shell	Maintaining the blade shape, resisting the wind and gravitational forces	Strong, lightweight composite
Unsupported parts of the shell	Resisting the buckling load	Biaxial lay-ups at +/-45°
Adhesive layers between composite plies, and the web and the blade shell	Ensuring the out-of plane strength and stiffness of the blade	Strong and highly adhesive matrix

Method

This study uses an experimental research, the experimental method is a systematic and scientific approach to research in which the researcher manipulates one or more variables, and controls and measures any change in other variables.


Start
Literature Studies
Tools and Materials Preparation
Fiber:
E-glass &
Carbon
Matrix:
Epoxy &
Polyester
COMPOSITE FABRICATION
E-Glass –
Epoxy
(Ratio: 1:1,
1:2, 2:3)
E-Glass –
Polyester
(Ratio: 1:1,
1:2, 2:3)
Carbon –
Epoxy
(Ratio: 1:1,
1:2, 2:3)
Carbon –
Polyester
(Ratio: 1:1,
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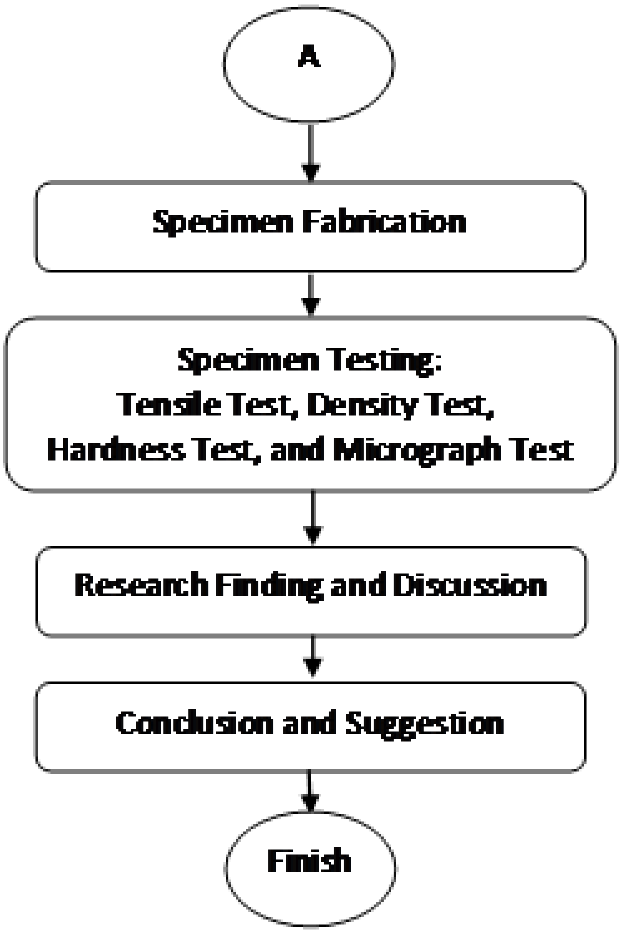

Composite Fabrication

The process of making a composite on this research by means of fiber and matrix is placed in a mould and let the resin to harden and dried. When making composite is used ratio between the fiber and the matrix that is 1: 1, 1: 2, 2: 3. The steps of composite fabrication are as follows:

First, determine the volume of mould (Vc) in order to find the volume fraction of fiber (*Vf*) and matrix (Vm): The dimension of mold used in this research is:

Length (L) = 26 cm
Width (W) = 17 cm
Thickness (T) = 0,5 cm
Vc = L x W x T
= 26 x 17 x 0,5
= 221 cm^3

For example the data we take from the calculations of E-glass fiber and polyester matrix with ratio 1: 1:

Vf = 50 % x Vc	Vm = 50 % x Vc
= 50 % x 221	= 50 % x 221
= 110,5 cm3	= 110,5 cm3
	= 110,5 ml

Mf = ρ x Vf
= 2, 58 gr/ cm^3 x 110, 5 cm^3
= 285, 09 gr
= 7 sheets (A weight of one piece E-glass in size 26 x 17 cm is = 40,7 gr)

By using the formula above, it is known about the combination or ratio between fiber and matrix to make composite which can be seen in the following table:

Table 3 Variation ratio between fiber and matrix

NO	Composite	fiber quantities (pcs)	matrix volume (ml)	hardener volume (ml)
1	E-glass with polyester (1 : 1)	7	110,5	1,105
2	E-glass with polyester (1 : 2)	4	147,33	1,4733
3	E-glass with polyester (2 : 3)	5	132,6	1,326
4	E-glass with epoxy (1 : 1)	7	55,25	55,25
5	E-glass with epoxy (1 : 2)	4	73,665	73,665
6	E-glass with epoxy (2 : 3)	5	66,3	66,3
7	Carbon with polyester (1 : 1)	7	110,5	1,105
8	Carbon with polyester (1 : 2)	4	147,33	1,4733
9	Carbon with polyester (2 : 3)	5	132,6	1,326
10	Carbon with epoxy (1 : 1)	7	55,25	55,25
11	Carbon with epoxy (1 : 2)	4	73,665	73,665
12	Carbon with epoxy (2 : 3)	5	66,3	66,3

Research Finding and discussion

Composite Tensile Test Result

Tensile test is one of testing to determine

Tensile test is one of testing to determine the composition of the composite fabrication to suit the desired spec. The purpose of the test is to know the tensile stress, strain and young's modulus of a composite. The number of tensile tests on specimens tested in total there are 36 pcs with the variation of the mixes composition can be seen in table 4 below

Table 4 the number of specimen tensile test

No	Composite	The number of specimens
1	E-glass with Polyester (1 : 1)	3
2	E-glass with Polyester (1 : 2)	3
3	E-glass with Polyester (2 : 3)	3
4	E-glass with Epoxy (1 : 1)	3
5	E-glass with Epoxy (1 : 2)	3
6	E-glass with Epoxy (2 : 3)	3
7	Carbon with Polyester (1 : 1)	3
8	Carbon with Polyester (1 : 2)	3
9	Carbon with Polyester (2 : 3)	3
10	Carbon with Epoxy (1 : 1)	3
11	Carbon with Epoxy (1 : 2)	3
12	Carbon with Epoxy (2 : 3)	3
Total		36

The detailed data of tensile test results can be seen in Appendix. Its result in average can be seen in table 5.

No.	Material No.	Tensile Strength (N/mm^2)	Elongation (%)	Young's Modulus (GPa)
1	E-glass with Polyester (1 : 1)	7,078	2.1	44
2	E-glass with Polyester (1 : 2)	3,515	1.8	25
3	E-glass with Polyester (2 : 3)	4,533	2	29
4	E-glass with Epoxy (1 : 1)	6,289	2.4	34
5	E-glass with Epoxy (1 : 2)	3,904	2	25
6	E-glass with Epoxy (2 : 3)	2,801	2.2	17
7	Carbon with Polyester (1 : 1)	20,548	1	267
8	Carbon with Polyester (1 : 2)	10,450	0.7	194

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9	Carbon with Polyester (2 : 3)	13,654	0.8	222
10	Carbon with Epoxy (1 : 1)	23,223	1.1	274
11	Carbon with Epoxy (1 : 2)	11,466	0.8	186
12	Carbon with Epoxy (2 : 3)	16,619	1	216

Table 5 Composite tensile test result

From the tensile test result as shown in the table 4.1, it is known that there are two groups of specimen taken for the test, first is six specimens from E-glass and the second is six specimens from Carbon. From the first group the highest value for tensile strength is E-glass-Polyester (1:1) with 7,078 N/mm^2, and the lowest is E-glass-Epoxy (2:3) with 2,801 N/mm^2. For elongation, the highest value is E-glass-Epoxy (1:1) with 2,4 %, and the lowest is E-glass-Polyester (1:2) with 1,8 %. Whereas, for the young modulus, the highest is E-glass-Polyester (1:1) with 44 GPa, and the lowest is E-glass-Epoxy (2:3) with 25 GPa.

Therefore, the best specimen for the first group is E-glass-Polyester (1:1) with 7,078 N/mm^2 for tensile strength, 2,1 % for elongation and 44 GPa for young modulus.

From the second group the highest value for tensile strength is Carbon-Epoxy (1:1) with 23,223 N/mm^2, and the lowest is Carbon-Polyester (1:2) with 10,450 N/mm^2. For elongation, the highest value is Carbon-Epoxy (1:1) with 1,1 %, and the lowest is Carbon-Polyester (1:2) with 0,7 %. Whereas, for the young modulus, the highest is Carbon-Epoxy (1:1) with 274 GPa, and the lowest is Carbon-Epoxy (1:2) with 186 GPa. Therefore, the best specimen for the second group is Carbon-Epoxy (1:1) with 23,223 N/mm^2 for tensile strength, 1,1 % for elongation and 274 GPa for young modulus.

Thus, from the entire tensile test it is known that the best is from the second group which is Carbon-Epoxy (1:1). It has 23,223 N/mm^2 for tensile strength, 1,1 % for elongation and 274 GPa for young modulus.

Figure 1 Sample specimen of tensile test result

Based on graphs stress, strain and young modulus obtain data highest on specimens the number ten with stress 23,22 N/mm², strain 7,389 % and young modulus 315 N/mm² on composite carbon with epoxy (1 : 1). The second are on specimens number twelve with stress 16,62 N/mm², strain 5,933 % and young modulus 280,4 N/mm² on composite carbon with epoxy (2 : 3).The third are on specimens number eleven by stress 11,46 N/mm², strain 4,854 % and young modulus 236,8 N/mm² on composite carbon with epoxy (1 : 2).The forces that hold the maximum load occurs on a composite containing a lot of adherents there is mixing between the fiber and resin evenly. It was not able to withstand the loads then the composite will break up.The imposition of which was given to a composite specimen tensile testing which is the application of axial forces (axial forces) at the ends of the specimen. Axial styles pose an equal attraction (uniform) on specimens that tensile (tension). Assuming that stress is distributed evenly on the entire specimen, then the resultant equals to the intensity once the cross-sectional area of the rod (*Gere and Timoshenko, 2001*).

Composite density test result: The density test is one of the tests for determining the mass of the type specimens of composite fabrication on the composition corresponding to the desired spec. On testing the density of mass data obtained by dry, wet mass, volume and density of a wet. It can be seen in attachment of the density test result. There are 36 pcs of specimens tested which can be seen in table 6 below.

No	Composite	The number of specimens (pcs)
1	E-glass with Polyester (1 : 1)	3
2	E-glass with Polyester (1 : 2)	3
3	E-glass with Polyester (2 : 3)	3
4	E-glass with Epoxy (1 : 1)	3
5	E-glass with Epoxy (1 : 2)	3
6	E-glass with Epoxy (2 : 3)	3
7	Carbon with Polyester (1 : 1)	3
8	Carbon with Polyester (1 : 2)	3
9	Carbon with Polyester (2 : 3)	3
10	Carbon with Epoxy (1 : 1)	3
11	Carbon with Epoxy (1 : 2)	3
12	Carbon with Epoxy (2 : 3)	3
Total		36

Table 6 the number of specimen for density test

Average results of the density test of a composite using fiber that of E-glass and carbon as well as polyester and epoxy for the matrix can be seen in table 7 below.

NO	COMPOSITE	DENSITY (gr/cm^3)
1	E-glass with Polyester (1 : 1)	1,14
2	E-glass with Polyester (1 : 2)	1,08
3	E-glass with Polyester (2 : 3)	1,11
4	E-glass with Epoxy (1 : 1)	1,08
5	E-glass with Epoxy (1 : 2)	1,04
6	E-glass with Epoxy (2 : 3)	1,05
7	Carbon with Polyester (1 : 1)	1,11
8	Carbon with Polyester (1 : 2)	1,06
9	Carbon with Polyester (2 : 3)	1,06
10	Carbon with Epoxy (1 : 1)	1,04
11	Carbon with Epoxy (1 : 2)	1,04
12	Carbon with Epoxy (2 : 3)	1,04

Table 7Composite density test result

From the density test result as shown in the table 5, it is known that there are two groups of specimen taken for the test, first is six specimens from E-glass and the second is six specimens from Carbon. From the first group the highest value for density is E-glass-Polyester (1:1) with 1, 14 gr/cm3, and the lowest is all E-glass-Epoxy (1:2) with 1,04 gr/cm3. Therefore, as the density must be low so the best specimen for the first group is E-glass-Epoxy (1:2) with 1,04 gr/cm3.

From the second group the highest value for tensile strength is Carbon-Polyester (1:1) with 1,11 gr/cm3, and the lowest is all Carbon-Epoxy (1:1), (1:2) and (2:3) with 1,04 gr/cm3 each. Therefore, the best specimen for the second group is all Carbon-Epoxy (1:1), (1:2) and (2:3) with 1,04 gr/cm3 each.

Thus, from the density test it is known that the best is E-glass-Epoxy (1:2) and all Carbon-Epoxy (1:1), (1:2) and (2:3) with 1,04 gr/cm3 each. If it is compared by the theory from Zweben (1989) that density for E-glass is 2,60 gr/cm3, and for Carbon is 1,8 gr/cm3, the E-glass and Carbon found in this research is better than Zweben's.

Based from graph 7 the lowest density value is present on the specimen number ten, eleven and twelve in the carbon composite with epoxy (1: 1), carbon composite with epoxy (1: 2), carbon composite with epoxy (2: 3) amounting to 1.04 gr/cm^3

Composite hardness test result

No	Composite	The number of layers	The number of specimens (pcs)
1	E-glass with Polyester (1 : 1)	7	3
2	E-glass with Polyester (1 : 2)	4	3
3	E-glass with Polyester (2 : 3)	5	3
4	E-glass with Epoxy (1 : 1)	7	3
5	E-glass with Epoxy (1 : 2)	4	3
6	E-glass with Epoxy (2 : 3)	5	3
7	Carbon with Polyester (1 : 1)	7	3
8	Carbon with Polyester (1 : 2)	4	3
9	Carbon with Polyester (2 : 3)	5	3
10	Carbon with Epoxy (1 : 1)	7	3
11	Carbon with Epoxy (1 : 2)	4	3
12	Carbon with Epoxy (2 : 3)	5	3
Total			36

Table 8 The number of specimen for hardness test

Average value of hardness VHN on hardness testing results composite using fiber E-glass and carbon as well as polyester and epoxy matrix can be seen in table 9.

NO	COMPOSITE	VHN(N/mm2)
1	E-glass with Polyester (1 : 1)	25,86
2	E-glass with Polyester (1 : 2)	48,42
3	E-glass with Polyester (2 : 3)	77,75
4	E-glass with Epoxy (1 : 1)	30,2
5	E-glass with Epoxy (1 : 2)	20,17
6	E-glass with Epoxy (2 : 3)	18,6
7	Carbon with Polyester (1 : 1)	24,04
8	Carbon with Polyester (1 : 2)	22,44
9	Carbon with Polyester (2 : 3)	21,7
10	Carbon with Epoxy (1 : 1)	6,54
11	Carbon with Epoxy (1 : 2)	3,54
12	Carbon with Epoxy (2 : 3)	35,53

Table 9 Composite hardness test result

Thus, from the hardness test it is known that the best is from the first group which is E-glass-Polyester (2:3) with 77, 75 VHN.

However, the E-glass-Polyester has the highest hardness result as mention in the beginning; it needs consideration to choose the best composite, as the density is more important than the hardness.

It can be compared with the density test that the best is E-glass-Epoxy (1:2) and all Carbon-Epoxy (1:1), (1:2) and (2:3) with 1,04 gr/cm3 each.

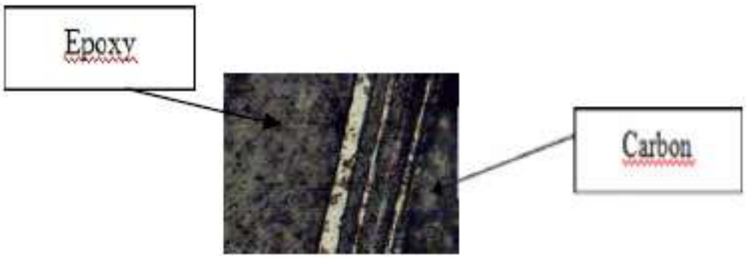
Micrograph Test Result

Micrograph test is to recognize the microstructure of materials. This test used magnification 200 x. It is discussed in two ways, firstly based on the horizontal view, and secondly vertically

From the micrograph test result as shown in the previous, it is known that there are also two groups of specimen taken for the test, first is six specimens from E-glass and the second is six specimens from Carbon. From the first group the best specimen is E-glass-Epoxy (1:2) with 6 dots, and the lowest is all E-glass-Polyester (1:1) with 21 dots. Therefore, the best specimen for the first group is E-glass-Epoxy (1:2) with 6 dots.

From the second group the highest value for tensile strength is Carbon-Epoxy (1:1) with 4 lines, and the lowest is all Carbon-Epoxy (1:2) and (2:3), also Carbon-Polyester (2:3) with 12 lines. Therefore, the best specimen for the second group is Carbon-Epoxy (1:1) with 4 lines.

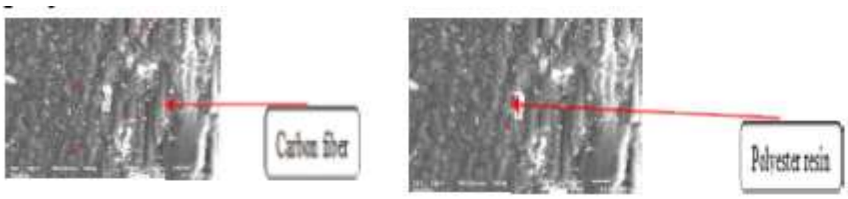
Thus, from the hardness test it is known that the best is from the first group which is Carbon-Epoxy (1:1) with 4 lines.



SEM Test Result

A scanning Electron Microscopy (SEM) machine model Jeoul JSM-6510, as seen in figure 4.14, is used to study the effect of the microstructure of composites specimens. It is also aimed to know the combination/mix of composite between the fiber and the matrix. In this research, the specimens to test by SEM are Carbon-Epoxy (1:1) and Carbon-Polyester (1:1), the results are as follows:

Firstly, as shown in figure 4.15 (a) and (b), in which Carbon-Epoxy composite scanned in 300x and 600x magnification, it is found that Carbon fiber formed neatly covered by epoxy resin. Whereas Carbon-Polyester composite which is magnified in 1000x, as in both figures 4.16 (a) and (b), shows the carbon fiber not covered firmly by the polyester resin.



As the result of the experiments above, it is found that not all composite meet its requirements. The volume fraction has influenced the quality of the composite made. It is proved that, for example, from the tensile test on composite tensile stress resulted that the best is the carbon-epoxy with ratio 1:1 (10th specimen) has 23.223 N/mm^2. It is also found that even with the same combination of composite, the carbon-epoxy with ratio 1:2 (11th specimen) only has 11.466 N/mm^2. Moreover on carbon-epoxy with ratio 2:3 (12th specimen) has 16.619 N/mm^2. By this means that ratio of volume fraction is influence the composite quality.

CONCLUSION AND SUGGESTION

Conclusion

Based on data analysis and from the testing to composite fabrication of E-glass and carbon fibers with polyester and epoxy matrix, with the variation of a fraction the volume of 1:1, 1:2, and 2:3, it can be conclude that:

1. It is found that the highest tensile strength, strain and young's modulus composite is 23,22 N/mm, 7,389% and 315 N/mm in carbon with epoxy (1: 1).
2. The lowest density of composite is 1,04 gr/cm3 found in the carbon with epoxy (1: 1).
3. The highest hardness is 77,75 VHN on E-glass with polyester (2: 3) composite.
4. From the micrograph test it is found that the best composite is Carbon-Epoxy (1:1) with 4 lines.

Suggestion

1. Composite fiber manufacturing process should really note that will produce composite with strength and stiffness is high.
2. An amplifier that should be selected either uniform fiber, both dimensions and its characteristics.
3. Research on composite materials, especially with synthetic fibers is very open to more develop.

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