Solar Curing of Glass Fibre Reinforced Epoxy (GRE) Composite

by

Nurizuan Bin Sahar

Dissertation submitted in partial fulfilment of

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CERTIFICATION OF APPROVAL

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Mechanical Engineering Programme
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Approved:

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TRONOH, PERAK

January 2009

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 or persons.

Nurizuan Bin Sahar

ABSTRACT

The method of curing is very important in producing composites. This project studies the comparison of mechanical properties of composites in different types of curing. The objective of this project is to compare the effects of method of curing between direct solar heating and oven curing on the properties of Glass Fibre Reinforced Epoxy (GRE). The methods used for fabrication process are hand lay up technique or if circumstances permit, Vacuum Infusion Process (VIP). Flexural test was conducted on the resin epoxy and GRE composite. The testing was based on ASTM D790M. The result of this project; solar cured resin has much difference than oven cured resin in term of flexural modulus, maximum bending stress at maximum load and also maximum deflection. Solar cured GRE composite has less difference than oven cured GRE composite. For GRE composite, all standard deviations for all the properties were overlapping. It means that there is not much difference between solar cured composite and oven cured composite. As a conclusion, a curing process using direct solar heating for GRE composite has the potential to cure resin epoxy, composites and replacing the oven curing process. For recommendation, FVF, porosity, density of the composite and also resin epoxy affect shall be isolate to get better result. The degree of cure also shall be determined by using DSC equipment.

ACKNOWLEDGEMENTS

First and foremost, all praise to Allah s.w.t for granting me the opportunity to complete this final year project, which has proven to be a very enriching experience.

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LIST OF ABBREVIATIONS

ASTM	American Standard for Testing and materials
GRE	Glass Fibre Reinforced Epoxy
UV	Ultraviolet
UTM	Universal Testing Machine
VIP	Vacuum Infusion Process
FVF	Fibre Volume Fraction
DSC	Differential Scanning Calorimeter
UTP	Universiti Teknologi PETRONAS

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Materials have such an influence on our lives. The periods of mankind have been dominated, and named, after materials. Over the last 30 years, composite materials, plastics, and ceramics have been the dominant materials. The number of applications of composite materials has grown steadily, and conquering new markets. Most of us are familiar with fibreglass boats and graphite sporting goods, and possible applications of composite materials are limited only by the imagination of the individual [1].

A composite material is formed by the combination of two or more distinct materials to form a new material with enhanced properties. The most common composites are those made with strong fibres held together in a binder. Particles or flakes are also used as reinforcements, but they are not as effective as fibres. For example, the combination of epoxy and glass fibre will produce GRE. Fibre-reinforcement is more preferable because it is much stronger than the bulk form. The main factors to use the composites are weight reduction, corrosion resistance, and part-count reduction. Besides that, the other advantages are electromagnetic transparency, wear resistance, enhanced fatigue life, thermal-acoustical insulation, low thermal expansion, low or high thermal conductivity, etc.

Fibres cannot be used alone, a binder or matrix required to hold the fibre together. This is to protect the fibres from environmental attack, determining the corrosion resistance, and also chemical attack.

Fibres also can not contribute to the strength transversely to the fibre direction, and the strength of the matrix is low. To overcome this, it is necessary to add layers with various orientations to face all the applied loads by creating a laminate [1].

1.2 Problem Statement

In industry of composites, it is necessary to cure it at elevated temperature. The common technology used for curing process required high cost in term of electricity, maintenance, expertise, and many more so that the curing process is optimum and does not reduce composite's properties.

Basically the Epoxy-based composites normally require prolonged heating at elevated temperature to completely cure. One of the alternative curing processes which is low cost is direct solar curing. The abundance of solar energy which can reach up to 40°C in tropical climate can be exploited to formulate a low cost and environmental friendly manufacturing process for composites.

In this project, the mechanical properties of the composite shall be tested and prove that direct solar curing can be applied in industry.

1.3 Objectives and Scope of Study

The objective of this Final Year Project is:

- To compare the effects of method of curing between direct solar heating and oven curing on the properties of GRE.

The scope of study for this Final Year Project is:

- Fabrication of composite which specify in this project is hand lay-up technique.
- Various types of curing which are direct solar curing and oven curing.
- The method to evaluate the specimens by using flexural testing.

CHAPTER 2

LITERATURE REVIEW

2.1 Curing of Composites

In curing process, the composites are cured whether in at room temperature or elevated temperature. Curing process will begin the cross-linking reaction and develop the strength. The composite or liquid resin will have the cross-linking process which forms a molecule with a larger molecular weight. When molecular weight is increased, the melting point of the materials also increases. It means that the composite or liquid resin after curing process will have higher melting point. Besides that, the water and alcohol vaporised during this process.

2.1.1 Direct Solar Curing

Malaysia has a tropical climate, and is hot and humid throughout the year. Daily temperatures average between 21°C and 32°C [3]. Based on this situation, our country has high potential to use sunlight for curing the thermosetting and composite. Under certain circumstance, the maximum temperature can reach up to 40°C of surface composite. It is possible to use direct solar curing as one the alternative method to cure the composites. In some study, the epoxy which cured in ambient temperature has been used to repair the laminated beam samples [8].

This type of curing is still not documented yet. In this project, it would be the first solar curing. The effect of solar curing could also affect the mechanical properties of the resin and composite in general.

2.1.2 Oven Curing

Curing by oven is one of the common methods for curing composites. The composite placed in the oven and the desired temperature is set based on the material's curing requirements. The advantages are long working life, high-temperature resistance, good chemical resistance, and also decrease the viscosity [6].

2.1.3 Ultraviolet (UV) Light Curing

The resin is formulated with a photo-initiator (phosphine oxide-based), which initiates a rapid cross-link cure mechanism upon exposure to UV light. Before cured by UV light, the resin has been cured in conventional room temperature with a gel time of 20-40 minutes. The UV light would give the effect to resin for 10 minutes under a 400 W mercury vapour lamp. The advantages of this curing process are ease of formulation and operation, reduced costs and rapid production times [6].

2.1.4 Pulsed Blue Laser Curing

The light source used for this type of curing is a pulsed laser which consisting of an aimer laser which optically pumped a dye laser. The intensity of blue light is important in producing a sufficient number of free radicals to provide an adequately cured material. It affects the polymerization process and also cross-links process of composite. With the wavelength about 470nm, the composite can be cured effectively [7].

2.2 Standard of Testing

2.2.1 Flexural Test

In flexural testing for materials composite, the rectangular cross section on two supports and is loaded by means of a loading nose midway between the supports. The specimen is deflected until rupture occurs in the outer surface of the test specimen or until a maximum strain of 5.0% is reached, whichever occurs first [9].

The common flexural test is three points flexural test. In this test, we could obtain the modulus of elasticity in bending, E_{bend} of the composite and thermosetting. The advantage of it is easy to prepare and test the specimen. By applying the load at three points and causing bending, a tensile force acts on the material opposite the midpoint. Fracture begins at this location [5].

Based on International Standard American Society for Testing and Materials (ASTM), the minimum specimens fabricated are five in number. For flexural test, the standard used is ASTM D 790M. The average sample dimensions were width 10 mm and thickness 2.1 mm. A span-to-thickness ratio of 16 to 1 was used to set the span length [6].

2.3 Vacuum Infusion Process (VIP)

VIP is a technique which uses vacuum pressure to drive the resin into the laminate. At that process, the materials will dried and lay into the mould. After that, resin will flow into the materials at the inlet and vacuum pressure will apply at the outlet. The resin flow certain order in all material completely covered with resin.

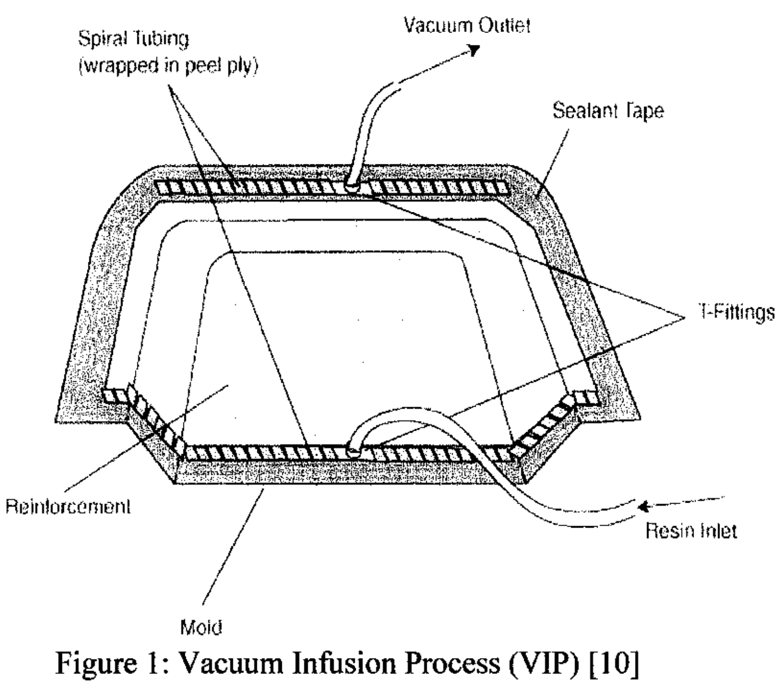


Figure 1: Vacuum Infusion Process (VIP) [10]

CHAPTER 3

METHODOLOGY

3.1 Materials

The main materials used for this project are glass fibre and resin epoxy. To fabricate composite, these materials are the materials which can produce composite. Below are details of the materials.

3.1.1 Glass Fibre

The E-glass fibre is available in the form of strands, yarns and roving. It is also possible to obtain long fibres of glass form short fibres by spinning them. The glass fibres have a good tensile strength (2400 MPa), low tensile modulus (73 GPa), and lowest cost fibre, available in may forms, widely used in commercial and industrial products [5]. In this project, woven glass fibre used and it available in UTP.

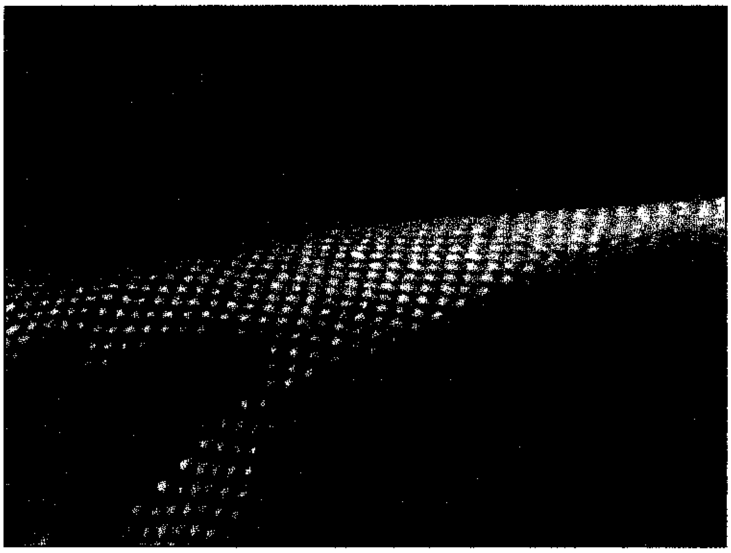


Figure 2: Woven E-Glass Fibre which is Available in UTP

3.1.2 Resin Epoxy

Epoxies have high mechanical properties, high corrosion resistance and also their versatility. Epoxies also shrink less than other materials which is excellent bond characteristics when used as adhesives. Besides that, it is less affected to water, heat and simply cure at any temperature between 5°C to 150°C. Furthermore, epoxy can be used as casting compounds for the fabrication of prototype moulds, patterns and also tooling [1].

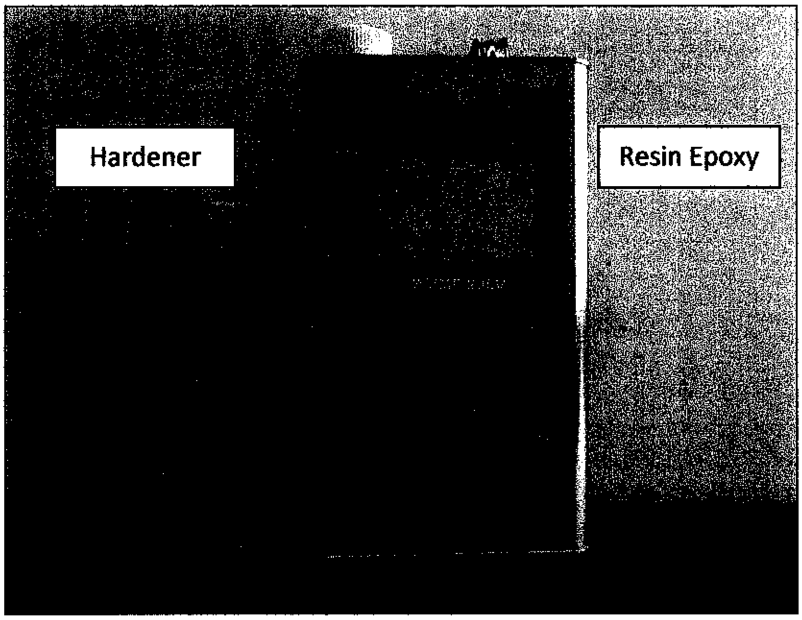


Figure 3: The Resin Epoxy and the hardener which is Available in UTP

3.2 Fabrication of Resin and Composite

3.2.1 Preparing Moulding

Before preparing the resin and composite, the other thing which is important shall be prepared first. The function of cup is to insert the resin and hardener as container. The moulding which used to locate the resin and glass fibre should be fabricated first. The dimension of moulding shall be accurate and can be used repetitive without any damage. The tolerance shall be considered to fabricate moulding.

To know it, the dimension of specimen is our reference to calculate the dimension of moulding. The dimension of a specimen is 10 mm x 68 mm x 2.1 mm; the dimension for 7 specimens is 70 mm x 68 mm x 2.1 mm. For tolerance of the specimen shall be considered for fabricating the moulding. The simple calculation has been conducted to determine the exact dimension of the moulding. And the final dimension would be 90.32 mm x 135 mm. In this project, 20 mm of height is taken as height of moulding.

The most suitable material used for fabricating moulding is thin aluminium sheet. The aluminium sheet is not very hard and not very soft. The minimum thickness of aluminium sheet is 0.032 mm and maximum thickness aluminium sheet is 0.25 mm.

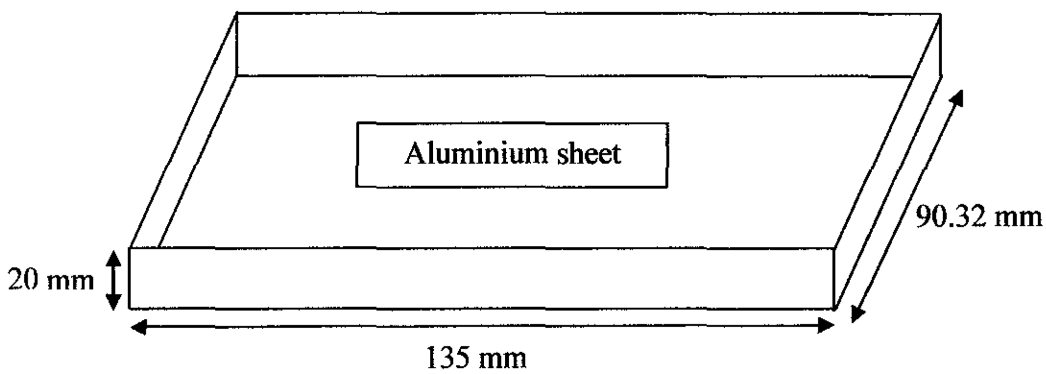


Figure 4: Dimension of Moulding for Flexural Testing

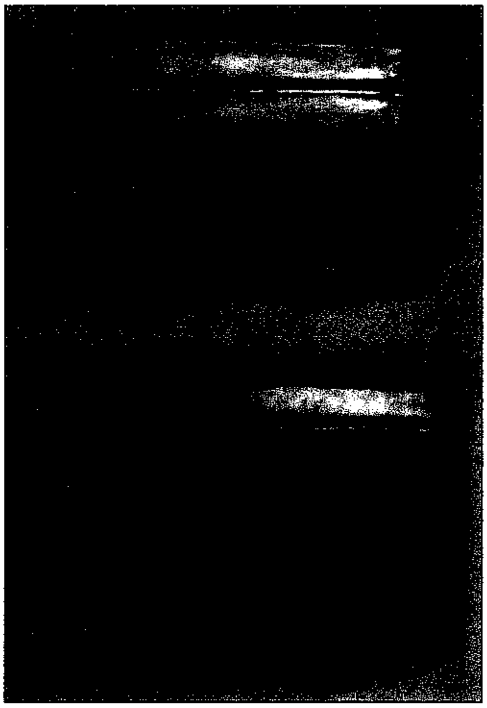


Figure 5: The Moulding Fabricated in Block 21

3.2.2 Degassing Process

Before go to fabrication of composite, the resin mixed with hardener with recommended portion of ratio (refer to Appendix B). The mixture (resin + hardener) stirred finely to ensure that the oxygen (or air) does not mix with the mixture. The air trapped would give some problem to the mixture even in microscopic in size. Gaseous bubbles trapped in liquid, will expand when heated (curing process) and can grow to become large. In that situation, the composite or resin will decrease in porosity and density. The decrease of density and porosity of composite would affect the testing process. To ensure that no air in the mixture, degassing process conducted by using vacuum machine as below;

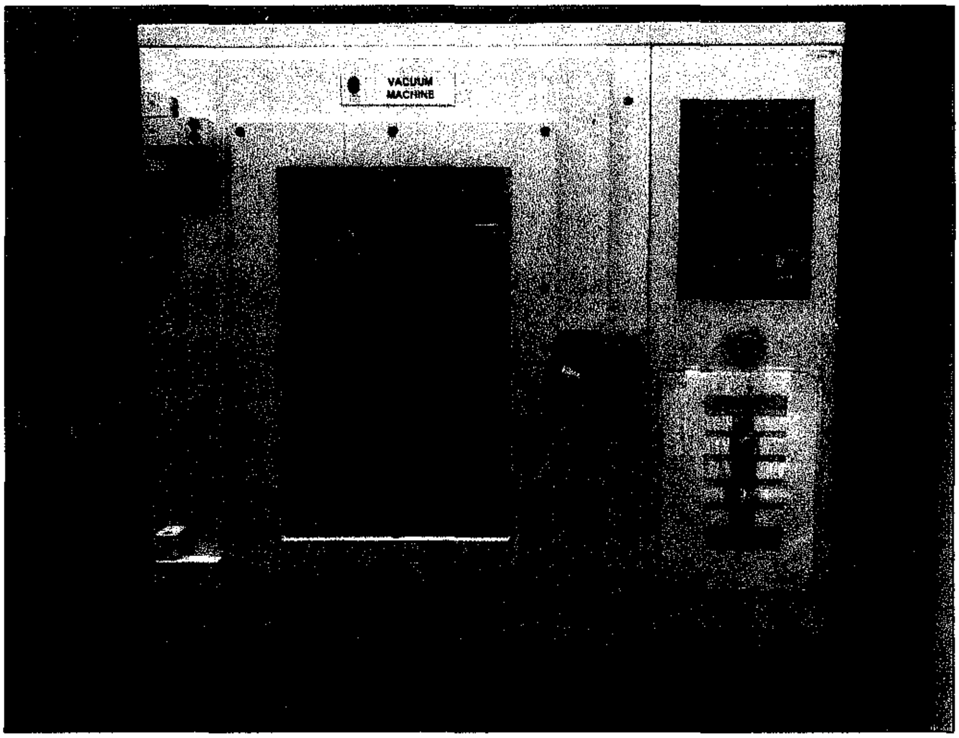


Figure 6: Vacuum Machine which available in UTP, Block 16

The mixture placed in the chamber, the pressure set from atmospheric pressure and reduced to -1 bar so that no air occurs in the mixture. After degassing process, the mixture carefully poured into moulding to prepare the resin sample. But for GRE, hand lay-up technique conducted and the technique elaborated in next part.

3.2.3 Hand Lay-up Technique

The brand of resins PRIME^{TM} 20LV and hardener is PRIME^{TM} 20. Based on the datasheet and also MSDS of this resins, this resins have very low viscosity, variable infusion times, suitable for infusing very large structures and also has LLOYD and Germanischer LLOYD approved.

Hand Lay-up Technique is the simplest and most widely used manufacturing process. For hand lay-up technique, the liquid resin lay into the moulding. After that, reinforcement is placed on top. A roller or brush is used to impregnate the fibre with the resin. Another resin and reinforcement layer is applied until a suitable thickness builds up. The advantages of this technique are versatility (little limitation on the size and complexity of the moulding) and low cost. The disadvantages of this technique are low fibre volume fractions and also low mechanical properties [2].

The procedure to fabricate the composite in this project is:

1. A release agent is applied to the mould surface. The purpose of it is to remove impurities and for ease removal a sample.
2. The desired size of woven glass fibre is placed on the mould and impregnated with epoxy resin.
3. By using a roller, epoxy is distributed uniformly around the surface.
4. Apply another woven glass fibre and pour another resin until the desired thickness is achieved.
5. The epoxy is distributed uniformly around the surface.

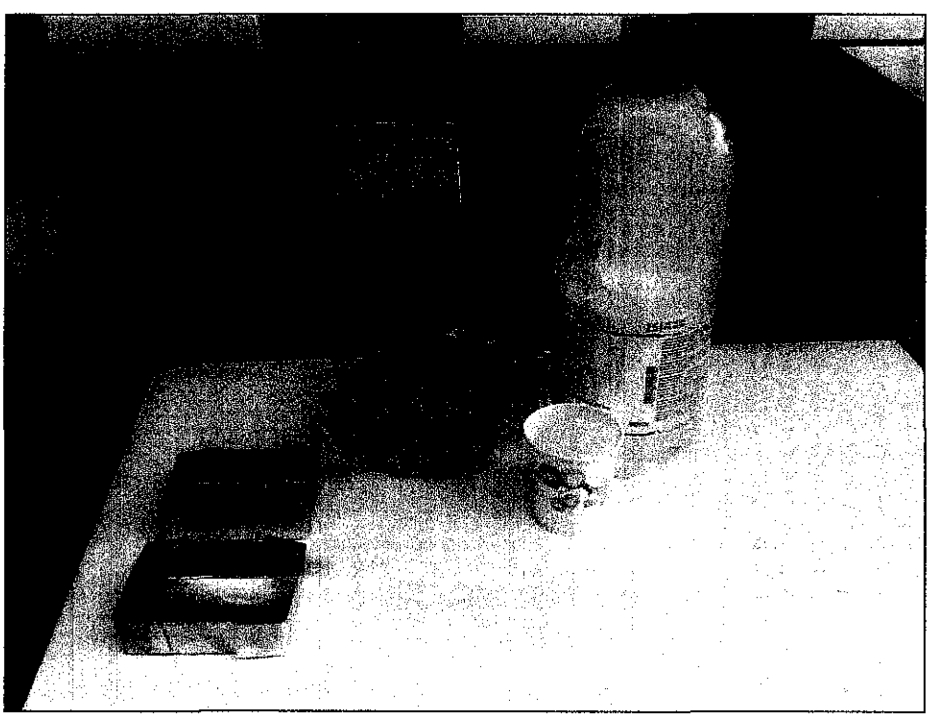


Figure 7: The Materials used for Cleaning the Moulding

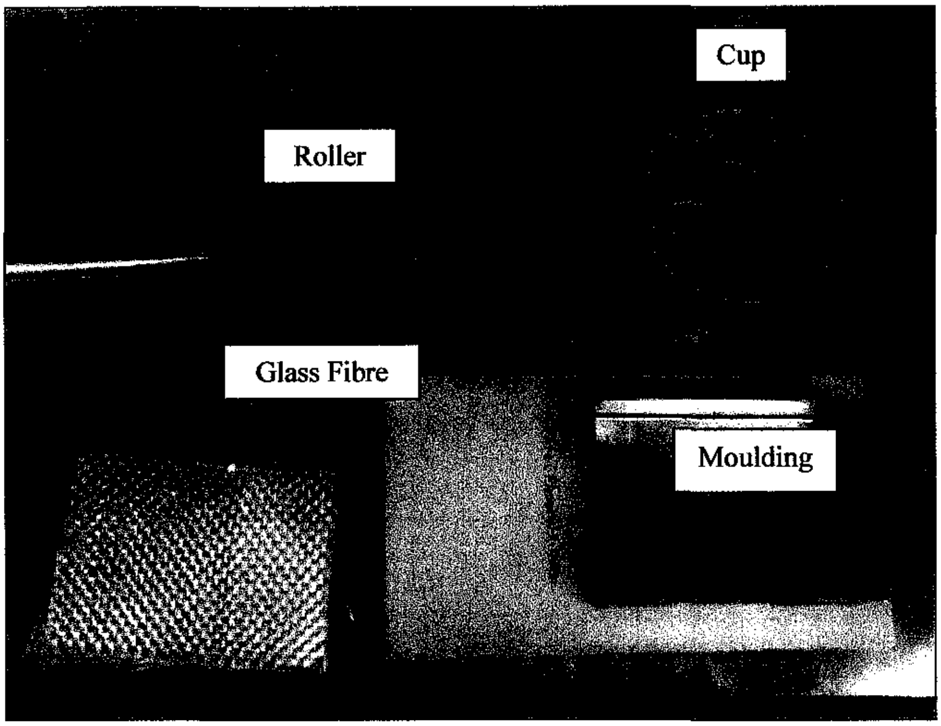


Figure 8: List of Tools for Hand Lay-up Technique

3.3 Curing Process

For curing process, epoxy and GRE cured under certain conditions which can be divided into four groups, oven curing epoxy group; oven curing GRE; direct solar curing epoxy group; and direct solar curing GRE group. The table 1 shows the method of curing process between oven curing and direct sunlight curing and also shows the comparison between epoxy and GRE.

The equipment used to cure the GRE and resin is by using oven which is available in UTP, Block 17. The oven set as recommended curing period. The recommended curing period was based on supplier's recommendation (refer to Appendix B). During curing process, the liquid or water in GRE and resin vaporized and the polymerization occur.

For direct solar curing, the resin and GRE placed at highest and maximum exposure area which is at Level 3 (Block 17). This is to ensure that maximum solar heating exerted by the resin and GRE occurred and contributed better result.

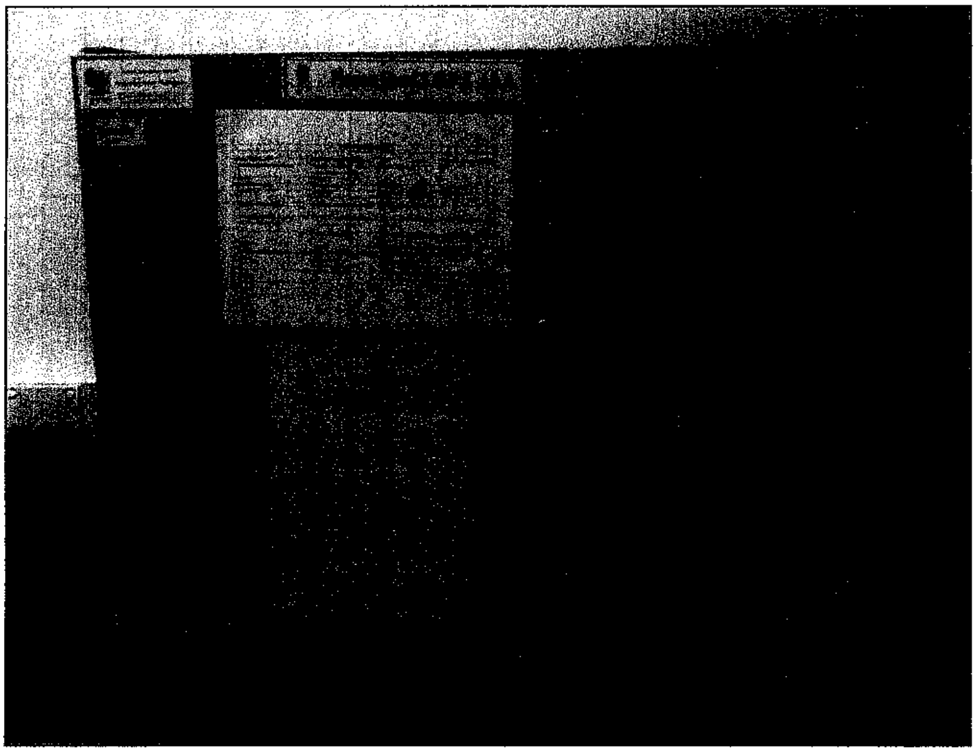


Figure 9: Oven (Carbolite 450 Model) in UTP Laboratory for Curing Process

Table 1: Table of Curing Process Based on Type of Composite and Type of Curing Process

Resin Epoxy	Glass Fibre Reinforced Epoxy (GRE)
Oven : refer to product data sheet in Appendix B	Oven : refer to product data sheet in Appendix B
Direct Solar : 3 days curing, each day 5 hours exposure	Direct Solar : 3 days curing, each day 5 hours exposure

If raining, the specimens placed and kept it at safe place and cured it in other days. The curing process continues when the weather bright until three-day-curing done successfully. The figures showed the resin and also GRE in solar curing process and oven curing process.

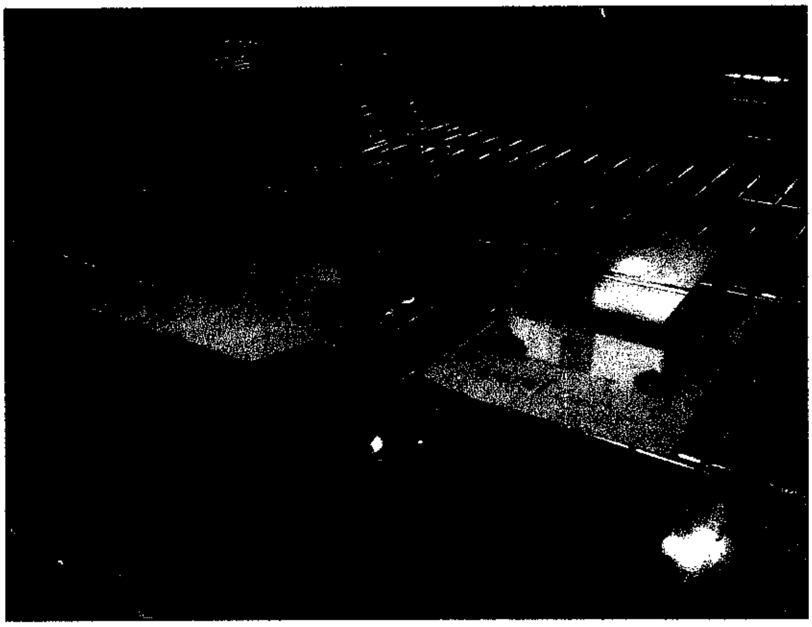


Figure 10: Specimens (GRE and Resin) in Oven Curing Process

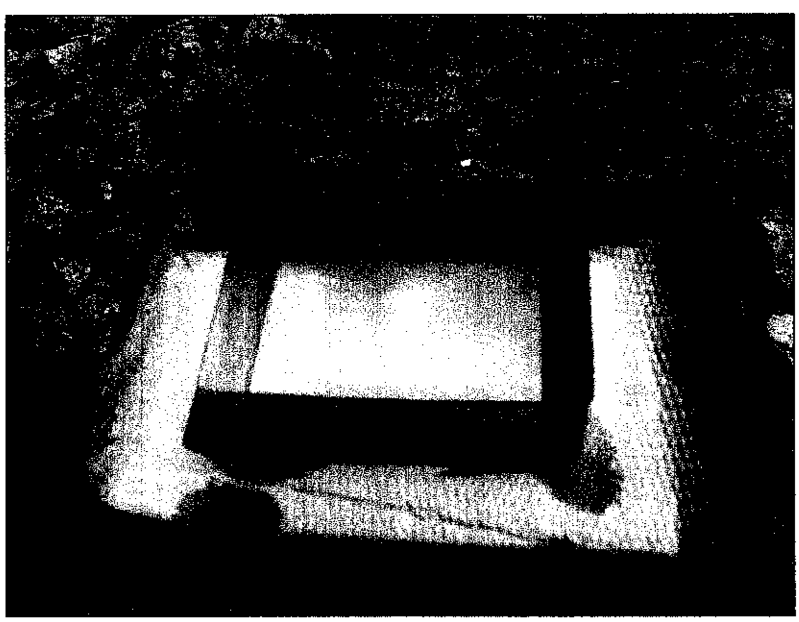


Figure 11: Specimen (Epoxy) in Solar Curing Process at Level 3, Block 17

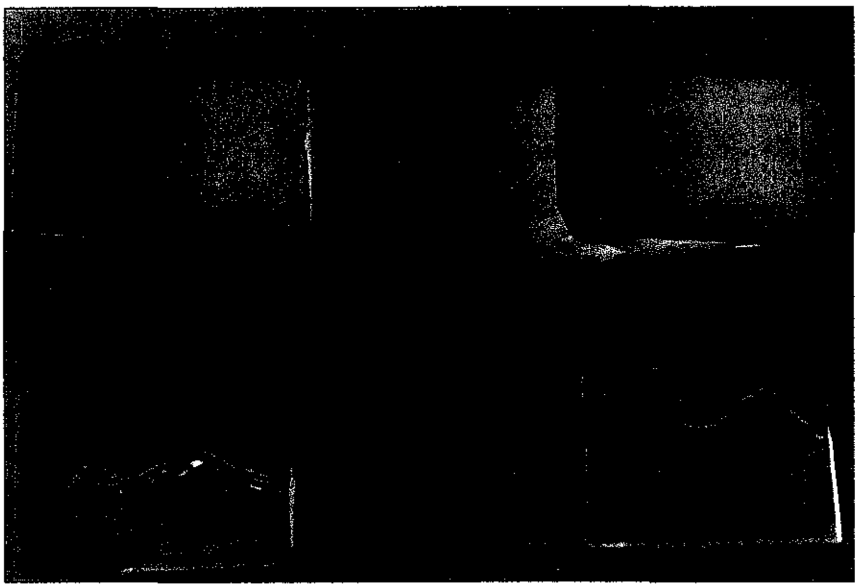


Figure 12: Final Solar Cured (left) Resin and Oven Cured (right) Resin

3.4 Composite and Thermoset

After curing process, the final specimens (Resin and GRE) cut into seven specimens for testing purpose. The cutter used was non-metal abrasive cutter which available in UTP, Block 17. The fabricated resin and GRE showed as below;

Figure 13: Resin Specimen Solar Cured (before cutting process)

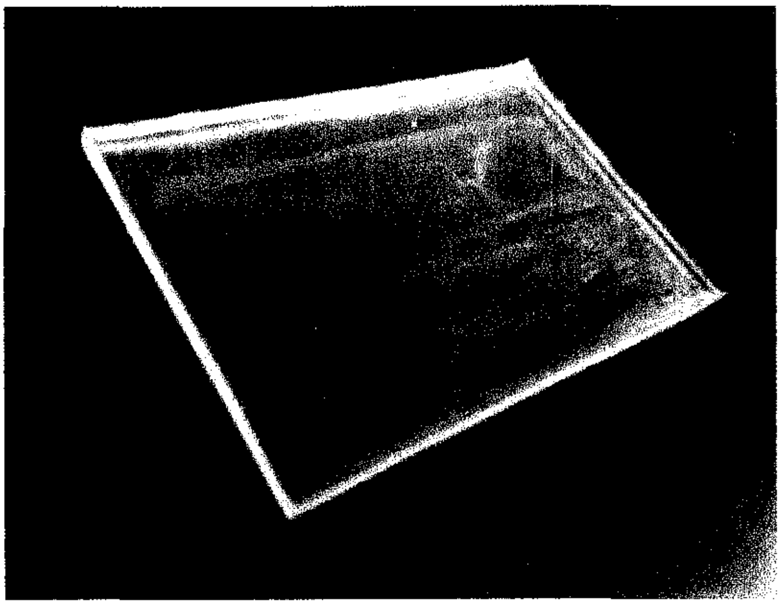


Figure 14: Resin Specimen Oven Cured (before cutting process)

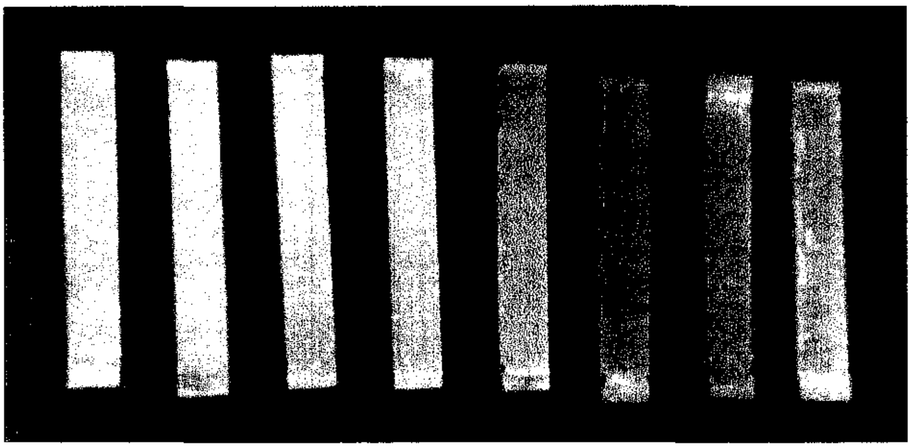


Figure 15: Composite Specimens Oven Cured (after cutting process)

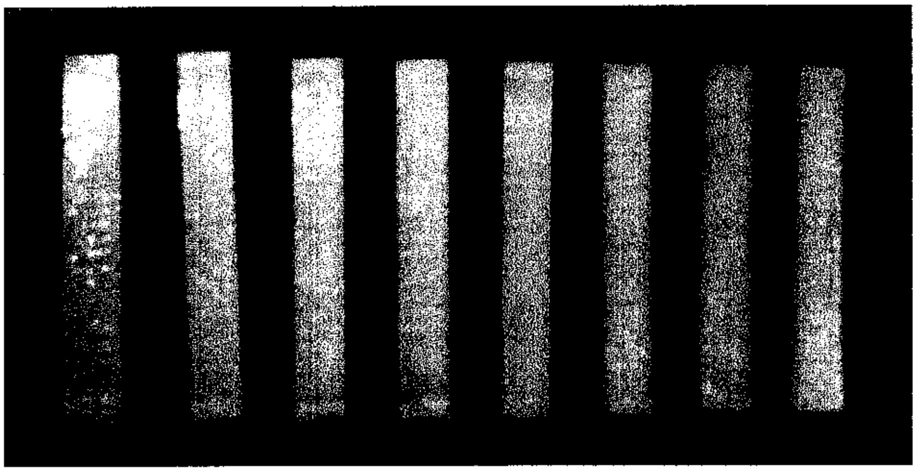


Figure 16: Composite Specimens Solar Cured (after cutting process)

3.5 Evaluation

After curing, testing would be the next stage to complete the project. The purpose of it is to evaluate the thermosetting and composite which have been cured by direct solar and also by oven. In this project, only one testing would be conducted which is flexural test.

3.5.1 Flexural Test

In UTP laboratory, UTM (Universal Testing Machine) is available. It can be used for tensile testing and also flexural testing. Flexural machine is LLOYD Instruments and provided for detecting the flexural strength, flexural modulus etc. For oven which used for curing process also available in UTP laboratory.

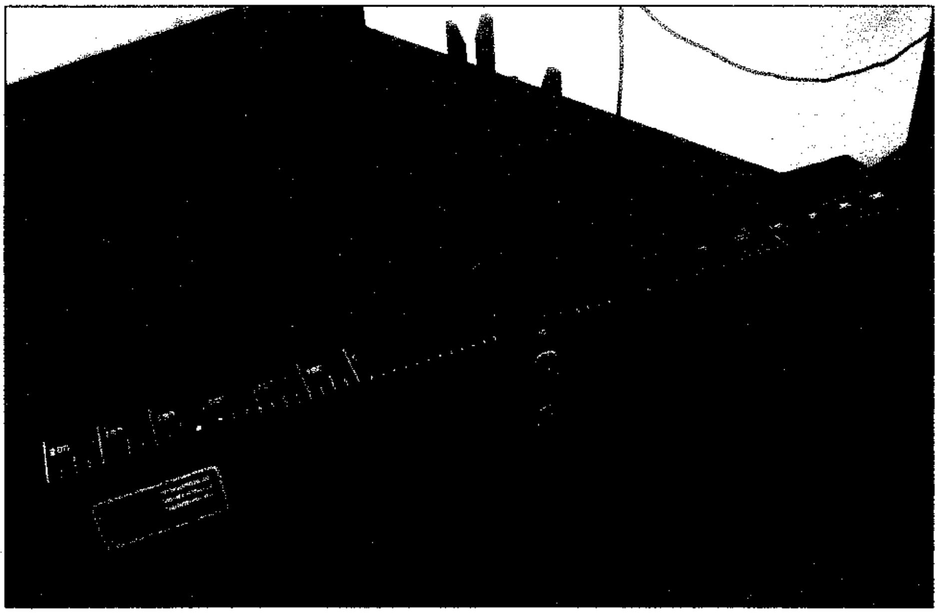


Figure 17: LLOYD Instruments of Lower Flexural Testing Jig

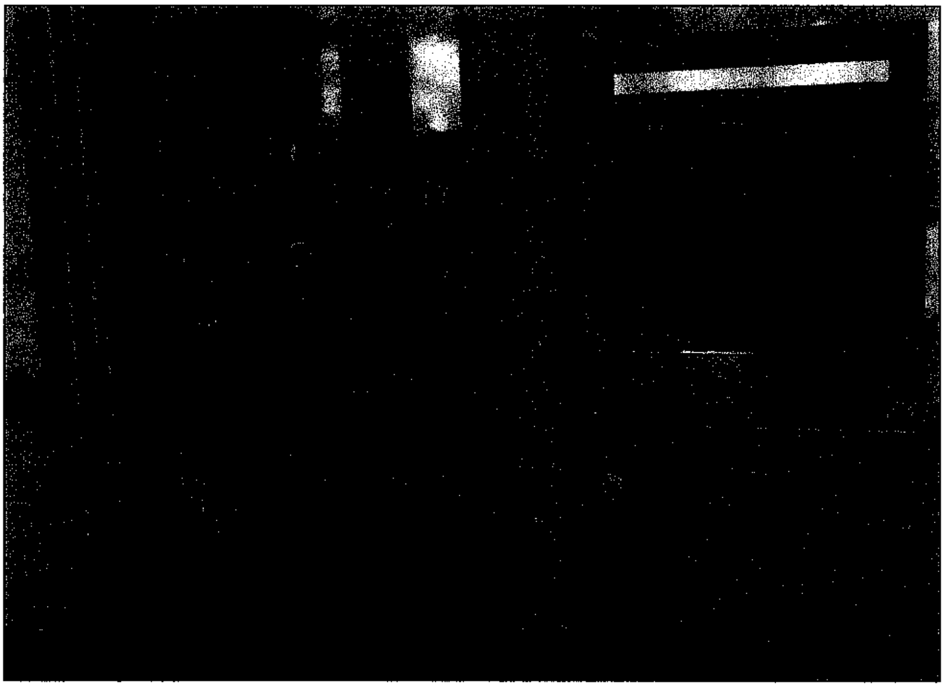


Figure 18: UTM Machine for Flexural Test Available in UTP Laboratory

The testing will be conducted on a 3-point bend fixture at 1 mm/min in the Lloyd UTM. A minimum of 5 specimens are to be tested for each curing condition (oven and solar curing). The test speed for flexural testing is 5 mm/min and this test speed is common speed for polymer.

The dimension of each specimen based on ASTM D 790M is as below:

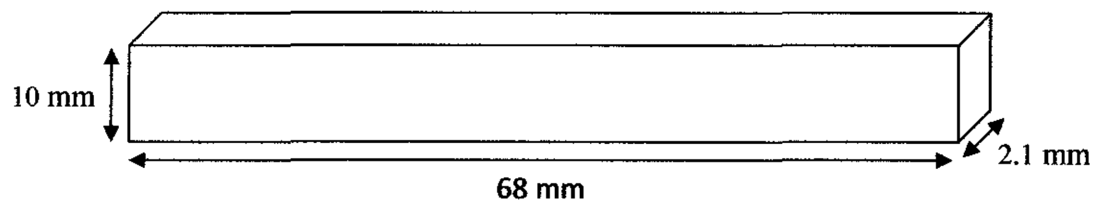


Figure 19: Dimensional of Composite and Thermosetting for Flexural Test based on ASTM D 790M

The dimension of a 7 specimens when combine together and become a plate is as below:

100 mm (length) x 68 mm (width) x 2.1 mm (thickness)

To evaluate the testing, stress-strain graph is the most suitable to show the desired property which is Modulus of Elasticity or Flexural Modulus, maximum stress at maximum load and also maximum deflection.

3.5.2 Flexural Modulus

Based on ASTM D790M, the maximum stress in the outer surface of the specimens occurs at the midpoint. This stress may be calculated by the following equation;

$$\sigma_f = 3PL / 2bd^2$$

where:

σ_f = stress in the outer fibres at midpoint, MPa

P = load at a given point on the load-deflection curve, N

L = support span, mm

b = width of beam tested, mm, and

d = depth of beam tested, mm

3.5.3 Flexural Strength

Based on ASTM D790M, the flexural strength is defined as maximum flexural stress sustained by the specimens. It is a point at which the load does not increase with an increase in strain. It also called yield point. Based on the equation above, the flexural strength may be calculated by letting P equal to the point Y (refer to Figure 20).

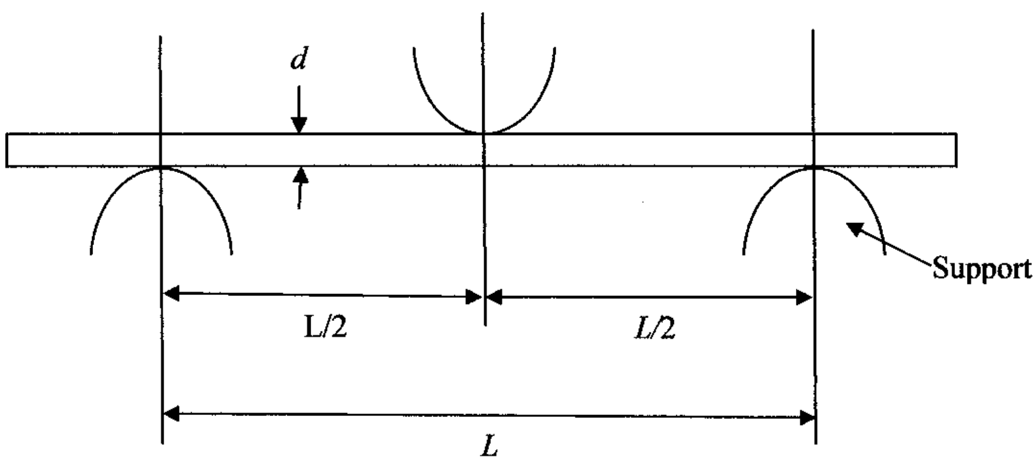
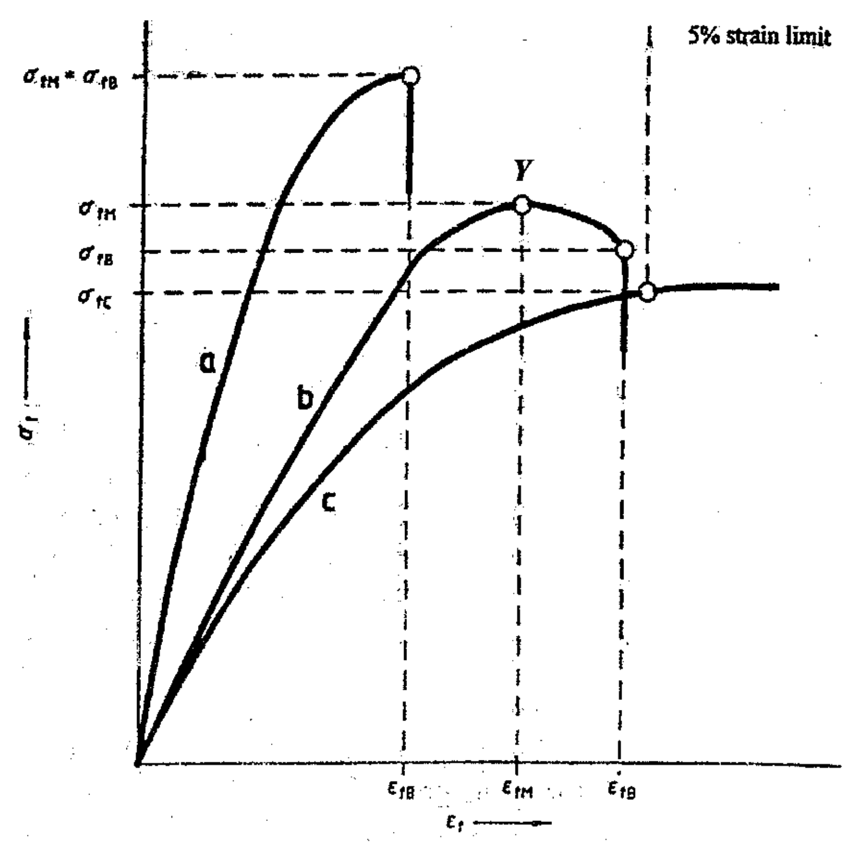


Figure 20: Flexural (Three Point Bending) Test Arrangement



Curve a: Specimen that breaks before yielding.
Curve b: Specimen that yields and then breaks before the 5 % strain limit.
Curve c: Specimen that neither yields nor breaks before the 5 % strain limit.

Figure 21: Typical Curves of Flexural Stress vs Flexural Strain (ASTM D790M)

3.5.4 Standard Deviation

Based on ASTM D790M, the mean value is the average of the specimens during testing. The standard deviation shall be calculated as follows;

$$s = [\Sigma (X_1 - X)^2 / (n - 1)]^{1/2}$$

where:

s = standard deviation

X_1 = the value of single observation

X = arithmetic mean of the set of observations, and

n = number of observation

3.5.5 Rate of Crosshead Motion

Based on ASTM D790M, rate of crosshead motion is the strain rate which set to the UTM. To calculate it, the equation is as below (refer to Appendix C);

$$R = ZL^2 / 6d$$

where:

R = rate of crosshead motion, mm/mm

L = support span, mm

d = depth of beam, mm

Z = rate of straining of the outer fibre, mm/mm/min. Z shall equal to 0.01

CHAPTER 4

RESULT AND DISCUSSION

The composite has been fabricated and fully cured. All the data taken are recorded and analysed. The result discussed below are; flexural modulus of the resin and composite with different curing method, maximum bending stress at maximum stress at maximum load of the resin and composite with different curing method, and last is maximum deflection of the resin and composite with different curing method.

4.1 Physical Appearance

Based on the figures in methodology, the physical appearance of the specimens was the first thing to observe. The purpose of it is to differentiate between solar cured specimens and also oven cured specimens.

4.1.1 Resin Epoxy

For the solar cured composite, the colour of it was whitish in colour. For the oven cured composite, the colour of it was yellowish in colour.

4.1.2 GRE Composite

For resin, solar cured resin was yellowish in colour. For oven cured resin, the colour was whitish in colour.

4.2 flexural Modulus of Resins and Composite with Different Method of Curing

4.2.1 Resin Epoxy

Flexural modulus is one of the mechanical properties which can be analysed by using three-point bending testing. Flexural modulus can be defined as the gradient of stress-strain curve during three-point bending test. The table showed the flexural modulus for every tested specimen.

Table 2: Table of Flexural Modulus of Every Resin Specimen

Specimens	(Flexural Modulus) GPa Solar Cured	(Flexural Modulus) GPa Oven Cured
1	1.95	2.33
2	2.15	4.50
3	2.96	5.08
4	2.27	4.63
5	2.26	3.85
6	2.81	4.15
7	1.97	4.11
Mean	**2.34**	**4.09**
Standard Deviation	**0.37**	**0.81**

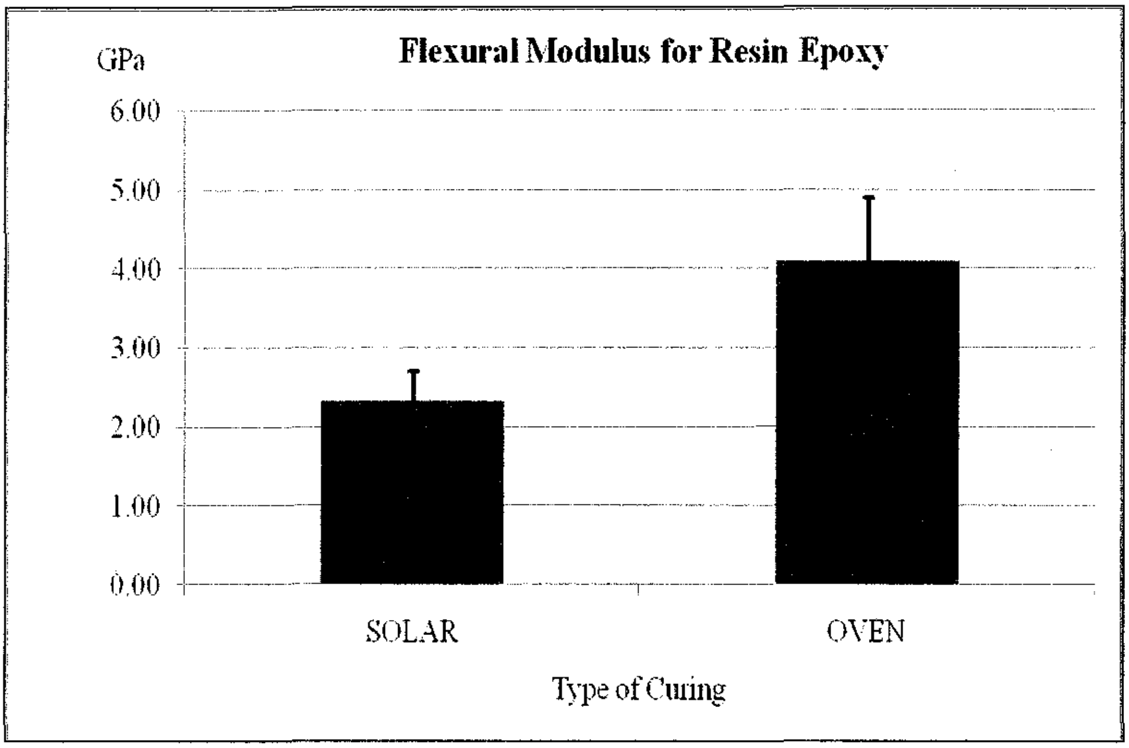


Figure 22: Comparison of Flexural Modulus for Resin Epoxy with different Type of Curing

Based on figure 22, the mean value of solar cured resin is much lower than oven cured resin. The percentage difference between these two types of curing was calculated, the value is 42.79%.

The graph also showed clearly the location of standard deviation for the resin epoxy with solar and also oven curing method. Solar cured resin has lower standard deviation value than oven cured resin. It means that the solar cured resin has better consistency flexural modulus compare to oven cured resin.

Based on this graph, the standard deviation for solar cured and oven cured of resin epoxy is not overlapping each other. It means that the maximum of flexural modulus for solar curing cannot reach the minimum flexural modulus for oven curing resin.

4.2.2 Composite (GRE)

For the composite (GRE), the table showed as below:

Table 3: Table of Flexural Modulus of Every Composite Specimen

Specimens	(Flexural Modulus) GPa Solar Cured	(Flexural Modulus) GPa Oven Cured
1	11.44	14.67
2	11.67	9.24
3	13.38	13.45
4	11.50	12.50
5	8.88	12.42
6	13.02	6.89
7	11.88	12.68
8	12.23	14.51
Mean	**11.75**	**12.04**
Standard Deviation	**1.27**	**2.50**

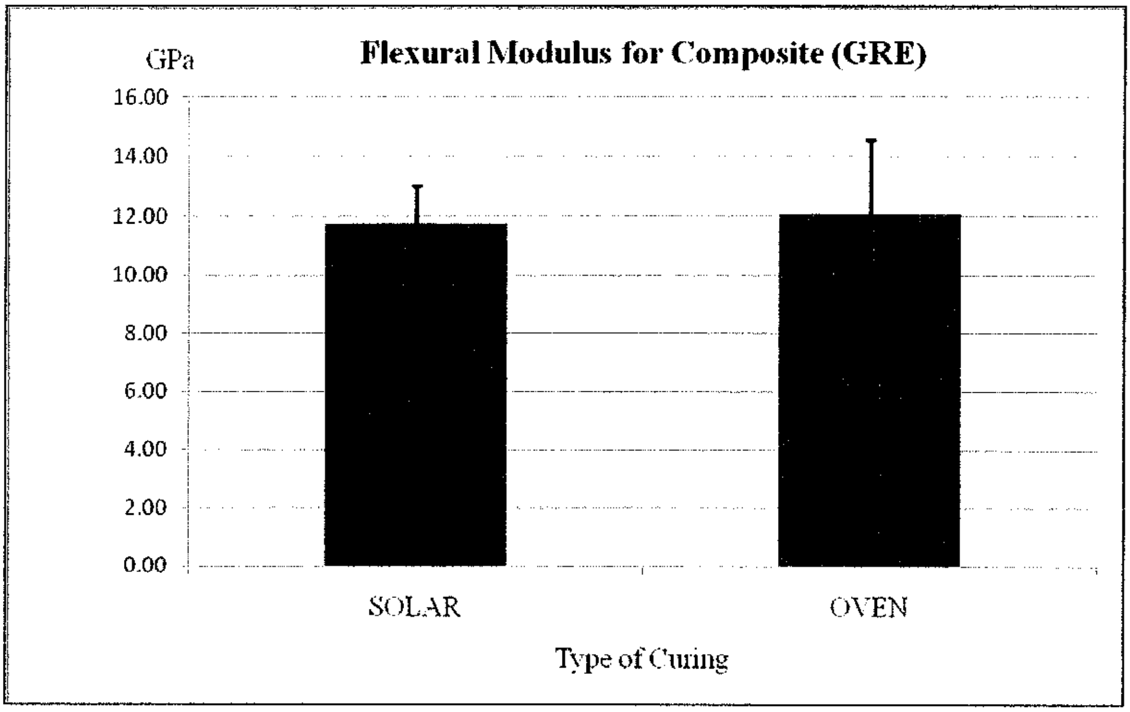


Figure 23: Comparison of Flexural Modulus for Composite (GRE) with Different Type of Curing

In Figure 23, the mean value of flexural modulus for over cured GRE is slightly higher than solar cured GRE. The percentage difference between solar cured GRE and oven cured GRE is 2.41%. It also clearly showed that the standard deviation of solar cured GRE and oven cured GRE is overlapping. Which means that the flexural modulus of solar cured GRE can be within the oven cured GRE and the value of it are not much different.

Based on Table 3, the standard deviation for solar cured GRE is lower than the oven cured GRE. It means that the value for flexural modulus of solar cured GRE was more consistent compare to the oven cured GRE's flexural modulus.

4.3 Maximum Bending Stress at Maximum Load of Resin Epoxy and Composite with Different Curing Method

4.3.1 Resin Epoxy

The term of maximum bending stress at maximum load mean that the stress exerted by the specimen during the maximum load in three-point bending testing. It also determined the strength of the resin or GRE.

Table 4: Table of Maximum Bending Stress at Maximum Load of Every Resin Specimen

Specimens	Maximum Bending Stress at Maximum Load (MPa)	Maximum Bending Stress at Maximum Load (MPa)
	Solar Cured	Oven Cured
1	53.29	79.57
2	63.63	124.05
3	39.03	160.87
4	70.57	140.66
5	54.59	125.67
6	36.26	128.93
7	56.74	133.32
Mean	**53.44**	**127.58**
Standard Deviation	**11.42**	**22.79**

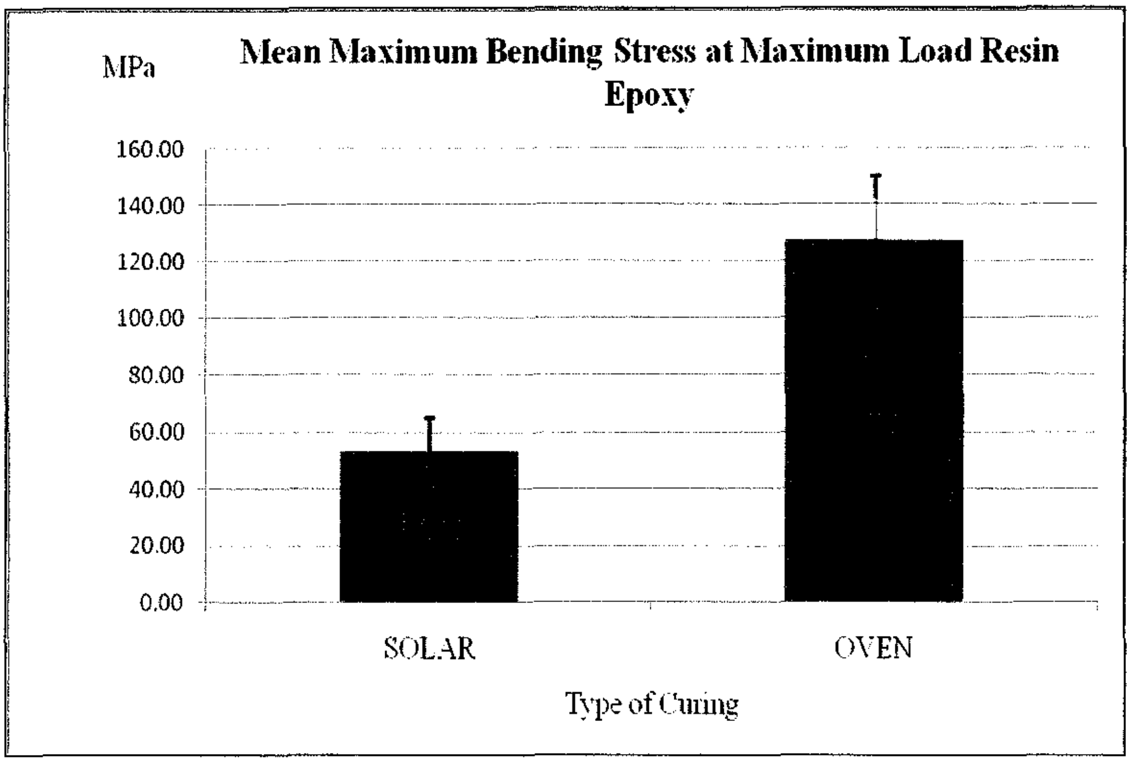


Figure 24: Comparison of Maximum Bending Stress at Maximum Load of Resin Epoxy with Different Type of Curing

From Figure 24, the mean value of maximum bending at maximum load for solar cured resin is much lower than oven cured resin.

The percentage difference between two types of curing is 58.11%. Based on the number of standard deviation, solar cured resin has lower value than oven cured. It showed that solar cured resin more consistence than oven cured.

The standard deviation which indicated by black line was not overlapping. It means that the minimum value of oven cured resin cannot reach by the maximum value of solar cured resin. The figure also can conclude that oven cured resin has better maximum bending stress than solar cured.

4.3.2 Composite (GRE)

Table 5: Table of Maximum Bending Stress at Maximum Load of Every Composite (GRE) Specimen

Specimens	Maximum Bending Stress at Maximum Load(MPa) Solar Cured	Maximum Bending Stress at Maximum Load(MPa) Oven Cured
1	146.66	281.35
2	266.01	227.45
3	302.80	266.61
4	243.34	254.64
5	187.34	261.17
6	282.69	163.81
7	260.71	292.93
8	266.93	273.44
Mean	**244.56**	**252.67**
Standard Deviation	**48.64**	**38.20**

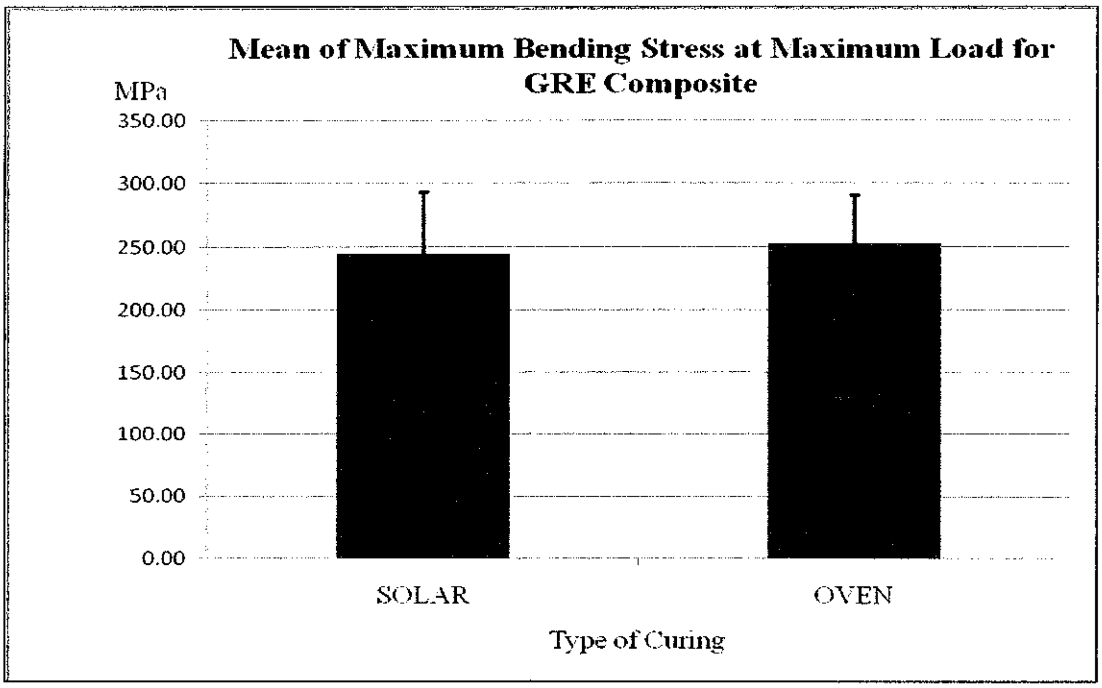


Figure 25: Comparison of Maximum Bending Stress at Maximum Load of Composite (GRE) with Different Type of Curing

In Figure 25, solar cured GRE has slightly lower value than oven cured GRE. The percentage difference between these two types of curing is 3.21%. The standard deviations are overlapping and it determined that both of the values are not much difference. The value of standard deviation for oven cured is lower than solar cured GRE, it means that oven cured GRE has better consistency level than solar cured GRE. The addition of glass fibre gave better flexural modulus for solar cured composite.

4.4 Maximum Deflection of Resin Epoxy and Composite with Different Curing Method

Maximum deflection is the maximum distance for the specimen from the initial condition (before testing) to the point of specimen in maximum load. The higher maximum deflection, the more elastic the specimen.

4.4.1 Resin Epoxy

Table 6: Table of Maximum Deflection of Every Resin Specimen

Specimens	Maximum Deflection (mm) Solar Cured	Maximum Deflection (mm) Oven Cured
1.00	4.57	5.97
2.00	5.67	2.92
3.00	1.79	4.61
4.00	4.15	4.91
5.00	3.23	3.87
6.00	2.03	5.25
7.00	4.82	4.52
Mean	**3.75**	**4.58**
Standard Deviation	**1.35**	**0.91**

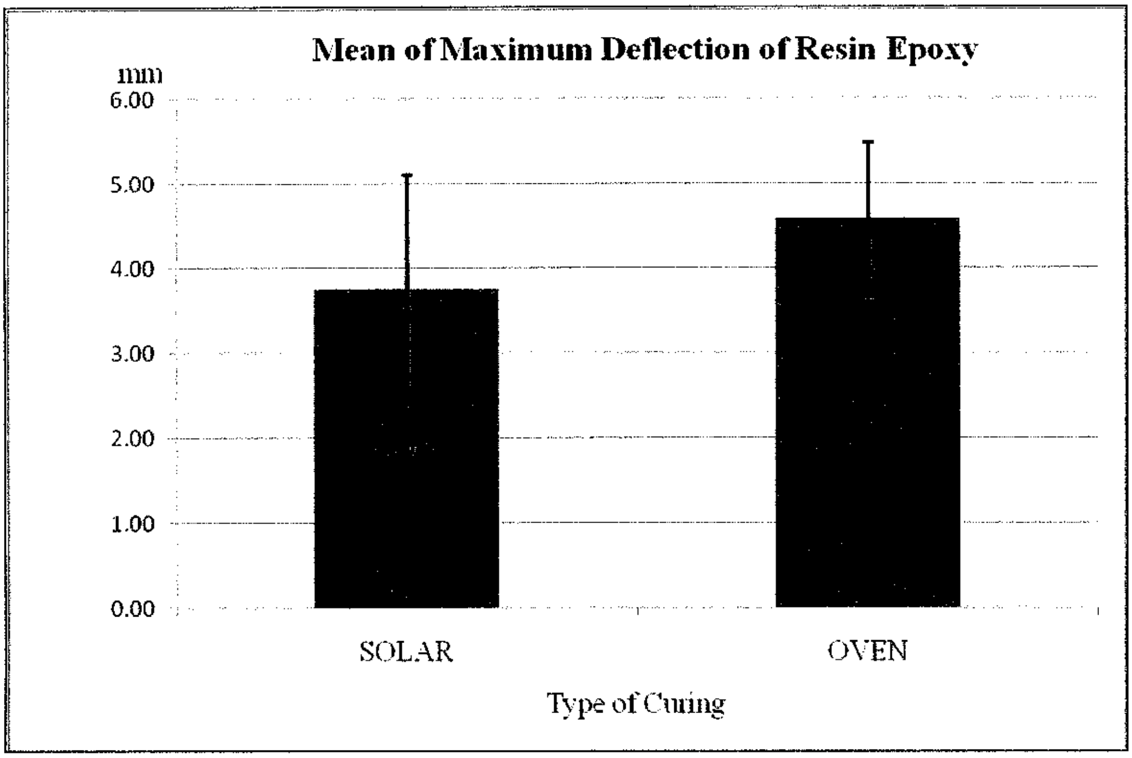


Figure 26: Comparison of Maximum Deflection of Resin Epoxy with Different Type of Curing

Based on figure 26, the mean value of maximum deflection of solar cured resin is lower than oven cured resin. The percentage difference between these two types of curing was calculated, the value is 18.12%.

The graph also showed clearly the location of standard deviation for the resin epoxy with solar and also oven curing method. Oven cured resin has lower standard deviation value than solar cured resin. It means that the oven cured resin has better consistency for maximum deflection compare to solar cured resin.

Based on this graph, the standard deviation for solar cured and oven cured of resin epoxy was overlapped each other. It means that the maximum standard deviation for solar cured resin was laid within range of standard deviation of oven cured resin.

4.4.2 Composite (GRE)

For the composite (GRE), the table showed as below:

Table 7: Table of Maximum Deflection of Every GRE Composite Specimen

Specimens	Maximum Deflection (mm) Solar Cured	Maximum Deflection (mm) Oven Cured
1	2.00	4.09
2	4.22	4.75
3	4.48	4.00
4	4.46	4.24
5	4.39	4.15
6	3.68	5.43
7	3.96	4.62
8	4.02	3.94
Mean	**3.90**	**4.40**
Standard Deviation	**0.76**	**0.47**

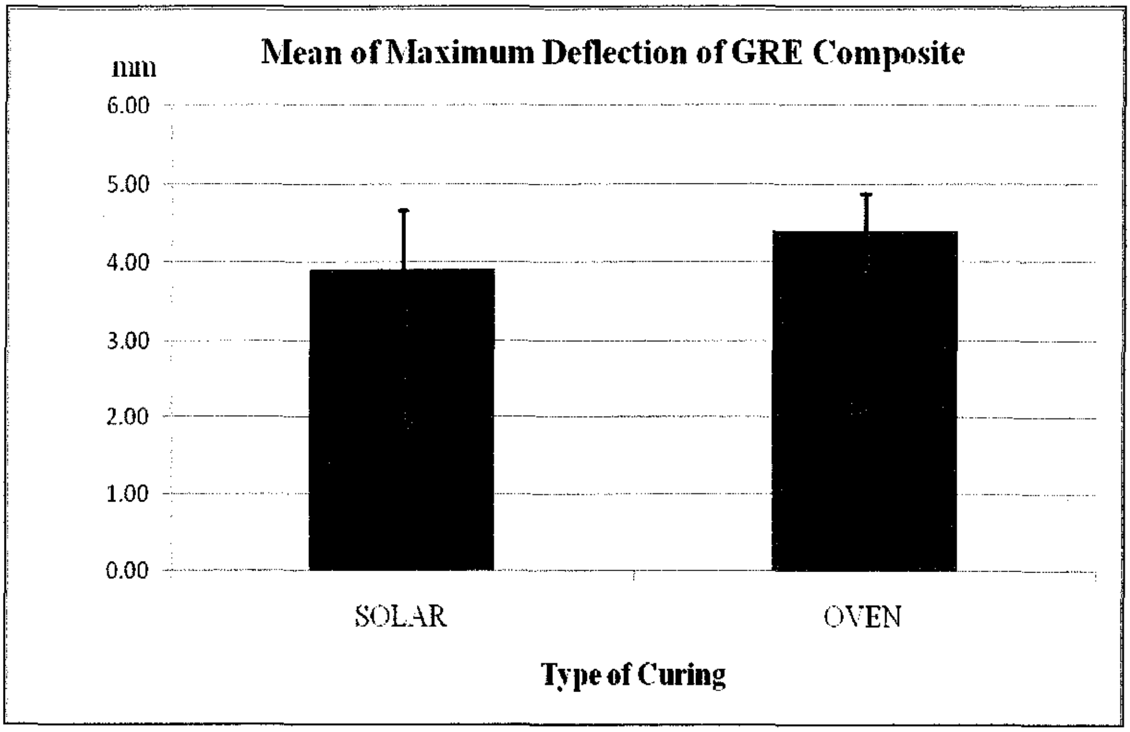


Figure 27: Comparison of Maximum Deflection of Composite (GRE) with Different Type of Curing

Based on figure 27, the mean value of maximum deflection of solar cured GRE is slightly lower than oven cured GRE. The percentage difference between these two types of curing was calculated, the value is 11.36%.

The graph also showed clearly the location of standard deviation for the resin epoxy with solar and also oven curing method. Oven cured GRE composite has lower standard deviation value than solar cured GRE composite. It means that the oven cured GRE composite has better consistency for maximum deflection compare to solar cured GRE composite.

Based on this graph, the standard deviation for solar cured and oven cured of resin epoxy was overlapped each other. It means that the maximum standard deviation for solar cured GRE composite was laid within range of standard deviation of oven cured GRE composite.

As a conclusion, the objective of this project is achieved and solar curing is one of the alternative energy and formulates a low cost and environmental friendly manufacturing process for composites.

5.2 Recommendation

All properties are not normalized value. It means that the effect of FVF, porosity, density of the composite and also resin epoxy is not isolated. FVF is the major effect whether the composite or resin epoxy has better properties or not. As recommendation, these affect shall be isolate to get better result.

Another effect which shall be analysed is degree of curing. The common equipment used to determine the degree of cure is DSC. DSC can measure the temperature and also heat flow associated with transition in materials in a controlled atmosphere. The two most common degree of cure are; quantifying residual cure in the material, measure the shift in the glass transition temperature.

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APPENDIX A

Calculation to Determine the Dimension of Moulding

Length between two span = 33.6 mm

The length of specimen

= (33.6 mm x 20%) + 33.6 mm

= 40.32 mm

The width of moulding

= 40.32 mm + (25 mm x 2)

= 90.32 mm

The width of a specimen = 10 mm

Seven specimens = 70 mm

The length of moulding

= 70 mm + (2 x 25 mm) + (6 x 2.5 mm)

= 135 mm

Final dimension of moulding = 90.32 mm x 132 mm

APPENDIX B

Data Sheet of PRIME 20LV Resin

Epoxy

PRIME™ 20LV

Epoxy Infusion System

PRIME™ 20LV resin: Prime 20 hardener (fast, Slow or Extra Slow)
100 : 26 (by weight)

Table 1. Component Properties

	LV Resin	Hardener		
		Fast	Slow	Extra Slow
Mix Ratio by Weight	100	26	26	26
Mix Ratio by Volume	100	31.4	31.4	31.4
Viscosity @20°C (cP)	1010-1070	25-27	22-24	16-18
Viscosity @25°C (cP)	600-640	20-22	15-17	13-15
Viscosity @30°C (cP)	390-410	16-18	12-14	10-12
Shelf Life (months)	12	12	12	12
Colour (Gardener)	1	7	Clear	1
Mixed Colour (Gardener)	-	3	1	1
Density (g/cm^3)	1.123	0.983	0.936	0.931
Mixed Density	-	1.089	1.084	1.083
Hazard Category	Xi, N	C	C	C

Table 3. Cured System Thermal Properties

Hardener used	Fast	Slow	Extra Slow
Cure Schedule	16hrs 50°C	16hrs 50°C	16hrs 50°C
Tg (DMTA - peak tan δ)	82.8	82.6	82.9
TgUlt (DMTA)	74-76	87-89	90-92
Tg1 (DMTA)	68-70	68-70	69-71
ΔH – DSC (J/g)	1.54	7.3	0.00
Estimated HDT	67	68	67

Table 4. Cured System Mechanical Properties

Hardener used	Fast	Slow	Extra Slow
Cure Schedule	16hrs 50°C	16hrs 50°C	16hrs 50°C
Tensile Strength (MPa)	75	73	69
Tensile Modulus (GPa)	3.2	3.5	3.5
Strain to failure (%)	4.1	3.5	3.1
Moisture Absorption (%)	tba	tba	tba
Cured density (g/cm^3)	1.153	1.144	1.132
Linear Shrinkage (%)	1.830	1.765	1.541
Barcol Hardness	21	27	25

APPENDIX C

The Data of Every Specimen during Three-Point Bending Test

		[redacted]	[redacted]	d, mm	L, mm	Z, mm/mm/min	R	D
	Sample			thickness	length of span	strain rate	rate of crosshead	deflection
resin solar	1	10.90	64.38	2.76	44.16	0.01	1.178	5.888
	2	10.00	64.12	2.66	42.56	0.01	1.135	5.675
	3	10.40	64.50	2.90	46.40	0.01	1.237	6.187
	4	10.34	64.40	2.80	44.80	0.01	1.195	5.973
	5	10.12	65.10	2.76	44.16	0.01	1.178	5.888
	6	9.62	68.30	2.56	40.96	0.01	1.092	5.461
	7	9.52	68.00	2.26	36.16	0.01	0.964	4.821
resin oven	1	10.10	60.40	2.80	44.80	0.01	1.195	5.973
	2	9.50	60.50	2.20	35.20	0.01	0.939	4.693
	3	9.10	61.00	2.16	34.56	0.01	0.922	4.608
	4	9.22	61.02	2.30	36.80	0.01	0.981	4.907
	5	9.90	62.40	2.18	34.88	0.01	0.930	4.651
	6	9.60	62.24	2.46	39.36	0.01	1.050	5.248
	7	10.40	62.66	2.12	33.92	0.01	0.905	4.523
	8	10.40	63.00	1.90	30.40	0.01	0.811	4.053

GRE solar	1	10.62	65.50	3.44	55.04	0.01	1.468	7.339
	2	10.00	64.32	3.48	55.68	0.01	1.485	7.424
	3	9.72	63.94	3.34	53.44	0.01	1.425	7.125
	4	10.00	63.50	3.30	52.80	0.01	1.408	7.040
	5	10.50	65.70	3.54	56.64	0.01	1.510	7.552
	6	10.00	65.80	3.24	51.84	0.01	1.382	6.912
	7	9.92	65.00	3.48	55.68	0.01	1.485	7.424
	8	9.74	64.62	3.50	56.00	0.01	1.493	7.467

GRE oven	1	9.86	69.14	3.04	48.64	0.01	1.297	6.485
	2	10.40	68.98	3.34	53.44	0.01	1.425	7.125
	3	9.70	69.20	3.22	51.52	0.01	1.374	6.869
	4	10.46	69.20	3.30	52.80	0.01	1.408	7.040
	5	9.92	69.20	3.24	51.84	0.01	1.382	6.912
	6	10.80	69.20	3.50	56.00	0.01	1.493	7.467
	7	10.10	69.20	3.20	51.20	0.01	1.365	6.827
	8	10.20	69.20	3.04	48.64	0.01	1.297	6.485