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EFFECTS OF FIBRE SIZE ON THE PERFORMANCE OF BIODEGRADABLE COMPOSITES

Abheshek Pandey

K1721449

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Supervised by Dr Doni Daniel

Warranty Statement

This is a student project. Therefore, neither the student nor Kingston University makes any warranty, express or implies, as to the accuracy of the data or conclusion of the work performed in the project and will not be held responsible for any consequences arising out of any inaccuracies or omissions therein.

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Abstract

The fibreglass composites currently used in aircrafts are very light and very strong, hence having a high specific strength. Despite everything working in its favour as a suitable material in an aircraft, the issue is that it is not biodegradable, hence very difficult to get rid of at the end of its life. This study seeks a potential biodegradable composites non-loadbearing application in aircrafts as a replacement for GFRP composites, while focusing on studying the effects of fibre size on biodegradable composites. Sugarcane Bagasse Fibre and Gum Arabica were chosen and simulated as composites of various fibre lengths (2 mm, 4 mm, 6 mm) and volume fractions (20%, 35%, 50%), and two fibre orientations (random and uniform). The simulations provided density and Young's modulus data. Virtual tests were performed on the simulated composites, including three-point bending test and tensile test. Observation and analysis of the results showed that the composite's density decreased with increasing fibre volume fraction, ranging between 1140 kg/m³ and 769.766 kg/m³, and performance improved with increasing fibre length and fibre volume fraction) at 1093.82 MPa. The composites with a uniform fibre orientation performed better than the composites with a random fibre orientation.

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Nomenclature

Notation Symbols	Description	Units
A	Cross-sectional Area	mm ²
b	Beam width	mm
d	Fibre Diameter	mm
E	Young's Modulus	MPa
F	Tensile Force	Ν
h	Beam Thickness	mm
L	Support Span / Beam Length	mm
Le	Elongated Beam Length	mm
P	Applied Force	Ν
S	Fibre Length	mm
V	Volume Fraction	
δ	Mid-Span Deflection (delta)	mm
ε _f	Flexural Strain (epsilon)	mm/mm
ε _t	Engineering Strain (epsilon)	mm/mm
ν	Poisson's Ratio (<i>nu</i>)	
σ	Density (<i>rho</i>)	kg/m ³
$\sigma_{ m f}$	Flexural Stress (rho)	MPa
σt	Engineering Stress (rho)	MPa
Abbreviations		
ABS	Acrylonitrile Butadiene Styrene	
GA	Gum Arabic	
GFRP	Glass Fibre Reinforced Polymer	
NFR	Natural Fibre Reinforced	
RVE	Representative Volume Elements	
SCB	Sugarcane Bagasse	
Subscripts		
С	Composite	
f	Fibre	
т	Matrix	

1 Introduction

1.1 Project Overview

Glass fibre reinforced polymer (GFRP) composites make for excellent structural material. They are light, but strong, and have found application in multitudes of industries, ranging from aerospace to wind-energy production, from automobile to sporting goods (Kumar et al., 2020).

The GFRP composites currently used in aircrafts are very light and very strong, hence having a high specific strength. This is very important in aviation, as every additional gram requires more fuel, and every drop of fuel saved results in better performance and lower costs.

Despite everything working in its favour as a suitable material in an aircraft, an issue is that it is not biodegradable and notoriously hard to recycle, hence very difficult to get rid of at the end of its life. This is very unfortunate in an industry that is striving to be more and more eco-friendly every day.

Hence, it is imperative that a replacement to this material be found. This potential replacement must meet specific criteria, as replacing it with a heavier, but biodegradable material will solve the postservice life issue, but will increase fuel consumption. This is unacceptable as it would solve a longterm problem by creating contributing to another problem, pollution.

Thus, it is extremely important that this issue is remedied by replacing it with a new material that provides similar a similar performance while being biodegradable. It must be about as, if not less, dense as GFRP, while displaying similar amount of strength.

One factor that affects the performance of composites is the length of the fibre being used. The effect of fibre length on biodegradable composites must be studied in order to eventually reach the most optimal composition that will become a green replacement for GFRP.

Hence, this project will focus on studying the effects of fibre sizes on the performance of biodegradable composites for the purposes of identifying a replacement for fibreglass in non-loadbearing applications in aircrafts. Concepts such as biodegradability and composite compositions will be discussed in addition to the provision of simulations to support the designs proposed.

1.2 Project Aims

The primary aim of this project was to design and manufacture a suitable replacement for the fibreglass components in the aircrafts that is also biodegradable while studying the effects of fibre sizes on composites.

The secondary aim was to provide testing guidelines, should more such projects be undertaken in the future.

However, due to the Covid-19 Lockdown, these aims had to modified to accommodate the lack of access to the University's labs.

Now, the primary aim of the project is to design a suitable replacement for the fibreglass components in the aircrafts that is also biodegradable while studying the effects of fibre sizes on composites through simulation.

The secondary aim is to provide a guideline, should more such projects be undertaken in the future.

1.3 Project Objectives

The following were the initial objectives for the project:

- Identifying a biodegradable composite with desirable properties similar to fibreglass.
- Manufacture the composite composed of various fibre sizes through the use of available resources at Kingston University.
- Perform physical testing of the manufactured composite, involving the application of a threepoint flexural test, impact resistance test and FTA test.
- Generate FEA simulations for further analysis.

The following are the modified objectives for the project to accommodate for the changes to the new aims of the project:

- Identifying a biodegradable composite with desirable properties similar to fibreglass.
- Simulate the composite composed of various fibre sizes.
- Perform virtual testing and analysis of the composite using FEA simulations, involving the application of a three-point flexural test, impact test and tensile test.

1.4 Deliverables

The following were the initial deliverables for the project:

- Project reports, both planning and final, with the corresponding logbook
- Manufactured composites
- Test results and simulation data

The following are the modified deliverables for the project to accommodate for the changes to the new aims and objectives of the project:

- Project reports, both planning and final, with the corresponding logbook
- Test results and simulation data

2 Literature Review

2.1 Glass Fibre Reinforced Polymers

Glass fibre reinforced polymer (GFRP), or fibreglass, composites have functionals properties comparable to that of steel while being less dense (Morampudi *et al.*, 2021). GFRP composites have been widely used in many engineering industries for many reasons. They have high specific strength to weight ratio, are chemical and corrosion resistant. Additionally, they are easy to manufacture into various forms with the need of fewer fasteners (Ma *et al.*, 2016).

2.1.1 Fibreglass in the Aerospace Industry

In the aerospace industry, GFRP composites are used primarily in secondary structural components, such as wing tips and cryogenic fuel tanks (Ma *et al.*, 2016). In these cases, the glass fibres are produced in special woven forms that offer resistance to an object during impact, and offer a lower material cost when compared to carbon fibre. Epoxies are the most common the most common matrix used in the industry (Simeoli *et al.*, 2014).

Figure 1 shows how GFRP, along with other composites and materials, were utilised in a Boeing 787 Dreamliner, which is made up of 50% composites.



Figure 1: Composite Solutions Applied Throughout the 787 (JCFA, 2014)

2.1.2 Fibreglass Recyclability

With the growth of the the aerospace industry and the use of GFRP, an increasing concern arises in the handling of the composite waste at their end-of-life. Fibreglass is not an easily recyclable material and have a major impact on the environment and the resources required for the recycling process are great (Naqvi *et al.*, 2018). Additionally, the current mechanical and chemical recycling methods yeild a lower quality fibre (Liu *et al.*, 2017).

2.2 Natural Fibres

One solution to the issue surrounding the lack of efficient methods of recycling fibreglass could be to not use fibreglass at all. Natural fibres are low cost and light weight. They are also environmentally superior to glass fibre just by the virtue of their biodegradability, but that is not the only reason.

Natural fibre production has a lower impact on the encvironment in comparison with glass fibre as they are produced ainly by solar energy and their extraction requires minimal use of fossil fuels. Natural fibre reinforced (NFR) composites have a higher fibre content as glass fibres has better mechanical properties. This does however reduce the need of the base polymer in the matrix, which can be a major pollutant. NFR composites are lighter, which improves fuel efficiecy during the use phase (Joshi *et al.*, 2004).

Component Material \rightarrow	ABS	Hemp-
Environmental Indicator \downarrow	copolymer	Ероху
Total energy (MJ)	132	73
CO₂ emissions (kg)	4.97	4.19
Methane (g)	17.43	16.96
SO ₂ (g)	17.54	10.70
NO _x (g)	14.14	18.64
CO (g)	4.44	2.14
Phosphate emissions to water (g)	0	0.09
Nitrate emissions to water (g)	0.08	12.05

Table 1: Life Cycle Environmental Impact from production of an auto side panel (Wötzel, Wirth and Flake, 1999)

A study by Wötzel, Wirth and Flake (1999) assessed the life cycles of a side panel for an Audi A3 car made with Acrylonitrile Butadiene Styrene (ABS) co-polymer and himp fibre (66 vol%) epoxy resin composite. Table 1 shows the environmental impacts from the production of the side panel made with each material. The natural fibre component uses 45% less energy and most of the environmental impact from the hemp-epoxy composite was a result of the resin production. Despite being 66% of the volume, the hemp fire used only contributed to 5.3% of the energy demand.

2.2.1 Natural Fibres in the Aerospace Industry

Natural fibres have found applications in the aerospace industry for a combination of reasons. They are cheaper to produce and are very lightweight, with reasonable mechanical strength for aerospace application. A very significant reason for this is their biodegradability (Khan *et al.*, 2018).

Green composites are used in the aerospace industry in various ways, such as adhesives for attaching aeospace components (Tegegne and Argu, 2014).

2.2.2 Biodegradation

Biodegradation is the biologically catalysed reduction in the complexity of a chemical compound (Alexander, 1999). The material is biologically degraded by living organisms down to the base substances such as water, carbon dioxide, methane, basic elements and biomass. Materials such as many plastics and polymers can be very slow to biodegrade, and this leads to their accumulation at high rates of 25 million tonnes per year (Goswami and O'Haire, 2016), which has a major impact on the environment. All natural fibres are biodegradable, thus they do not have to be recycled into inferior products at high costs (Joshi *et al.*, 2004).

2.3 Sugarcane Bagasse

Sugarcane Bagasse (SCB) is the fibrous residue of sugarcane after crushing and extracting its juice. It is one of the largest agricultural residues in the world and has use in manufacture of paper, feed stock and biofuel (Pandey *et al.*, 2000). SCB mainly constitutes of cellulose, hemicellulose, lignin, ash and wax. Figure 2 shows the basic composition of SCB.



A: cell-soluble matter
 B: hemicellulose
 C: cellulose
 D: lignin
 E: ash
 F :crude proteined

 G:glucose yield by acid hydrolysis
 H: glucose yield by enzymatic hydrolysis
 +
 Figure 2: Chemical composition and sugar yield of sugar cane bagasse and its fractionated components (percent dry matter) (Ciegler, Catalano and Han, 1983)
 +

SCB can be an effective reinforcement fibre in polymeric composites It also produces good reactions when mixed with other chemicals, which derives materials with improved properties and characteristics. Certain chemical modifications of SCB are necessary as they significantly improve the matrix-fibre adhesion and enhances the desired mechanical properties of the manufactured composite (Loh *et al.*, 2013).

2.4 Gum Arabic

Gum Arabic (GA), also known as acacia gum, seen in Figure 3, is a mixture of polysaccharides and glycoproteins (Mariod, 2018). It has the properties of a glue and binder. It is the amorphous exudate derived from the stems of the Acacia tree, most commonly *Acacia senegal* and *Acacia arabica*. These trees are most commonly found in the tropics and subtropics (Nicholson, Shaw and Nicholson, 2000).



Figure 3: Gum Arabic Sample (Williams and Phillips, 2021)

3 Methodology

The project consisted of two main tasks. Owing to the Covid-19 pandemic and restrictions, physical experiments and tests could not be carried out at the University labs.

The effect of fibre length on the performance of biodegradable composites was investigated in this study. The composite studied comprised of a natural fibre and matrix.

The Rule of Mixture was used to calculate composite density, Young's modulus and strength.

ANSYS was used to perform composite simulations based on three variables:

- i. Fibre Orientation (Random, and Uniform)
- ii. Fibre Length (2 mm, 4 mm, and 6 mm)
- iii. Fibre Volume Fraction (20%, 35%, and 50%)

The simulated composites were assigned as material to virtual test specimens. The models of the specimen were meshed and sized using an automatic method.

The simulated composites were evaluated for their mechanical properties. This included Young's modulus, Three-Point Bending strength, Tensile strength, and Impact strength.

The obtained results were compared to study the effect of fibre length on the mechanical properties in both random and uniform distribution of fibres in the biodegradable composite.

4 Experimental Details

4.1 Materials

Sugarcane Bagasse and Gum Arabic was provided by Kingston University from the surplus after previous experiments. However, this was unused due to the pandemic.

Table 2 shows the characteristics of the materials, based on previous experimental data used to simulate the composites (Tian and Zhang, 2015; Rumble, 2017; Savalagi and Chittappa, 2017; Ciegler, Catalano and Han, 1983).

Material	Density σ (kg/m ³)	Young's Modulus <i>E</i> (MPa)	Poisson's Ratio v					
Sugarcane Bagasse	120	17000	0.3					
Gum Arabic	1400	38.2	0.49					
GFRP	2000	21000	0.33					

Table 2: Material Characteristics

4.2 Hand-Calculating Density

The density of the composites was in accordance to the Rule of Mixture, expressed in Equation 1. It is used to predict the properties of a composite based on the known properties of the fibre and matrix and their respective volume fractions (De Garmo, Black and Kohser, 2017).

$$P_c = V_f P_m + V_m P_m$$

Equation 1: Rule of Mixture

Where *P* is the property being calculated, *V* is the Volume Fraction.

Equation 1 is modified in Equation 2 to calculate density of the composite based on the known densities of the fibre and matrix being used.

$$\rho_c = V_f \rho_m + V_m \rho_m$$

Equation 2: Rule of Mixture - Density

4.3 Manufacture

The bagasse was initially treated with ionized liquid to ensure best possible yield. The proposed method was of manufacturing the composites and prepare them for testing was as follows:

A trial batch of composite samples of about 1-inch squares would have been produced with and without the use of vacuum bagging in order to determine which process will yield the desired thickness, which is 3-5 mm.

Once the most optimum method is determined, the composites with the various fibre sizes in a random arrangement were made of approximately 350mm x 100 mm.

These sheets would then be cut down to coupons of the ASTM dimension standards of 300 mm x 20 mm x 3-5 mm.

However, this has to be cancelled due to the pandemic, and instead, composite simulations were relied upon.

4.4 Composite Simulation

The composites with various fibre lengths and fibre volume fractions were simulated using the Material Designer component within ANSYS. This included defining the properties of the fibre and the matrix being used, defining the parameters for the simulation, and recording the simulation data.

ANSYS was used to simulate a GFRP. This was done to provide a benchmark for comparison with the simulated Bagasse Fibre and Gum Arabic composite.

The GFRP had a density σ of 2000 kg/m³, Young's modulus *E* of 21000 MPa, and Poisson's ratio ν of 0.33 and a Tensile strength ranging between 483 MPa - 4580 MPa (Shakir Abbood *et al.,* 2020; Li, Hsu and Hsieh, 2019).

4.5 ANSYS

ANSYS 2019 R2 was used to simulate the composites with various fibre lengths and fibre volume fractions using the Material Designer Component. The data acquired from these simulations was then used to perform Three-Point Bending Test and Tensile Test in the Static Structural analysis system. Figure 4 illustrates the project schematic within the ANSYS Workbench.



Figure 4: ANSYS Project Schematic

4.5.1 Defining Material Properties

The data known about the fibre and the matrix was input in A2: Engineering Data (Material Designer). These included density, Young's Modulus, and Poisson's ratio. This is illustrated in Figure 5.

Outline	of Schematic A2: Engineering Data					• 1	хţ	Outline	of Schematic A2: Engineering Data				- 5	X
	A	в	С	D	E		^		A B	С	D	E		'
1	Contents of Engineering Data	0	8	Source	Description			1	Contents of Engineering 🗦 🥥	8	Source	Description		
2	Material							2	= Material					
3	📎 Bagasse Fibre	•		S C				3	📎 Bagasse Fibre 🔄		📆 c			
4	📎 E-Glass	-		🔮 C Fiber	's only			4	🗞 E-Glass		🔮 C Fibe	rs only		
5	Sepoxy E-Glass UD			œ₽ c				5	🗞 Epoxy E-Glass UD		œ c			-
6	📎 Gum Arabic			📆 c			~	6	🗞 Gum Arabic		S C			1.
Proper	ties of Outline Row 3: Bagasse Fibre					y 1	ч х	Proper	ties of Outline Row 6: Gum Arabic				• Ç	, x
	A			В	С	D	E		А		в	с	D	Е
1	Property			Value	Unit	8	(p)	1	Property		Value	Unit	8	ip.
2	Material Field Variables			Table				2	🔁 Material Field Variables		Table			
3	🔁 Density			120	kg m^-3 💌		0	3	🔁 Density		1400	kg m^-3 💌		100
4	🗉 📔 Isotropic Elasticity					1		4	🗉 🔀 Isotropic Elasticity					
5	Derive from		Ì	Youn 💌				5	Derive from		Youn			
6	Young's Modulus			17000	MPa 💌	1	10	6	Young's Modulus		38.2	MPa 💌		0
7	Poisson's Ratio		8	0.3				7	Poisson's Ratio		0.49			0
8	Bulk Modulus			1.4167E+10	Pa		0	8	Bulk Modulus		6.3667E+08	Pa		0
9	Shear Modulus		1	6.5385E+09	Pa			9	Shear Modulus		1.2819E+07	Pa		

Figure 5: ANSYS Material Designer - Defining Material Properties

4.5.2 Material Designer

After the Engineering Data is defined, the A: Material Designer component system was started and the type of composite to be simulated was selected. From the choices between various Representative Volume Elements (RVE), the Chopped RVE Model was selected. This was done for both, the random fibre orientation and the uniform fibre orientation.

Figure 6 depicts the process of defining various parameters for the simulation of the composite. First, the materials being simulated in the composite are selected (Figure 6(a)). The options were based on the materials selected and defined in A2: Engineering Data (Material Designer).

The geometry of the fibre used was defined (Figure 6(b)). This includes the fibre volume fraction, the fibre's aspect ratio (fibre length to fibre diameter), and the fibre diameter. The orientation tensor was left at the default values for the composites with the random fibre orientation, and defined the composites with the uniform fibre orientation to allow for minor variations in the fibre arrangement. The geometry for a composite with the uniform fibre orientation is illustrated in Figure 7.

6(a)	6(b)	6(c)
Outline	[#] Outline	부 Outline 부
RVE Model (Chopped)	RVE Model (Chopped)	RVE Model (Chopped)
Struct., Laye.,, Selecti.,, Grou.,, Vie	ws Outli_ Struct. Laye Selecti Grou Vie	ews Outli Struct. Laye Selecti Grou Views Outli
Options - Materials	[‡] Options - Chopped fiber	P Options - Mesh P
General	ieneral	△ General
Matrix: Gum Aral Fiber: Bagasse	bic ▼ Fiber volume fraction: 0.2 F Fibre ▼ Seed: 56550 F Orientation Tensor: a11: 0.98 F a22: 0.02 F a33: 1.73472347 Aspect ratio: 5.128 F Fiber diameter: 390 µm F	P Maximum size: 250 P Regenera Adapt towards edges Use Block Meshing Vuse Conformal Meshing Use Periodic Meshing Use Periodic Meshing
6(d)	6(e)	
Outline RVE Model (Chopped) Meterials Geometry Mesh Settings Analyses	Outline RVE Model (Chopped) Waterials Geometry Settings Analyses Constant Material Evalue Results	ation 6(a): Selecting the Materials 6(b): Defining Fibre Geometry 6(c): Defining Meshing Parameters 6(d): Defining Anisotropy Settings
Struct Laye Selecti Grou View	s Outli Struct Laye Selecti Grou Vie	ws Outling Composito
Options - Settings General	Options - Constant material solve General	a d(e). Analysing composite
Type of anisotropy: Orthotropic Compute linear elasticity Compute coefficients of thermal Compute thermal conductivity Use periodic boundary condition Use material symmetry in XY Use material symmetry in XZ Use material symmetry in YZ	expan:	

Figure 6: ANSYS Material Designer - Simulating Composites



Figure 7: ANSYS Material Designer - Uniform Fibre Orientation Geometry

The meshing parameters were then defined (Figure 6(c)). This includes the maximum mesh size and the use of conformal meshing. Figure 8 illustrates the meshed geometry for a composite with the uniform fibre orientation.



Figure 8: ANSYS Material Designer - Uniform Fibre Orientation Meshed Geometry

The type of anisotropy selected was Orthotropic in the simulation settings. (Figure 6(d)). Finally, the composite was simulated and analysed (Figure 6(e)).

4.5.3 Uniform Fibre Orientation

ANSYS was used to simulate the uniform orientation of the fibres in the composite. Here, the uniform direction does not mean perfectly aligned unidirectional fibres, but slightly misaligned fibres that follow a uniform direction. The Material Designer component within ANSYS was used to simulate the uniform orientation of the fibres.

The simulated SCB fibres had a constant diameter *d* of 0.39 mm, density σ of 120 kg/m³, Young's modulus *E* of 17000 MPa, and Poisson's ratio v of 0.3.

The fibres were simulated at three lengths s: 2 mm, 4 mm, and 6 mm.

Each fibre length was then simulated in the composite at various Fibre Volume Fractions: 20%, 35% and 50% (Fibre Volume Fraction V_f 0.2, 0.35, 0.5).

The simulated GA matrix had a constant density σ of 1400 kg/m³, Young's modulus *E* of 38.2 MPa, and Poisson's ratio v of 0.49.

These composites are referred to as, for instance, U2-20, where U signifies the Uniform fibre orientation, 2 signifies the fibre length at 2 mm, and the 20 signifies the 20% fibre volume fraction.



Figure 9: U2-20 Composite Simulation

Figure 9 shows the model of the meshed simulation for the U2-20 composite within the Material Designer component of ANSYS. U2-20 has a density σ_{U2-20} of 1143.8 kg/m³. Further material characteristics of all simulated composites with a random fibre orientation are listed in Appendix B.

4.5.4 Random Fibre Orientation

ANSYS was used to simulate the random orientation of the fibres in the composites. The Material Designer component within ANSYS was used to simulate the random orientation of the fibres.

The simulated SCB fibres had a constant diameter *d* of 0.39 mm, density σ of 120 kg/m³, Young's modulus *E* of 17000 MPa, and Poisson's ratio v of 0.3.

The fibres were simulated at three lengths s: 2 mm, 4 mm, and 6 mm.

Each fibre length was then simulated in the composite at various Fibre Volume Percent: 20%, 35% and 50% (Fibre Volume Fraction V_f 0.2, 0.35, 0.5).

The simulated GA matrix had a constant density σ of 1400 kg/m³, Young's modulus *E* of 38.2 MPa, and Poisson's ratio v of 0.49.

These composites are referred to as, for instance, R2-20, where R signifies the Random fibre orientation, 2 signifies the fibre length at 2 mm, and the 20 signifies the 20% fibre volume fraction.



Figure 10: R2-20 Composite Simulation

Figure 10 shows the model of the meshed simulation for the R2-20 composite within the Material Designer component of ANSYS. R2-20 has a density σ_{R2-20} of 1151.1 kg/m³. Further material characteristics of all simulated composites with a random fibre orientation are listed in Appendix A.

4.5.5 Defining Composite Properties

The Engineering Data acquired from each Composite Simulation (A: Material Designer) was manually input into B: Engineering Data, as illustrated in Figure 11. This was done to avoid overloading the system while simulating the later tests, which occurred when A2: Material Designer was directly linked with the Static Structural analysis systems.

Outline	of Schematic B2, C2, E2: Engineering) Data					Ą	×
	A	С	D	E			^	
1	Contents of Engineering Data	8	Source	Description	n			
2	Material							
3	S GFRP	-		🛐 c				12
4	📎 R2-20	-		📆 c				
5	📎 R2-35	-		📆 c				
6	📎 R2-50	-	1	📆 c				
7	📎 R4-20	F		📆 c				
8	📎 R4-35			📆 c				~
Propert	ties of Outline Row 4: R2-20			, ,		¥	ą	×
	A			в	С		D	Е
1	Property			Value	Unit	6	×	कि
2	🔀 Material Field Variables			Table				
3	🔀 Density			1151.1	kg m^-3	•		
4	🖃 🔀 Orthotropic Elasticity					[
5	Young's Modulus X direction			103.86	MPa	-		
6	Young's Modulus Y direction	ŝ		105.12	MPa	-		
7	Young's Modulus Z direction	8		100.73	MPa	-		
8	Poisson's Ratio XY			0.45713				
9	Poisson's Ratio YZ			0.49929				
10	Poisson's Ratio XZ		0.49398					
11	Shear Modulus XY]	29.761	MPa	-		
12	Shear Modulus YZ			30.277	MPa	-		
13	Shear Modulus XZ	29.969	MPa	-				

Figure 11: ANSYS Engineering Data - Composite Properties

4.6 Testing

The composite coupons were to be used to perform various tests: Three-Point Bending Test, Impact Test, and Tensile Test.

However, due to a lack of access to the University's labs, the simulated composites were used to perform the virtual tests through FEA simulations within ANSYS.

ANSYS was initially supposed used to perform additional simulations to gather as much data as possible. However, it was used to perform the required tests virtually instead to provide the data for analysis.

4.6.1 Three-Point Bending Test

The Three-Point Bending Test is a static structural test and is used to determine the flexural properties such as the Flexural Stress, Flexural Strain, and Flexural Modulus (ASTM, 2015).

The Flexural Stress σ_f (MPa) is the maximum stress at the outer surface conforming with the maximum applied force and is calculated using the following formula:

$$\sigma_f = \frac{3PL}{2bh^2}$$

Equation 3: Flexural Stress

Where, P is the applied force (N), L is the support span length (mm), b is beam width (mm), and h is the beam thickness (mm).

Flexural Strain ε_f (mm/mm) is the maximum strain at the outer surface and is calculated using the following formula:

$$\varepsilon_f = \frac{6dh}{L^2}$$

Equation 4: Flexural Strain

Where, *d* is the mid-span-deflection (mm).

Flexural Modulus E_f , which describes the resistance a material has to bending, is calculated using the following formula:

$$E_f = \frac{L^3 P}{4bh^3 d}$$

Equation 5: Flexural Modulus

Each simulated composite sample was assigned to a shell component of dimensions 150 mm x 20 mm x 5 mm. Boundary values were assigned such that the bar rested on two virtual supports with a span of 120 mm between them. Then, a downward force was applied to the middle of the bar, at an equidistant point between the two supports until it was deflected by 1 mm.

The simulation provides the value for the flexural stress σ_f for each composite's analysis. This value is then plugged into Equation 3 and the applied force *P* is calculated. This value of *P* is then used to calculate the Flexural Modulus E_f using Equation 5.

The Three-Point Bending Test was simulated using the Static Structural analysis system within ANSYS. This included modelling a shell element, defining thickness, applying a mesh and boundary conditions, and performing the analysis.

4.6.1.1 Shell Element and Model

A shell element with the length and thickness of the specimen being tested was designed in F2: SpaceClaim (Figure 12(a)). The Pull feature was used to assign the element a surface (Figure 12(b)).



Figure 12: SpaceClaim Shell Element

Reference lines were added to the shell element to provide positions for applying the boundary conditions (Figure 13(a)). The first reference line was drawn across the middle of the element, and 13(a)



Figure 13: SpaceClaim Shell Element with reference lines

the other two were equidistant from it to simulate a support span. Figure 13(b) illustrates the surfaced element with the reference lines.

The shell element was then imported into E: Three-Point Bending Test (Static Structural) and opened in ANSYS Mechanical as illustrated in Figure 14.



Figure 14: ANSYS Mechanical - Shell Element (Bending Test)

The shell element was assigned a material from the available in B: Engineering Data, as illustrated in Figure 15. This was repeated for each composite tested. The model was also assigned a thickness, and based on the settings of ANSYS Mechanical, this thickness would be visible either at this or a later stage.



Figure 15: ANSYS Mechanical - Shell Model with Material and Thickness (Bending Test)

4.6.1.2 Meshing

The composite model was assigned an Automatic Meshing Method and a default mesh size. This is illustrated in Figure 16, which also illustrates the model's thickness.



Figure 16: ANSYS Mechanical - Meshed Shell Model (Bending Test)

4.6.1.3 Boundary Conditions

Boundary conditions were applied to the model with the aid of the reference lines, as illustrated in Figure 17. Lines A and B were assigned a Simply Supported boundary condition and line C was assigned a Displacement Support boundary condition to facilitate the bending simulation.



Figure 17: ANSYS Mechanical - Boundary Conditions (Bending Test)

4.6.1.4 Analysis

The Three-Point Bending Test was simulated, and the composites were tested and using the Normal Elastic Strain (Figure 18), and the Normal Stress (Figure 19) solutions.



Figure 18: ANSYS Mechanical - Solution - Normal Elastic Strain (Bending Test)



Figure 19: ANSYS Mechanical - Solution - Normal Stress (Bending Test)

4.6.2 Tensile Test

The Tensile Test is a static structural test and is used to determine the tensile properties such as the Engineering Stress, Engineering Strain, and the Tensile Strength, and Flexural Modulus (ASTM, 2017).

The Engineering Stress σ_t (MPa) is calculated using the following formula:

$$\sigma_t = \frac{F}{A}$$

Equation 6: Engineering Stress

Where, F is the tensile force, and A is the cross-sectional area.

The Engineering Strain ε_t (mm/mm) is calculated using the following formula:

$$\varepsilon_t = \frac{\Delta L}{L} = \frac{L_e - L}{L}$$

Equation 7: Engineering Strain

Where, *L* is the length of the beam, L_e is the elongated length of the beam, ΔL is the change in the length of the beam.

Each simulated composite sample was assigned to a solid component of dimensions 150 mm x 20 mm x 5 mm. Boundary values were assigned such that one end of the bar was provided a fixed support. Then, a force F that increases up to 1000 N was applied to the other end of the bar and the deformation was measured.

The simulation provides the value for the Engineering stress σ_t for each composite's analysis. Since the simulation does not apply force until the specimen yields and fractures, the Ultimate Tensile strength could not be calculated. This also means that not enough data is generated to plot an Engineering Stress / Engineering Strain curve, as illustrated in Figure 20. The plot can be used to derive the material's Young's Modulus. In this case, fortunately, the simulation of the various composites provides all the data regarding the Young's Modulus (See Appendix A and Appendix B).



Figure 20: Typical Engineering Stress/Strain Plot (Guo et al., 2017)

The Tensile Test was simulated using the Static Structural analysis system within ANSYS. This included modelling a 3D solid element, applying a mesh and boundary conditions, and performing the analysis.

4.6.2.1 Solid Model

A sketch with the length and thickness of the specimen being tested was designed in D2: DesignModeler (Figure 22). It was then extruded to the required thickness, forming the solid model (Figure 21).



Figure 22: DesignModeler - Sketch



Figure 21: DesignModeler - Solid Model

The solid model was then imported into C: Tensile Test (Static Structural) and opened in ANSYS Mechanical. The solid model was assigned a material from the available in B: Engineering Data, as illustrated in Figure 23. This was repeated for each composite tested.



Figure 23: ANSYS Mechanical - Solid Model with Material (Tensile Test)

4.6.2.2 Meshing

The composite model was assigned an Automatic Meshing Method and a default mesh size. This is illustrated in Figure 24.



Figure 24: ANSYS Mechanical - Meshed Solid Model (Tensile Test)

4.6.2.3 Boundary Conditions

Boundary conditions were applied to the model, as illustrated in Figure 25. Face A was assigned a Fixed Support boundary condition and Face C was assigned a Force along the x-direction to facilitate the tensile simulation.



Figure 25: ANSYS Mechanical - Boundary Conditions (Tensile Test)

4.6.2.4 Analysis

The Tensile Test was simulated, and the composites were tested and using the Total Deformation (Figure 26), the Normal Elastic Strain (Figure 27), and the Normal Stress (Figure 28) solutions.



Figure 26: ANSYS Mechanical - Solution - Total Deformation (Tensile Test)



Figure 27: ANSYS Mechanical - Solution - Normal Elastic Stress (Tensile Test)



Figure 28: ANSYS Mechanical - Solution - Normal Stress (Tensile Test)

4.6.3 Charpy Impact Test

Due to issues with time constraints and limited computational capacity, the Charpy Impact Test could not be performed physically nor simulated.

Since the test was not performed but remains significant in examining a material, this section describes how it may be performed.

The Charpy Impact Test is used to determine the absorption of energy by a material during fracture and its toughness. It is used to determine a material's impact resistance by impacting the specimen with a swinging pendulum on an anvil (Meyers and Chawla, 2008).

The specimen is placed in a similar way as in the Three-Point Bending Test, with two supports on one face and a force applied to the middle of the opposite surface. In this case, however, the force is derived from the swinging pendulum. Additionally, the face not being impacted is notched. Figure 29 illustrates a typical set up for a Charpy impact Test and the dimension of the notch.



Figure 29: Typical set up for a Charpy Impact Test (Hughes, 2009)

The decrease in the pendulum motion after impact is used to determine how much energy was absorbed by the material being tested. Factors such as temperatures, strain rates and stress concentrations at the notch and other cracks or void affect the material's toughness (Saba, Jawaid and Sultan, 2019). Measuring impact resistance and material toughness is important in the context of application in the aerospace industry since there is a risk of bird strikes, or impacting debris.

5 Results and Discussion

5.1 Composite Simulation

All the simulated SCB/GA composites display orthotropic properties. This means that don't behave symmetrically to loads. Their reaction depends on the direction of the force and hence they cannot provide a one-to-one comparison with the simulated GFRP, which is isotropic. However, since the simulated composite is in the shape of a beam, the orthotropic Young's Modulus values for the x-direction (length of the beam) are compared with the isotropic values of the GFRP.

5.1.1 Density

Density is a major factor for any material trying to replace the GFRP, as lower the density, lower the mass of a material for a given volume. The GFRP simulated in this project has a density of 2000 kg/m³.

The density for each fibre volume fraction was hand-calculated based on the Rule of Mixture using Equation 2. Since the equation accounts for the volume fraction, these density predictions are applicable for all the fibre lengths being tested (De Garmo, Black and Kohser, 2017). The results of the calculations are listed in Table 3.

Fibre Volume Fraction (%)	Density σ (kg/m ³)
20	1144
35	952
50	760

Table 3: Rule of Mixture - Density Results

These density values follow a simple trend: as the fibre volume fraction increases, the density decreases. This is because Sugarcane Bagasse has a density less than 10% of the density of Gum Arabic. Hence, as SCB occupies a larger volume, the density of the composite decreases.

Each of these predicted density values is much lower than the density of the GFRP, with the two composites with the greatest fibre volume fraction having a density of less than half that of GFRP.

Figure 30 depicts the densities of the simulated SCB/GA composites, along with the Rule of Mixture values. Every simulated composite has an advantage over the GFRP in terms of density, since each one is less dense than the GFRP. The densest composite, the R6-20, at 1225.2 kg/m³ is almost 40% less dense than the GFRP, and of six of the composites have less than half the density of GFRP (See Appendix A and Appendix B).



Figure 30: Graph - Density - SCB/GA

Low density is especially important in the aerospace industry, since every little weight reduction of an aircraft reduces the its fuel requirement. This is makes flight not only cheaper, but also greener, in addition to the use of an environmentally friendlier material.

Figure 30 might seem incomplete at first glance, but that is only because the plot for the U6 composites entirely covers the plot for the U4 composites.

The density values for the composites with the uniform fibre orientation follows very closely the density values predicted by the Rules of Mixture, as can be seem in Figure 31, which depicts a closer version of the same plot and focuses on the U composites along with the RoM values. The tiny variations in the simulated densities can be chalked up to inconsistencies in the processing of the simulations.



Figure 31: Graph - Density - Uniform Fibre Orientation

The simulated composites with the random fibre orientation, on the other hand, does not follow the trend set by the Rule of Mixture predictions and the simulated U composites, as seen in Figure 32, which depicts a closer version of the same plot and focuses on the R composites along with the RoM values.



Figure 32: Graph - Density - Random Fibre Orientation

The only fibre length that seems to be following the trend is the 2 mm fibre in the R2 composites, though at a much shallower gradient. The other two composite groups, R4 and R6 follow the trend between 20% and 35% fibre volume fraction at approximately the same gradient as that of R2, but instead of continuing to decrease after 35% fibre volume faction, the densities for R4 and R6 rise.

This seems to be an error in the simulation, since the orientation of the of the fibres does not make a difference in the volume occupied by them within the matrix. The simulations for the R composites were repeated, but the results were similar.

While unlikely that these values are correct, they will still need to be validated, along with the other results, once it is possible to manufacture and physically test SCB/GA at the University labs.

Since there is no relationship between the density and other tested properties of the composite being tested, the density values were not changed in the Engineering Data of the project.

5.1.2 Young's Modulus

The GFRP has an isotropic Young's modulus of 2100 MPa. In the x-direction (the length of the simulated beam), every composite has a lower Young's modulus. This means that the GFRP is very stiff and can take a larger load with lower strain when compared to the simulated composites, especially in comparison to the composites with the random fibre orientation, as seen in Figure 33.

Because the scope of this project is to look into bio-composites for the purposes of non-load-bearing applications in aircrafts, less stiff materials need not be the taken out of consideration because of a lower Young's Modulus.



Figure 33: Graph - Young's Modulus (x-direction) - SCB/GA

The Young's modulus for the composites with the random fibre orientation remains under 150 MPa for the most part. The values for the Young's modulus in the x-direction remain pretty uniform through the various fibre volume fractions for all the fibre lengths.

Figure 34 provides a closer look at the Young's modulus in the x-direction for the composites with a random fibre orientation. While the Young's modulus for R2 and R6 increases with the fibre volume fraction, it is the opposite R4. One conclusion that can be reached from this is that this occurs due to the random simulation of the fibres. If re-simulated with identical parameters, it is very likely that these moduli values will remain within a similar range, but they will not follow this exact trend.

Figure 35 provides a closer look at the Young's modulus in the x-direction for the composites with a uniform fibre orientation. His follows a more noticeable trend: The modulus values increase with an increase in both, the fibre volume fraction and the length of the fibres used. This can be attributed to the fact that all the fibres face a single direction (the x-direction in this case) and this certainly allows these composites to withstand higher stresses at lower strains.

However, the same cannot be said about the Young's modulus in the other directions for the composites with the uniform fibre orientation. They fall within the same range as the values for the random fibre orientation and are as low as $E_y = 86.54$ MPa in the case of U6-20.



For the composites of with the random fibre orientation, the Young's Modulus values in all direction fall within the same range, making them uniformly less stiff.

Figure 34: Graph - Young's Modulus (x-direction)- Random Fibre Orientation



Figure 35: Graph - Young's Modulus (x-direction)- Uniform Fibre Orientation

If the U composites are manufactured as laminated layers, it is likely that these composites, especially U4-35 and U4-50, and U6-35 and U6-50, would have major potential to become a viable replacement for GFRP, especially due to their low density and relatively high unidirectional Young's Modulus.

5.2 Three-Point Bending Test

The force applied to achieve a deflection of 1 mm has a great disparity between GFRP and the simulated composites. It took 133.33 MN to create a 1 mm deflection in the GFRP, whilst the average force to do the same to the simulated composites was much lower at 1.67 MN. These along with data regarding the three-point bending are listed in Appendix C.

Figure 36 shows the three-point bending test being performed on the composite R2-20.



Figure 36: Three-Point Bending Test on R2-50

This can be attributed to their much lower stiffness and Young's moduli in various directions. Of the simulated composites, the most force required to achieve this deflection was U6-35 at 3.186 MN. This is another reason why it would be beneficial to manufacture and test this and the previously composites as laminated composites.

Based on the measured flexural stress and strain, the flexural modulus, which describes the resistance a material has to bending, for the GFRP was calculated to be at 2687.904 MPa. Because of how much greater it is when compared with the values for the simulated composites, it is not plotted on the graph in Figure 37.



Figure 37: Graph - Flexural Modulus - SCB/GA

This further showcases why the composites with random fibre orientation was easier to deform when compared to the composites with uniform fibre orientation. The R composites mostly have a uniform Flexural modulus through the various fibre volume fractions, except for when R6-50 spikes up to almost 60 MPa.

The U composites on the other hand show an increase in the flexural modulus as both the fibre length and the fibre volume fraction increases. Here, once again U4 and U6 show similar properties at 35% and 50% fibre volume fractions, and they would benefit from further testing as laminated composites.

5.3 Tensile Test

A Tensile force of 1000 N was applied to one end of each simulated composite and the elongation measured, and the engineering stress and strain were measured. Unfortunately, yield and tensile strength were not calculated.



Figure 38 shows the tensile test being performed on the composite R2-20.

Figure 38: Tensile Test on R2-20

The Engineering Stress was calculated to be approximately 10 MPa for each composite, including GFRP. The engineering strain measured was below 0.1 mm/mm for each composite.

With the force of 1000 N, the GFRP experienced an elongation, ΔL , of 0.07 mm. The elongation experienced by the simulated composites were far greater, as evidenced by Figure 39, depicting the elongation experienced by the R composites, and Figure 40, depicting the elongation experienced by the U composites.

The R composites experienced greater levels of elongation, with R2-20 experiencing an elongation of 14.35 mm. One thing that should be noted is that at these levels of elongation, almost 10% of the body length, it is likely that the underwent yielding and necking. There also seems to be an off-trend plot here. R4's elongation increases with an increase in fibre volume fraction, instead of decreasing, like every other simulated composite.



Figure 39: Graph - Elongation - Random Fibre Orientation

The elongation levels for the U composites are comparatively low. R2-20 faces the highest elongation of these composites, at 6.6 mm. The elongation level or U6 almost uniform through the fibre volume fractions, and U4 has similar levels of elongation at 35% and 50% fibre volume fractions. This would be another property that would only be improved by the process of lamination.



Figure 40: Graph - Elongation - Uniform Fibre Orientation

It is necessary to point out that all these data points were collected through the use of simulation software and these results need to be validated by manufacturing and physically performing the mentioned tests on the SCB/GA composites of various fibre volume fractions and fibre orientations.

6 Conclusion

From the literature research and review undertaken for this dissertation, a biodegradable replacement for Glass Fibre Reinforced Polymer (GFRP) for use in non-load-bearing applications in the aerospace industry was proposed. This proposed composite was supposed to be manufactured and evaluated at Kingston University's material laboratory, but the Covid-19 pandemic caused these plans to be changed.

A biodegradable composite made of Sugarcane Bagasse (SCB) and Gum Arabic (GA) was identified to have the potential to be a suitable replacement for GFRP.

This composite was simulated consisting of three fibre lengths (2 mm, 4 mm, and 6 mm) and two fibre orientations (random and uniform) and their properties were studied. A standard GFRP was simulated as well to provide a benchmark.

FEA simulations were used to perform tests. This included a three-point bending test and a tensile test. The data acquired was then further analysed.

Due to time and computational constraints, a Charpy impact test was not carried out.

It was observed that the composites with a uniform fibre orientation was performed better than the composites with a random fibre orientation in the tested scenarios. They were less dense, ranging between 1140 kg/m³ and 769.766 kg/m³, with the density decreasing with increasing fibre length and fibre volume fraction; they had greater Young's and flexural moduli, which increased with fibre length and fibre volume fraction, and the greatest Young's modulus belonging to U6-50 (6 mm fibres at a 50% volume fraction) at 1093.82 MPa; and they faced the least amount of elongation, which decreased with increasing fibre length and fibre volume fraction.

Of the composites with a uniform fibre orientation, the performance of the composites with 4 mm and 6 mm fibres were almost identical, and better in comparison with the composites with 2 mm fibres. This implies that increasing fibre lengths improves the performance of biodegradable composites.

Composites U4-35, U4-50, U6-35, and U6-50 were identified as potential replacements for GFRP, and have been recommended for manufacture in the form of laminated composites for further testing.

Testing procedures have been provided within the report that outline how further tests and analysis can be carried out and how to further develop this research to find the best replacement for GFRP in the aerospace industry.

7 Future Work

Should this dissertation be further worked upon, there are developments that could be incorporated either into the set-up for the experiments, or the experiments themselves.

Foremost, the Sugarcane Bagasse/Gum Arabica composites of various fibre sizes and the volume fractions would be fabricated and manufactured, once the pandemic subsides. This would allow for physical testing to be performed on the composites and provide a wider range of data for analysis and validation for the simulations.

The SCB/GA composites could be manufactures through different methods, such as with and without the use of vacuum bagging. This would provide an additional dimension to the data being recorded.

The SCB/GA composite could also be manufactured with laminated layers. This would improve the desired properties of the material and would allow for further analysis and comparison of data.

Composites with different fibre and matrix combinations could be manufactured and tested in an effort to find the best possible replacement for the GFRP.

GFRP standard in the aerospace industry, especially those this green composite is trying to replace, could be manufactured or acquired to perform tests on. This would provide an accurate benchmark and industry standards that the potential replacement would be looking to improve upon.

These recommendations would obviously be limited by the project budget. However, each project based on the recommendations could stepping stones for the successive ones, something this dissertation aspires to be.

The Three-Point Bending Test could be physically performed on composite samples where the force applied is controlled instead of achieving a constant deformation.

The Tensile Test could be improved by using a dog bone shaped composite instead of just a simple beam. The test could be performed and tensile strength could be measured. Since the fibres simulated were orthotropic, a biaxial tensile test could also be performed.

Furthermore, additional tests could be performed on the composites. This would allow for a more thorough analysis of the performance of the biodegradable composite.

Tests such as a Charpy Impact Test, which could not be performed in this project, would provide valuable information regarding material's toughness. A rheology could be performed on the materials as well.

Regardless of what is done, the destination is a greener aerospace industry, and this is something that needs to be worked towards.

References

Alexander, M. (1999) Biodegradation and Bioremediation. 2nd edn.Academic Press.

'D3039 / D3039M-17 Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials' (2017) Available at:<u>www.astm.org</u>.

'D7264/D7264M Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials' (2015) Apr 1,.Available at:<u>http://www.astm.org/Standards/D7264/D7264M</u>.

Ciegler, A., Catalano, E.A. and Han, Y.W. (1983) 'Chemical and physical properties of sugarcane bagasse irradiated with γ rays', *Journal Agricultural Food Chemistry*, (31), pp.34-38.

De Garmo, E.P., Black, J.T. and Kohser, R.A. (2017) *DeGarmo's Materials and processes in manufacturing*. 12th edition, global edition edn. Hoboken, NJ: Wiley.

Goswami, P. and O'Haire, T. (2016) '3 - Developments in the use of green (biodegradable), recycled and biopolymer materials in technical nonwovens', in Kellie, G. (ed.) *Advances in Technical Nonwovens.* Woodhead Publishing, pp. 97-114.

Guo, Y.B. et al. (2017) 'Response of high-strength concrete to dynamic compressive loading', *International Journal of Impact Engineering*, 108 pp.114-135.

Hughes, S.E. (2009) 'Chapter 6 - Non-destructive and Destructive Testing', in Hughes, S.E. (ed.) *A Quick Guide to Welding and Weld Inspection.* Woodhead Publishing, pp. 67-87.

Joshi, S.V. *et al.* (2004) 'Are natural fiber composites environmentally superior to glass fiber reinforced composites?', *Composites Part A: Applied Science and Manufacturing*, 35(3), pp.371-376.

Khan, T., Hameed Sultan, Mohamed Thariq Bin and Ariffin, A.H. (2018) 'The challenges of natural fiber in manufacturing, material selection, and technology application: A review', *Journal of Reinforced Plastics and Composites*, 37(11), pp.770-779.

Kumar, K.V. *et al.* (2020) 'Effect of bio waste (conch shell) particle dispersion on the performance of GFRP composite', *Journal of Materials Research and Technology*, 9(4), pp.7123-7135.

Li, Y., Hsu, T. and Hsieh, F. (2019) 'A Study on Improving the Mechanical Behaviors of the Pultruded GFRP Composite Material Members', *Sustainability (Basel, Switzerland),* 11(3), pp.577.

Liu, X. et al. (2017) 'Composites recycling solutions for the aviation industry', *Science China. Technological Sciences*, 60(9), pp.1291-1300.

Loh, Y.R. *et al.* (2013) 'Sugarcane bagasse—The future composite material: A literature review', *Resources, Conservation and Recycling,* 75 pp.14-22.

Ma, H. *et al.* (2016) 'Impact properties of glass fiber/epoxy composites at cryogenic environment', *Composites Part B: Engineering*, 92 pp.210-217.

Mariod, A.A. (2018) Gum Arabic. San Diego: Elsevier Science & Technology.

Meyers, M.A. and Chawla, K.K. (2008) *Mechanical Behavior of Materials*. Cambridge: Cambridge University Press.

Morampudi, P. *et al.* (2021) 'Review on glass fiber reinforced polymer composites', *Materials Today: Proceedings*, 43 pp.314-319.

Naqvi, S.R. *et al.* (2018) 'A critical review on recycling of end-of-life carbon fibre/glass fibre reinforced composites waste using pyrolysis towards a circular economy', *Resources, Conservation and Recycling*, 136 pp.118-129.

Nicholson, P.T., Shaw, I.M.E. and Nicholson, P.T. (2000) *Ancient Egyptian materials and technology*. Cambridge: Cambridge University Press.

Pandey, A. *et al.* (2000) 'Biotechnological potential of agro-industrial residues. I: sugarcane bagasse', *Bioresource Technology*, 74(1), pp.69-80.

Rumble, J.R. (2017) *CRC handbook of chemistry and physics.* 2017-2018, 98th edition edn. Boca Raton ; London ; New York: CRC Press, Taylor & Francis Group.

Saba, N., Jawaid, M. and Sultan, M.T.H. (2019) '1 - An overview of mechanical and physical testing of composite materials', in Jawaid, M., Thariq, M. and Saba, N. (eds.) *Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites and Hybrid Composites.* Woodhead Publishing, pp. 1-12.

Savalagi, P. and Chittappa, H.C. (2017) 'Flight Design for Rotary Bagasse Dryer', *International Research Journal of Engineering and Technology (IRJET)*, 4(8), pp.920-925.

Shakir Abbood, I. *et al.* (2020) 'Properties evaluation of fiber reinforced polymers and their constituent materials used in structures – A review', *Materials Today : Proceedings,* .

Simeoli, G. *et al.* (2014) 'The role of interface strength on the low velocity impact behaviour of PP/glass fibre laminates', *Composites Part B: Engineering*, 62 pp.88-96.

Tegegne, A. and Argu, T. (2014) 'EXPERIMENTAL DEVELOPMENT OF BIO-BASED POLYMER MATRIX BUILDING MATERIAL AND FISH BONE DIAGRAM FOR MATERIAL EFFECT ON QUALITY', *International Journal for Quality Research*, 8(2), pp.277-292.

Tian, H. and Zhang, Y.X. (2015) 'Tensile behaviour of a sustainable fibre reinforced cementitious composite under different strain rates', in *Recent Advances in Structural Integrity Analysis: Proceedings of the International Congress (APCF/SIF-2014).* Elsevier Ltd, pp. 316-320.

Williams, P.A. and Phillips, G.O. (2021) 'Chapter 21 - Gum arabic', in Phillips, G.O. and Williams, P.A. (eds.) *Handbook of Hydrocolloids (Third Edition).* Woodhead Publishing, pp. 627-652.

Wötzel, K., Wirth, R. and Flake, M. (1999) 'Life cycle studies on hemp fibre reinforced components and ABS for automotive parts', *Die Angewandte Makromolekulare Chemie*, 272(1), pp.121-127.

Bibliography

Ashter, S.A. (2013) *Thermoforming of Single and Multilayer Laminates*. Binghamton: Elsevier Science & Technology Books.

Azzaoui, K. *et al.* (2017) 'Eco friendly green inhibitor Gum Arabic (GA) for the corrosion control of mild steel in hydrochloric acid medium', *Corrosion Science*, 129 pp.70-81.

Callister, W.D. and Rethwisch, D.G. (2014) *Materials science and engineering.* 9th edition edn. Hoboken, NJ: Wiley.

Cao, H. and Kuboyama, N. (2009) 'A biodegradable porous composite scaffold of PGA/ β -TCP for bone tissue engineering', *Bone (New York, N.Y.),* 46(2), pp.386-395.

D'Antino, T. and Pisani, M.A. (2019) 'Long-term behavior of GFRP reinforcing bars', *Composite Structures*, 227 pp.111283.

Ephraim, M.E. and Adetiloye, A. 'Mechanical Properties of Glass Fibre Reinforced Polymer Based on Resin from Recycled Plastic', *International Journal of Scientific & Engineering Research*, 6(3), pp.154-152.

Ghani, A.F.A. and Mahmud, J. (2017) 'Shear deformation behavior of hybrid composite (GFRP/CFRP): Verformungverhalten von Hybridverbundwerkstoffen (GFRP/CFRP) unter Scherung', *Materialwissenschaft Und Werkstofftechnik*, 48(3), pp.273-282.

Haq, M. *et al.* (2014) 'Hybrid Bio-Based Composites from UPE/EML Blends, Natural Fibers, and Nanoclay: Hybrid Bio-Based Composites from UPE/EML Blends', *Macromolecular Materials and Engineering*, 299(11), pp.1306-1315.

Jiménez, A.M. *et al.* (2017) 'Sugarcane Bagasse Reinforced Composites: Studies on the Young's Modulus and Macro and Micro-Mechanics', *Bioresources*, 12(2),.

Kumar, S., Gupta, M. and Satsangi, P.S. (2015) 'Multiple-response optimization of cutting forces in turning of UD-GFRP composite using Distance-Based Pareto Genetic Algorithm approach', *Engineering Science and Technology, an International Journal,* 18(4), pp.680-695.

Mahendran, T. *et al.* (2008) 'New Insights into the Structural Characteristics of the Arabinogalactan–Protein (AGP) Fraction of Gum Arabic', *Journal of Agricultural and Food Chemistry*, 56(19), pp.9269-9276.

Mahmood, H. *et al.* (2017) 'lonic liquids assisted processing of renewable resources for the fabrication of biodegradable composite materials', *Green Chemistry : An International Journal and Green Chemistry Resource : GC,* 19(9), pp.2051-2075.

Mehrnia, M. *et al.* (2017) 'Rheological and release properties of double nano-emulsions containing crocin prepared with Angum gum, Arabic gum and whey protein', *Food Hydrocolloids*, 66 pp.259-267.

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Meola, C. and Carlomagno, G.M. (2010) 'Impact damage in GFRP: New insights with infrared thermography', *Composites.Part A, Applied Science and Manufacturing*, 41(12), pp.1839-1847.

Nayak, B.B. *et al.* (2021) 'Parametric optimization in drilling of GFRP composites using desirability function integrated simulated annealing approach', *Materials Today : Proceedings,* .

Nedoseka, A. (2012) '6 - Supplementary sections: Numerical techniques and tests for welded structures', in Nedoseka, A. (ed.) *Fundamentals of Evaluation and Diagnostics of Welded Structures.* Woodhead Publishing, pp. 479-558.

Patil, A.Y. *et al.* (2019) 'Experimental and Simulation Studies on Waste Vegetable Peels as Biocomposite Fillers for Light Duty Applications', *Arabian Journal for Science and Engineering* (2011), 44(9), pp.7895-7907.

Pereira da Silva, J.,S. *et al.* (2017) 'Fully biodegradable composites based on poly(butylene adipateco-terephthalate)/peach palm trees fiber', *Composites.Part B, Engineering,* 129 pp.117-123.

Renpu, W. (2011) 'Chapter 5 - Production Casing and Cementing', in Renpu, W. (ed.) Advanced Well Completion Engineering (Third Edition). Gulf Professional Publishing, pp. 221-294.

Samal, S.K. *et al.* (2014) 'Bio-based Polyethylene–Lignin Composites Containing a Pro-oxidant/Prodegradant Additive: Preparation and Characterization', *Journal of Polymers and the Environment*, 22(1), pp.58-68.

Satyanarayana, K.G., Arizaga, G.G.C. and Wypych, F. (2009) 'Biodegradable composites based on lignocellulosic fibers—An overview', *Progress in Polymer Science*, 34(9), pp.982-1021.

Shivanagere, A., Sharma, S.K. and Goyal, P. (2018) 'Modelling of glass fibre reinforced polymer (Gfrp) for aerospace applications', *Journal of Engineering Science & Technology*, 13(11), pp.3710-3728.

Sparks, E. (2012) Advances in Military Textiles and Personal Equipment. Cambridge: Elsevier Science & Technology.

Tian, H. and Zhang, Y.X. (2014) 'Tensile behaviour of a sustainable fibre reinforced cementitious composite under different strain rates', in Ye, L. (ed.) *Recent Advances in Structural Integrity Analysis* - *Proceedings of the International Congress (APCF/SIF-2014)*. Oxford: Woodhead Publishing, pp. 316-320.

Yang, F. *et al.* (2020) 'Mechanical and biodegradation properties of bamboo fiber-reinforced starch/polypropylene biodegradable composites', *Journal of Applied Polymer Science*, 137(20), pp.48694-n/a.

Youssef, J. and Hadi, M.N.S. (2017) 'Axial load-bending moment diagrams of GFRP reinforced columns and GFRP encased square columns', *Construction & Building Materials*, 135 pp.550-564.

Zhou, R., Yu, J. and Chi, R. (2020) 'Selective removal of phosphate from aqueous solution by MIL-101(Fe)/bagasse composite prepared through bagasse size control', *Environmental Research*, 188 pp.109817.

Appendix

Appendix A - Composite Properties - Random Fibre Orientation

		Composite	
	R2-20	R2-35	R2-50
Fibre Volume Fraction (%)	20	35	50
Fibre Length s (mm)		2	
Fibre Diameter <i>d</i> (mm)		0.39	
Density σ (kg/m ³)	1151.1	1130.1	1106.8
Young's Modulus X-direction E_x (MPa)	103.86	126.45	122.1
Young's Modulus Y-direction E_y (MPa)	105.12	119.5	134.33
Young's Modulus Z-direction E_z (MPa)	100.73	105.6	140.21
Shear Modulus XY (MPa)	29.761	29.475	31.468
Shear Modulus YZ (MPa)	30.277	30.462	29.853
Shear Modulus XZ (MPa)	29.969	30.118	34.782
Poisson's Ratio XY v_{xy}	0.45713	0.41065	0.49094
Poisson's Ratio YZ v_{yz}	0.49929	0.54497	0.45834
Poisson's Ratio XZ ν_{xz}	0.49398	0.56197	0.40428

Table 4: Composite Properties - Random Fibre Orientation (2mm fibres)

Table 5: Composite Properties - Random Fibre Orientation (4mm fibres)

		Composite	•
	R4-20	R4-35	R4-50
Fibre Volume Fraction (%)	20	35	50
Fibre Length s (mm)		4	
Fibre Diameter <i>d</i> (mm)		0.39	
Density σ (kg/m ³)	1209.4	1179.4	1185.3
Young's Modulus X-direction E_x (MPa)	128.2	111.88	111.07
Young's Modulus Y-direction E_y (MPa)	87.117	119.64	136.66
Young's Modulus Z-direction E_z (MPa)	110.31	192.22	111.92
Shear Modulus XY (MPa)	29.729	26.494	27.103
Shear Modulus YZ (MPa)	31.181	43.255	31.739
Shear Modulus XZ (MPa)	30.322	25.937	28.81
Poisson's Ratio XY v_{xy}	0.61809	0.62058	0.38672
Poisson's Ratio YZ ν _{yz}	0.34305	0.2986	0.55585
Poisson's Ratio XZ v_{xz}	0.52446	0.28687	0.47847

		Composite	•
	R6-20	R6-35	R6-50
Fibre Volume Fraction (%)	20	35	50
Fibre Length s (mm)		6	
Fibre Diameter <i>d</i> (mm)		0.39	
Density σ (kg/m ³)	1225.2	1179.3	1211.7
Young's Modulus X-direction E_x (MPa)	107.72	120.45	131.26
Young's Modulus Y-direction E_y (MPa)	127.92	95.868	337.06
Young's Modulus Z-direction E_z (MPa)	164.1	158.02	154.8
Shear Modulus XY (MPa)	21.749	26.046	18.787
Shear Modulus YZ (MPa)	32.487	31.376	27.23
Shear Modulus XZ (MPa)	26.528	29.355	20.098
Poisson's Ratio XY v_{xy}	0.53924	0.6945	0.22277
Poisson's Ratio YZ v_{yz}	0.38168	0.25514	0.65758
Poisson's Ratio XZ v_{xz}	0.30505	0.38424	0.38973

Table 6: Composite Properties - Random Fibre Orientation (6mm fibres)

Appendix B - Composite Properties - Uniform Fibre Orientation

			1
	C	composite	
	U2-20	U2-35	U2-50
Fibre Volume Fraction (%)	20	35	50
Fibre Length s (mm)		2	
Fibre Diameter <i>d</i> (mm)		0.39	
Density σ (kg/m ³)	1140.5	995.35	781.42
Young's Modulus X-direction E_x (MPa)	226.24	460.72	709.13
Young's Modulus Y-direction E_y (MPa)	87.148	143.14	186.67
Young's Modulus Z-direction E_z (MPa)	87.43	146.01	196.15
Shear Modulus XY (MPa)	22.995	32.68	36.253
Shear Modulus YZ (MPa)	22.146	33.947	41.579
Shear Modulus XZ (MPa)	22.06	31.655	38.655
Poisson's Ratio XY v_{xy}	0.4897	0.48406	0.50911
Poisson's Ratio YZ v_{yz}	0.47644	0.45429	0.39354
Poisson's Ratio XZ $_{vxz}$	0.76442	0.77727	0.77844

Table 7: Composite Properties - Uniform Fibre Orientation (2mm fibres)

Table 8: Composite Properties - Uniform Fibre Orientation (4mm fibres)

		Composite	•
	U4-20	U4-35	U4-50
Fibre Volume Fraction (%)	20	35	50
Fibre Length s (mm)		4	
Fibre Diameter <i>d</i> (mm)		0.39	
Density σ (kg/m ³)	1141.2	980.84	775.46
Young's Modulus X-direction E_x (MPa)	429.31	964.93	1067.7
Young's Modulus Y-direction E_y (MPa)	84.676	150.76	133.83
Young's Modulus Z-direction <i>E</i> _z (MPa)	85.014	152.53	135.26
Shear Modulus XY (MPa)	22.683	32.763	31.083
Shear Modulus YZ (MPa)	21.589	32.161	32.99
Shear Modulus XZ (MPa)	21.111	30.148	30.307
Poisson's Ratio XY ν _{xy}	0.49276	0.48677	0.49131
Poisson's Ratio YZ v_{yz}	0.46924	0.44814	0.44244
Poisson's Ratio XZ ν_{xz}	0.85384	0.84642	0.86916

		Composite	•
	U6-20	U6-35	U6-50
Fibre Volume Fraction (%)	20	35	50
Fibre Length s (mm)		6	
Fibre Diameter <i>d</i> (mm)		0.39	
Density σ (kg/m ³)	1145.1	979.63	769.766
Young's Modulus X-direction E_x (MPa)	959.36	1045.7	1093.82
Young's Modulus Y-direction E_y (MPa)	86.544	156.6	129.93
Young's Modulus Z-direction E_z (MPa)	89.42	153.63	139.8
Shear Modulus XY (MPa)	23.85	31.932	30.92
Shear Modulus YZ (MPa)	22.566	33.145	33.09
Shear Modulus XZ (MPa)	21.343	29.98	31.75
Poisson's Ratio XY ν_{xy}	0.4865	0.49023	0.4932
Poisson's Ratio YZ v_{yz}	0.46467	0.4214	0.43924
Poisson's Ratio XZ v_{xz}	0.8773	0.8611	0.87623

Table 9: Composite Properties - Uniform Fibre Orientation (6mm fibres)

Appendix C - Results - Three-Point Bending Test

Composito	Force Applied P	Flexural Stress of	Strain ε _f	Flexural Modulus Ef
Composite	(MN)	(MPa)	(mm/mm)	(MPa)
R2-20	0.708527778	0.25507	0.0020545	24.48672
R2-35	0.802194444	0.28879	0.0020101	27.72384
R2-50	0.886583333	0.31917	0.0021024	30.64032
R4-20	0.776361111	0.27949	0.0019256	26.83104
R4-35	0.905388889	0.32594	0.0019417	31.29024
R4-50	0.793888889	0.2858	0.002214	27.4368
R6-20	0.854166667	0.3075	0.0020952	29.52
R6-35	0.849388889	0.30578	0.0018903	29.35488
R6-50	1.672694444	0.60217	0.0032128	57.80832
U2-20	0.964222222	0.34712	0.0023273	33.32352
U2-35	1.792944444	0.64546	0.002526	61.96416
U2-50	2.607111111	0.93856	0.0026896	90.10176
U4-20	1.426611111	0.51358	0.0030399	49.30368
U4-35	2.975277778	1.0711	0.0033266	102.8256
U4-50	3.104166667	1.1175	0.0036666	107.28
U6-20	2.550055556	0.91802	0.004272	88.12992
U6-35	3.186111111	1.147	0.0033794	110.112
U6-50	3.141111111	1.1308	0.0037581	108.5568
GFRP	133.3305556	27.999	0.0020831	2687.904

Table 10: Results - Three-Point Bending Test

Appendix D - Results - Tensile Test

Composito	Norr	nal Stress	s σ_t (MPa)	Norma	Elongation		
Composite	Max	Min	Engineering	Max	Min	Engineering	Δ <i>L</i> (mm)
R2-20	7.9526	14.095	10.015	0.048037	0.10213	0.094964	14.35
R2-35	8.029	13.942	10.014	0.040188	0.083244	0.078008	11.79
R2-50	8.3769	13.246	10.012	0.045536	0.087229	0.080948	12.22
R4-20	8.2805	13.439	10.012	0.039453	0.082892	0.076944	11.63
R4-35	8.909	12.182	10.008	0.05408	0.095696	0.088466	13.35
R4-50	9.1996	11.601	10.004	0.074401	0.09343	0.089744	13.49
R6-20	8.8681	12.264	10.008	0.058434	0.098654	0.091963	13.87
R6-35	8.5819	12.836	10.01	0.045355	0.089173	0.082018	12.39
R6-50	9.0132	11.974	10.005	0.054567	0.079446	0.075677	11.39
U2-20	8.9405	12.119	10.005	0.027781	0.045785	0.043755	6.60
U2-35	9.2351	11.53	10.003	0.015271	0.02237	0.021535	3.25
U2-50	9.3956	11.209	10.002	0.010634	0.01447	0.014012	2.11
U4-20	9.4016	11.197	10.002	0.017851	0.023766	0.023151	3.49
U4-35	9.6058	10.788	10.001	0.0086043	0.010538	0.010318	1.55
U4-50	9.6345	10.731	10.001	0.0079748	0.009484	0.009331	1.40
U6-20	9.6631	10.674	10.001	0.0088809	0.010554	0.010384	1.56
U6-35	9.6323	10.735	10.001	0.0080492	0.009709	0.009524	1.43
U6-50	9.6234	10.753	10.001	0.0077499	0.009259	0.009107	1.37
GFRP	8.9487	12.103	10.005	0.0003481	0.000497	0.000473	0.07

Table 11: Results - Tensile Test

Appendix E - Project Gantt Charts

					00	t '20			Nov '20			Dec '20			Jan	21			Feb '21			Mar	21		
	Task Name 👻	Duration 👻	Start 👻	Finish 👻	28	05	12 19	26	02 0	16	23	30 07	14	21	28	04	11 18	25	01 08	15	22	01	08	15	22
1	Individual Project	126 days	Mon 05/10/20	Mon 29/03/21																					
2	Project Proposal	6 days	Tue 06/10/20	Tue 13/10/20																					
3	Literature Review	29 days	Wed 14/10/20	Sun 22/11/20																					
4	Research	29 days	Wed 14/10/20	Sun 22/11/20																					
5	Write Up	29 days	Wed 14/10/20	Sun 22/11/20																					
6	Project Planning Report	6 days	Mon 23/11/20	Mon 30/11/20																					
7	Material Selection	9 days	Tue 01/12/20	Fri 11/12/20																					
8	Manufacture	10 days	Mon 04/01/21	Fri 15/01/21											Г										
9	Samples	4 days	Mon 04/01/21	Thu 07/01/21																					
10	Final Composites	5 days	Fri 08/01/21	Thu 14/01/21																					
11	Trimming	1 day	Fri 15/01/21	Fri 15/01/21																					
12	▲ Testing	5 days	Mon 18/01/21	Fri 22/01/21														I							
13	Three Point Flexural Test	2 days	Mon 18/01/21	Tue 19/01/21																					
14	Impact Resistance Test	2 days	Wed 20/01/21	Thu 21/01/21																					
15	FTA Test	1 day	Fri 22/01/21	Fri 22/01/21														L							
16	FEA Simulation	20 days	Mon 25/01/21	Sun 21/02/21																					
17	Analysis of Results	11 days	Mon 22/02/21	Mon 08/03/21																					
18	Final Report	12 days	Tue 09/03/21	Wed 24/03/21																					
19	▲ Seminar	4 days	Wed 24/03/21	Mon 29/03/21																					
20	Preparation	4 days	Wed 24/03/21	Sun 28/03/21																					
21	Presentation	1 day	Mon 29/03/21	Mon 29/03/21																					1
22	Logbook	126 days	Mon 05/10/20	Mon 29/03/21																					

Figure 41: Project Gantt Chart as of November 30, 2020



Figure 42: Project Gantt Chart as of April 07, 2021

Appendix F - Risk Analysis

Table 12 identifies a selection of risks associated with the study. An analysis was performed to identify any potential risks at might hinder the progress of this project at the beginning. These risks are assessed with possible methods of mitigating the identified risks to minimise its impact on the study. The potential of the lab facilities being closed due to the Covid-19 pandemic and the unavailability raw of materials have been identified to be the greatest risks to the progression of the project.

Risk Description	Potential Severity	Likelihood	Risk Rating	Mitigation
The laboratory facilities may be closed, for example due to health and safety reasons.	2	3	6	Proceed to the other sections, such as FEA simulations, to ensure that as much of the project is completed until access is granted again.
Raw materials unavailable	3	2	6	Try to source materials from different suppliers. If not possible, change the materials used.
Undesirable manufacture	2	1	2	Manufacture samples to ensure that the final composite meets the required conditions.
Unable to access ANSYS	3	1	3	Proceed to working on other sections of the project until the software is available.
Loss or corruption of ANSYS files	2	1	2	Ensure that work is saved frequently and multiple copies are kept in different locations.
Inaccurate results for simulations	2	1	2	Evaluate observations from physical testing to assess the cause of inaccuracies in the simulation results. Repeat simulations under different conditions, if possible.
Poor work schedule due to demands of other modules	2	1	2	Ensure time management skills are developed and specific timeframes are imposed to ensure that enough attention is provided to every task.
Unexpected illness or injury that affects ability to complete tasks	2	2	4	Maintain wellbeing as best as possible by following Covid-19 guidelines while keeping track to deadlines to ensure that there are no delays.

Table 12: Risk Analysis with corresponding key

Severity	
1	Low
2	Medium
3	High

Likelihood	
1	Low
2	Medium
3	High

Risk Rating = severity x likelihood	
1 to 3	Low
4 to 6	Medium
7 to 9	High