University of Southern Queensland

Faculty of Engineering and Surveying

COMPOSITES FROM NATURAL RENEWABLE RESOURCES IN CIVIL ENGINEERING: EPOXIDISED VEGETABLE OIL WITH EPOXY RESIN, FLY ASH AND SAWDUST FILLERS (MECHANICAL, PHYSICAL AND STRUCTURAL PROPERTIES)

A dissertation by

David Ayuen Mayen

In fulfilment of the requirements of

ENG4111/4112 Research Project and Dissertation

Towards the Degree of

Bachelor of Engineering (Civil)

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DEDICATION

This dissertation is dedicated to my dear father who passed away in the January 2007, loving wife, son and family.

DECLARATION

I certify that the research and numerical investigation work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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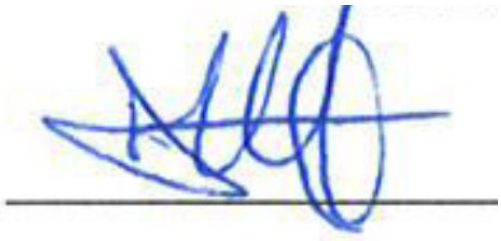

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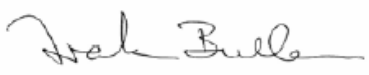

Professor Frank Bullen
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I am also thankful to my beloved wife, family members, relatives and friends for their encouragement and advise which help me during the course of this project and overall studies.

ABSTRACT

In this project composite was made from epoxy resin of the type GY-191 produced by Hexion Speciality Chemical Pty Ltd , epoxidised linseed oil locally produced from University of Southern Queensland Lab and fillers of sawdust and Evirospheres (SLG). Aradur-250 amine was used as hardener. Ratio of epoxy resin to Aradur hardener was varied; the first ratio was 2:1 and last one was 3:1.

Background Information

Pressure on traditional building material such as concrete, timber and steel is becoming unbearable. As such a number of researches are being carried out throughout the world to look for material that will release pressure on building materials. For material to be accepted as a building material it's physical, mechanical and structural properties have to be known to meet basic criteria for building material.

Aims and objectives:

The aims of the project were to investigate the physical, mechanical and structural properties of composite made from renewable resources (Epoxy resin and epoxidised vegetable oil (linseed oil (ELO)) and by using wastes material such as sawdust and SLG as fillers.

Preparation

Samples were prepared with different percentage in weight of sawdust and SLG. The two main sizes of sawdust used were 600 and 1650 microns. Percentage of SLG was varied as well as sawdust. The composite was subjected to preparation that includes weighing, mixing, curing, cutting to sizes and polishing. Curing was done at room temperature for 24 hours followed by 4 hours of 80 degrees Celsius in an industrial oven.

Methodology:

Three main tests were used in the investigation of the composite properties. The tests were flexural, impact fracture toughness and DMA analysis. Each of these tests was adopted to determine different expects of the mechanical, physical and structural properties. Both flexural and Impact fracture toughness tests were carried out using MTS alliance provided by CEEFC. The properties investigate in this methods include flexural modulus, peak load, peak

stress, deflection and strain at failure. Samples specimen for flexural and impact toughness were made of bar shape with dimensions of 64x15x10mm according MTS alliance specifications. DMA samples were smaller made according Q800 specifications of 35x12x4mm.

DMA was used to determine thermal mechanical properties. The thermal properties determined were glass transition temperature (Tg), storage modulus, and tan delta.

Results and Conclusion:

Results obtained for the samples for flexural revealed flexural modulus of up to 1880MPa for composite with sawdust and SLG in its composition. Composites samples with ELO have lower flexural modulus as compare to ones without ELO. The trend observed was that when more sawdust was added to the composite, storage, peak load, and flexural modulus increased up to a certain limit at which they drop. Addition of more sawdust was observed to lower deflections of composite bars.

The result from various combinations of epoxy resin and waste material was compared to the one for the pure or neat epoxy resin. It was found that with addition of ELO, the physical, mechanical and structural properties were much lower compared with the neat epoxy resin properties.

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Notations

CEEFC	is the Centre for Excellence in Engineered Fibre Composite, USQ
Tg	Glass transition temperature
σ	Stress at failure or peak stress Eq 1
F	load at failure
DGEBA	is diglydyl ether of bisphenol of the types Glycidyl ether epoxies
L	span length of specimen Eq 1
b	width of the specimen
d	depth or thickness
E_f	flexural modulus equation Eq 2
m	gradient of the initial straight line portion of the load deflection measured in N/mm Eq 2
K	Stress intensity factor also known as the plain fracture toughness.
a	flaw or length of the notch on fracture toughness specimen
Kc	property that measure material resistance to brittle fracture Eq4
f	geometry factor for specimen and flaw Eq 3
σ_c	critical applied stress
E’	storage modulus Eq 5
E’’	loss modulus

ε_0	Strain
ω	Period of strain oscillation
δ	is a phase (wave) lag between stress and strains Eq 6, 9
Mc	cross-links density as in equation 11
t	time
R	is the ideal gas constant at temperature (100°c)
Ve	is the crosslink density in moles/ml
T	is temperature in degree Celsius (°c)
ρ	is the polymer density
ELO	stands for epoxidised linseed oil.
SLG	stands for environsphere also known as fly ash spheres

Chapter 1

Introduction

1.1 Composites from Natural Renewable Resources

Composites as their name suggested are made from various materials with different quantities in their composition. In particles arrangement in composite materials W. Bolton (1996) stated that composites take number of forms which include random particles matrix, short discontinuous fibres all lined up on the same direction, short discontinuous fibres randomly oriented in a matrix and finally long continuous fibres all line up in the same direction in a matrix.

In this project composites were made from plant based materials which included epoxy resin, epoxidised vegetable oil, sawdust and waste material such as fly ash spheres (SLG). Particles arrangement in the composite in this could be said to be arranged in randomly particles in a matrix in that filler particles are of different sizes and no particles arrangement in particles orientation. The reaction and hardening in this kind of composite is sped up by aradur-250 amine hardening agent.

A number of research carried out throughout the world indicate that composite is a future way of releasing pressure on traditional building materials such as concrete, steel and timber. It is state the by using renewable plant based material, the aim will not only be the releasing pressure on traditional material but also recycling of waste and unusable material for instant sawdust and fly ash which are normally throw away as waste.

Composites made from plant material are not only good as building material but possess structural advantages which include light in weight, readily available, strong and stiff.

1.2 Aims of This Research Project

The main aim of this project is to investigate the mechanical and structural properties of composite made from natural renewable resources (epoxidised vegetable oils) blended with traditional synthetic resin and using sawdust and or SLG as fillers, Their preparations, testing

and their possible applications in civil engineering structures. Also this study will evaluate the improvement on impact resistance, thermal and fracture toughness of synthetic traditional composites using waste material and renewable plant based resins.

Rationale and Objectives

The objectives to be achieved after the project are to;

- Understand the mechanical properties of composites made from renewable natural resources: epoxy resin
- Understand the structural properties of composite made from renewable resources epoxidised vegetable oil (linseed oil).
- Ascertain any use of composite made from renewable resources in civil engineering
- Understand the impact fracture toughness of neat herez epoxy resin GY-191.
- Understand the effect improvement on the epoxy resin and compare it with the neat epoxy result results. From that make a conclusion on the behaviour when improved epoxy resin.

1.3 Layout of the Research Dissertation

In the next few paragraphs the layout of the whole project is outlined. Each chapter will be dealt with and what to be covered in each chapter is summarised.

Chapter 2 deal with literature review and project background information's in context with previous researchers. Work done by previous researchers is revealed and how it relates to this project. Chapter 2 reveals experimental work done on flexural, toughness and DMA. Also analysis done on flexural, toughness and DMA are elaborated. In the chapter the advantages of composite are also explained.

Chapter 3 covers materials/resources and equipment that are used in the production of the composites. Things such as epoxy resin GY-191, epoxidised linseed vegetable oils (ELO), hardener (aradur-250 amine), fillers such as sawdust and fly ash spheres/environ-sphere (SLG), and equipment for instant laboratories at P9 and machine for instant MTS Alliance

which are used in testing of flexural and toughness and dynamic mechanical analysis. The use of each of these equipment, resource and machine are discussed in this chapter.

Chapter 4 describes the preparation of sample for the whole project which includes sample for flexural strength test, impact fracture toughness and DMA tests. The preparation of the sample includes weighing in to required ratios, mixing, curing in industrial oven for 24 hours at room temperature followed by 4 hours post curing at 80 degrees Celsius, cutting into required sizes and polishing off unwanted protrusion on samples.

Chapter 5 is the main heart of the project. It is in this chapter that the methodology is described. The main methodologies that will be covered in the project are flexural strength test, impact fracture toughness test and dynamic mechanical analysis (DMA). These three tests are used to find or reveal the physical, mechanical and structural properties of these composites. The physical, mechanical and structural properties that will be investigate are peak stress (yield stress), structural modulus, storages modulus, deflection under load, tan delta, failure mode, glass transition temperature (Tg) and strain at failure.

Discussion and analysis of results from three tests is done in **chapter 6**. The trend of properties will be ascertained in a sense that they increases with increase in amount of sawdust added or whether they decrease with amount of sawdust added. Same things will be done on SLG filler amount added either properties increases or decreases with amount of SLG added. The effect of hisotropic agent (silica fume) will not be assessed as it is added to let the composite mix homogenously. Analysis of Flexural, impact toughness and DMA results will be covered here in this chapter.

Chapter 7 deal with drawing of conclusion from the tests carried out in the project.

Conclusion will be drawn from the analysis done in chapter 6 on the tests done (flexural, DMA, and impact toughness tests). At this chapter, based on analysis done on the physical, mechanical, structural properties of this composite will be revealed and conclusion made. Let now look at each chapter in turn:

Chapter 2

Literature Review

2.1 Introduction

Whatever is investigated today had been investigated in the past in one way or other form. For this reason a background literature of any topic taken for as a research project /thesis or a study have to have a literature review. In other word literature review reveals what has been done in a particular topic by previous/other authors.

2.2 Experimental Work Done

Literature review will be a major part of this project work as it acts as a base for work to be done. It will look into the areas related to this topic covered by other authors in the past. Composite has recently been a subject of interest throughout the world. This interest in composite is said to be due to pressure on traditional building materials such as steel, timber and concrete. Also the interest in composite has been a case due to its advantages which includes being renewable, cheap, readily available, strong and light in weight that is in other ward low density compare to steel and concrete.

2.3 Advantages of Composite from Natural Renewable Resources

The advantages of renewable composite are outstanding. J Crivello et al reported that high strength, stiffness to weights ratio of organics matrix composites are the chief advantages of composites materials over metals structural's application. It was also reported by the Hiroaki 2004 et al that from epoxy high tensile strength, the most important property of epoxy resin is its resistance to chemical attack and exceptional solvent resistance. He also ascertained that cured epoxy resin has good head resistant and high stiffness. On the best part of composite made from epoxy resin, A.O.Donnel et al on top of the advantages of resin mentioned by J.Crivello added that cost advantages and ease of processing are also paramount. These low densities material when composite is made from them, it results in relatively light weight

composite. They also went on and stated that those fibres offer significant cost advantages and ease of processing along with being renewable resource. The test they did yielded on composite made from soybean oil and form at room temperature and cured with natural fibres reinforcement of about 10-20 weigh % increased flexural modulus to a range of 1.5 and 6 GPA. Acrylated soybean oil resin with wove glass was tested as reference and gave a flexural modulus of 17 GPA while a room temperature cured neat resin gave a flexural modulus of about 1.1 GP.

Despites those goods properties Hiroaki Miyagwa found that they owe a few disadvantages which can be corrected through research. One of these disadvantages is that pure cured epoxy resin fails with brittle failure. For that reason a number of researches are being under taken to make improvement on the epoxy resin. The improvement includes adding some other natural resources as fillers to modify the structural, mechanical and physical properties of epoxy resin. From modification, Hiroaki 2004 et al elaborated that tougher flexible materials could be obtained by incorporating a flexible epoxy resin, curing agent or reactive additives into their networks during curing. When fillers for instant sawdust is incorporated in to the resin and cured the final improved product does not fail in a brittle way as the epoxy resin without filler.

In contrast to those who did some related work on epoxy resin and epoxidised vegetable oils, in this project Aradur-250 Amine hardener is used instead of anhydride hardener. For the anhydride cured epoxy it was found that heat distortion temperature (HDT) measured with TA instrument DMA 2980 operating in three points bending mode at 170 degree Celsius at a scanning of 2 degree /minute was found to be decreasing with increasing amount of epoxidised linseed oil. Also the storage modulus as well as the glass transition temperature were found to decrease with increasing amount of epoxidised linseed oils.

2.4 Availability of Resources for Composite

For the availability of linseed oil, it is noted by Amar Mohanty (2004) et al that linseed oils is available abundantly around the world and epoxidised linseed oils is already commercially available. This availability solved the question of being worry about its supply and where to

get it from when it is to be used in composites. Being plant part it is renewable and can be produced in huge amount throughout the world.

2.5 Fly Ash as Filler

Fly ash is other filler that will be used in project and has been tried by some other studies in the past. As filler fly ash is believed to have some advantages when used as filler in epoxy and epoxidised vegetable oil composites. It is a bye product from coal power plants which have very fine particles. It is found as a result of burning of pulverised coal in power station. Most fly ash are collected from flue gases of the coal fired power plant.

The use of composites in engineering is becoming important and as such studies are being done to find out the mechanical properties of this composite. Devi et al highlighted that some classes of fly ash have been used in amount of 50% or high of cementitous material for building paramount. On inexpensiveness of fly ash Devi et al pointed out that it can cut cost when used as filler in composites. It was also revealed that not much has been done on the utilisation of the fly ash as it normally damp as a waste material at the power plants. The author's thoughts if fly ash could be used as fillers it would be beneficial in two ways; one it would cut or reduce the overall cost of composites and two it would be useful for the disposal of fly ash which is otherwise a hazard to the environment. Devi et al contrasted that the decision not to use or use fly ash could be based on the quality of the material available on the ability to compensate for any deficiency of the composites produced and on the cost reduction.

2.6 Sawdust as Filler

Sawdust is a natural occurring material since it is found from wood processing industry. It is always throw away as a waste product. As environment concerns and sustainability of materials are increasingly becoming very important in the last century a number of studies are being done to incorporate and bring sawdust into use. Those studies have tried to use sawdust as filler for composites made from epoxy resin and other materials. Norma et al reported that sawdust is added as a filler to improve thermal and mechanical properties of resin. As a filler

it has many advantages namely cost reducing compared to mineral filler, availability, renewability, low density, and resistance to break during processing. However in connection to those advantages Norma et al figured out that some adverse effect exist; toughness reduction and ultimate elongation often suffers with addition of more filler (sawdust). Other drawback of sawdust used as reinforcement is the low degradation temperature and their hygroscopicity which weaken their adhesion with hydroscopic polymers.

Conclusions

The literature that related to the project has been examined. It is found from the literature that interest in composite is due to pressure on traditional building material such as steel, timber and concrete. The interest on composite is also due the very excellence properties of composites which include light in weight, high strength, stiffness and inexpensiveness of composite materials.

Chapter 3

Materials and Equipments

3.1 Introduction

Any project or piece of work needs equipment and material. Materials are the one to be turn around to produce a new materials or product (composites in this case). As such the materials which were turned around here were epoxy resin, epoxidised linseed oil, sawdust envinospheres (SLG) and Aradur hardener. The main equipment used in the process were testing machine such as MTs Alliance, dynamic mechanical analyser (DMA), Industrial oven, wetsaw and polishing machine to investigate physical, mechanical and structural properties of composite which is in consideration here. The facilities were the laboratories at the P9 Centre at University of Southern Queensland. Each of these material and equipment will be considered in turn as below:

3.2 Epoxy Resin

Epoxy resin is defined as a molecule containing more than one epoxide groups. The epoxides also termed as oxiriance group is shown.

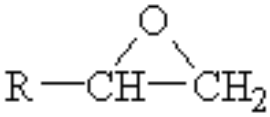


Figure 3.1: Structure of epoxy group (oxiarance)

Epoxy resin is relatively new epoxy developed in 1940 and has found uses in commercial importance only in the last century.

The epoxy resin used in this project was GY-191 from Hexion Speciality Chemical Pty Ltd.

3.2.1 Types of Resin

There are two types of epoxy resin in use today. These epoxy resin are glycydyl epoxy resin and non-glycydyl. The main different between Glycidyl and glycidyl is that glycidyl epoxy resin are prepared by condensation reactions of appropriate dihydroxy compound, dibasic

acids or diamine and epidchlkorohydrin whereas non-glycidyl epoxies are formed by peroxidation of olefinic double bond. Glycidyl ether epoxies such as diglydyl ether of bisphenol –A (DGEBA) and novalac epoxy resin are most commonly used epoxies. Figure shows the chemical structure of DGEBA epoxy and figure shows the chemical structure of novolac epoxy resins

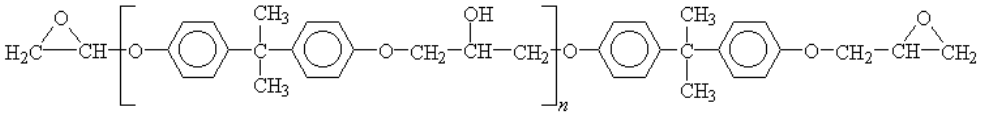


Figure 3.2: Chemical structure of DGEBA

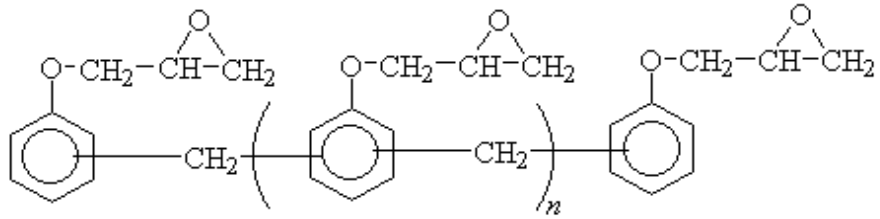


Figure 3.3: Chemical structure of novolac resins.

3.2.2 Uses of Epoxy Resin

In today life Epoxy resin are extensively used in;

- coating of surfaces,
- composite materials such as those using carbon fibres and fibre glass reinforcement
- Adhesion to various materials such as metals, wood, plastics and glass.

They are thermosetting resins that will cure at room temperature to form solids having good strength and chemicals stability.

3.2.3 Curing of Epoxy Resin

Curing is a chemical reactions in which the epoxides groups resin reacts with a curing agent (hardener) to form a highly cross-linked three dimensional network Maurin Romain (2006).

In order to convert epoxy resins into a hard, infusible and rigid material, it is necessary to cure the resins with hardener.

Epoxy resins cured quickly and easily practically at any temperature between 5 -150 degree Celsius depending on choices of curing Maurin Romain (2006).

Epoxy resin, aradur, sawdust, fly spheres, silica fumes with specified amount were mixed in a bowl and subject to 24 hours at room and then followed by 80 degree Celsius for 4 hours in industrial oven. After that the composite was found have cured and was rigid and hard. The samples were subjected to various processes which include cutting, polishing and testing**.**

3.3 Epoxidised Vegetable Oil (linseed 82.5%)

Epoxidised vegetable oil used in this was locally made from university of southern Queensland laboratory and the vegetable oil used was epoxidised linseed oil (ELO). This was chosen because different plant based oils have different have behaviour and therefore it was decided to use only ELO to reveal its properties. Also ELO was chosen because it available as it was produced from University of Southern Queensland laboratory.

3.3.1 Process of Epoxidation

The process of oxidation are complex but in simple principle of oxidiation made it easy to understand. Vegetable oil is made up of glycerine of saturated and unsaturated fatty acids. The saturated fatty acids are not reactive but unsaturated acid are much more reactive Maurin Romain (2006). The unsaturated molecules contain double bond and that there are ones or more alkenes functional group along the chain. The molecule has two or more points in its structure capable of supporting other atoms not currently part of the structure. In connection to that statement the oxidation reaction consist of opening of the C-C double bond and replacing it by a C-0-C cycle (oxirance ring) Maurin Romain (2006). Where C and O are carbon and oxygen atoms respectively see figure 3.4.

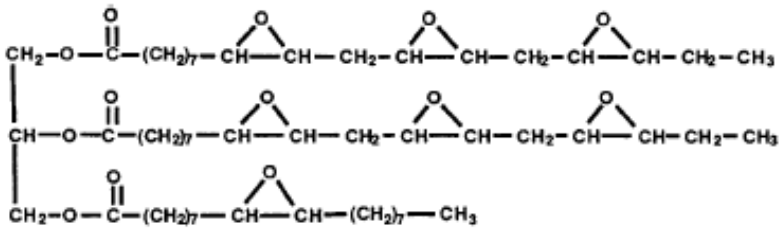


Figure 3.4: Chemical structure of epoxidised linseed oil.

3.4 Hardener Aradur-250 Amine (Curing agent)

The functional group of amine is the nitrogen atom which is connected to three sigma bond of hydrogen. Amines hardeners that are used in the curing of epoxy resin are divided into three main groups namely, primary, secondary and tertiary amine according to the number of carbons bonded directly to nitrogen. Primary amine have one carbon bonded to the nitrogen, secondary amine have two carbons bonded to nitrogen and tertiary have three carbons bonded to nitrogen as shown in the chemical structure of the amine figure 3.5 -3.6.

Hardener is also known as curing agent in that it is a chemical that is used in curing of epoxy resin to convert it from liquid stage to solids stages. In the process of hardening a number of reactions take place. These reactions will not be examined in this project.

In the world today there are many curing agent for epoxy resins which are dictated by properties required in the end result. The commonly used hardeners include amine, polyamides, phenolics resins, anhydrides, isocyanate and polymercaptans. The cured kinetics and Tg of cured system are dependent on the molecular structure of hardener.

Amine based curing agent is used for this project. The type of amine used is aradur-250 amine.

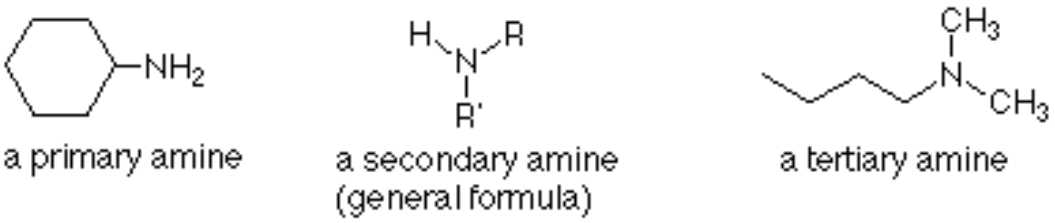


Figure 3.5 Amine hardener groups

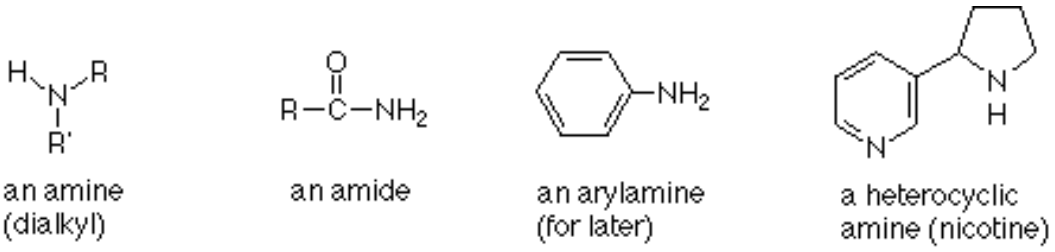


Figure 3.6: Amine hardener chemical structure.

3.5 Fillers

Two main fillers were used in this project. These two fillers are fly ash spheres (SLG) also known as enviro-spheres and sawdust. These will be looked into inturn but let explain what is meant by a filler in composites. Filler is material that is added into resin to improve its properties. It is credited with the following actions or qualities in composites:

Firstly it reduces the shrinkage of composite parts and when composite is subjected to hardening it sometime reduces it volume or contract in sizes (become smaller than it original sizes), fillers help to reduce that and maintain composite as first moulded.

Secondly fillers lower compound cost of composite by diluting more expensive epoxy resin and may reduce the amount of reinforcement required in a composite. This is the case when fillers are mixed with resin and occupied some spaces that could have been occupied by more resin which normally result in making overall cost of composite higher.

Finally fillers act as bridge to transfer stresses between primary structural components of laminates thereby improving mechanical and physical performances.

Now let look at each of these fillers in turn;

3.5.1 Fly ash spheres / Envirospheres (SLG)

Environspheres is a commercial ceramic microsphere product obtained as fly ash by-product. Its sizes of particles range from 20-300 micron with mean of about 130 micron. Its density was measured with Pycnometer Pecupyc -133 and was found to be 0.7566g/cm^3.

Figure 3.7: SLG filler ready to be used.

3.5.2 Sawdust

Two different sizes of saw dust were used. These sizes were 1650 micron and 600 microns. Prior to use it was sieved into those sizes mentioned above. The two different sizes were selected with big range in order to investigate the effect of each of sawdust sizes hence fine and course sizes where selected.

The sawdust was not from any particular type of woods but was a mixture of different sawdust from different woods. It was brought from local saw mill based in Toowoomba. Prior to used, it was subjected to check for moisture contents. The check was just in case of moisture content but actually it was kept in-door at the CEEFC laboratory.

Figure 3.8: Sieved 1650 micron Sawdust filler.

3.6 Fumed Silica (Hisotropic agent TS-720)

Mixing epoxy resin, hardener of aradur types, sawdust and SLG can be quite challenging. To mix the composite well and evenly to get a homogenous mixture fumed silica should be used. As a matter of getting homogenous mixture fumed silica was added in every sample that was moulded.

Fumed silica is a white powdery product which has very fine particles ranging from 0.007 to 0.05 micron. It is light in weight and can be carried by air if exposure it.

It is produced by action of silicon dioxide made by reacting silicon tetrachloride in oxy-hydrogen flames (CH3SiCL3 + 2H2+3O2 burn under higher temperature with H2 and O2).

3.7 Laboratories and Equipment

Most of this project works were carried out at the laboratories in the CEEFC. At this centre there are a quiet a number of different Equipment and facilities for different composites analysis work.

Like the case of resources a number of equipments would be needed during this project. As CEEFC is a well equipped centre for composite work, there will were no much aisle in the project in term of equipments and facilities. The following are the equipments that were of help in throughout the project.

- Machine for dynamic analysis (DMA) Q800,
- Toughness testing machine: MTS Alliance,
- Flexural testing: MTS Alliance ,
- Wetsaw which can measure and cut samples
- Sanding machine to be used in sizing samples,
- Industrial microwave for curing prepared sample.
- Weighing machine to weigh required component parts
- Casting bowls

All of these equipments are available at CEEFC. For the facilities the laboratories of CEEFC houses those equipment as well as computers connected to some of equipment. The below figure shows MTS Alliance machine (10kN) which is used for both flexural and fracture toughness tests.

Figure 3.9: MTS Alliance (flexural and impact toughness testing machine (10 kN).

Conclusions

The materials and equipment that were used in the project have been outline and explained. The purposed for each material and equipment has been looked into and elaborated.

The main equipment and facilities that were used in the project included MTS alliance machine, wetsaw, sanding machine, DMA machine and laboratories at the CEEFC.

Materials that made the base composites for the project were epoxy resin from Hexion Company Pty Ltd, Epoxidised vegetable oil made from the laboratories at CEEFC, sawdust local brought from local saw mill in Toowoomba, Fumed silica and SLG.

Chapter 4

Preparation of Composites Samples

4.1 Introduction

The preparation of samples for the three tests (flexural, fracture toughness and DMA) that were done, were made using the following preparations which include checking moisture contents, weighing various materials quantities, mixing material into required ratios, curing mixed material in industrial oven, cutting in required dimension using wetsaw, and finally polishing off unwanted shape on samples by sanding machine. 42 samples were made for these three tests. Variations were made on the amount of epoxidised linseed, sawdust, SLG and fumed silica. The samples were grouped in three groups where by the quantity of sawdust were 5g, 10g and 20g for each size of sawdust. Variation on SLG filler were also the same as that one of sawdust and were 5g, 10g, 20g, and 30g. Also fumed silica was varied at 0.3g and 0.6g. Table 4.1 given below shows different quantities for of the 42 samples made. A and B samples were produced from one bowl and it was the cutting on sample and dimensions of specimens that were differed.

Table 4.1: Sample quantities formulation.

Sample numbers	Epoxy GY-191 weight (g)	Hardener aradur 250 weight (g)	Natural sawdust weights (g)	Sizes (micron)
1 A&B	80	40	0	600
2 A&4	80	40	5	600
3 A&B	80	40	10	600
4 A&B	80	40	20	600
5 A&B	80	40	5	1650
6 A&B	80	40	10	1650
7 A&B	80	40	20	1650

Table 4.2: Composites prepared with ELO, Epoxy resin gy-191 and Aradur-250 Amine in ratio of 3:1:2 for fracture toughness test.

Sample numbers	Epoxy 6y-191 weight (g)	82.5% Epoxidised Linseed oil (g)	Hardener aradur 250 weight (g)	Natural sawdust weights (g) as filler	Sizes (micron of sawdust)
8 A&B	60	20	38	5	600
9 A&B	60	20	38	10	600
10 A&B	60	20	38	20	600
11 A&B	60	20	38	5	1650
12 A&B b	60	20	38	10	1650
13 A&B	60	20	38	2-	1650

Table 4.3: Composites prepared with Epoxy resin GY-191 and Aradur-250 Amine in ratio of 2:1 for fracture toughness testing.

Sample numbers	Epoxy 6y-191 weight (g)	Hardener aradur 250 weight (g)	Hisotropic agent (g) for homogenous reaction	Fly ash (SLG spheres) (g)
14 A&B	80	38	5	5
15 A&B	80	38	10	10
16 A&B b	80	38	20	15
17 A&B	80	38	5	20
18 A&B	80	38	10	30

Table 4.4: Preparation of composite with ELO, Epoxy and Aradur Amine in ratio of 3:1:2 for fracture toughness test.

Sample numbers	Epoxy 6y-191 weight (g)	82.5% Epoxidised Linseed oil (g)	Hardener aradur 250 weight (g)	Hisotropic agent (g) for homogenous reaction	Fly ash (SLG spheres) (g)	Sawdust (g)	Sizes (micron)
19 A&B	60	20	38	0.3	10	5	600
20 A&B	60	20	38	0.3	10	10	600
21 A&B	60	20	38	0.3	20	20	600
22 A&B	60	20	38	0.3	10	5	1650
23 A&B	60	20	38	0.3	10	10	1650
24 A and B	60	20	38	0.3	10	20	1650

Table 4.5: Composite with ELO, Epoxy and Aradur Amine in ratio of 3:1:2 and SLG.

Sample numbers	Epoxy 6y-191 weight (g)	82.5% Epoxidised Linseed oil (g)	Hardener aradur 250 weight (g)	Hisotropic agent (g) for homogenous reaction	Fly ash (SLG spheres) (g)	Sawdust (g)	Sizes (microns)
25 A&B	60	20	38	0.3	20	5	600
26 A&B	60	20	38	0.3	20	10	600
27 A&B	60	20	38	0.3	20	20	600
28 A&B	60	20	38	0.3	20	5	1650
29 A&B	60	20	38	0.3	20	10	1650
30 A & B	60	20	38	0.3	20	20	1650

Table 4.6: Composite with Epoxy and Aradur Amine in ratio of 2:1 and SLG.

Sample number	Epoxy resin GY-191 (g)	Aradur - 250 hardener (g)	Hisotropic agent TS-720 (silica fumes) (g)	Fly ash SLG Spheres (g)	Sawdust (g)	Sawdust sizes (microns)
31 A&B	80	40	0.3	10	5	600
32 A&B	80	40	0.3	10	10	600
33 A&B	80	40	0.3	10	20	600
34 A&B	80	40	0.3	10	5	1650
35 A&B	80	40	0.3	10	10	1650
36 A&B	80	40	0.3	10	20	1650
37 A&B	80	40	0.6	20	5	600
38 A&B	80	40	0.6	20	10	600
39 A&B	80	40	0.6	20	20	600
40 A&B	80	40	0.6	20	5	1650
41 A&B	80	40	0.6	20	10	1650
42 A&B	80	40	0.6	20	20	1650

To avoid segregation sample material in mixture especially with fly ash and SLG the density of the SLG spheres was measured using pycnomter Ipencupy-1330 and was found to be: Density = 0.7566g/cm^3

SLG was used because other type of fly ash is much denser than resin and aradur as well as the sawdust. This was to avoid segregation or formation of different layers as denser material would settle in to the bottoms of casting beaker

Each of the test and preparation involved will be considered as followed;

4.2 Flexural Sample Preparations

Bars with 64mm span length by 15 mm by 10mm depth were prepared. The preparation starts with weight of different material quantities to required amount of each material. The base material was epoxy resin of hexion types whose first amount used in the sample preparation was 60 grams. The amount of epoxy resin was then increase to 80 gram after wards and kept at 80 gram for the rest of the samples made.

Hardener amount was kept constant at 40 gram and each of the material such as sawdust, epoxidised linseed oil, SLG and fumed silica were increase each at a times. This was done actually to investigate the effect of each material on epoxy resin.

When weighing and checking of moisture contents were done, the material was mixed in plastic bowls. Adding of materials into bowls was done in a certain order. Firstly, epoxy resin was poured in bowl and its weight was measured using weighing machine followed by aradur hardener. The two were then homogenously mixed for 2 to 3 minutes until they formed a semi liquid mixture. When they were mixed, sawdust of different sizes and different percentage weight were then added and mixing continued for another 2 to 3 minutes until it's formed dough when 20 gram of sawdust was added or a semi liquid when 5 gram was added.

Composite samples that content fumed silica and SLG have different order of mixing in that the same procedure was followed except that fumed silica was added after mixing of epoxy resin and aradur hardener before sawdust could be added. This was done to allow epoxy resin and aradur hardener to mix homogenously. After that SLG was added to the mixture and stirred to mix and sawdust added to the mixture at a final stage and then mixing until the mixture form a semi liquid or dough like structure when it had 10 to 20 grams of sawdust and SLG. Figure 4.1 shows the mixing of composite materials.

Figure 4.1: Mixing of composite with plastic spoon.

4.2.1 Curing of Composites

Mixture that has been mixed has semi or dough like material were subjected to curing at room temperature and in an industrial oven.

The bowls of mixed materials were left at room temperature for 24 hours without being disturbed. At that period of time the reaction between the epoxy resin and aradur hardener took place. The reaction involved releasing of heat from the mixture. After few minutes of mixing and leaving the mixture if one touch the bowl that contains the mixture, one could feel the heat.

Figure 4.2: Curing of Samples in Industrial Oven.

After 24 hours at room temperature, samples were put into the industrial oven where they were subjected to 80 degree Celsius for 4 hours (figure 4.2). Here the reaction of cross-linking of material continued as well as the reaction between the various materials to form harder material that could act as one single unit material. When the 4 hours with 80 degree Celsius finished the cross-linking of material particle was now over and mixture was found to be hard and strong. At this, formed composites were ready to be cut to required sizes according testing machine MTS Alliance.

4.2.2 Cutting to Required Sizes

Cutting into required sizes was needed because the samples were moulded in bowls with a base radius of 80 mm. The bars required for flexural test method have dimension of 64mm span length by 10mm wide by 15mm depth (thickness). To get these dimensions wetsaw was used. Span length of 64 was not required as it was already measured by the diameter of the moulding bowl and easily achieved by polishing. Thickness of 15mm and width of 10mm were found by making a 4.9 turns on the wetsaw scale. Initially, the rotating wheel of the wetsaw was turned to zero and first cut made. At least three specimens were cut from one sample casted in a bowl and it was the average of three specimens that was in the

investigation of the properties. When cutting each specimen the wheel has to be turned to zero and then 4.9 turns made followed by cut. The composites were cut to the specimens as shown in the figure 4.3 below.

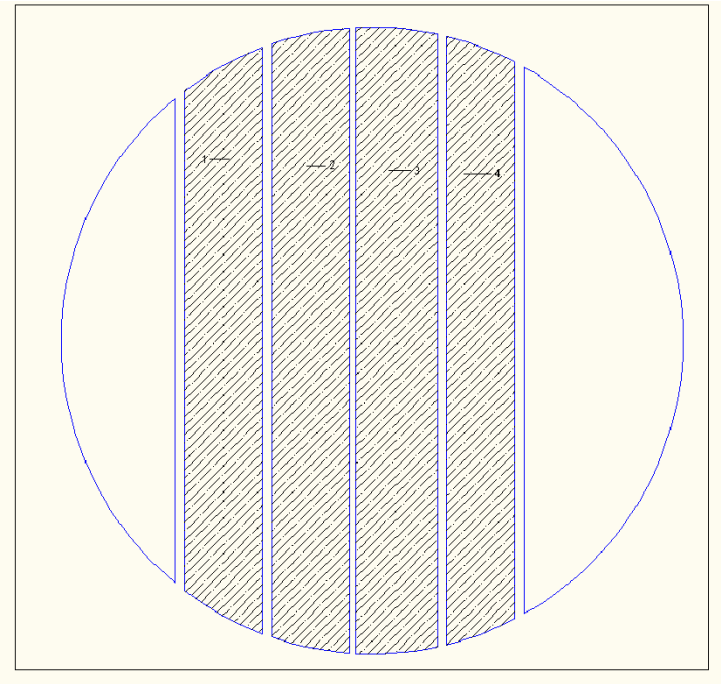


Figure 4.3: Top view of sample displaying cutting lines and four samples cut.

4.2.3 Polishing of Samples

When samples were cutting into the required sizes the samples were not even especially on the bottom of the moulding or casting bowls. To remove that an evenness on the samples, they were polished with polishing machine. Before polishing was done the sample specimens were as shown in figure 4.4 below. Polishing was done by holding specimen against the rolling head of the sanding/polishing machine.

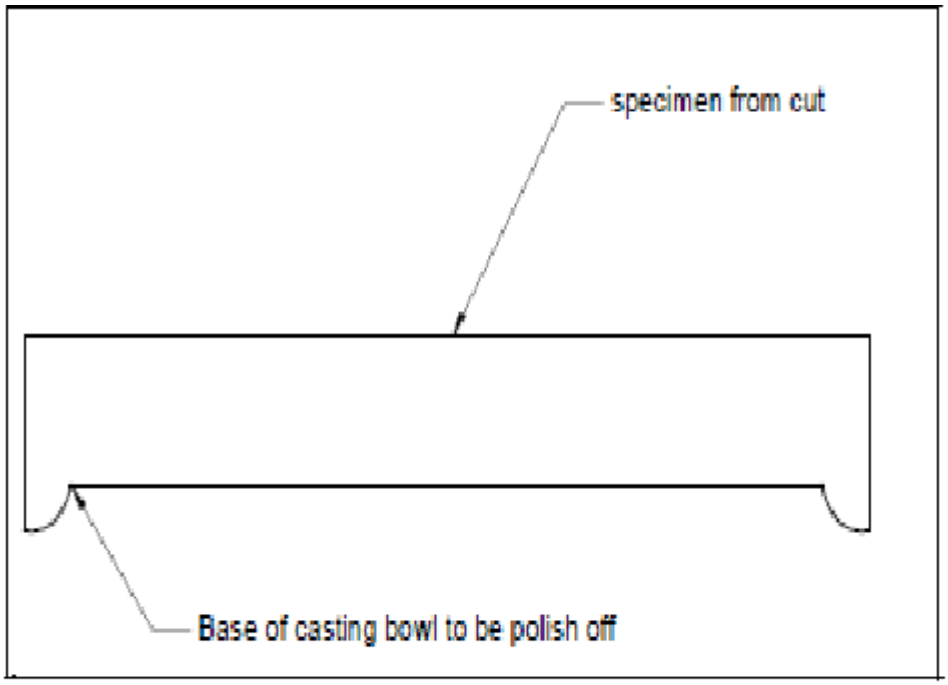


Figure 4.4: Sketch showing cross section of samples with unevenness after cut from wetsaw (front view).

The wetsaw and polishing machine produce dust from their rotating edges as they cut the samples. Dust produced was sucked by vacuum sucker installed at the lab at P2.

4.3 Impact Fracture Toughness Sample Preparation

Bars with 64mm span length by 10mm width by 15 mm depth by were prepared. The preparation starts with weight of different material quantities to required amount of each material. The base material was epoxy resin of hexion types whose first amount used in the sample preparation was 60 grams. The amount of epoxy resin was then increase to 80 gram after wards and kept at 80 gram for the rest of the samples made.

Hardener amount was kept constant at 40 gram and each of the material such as sawdust, epoxidised linseed oil, SLG and fumed silica were increased each at a times. This was done actually to investigate the effect of each material on properties of epoxy resin.

When weighing and checking of moisture contents were done, the materials were mixed and casted (moulded) in plastic bowls. The adding of materials into bowls was done in a certain order. Firstly epoxy resin was poured and amount measured using weighing machine and followed by addition of aradur hardener. The two were then homogenously mixed for 2 to 3 minutes until they formed a semi liquid mixture. When they were mixed, sawdust of different sizes and different amount were then added and mixing continued for another 2 to 3 minutes until it's formed dough when 30 gram of sawdust is added or a semi liquid when 5 gram was added.

Sample that content fumed silica and SLG have different order of mixing in that the same procedure is followed except that fumed silica was added after mixing of epoxy resin and aradur hardener before sawdust could be added. This was done to allow epoxy resin and aradur hardener to mix homogenously. After that SLG is added to the mixture and stirred to mix and sawdust added to the mixture at a final stage and then mixing until the mixture form a semi liquid or dough like structure when it had 20 to 30 grams of sawdust and SLG.

4.3.1 Curing of Composites Samples

Mixture that has been mixed has semi or dough like material were subjected to curing at room temperature and in an industrial oven.

The bowls of mixed materials were left at room temperature for 24 hours. At that period of time the reaction between the epoxy resin and aradur hardener took place. The reaction involved releasing of heat from the mixture. After few minutes of mixing and leaving the mixture if one touch the bowl that contain the mixture one could feel the heat.

After 24 hours at room temperature, samples were put into the industrial oven where they were subjected to 80 degree Celsius for 4 hours. Here the reaction of cross-linking of sample continued as well as the reaction between the materials to form harder material which could act as one material. When the 4 hours with 80 degree Celsius finish the cross-linking of material particle was now over and mixture was found to be hard and strong. At this formed material was ready to be cut to required sizes according testing machine MTS Alliance.

4.3.2 Cutting to Required Sizes and Notch Making

The main difference between the flexural and fracture toughness samples is the notch of 5mm depth similar to figure 4.5 was made in the centre of the 64mm span length of fracture toughness samples and the way sample are test.

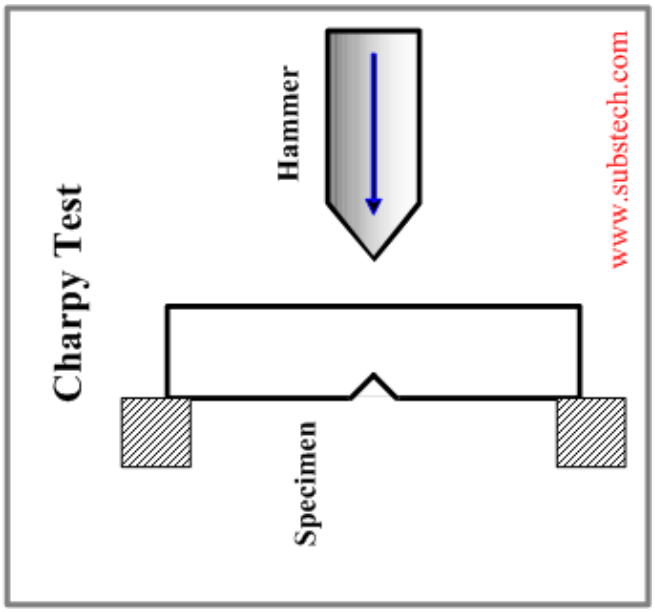


Figure 4.5: Impact Fracture Toughness Sample Mounting (sources: www.substec.com).

Cutting into required sizes was needed for the samples moulded in bowls. The bars required for fracture toughness test method has dimension of 64mm span length by 10mm wide by 15mm depth (thickness). To get these dimensions wetsaw was used in the process. Firstly lines were mark across each specimen where the cut for 5mm notch were to be made. When specimens were marked they were then brought to the wetsaw cutting board and adjustment for 5mm notches by adjusting high on wetsaw and then cut made on each specimen. Span length of 64 was not required as it was already measured by the diameter of the moulding bowl. Notches were then cut at the centres on the sample marked 'B' on bowl at about 32mm of the 64mm span length on the smooth face of the samples.

Thickness of 15mm and width of 10mm were found by making a 4.9 turn on the wetsaw scale. Initially, the rotating wheel of the wetsaw was turned to zero and first cut made. When cutting each specimen the wheel has to be turned to zero and then 4.9 turns and cut made.

Figure 4.6 show the specimen for the fracture toughness with notch of 5mm cut in the centre of the span.

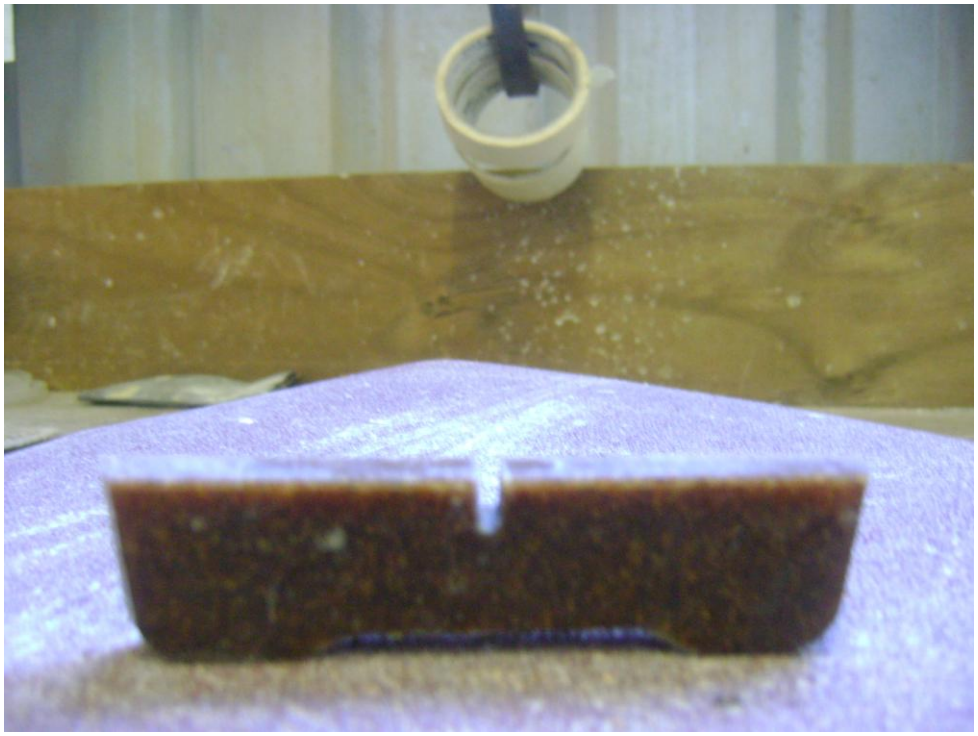


Figure 4.6: Impact fracture toughness sample with 5mm notches.

4.3.3 Polishing Of Cut Samples Composites

When sample was cutting into the required sizes the samples were not even especially on the bottom of the moulding or casting bowl. To remove that an evenness on the sample, they were polished with polishing machine by carefully holding specimen against the rotating head of the polishing machine. The wetsaw and polishing machine produce dust from their rotating edges as they cut the samples. Dust produced was sucked by vacuum sucker installed in the lab.

4.4 DMA Samples Preparations

For the case of the DMA sample the same procedure was followed as for the flexural samples. The process of mixing, curing, cutting and polishing was all the same with flexural as DMA samples were cut from the flexural samples.

4.4.1 Cutting of composite to Sizes

The main different was the sizes of the DMA. Samples for DMA were cut according to the specification and requirement of the Q800 DMA machine which required sizes bar with dimensions of 35mm by 12mm by 4mm.

Thickness of 4mm and width of 12mm were found by making a 2.6 turn on the wetsaw scale. Initially, the rotating wheel of the wetsaw was turned to zero and first cut made. When cutting each specimen the wheel has to be turned to zero and then 2.6 turns and cut made.

4.4.2 Polishing of Composite Samples

When samples were cutting into the required sizes the samples were not even especially on the bottom of the moulding or casting bowl. To remove that an evenness on the sample, they were polished with polishing machine. The wetsaw and polishing machine produce dust from their rotating edges as they cut the samples. Dust produced was sucked by vacuum sucker installed at the lab.

Conclusions

Composites samples specimens have been prepared. The preparation that were undertaken include weighing of material into required ratios, mixing by stirring using plastic spoon, curing in an industrial oven for 24 hours, cutting to required sizes and finally polishing unwanted sizes.

The three major samples that were prepared were for flexural, fracture toughness and DMA. For three different samples bars of different dimension were cut from the casted composites. Flexural and DMA specimens were left plain bar while fracture toughness specimen were made with notches of 5mm at the centre of the specimens span.

Chapter 5

Methodology

5.1 Introductions

As composite is becoming part of today engineering and structures that are built or constructed contents some composites, there is a need to know exactly know how different composites behave under loading. To understand their behaviours various tests are used to investigate the physical, mechanical and structural properties of composites.

Three main tests were carried out on the 42 samples produced in this study. The tests include flexural strength, impact fracture toughness and DMA. Each of the tests is meant to investigate different aspect of the physical, mechanical and structural properties of the composite made from epoxy resin GY-191 and aradur-250 hardener combined with various quantities of sawdust with two different sizes, epoxidised ELO, SLG filler and fumed silica.

In the next few paragraphs, the procedure on how each of these tests was done is explained.

5.2 Flexural Strength Test

Flexural strength is the strength of material in bending express as stress on the outermost fibre of bent test specimen at instant of failure. For rectangular specimen as the case in this project the highest stress at failure is calculated as;

$$\sigma = \frac{3FL}{2bd^2} \qquad \text{Equation (1)}$$

Where F is the is load at failure

L is the span length of specimen

b is the width of specimen

d is the thickness of specimen

The flexural modulus given $E_f = \frac{L^3 m}{4bd^3}$ Equation (2)

Where b is width of specimen'

d is depth or thickness

m is gradient of the initial straight line portion of the load deflection curve measured in N/mm

To be certain of flexural strength of any material flexural test is carried out. As part of physical, structural and mechanical properties of composites made from natural renewable resource flexural test was carried out on prototype rectangular bar beams made from the composite with dimensions of span of 64mm, width of 15 mm and depth of 10 mm. These beams were subjected to load until they reached their failure stage. This schematic figure 5.1 shows how samples for flexural were placed on testing machine.

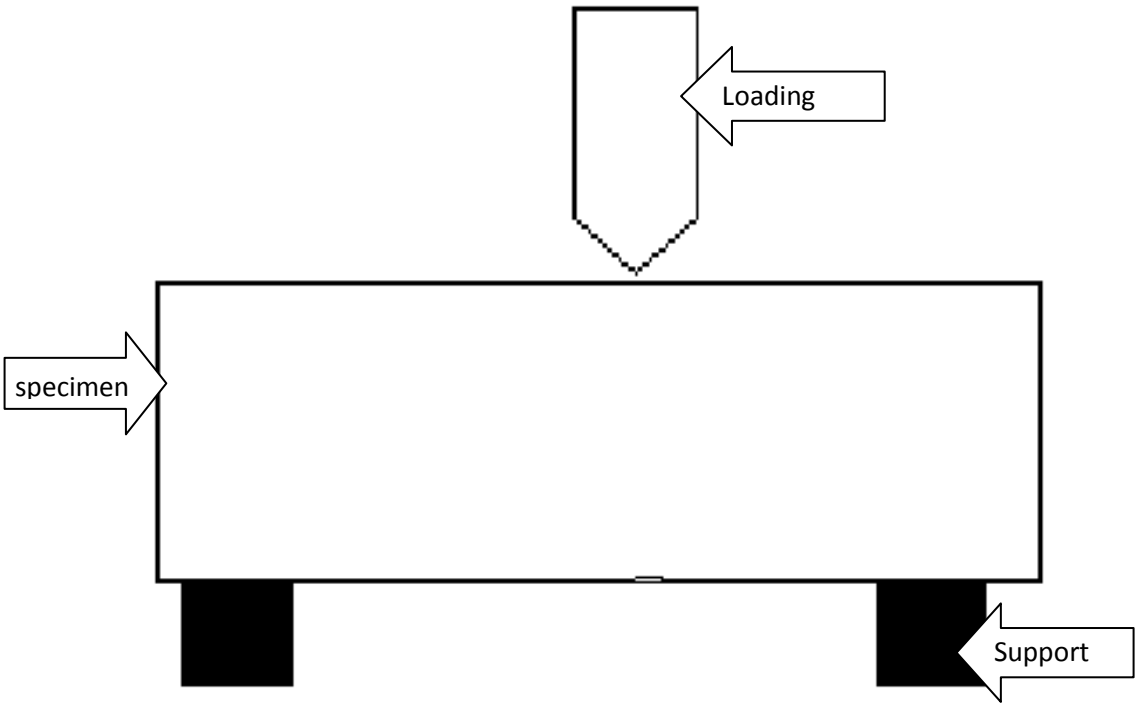


Figure 5.1: The way how flexural specimens were placed on testing machine.

When they failed the failure strengths, loads or peak load, stresses and strains were noted and from the results the flexural strength could be known.

The reason for the flexural testing in this project is that all beams that are made are usually subjected to flexural loading in real structures and loading on structures is either done longitudinally or as compressive load. MTs Alliance machine which measure both flexural and impact toughness has load capacity up to 10Kn. Each of the samples prepared were ready and dimensions of each specimen were measured. After measuring, the dimensions were entered into the computer connected to the MTs Alliance and sample specimen put in position at centre of the 64mm as shown in the schematics diagram figure 5.1. Specimens were support at three point bending position and load applied at the middle of the specimen length. To avoid premature failure of sample specimen's load was applied at a speed of 4mm per minute (4mm/min) until failure. During load application computer plotted graphs of stress strain and then recorded failure load and flexural modulus. For each sample, three specimens were made and tested. The computer averages the flexural strength of the three specimens. Results output from computer were in form of tables and plot of stress-strain relationship and will be shown in chapter 6.

5.3 Impact Fracture Toughness Test

It was pointed out by H. Ku and F. Cardona that fracture toughness is an indication of the amount stress required to propagate a pre-existing flaw (notch). A parameter calls stress intensity factor K is used to determine the fracture toughness of most material.

Impact toughness test is also known as compressive test. It involves subjecting specimen to compressive loading until it fail. When failure occurs, things like failure load, failure stress and failure strain as well as the strength are known. From this the result can be compare to those one of traditional building material (concrete, timber and steel). The resistance of material to fracture is known as it fractures toughness.

Fracture toughness always depends on factors for instance temperature, environment loading rate, the compositions of material and it microstructure as well as geometric effects. Fracture toughness is a critical input parameter for fracture machine based fitness services assessment.

Although fracture toughness can sometimes be obtained from the literature or materials properties databases, it is preferable to determine this by experiment for the particular material and joint being assessed.

Various measures of 'toughness' exist, including the widely used but qualitative Charpy impact test. Although it is possible to correlate Charpy energy with fracture toughness, a large degree of uncertainty is associated with correlations because they are empirical. It is preferable to determine fracture toughness in a rigorous fashion, in terms of K (stress intensity factor) and CTOD (crack tip opening displacement). Figure 5.2 is representation of how loading was done on the specimens for the fracture toughness test.

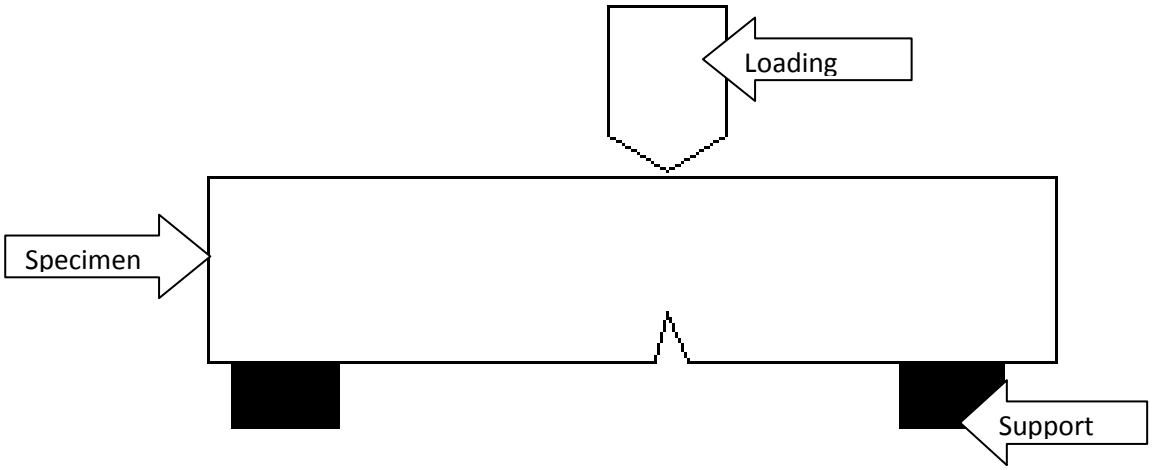


Figure 5.2: The way how impact fracture Toughness specimen are placed on testing machine (the arrow show the 5mm notch).

Unlike the case flexural strength, Load for impact fracture toughness test was applied at slower rate of 2mm per minute. This was actually half of the rate for flexural strength. It was done mainly to avoid premature failure since specimens for impact toughness have notches made in the middle of the span length.
This equation below is used to calculate the stress intensity factor or also known as the plain fracture toughness (H.Ku, R.Davey and F. Cardona).

$$K = f\sigma\sqrt{\pi a} \qquad \text{equation (3)}$$

Where f is a geometry factor for the specimen and flaw (notch). If specimen is assumed to have infinite width then f = 1 for this case f = 1.1 since the width of specimen is not infinite and width of each specimen are known from specimen preparation.

σ is the ultimate applied stress

a is the flaw size or the length of the notch made in the centre of specimen length.

The critical stress intensity factor is defined as the fracture toughness Kc is the K required for a crack to propagate and is given as

$$K_c = f\sigma_c\sqrt{\pi a}$$ Equation (4)

Since Kc is the property that measure the material resistance to brittle fracture when a crack is present its unit is MPa m^1/2

σ c is critical applied stress and the rest are as explained above.

5.4 DMA Test

Dynamic mechanical analysis is one of the machines that are used at CEEFC for purpose of analysis of thermosetting properties of material. It is one of the best available machines that carry out the testing and at the same time analysing the result and put them out as figure or graph.

The main properties of composites determine by DMA are temperature's dependencies properties which include storage modulus E', loss modulus E'' and mechanical loss factor tan delta (damping factor).

The most important of these temperature dependent properties is the dynamic storage modulus (E'). E' is so important because it assesses the load bearing capabilities of a composite material and it is close to flexural modulus.

Both storage and loss modulus in viscoelastic solids measure the storage energy which represent the elastic portion and energy dissipated as heat, representing viscous portion.

The relationship that exists between these thermosetting properties is that tan delta (mechanical loss factor) is a ratio of loss modulus E'' to storage modulus E'.

Each of one of them is calculated using the following equations;

Storage modulus $E' = \frac{\sigma_o}{\varepsilon_o}\cos\delta$ **E**quation (5)

Loss modulus $E'' = \frac{\sigma_o}{\varepsilon_o}\sin\delta$ Equation (6)

$$Tan\delta = \frac{E''}{E'}$$ Equation (7)

Strain $\varepsilon = \varepsilon_o \sin(t\omega)$ Equation (8)

Stress $\sigma = \sigma_o \sin(t\omega + \delta)$ Equation (9)

Where ω is a period of strain oscillations

t is time

δ is a phase (wave) lag between stress and strains.

Tan delta is a quantity that measures the balance between the elastic phase and viscous phase of polymeric structure. It can also relate impact properties of material.

In this project DMA Q800 was used to find out these properties and thermosetting properties of composites made from natural renewable resources. Specimens were cut into rectangular bars according to DMA Q800 specifications. The dimensions of the sample specimens were

35 x 12 x 4 mm. These bar samples were analysis by DMA Q800 as given in the following paragraphs.

The operation of the DMA is simple to understand. It involves application of stress or forces on the samples through a motor. The stress is transmitted through the drive shaft onto the samples which were mounted and clamped on a clamping mechanism. When sample started to deform the amount of displacement was measured by positioned sensor. The strain was calculated from displacement. The force (stress) is applied sinusoidally with defined frequency. Figure 5.3 shows the DMA machine with specimen mounted on it.

The magnitude of applied stress and resultant strain are used to calculate the stiffness of the material under stress as shown in equation 5 to 9 above.

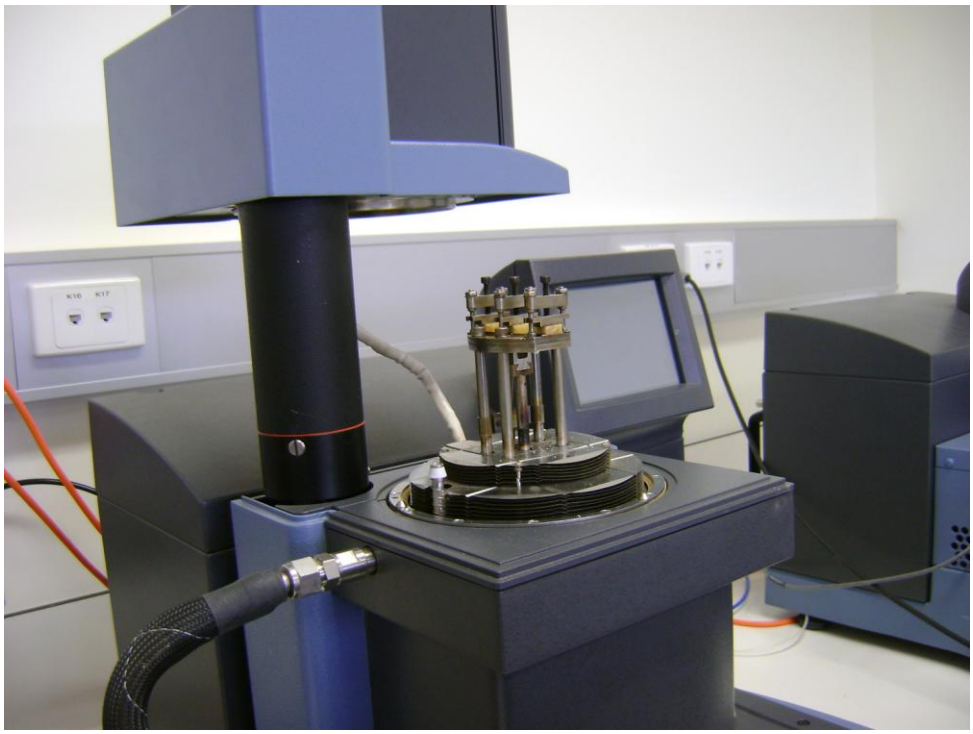


Figure 5.3: Specimens mounting on DMA testing machine.

There are about six ways of mounting Samples in DMA namely single cantilever way, dual cantilever (Liu et al), 3-point bending, tension bending, compression and shear mounting way.

3 point bending was selected for this project sample as it is suitable for bar samples.

Bars with the above dimensions were mounted on testing face of DMA at three bending. Each specimen was allowed about 35 minutes for the test to finish. The outcomes of the 42 tests are discussed in chapter six of this project. The responses from DMA show tan delta and storage Modulus where Tg (glass transition temperature) is the peak of graph of tan delta verses temperature. As material goes through its Tg the modulus reduces which mean composite material becomes less stiff and tan delta goes through a peak.

Conclusions

The Three different methods that were selected for used in this study have been outlined.

Each of the method was selected because it investigates different aspect of the physical, mechanical and structural properties of the composites. Flexural test was selected as it reveal the flexural modulus, peak, peak flexural stress and strain at break, and deflection of composites when subjected to concentrated load. On the other hand fracture toughness test reveal the indication of stiffness of material when a flaws or notches are added in the centre of the specimens.

DMA was selected to investigate the thermal properties of the composite as we know any material used in construction is subjected to heat at some points in time in its construction and design life. Tg is very important to be known in material as it indicate the temperature at which a composite or any material change it behaviour.

Chapter 6

Analysis and Discussions of Results

6.1 Introductions

This chapter deals with the analysis of results of the practical tests carried out in this project. It is the main part of the project that reveals the physical, mechanical and structural properties of the composites made from natural renewable resources. The analysis of results is divided into three major parts namely flexural, impact toughness and DMA results analysis.

Each of part of analysis is carried out by observing behaviour of various tests done on all samples with different quantity of fillers. The properties of composites that are of interest for both flexural and impact toughness are peak load, failure stress, deflection at failure, flexural modulus and strain at failure.

Also in flexural and impact fracture toughness tests, failure mode of each composite will be reveal as well as the effect of each of the material such as sawdust and SLG fillers on the composites. Moreover the effect of sizes of sawdust will be analysed and revealed.

For DMA samples, the properties of interest are thermosetting properties which include storage modulus, Tg and tan delta and their relation to increasing amount of different fillers as well as the effect of ELO.

6.2 Flexural Results Analysis

In this section analysis is done on flexural stress, strain, flexural modulus and deflection at peak from the testing machine MTs Alliance. Each of these is analysed based on the quantity of filler (sawdust and SLG) that is in a composite. Comparison is made on the effect of ELO, and size of sawdust fillers that are part of the composites. Figure 6.1 and table 6.1 shows some of the results for the composites with 5 grams of 600 microns sawdust filler.

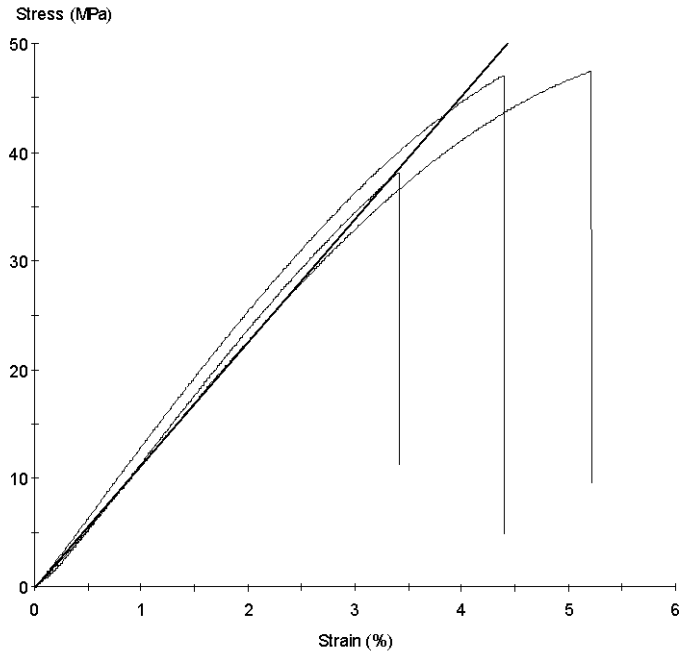


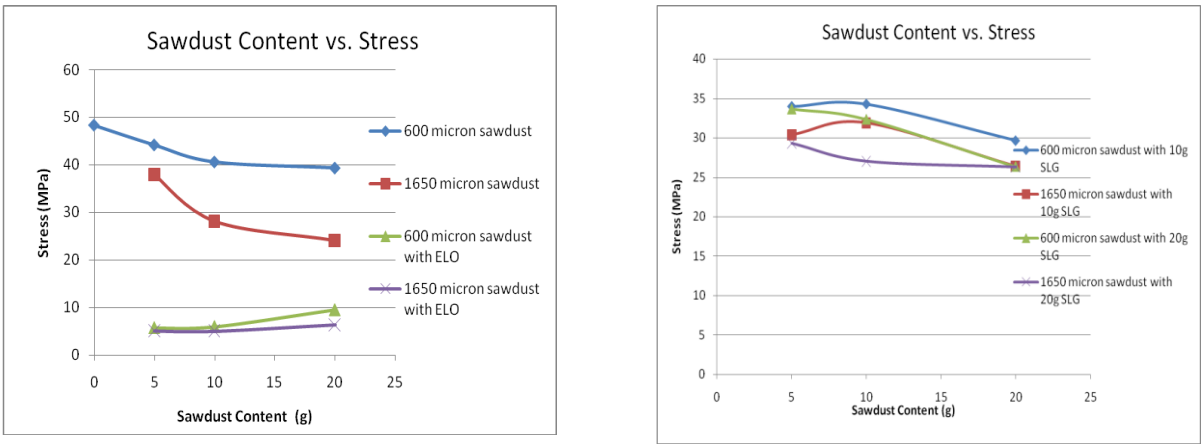
Figure 6.1: Stress-Strain relationship curves for Composite with 5g of 600 micron Sawdust prepared with Epoxy Resin GY-191 and cured with aradur-250 amine hardener.

Table 6.2: Sample results for Composite with 5g of 600 micron Sawdust

Specimen 2.A	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	13.69	10.18	701	47.44	5.21	5.21	3.50	3.50	1147
2	14.01	9.87	669	47.09	4.39	4.39	3.04	3.04	1317
3	14.47	9.85	558	38.17	3.42	3.42	2.37	2.37	1157
Mean	**14.06**	**9.97**	**643**	**44.23**	**4.34**	**4.34**	**2.97**	**2.97**	**1207**
Std Dev	**0.39**	**0.19**	**75**	**5.25**	**0.90**	**0.90**	**0.57**	**0.57**	**96**

6.2.1 Flexural Stress

Effect of sawdust quantities in composite is shown clear from the figure 6.2. It is shown that composites with 600 micron sawdust filler can carry higher stress compare to 1650 micron sawdust composites. This is evident in the figure as composites with 600 microns sawdust have their lines of plots above the composites with 1650 microns on both cases where composites have no and where they have certain amount of ELO. The effect of ELO is that it reduces the stresses as could be seen from the figure 6.2. The reduction in the stress is very dramatics. What does this reduction in stress and relation between 600 and 1650 micron sizes sawdust mean in real life? First of all reduction of stresses by ELO means that the carrying capacity of the composites is reduced and that composite deflected a lot when it fails. And secondly 600 micron sawdust filler composite is stronger than the 1650 micron sawdust composites. This could be because composite with 600 micron sawdust have fine particle that mixed well and formed composites that do not or have few air spaces than the 1650 microns sawdust which mixed and there is room for air spaces since we have larger particles.



(a) (b)

Figure 6.2: Flexural stress (MPa) vs sawdust content (g) of composites prepared with Epoxy Resin GY-191 and aradur-250 amine hardener and without SLG (a) and with SLG (b).

In figure 6.2 (a) and (b) no much difference was observed bewtween the effect of sawdust and the SLG fillers. Stresses lie in the same range as was the case with the sawdust composites. The great different that could be observed with the increased amount of SLG was that stress reduced as quantity of SLG was added to the composites. This can be seen in figure 6.3 where composite with 5 grams of SLG has higher stress compared to the one with 30 grams of SLG. This means addition of the SLG filler not only reduced the adhesibility of the composite but also reduced it strength. This also mean

that when more SLG is added into a composite toughness of a composite suffered and it become brittle.

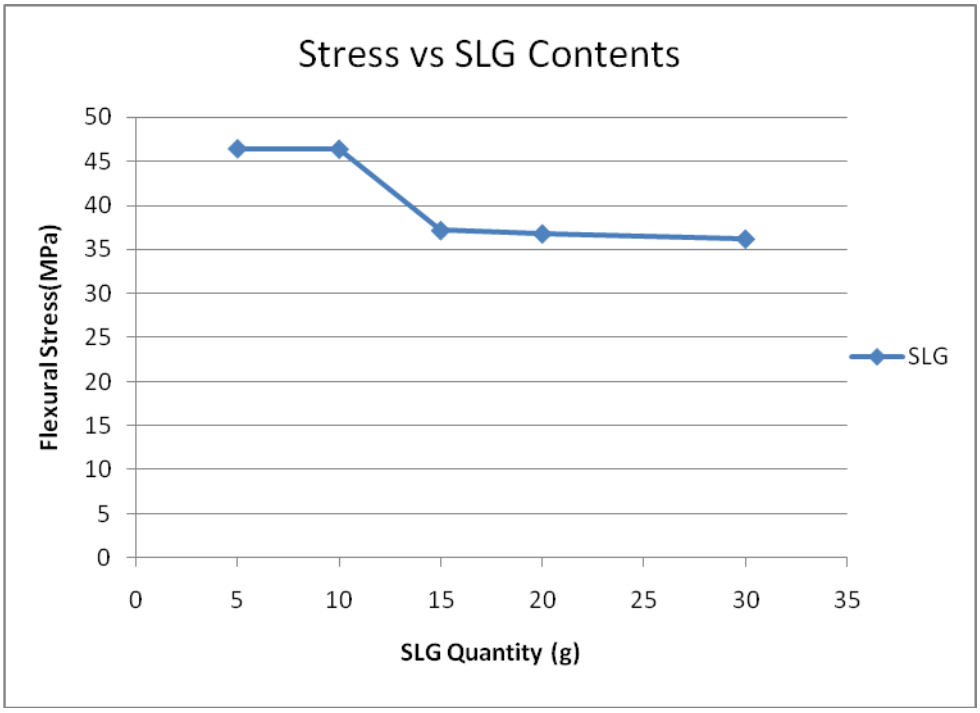


Figure 6.3: Flexural stress (MPa) vs SLG content (g) of composites prepared with Epoxy Resin GY-191 and aradur-250 amine hardener.

Combination of sawdust, ELO and SLG as composites have different behaviour in term of stresses. Their stresses increease with percentage by weight of both sawdust and SLG filler but much low compared to composite with any of them in a single form. When all the materials used in this project are combined in one composite, the resulted composite has its stress increasing with the quantity of both sawdust and SLG as well as the ELO state (see figure 6.4). The difference of this composite when compared to its counter part without ELO is that stress is higher. This mean that when ELO is added to any sample composite, stiffness of material suffers and hence it stress is reduced. Composites material with ELO were found to fail with flexible failure that has a lot of warning. It was also observed that composites with ELO did not failure completly but failure were observed to retract back but to their original postion when load was released.

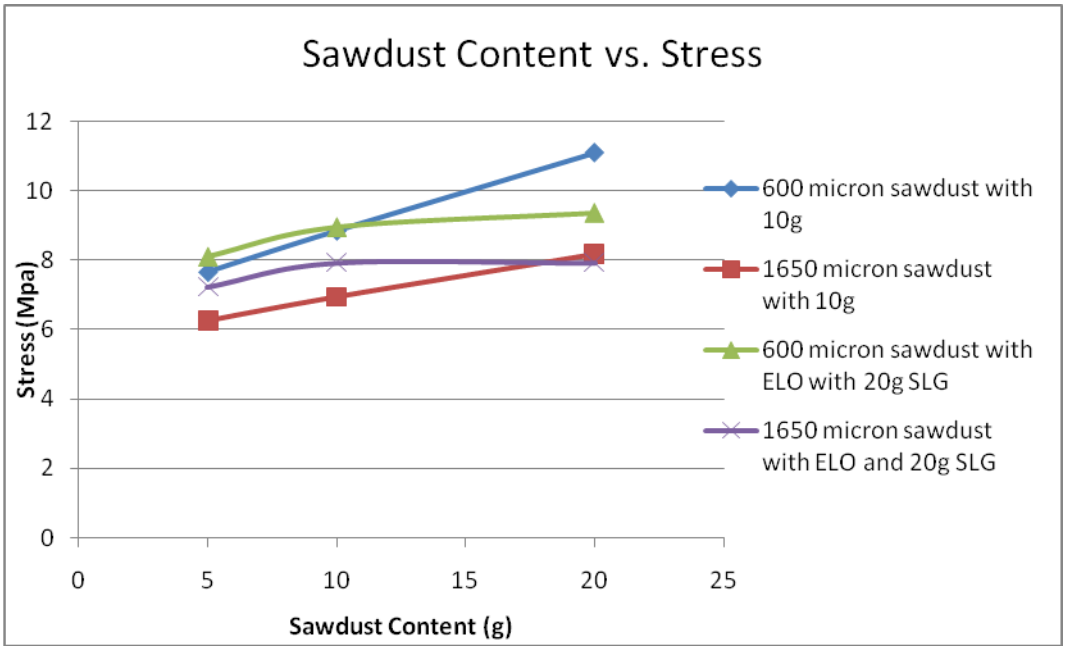


Figure 6.4: Flexural stress (MPa) vs Sawdust Contents (g) of composites prepared with Epoxy Resin GY-191 and aradur-250 amine hardener with ELO (20g).

6.2.2 Strain at Peak

Strain is defines as the geometrical deformation representing the relative displacement between particles in a material body i.e. measure of how much a given displacement differs locally from a rigid body displacement (Jacob Lubliner). Strain defines the amount of stretch or compression along a material line element or fibre. It is given by change in length over original length given in the following equation:

Strain $\varepsilon = \Delta L/L$ Equation (10)

Where ΔL= Change in length

L= length of specimen in consideration

ε =strain

The strains of the composites in this project where calculated from the machine MTS alliance that was used in the testing. The graph below was produced for the sample with sawdust and SLG as fillers from the analysis by collecting strains of difference composites with increasing quantity of filler. For the sawdust case, it is observed that composites with 600 micron sawdust filler have greater strains than composites with 1650 micron sawdust filler as can be seen from figure 6.5. This means that stiffer composite (600 micron composite) do not elongated as soft composites.

The trend is that when more quantity of sawdust was added to the composites, strains reduced up to some level when it was observed to be constant.

ELO effect on strain was observed to be clear. As can be seen from the figure 6.5 the strains for composites with ELO are much bigger compared to strain for composites without ELO. This is because ELO added flexibility to composite hence composites deflect a lot when subject to load.

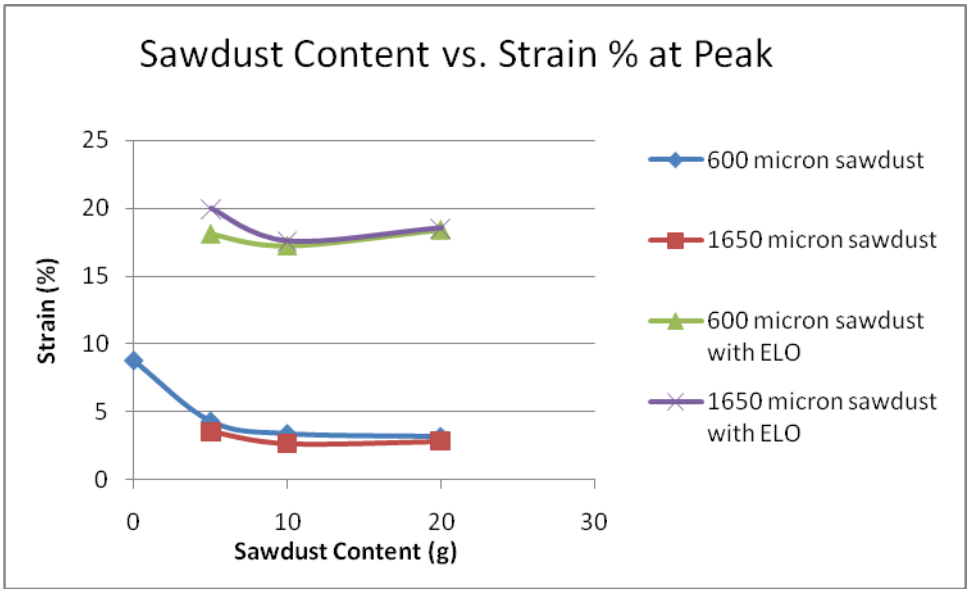


Figure 6.5: Flexual Strain (%) vs Sawdust content (g) of composites prepared with Epoxy Resin GY-191 and aradur-250 amine hardener with and without ELO.

Effect of SLG on composites is that when more SLG form part of the composites, the strains decreases as more SLG filler is added to composites. As can be seen in figure 6.6 composite with only 5 grams have higher strain compared to the composites with 10g and 20 grams. SLG filler has the same effect as the sawdust filler in the above cases. When more SLG filler is in the composite adhessionness of composite is reduced as more SLG filler occupies more space hence reducing the adhession capacity of the epoxy resin that acts as a holding forces.

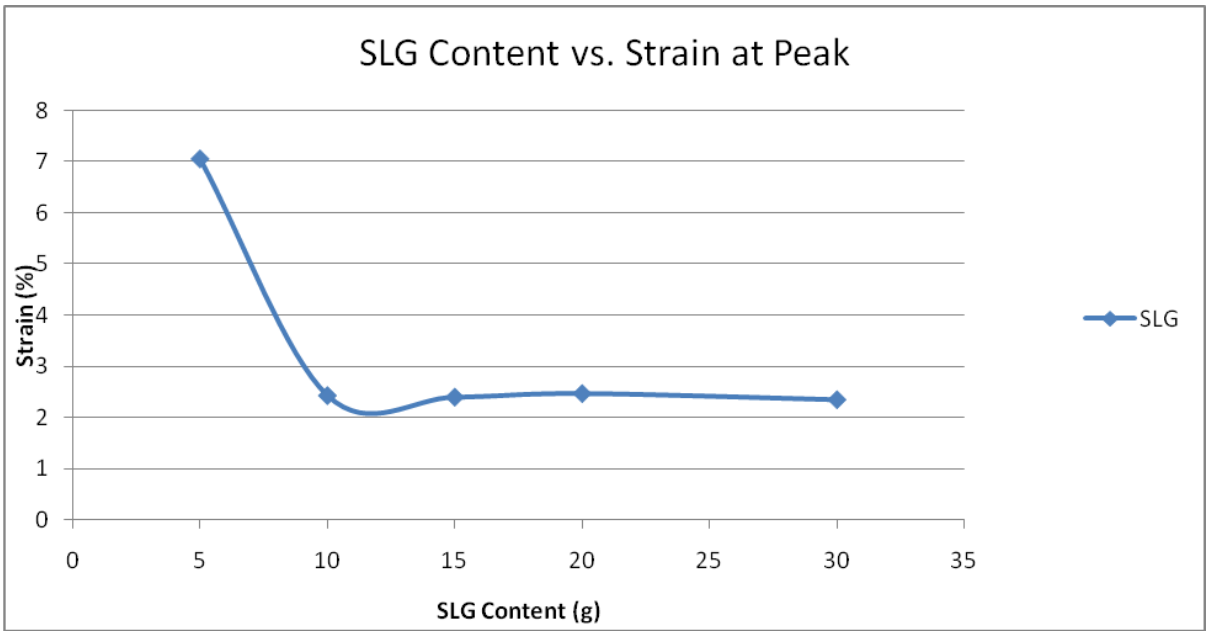


Figure 6.6: Flexural Strain (%) vs. SLG content (g) of composites prepared with Epoxy Resin GY-191 and aradur-250 amine hardener.

6.2.3 Flexural Modulus

Flexural modulus of a material is defines as the ratio of stress to strain in deformation or in other word it is the tendency of material to bend. Its equation has already been given in the previous sections (chapter 5). Flexural modulus were taken from testing machine MTS Alliance and are presented here as graphs.

The flexural modulus of the samples that have 600 micron sawdust fillers in their content are greater than those of sample with 1650 micron sawdust fillers. The reason for this behaviour is that composites that have fine particles of sawdust are stronger as flexural modulus reveals the strength of material. As mentioned before adhesion of composite suffers when fillers particles are big and when fillers quantity is increased. Refer to figure 6.7 as it shows these behaviours in a graph. It is also observed that flexural modulus for samples with ELO in their composition are lower than those for composites without ELO.

Addition of ELO is also observed to have improved the behaviour of composites in that flexural modulus is observed to increase with addition of sawdust quantity although they are much lower compare to modulus of composites without ELO.

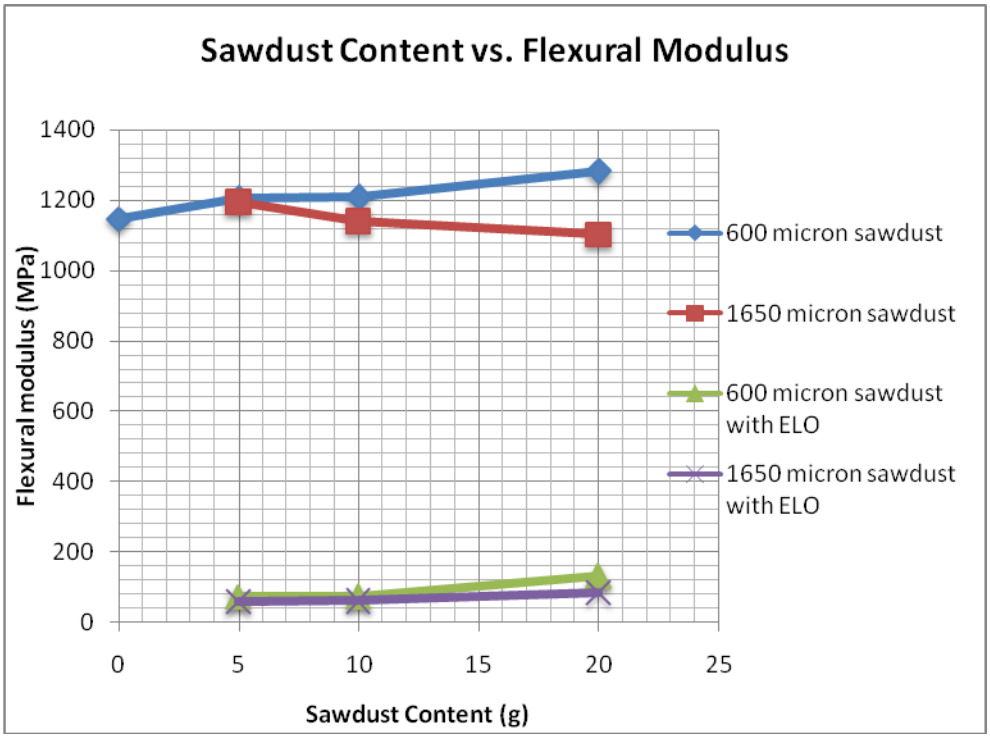


Figure 6.7: Flexural Modulus (MPa) vs Sawdust Content (g) of composites prepared with Epoxy Resin GY-191 and aradur-250 amine hardener with and without ELO.

Flexural modului for the composites with SLG fillers increased with increasing amount of SLG up to a certain limit (20g) where it reduces as can be seen from figure 6.8. This means that when more SLG filler is added after that limit the strength of the composites suffers and can not perform well at that stage.

As shown in the same figure 6.8 compoosites that have all the material used in this project with sawdust and SLG fillers, have their flexural modulus lower than that for the composites with only SLG fillers. This shows that SLG perform well if it is used in a composite as a filler by it self.

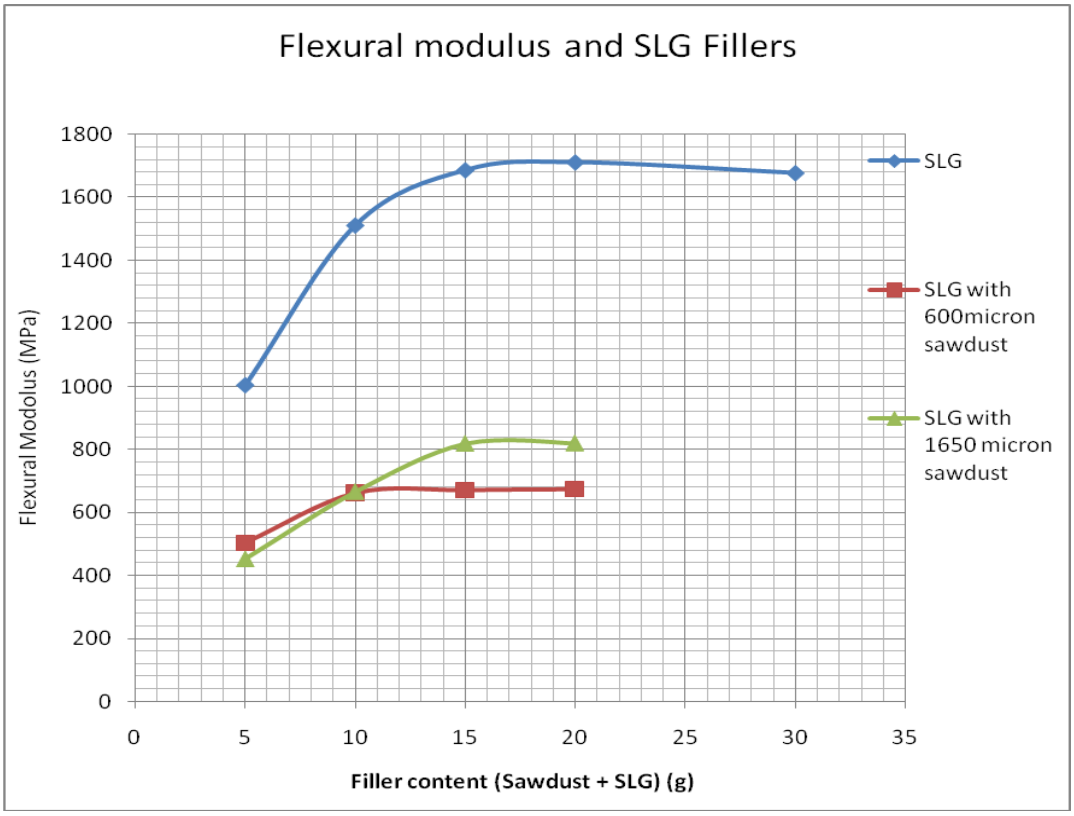


Figure 6.8: Flexural modulus (MPA) vs SLG filler content (g) of composites prepared with Epoxy Resin GY-191 and cured with aradur-250 amine hardener.

6.2.4 Deflections

Deflection values were found from the testing machine MTS Alliance for the entire project. The behaviour of various composites is explained as follows; Sample composites with ELO deflected a lot. As can be seen in figure 6.9, composites that have ELO in their compositions have their deflections lie above the deflections for composites without ELO in their compositions. This is an improvement that is added by ELO because it softens composites and hence samples have long time to stretch before they could actually fail. Also ELO composites samples were found to fail with flexible failure as the result of the addition of ELO into the composites. Samples that have no ELO do not deflect a lot due to their brittleness.

Another observation that could be made from deflections of composites is that as quantity of sawdust increased in any composite content, deflections reduced. This is because more sawdust fillers when added into the composites tend to occupy more space which results in reduction of the adhesion of epoxy resin.

Difference between the sawdust sizes is also clear as seen in the figure 6.9. Composites with 600 micron sawdust tend to be above in plots of samples with 1650 micron in their compositions.

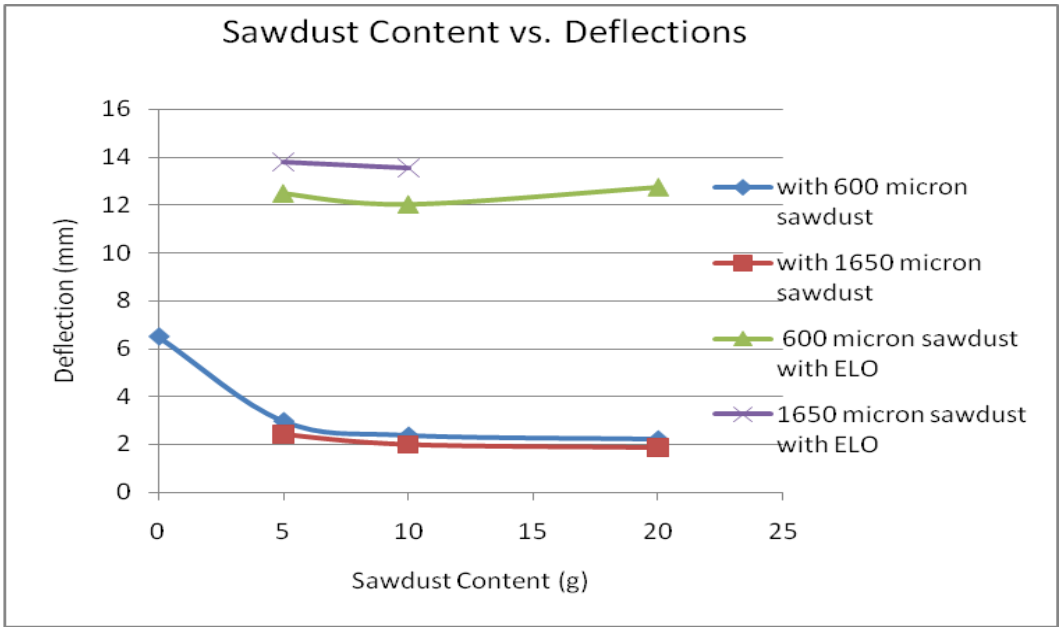


Figure 6.9: Deflection (mm) vs. Sawdust Content (g) of composite prepared with Epoxy Resin GY-191 and cured with aradur-250 amine hardener and with and without ELO.

Big difference was seen in deflection for sample composites with SLG in their contents. Deflection reduces by about 50% when compare sample with ELO. However, the same pattern was observed for both SLG and sawdust without ELO in their compositions. Their deflection is in the same range as can be seen from figure 6.9 and figure 6.10. Deflectioins also decrease with increasing quantity of SLG as evident in figure 6.10.

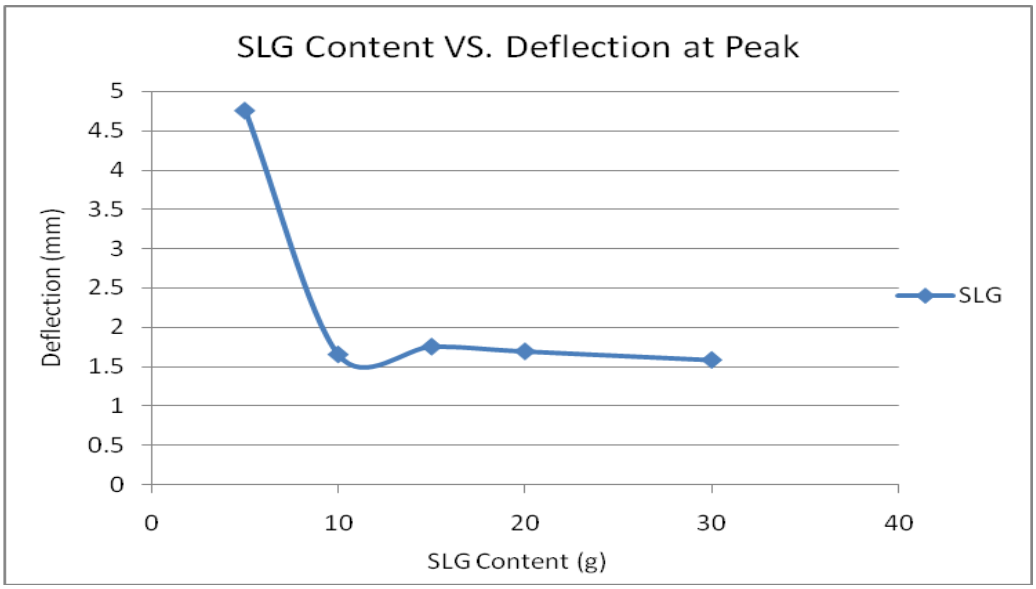


Figure 6.10: Deflection (mm) vs. SLG content (g) of composites prepared with Epoxy Resin GY-191 and cured with aradur -250 amine hardener.

6.3 Impact Fracture Toughness Results Analysis

In this section analysis of results for fracture toughness is carried out. The analysis is carried out in the following order; Impact fracture flexural stress would be examined followed by flexural strains and then impact flexural modulus for samples with notches and finally deflections. Each of these is done based on the filler content in composites; sawdust and SLG fillers. All the values for impact fracture toughness stresses, strains, and deflection were from the output of flexural testing machine MTs Alliance used in the testing.

6.3.1 Impact Fracture Toughness Stress.

Effect of sawdust quantities in composite is well displayed in figure 6.11. It is shown that composites with 600 micron sawdust can carry larger stresses compare to composites with 1650 micron sawdust in their compositions. This is seen in the figure 6.11 as composites with 600 microns sawdust have their lines of plot above the composites with 1650 micron on both cases i.e. where composites have no ELO and where they have certain amount of ELO. The effect of ELO is that it reduces the stress as could be seen from the same figure.

The reduction in the stress is very dramatics as shown in the same figure 6.11. From this dramatic drop in stresses one can ask himself, what does this reduction in stress and relation between 600 and 1650 micron sizes sawdust filler composite mean in real life? First of all reduction of stress by ELO means that the carrying capacity of the composite is reduced and making it to deflects a lot when it fails because of toughening effect of ELO. Secondly 600 micron sawdust composites are stronger than the 1650 micron sawdust fillers. This may be because composites with 600 micron sawdust have fine particles that mixed well and formed composites that do not or have few air spaces than the 1650 microns sawdust, which when mixed may have room for air spaces since there are larger particles.

The overall behaviour is the same as for the impact flexural stress for composite without notch except that stresses are smaller: reduce from forties to less than 20PMa

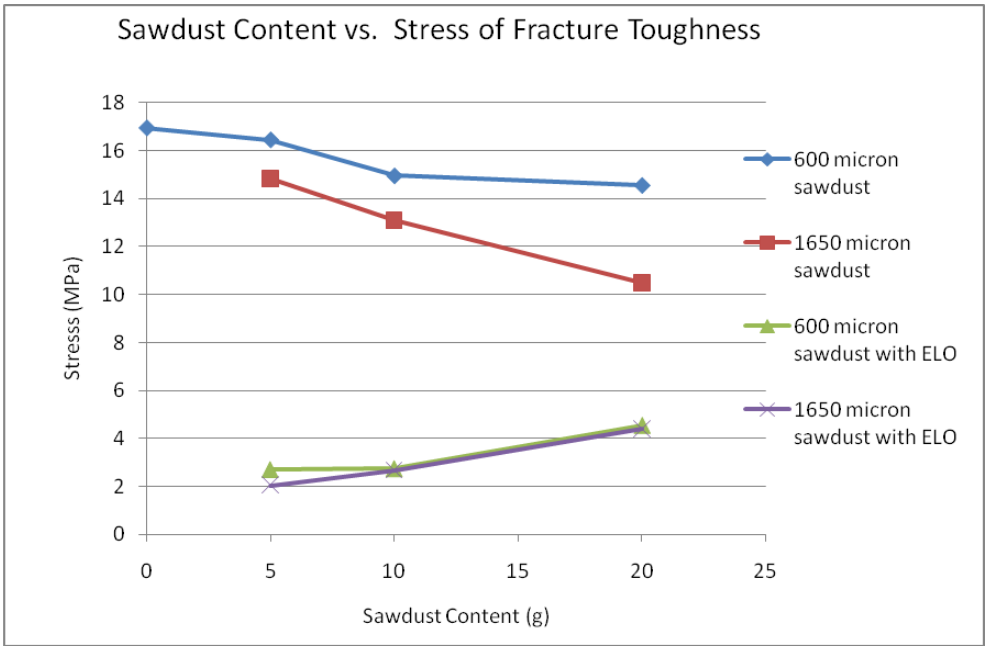


Figure 6.11: Maximum Stress (MPa) from the Impact Fracture Toughness tests vs Sawdust content (g) of composites prepared with Epoxy Resin GY-191 and aradur-250 amine hardener with and without ELO (20g).

Penctentage by weight of SLG has clear effect on the composites strains. The effect that could be seen clearly is that when percentage by weight of SLG increased in composites, the stress decreases. As seen in figure 6.12 composites with only 5 grams have higher strains compare to the composites with 10g and 20 grams. SLG filler has the same effect as the sawdust fillers in composites. The reason for this behaviour is that when more SLG filler is in the composites, adhessionness of composites is reduced as more fillers occupies more space which resulted in reducing the adhession capacity of the epoxy resin that acts as a holding force.

The differences that could be seen from flexural stress and fracture toughness stress is that notches made at the centre of span of composites reduced the fracture toughness stress by about a half.

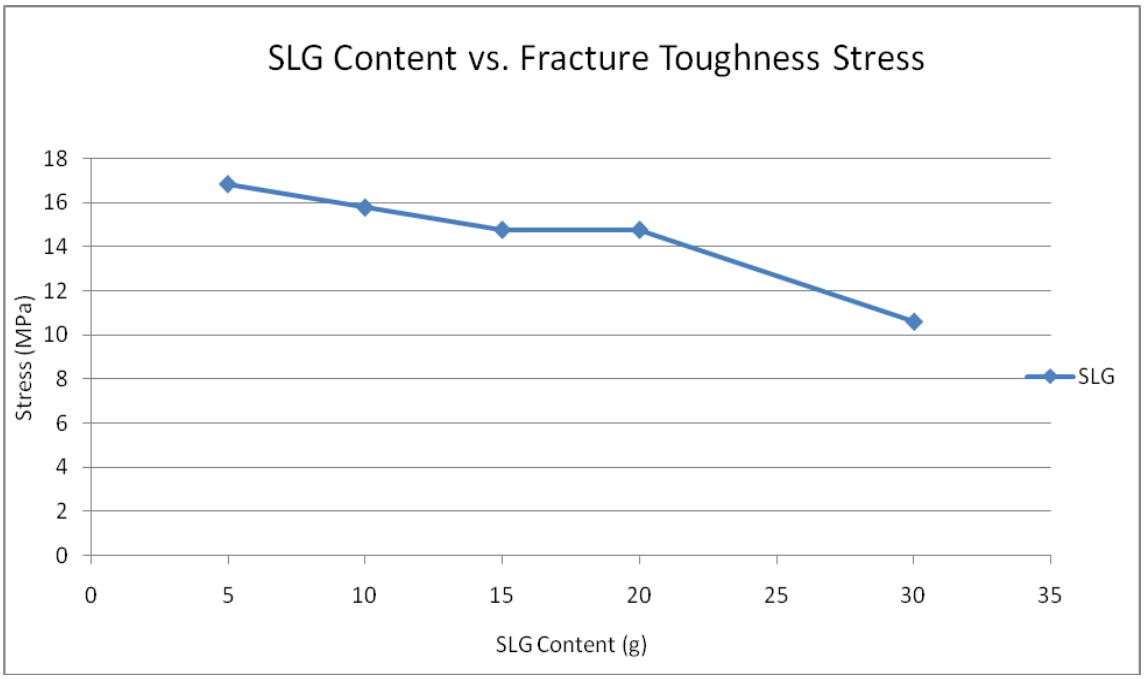


Figure 6.12: Maximum Stress (MPa) from the Impact fracture toughness tests vs SLG content (g) of composites prepared with Epoxy Resin GY-191 and cured with aradur-250 amine hardener.

6.3.2 Impact Fracture Toughness Strains

The strains of the composites in this project where calculated from the machine MTS alliance that was used in the testing in the same way as flexural strains. The graphs below were produced for the samples results with sawdust and SLG as fillers from the analysis by collecting strains of difference composites. For the sawdust case it is observed that composites with 600 micron sawdust have greater strains than composites with 1650 micron as presented in figure 6.13. This means that stiffer composites do not elongated as soft composites.

The trend is that when more quantity of sawdust was added to the composites, the strains reduce up to some level when it was observed to be constant.

ELO effect on strain was observed to be clear. As can be seen from figure 6.13 the strains for composites with ELO are much bigger compared to strains for composites without ELO. This is because ELO added flexibility to composites hence they deflected a lot when subjected to load. The overall differences that could be seen from the flexural and fracture toughness strains is that fracture toughness stains are lower compare to flexural strains which is normal. This reduction in strain was due to inclusion of notches at each centre of span for the fracture toughness which reduced the stiffness of samples.

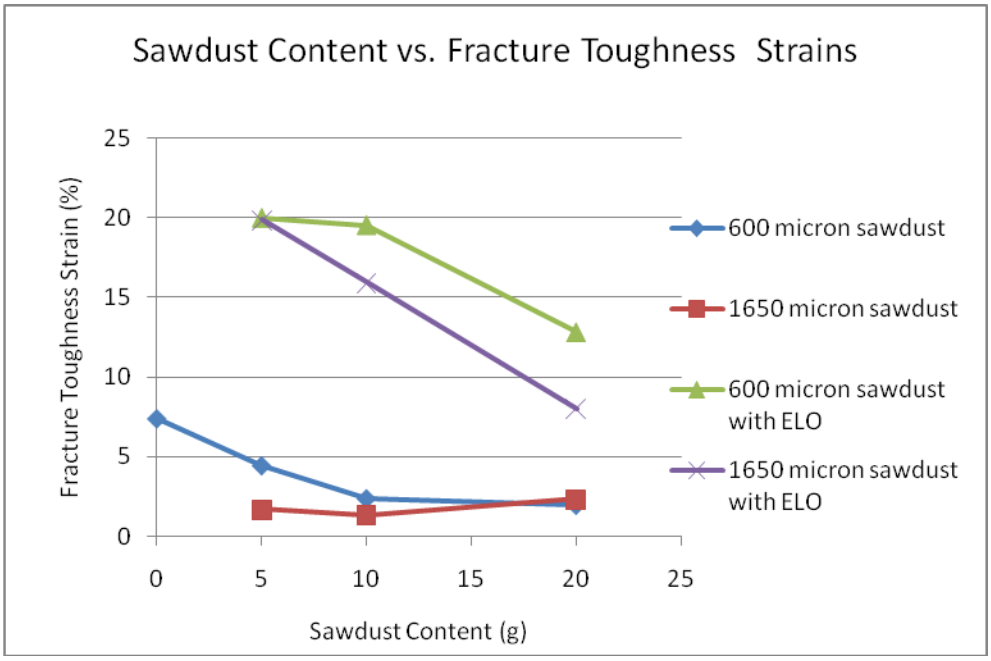


Figure 6.13: Impact fracture Toughness strains (%) vs sawdust content (g) of composites prepared with Epoxy Resin GY-191 and aradur-250 amine hardener with and without ELO.

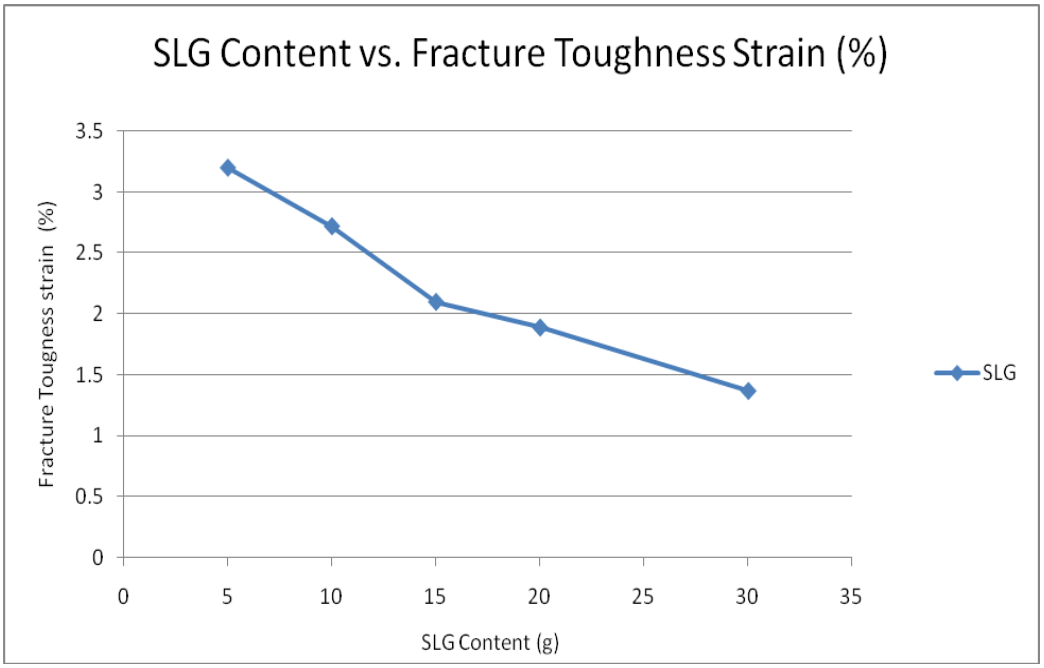


Figure 6.14: Impact Fracture Toughness strain (%) vs SLG filler content (g) of composites prepared with Epoxy Resin GY-191 and cured with aradur-250 amine hardener.

6.3.3 Fracture Toughness Modulus

The flexural modulus of the samples that have 600 micron sawdust fillers in their contents are greater than those of sample with 1650 micron sawdust fillers as can be seen from figure 6.15. The reason for this behaviour is that composites that have fine particles of sawdust are stronger as flexural modulus reveals the strength or stiffness of material. As mentioned before adhesion of composite suffers when fillers particles are big and when fillers quantity is increased.

It is also observed that flexural modulus for samples with ELO in their compositions are lower than those for composites without ELO. This is because present of ELO in a composite reduce stiffness of material hence composite deflected a lot when subjected to loads.

Addition of ELO is also observed to have improved the behaviour of composites in that flexural modulus is observed to increase with addition of sawdust quantity although it is much lower compare composites without ELO.

One other thing that is observed here when notch is made in composite span the fracture toughness modulus are lower compare to normal flexural modulus.

Behaviour of composites with SLG filler in their content is their sample follows the same pattern of the sawdust samples in that increment in percentage of weight of SLG increase the flexural modulus to some limit where it is seen to decrease with increasing percentage. It was only 5g and 10g weight of SLG in samples that fractures toughness modulus increased. On other hand when amount of SLG was increased to 20g the fracture toughness modulus decrease as can be seen from figure 6.16.

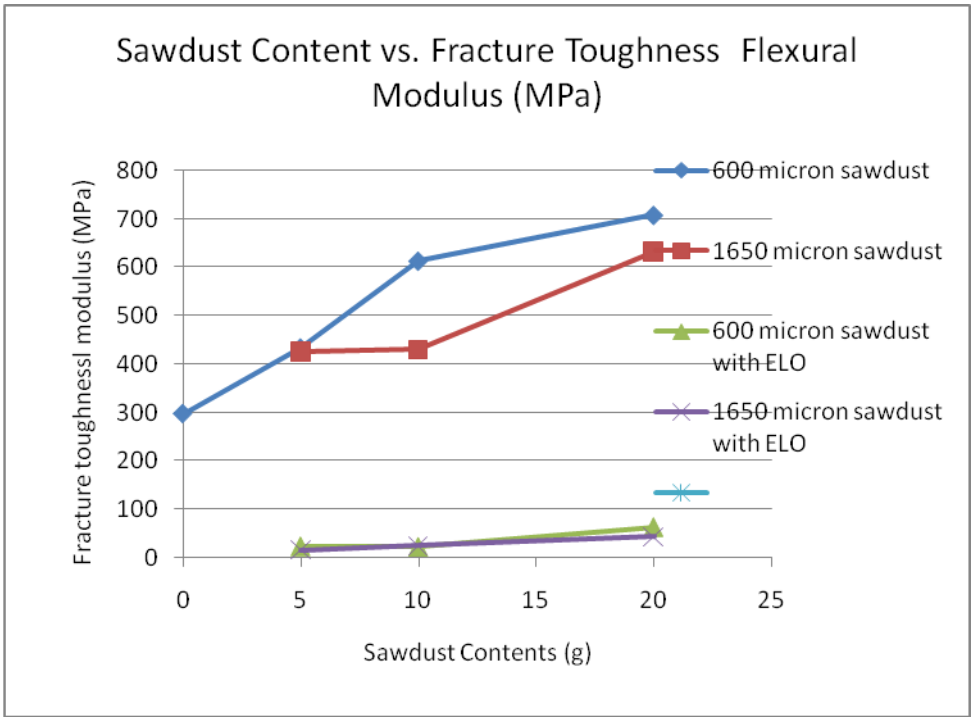


Figure 6.15: Fracture Toughness Modulus (MPa) vs. sawdust content (g) of composite prepared with Epoxy Resin GY-191 and aradur-250 amine hardener and with and without ELO (20g).

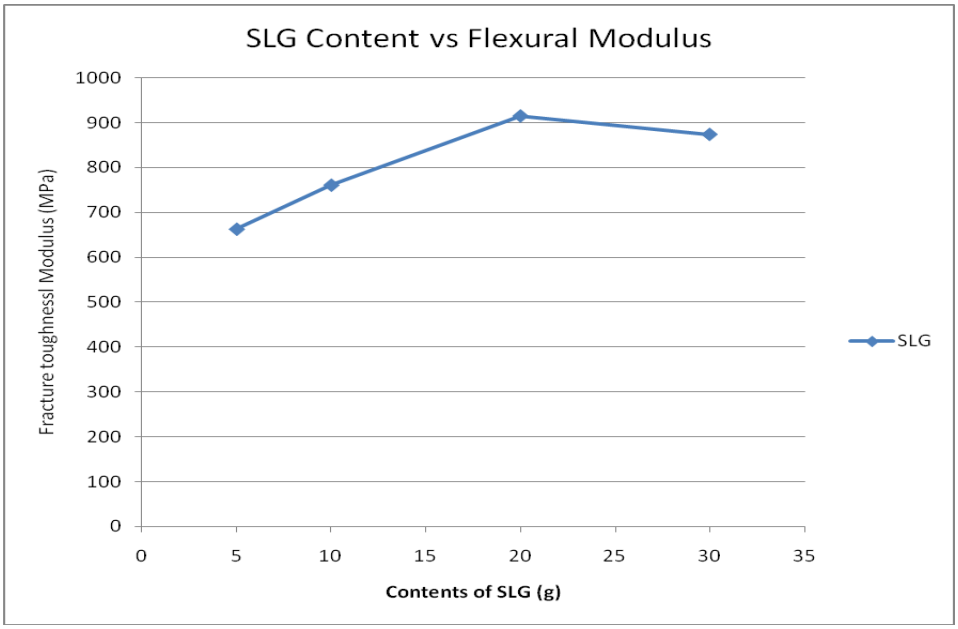


Figure 6.16: Fracture Toughness Modulus (MPa) vs SLG contents (g) of composites prepared with Epoxy Resin GY-191 and cured with aradur-250 amine hardener.

6.3.4 Fracture Toughness Factor Kc

Figure 6.17 shows plot of the Kc verses quantity of filler for all the specimens. It is found that composites that have ELO in their composition have lower Kc. This Kc ranges between 0.0009 to 0.0016 MPa m^1/2. However, specimens with no ELO in their composition have higher Kc as compare to those ones without ELO and their Kc are in range of 0.002 to 0.0032 MPa m^1/2. This increment in the Kc is about 55% and this may be due to the toughening effected and flexible failure added by ELO. On the side of sawdust and SLG fillers, there was no clear difference seen in Kc since all the Kcs values are in the same ranges except the composites with no filler in its compositions which tends to have higher Kc values as in figure 6.17.

However, all the composites with both sawdust and SLG in their compositions have slight increment with the increasing quantity of SLG as displayed in figure 6.17 and 6.18.

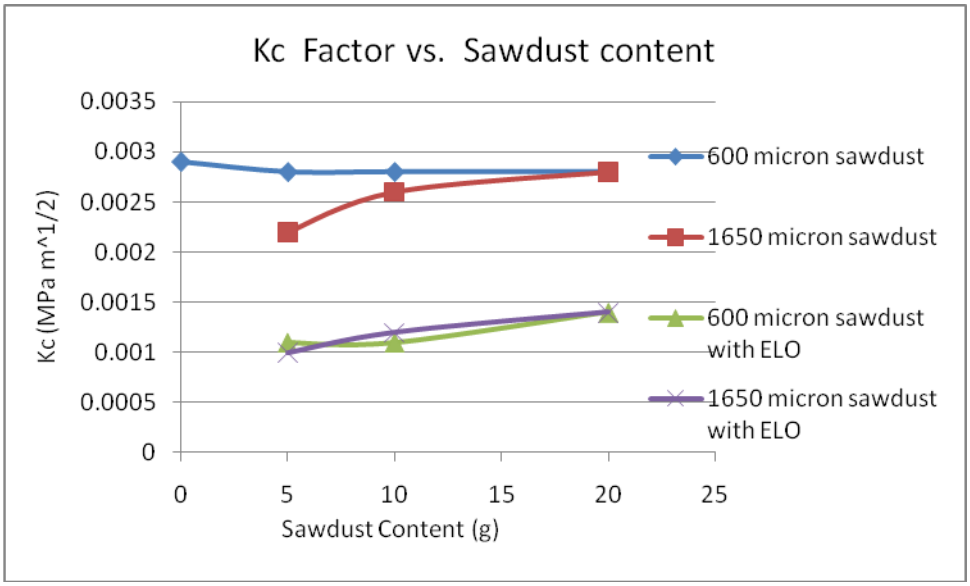


Figure 6.17: Kc Factor vs Sawdust content (g) for composites prepared with epoxy resin GY-191 with and without ELO and cured with aradur-250 hardener.

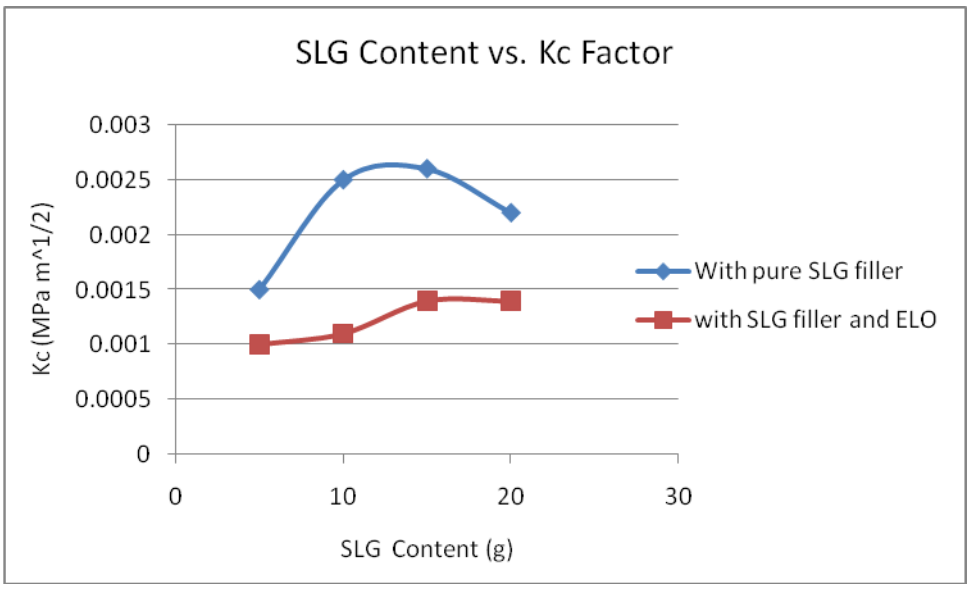


Figure 6.18: Kc Factor (MPa m^1/2) vs. content of SLG (g) for composites prepared with epoxy resin GY-191 and aradur -250 amine hardener with and without ELO.

6.3.5 Deflection for Fracture Toughness Specimens

Sample composites with ELO deflected a lot. As was the case the flexural sample deflection follows the same except that the deflection values for the fracture toughness sample are lower than for the flexural samples. The deflections values in this section range from 0.1mm to 7mm. Differences existed between samples with sawdust and SLG fillers. It is evident that SLG filler contents in a composite reduce the deflections. Those composites with SLG fillers in their composites were found to have little deflection which means they are little brittle compare to their counterparts with sawdust fillers.

As shown in figure 6.19 and 6.20 samples that have ELO in their composition have their deflections lie above the deflections for samples without ELO in their compositions. This is an improvement that is added by ELO because it softens the composites and hence samples have long time to stretch before they actually failed. Also ELO composites sample were found to fail with flexible failure as a result of addition of ELO into composites. Sample that has no ELO do not deflect a lot due to their brittleness.

Another observation that could be made from deflection is that as quantity of sawdust increased in composite content, deflection reduces. This is because more sawdust fillers when added into the composites tend to occupy more spaces which results in reduction of the adhesion of epoxy resin GY-191.

Difference between the sawdust sizes is also clear as displayed in figure 6.19. Composites with 600 micron sawdust filler tends to be above samples with 1650 micron sawdust in their composition.

In figure 6.20 the relationship of deflection in relation to increasing amount of SLG is shown.

As seen in figure 6.20 the deflection reduced as the SLG amount increased in the composites.

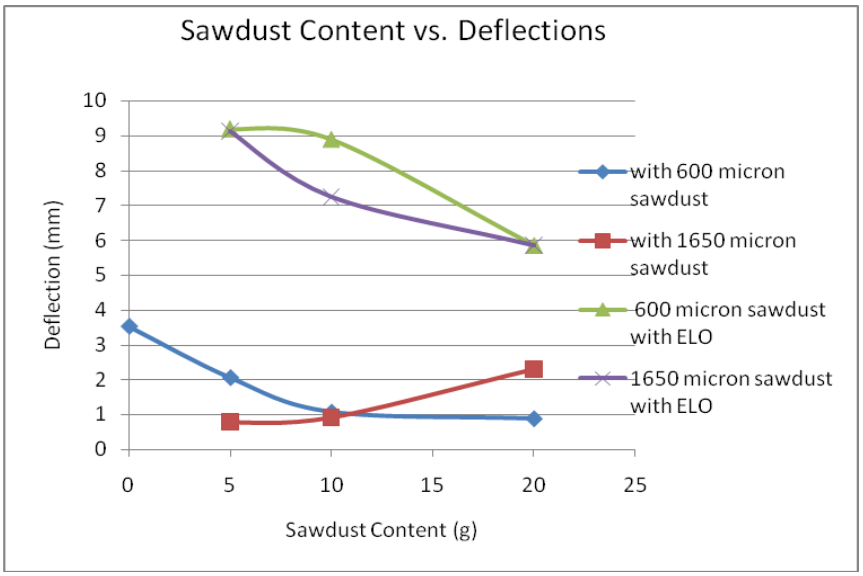


Figure 6.19: Fracture toughness Deflection (mm) vs. Sawdust content (g) of composites prepared with epoxy resin GY-191 and cured with aradur-250 amine hardener with and without ELO.

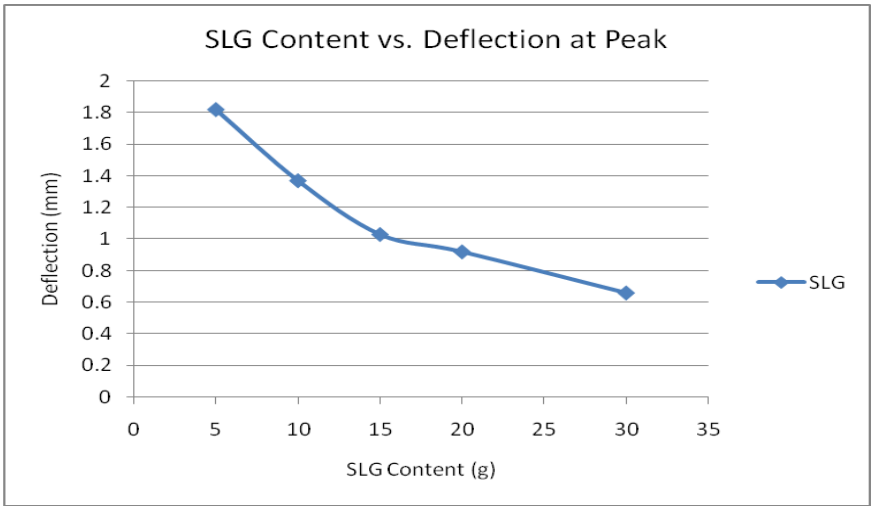


Figure 6.20: Fracture toughness deflections vs. SLG fillers content in composites prepared with epoxy resin GY-191 and cured with aradur-250 amine hardener.

6.4 DMA Results Analysis

This section deals with the analysis of results for DMA for various samples prepared with epoxy resin GY-191 and some filler (sawdust and SLG). It reveals and discusses the thermal mechanical properties of the composite which include storage modulus and Tg as opposed to other section which deal with different properties. As different combination of materials have already been made and tested, the outcomes from DMA test are made known in this section of the report. Results include the behaviour of epoxy resin GY-191 with different combinations of sawdust and SLG fillers. How different fillers affect the thermal properties and what the trend or patterns are revealed and discussed.

6.4.1 Neat Epoxy Results

Pure or neat epoxy resin composite show strong thermal properties. This is shown in the figure 6.21 where we have Tg of a temperature about 108 degrees Celsius and a storage modulus of 2200MPa at a temperature of 35.96 ºc.

Neat epoxy is used as a base point in this project and all other composites results from composites found from various combination of material were discussed in relation to neat epoxy resin GY-191 cast. Any composites found to be having better than neat epoxy resin or the same as neat/pure resin properties would be the ones needed for consideration as a building material in civil engineering.

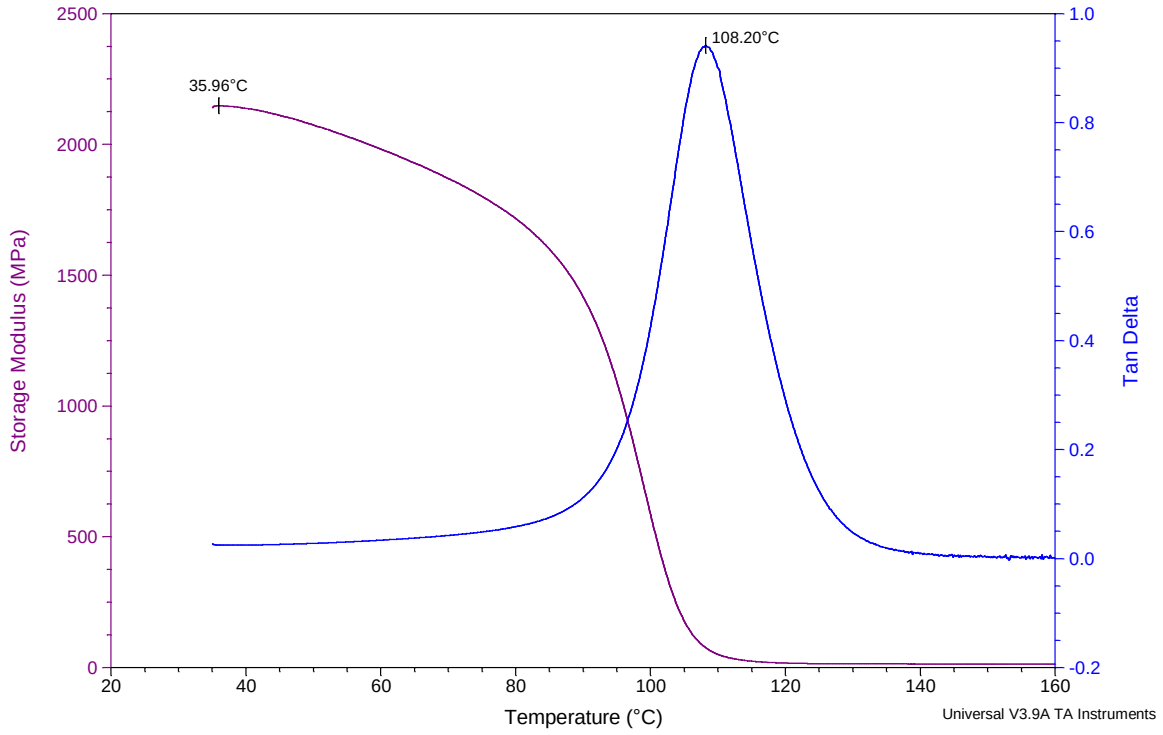


Figure 6.21: DMA curves for storage Modulus (MPa), temperature and tan delta for neat Epoxy Resin GY-191 cured by aradur-250 amine hardener.

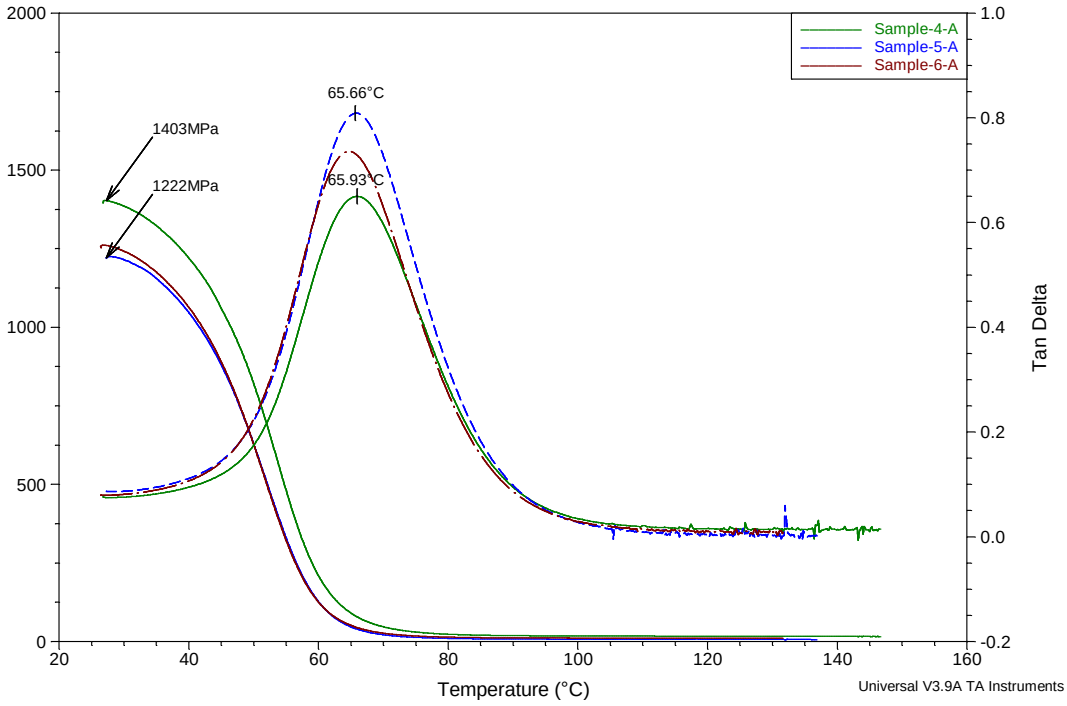


Figure 6.22: DMA Curve for Storage Modulus (MPa), Temperature and tan delta for composite sample 4-6A prepared with Epoxy Resin GY-191 and cured with aradur-250 amine hardener.

6.4.2 Storage Modulus of Composites

The Storage Modulus from the DMA analysis corresponds to the modulus of elasticity of the cured resin, and the plots below shows the storage Modulus (MPa) for each sample that were taken at their maximum values (at 30˚c) from the DMA plots. Generally results for storage modulus for composites with 600 micron were greater than that for composites with 1650 microns.

The effect of 600 microns sawdust on the thermal properties of epoxy resin GY-191 is very clear. From the figure 6.21 and figure 6.22 the storage modulus drops from 2200MPa for neat epoxy to a range of 1200MPa and 1400MPa for the composite with 600 micron sawdust. It is also clear from the graph that as sawdust percentage by weight increases storage modulus increases but to a certain limit (when 20g is added). At that limit, it does however not continue increasing infinitively but increment in storage modulus is observed when 5g and

10g 600 micron sawdust fillers are added. When 20g of sawdust filler is added the result show decreased in storage modulus.

On the other hand samples that have ELO in their compositions tend to have very low storage modulus. The range of the storage modulus for these composites is from 165.5 to 230MPa. However, the trend is the same as that one's of composites without ELO i.e. storage modulus increase with increase of sawdust filler to some limit. This behaviour of the composites is depicted in the figure 6.23.

Effects of SLG contents in the composites were observed to be different as compare to those of sawdust fillers. With the SLG fillers storage increased with increasing quantity of SLG (figure 6.24). However storage moduli of the same composites are smaller by 50% compare to neat/pure epoxy resin storage modulus.

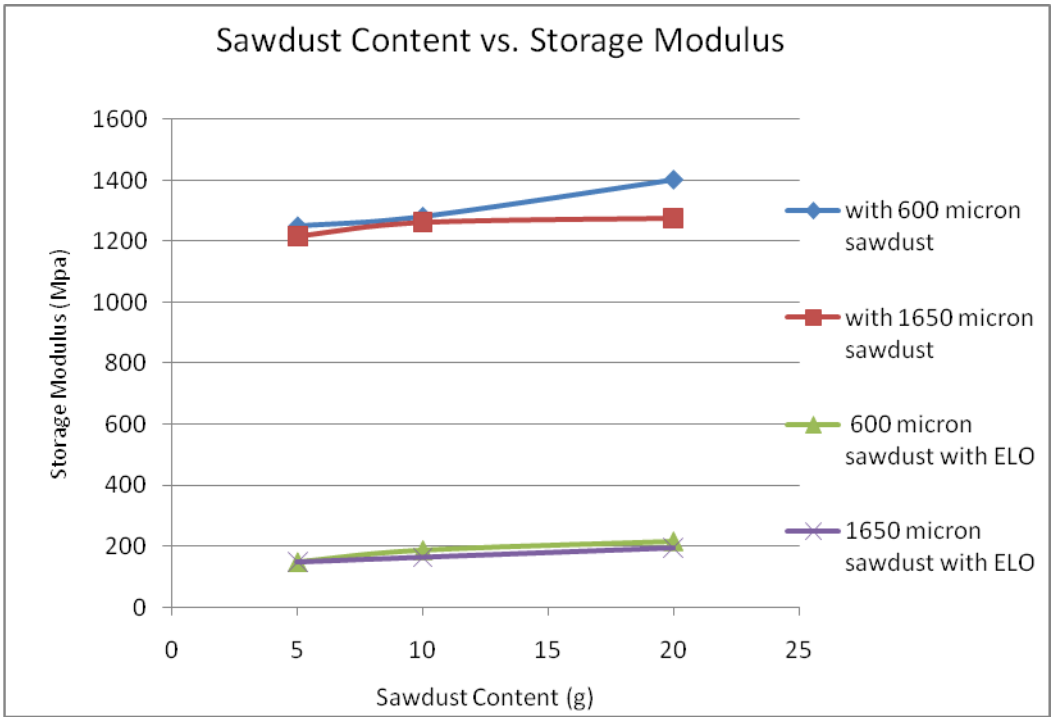


Figure 6.23: Storage Modulus (MPa) vs sawdust content (g) of composites prepared with Epoxy Resin GY-191, with and without ELO and cured with aradur-250 amine hardener.

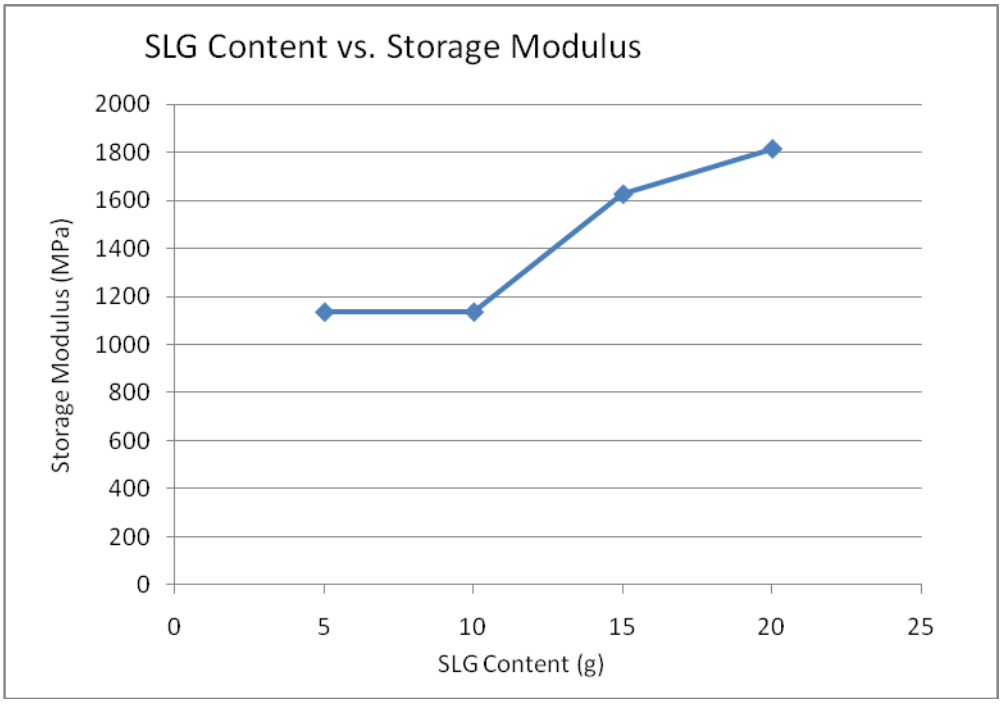


Figure 6.24: Storage Modulus (MPa) vs. SLG fillers content (g) of composites prepared with Epoxy Resin GY-191 and cured with aradur-250 amine hardener.

6.4.3 Glass Transition Temperature (Tg)

Tg behaves differently to storage modulus in that as the quantity of sawdust is increased the Tg increased and the top Tg is about 65 ºc a much more smaller than 108 ºc for the neat epoxy resin. Also it does not continue increasing infinitively but increment in Tg temperature is observed when 5g and 10g 600 micron sawdust filler are added. When 20g is added the result showed decreased in Tg.

Again as usual the composites with ELO quantity have lower Tg as compared to the composites without ELO. Also composites with 600 micron sawdust filler have greater Tg as compared to the one with 1650 micron sawdust filler (figure 6.25).

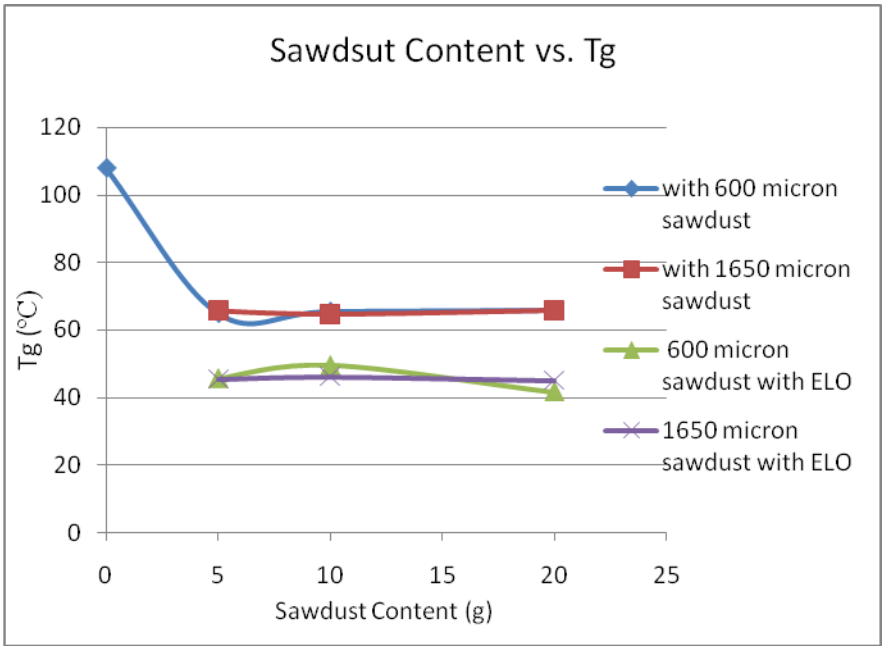


Figure 6.25: Sawdust content (g) vs. Tg of composites prepared with Epoxy Resin GY-191, with and without ELO and cured with aradur-250 amine hardener.

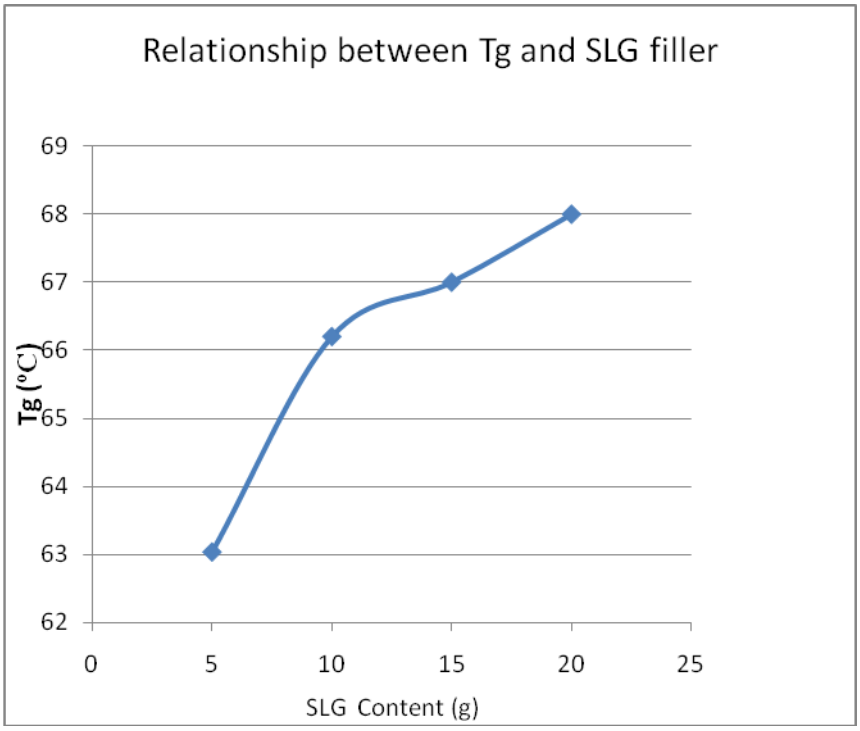


Figure 6.26: SLG content (g) vs. to Tg (°C) of composites prepared with Epoxy Resin GY-191, and cured with aradur -250 amine hardener.

Figures 6.27 to 29 show the variations in Tan delta for the composites that have different compositions of materials used in this project. They also show the peak of Tan delta which is the Tg plotted already in this section 6.4.3.

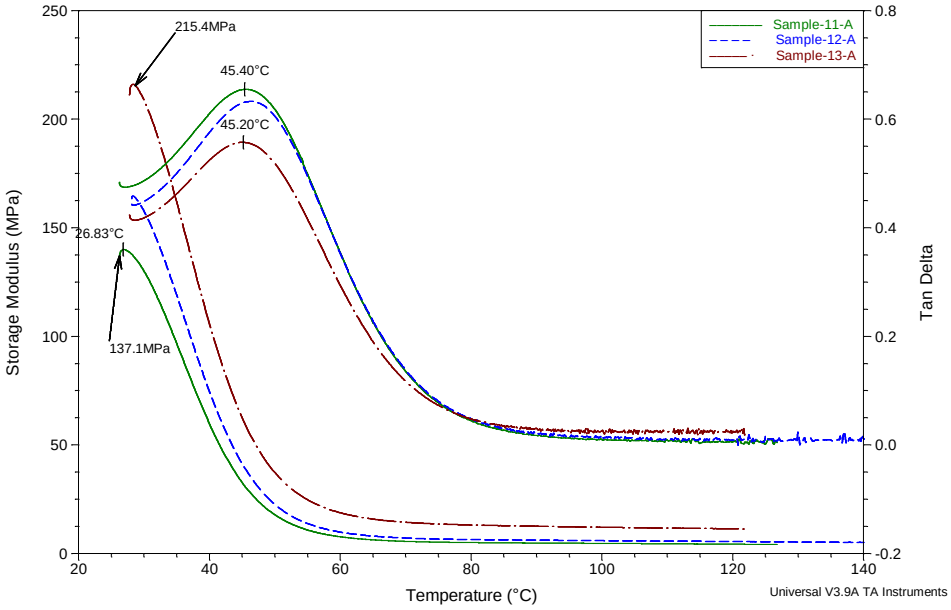


Figure 6.27: DMA Curves for Storage Modulus (MPa), Temperature and tan delta for composites (samples 11-13A) with ELO prepared with Epoxy Resin GY-191 and cured with aradur-250 amine hardener.

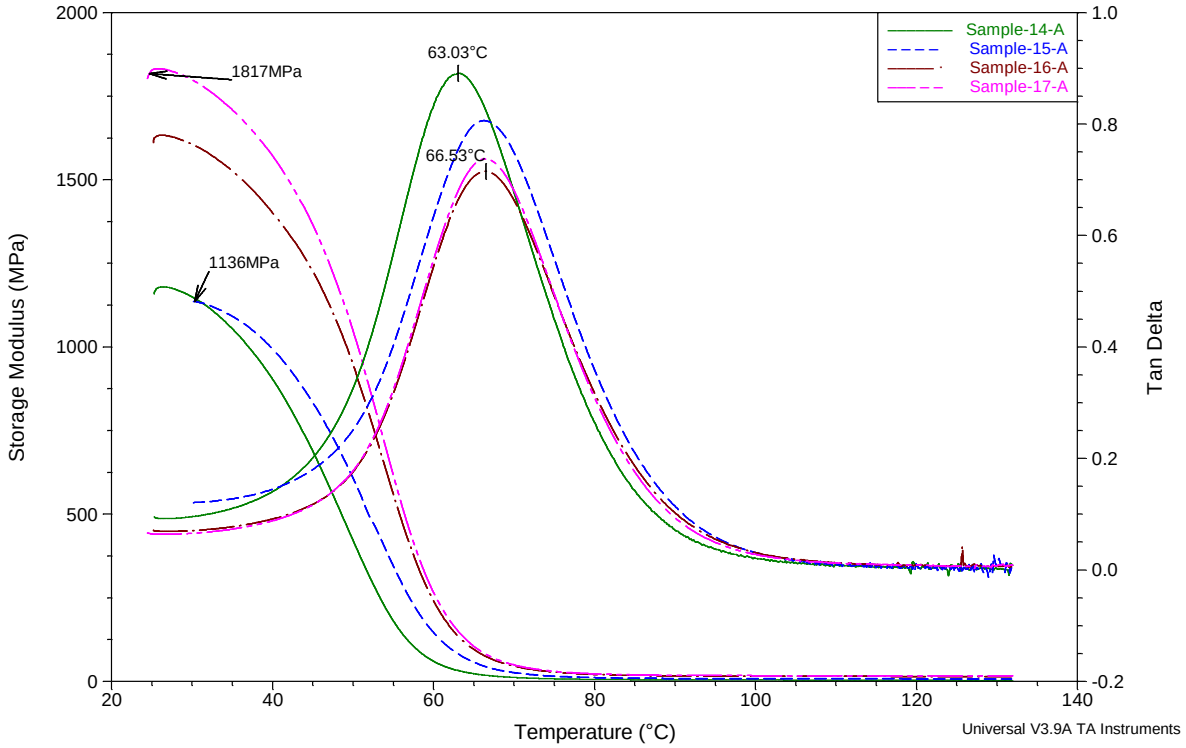


Figure 6.28: DMA Curve for Storage Modulus (MPa), Temperature and tan delta for composites (samples 14-17A) prepared with Epoxy Resin GY-191 and cured with aradur-250 amine hardener.

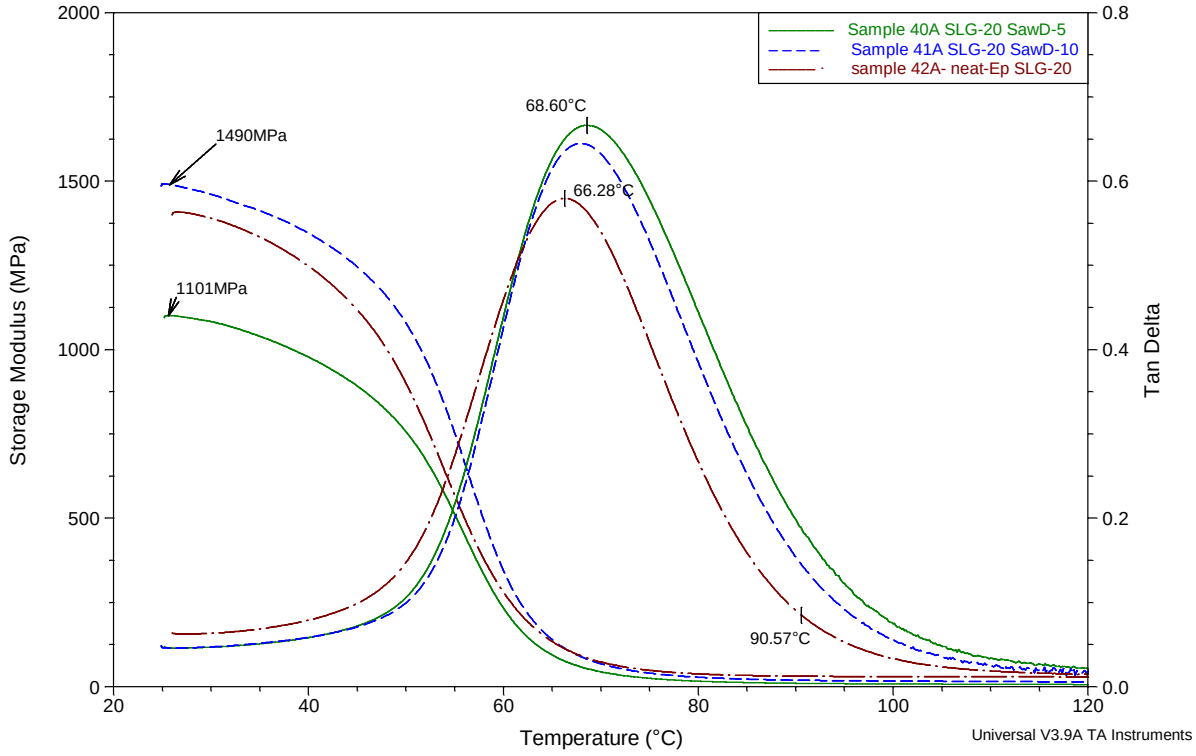


Figure 6.29: DMA Curve for Storage Modulus (MPa), Temperature and tan delta for composites (samples 40-42A) prepared with Epoxy Resin GY-191 and cured with aradur-250 amine as hardener.

6.4.4 Crosslink Density

Cross-link density of composites in this study were calculated from the DMA results using storage Modulus from the DMA and by using the following general crosslink density equation which have been used by other researchers in determination of cross-link density (Hegedus et al);

$$M_c = \frac{E'}{3RT} \qquad \text{Equation (11)}$$

Where

Mc is the crosslink density

E' is the Storage Modulus of composites

R is the ideal gas constant at temperature (100°c)

T is temperature in degree Celsius (°c)

The figures that follow show the cross-link densities of the composites for the all the samples in this work. See 6.30-34 which show various plots of cross-linking density verses filler content in each composite.

The crosslink density has minor differences as amount of sawdust is increased. Each of the plots has three samples plotted against the sawdust content. Each dot point is a sample specimen and can be clearly seen in figure 6.30 -34 below.

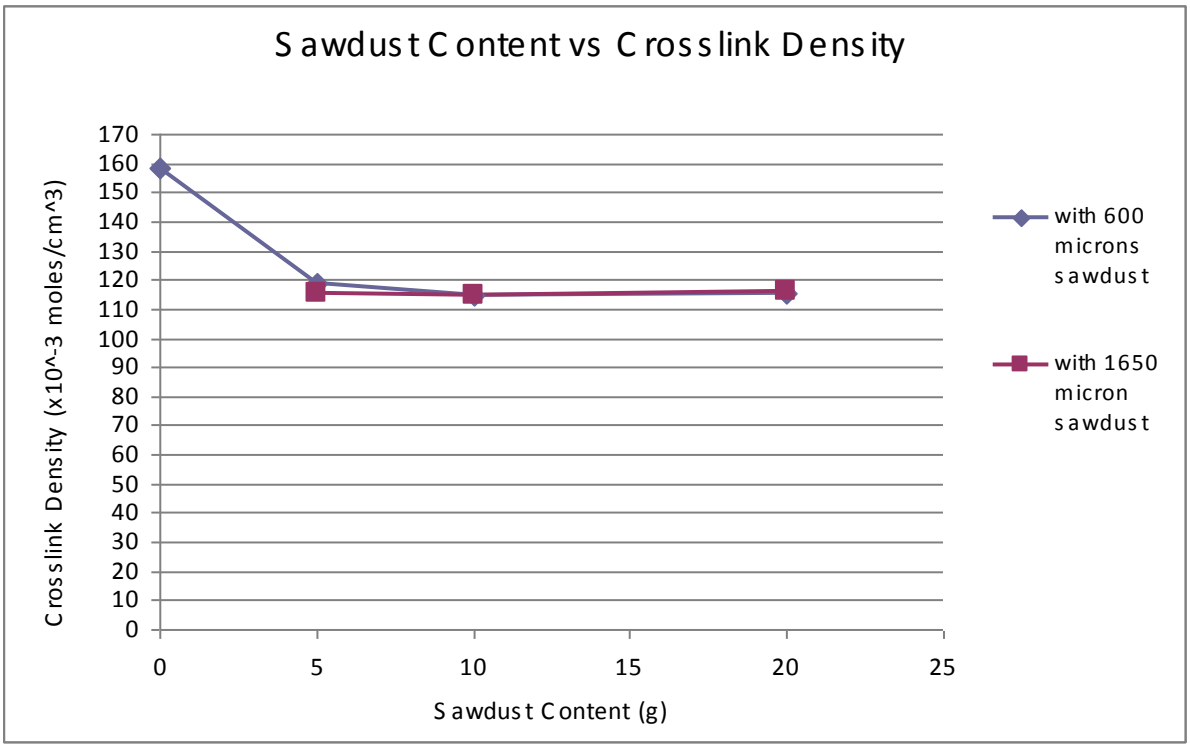


Figure 6.30: Crosslink density vs Sawdust Content (g) for composites prepared with Epoxy GY-191 and cured with aradur-250 amine hardener.

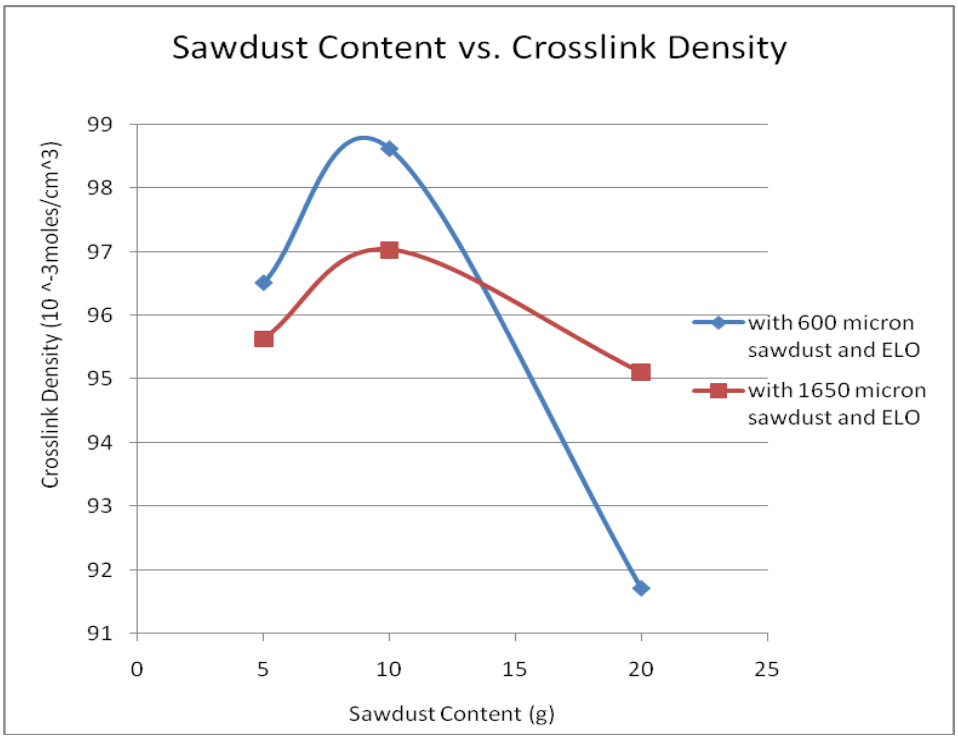


Figure 6.31: Crosslink density vs sawdust content (g) for composites prepared with Epoxy GY-191 and cured with aradur-250 amine hardener with and without ELO.

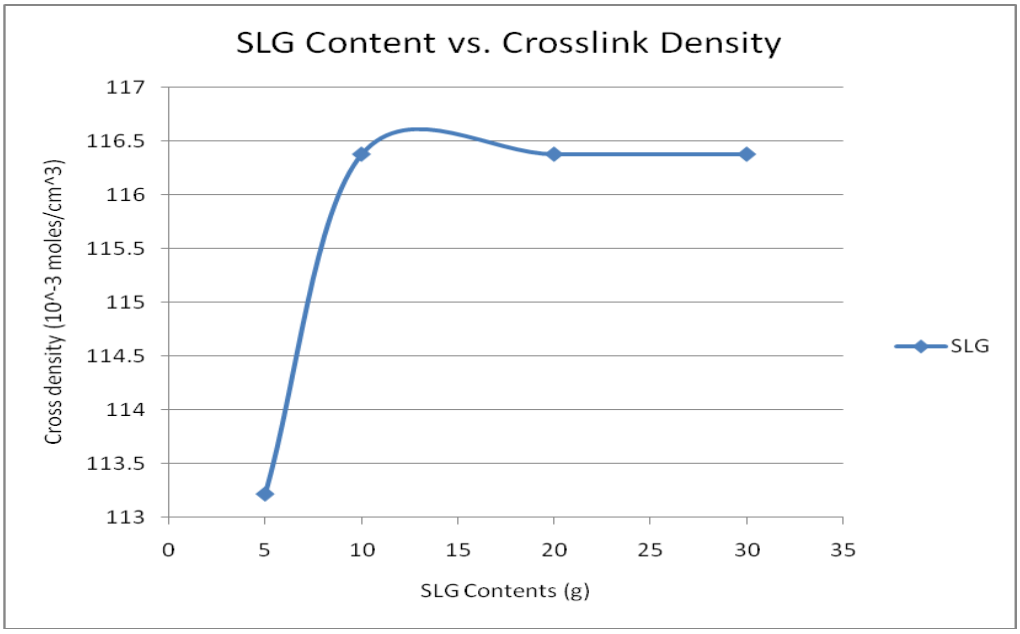


Figure 6.32: Crosslink density vs Slg content (g) for composites prepared with Epoxy GY-191 and cured with aradur-250 amine hardener.

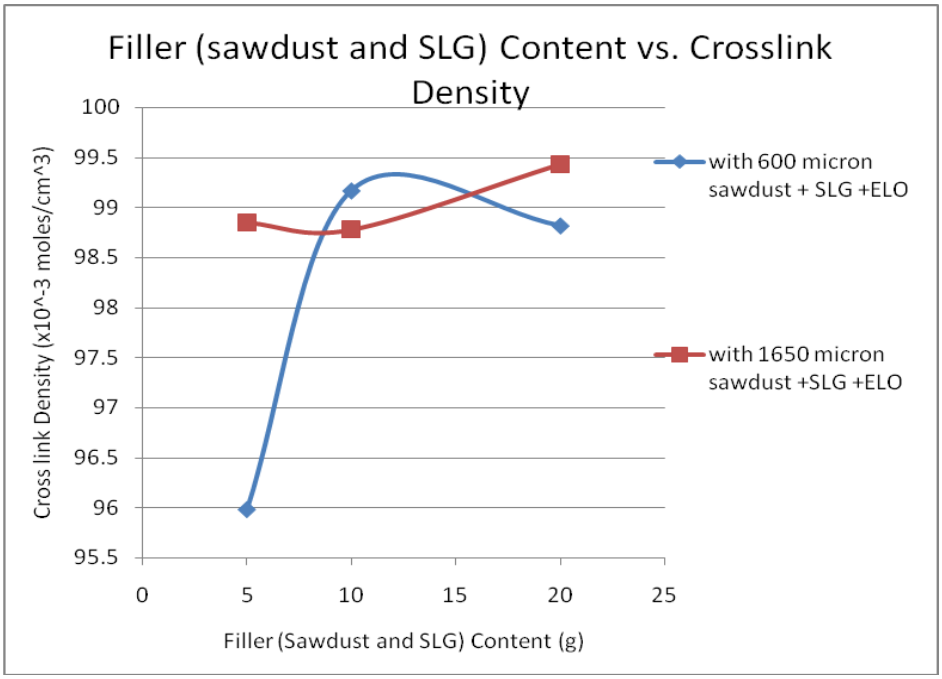


Figure 6.33: Crosslink Density vs sawdust and SLG content (g) for composites prepared with Epoxy GY-191 and cured with aradur-250 amine hardener.

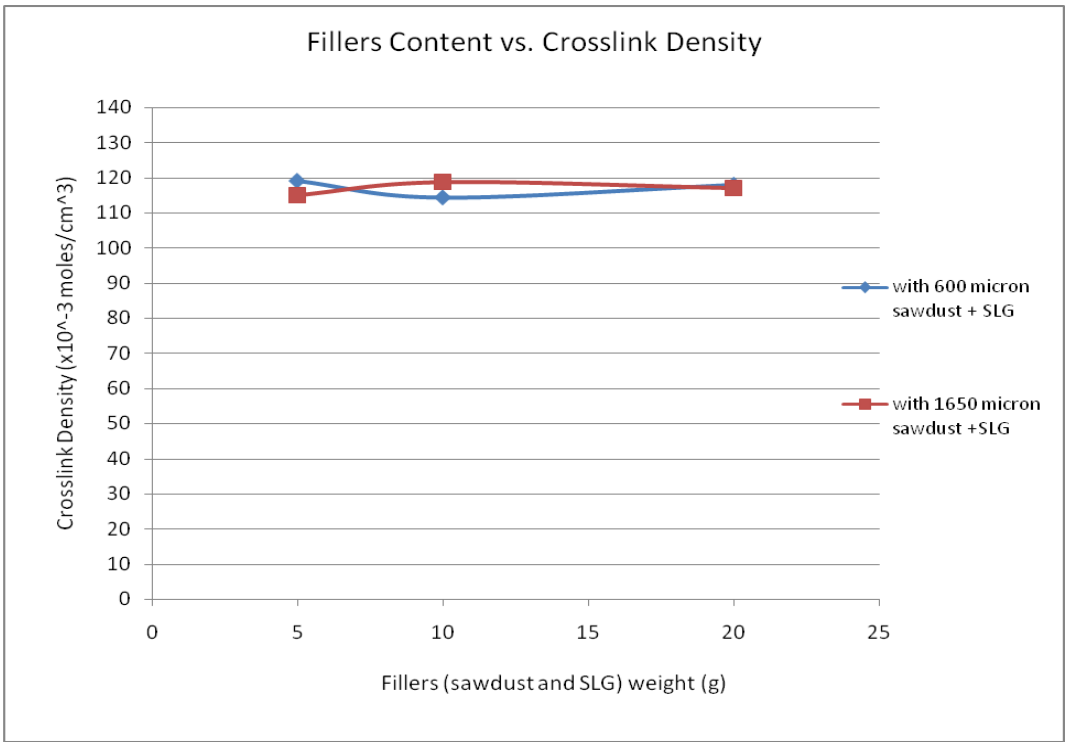


Figure 6.34: Crosslink density vs sawdust content (g) for composites prepared with Epoxy GY-191 and cured with aradur-250 amine hardener.

Conclusions

The analysis has been carried out for the samples for the three main tests; flexrual, impact fracture toughness and DMA. The results showed different behavours as each of the material was varied. ELO was found to have substantial effect on all the samples of which it formed part of. The effect ELO was that it lowered the properties such as peaks stress, peak load flexural modulus of composite and and increased properties such as deflections. Overall effect was that it make them to fail with flexible failure. Samples that have ELO in their composition were found not to failure with complete failure.

It could be concluded that addition of both 600 and 1650 micron sawdust percentage in weight increased flexural modulus, peak and flexural stress to a certain limit at which addition of more more sawdust fillers resulted in decrease of those properties. The amount of sawdust that was found to decrease some properties was 20 gram added in composites.

Things like deflections at failure when more of sawdust or SLG was added to sample were found to decreased as more sawdust or SLG filler was added. This may be due to crosslinking and poor holding capacity of resin when more sawdust or SLG was in sample and as a result of fillers occupies more space that would other wise be occupied by epoxy resin.

Tg and storage were also affected by more percentage by weight of sawdust or SLG filler in that they reduced when more of the sawdust fillers was present in a composite.

Chapter 7

General Conclusions

7.0 Introductions

Composites have been prepared from natural renewable resources which includes epoxy resin GY-191, epoxidised linseed oil and using Aradur-250 amine as hardener. Waste product like sawdust and SLG were used as fillers.

Their physical, mechanical and structural properties were determined by three main tests which included flexural, impact fracture toughness and DMA tests. The conclusion drawn out from the three tests is outlined as follows;

7.1 Conclusions on Flexural Test

From all samples for flexural method it could be concluded that composites made from these epoxy resin GY-191 with sawdust and SLG as fillers have a flexural modulus of up to 1889 MPa, peak load between 450 to 700 N and peak flexural stress of 47MPa for sample without ELO in their compositions.

The effect of increased percentage by weight of sawdust and SLG on structural modulus, peak load, flexural stresses and deflections were different. The trend of the flexural modulus was that as percentage by weight of sawdust was increased, flexural modulus increased. Flexural stresses and peak loads on the other hand increased up to a certain limit at which they dropped (when 20g is added).

One of the drawbacks observed was their brittle failure mode for composites without ELO (figure C-25 (a)).

For sample with ELO, it was found that all the above properties were lowered to a range of 50 to 160MPa for flexural modulus, for 50 to 150N peak load and 4 to 10MPa for peak flexural stress, deflections between 12 and 13mm while strain percentage was 13 to 20%.

One thing was found to have improved from the addition of ELO. This thing was the improvement on the failure mode for the sample with ELO. They were found to fail with flexible failure and their failure (figure C-25 (B)) has a lot of warning and does not failure with complete failure as for the case for samples without ELO.

7.2 Conclusions on Impact Fracture Toughness

For all the composites samples for impact fracture toughness method, it can be concluded that composites made from epoxy resin GY-191 with sawdust and SLG as fillers have a flexural modulus of up to 750MPa, peak load between 450 to 700 N and peak flexural stress of 47MPa for sample without ELO lower for specimen with dimensions: 64mm span length thickness of 15mm and width of 10mm. For sample with ELO, it was found that all the above properties were lowered but one improvement in that sample with ELO fail with flexible failure. This failure has a lot of warning and does not failure with complete failure as for the case of brittle for the sample without ELO.

Their lowering of properties by ELO for flexural modulus was found to range from 20 to 90MPa. For peak load range was from 50 to 120 N while flexural was much reduced and between 2.5 to 5MPa. Deflection on the other hand suffers and the range of 5 to 10mm while strain was between 7 to 20%.

7.3 Conclusions on DMA Results

For DMA storage modulus of 1440MPa and Tg of 65 degree Celsius was reached for sample with no ELO. Sample with ELO have lower storage modulus and Tg as compared to the one with no ELO.

The behaviour of composites with different sizes and amount of sawdust was also observed. It was found that Tg behave differently to storage modulus in that as the quantity of sawdust was increased the Tg increased.

Also this increment did not continue increasing infinitively but Tg temperature is observed to increase when 5g and 10g 600 micron sawdust filler were added. When 20g was added the results showed decreased in Tg.

7.4 Applications of These Composites in Civil Engineering

The result for flexural stress and modulus are far below the stresses and flexural modulus for concrete, steel and timber. This means that composites made from natural renewable natural

resources such as this should not be used in major structural force bearing members such as beams, joists, columns foundation piles unless further improvement is made on the composites. However these composites should get applications in structural field in areas such as ceiling, facade and cladding, deck panel for fences, inner house partitioning, window framing etc. Research shows that structures such as ceiling do not carrying much loading.

Flexibility of material is solved by addition of epoxidised linseed oil into the composite. Composites that have amount of epoxidised linseed where found to fail with non-brittle failure which is what we want in designing of structures. We need materials that fail with a lot of warning and it is with sample that had addition of ELO. Reducing epoxy resin GY-191 (from 80g to 60g) was found to have minor effect all the properties investigated in this project.

7.5 Suggested Future Research on This Project

In this project amount of ELO was not varied but was kept constant at 20g in all the samples that had ELO in them. In my view this can lead to further investigation or research on how various amounts ELO affect the properties of the composites with these materials as carried on this project. Perhaps if little amount of ELO is added into a sample composite it may make composite to fail with non-brittle failure but would not low lower things like flexural stress, flexural modulus and peak loads as have been done by 20g ELO in some of the samples composites in this project.

Large variation and deviation in results were observed in some samples results. This may be due to the way composites were prepared. I think that if there could be a way that polishing and cutting to sizes of samples could be avoided than that could result in better and uniform results with less deviation. What I mean here is that if there is a way we can get casting mould that will have exact dimension as required by testing machine then huge variation could be avoided and as a result uniform and better outcome could be obtained.

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Appendix A: Project Specifications Issue B

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project

PROJECT SPECIFICATION

FOR: David Ayuen MAYEN

TOPICS:

Composites from Natural Renewable Resources in Civil Engineering: Epoxidised Vegetable Oil with Epoxy Resin, Fly ash and Sawdust Fillers (mechanical, physical and structural properties)

SUPERVISOR: DR Francisco Cardona

ENROLMENT: ENG4111 SEMESTER 1 2009

ENG4112 SEMESTER 2 2009

PROJECT AIMS: This project seeks to investigate the mechanical and structural properties of composite made from renewable resources (epoxidised vegetable oils), preparation, testing and their possible application in civil engineering. It provides the improvement on impact resistance, thermal and fracture toughness of synthetic traditional composites using waste and renewable material.

SPONSORSHIP: Faculty of Engineering and surveying, University of Southern Queensland

PROGRAMME: **Issue B 19th October 2009**

1. Research background information's about the fibre composite made from renewable resource especially epoxidised linseed oils improved with saw dust, its structural, thermal, mechanical and physical properties.
2. Examine lab equipment and experimental techniques to be used in the process of analysis of sample tests and experiments.
3. Prepare specimens from the composite using waste and renewable materials (expoxidised linseed oils and saw dust).
4. Carry out tests on prepared specimens, the tests include fracture toughness testing, flexural and thermal testing
5. Analyse the result to get the structural and mechanical properties of the composite.
6. Examine the structural, thermal and physical properties from analyses result to see if it can be used or apply in civil engineering
7. Write dissertation
8. Further research on this topics

AGREED:

_____(Student) _____, _____(supervisor)

20/10/2009 __/__/____ 20/10/09.

Examiner/co-ordinator:_____

Appendix A: Project Specifications Issue A

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project

PROJECT SPECIFICATION

FOR: David Ayuen MAYEN

TOPICS: Composites from natural renewable resources in civil engineering: improvement of impact resistance, thermal properties and fracture toughness of synthetic traditional composites using resins from renewable plant-based oils (epoxidised vegetable oils, EVO resins) and waste and renewable materials such as Sawdust and Fly Ash (SLG spheres).

SUPERVISOR: DR Francisco Cardona

ENROLMENT: ENG4111 SEMESTER 1 / 2009 and ENG4112 SEMESTER 2 / 2009.

PROJECT AIM: This project seeks to investigate the mechanical and structural properties of composites made from renewable resources (epoxidised vegetable oils), blended with traditional synthetic resins and using Sawdust and /or SLG as fillers. Preparation, testing and their possible application in civil engineering structures will be investigated. This study evaluate the improvement on impact resistance, thermal and fracture toughness of synthetic traditional composites using waste materials and renewable plant-based resins.

SPONSORSHIP: Faculty of Engineering and surveying, University of Southern Queensland

PROGRAMME(what to be covered in the projects): Issue A 27th March 2009

1. Research background information's about the natural fibre composites made from renewable resource especially epoxidised vegetable oils with sawdust and SLG fillers; its structural, thermal, mechanical and physical properties.
2. Examine lab equipment and experimental techniques to be used in the process of analysis of sample tests and experiments.
3. Prepare specimens from the composite using waste and renewable materials (resins from epoxidised vegetable oils with different amounts of sawdust/SLG reinforcement).
4. Carry out tests on prepared specimens, the tests include fracture toughness testing, flexural and thermal testing.
5. Analyses the results to get the structural and mechanical properties of the different composites.
6. Write the final Report & Dissertation.

AGREED:

_____(Student) _____, _____(supervisor)

24/03/09 / / 24/03/09

Examiner/co-ordinator:_____

Appendix B

Risk Involve in Project Specimen Preparation

These were some of the risk and hard involved during this project;

- Rotating edges of machines
- Dust and fumes from sanding and cutting sample specimens
- Chemical spill during sample mixing. Chemical such epoxy resin, radur-250 amine hardener and fumed silica contact with skin should be avoided.
- Noise from testing machines
- Heat from industrial oven for curing of specimen.
- flying particle from testing of specimens

Risk control

Hard	Exposure	Risk Control	PPE
Moving part	Regularly (weekly)	Work behind the edges and do with care. Avoid putting hand on rotating parts	-
Dust/fumes	weekly	Use nose mask goggles	Eyes goggles
Chemical spill	Occasionally	Use gloves	gloves
Noise	weekly	Use ear flux	Ear flux
Heat	weekly	Avoid contact with hot objects	-

Appendix C: Results from test machine MTS Alliances for each of the composites sample:

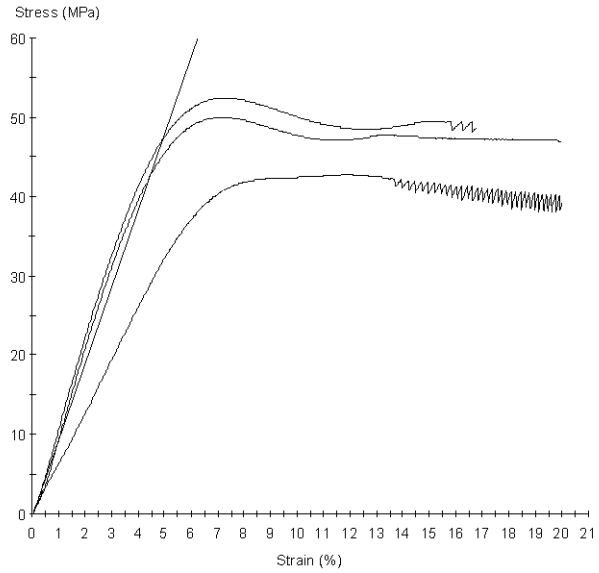


Figure C-1: Stress-Strain relationship curves for Neat Epoxy Resin GY-191 composite prepared with aradur-250 amine hardener.

The results from the pure epoxy resin with aradur-250 hardener are amazing. Shown in the table 2.1 the average flexural modulus is 921MPa. Peak average peak load is 590N and a flexural stress of 48MPa. The composite fail with non-brittle failure as can be seen by damping after failure. Refer to figure C-1 above.

Table C-1: Specimen results for Neat epoxy resin

Specimen 1 A	**Width mm**	**Thickness mm**	**Peak Load N**	**Peak Flexural Stress MPa**	**Strain At Peak %**	**Strain at Break %**	**Deflection At Peak mm**	**Deflection At Break mm**	**Flexural Modulus MPa**
1	12.91	8.65	430	42.78	11.92	****	9.41	****	626
2	13.26	9.88	706	52.40	7.32	****	5.05	****	1147

3	13.89	9.35	632	49.97	7.16	****	5.23	****	989
Mean	**13.35**	**9.29**	**590**	**48.38**	**8.80**	****	**6.56**	****	**921**
Std Dev	**0.50**	**0.62**	**143**	**5.00**	**2.71**	****	**2.47**	****	**267**

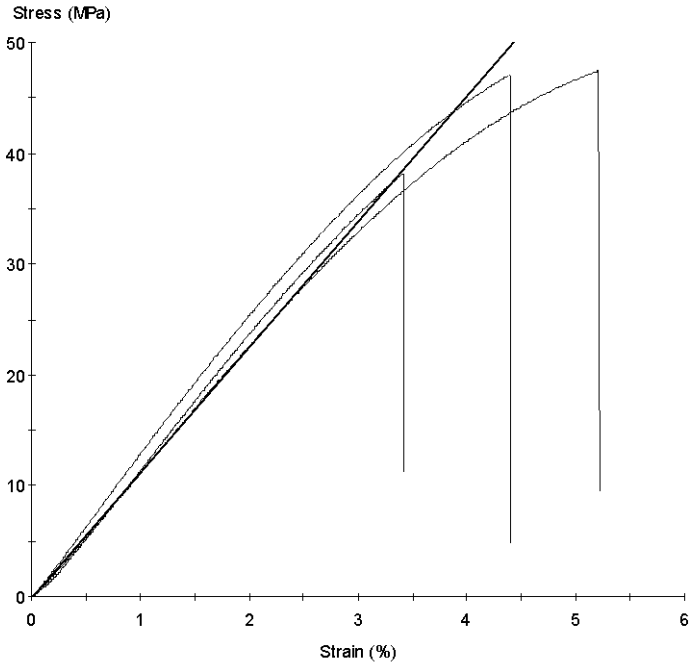


Figure C-2: Stress-Strain relationship curves for Composite with 5g of 600 micron Sawdust prepared with aradur-250 amine hardener

Table C-2 : Sample results for Composite with 5g of 600 micron Sawdust

Specimen 2.A	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	13.69	10.18	701	47.44	5.21	5.21	3.50	3.50	1147
2	14.01	9.87	669	47.09	4.39	4.39	3.04	3.04	1317
3	14.47	9.85	558	38.17	3.42	3.42	2.37	2.37	1157
Mean	**14.06**	**9.97**	**643**	**44.23**	**4.34**	**4.34**	**2.97**	**2.97**	**1207**
Std Dev	**0.39**	**0.19**	**75**	**5.25**	**0.90**	**0.90**	**0.57**	**0.57**	**96**

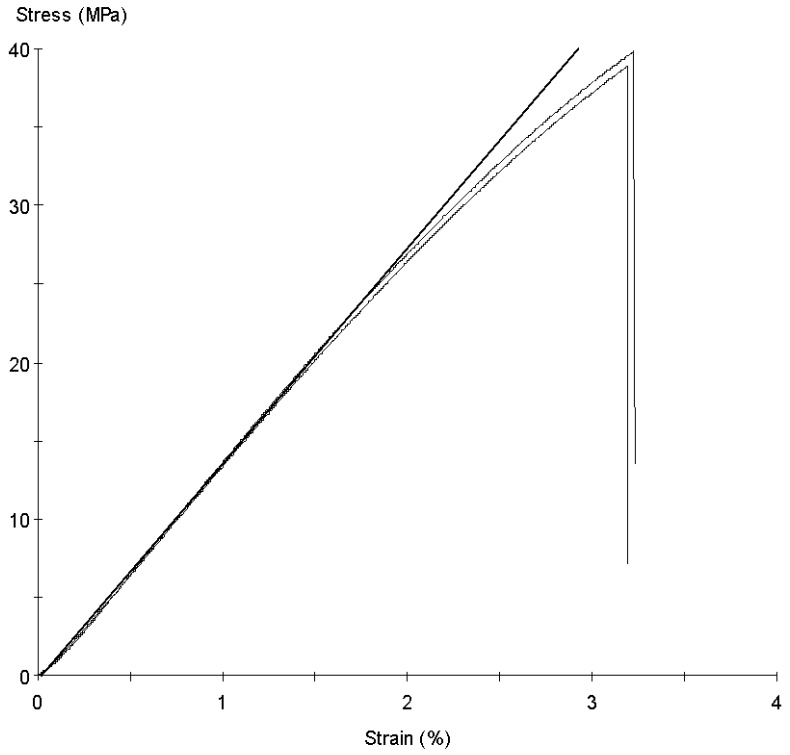


Figure C-3: Stress-Strain relationship curves for Composite with 10g of 600 micron Sawdust

Table C-3: Sample Results for Composite with 10g of 600 micron Sawdust

Specimen 3.A	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	13.95	9.86	580	41.08	3.47	3.47	2.40	2.40	1379
2	14.47	9.90	549	37.15	3.08	3.08	2.13	2.13	1292
3	14.84	9.80	649	43.72	3.69	3.69	2.57	2.57	961
Mean	**14.42**	**9.85**	**593**	**40.65**	**3.42**	**3.42**	**2.37**	**2.37**	**1210**
Std Dev	**0.45**	**0.05**	**51**	**3.31**	**0.31**	**0.31**	**0.23**	**0.23**	**221**

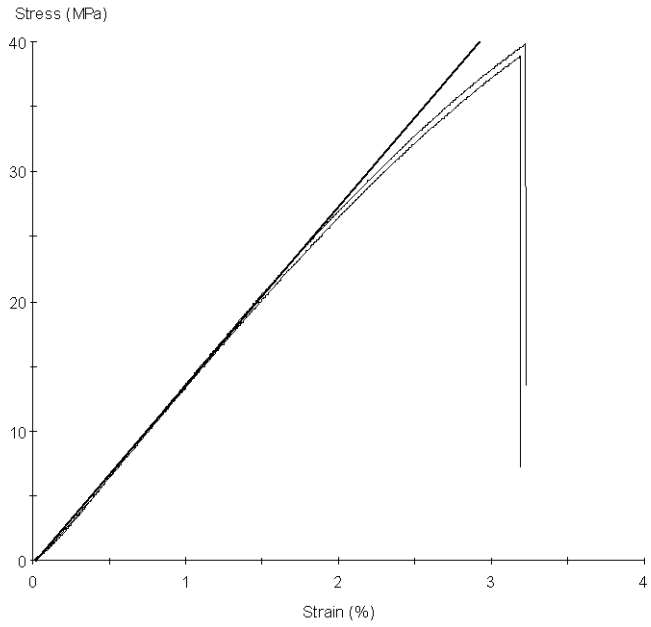


Figure C-4: Stress-Strain relationship curves for Composite with 20g of 600 micron Sawdust prepared with epoxy resin GY-191 AND aradur-250 amine hardener

Table C-4: Sample Results for Composite with 20g of 600 micron Sawdust

Specimen 4.A	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	14.98	10.01	608	38.92	3.19	3.19	2.18	2.18	1353
2	14.91	9.85	600	39.84	3.22	3.22	2.23	2.23	1415
Mean	**14.94**	**9.93**	**604**	**39.38**	**3.21**	**3.21**	**2.21**	**2.21**	**1384**
Std Dev	**0.05**	**0.11**	**6**	**0.65**	**0.02**	**0.02**	**0.04**	**0.04**	**44**

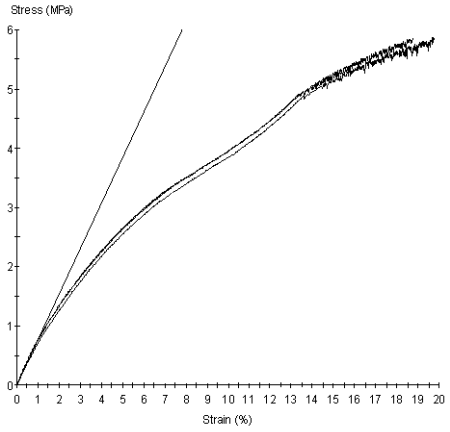


Figure C-5: Stress-Strain relationship curves for Composite with 5g of 600 micron Sawdust composite prepared with epoxy resin GY-191 AND aradur-250 amine hardener and ELO in ration 2:3

Table C-5: Sample Results for Composite with 5g of 600 micron Sawdust and Epoxy resin and ELO in ration 2:3

Specimen 8.A#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	14.72	9.98	90	5.87	19.76	****	13.52	****	69
2	15.00	9.93	90	5.87	18.74	****	12.88	****	76
3	14.32	9.81	78	5.40	15.85	****	11.03	****	73
Mean	**14.68**	**9.91**	**86**	**5.71**	**18.12**	****	**12.48**	****	**73**
Std Dev	**0.34**	**0.09**	**7**	**0.27**	**2.03**	****	**1.29**	****	**3**

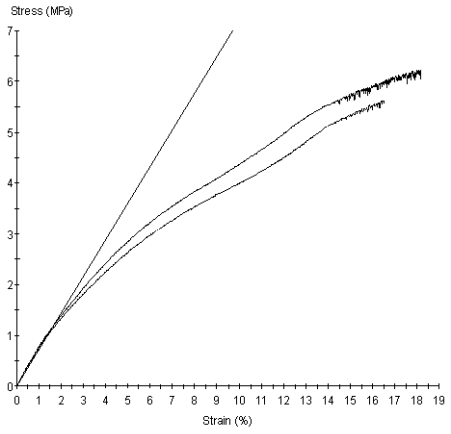


Figure C-6: Stress-Strain relationship curves for Composite with 10g of 600 micron Sawdust and Epoxy resin and ELO in ration 2:3

Table C-6: Sample Results for Composite with 10g of 600 micron Sawdust and Epoxy resin and ELO in ration 2:3

Specimen 9.A#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	15.65	9.98	91	5.63	16.49	****	11.28	****	73
2	15.49	9.61	93	6.23	17.98	****	12.78	****	74
Mean	**15.57**	**9.80**	**92**	**5.93**	**17.24**	****	**12.03**	****	**74**
Std Dev	**0.11**	**0.26**	**1**	**0.42**	**1.05**	****	**1.06**	****	**1**

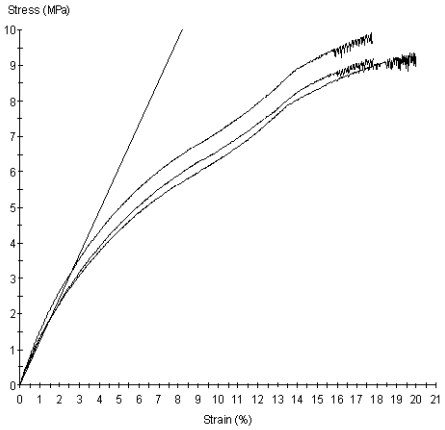


Figure C-7: Stress-Strain relationship curves for Composite with 20g of 600 micron Sawdust and Epoxy resin and ELO in ration 2:3

Table C-7: Sample Results for Composite with 20g of 600 micron Sawdust and Epoxy resin and ELO in ration 2:3

Specimen 10.A#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	17.10	9.91	161	9.20	17.83	****	12.28	****	120
2	15.58	9.84	156	9.91	17.74	****	12.31	****	151
3	15.97	9.84	151	9.35	19.68	****	13.65	****	131
Mean	**16.22**	**9.86**	**156**	**9.49**	**18.42**	****	**12.75**	****	**134**
Std Dev	**0.79**	**0.04**	**5**	**0.37**	**1.10**	****	**0.78**	****	**15**

Toughness result from the MTS Alliance machine

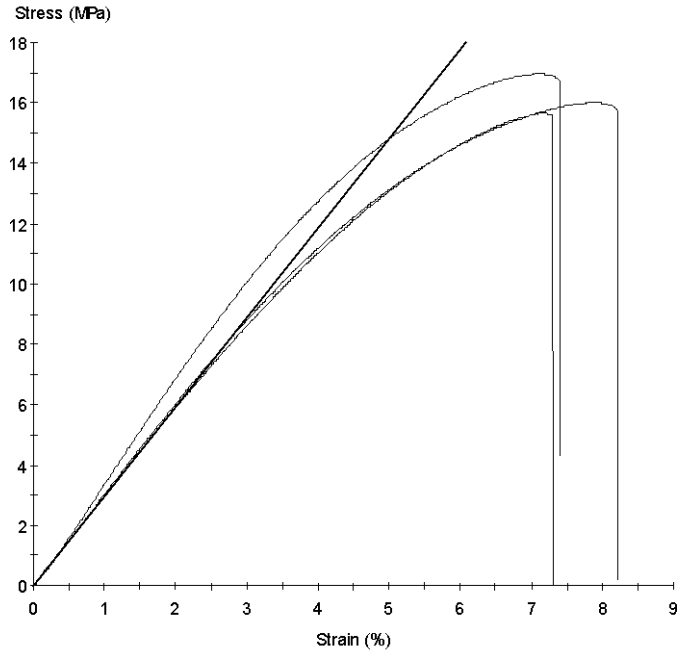


Figure C-8: fracture toughness strain stress relationship for neat epoxy resin prepared with aradur-250 amine hardener

Table C-8: Fracture tough neat epoxy resin composite results

Specimen 1B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	9.86	14.73	349	15.64	7.17	7.29	3.32	3.38	296
2	10.00	14.86	368	16.00	7.92	8.23	3.64	3.78	292
3	9.09	14.82	353	16.96	7.14	7.40	3.29	3.41	305
Mean	**9.65**	**14.80**	**356**	**16.20**	**7.41**	**7.64**	**3.42**	**3.52**	**297**
Std Dev	**0.49**	**0.07**	**10**	**0.68**	**0.44**	**0.51**	**0.19**	**0.22**	**7**

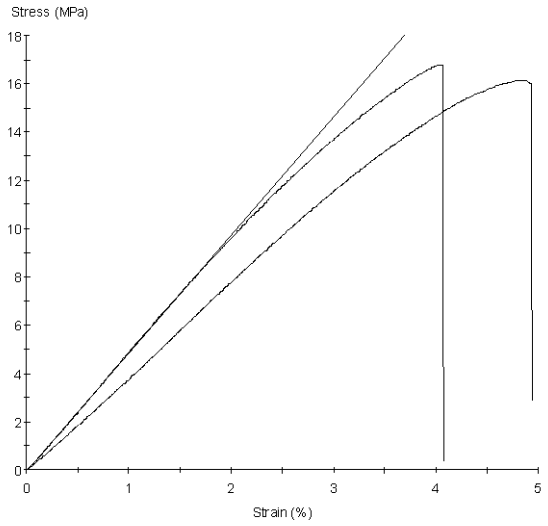


Figure C-9: Stress-Strain relationship curves for Composite with 5g of 600 micron Sawdust and prepared with epoxy resin GY-191 and aradur-250 amine hardener

Table C-.9: Results for Composite with 5g of 600 micron Sawdust filler

Specimen 2B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	8.47	14.80	312	16.12	4.84	4.93	2.23	2.27	376
2	9.90	14.98	389	16.80	4.05	4.06	1.85	1.85	490
Mean	**9.18**	**14.89**	**350**	**16.46**	**4.45**	**4.50**	**2.04**	**2.06**	**433**
Std Dev	**1.01**	**0.13**	**55**	**0.48**	**0.55**	**0.61**	**0.27**	**0.30**	**80**

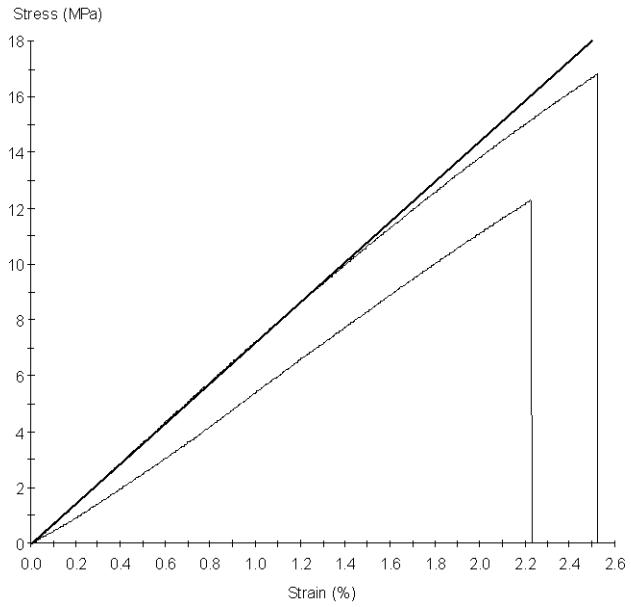


Figure C-10: Stress-Strain relationship curves for Composite with 10g of 600 micron Sawdust and prepared with epoxy resin GY-191 and aradur-250 amine hardener

Table C-10: Specimen Results for with 10g of 600 micron Sawdust filler

Specimen 3B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	9.94	14.98	391	16.81	2.52	2.53	1.15	1.15	727
2	10.02	14.98	288	12.28	2.23	2.23	1.01	1.02	498
Mean	**10.08**	**14.98**	**339**	**14.55**	**2.37**	**2.38**	**1.08**	**1.08**	**613**
Std Dev	**0.18**	**0.00**	**73**	**3.20**	**0.21**	**0.21**	**0.10**	**0.10**	**162**

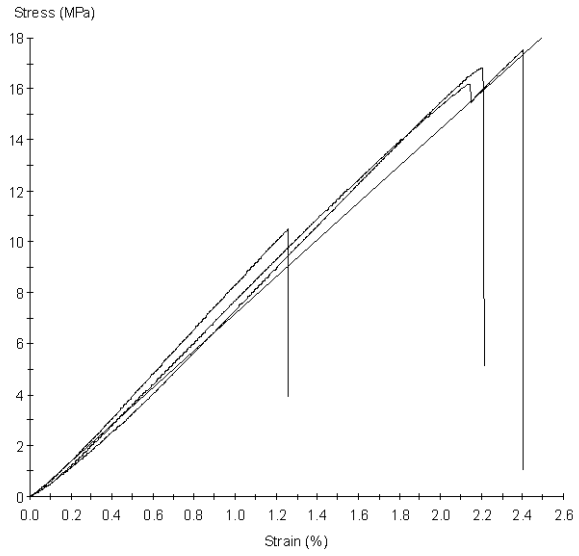


Figure C-11: Stress-Strain relationship curves for Composite with 20g of 600 micron Sawdust and prepared with epoxy resin GY-191 and aradur-250 amine hardener

Table C-11: Specimen Results for Composite with 20g of 600 micron Sawdust filler

Specimen 4B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	10.23	14.99	404	16.85	2.21	2.21	1.01	1.01	656
2	9.79	15.00	402	17.52	2.40	2.40	1.09	1.09	744
3	10.35	15.00	254	10.49	1.26	1.26	0.57	0.57	724
Mean	**10.12**	**15.00**	**353**	**14.95**	**1.96**	**1.96**	**0.89**	**0.89**	**708**
Std Dev	**0.29**	**0.01**	**86**	**3.88**	**0.61**	**0.61**	**0.28**	**0.28**	**46**

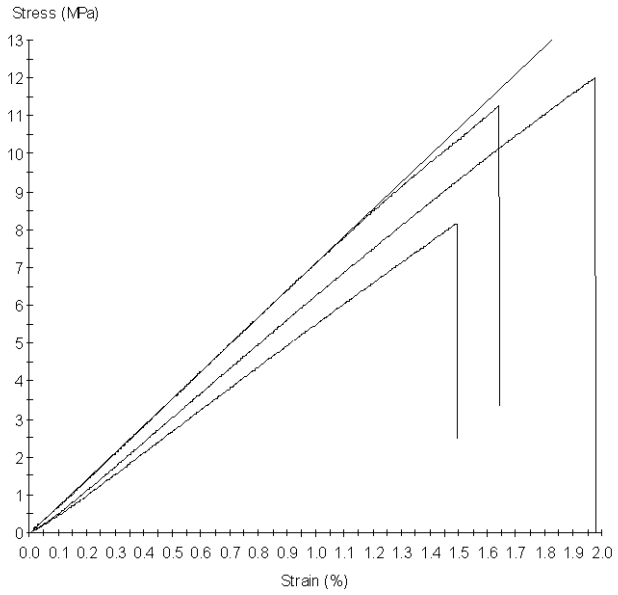


Figure C-12: Stress-Strain relationship curves for Composite with 5g of 1650 micron Sawdust filler

Table C-12: Specimen Results for composite with 5g of 1650 micron Sawdust

Specimen 5B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	9.88	15.00	189	8.15	1.49	1.49	0.68	0.68	558
2	8.30	15.00	219	11.27	1.64	1.64	0.75	0.75	717
3	9.89	15.00	278	12.01	1.98	1.98	0.90	0.90	623
Mean	**9.36**	**15.00**	**229**	**10.48**	**1.70**	**1.70**	**0.78**	**0.78**	**633**
Std Dev	**0.92**	**0.00**	**46**	**2.05**	**0.25**	**0.25**	**0.11**	**0.11**	**80**

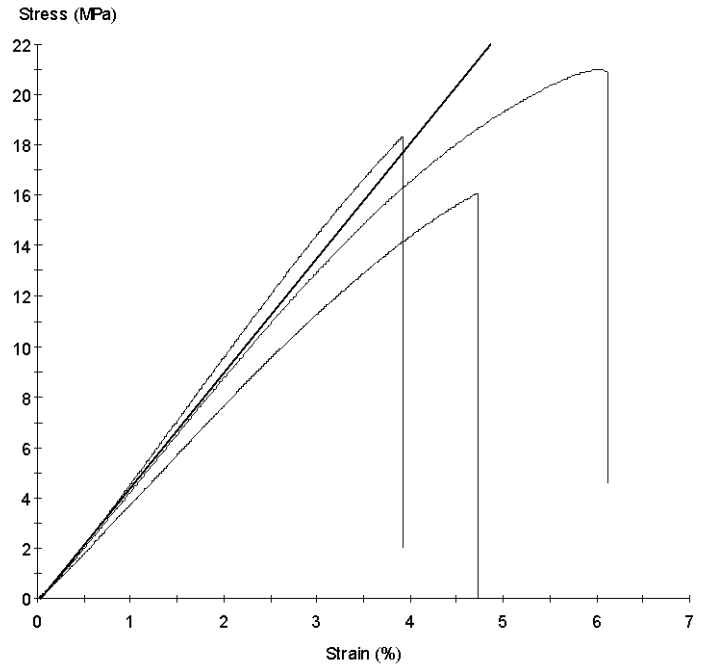


Figure C-13: Impact fracture toughness stress-strain relationship curve for Composite with 10g of 1650 micron Sawdust filler

Table C-13: Specimen Results for Composite with 10g of 1650 micron Sawdust

Specimen 7B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	9.96	15.00	376	16.09	4.72	4.72	2.15	2.15	381
2	9.96	14.44	454	21.01	6.01	6.12	2.84	2.89	445
3	9.95	13.75	359	18.34	3.92	3.92	1.95	1.95	464
Mean	**9.96**	**14.40**	**396**	**18.48**	**4.88**	**4.92**	**2.31**	**2.33**	**430**
Std Dev	**0.01**	**0.63**	**51**	**2.46**	**1.06**	**1.12**	**0.47**	**0.50**	**43**

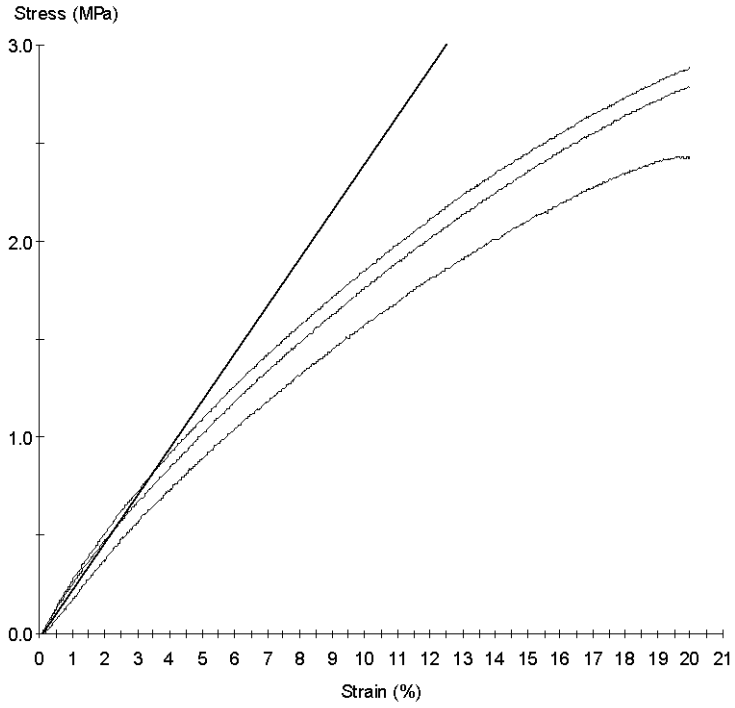


Figure C-14: Impact toughness Stress-Strain relationship curve for Composite with 5g of 600, micron Sawdust and prepared with epoxy resin GY-191 and aradur-250 amine hardener and ELO

Table C-14: Impact fracture toughness for composite with 5g of 600, micron Sawdust and ELO

Specimen 8B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	9.95	14.95	67	2.89	19.97	****	9.12	****	25
2	8.36	14.59	45	2.43	20.00	****	9.36	****	20
3	9.83	14.98	64	2.79	19.98	****	9.11	****	24
Mean	**9.38**	**14.84**	**59**	**2.70**	**19.98**	****	**9.19**	****	**23**
Std Dev	**0.89**	**0.22**	**12**	**0.24**	**0.02**	****	**0.14**	****	**3**

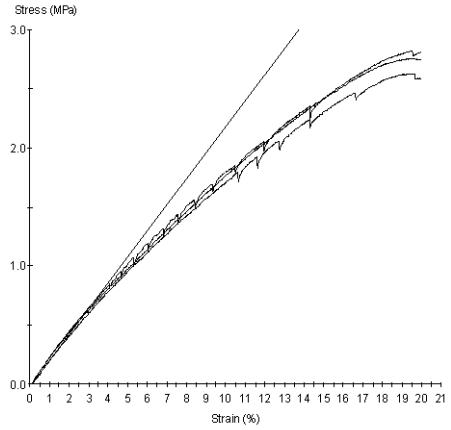


Figure C-15: Impact toughness Stress-Strain relationship curve for Composite with 10g of 600, micron Sawdust and prepared with epoxy resin GY-191 AND aradur-250 amine hardener and ELO

Table C-15: Impact fracture toughness result for composite with 10g of 600, micron Sawdust and ELO

Specimen 9B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	9.96	15.00	61	2.63	19.54	****	8.89	****	21
2	9.80	15.00	63	2.76	19.52	****	8.88	****	22
3	10.03	15.00	66	2.82	19.52	****	8.88	****	22
Mean	**9.93**	**15.00**	**64**	**2.74**	**19.53**	****	**8.89**	****	**22**
Std Dev	**0.12**	**0.00**	**3**	**0.10**	**0.01**	****	**0.01**	****	**1**

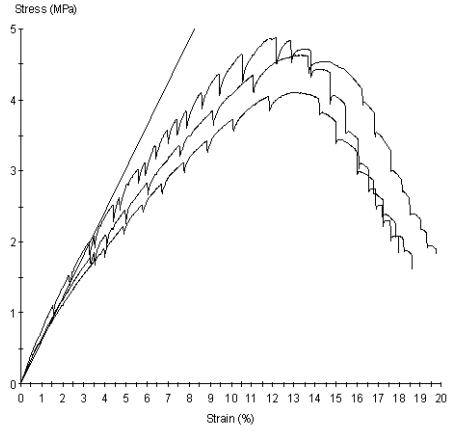


Figure C-16: Impact toughness Stress-Strain relationship curve for Composite with 20g of 600, micron Sawdust and prepared with epoxy resin GY-191 AND aradur-250 amine hardener and ELO

Table C-16: Impact fracture toughness results for composite with 20g of 600, micron Sawdust and ELO

Specimen 10B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	9.78	15.00	112	4.88	12.16	17.20	5.53	7.83	67
2	9.93	15.00	108	4.63	13.38	19.00	6.09	8.65	61
3	10.00	15.00	96	4.11	12.96	18.14	5.90	8.26	61
Mean	**9.90**	**15.00**	**105**	**4.54**	**12.83**	**18.11**	**5.84**	**8.24**	**63**
Std Dev	**0.11**	**0.00**	**8**	**0.39**	**0.62**	**0.90**	**0.28**	**0.41**	**4**

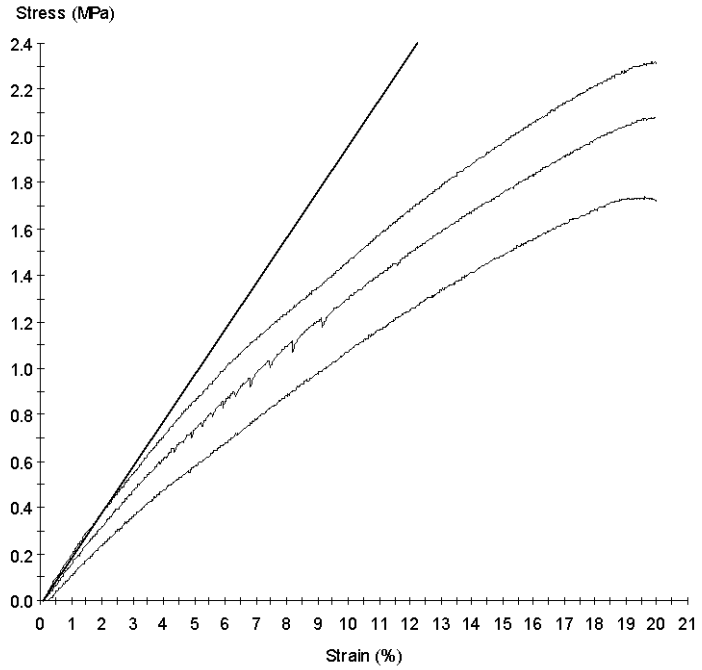


Figure C-17: Impact toughness Stress-Strain relationship curve for Composite with 5g of 1650, micron Sawdust and prepared with epoxy resin GY-191 AND aradur-250 amine hardener and

ELO

Table C-17: Impact fracture toughness results for composite with 5g of 1650 micron Sawdust and ELO

Specimen 11B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	9.93	14.98	48	2.08	20.00	****	9.11	****	16
2	7.91	14.84	32	1.74	19.64	****	9.03	****	13
3	9.77	14.77	52	2.32	19.98	****	9.24	****	19
Mean	**9.20**	**14.86**	**44**	**2.05**	**19.87**	****	**9.13**	****	**16**
Std Dev	**1.12**	**0.11**	**11**	**0.29**	**0.21**	****	**0.10**	****	**3**

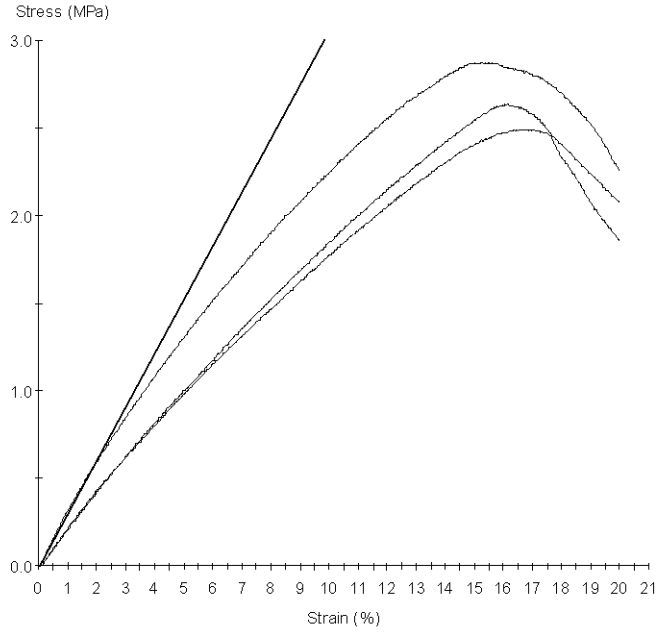


Figure C-18: Impact toughness Stress-Strain relationship curve for Composite with 10g of 1650, micron Sawdust and prepared with epoxy resin GY-191 AND aradur-250 amine hardener and ELO

Table C-18: Impact fracture toughness results for composite with 10g of 1650 micron Sawdust and ELO

Specimen 12B #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	9.85	14.99	57	2.49	16.65	****	7.58	****	22
2	9.95	15.00	61	2.63	16.08	****	7.32	****	21
3	9.75	14.99	66	2.87	15.01	****	6.84	****	31
Mean	**9.85**	**14.99**	**62**	**2.67**	**15.91**	****	**7.25**	****	**25**
Std Dev	**0.10**	**0.01**	**4**	**0.19**	**0.83**	****	**0.38**	****	**5**

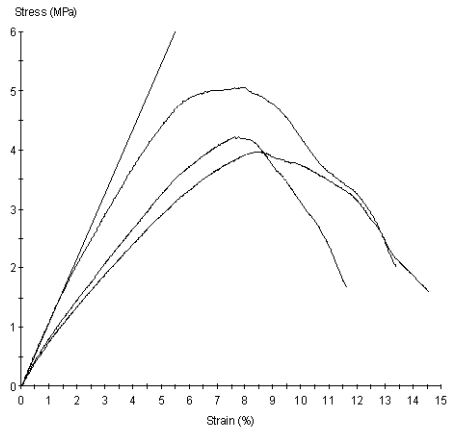


Figure C-19: Impact toughness Stress-Strain relationship curve for Composite with 20g of 1650, micron Sawdust and prepared with epoxy resin GY-191 AND aradur-250 amine hardener and ELO

Table C-19: Impact fracture toughness results for composite with 20g of 1650 micron Sawdust and ELO

Specimen 13B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	14.98	10.01	62	3.97	8.51	13.75	5.80	9.37	74
2	15.00	9.70	62	4.21	7.62	11.21	5.36	7.89	77
3	15.00	8.41	56	5.05	7.88	12.93	6.40	10.50	110
Mean	**14.99**	**9.37**	**60**	**4.41**	**8.00**	**12.63**	**5.86**	**9.25**	**87**
Std Dev	**0.01**	**0.85**	**4**	**0.57**	**0.45**	**1.29**	**0.52**	**1.31**	**20**

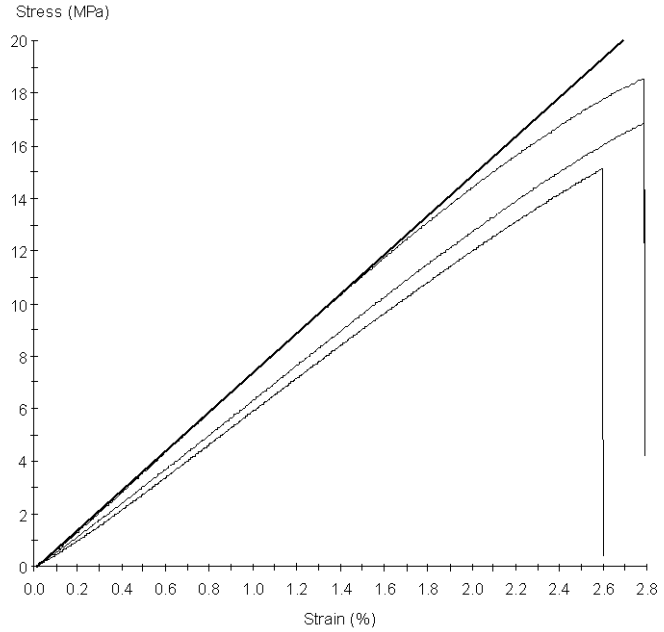


Figure C-20: Impact toughness Stress-Strain relationship curve for Composite with 0.1g Fumed silica and 5g SLG and Epoxy resin and Aradur-250 in ration 2:1

Table C-20: impact fracture toughness result for Composite with 0.1g Fumed silica and 5g SLG and Epoxy resin and Aradur-250 in ration 2:1

Specimen 15B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	10.05	13.42	350	18.54	2.79	2.79	1.42	1.42	755
2	10.02	13.69	330	16.85	2.79	2.79	1.39	1.39	646
3	9.72	13.70	287	15.12	2.60	2.60	1.29	1.29	589
Mean	**9.93**	**13.60**	**322**	**16.84**	**2.72**	**2.72**	**1.37**	**1.37**	**663**
Std Dev	**0.18**	**0.16**	**32**	**1.71**	**0.11**	**0.11**	**0.07**	**0.06**	**85**

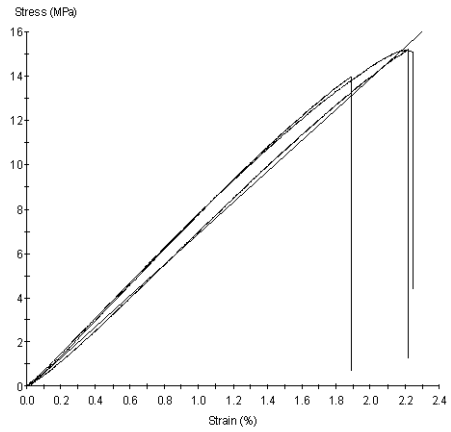


Figure C-21: Impact toughness Stress-Strain relationship curve for Composite with 0.2g Fumed silica and 10g SLG and Epoxy resin and Aradur-250 in ration 2:1

Table C-21: Impact fracture toughness results for composite with 0.2g Fumed silica and 10g SLG and Epoxy resin and Aradur-250 in ration 2:1

Specimen 16B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	9.90	13.98	306	15.17	2.21	2.25	1.08	1.10	787
2	8.86	13.84	246	13.94	1.89	1.89	0.93	0.93	782
3	10.05	14.19	321	15.21	2.22	2.22	1.07	1.07	713
Mean	**9.60**	**14.00**	**291**	**14.77**	**2.10**	**2.12**	**1.03**	**1.03**	**761**
Std Dev	**0.65**	**0.18**	**39**	**0.72**	**0.19**	**0.20**	**0.08**	**0.09**	**41**

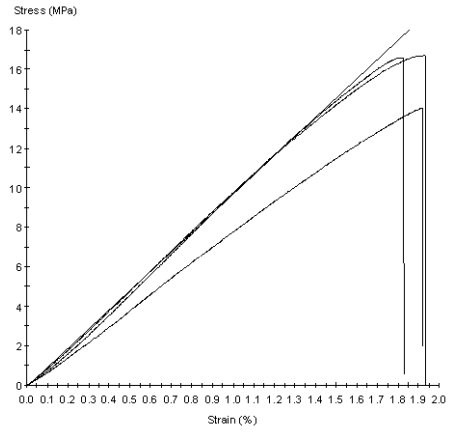


Figure C-22: Impact toughness Stress-Strain relationship curve for Composite with 0.3g Fumed silica and 20g SLG and Epoxy resin and Aradur-250 in ration 2:1

Table C-22: Impact fracture toughness results for composite with 0.2g Fumed silica and 20g SLG and Epoxy resin and Aradur-250 in ration 2:1

Specimen 17B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	9.97	13.75	276	14.04	1.91	1.91	0.95	0.95	800
2	10.06	14.92	387	16.60	1.83	1.83	0.84	0.84	961
3	9.91	13.71	324	16.70	1.93	1.93	0.96	0.96	986
Mean	**9.98**	**14.13**	**329**	**15.78**	**1.89**	**1.89**	**0.92**	**0.92**	**915**
Std Dev	**0.08**	**0.69**	**56**	**1.51**	**0.05**	**0.06**	**0.07**	**0.07**	**101**

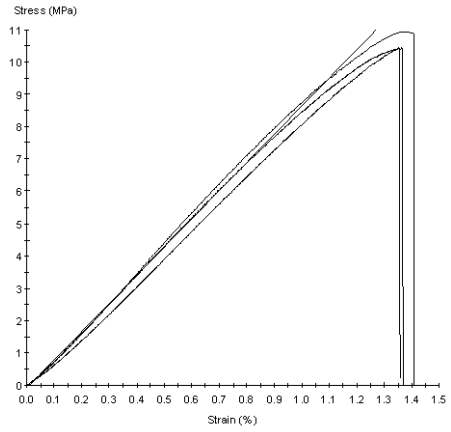


Figure C-23: Impact toughness Stress-Strain relationship curve for Composite with 0.3g Fumed silica and 30g SLG and Epoxy resin and Aradur-250 in ration 2:1

Table C-23: Impact fracture toughness results for composite with 0.3g Fumed silica and 30g SLG and Epoxy resin and Aradur-250 in ration 2:1

Specimen 18B#	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	9.50	14.91	230	10.44	1.35	1.36	0.62	0.62	816
2	10.38	13.74	223	10.95	1.38	1.41	0.69	0.70	916
3	9.25	14.04	198	10.43	1.36	1.37	0.66	0.66	888
Mean	**9.71**	**14.23**	**217**	**10.61**	**1.37**	**1.38**	**0.66**	**0.66**	**874**
Std Dev	**0.59**	**0.61**	**17**	**0.29**	**0.02**	**0.03**	**0.03**	**0.04**	**51**

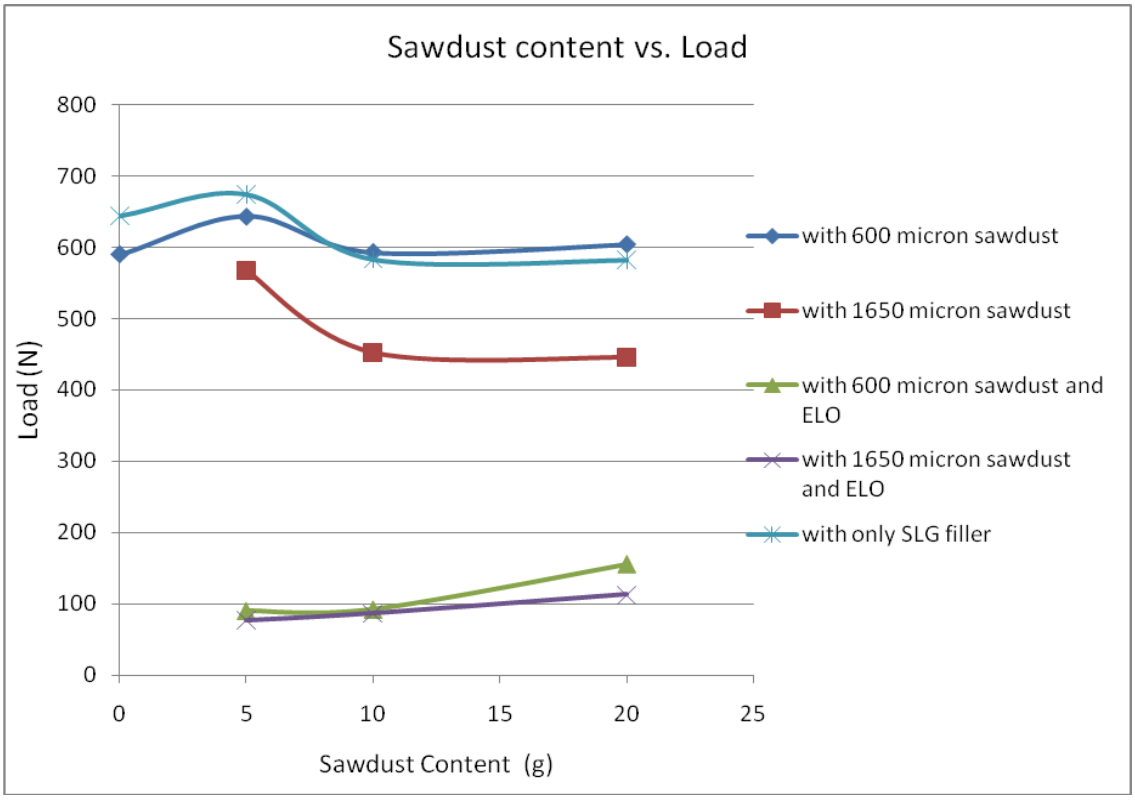


Figure C-24: Relationship of flexural peak load and quantitiy of fillers

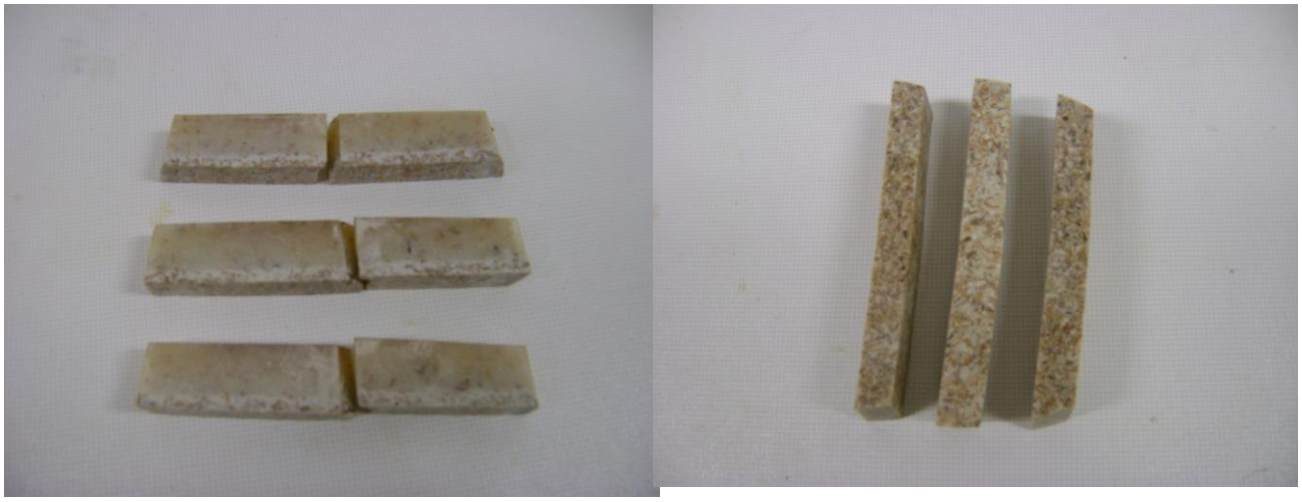
Table C-24: Kc for the fracture toughness

Samples	Notch (mm)	Notch /flaw (m)	Width factor f	Peak stress σ	pi	Kc (MPa m^1/2)
1B	5.5	0.0055	1.1	15.64	3.1416	0.0031
	5.2	0.0052	1.1	16	3.1416	0.0029
	5	0.005	1.1	16.96	3.1416	0.0028
2B	5	0.005	1.1	16.12	3.1416	0.0028
	5	0.005	1.1	16.8	3.1416	0.0028
	5	0.005	1.1	16.46	3.1416	0.0028
3B	5	0.005	1.1	16.81	3.1416	0.0028
	5	0.005	1.1	16.71	3.1416	0.0028
	5	0.005	1.1	16.12	3.1416	0.0028
4B	5	0.005	1.1	16.86	3.1416	0.0028
	5	0.005	1.1	17.52	3.1416	0.0029
	5	0.005	1.1	10.49	3.1416	0.0022
5B	5	0.005	1.1	8.15	3.1416	0.0020
	5	0.005	1.1	11.27	3.1416	0.0023
	5	0.005	1.1	12.01	3.1416	0.0024
6B	4.94	0.00494	1.1	15.08	3.1416	0.0026
	4.9	0.0049	1.1	15.02	3.1416	0.0026
	5.08	0.00508	1.1	13.49	3.1416	0.0026
7B	5	0.005	1.1	16.09	3.1416	0.0028
	4.9	0.0049	1.1	21.01	3.1416	0.0031
	5	0.005	1.1	18.34	3.1416	0.0030
8B	4.9	0.0049	1.1	2.89	3.1416	0.0011
	4.8	0.0048	1.1	2.43	3.1416	0.0010
	5	0.005	1.1	2.79	3.1416	0.0012
9B	5	0.005	1.1	2.63	3.1416	0.0011
	5	0.005	1.1	2.76	3.1416	0.0011
	4.9	0.0049	1.1	2.82	3.1416	0.0011
10B	5	0.005	1.1	4.88	3.1416	0.0015
	5	0.005	1.1	4.63	3.1416	0.0015

	5	0.005	1.1	4.11	3.1416	0.0014
11B	5	0.005	1.1	2.08	3.1416	0.0010
	5	0.005	1.1	1.74	3.1416	0.0009
	5	0.005	1.1	2.32	3.1416	0.0010
12B	5	0.005	1.1	2.49	3.1416	0.0011
	5.11	0.00511	1.1	2.63	3.1416	0.0012
	5	0.005	1.1	2.87	3.1416	0.0012
13B	5	0.005	1.1	3.97	3.1416	0.0014
	4.96	0.00496	1.1	4.21	3.1416	0.0014
	5.12	0.00512	1.1	5.05	3.1416	0.0016
14B	5	0.005	1.1	5.05	3.1416	0.0015
	5	0.005	1.1	5.05	3.1416	0.0015
	5	0.005	1.1	5.05	3.1416	0.0015
15B	5	0.005	1.1	18.54	3.1416	0.0030
	4.54	0.00454	1.1	16.85	3.1416	0.0024
	4.64	0.00464	1.1	15.12	3.1416	0.0024
16B	5	0.005	1.1	15.17	3.1416	0.0027
	5	0.005	1.1	13.94	3.1416	0.0026
	4.78	0.00478	1.1	15.21	3.1416	0.0025
17B	3.88	0.00388	1.1	14.04	3.1416	0.0018
	4.44	0.00444	1.1	16.6	3.1416	0.0024
	4.25	0.00425	1.1	16.7	3.1416	0.0022
18B	5	0.005	1.1	10.44	3.1416	0.0022
	5	0.005	1.1	10.95	3.1416	0.0023
	5	0.005	1.1	10.43	3.1416	0.0022
19B	5	0.005	1.1	3.1	3.1416	0.0012
	5	0.005	1.1	3.23	3.1416	0.0012
	5	0.005	1.1	3.23	3.1416	0.0012
20B	5	0.005	1.1	2.77	3.1416	0.0011
	5	0.005	1.1	3.2	3.1416	0.0012
	5	0.005	1.1	2.74	3.1416	0.0011
21B	5	0.005	1.1	3.21	3.1416	0.0012
	5	0.005	1.1	2.87	3.1416	0.0012

	5	0.005	1.1	3.23	3.1416	0.0012
22B	5	0.005	1.1	2.42	3.1416	0.0011
	5	0.005	1.1	3.21	3.1416	0.0012
	5	0.005	1.1	3.21	3.1416	0.0012
	5	0.005	1.1	2.61	3.1416	0.0011
23B	5	0.005	1.1	2.25	3.1416	0.0010
	5	0.005	1.1	2.35	3.1416	0.0011
	5	0.005	1.1	2.4	3.1416	0.0011
24B	5	0.005	1.1	2.35	3.1416	0.0011
	5	0.005	1.1	2.81	3.1416	0.0012
	5	0.005	1.1	2.55	3.1416	0.0011
25B	5	0.005	1.1	3.38	3.1416	0.0013
	5	0.005	1.1	2.95	3.1416	0.0012
	5	0.005	1.1	2.95	3.1416	0.0012
26B	5	0.005	1.1	3.12	3.1416	0.0012
	5	0.005	1.1	3.53	3.1416	0.0013
	5	0.005	1.1	3.28	3.1416	0.0012
27B	5	0.005	1.1	3.01	3.1416	0.0012
	5	0.005	1.1	3.2	3.1416	0.0012
	5	0.005	1.1	3.52	3.1416	0.0013
28B	5	0.005	1.1	2.49	3.1416	0.0011
	5	0.005	1.1	2.79	3.1416	0.0012
	5	0.005	1.1	2.17	3.1416	0.0010
29B	5	0.005	1.1	2.42	3.1416	0.0011
	5	0.005	1.1	2.37	3.1416	0.0011
	5	0.005	1.1	2.57	3.1416	0.0011
30B	5	0.005	1.1	2.45	3.1416	0.0011
	5	0.005	1.1	1.9	3.1416	0.0010
	5	0.005	1.1	2.08	3.1416	0.0010
31B	5	0.005	1.1	11.44	3.1416	0.0023
	5	0.005	1.1	10.51	3.1416	0.0022
	5	0.005	1.1	10.51	3.1416	0.0022
32B	5	0.005	1.1	8.73	3.1416	0.0020

	5	0.005	1.1	12.03	3.1416	0.0024
	5	0.005	1.1	12.03	3.1416	0.0024
33B	5	0.005	1.1	10.64	3.1416	0.0022
	5	0.005	1.1	14	3.1416	0.0026
	5	0.005	1.1	11.16	3.1416	0.0023
34B	5	0.005	1.1	12.96	3.1416	0.0025
	5	0.005	1.1	8.91	3.1416	0.0021
	5	0.005	1.1	12.56	3.1416	0.0024
35B	5	0.005	1.1	11.69	3.1416	0.0024
	5	0.005	1.1	11.94	3.1416	0.0024
	5	0.005	1.1	11.94	3.1416	0.0024
36B	5	0.005	1.1	20.69	3.1416	0.0031
	5	0.005	1.1	19.52	3.1416	0.0030
	5	0.005	1.1	15.21	3.1416	0.0027
37B	5	0.005	1.1	14.66	3.1416	0.0026
	5	0.005	1.1	15.35	3.1416	0.0027
	5	0.005	1.1	14.7	3.1416	0.0026
38B	3.5	0.0035	1.1	15.81	3.1416	0.0016
	3.5	0.0035	1.1	16.62	3.1416	0.0016
	3.5	0.0035	1.1	17.77	3.1416	0.0017
39B	4	0.004	1.1	15.36	3.1416	0.0019
	4	0.004	1.1	15.12	3.1416	0.0019
	4	0.004	1.1	14.1	3.1416	0.0019
40B	5	0.005	1.1	12.59	3.1416	0.0024
	5	0.005	1.1	13.96	3.1416	0.0026
	5	0.005	1.1	13.37	3.1416	0.0025
41B	3.6	0.0036	1.1	14.44	3.1416	0.0016
	3.6	0.0036	1.1	15.76	3.1416	0.0017
	3.6	0.0036	1.1	16.67	3.1416	0.0017
42B	4.3	0.0043	1.1	10.96	3.1416	0.0018
	4.3	0.0043	1.1	12.17	3.1416	0.0019
	4.3	0.0043	1.1	13.05	3.1416	0.0020



(a) Composites without ELO **(b)** composites with ELO

Figure C-25: failure modes of the composites prepared with epoxy resin GY-191 with different content of sawdust and cured with aradur-250 amine hardener with (a) and without (b) ELO