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Method of Recycling in Attempt to Reduce CFRP and GFRP Waste

THIRD YEAR PROJECT



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Project Title: Method of Recycling in Attempt to Reduce CFRP and GFRP Waste

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Date: 23/04/2017

Declaration of authenticity

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed:

Date:

Abstract

This engineering project is an individual project which its intentions are to tackle real life issues the industries are facing relating to recycling, the purpose of the chosen materials used in this project is to reduce the amount of these specific materials going to the landfill sites per year with conjunction of possibly developing a new material which will be light weight and cheap to produce with a large quantity of these materials already available at a very low cost. This report will contain the full research and achievements acquired during the year and provide knowledge of how the practical side of the project is conducted.

Acknowledgements

During the yearlong project, there has been a substantial amount of help and support I received from people at the UWTSD institution.

Firstly, I would like to thank Robert Goodson, my project supervisor who continuously gave guidance to me throughout the year and was the first person to bring up the idea of recycling fibres which has brought me into this project as far.

Secondly, I would like to thank the two-following people: Dave Cooper, the workshop machinist who helped me in producing the workpiece mould and Gareth Staddon, the technical support for computing and engineering who assisted me during the universal tensile test.

Finally, a special thanks to Andrew Tibbott who helped me develop the essential skills I needed for the use of the workshop necessary to complete this project. Andrew was the man with the knowledge when it came to complicated composite fibres as it is his original background, he has given me many opinions and tips along the year of this project and I'm most thankful for his time, patience, and knowledge.

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Project Introduction

The term recycling has been used for thousands of years, by processing and reusing waste into new usable products. The act began when the demand of a specific material was greater than the supply that was available, much like today where various metals and plastics are running out of supply as they're being used every day. In the early days of recycling there didn't exist as many types of recycling methods that are available today, the demand to recycle glass bottles prove that it is an efficient way to reduce waste as over 90% of glass can be recycled. By introducing new techniques of recycling for various materials, the world can be a better place by controlling over pollution and along with reducing the amount of waste carried to the landfill sites, this will not only save a lot of money but also reduce the need to introduce raw material into the production.

Aims

This report specialises on recycling the two main materials: (CFRP) Carbon fibre reinforced plastic and (GFRP) Glass fibre reinforced plastic, these two materials have composite properties and is pre-cured with the resin epoxy. Currently there are no effective way to recycle these materials therefore a solution is needed to think further ahead, which is why this project is dedicated to attempt to reduce the amounts of these materials that are destined to be wasted, disposed, and possibly giving them a purpose by reusing them.

Objectives

As the institution has a vast variety of composite materials to work with I have decided to study the most commonly used composites in the industry today, industries ranging from automotive, robotic to aeronautic.

In this project, I will be experimenting on two types of non-recyclable materials, I will be combining the two materials to construct an unidentified composite material.

I will be using waste counterpart materials as this will tackle recycling problems many industries are facing. In using these materials, I hope to achieve an alternative technique on using these counterparts and doing so may result in a production of cheap and yet strong material.

There will be a tensile test which will determine primarily the mixed (CFRP and GFRP) composites properties but also their individual properties for a comparison.

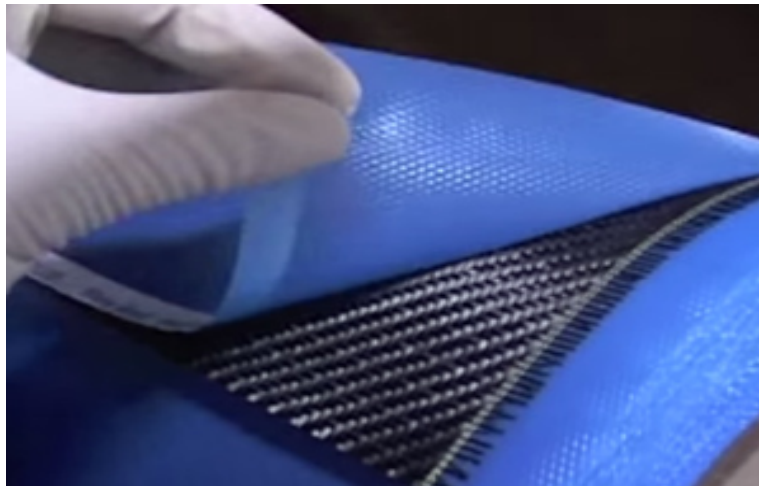
If the unidentified material is successful, this will reduce waste shipped to landfill sites and the two material will have a market value for their usefulness.

This investigation will be a great challenge in developing a profitable recycling process of end life materials.

Research

The use of carbon fibre has been vastly increasing during the years and productions of carbon fibre is undoubtedly rising, in the year 2000 only 20,000 million tons of carbon fibre were produced where in 2016 this number had tripled to 60,000 million tons produced each year, now the predictions of carbon fibre productions will 100,000 million tons point in 2020.

In the aeronautic industry, they are always considering advancing their technology, having the lightest materials means saving fuel, better dynamic designs will reduce travelling times, these potentials can create desire for a better plane build and efficiency. Due to these demands I have investigated on airplanes and have found that the aviation industry is under pressure to reduce landfill waste from scrapped airplanes. Aircraft Fleet Recycling Association (AFRA) research shows that in the next 20 years approximately 12,000 aircrafts are destined to be dismantled and transported to junk yards. Big aeronautic companies such as Airbus and Boeing are also facing these recycling problems from materials such as fibre glass which does not have a value when recycled. This problem gave me an idea to reuse some of these waste materials to improve upon the aeronautic industry. Furthermore, during manufacturing processes of aircrafts and motor vehicles there is often extra materials that can be harvested during the moulding process.



The process from manufacturing carbon fibre to production of finished components is wasteful; it is estimated that more than 30% of produced carbon fibre ends up as waste at some point in the process. Where the carbon fibre composites industry most differs from other industries that produce high proportions of waste is that it lacks an effective recycling solution.

This is not to say that we cannot recycle carbon fibre at all, from manufacturing waste and end-of-life components the recovery of carbon fibre without significantly degrading the material properties is currently impossible which brings a barrier to the industry on returning reclaimed carbon fibre to the market.

Currently, recycled products exist in many forms most suitable for compounders (milled and chopped fibres in powder or pellet form) and in composite layups (nonwoven mats as dry fabric as well as prepregs and SMC materials).

Recycling carbon fibre products can reduce the cost of light weighting, used either on their own or in conjunction with virgin carbon fibres, and making light weighting strategies affordable is a primary goal to industries like aeronautic and automotive where lightweight can save both time and fuel. The use of carbon fibre is increasing due to demand in lightweight structures and its strong properties, carbon fibre was first introduced only for the aeronautic industry to reduce weight of aircrafts but now it has a variety of application to be used in ranging from sports to building.

As for glass fibre reinforced plastics (GFRP) are strong and lightweight materials that find a wide range of uses in the industry. Products range from wind turbines and sports equipment, to automotive and construction components. However, GFRPs are difficult to recycle.



This type of composite material is often produced with thermosetting polymers that cannot be re-melted. In the past, several methods have been evaluated and tested but these have not proved economically feasible or become established. Therefore, glass fibre reinforced composites often end up on landfill sites. The cost of landfill is increasing and legislation requires that waste containing more than 10% organic material should not be land filled.

The use of wind power as an energy source is growing fast. Being renewable, wind power is an attractive method of generating energy. The blades from the wind turbines are typically made from GFRPs and have a life span of about 20 years. As the use of wind power increases, large quantities of GFRPs will need to be recycled in the future.

Most GFRPs contain more than 10% organic material they are not allowed to be disposed of in this way. As there are currently no viable methods for recycling GFRPs, despite the legislation, this material is land filled anyway. When GFRPs are land filled, large amounts of energy are lost.

Production of Fibres

Types of fibre compositions

- Filament – equal to a single strand of carbon fibre, thousands of filaments make up a fibre yarn
- Fibre – made up of thousands of filaments that are grouped together
- Tow – a term used to denote the amount of continuous filaments per fibre bundle

To produce carbon fibres, carbon atoms are bonded together in crystals that are more or less aligned parallel to the long axis of the fibre, as the crystal alignment gives the fibre high strength and volume ratio.

Several thousand carbon fibres are bundled together to form a tow, which may be used itself or woven into fabric form.

Each carbon filament in the tow is a continuous cylinder with a diameter of 5 – 10 micrometres and consists almost exclusively of carbon.

The most attractive properties of carbon fibres are its high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion.

Carbon fibre are usually combined with other materials to form a composite, when combined with a plastic resin it has a very high strength to weight ratio, and is extremely rigid although it is somewhat brittle.

Glass fibres are made of various types of glass depending upon the fiberglass use. These fibres contain silica or silicate, with varying amounts of oxides of calcium, magnesium, and sometimes boron. To be used in fibreglass, glass fibres must be made with very low levels of defects.

Fiberglas is a strong lightweight material and is used for many products. Although it is not as strong and stiff as composites based on carbon fibre, it is less brittle, and its raw materials are much cheaper. Its bulk strength and weight are also better than many metals, and it can be more readily moulded into complex shapes. Applications of fibreglass include aircraft, boats, automobiles, bath tubs and enclosures.

Chosen Idea

Recycling typically involves five basic steps: collection, identification, separation, reclamation, and remarketing. Recycling is practically only valuable if the reclaimed raw material exceeds the cost of recycling process.

When it comes to recycling composite fibres, it is a very complicated process, because either the materials need to be separated from its counterpart or either the use of the same material to make anew by heat treating. There aren't many methods around recycling them as their structural bonds will weaken one way or the another, and the efficiency of the material will drop either way. However, for metals like aluminium it is relatively easy to reclaim, by heating the alloy to a certain degree the metals will separate. In recycling the greatest challenge has always been to develop a profitable recycling process.

This idea made me realise that mixing the two fibres together will mean that it could potentially be a new material while also reducing the amount of waste if the material is successfully good. The assumptions made for CFRP and GFRP is that they're both very light and strong, much like aluminium it is used to mainly reduce weight for structures of an aircraft or an automobile and is a cheaper alternative to using carbon fibre.

In mixing the two composite fibres together it is no doubt that the properties of this new material will differ from the original contents alone. If the material is as good as aluminium in weight and strength this will give a use to what it is called waste composites right now into a useful material afterwards.

Project planning

The plan of this project was first to research any reliable information on the recycling of composite materials in the industry, there onwards I would build a background to what I would supposedly do and achieve in this project.

As enough information is in hand I could then work on the comparison side of the industry and pin point the issues they're facing and making assumptions of how I could possibly tackle these problems.

After studying and analysing the current problems I will be able to conduct my own thoughts and opinion and start to provide somewhat of a solution for the problem, and how it can impact the industry if it was to be successful.

With the chosen idea, I will begin to look for various staffs around the institution for opinions on making the specimen samples.

Next comes the procedures in making the specimen samples and the type of equipment's needed to make them a reality, typically a milling machine, a hot press machine and the universal testing machine.

Then when the specimen samples are made I will establish the experiment with all the conditions met previously and gain the results of the materials tested in order to make a final decision on its overall properties.

Once I have concluded on the material I will begin to compare its properties with the metal aluminium.

Time planning

The time given to complete this project is within 9 months and it is expected that 385 hours of independent work is allocated in this project. This is quite a short time to complete what I was hoping to achieve as other course assignments are happening with an addition of in real life work and revision for end of year exams.

The project progress had started in November 2016 with the research taking place during that month. It is not until January 2017 I had enough information to start the write up of this report, and the following month in February I had been planning arrangements to meet the UWTSD institution staffs to progress in the practical side of the project.

During March 2017, the process of making the specimen mould and cutting of the fibre materials initiated. In late March 2017, I have been held up by some issues of the mould where the specimen wouldn't release properly and after had to be snapped apart in order to try again, this took various amount of tries to tackle the problem and had wasted valueless time in this incident. Around early-April of 2017, all the specimen samples were made and ready to be tested on the universal testing machine. After the experiments are complete the data retrieved is then calculated to a mean, this is to keep it as reliable as possible to compare with the metal aluminium.

Now, the project was expected to be handed in by end of April of 2017, which left me a few weeks to write up the results of the experiment and the comparison.

July	Nov	Dec	Jan	Feb	Mar	Apr
Start 01/07/2016	Research 04/11/2016	Research 06/12/2016	Plan 15/01/2017	Mould Milling 08/02/2017	Material Lab 8/03/2017	Material Lab 5/04/2017
	Research 05/11/2016	Research 08/12/2016	Plan 16/01/2017	Mould Milling 09/02/2017	Material Lab 15/03/2017	Material Lab 6/04/2017
	Research 17/11/2016			Material Lab 15/02/2017	Material Lab 22/03/2017	Tensile testing 6/04/2017
				Material Lab 16/02/2017	Material Lab 29/03/2017	

Creating the Mould

The mould must be designed to suit the specifications of the specimens, the specimen dimensions are an important aspect of this project as there are a variety of specimen sizes each with their own type of application depending on the structural rigidity of the material. In this instance of the project, I will be working with discontinuous and randomly orientated fibre parts.

The mould is designed on the software Solidworks, because the milling machine in the institution was only compatible with this particular software therefore it was the only choice I could take in making the mould from. The software model is built around the specimen's dimensions given in the American SI format ASTM D 3039. ASTM standards is chosen as it generally gives more information than most other standards for the rationale behind details of specimen design and testing procedure.

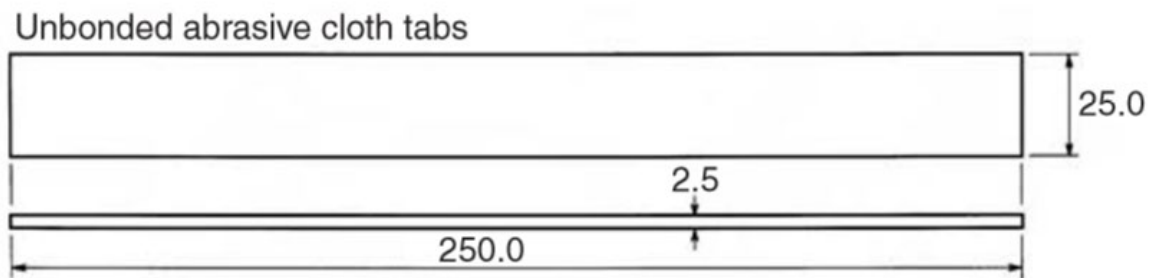


Figure 1 the Dimensions for composite materials which are discontinuous ASTM D3039

Standard	ASTM D3039
Applicability	Balanced symmetric composites reinforced with continuous or discontinuous high modulus fibre.
Thickness (t)	1.0 (0° UD) $\pm 4\%$ 2.0 (90° UD) " 2.5 (Other) ^b "
Width (W)	15 (0° UD) $\pm 1\%$ 25 (90° UD and other)
Overall length (L)	250 $\pm 4\%$ (0° UD and other) 175 (90° UD) Gauge length 10 to 50
Tab length (L_T)	56 (0° UD) 25 (90° UD)
Tab thickness	1.5
Tab material recommended	0°/90° GFRP, commonly applied at $\pm 45^\circ$ Emery cloth (Other)

Figure 2 Standards for ASTM D3039

The mould is made from Aluminium which has a very high melting point of 660.3 °C, it is very easily machined because of its soft nature and is also very light in weight. Before any operations on the milling machine is initiated a minimum of 15 minutes' is needed for the spindle to warm for the system to run efficiently.



The mould comes in two separate pieces the pocket and the insert, each piece of the mould is then placed inside a milling machine and its milled to the correct dimensions of the software model. The milling machine is connected to a computer which transfers the data of the model to the milling machine,



The processing time for each piece of the mould took roughly 20-25 minutes of machining time, as the milling was in progress a stream of water and oil coolant are surged onto the work tool during the cut to reduce heat built up.

After the milling was complete I have noticed that both mould pieces have some rough edges, so I had applied some sanding on the mould to smoothen the edges before further using it to create the specimen samples. The mould has some milling lines which are very smooth, they are just marks of where the milling took place as the tool rotates clockwise with a 2mm cut per cycle. The tool speed rate reached over 3448 rpm, and is powered by an air tower compressor.



As the mould is fully made, 10 layers of release agent is applied to both pieces of the mould, this is done to help the release of the specimen. Each layer was given 5 – 10 minute of rest before another layer was added until the final layer.



Materials

Prepregs have a limited lifetime of 180 days before expiring in the freezer, when this time is reached the bonding of the material weakens and the resin becomes less effective. Prepreg cannot be recycled, when diffused from its curing agent the material will result in weaker bonds.

The prepreg carbon fibre used in this experiment is in sheet form and is considered waste as it has been out of date for over 4 years. The prepreg is a unidirectional aligned fibre composite pre-cured with epoxy. The prepreg has been stored in various conditions from freezer to room temperature.

GFRP is expensive to recycle and many industries have applications of glass fibres. As glass fibres are produced by recycled glass, the process of recycling glass fibre would be very difficult.

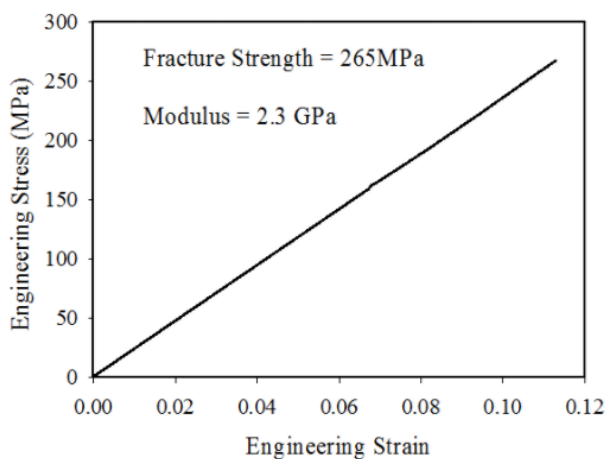
The Glass fibre reinforcement plastic used is a woven aligned fibre pre-cured with a resin obtained from left over sheet scraps, like the carbon fibre it is considered as waste and has been out of date for over 8 years. The storing condition of the glass fibre is similar of that of the prepreg carbon fibre.

Epoxies are thermosetting network polymers, which are very hard and strong, but on the brittle side.

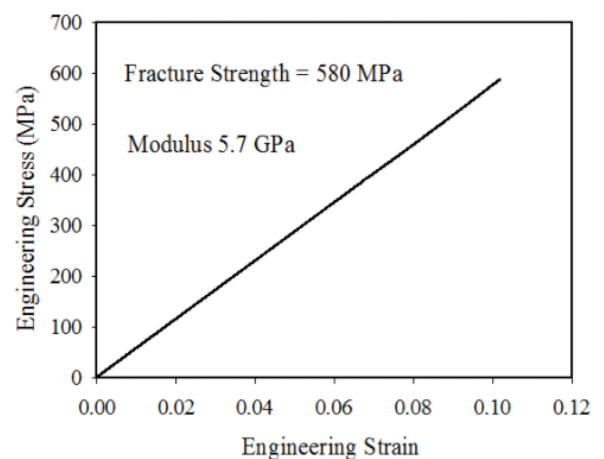
Material	Price £/kg	Density (gr/cm ³)	Price £/(MN*m)
GFRP	3.75	2.5	10.4
CFRP	10.625	1.7	8.2102

Material	GFRP	CFRP
Strength (MPa)	900	2200
Elastic Modulus (E) (GPa)	40	130
Failure Strain	0.022	0.013

Figure 3



Fibre glass



Carbon fibre

In figure 3 the graphs show the tensile data of pure carbon and glass fibres without the addition of epoxy resin tested by "Michigan Technological University".

Cutting Process

In the materials lab, the prepreg carbon fibre and glass fibre reinforced plastic available to me was in sheet form, because the project is dedicated to reducing the amount of waste produced in the industry, it is necessary to be realistic that fibre parts are not often retrieved in large quantity or of in a sheet form. I had made a conclusion that the fibre sheets shall be cut up into small pieces of 10mm x 10mm chip size, this will benefit me as it will fit nicely into the pocket of the mould and show that small pieces of material are applicable to the process as well.

The two materials were cut manually by hand using scissors and Stanley knife, this was chosen because the epoxy resin had become quite sticky on both materials.

The sheets of fibres were cut to 10mm strips before cutting them to chip sizes, this was done by being measure on a ruler to be exact.

Rubber gloves were worn during the cutting process for protection as small fibre filaments can enter the skin very easily.

A total of 192 grams of prepreg and 144 grams of GFRP is need to make the 12 specimen samples, the material will be scaled to weight before putting them into the mould for pressing.





The cutting process took the most amount of time in the project, as fibre tended to stick to the surfaces of things including the scissors; it took about 35minutes of cutting for enough material to be put into a single mould to make the specimens. Of course, this is repeated 12 times during the project as there will be 4 specimens made for each type of material.

~~Prepreg~~ Prepreg

$$225 \text{ gm}^2 \times 0.1 \text{ mm} = 5062.5$$

$$\text{Area } 250 \times 25 = 6250 \text{ mm}^2$$

$$\frac{5062.5 \times 6250 \text{ mm}^2}{6.25 \times 10^{-3}} = 31.6 \rightarrow 32 \text{ grams}$$

GFRP

0.4mm thick

$$0.4 \times 6 = 2.4$$

$$6 \times 6 = 36 \text{ grams} +$$

$$6.25 \times 10^{-3} \text{ m}^2 \quad 1000 \text{ Kg m}^2$$

$$1000 \times 0.25 = 250 \text{ m}^2$$

$$0.5 \text{ Kilo per mm}^2 \rightarrow 6250 \text{ Kg m}^2$$

$$6250 \times 3 \text{ Bar} = 18,750 \text{ Kg m}^2$$



The materials are now in 10mm x 10mm chip size, they are manually fitted into the mould covering any gaps that can be seen by eye. Putting these chips in was challenging as the material were hardened due to being at room temperature, also that there are a lot of spacing so a lot of pressing was needed to fit them all in. Some places have big bulges sticking out this was fixed by preheating the material in the hot press before applying a force on the mould.



Hot Press Machine

The mould is placed in the hot press for several minutes at 70 – 80 degrees before reaching a maximum of 120 degrees; this is done so that the fibre will run easier within the mould as the epoxy resin is hard as it had been stored at room temperature for several weeks. When 120 degrees is reached, the mould is put in again and ready to close and be pressed, a force of 3 tonnes is needed for the materials to compress in the mould, the mould is then kept inside the hot press for 60 minutes.



The hot press machine at the institution only supported to an input value of 1 tonne each time so an exact number of 2.6 tonnes wasn't available therefore 3 tonnes was inputted.

from 3tonne

$0.48 \times 1000000 = 480000 \text{ kg m}^2$

$3060 \div 6250 = 0.48$

2.5mm

192g per m² for carbon fiber sheets

tencate moulding compound

694 Psi $\times$ 9.68 in² tooling

= 6720 LBS in to Kg 3000

1mm² = 0.00155 in²

6250 $\times$ 0.00155 in² = 9.688 in²

1 tonne = 2204.623 LBS

3 tonne $\times$ 2204.623 = 6613.869.

Pounds per Square inch

$\frac{6613.869}{9.688} = 682.69 \text{ psi}$

9.688 $\times$ 600 = 5812.8

600 psi -

5812.8 $\div$ 2204 ton = 2.637 tons

Preparing the Specimen Samples

At first when the aluminium mould came out of the hot press machine the specimen wouldn't release properly, 10 layers of release agent had already been applied before this step making me troubled for some time. It is not until a solution was made where a nib was drilled onto the mould making the release much easier by using a chisel on the overflow fibres at the edges of the nib. After the nib had been drilled onto the mould the first sample which came out also stuck to the mould and had to be snapped out in order to test again however, the following sample that went into the hot press which came out to be releasable although a bit of hammering was needed. This had already been the 3rd sample being pressed, a hammer and chisel is used to remove the specimen, this is done by chiselling the edges of the fibres which flooded out of the mould.



All the specimen samples which came out of the mould are not smooth or flat, a lot of work is required to shape them up to look like an actual specimen samples. There is a thin layer of fibre which is pushed out of the mould during the press, this leaves an attached part of extra fibre around the specimen samples which needs to be cut off and sanded before testing.



CFRP Specimen

It takes 32grams of prepreg to fill the aluminium mould before closing the mould and into the hot press machine.



GFRP Specimen

It takes 36 of GFRP to fill the aluminium mould before closing the mould and put into the hot press machine.



Material Mix Specimen

It takes 34grams of material from both materials to fill the mould, 16g of CFRP and 18g of GFRP.





Specimen was grinded to smoothen the edges before tabbing is applied, there was the use of tungsten carbide abrasives and sanding, some thick parts are grinded out before sanding.



Tabbing of Specimen

Composite materials are commonly tabbed prior to testing, this is to protect the material from any damaged which would be caused by the applied load which increases during the experiment making an increase of local stress concentration. Composites that are strong and highly orthotropic the greater the need for tabbing them, in this instance both materials used in this experiment are of very strong properties.

The purpose of the tabs on a specimen sample is to protect the sample from damage by the grip of the clamp, the specimens ends to apply the axial tensile load. As the axial load is introduced onto the specimen sample from forces of stress or shear, the frictional forces developed between the grips surfaces and the tabs surfaces. By reducing any damages a normal clamping force must be applied which is done manually by the operator, this induces undesirable through the thickness compressive stresses in the composite material.



Emery cloth was used in the experiment to tab onto the specimen samples, the emery cloth has a 0.1mm depth while they were cut out to be 50mm long and 25mm wide. The emery cloth was attached with a mixture of super glue called Araldite, a thin layer was applied onto the 2 ends of the specimen and repeatedly on the opposite side. The Araldite super glue brand advised to leave the super glue to dry for at least 4 hours before using it, this is being further extended to 24 hours of curing as I had applied the glue in the afternoon and returned the following day to use them for the universal tensile test.

The primary geometric variables of the tabbed specimen are the composite material, thickness of the tab, and the type of adhesive used.



Testing Method

There will be 3 different specimen's samples conducted during the experiment, the first type of specimen sample will be made of 100% chopped prepreg carbon fibre, the second type would be made of 100% glass fibre reinforced plastic (GFRP) and the last type of sample will be a 50% / 50% mixture of the two and controlled by the weight of each material and the volume of the mould. There will be exactly four specimen samples made for each type of specimen to experiment on, this is so that it is somewhat more reliable than just testing one sample and anomalous results can be identified. Although further increasing the number of samples can be make the results more accurate, but time scale in making the samples takes approximately 1 hour to make in the hot press machine making a restriction to me as other students at the institution also operate the same machine.

- There is a lack of equipment on the universal testing machine, as an extensometer is not available at the institution which is used to determine the elongation and tensile modulus of the material.
- But overall the universal testing machine will give me enough results to achieved the values of Modulus of elasticity (E) and a completed stress strain curve graph for each specimen sample showing the behaviours of the material when it is pulled.
- Specimens will be placed in the grips of a universal testing machine at a specified grip separation and pulled until failure.
- Each type of specimen samples that are tested will have their own records, using these records I will conduct a mean to calculate a result for each of the sample types.

Universal Testing Machine

A universal testing machine is used to test the tensile stress and compressive strength of materials.



The test should give me the results of Modulus of elasticity (E) and a stress-strain curve showing the behaviour of the material while deforming.

Elastic modulus (Young's modulus) is a number that measures an object or substance's resistance to being deformed elastically when a force is applied to it. The elastic modulus of an object is defined as the slope of its stress–strain curve in the elastic deformation region. Stiff materials like carbon fibre will have a high value of elastic modulus.

- The deformation of each material strain at distinct intervals in tensile or stress in compressive loading.
- The stress train curve reveals many of the properties of a material.

The universal machine was very easy to use, the specimen would be placed inside the grips and tightened up manually, I specifically didn't tighten the specimen too tightly as it could damage them and affect the results. However, if the specimen was to be too loose it could slip during the experiment which causes a lot of trouble and specimen may need to be disposed because the length may have already be stretched, this did not occur during my testing.

All specimens are pulled until breakage, as the specimen gets pulled the stress strain curve graph on the computer screen increases and at the point of failure the pointer will drop dramatically.



Figure 4 GFRP Specimens After the Tensile Test Experiment.

The test specimens for glass fibre shown in figure 4 are all intact after the test, showing that it is not brittle. The snapping points for the four-test piece are identical, where it broke just a few centimetres from where the grip was.



Figure 5 CFRP Specimens After the Tensile Test Experiment.

Figure 5 shows the prepreg specimen samples, they are all intact but with a bit of examining I can see that it is slightly more intact compared to the glass fibre samples.

Unlike the GFRP specimen samples, 3 out of 4 carbon specimens broke inside the grip area, I cannot identify why this occurred but it is certainly tested the same way as other type of samples.

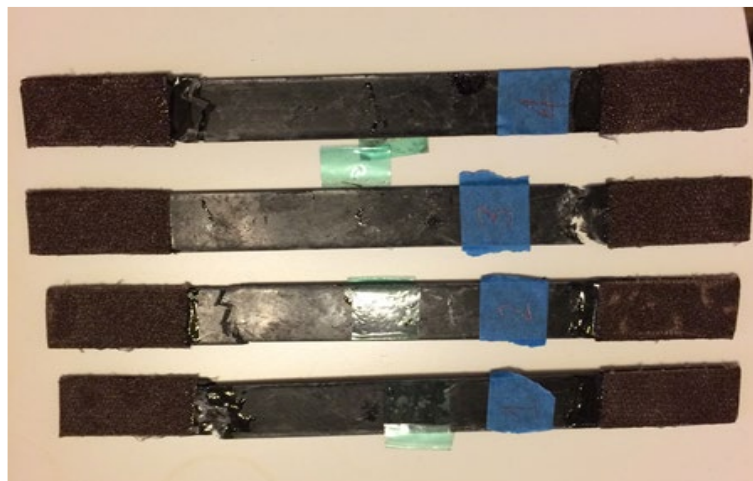


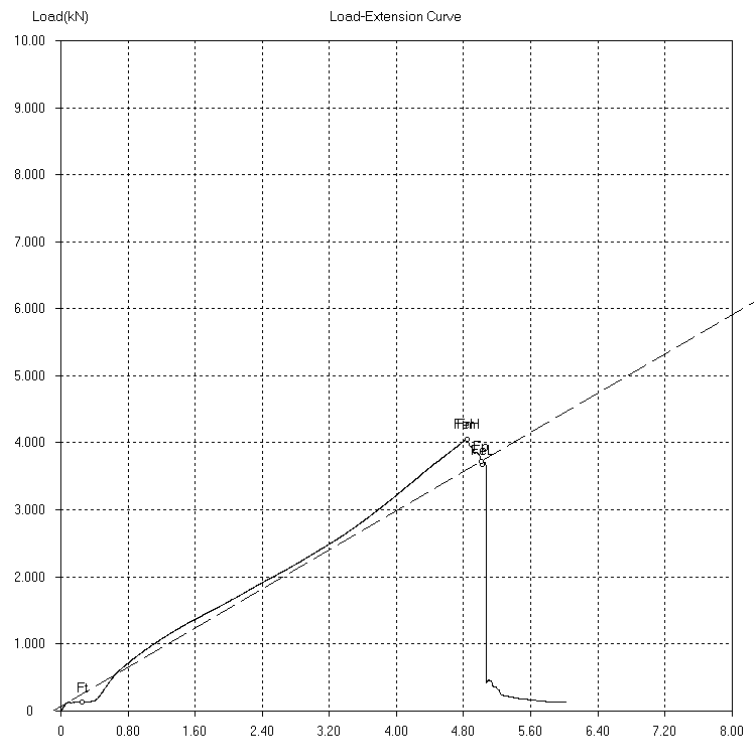
Figure 6 Mixed Fibre Specimen Samples After the Tensile Test.

The mixed fibre specimen samples after the tensile test shown in figure 6 are notably more fractured, in fact 2 of 4 specimen samples had the end pieces broken off. Like GFRP specimen samples the fracture point are near the grip of the jaws, but just a few centimetres away from it. When I examined closely the breakage differed from the two other samples, in the mixed samples I can see that the fracture is zig zagged. The mixed fibre material is more brittle compared to its original materials.

Results Data

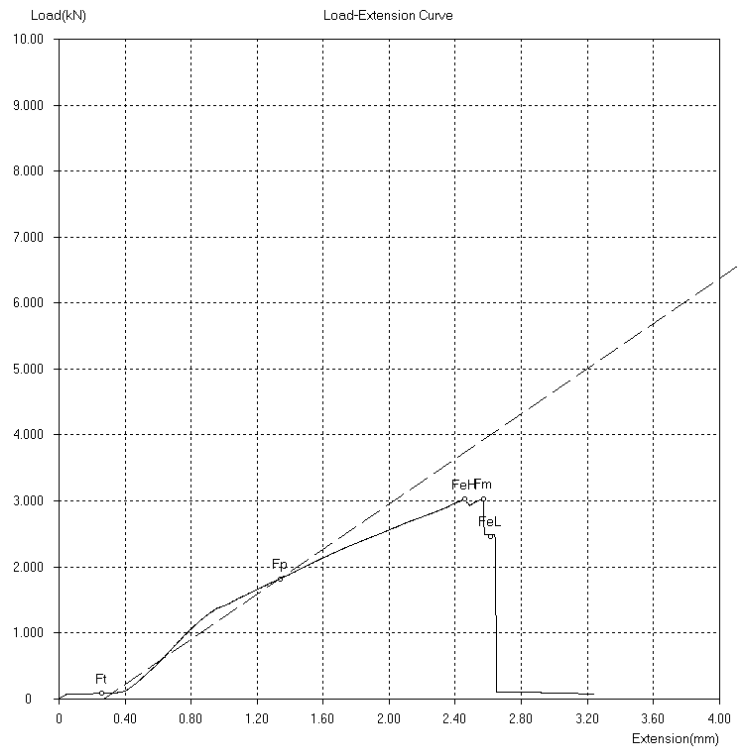
Fm(kN)	4.060
Rm(MPa)	1624
FeH(kN)	4.060
ReH(MPa)	1624
FeL(kN)	3.670
ReL(MPa)	1468
Fp(kN)	3.725
Rp(MPa)	1490
Ft(kN)	0.125
Rt(MPa)	50
E(GPa)	14

Graph 1 Stress strain curve for glass fibre specimen 1



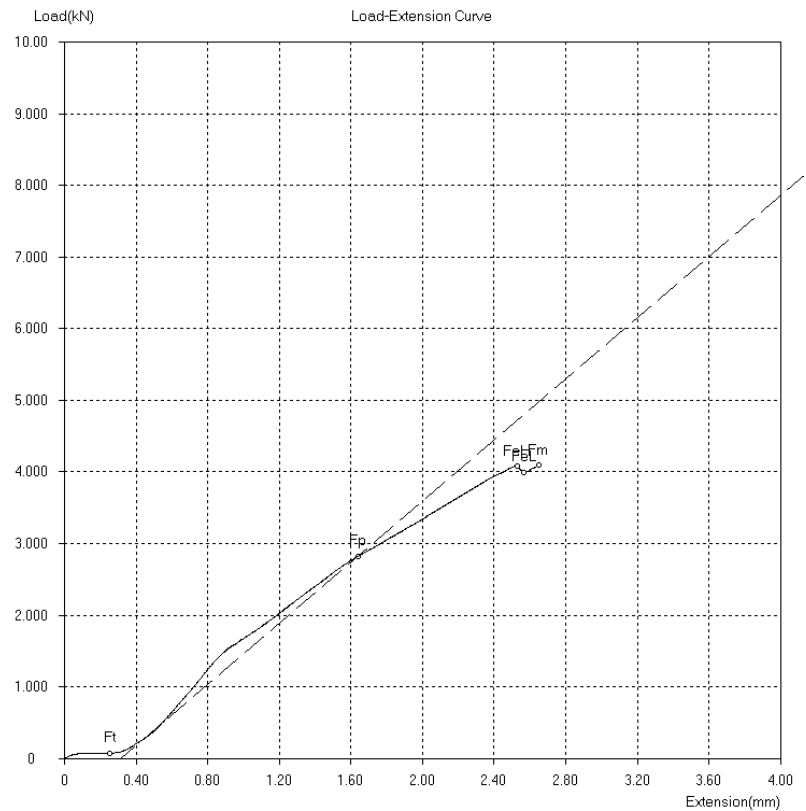
Graph 2 Stress strain curve for glass fibre specimen 2

Fm(kN)	3.035
Rm(MPa)	1214
FeH(kN)	3.025
ReH(MPa)	1210
FeL(kN)	2.465
ReL(MPa)	986
Fp(kN)	1.820
Rp(MPa)	728
Ft(kN) /	
Rt(MPa)	/
E(GPa)	33



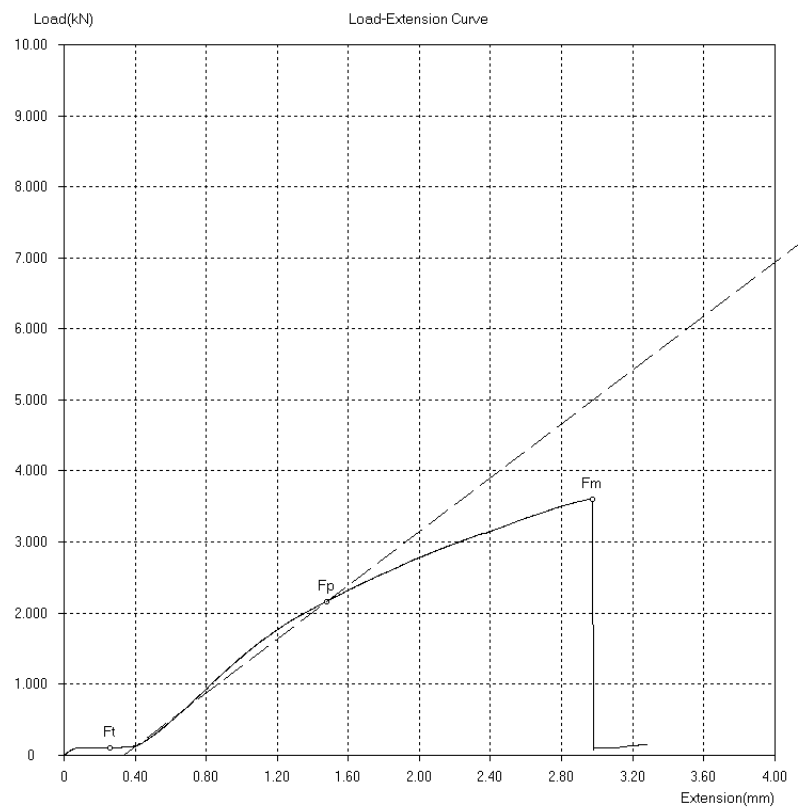
F _m (kN)	4.095
R _m (MPa)	1638
F _{eH} (kN)	4.080
R _{eH} (MPa)	1632
F _{eL} (kN)	3.995
R _{eL} (MPa)	1598
F _p (kN)	2.820
R _p (MPa)	1128
F _t (kN) /	
R _t (MPa)	/
E(GPa)	40

Graph 3 Stress strain curve for glass fibre specimen 3



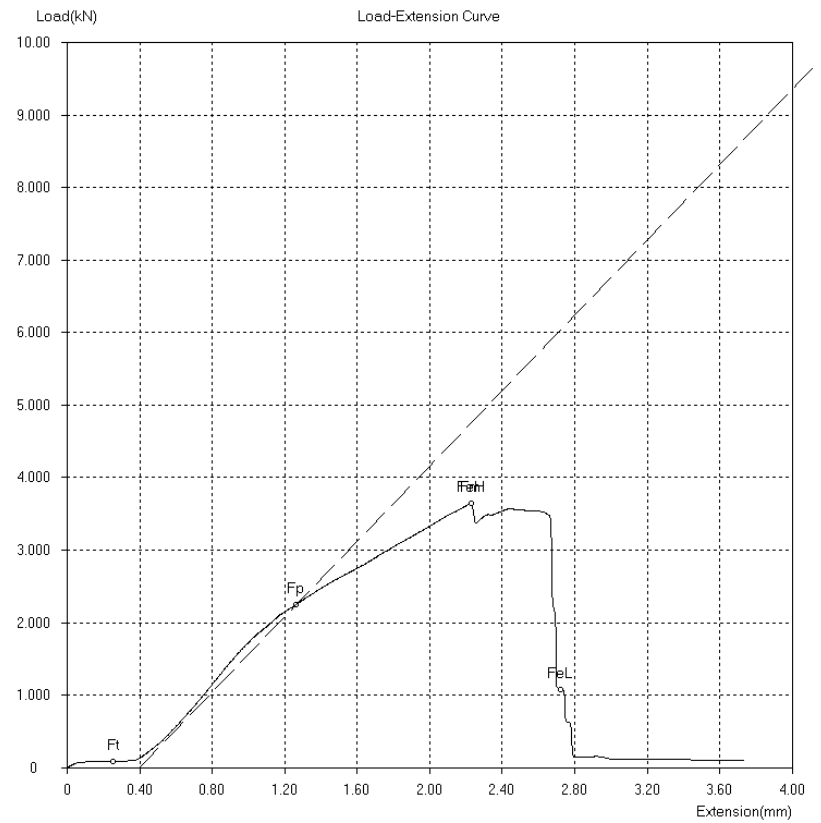
F _m (kN)	3.600
R _m (MPa)	1440
F _{eH} (kN)	/
R _{eH} (MPa)	/
F _{eL} (kN)	/
R _{eL} (MPa)	/
F _p (kN)	2.165
R _p (MPa)	866
F _t (kN) /	
R _t (MPa)	/
E(GPa)	38

Graph 4 Stress strain curve for glass fibre specimen 4



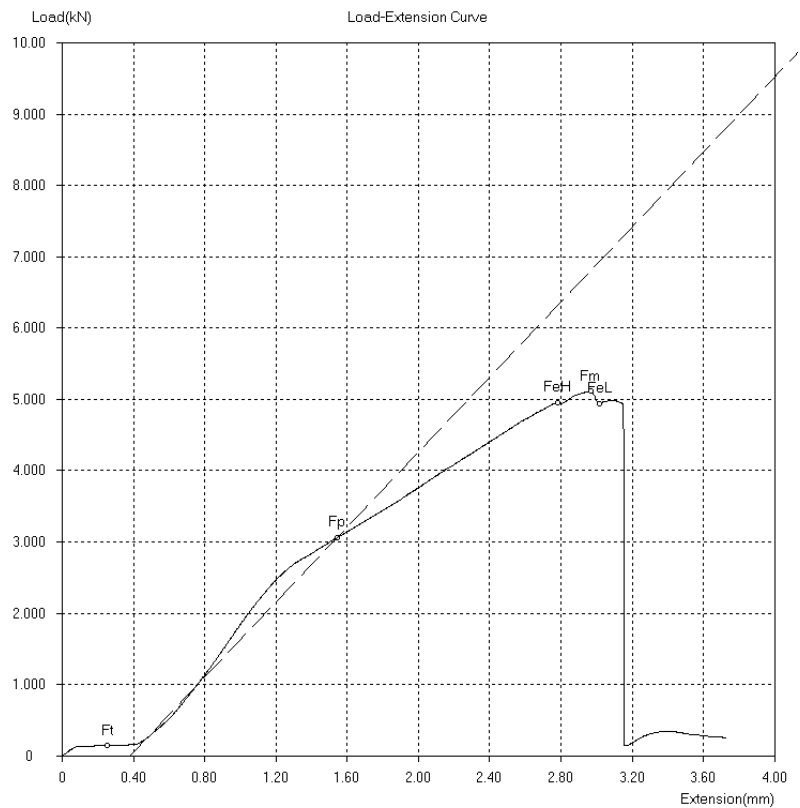
Graph 5 Stress strain curve for carbon fibre specimen 1

F _m (kN)	3.645
R _m (MPa)	1458
F _{eH} (kN)	3.645
R _{eH} (MPa)	1458
F _{eL} (kN)	1.080
R _{eL} (MPa)	432
F _p (kN)	2.255
R _p (MPa)	902
F _t (kN) /	
R _t (MPa)	/
E(GPa)	53

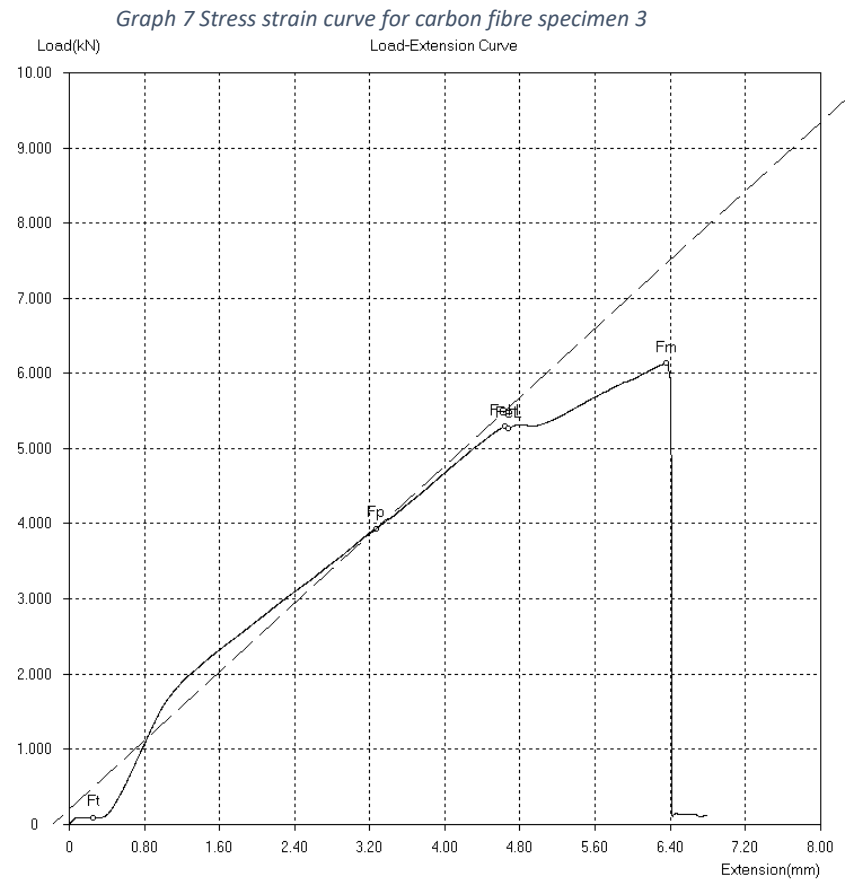


Graph 6 Stress strain curve for carbon fibre specimen 2

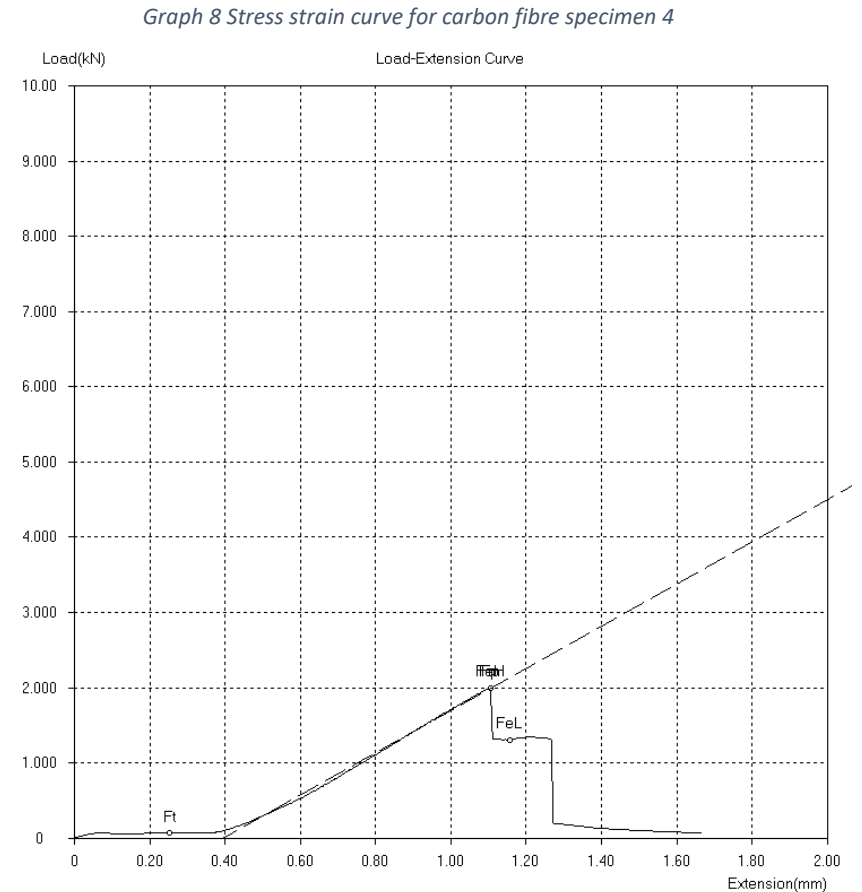
F _m (kN)	5.115
R _m (MPa)	2046
F _{eH} (kN)	4.955
R _{eH} (MPa)	1982
F _{eL} (kN)	4.945
R _{eL} (MPa)	1978
F _p (kN)	3.065
R _p (MPa)	1226
F _t (kN)	0.140
R _t (MPa)	56
E(GPa)	54



Fm(kN)	6.135
Rm(MPa)	2454
FeH(kN)	5.295
ReH(MPa)	2118
FeL(kN)	5.265
ReL(MPa)	2106
Fp(kN)	3.935
Rp(MPa)	1574
Ft(kN) /	
Rt(MPa)	/
E(GPa)	21

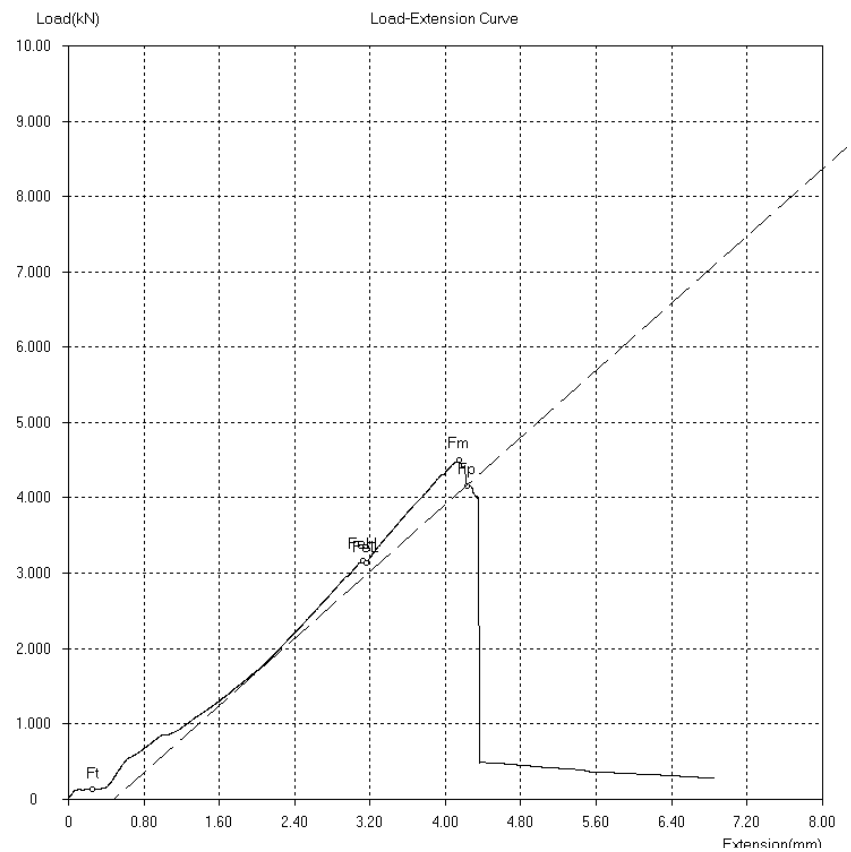


Fm(kN)	1.995
Rm(MPa)	798
FeH(kN)	1.995
ReH(MPa)	798
FeL(kN)	1.305
ReL(MPa)	522
Fp(kN)	1.995
Rp(MPa)	798
Ft(kN) /	
Rt(MPa)	/
E(GPa)	57



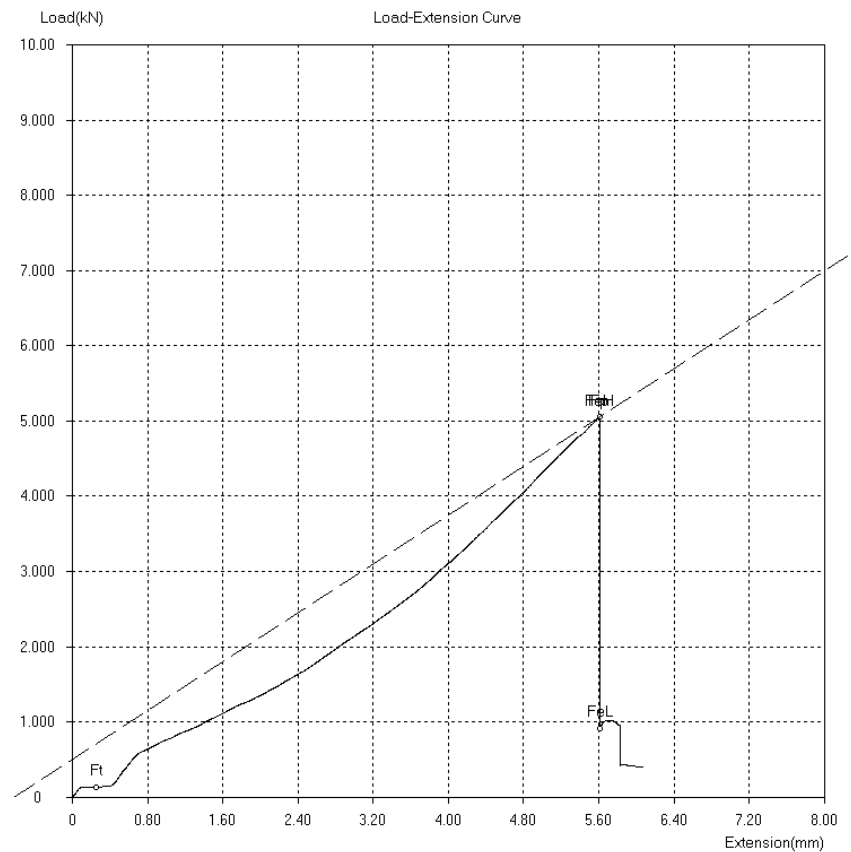
Graph 9 Stress strain curve for mixed fibre specimen 1

F _m (kN)	4.510
R _m (MPa)	1804
F _{eH} (kN)	3.165
R _{eH} (MPa)	1266
F _{eL} (kN)	3.130
R _{eL} (MPa)	1252
F _p (kN)	4.165
R _p (MPa)	1666
F _t (kN)	0.125
R _t (MPa)	50
E(GPa)	22



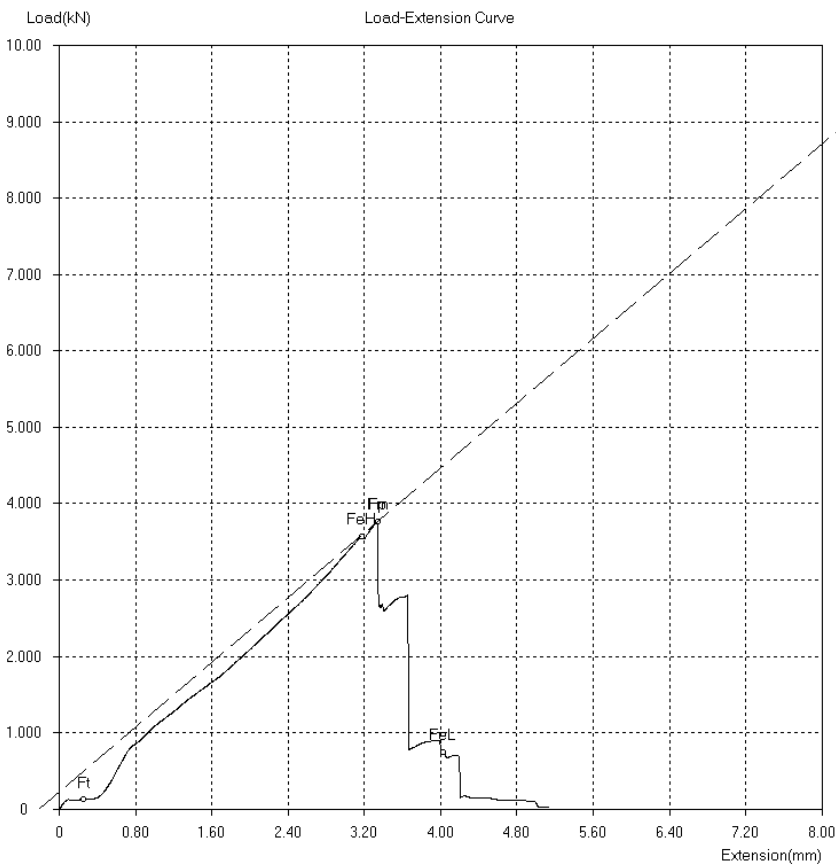
Graph 10 Stress strain curve for mixed fibre specimen 2

F _m (kN)	5.055
R _m (MPa)	2022
F _{eH} (kN)	5.055
R _{eH} (MPa)	2022
F _{eL} (kN)	0.910
R _{eL} (MPa)	364
F _p (kN)	5.055
R _p (MPa)	2022
F _t (kN)	0.135
R _t (MPa)	54
E(GPa)	16



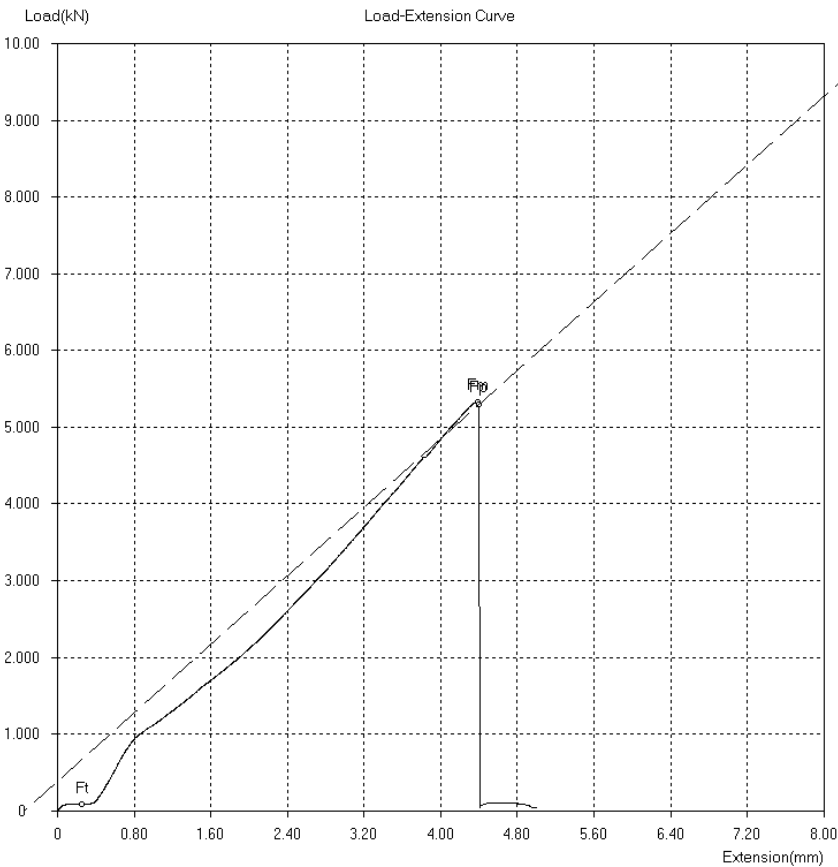
Graph 11 Stress strain curve for mixed fibre specimen 3

Fm(kN)	3.770
Rm(MPa)	1508
FeH(kN)	3.575
ReH(MPa)	1430
FeL(kN)	0.750
ReL(MPa)	300
Fp(kN)	3.770
Rp(MPa)	1508
Ft(kN)	0.125
Rt(MPa)	50
E(GPa)	20



Fm(kN)	5.335
Rm(MPa)	2134
FeH(kN)	/
ReH(MPa)	/
FeL(kN)	/
ReL(MPa)	/
Fp(kN)	5.300
Rp(MPa)	2120
Ft(kN)	/
Rt(MPa)	/
E(GPa)	22

Graph 12 Stress strain curve for mixed fibre specimen 4



Results analysis

Glass Fibre Specimens

E = (14)		F(KN) = 4.060	
E = 33	125/4 = E 31.35 GPa	F(KN) = 3.035	14.79/4 = F(KN) 3.697 UTS
E = 40		F(KN) = 4.095	
E = 38		F(KN) = 3.600	

3.697 kilonewton/meter² = 0.003697 megapascal

4.668 kilogram-force/millimeter² = 45.7774422 megapascal

Carbon fibre specimens

E = 53		F(KN) = 3.645	
E = 54	185/4 = E 46.25 GPa	F(KN) = 5.115	16.89/4 = F(KN) 4.223 UTS
E = (21)		F(KN) = 6.135	
E = 57		F(KN) = 1.995	

4.223 kilonewton/meter² = 0.004223 megapascal

4.223 kilogram-force/millimeter² = 41.41348295 megapascal

Mixed fibre specimens

E = 22		F(KN) = 4.510	
E = (16)	80/4 = E 20 GPa	F(KN) = 5.055	18.67/4 = F(KN) 4.668 UTS
E = 20		F(KN) = 3.770	
E = 22		F(KN) = 5.335	

4.668 kilonewton/meter² = 0.004668 megapascal

4.668 kilogram-force/millimeter² = 45.7774422 megapascal

Comparison

Aluminium is the second most used metal in the world currently, the properties of aluminium that are attractive includes: low density to weight ratio, high strength, superior malleability, easy to machine, excellent corrosion resistant and good thermal and electrical conductivity are amongst aluminium's most important properties.

Aluminium is easily worked using most machining methods – milling, drilling, cutting, punching, bending, etc. Furthermore, the energy input during machining is low.

Metal	Modulus of Elasticity	
	GPa	10 ⁶ psi
Aluminum Alloy 1100	69	10
Aluminum Alloy 2024	72.4	10.5
Aluminum Alloy 6061	69	10
Aluminum Alloy 7075	71	10.3
Aluminum Alloy 356.0	72.4	10.5

Element ♦	Young's modulus ♦ (GPa)	Offset or yield strength ♦ (MPa)	Ultimate strength ♦ (MPa)
aluminium	70	15–20	40-50

In looking at aluminium's material properties it can be seen that it is stronger than the mixed fibre material, but also a higher modulus of elasticity as well.

The mixed materials are much weaker than the aluminium, never the less

It can be seen in the results data that the mixed fibre had a much less (E) value compared to its counterparts, carbon fibre having double the (E) value of this mixed material.

The mixed material withstood the most force (KN) before reaching the materials ultimate tensile strength just a little more than carbon fibre of + 0.44 (KN).

The mixed material has half the amount of elasticity of a pure glass fibre shown in the table of page 15, which is not the samples tested in this report.

When it comes to the difference in weight of the aluminium and mixed material, the mixed material is 34g and a piece of aluminium with exact dimensions of the specimen samples will be 40g a +6g in weight.

Health and Safety

Throughout the stages of making the specimen samples, there can be numerous of hazards within the materials workshop, as heavy machinery can cause injury or death.

During the time, I have been in hazards such as hot surfaces or tripping, these could have been very high risk if I had now worn protective equipment's.

Equipment's used:

- **Gloves**
- **Goggles**
- **Face Mask**
- **Lab Coat**
- **Steel Toed Boots**



Workshop Ruling

It essential to know the rules of the workshop before using the workshop, this is because being unaware of the workshops surroundings can cause yourself or another person to get hurt.

It is very important to listen and to do what is instructed by the technician for each piece of machinery inside the materials workshop.

It is always appropriate to make an appointment with the technician to use the workshop so that at least someone knows that you're inside the workshop so that if anything goes wrong they can be aware about it.

Tools should always be placed where they are originally stored at all times after use, this ensures that the surfaces and floors are clean preventing any accidents from happening within the workshop.

Hazards sign are there to indicate the type of risk one is in, it is very important that the person understands the signs that are available to them in the room.

Limitations

All fibre wastes used in this project were already pre-cured with epoxy, meaning that a wider research will need to take place if one aims to use dry cut fibre.

This project does not determine all states of waste carbon fibre and glass fibre as I have not experimented further into other types of waste such as used scraps from high end automotive vehicles or aircrafts that are treated and hardened.

Materials conducted in this research are from left over prepreg carbon fibre sheets and left over glass fibre reinforced plastic sheets, both materials are wastes available in the institution due to being out of date for over a year.

There were only 4 samples of each specimen made for each material and by introducing more samples I could have achieved better accuracy and reliable result.

The curing agent used to attach the emery cloth tabs was super glue, which was the only glue available to me at the institution, possibly a more applicable curing agent can be used.

In this experiment only the tensile test was applied to the specimen samples, as a wider range of tests are available from flexural, compressive to shear.

There was no use of an extensometer which is an instrument that measures the specimen samples elongation to characterize the strain.

Specimen samples were not all identical as some specimen samples were 2.3mm – 2.4mm thick than what it is supposed to be the original 2.5mm in depth.

The cut-out chip size of the materials was done manually therefore some sizes may differ so slightly, although this shouldn't affect the specimens at all as it is discontinuous and randomly orientated anyway.

The mould has received some damage and small indentation is visible with a lot of scratched, this was done when trying to get the specimens out from the first 3 tries as hammering and budging of the mould was necessary to get the specimen out.

Both materials used were out of date for a few years and stored in various temperature conditions.

Conclusion

The aim of this project was to reduce the amount of waste dedicated to the landfill site, by bringing in my idea of mixing two waste composite fibres together I hoped to achieve something that is new and can be used in the aerospace and automotive industries. There are tonnes of carbon fibre waiting to be delivered to waste yards as airplanes are destined to be dismantled due to age and technology advancements.

Considering end of life material into the industry is a big hurdle, as it is not accepted easily, failure can occur using aged products and for an expired composite material's standpoint the characteristics bonding will have weakened at a considerable amount.

Most of the time during the project was spent into cutting up the materials, this took a large amount of time due to the size of the chips and no good alternative cutting method was available other than scissors. Finding time slots for the material lab was also an issue as the last couple of months before the project deadline was busy and needed to be scheduled.

Material chips are weighted, to fill the moulds volume as different materials need a changing amount of cut up chips to completely fill the gaps, for most specimen samples ready to press I have usually put 1g more of that specific material as this eliminates any errors of the mould filling.

Specimen sizes came out to be fairly accurate with only some imperfections due to scratches on the mould while releasing the specimens, specimens which came out of the mould were flat and not curved like most plastic would do after heats threatening. Although some specimen depth came out short

All the testing conditions for the specimen samples were kept the same, the experiment conducted the glass fibre samples first onto the carbon and so on. The specimen samples are kept separate from each other and marked to identify which material it is.

It is disappointing that the material wasn't what I had expected to be, a lot of thoughts have been put into whether the mix material will be stronger than aluminium as carbon properties are very strong compared to aluminium. It was expected that the weight of the mix material is superior to aluminium because it was basically polymer and fibres which has the least amount of weight in the composite world.

If only a purpose can be found for this new material it can still reduce waste overall, but unlikely with the current data shown as it is relatively weak even compared to aluminium and glass fibre. Making aluminium from raw ores will still be the most expensive and a lot of stages and processes are involved from separation to marketing, and as for the mix material it can be just retrieved in a waste form of overcut fibre parts.

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