

University of Southern Queensland
Faculty of Engineering and Surveying

**Sugarcane bagasse reinforced
thermoplastic composites**

A dissertation submitted by

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Courses ENG4111 and 4112 Research Project

towards the degree of

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Abstract

Wood fibre composites are forging a place in the industrial and commercial market as a replacement for timber products. Although many of these products are produced from recycled materials, fully sustainable products are in limited use. The following document details an investigation into the viability of sugarcane bagasse as a fibre additive in the production of hardwood replacement products. The investigation is initiated with the use of LDPE and LLDPE polymers as the matrix material to review the affects of the bagasse in varying percentage weight composites. The affects of the bagasse content have been reviewed using mechanical testing processes.

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CERTIFICATION

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

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

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Date

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Nomenclature

DMA - Dynamic Mechanical Analysis

LDPE – Low Density Polyethylene

LLDPE – Linear Low Density Polyethylene

1 Introduction

1.1 Introduction

As scientific research into the ecological balance of the Earth improves and society's interest grows, the importance of old growth forest is being recognised. Whilst there are now reforestation programs and sustainable forestry practices making a mark on the market, it is reasonable to assume that with an increasing population and increasing level of quality of life, there will continue to be an increase in demand for timber products. New products must be developed to curve the demand and help sustain the environment.

Wood-plastic composite is becoming a very common replacement for hardwoods in non-structural applications such as outdoor decking and furniture, landscaping, and cladding. It has advantages such as, rot resistance, lower density and reduced maintenance, over real timber and is viewed as an environmentally friendly alternative. A large majority of the wood-plastic composites on the market are produced from recycled plastics and sawdust/woodchip waste and are promoted as an environmentally positive product for this reason.

The plastics used in current wood-plastics, although recycled, are petroleum based and as such are not renewable or sustainable.

The aim of this research is to develop a composite of environmentally sustainable fibre and polymer that aesthetically and properties wise imitates hardwood, to help reduce the impact of high consumer demands on our forests.

The fibre under investigation in this project is sugarcane bagasse. Bagasse is the fibrous waste left after the sugar has been removed from the cane. Approximately 3 tonnes of wet bagasse is produced for every 10 tonnes of sugarcane processed. There are over 6500 sugarcane farmers in Australia who in 2001-02 produced 4.6 million tonnes of sugar (DAFF 2008). With sugarcane being a prominent industry throughout the world bagasse supplies are none the less abundant.

1.2 Research Objective

This project is part of a larger research investigation aimed at producing an environmentally friendly and sustainable replacement for hardwood. This project aims to take the first steps in this larger investigation by determining the viability of researching sugarcane bagasse as a fibre for use in hardwood replacement composites.

The objectives of this project are:

1. Investigate the suitability of sugarcane bagasse for use in fibre composites, including sustainability, cost effectiveness and abundance.
2. Ascertain the properties of a chosen polymer/fibre combination by conducting tensile and flexural.
3. Compare the strengths and weaknesses of varying compositions, providing information on the effects of fibre/polymer ratios. This may also provide information on predicted material costing.
4. Determine if further investigation into the chosen fibre for the application of hardwood imitation products is warranted.

2 Literature Review

2.1 Introduction

The following information is provided for background knowledge, relating to the material, topics and processes involved in this research project.

2.2 Composite Material

Composites are a combination of two or more materials or phases, produced for the purpose of combining desired properties into one material. Composites are a vast area of engineering and much investigation is put towards creating and refining properties for a single material.

Although there are many different combinations that may be called a composite the most common are a product of two phases being the matrix phase and the dispersed phase. The matrix phase is a continuous constituent used to bind and provide form for the dispersed phase, a stronger reinforcement constituent (Miracle and Donaldson 2003). These may be further broken down, with reference to the dispersed phase, into particulate, fibre and laminar. For the purpose of this report we will further investigate fibre composites.

2.3 Matrix

The matrix is a continuous material that forms the body of the composite, bonding with the fibre. The matrix works to transmit the load to the fibres. Often polymeric materials are used as the matrix with fibre because of their formability, however they have low strength and as such use the stiff fibre content to increase the strength.

The matrix can also provide protection to the fibre from such factors as UV radiation, moisture, light, abrasion, temperature and other environmental impacts.

2.4 Polymers

Polymer compounds consist of chain like molecules made up of repeating units called monomers. Polymers can be both natural and synthetic, most commonly organic.

Polymers are advantageous in industry because:

- They are easily formed into desired shape using a wide range of processes included casting, a variety of moulding techniques and spinning.
- Most are inexpensive
- Compared to metals and ceramics low temperatures are required for processing
- Additives can be used to create a wide variety of behaviours;
- Electrical insulator
- Some polymers degrade with radiation, however many are produced to be chemically inert and/or resist radiation deterioration.

Polymers display a wide variety of mechanical behaviours that are best distinguished in the sub-groups, thermoplastics, thermosets and elastomers

2.4.1 Thermoplastic

Thermoplastics are linear chain polymers held together by entanglement and weak van der waals forces. They demonstrate

- Low strength, especially when a little heat is added, as the long smooth chains can easily slide past one another producing deformation. Anything that restricts the movement of the chains against each other increases the strength of the polymer, this includes isotactic and atactic chain formation.
- Low melting point compared with metal
- Generally Low mechanical strength
- Most thermoplastics are recyclable
- Good ductility

2.4.2 Thermosetting

Thermosetting polymers are characterised by a large quantity of cross-linking producing a network type structure. They display:

- strength - Melting point and mechanical strength increase with chain length and complexity of shape. Entanglement and cross-linking of polymer chains increases the strength by making it harder for chains to move past one another and hence deform.
- stiffness and low ductility
- hardness
- brittle behaviour - With impact testing thermoplastics behave in a brittle manner because there is not enough time for the chains to slide past each other as happens with deformation.

- non-recyclable - Thermosets are generally not recyclable as they decompose rather than melt at elevated temperatures
-

2.4.3 Elastomers

Coiled chains referred to as cis type chains produce elastic behaviour – Elastomers are characterised by very large reversible strain, commonly over 200%.

2.5 LDPE

Low density polyethylene (LDPE) and linear low density polyethylene (LLDPE) are petroleum based thermoplastics. Both plastics are widely used for both domestic and commercial items including, food or beverage containers, laboratory equipment, computer and electronic components, corrosion resistant work surfaces and plastic bags.

LDPE is characterised by:

- small side branching causing molecules and chains to be less tightly packed
- low tensile strength
- nonreactive at room temperature
- can withstand 80 °C continuously and 95 °C for a short time
- can strain harden

LLDPE is characterised by:

- high tensile shear strength than LDPE
- increased strength with increased side chain length
- higher impact strength than LDPE
- harder to process than LDPE
- does not strain harden
- resistant to a wide range of chemicals and UV light

2.6 Fibre

Typically fibre is added to a matrix material to provide strength and stiffness. Examples of fibre-reinforced composites are present throughout history from straw mud bricks used for houses to fibre glass boats.

Common fibres used in composites include glass, carbon, aramid and ceramic, and are used according to the desired properties and compatibility with the matrix material. The fibres may be any length, including continuous fibres that are woven in sheets or to a form.

Singha and Thakur, (2008), list a number of benefits of natural fibres over synthetic including:

- Specific strength properties
- Easy availability,
- Light weight
- Ease of separation,
- Enhanced energy recovery,
- High toughness,
- Non-corrosive nature
- Low density
- Low cost
- Good thermal properties
- Reduced tool wear
- Reduced dermal and respiratory irritation, and
- Less abrasion to processing equipment.

Glass and carbon fibres provide considerable strength qualities and can be produced into directional applications such as woven sheets. However for many applications the cost, monetarily and environmentally of producing these fibres are not viable and outweigh the benefits or even property requirements.

The percentage fibre content is a common variable investigated when producing new composites. Increasing the fibre content may be presumed to increase the strength and stiffness however the matrix content must be able to cover, or wet, all the fibres and maintain continuity for the purpose of transferring the load to the fibres.

2.7 Sugarcane bagasse

Sugarcane bagasse is the fibrous by-product of the sugar industry left over after crushing and processing has extracted the juice from the cane. 'The fibre consists mainly of cellulose (27 percent), pentosans (30 percent), lignin (20 percent) and ash (3 percent)' (Paturau), although this can vary between processors and geographical areas. Bagasse is considerably inhomogeneous containing 30-35% pith cells.

Bagasse is commonly used as fuel in the sugar mills; however the burning process produces a fine particulate that can cause damage to the environment and people. Many other uses for bagasse are being investigated and currently used including, pressed building boards, acoustic tiles, compostable food/beverage serving products and paper in countries where wood is a scarce commodity. World Centric, suppliers of compostable food service packaging products, promotes the use of bagasse by comparison with competing products Styrofoam, recycled paper and new paper. Of these products bagasse reportedly uses the least amount of energy and water to produce and is biodegradable.

Paturau reports an estimated 60 million tonnes of bagasse is produced each year. Sugar production is a well established industry in a large number of countries around the world, particularly Australia, India and South America. With the world demand for sugar products the industry shows no sign of decline and therefore a continued significant supply of waste material can be expected.

2.8 Sample Size

Sample cut sizes are dictated by Australian or International standards for each particular test being performed.

2.9 Testing

Three mechanical tests will be performed on the composite samples, flexural, tensile and DMA. The selection of these tests was made to provide a variety of material properties for comparison. Observing a variety of properties is important as one the affects of the fibre content may be negative in one aspect but beneficial in another. This will also help to ascertain how the fibre integrates with and affects the polymer.

From the test the properties of Young's Modulus, flexural modulus, storage modulus and damping factor will be calculated and compared.

2.10 Flexural Testing

Flexural strength is defined as the maximum stress in the outermost fibre (Instron, 2011), and is defined by the equation:

$$\sigma = \frac{3FL}{2wh^2}$$

Where F is the fracture load, L is the distance between two outer loading points, w is the specimen width and h is the specimen height (Askeland & Phule 2005).

Flexural testing consists of a simple beam loading causing compression on the top surface and tension on the bottom surface of the sample. Load and deflection are recorded and calculated to produce a stress, strain plot.

Specifications for load point span vs. sample height (depth) ratios are standardised to ensure primary failure occurs due to tension and compression stresses not shear stress at the centre of the sample.

The flexural modulus can be calculated using the deflection δ of the sample when force F is applied:

$$E = \frac{L^3 F}{4wh^3 \delta}$$

This also represents the slope of the stress versus deflection curve.

Two types of flexural testing set ups are used, viz three-point and four-point. The three-point concentrates stress at the centre loading point and is the typical set up used for polymers. The four-point set up creates a more uniform stress between the inner span loading points, usually used on samples containing flaws.

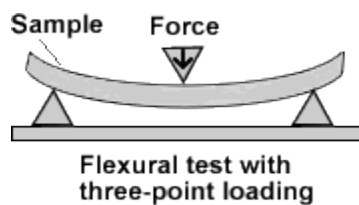


Figure 1: Three-point loading configuration (Instron 2011)

2.11 Tensile Testing

Tensile testing is performed using a universal testing machine set up with vice fixtures. The sample to be tested is clamped at either end and a tensile load applied at a constant rate of elongation.

Tensile strength is the stress obtained at the highest applied load, observed on a stress-strain curve as the peak stress and in practice as the point at which necking begins, for ductile materials.

$$\text{Tensile Strength} = \frac{F}{A} = \frac{\text{Maximum load}}{\text{Original cross-sectional area}} \text{ (MPa)}$$

When performing tensile testing it is important to installed the correct size apparatus to ensure the sample remains in place during testing but is not broken by the gripping mechanism from excessive pressure.

2.12 DMA

Dynamic material analysis uses a small oscillating load applied within the elastic region of a materials stress-strain curve to investigate the elastic and damping behaviour of the material measured against time or temperature. The behaviour is interpreted as E' , the storage modulus, E'' , the load modulus and the $\tan \delta$, the ratio of E' to E'' .

Modes of measurements including tension, compression, flexure, shear and compression can all be assessed, under the operations of fixed frequency, resonant frequency, creep relaxation and stress relaxation (Brady 2003).

Depending on the machine used a variety of sample lengths can be tested ranging from 1mm to 65mm. The samples are clamped into the machine allowing only horizontal movement which is applied by small electrical motors. The sample is sealed within a chamber to provide temperature control. During testing a load is applied in a sinusoidally oscillating fashion, the load always being within the elastic region of the materials stress-strain curve. The deformation and strain are recorded against time or temperature.

E' is a measure of a materials elastic response to load, being its ability to store energy like a spring would. E'' indicates energy that is dissipated, comparable to a viscous dashpot. Storage modulus and Young's modulus are similar in concept however they do not provide the same value and are not comparable.

As the load is applied analysis of the materials viscous response and elastic response are recorded. A purely elastic response will produce a strain reaction that is in cycle with the load. A purely viscous reaction will have a phase difference, δ , of 90 degrees. Most polymeric materials display a combination of viscous and elastic behaviour (namely viscoelastic materials) producing a phase difference between 0 and 90 degrees.

DMA is the most sensitive of all thermal analytical techniques and is particularly useful in evaluating viscoelastic polymers (Brady 2003).

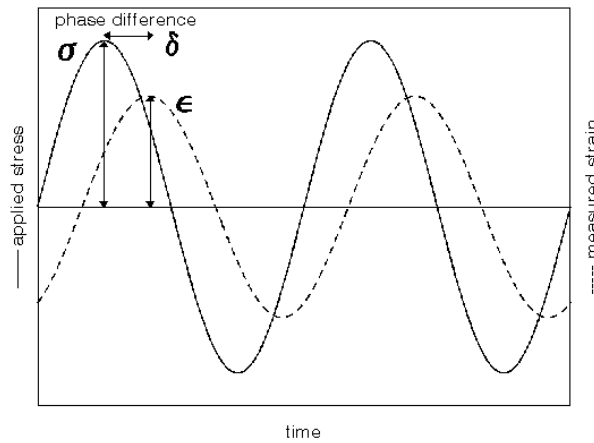


Figure 2: Stress cycle and strain cycle plotted together demonstrating phase difference δ produced by a viscoelastic response (Introduction to DMA)

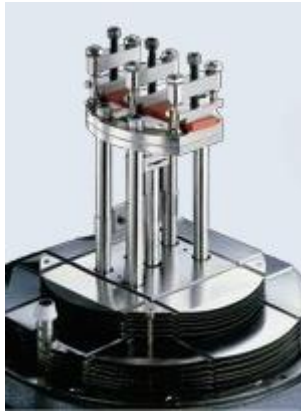


Figure 3:TA instruments cantilever set up

2.13 Work of Others

Investigations by Acharya, Mishra and Mehar (2009) found bagasse to be a viable fibre to use in composites, carrying out tests using bagasse and epoxy. Many investigations continue to be performed into the area of natural fibre composites and this will continue to expand whilst there is a push in society to be eco-friendly.

Many investigations have been focused on the processing required to create good bonding between natural fibre, including bagasse, and polymers, with varying conclusions. The investigations have included varying the practical size of the fibre, chemical treatments and additives.

An important conclusion from investigations is the superior bonding of the fibre with the matrix after treatment with acetone.

3 Methodology

3.1 Introduction

The following chapter details the processes that were undertaken to perform the testing part of this research paper. The processes were formed through theoretical investigation, recommendations from supervising staff and trial and error. All research should prove to be repeatable and accurate.

3.2 Experimental equipment specifications

Universal testing machine:

Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, Fibre Composites Research Centre, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	18/07/2011
Expiration Date:	18/07/2012
Strain Measurement Device:	Axial Displacement of Crosshead MTS Extensometer Model No. LX300
Operating Software	Testworks 4

DMA machine:

Test Machine:	TA Instruments Q800
Location:	Test Laboratory, Fibre Composites Research Centre, USQ
Max force	18 N
Min force:	0.0001 N
Strain Resolution	1 nanometer
Dynamic deformation range	± 0.5 to 10,000 μm

3.3 Preparation of bagasse

Two kilograms of bagasse was removed from storage and prepared for manufacturing. Preparation required cleaning, drying and cutting processes detailed in the following sections.

3.3.1 Cleaning

From the literature reviewed it was decided that an alkaline treatment of the bagasse was required to ensure sufficient bonding between the bagasse and polymer was achieved. Alkaline treatment alters the fibre surface creating a better interface between the polymer and fibre.

The bagasse was soaked in a solution of water and domestic cleaning agent, 'Nappy Treatment Plus', for twenty four hours. The solution was mixed according to recommended dosage on the cleaning agent. A minimum of 2hrs is required for soaking but recommendation of 'over night' soaking is made for heavy soiling. The bagasse was soaked for twenty four hours to ensure that all the fibre was fully treated and affected by the alkaline solution.

The active ingredient of the cleaning agent is sodium percarbonate.

The bagasse was then thoroughly rinsed to remove all the cleaning agent and waste. The bagasse was immersed in clear water and drained numerous times removing dirt, gravel, cleaning agent and waste from the surface and in between the fibres.

The bagasse was spread out onto three baking trays in a layer approximately 25 – 40mm thick and dried in an oven for 24 hrs at 60°C. The bagasse covered three trays allowing them to be processed in one oven. The oven was run at 60°C to remove the excess water from the bagasse through evaporation without damaging the fibre through excessive temperature levels. Twenty four hours allowed sufficient time to remove all the excess water through the thickness of the bagasse layer.

3.3.2 Cutting

Initially it was planned to produce the composite using an extrusion process. The available machinery required a fibre length of less than 10mm, necessitating considerable cutting of the bagasse to be undertaken. Several cutting devices were tested before it was decided upon to use a domestic food processor. This was heavy enough to handle the fibre and cutting the bagasse quickly to the desired length.

Before the bagasse was processed it was manually filtered to remove any remaining gravel and dense wood fibres that were not suitable to the project and may have caused damage to the cutting machine. The bagasse was processed in small batches, sifted and reprocessed until the correct length was attained. Larger denser fibres were removed to maintain a moderate consistency in the fibre.

3.3.3 Sifting

The processed batches of bagasse were sifted using a 2mm kitchen sieve. Sifting had to be done very lightly because of the shape of the fibres meant that long fibres could pass through the sieve if attention was not paid.

3.4 Mixing of samples

The bagasse and polymer pellets were weighed to the correct percentage weight ratios on Mettler Toledo laboratory scales. The scales measure in 0.1g increments and are zeroed between batches to ensure accuracy of measurement.

The following compositions were produced:

- Neat polymer
- Polymer with 10% fibre
- Polymer with 20% fibre
- Polymer with 30% fibre

The mould required approximately eighty grams of neat polymer for one sample so batches of 200 grams were produced in each composition variation to allow for excess to be stored for research repeatability.

The samples were then mixed in a commercial blender for 2 minutes to achieve a homogeneous mixture of polymer and bagasse. The blender was stopped every 20 seconds during mixing to allow the contents to settle, the starting of the blender creates a big pulse through the mixture moving the contents on the bottom to the top. If this is not performed it was observed that parts of the mixture did not get mixed into the moving mixture.

The samples were left for several minutes after mixing to allow the fine bagasse particles to settle and prevent inhalation of the fine dust particles stirred up in the blender.

From the blender the samples were poured into air-lock bags to maintain consistent humidity until processing was undertaken.

It was observed during the bagging of the samples that, although a suitable time of blending the mixture was performed, due to the large difference in size between the LDPE pellets and the bagasse the sample separated considerably. Consistent mixture with such large pellets is not achievable.

An attempt was made to reduce the pellet sizes to try create a more consistent mixture, however this was not possible with the available machinery.

3.5 Manufacturing samples

Mould of the samples was done with a heat press. It was discovered that an even sample could be produced only if preheating of the moulds was performed. The upper and lower plates were set at 300°C.

The mould used produced a 138x138x3mm square.

The samples are poured onto the base of mould and with a slightly raised area across the diagonals of the square. This ensured the polymer spread evenly to all edges of the mould.

The mould is placed into the machine and it does its thing. When the machine is finished a sample as per Figure 4 is produced.



Figure 4: Neat LDPE sample

Polymeric materials take a significant time to cool, so once the mould is removed from the machine it is placed on large thick metal surfaces, such as a work bench or other mould, to act as a heat sink to help cooling.

3.6 Dimensioning of specimens

Cutting of the pallets into the required testing size was done on a diamond blade wet saw. The samples are clamped down and the cutting wheel is passed across the

pallet at measured intervals. An initial cut is made to align the first edge of the sample and check for correct cutting depth.

The mould used produced a sample that was 138x138x3mm. The sample was cut into 4 x 10mm strips for flexural testing and 4 x 15mm strips for tensile testing.

60x10mm strips were cut from the flexural specimens once they had been tested for use in the DMA.

Australian and international standards require 6 samples per material to be tested, however due to limitations in manufacturing only four samples could be obtained for each test. This has a negative effect on the results as it reduces the accuracy of the mean value, and consequently the results.

3.7 Flexural test

The universal testing machine was set up with three point testing apparatus and the computer program set to ISO14125 laminate flexural testing procedures. This setting was recommended by the laboratory supervisor as the correct procedure for this material type.

The three-point testing apparatus was adjusted to have a 50mm support span, the appropriate size for the 10mm wide samples.

Before being tested each sample was measured three times in the width and three in the thickness with the measurements being entered into the computer program. All calculations involving sample size have been done using the average of the three measurements. Measurements were done with electronic vernier callipers, accurate to two decimal places.

The sample is placed centrally lengthways across the lower two points and the third is brought down to meet the middle of the sample.

The test is initiated with the computer which moves the top crosshead downwards at a constant velocity whilst recording the load applied to maintain the movement. The machine would normally stop once failure had been detected, however with the elastic nature of the polymer the test had to be stopped manually.



Figure 5: Three-point flexural testing set up

Peak load and deflection at peak are recorded and from this peak flexural stress, strain at peak, and flexural modulus are calculated. The data of stress versus strain is graphed.

3.8 Tensile Test

Before testing commenced each sample was measured three times in the width and depth with electronic vernier callipers and the measurements recorded in the testing program.

The computer program was set to run testing as per ISO 527-Neat Resin Tension.

The sample is fixed to the crossheads by clamping apparatus. It is important to ensure the sample is positioned hard up against the back and the clamp is done up tight enough to prevent slippage. The test does not require the sample to be positioned facing any certain direction as directional properties do not alter this test.

A free length, being the testing length, of 38-40mm was measured.

The test is initiated and run through the computer software. The test is started and the hydraulic system applied load to the sample to produce a constant crosshead movement in the direction of separation.

The test is stopped once failure is detected. Failure was observed in the composite samples however, several of the neat samples showed extremely large strain, and the testing was stopped manually as the machine had reached its extension limit.

The peak load, peak stress and change in crosshead position were recorded and from this strain and elastic modulus were calculated.

3.9 DMA

A 60mm x 10mm sample is positioned on the testing apparatus and the positioning screws tightened to hold the sample in place. The chamber is then sealed to allow temperature control and the test is run via the computer.

3.10 Resolution of non-homogeneous samples

At the mixing stage of producing the samples the problem of mixture separation was observed, caused by the difference in size and weight between the polymer pellets and the bagasse fibre. This inconsistency became a larger problem in the moulding stage where a non-homogeneous material resulted.

Wetting, the bonding of matrix to fibre, is an important aspect of composite production as it allows the load to be transferred from the soft matrix to the strong fibre and it stops the fibres from dislodging from the material.

The original LDPE mixture used produced increasingly larger clumps of un-wet bagasse in moulded materials, a highly undesirable property, so a finer sized pellet polymer was sort.

A LLDPE polymer in a 1mm grain size was available and so samples were produced using this as the matrix with bagasse fibre. All procedures were followed as per the original LDPE samples.

3.11 Safety Measures

During the use of manufacturing and testing apparatus, standard safety procedures and use of safety equipment must be observed.

Bagasse has no health concerns other than fine airborne particles aggravating respiratory issues.

4 Results and Discussion

4.1 Introduction

This chapter discusses the results of testing performed following the procedure listed in the previous chapter, 3 Methodology.

Sugarcane bagasse was sourced from Sucrogen Limited situated in north east Queensland. The LDPE is a product of Qenos, product name Alkathene, product details are listed in Appendix B.

4.2 LDPE Samples

The difficulties encountered with the separation of the raw polymer pellets and bagasse due to the size difference had a large effect on the final product properties. A homogeneous mixture of the fibre and polymer could not be achieved nor could a guaranteed weight ratio be maintained when the mixture was poured into the mould. The resulting material showed areas of dense fibre content to almost no fibre content and had increasingly large clumps of un-wet fibre increasing in frequency and size with percentage fibre content.

When pouring the mixture into the mould the separation of the fibre and pellets and it difficult to maintain the weight ratio, although the samples are marked as ten, twenty and thirty percent fibre it is uncertain how close the samples are to these figures. This problem was amplified by the runoff from the mould at the joints which was mostly polymer, altering the percentages of polymer to fibre. This can be seen in the figures below.



Figure 6: LDPE 10% Bagasse full sample



Figure 7: LDPE 20% Bagasse full sample piece



Figure 8: LDPE 30% Bagasse full sample

Figures 6,7,8 demonstrate the inconsistency of the material. The dark areas are denser with bagasse and the light areas mostly polymer. In Figure 8 bagasse is visible on the surface of the composite in large areas that have no connection with the polymer matrix. When handling this sample the fibres consistently fell away and were easily further loosened by small amounts of friction.

The inconsistency was most evident through the thickness of the samples. The polymer appeared to sink to the bottom of the mould, with the bagasse rising to the upper portion. This was extremely evident with the 30% bagasse samples in which the bagasse fell away from one side of the sample when handled.

The largest problem with the inconsistency of the samples was the amount of bagasse that was un-wet by the polymer. As the bagasse percentage increased larger clumps of fibre remained un-wet. The bagasse failed to integrate so poorly for the 30% samples one flexure sample had to be recut because it broke during the cutting stage due there being no polymer across the 10mm width of the sample.

4.3 LLDPE Samples

The LLDPE granules were of a comparable size to the bagasse fibre, creating a homogeneous mixture before and after moulding. The LLDPE samples were more rigid than the LDPE due to the molecular structure of the polymer.

The fibres were consistently mixed through the thickness, width and length of all the samples.



Figure 9: Sample of LLDPE in 20% and 30% fibre content

4.4 Flexural test

Peak Flexural Stress (MPa)								
Specimen #	Neat LDPE	10% Bagasse	20% Bagasse	30% Bagasse	Neat LDPE	10% Bagasse	20% Bagasse	30% Bagasse
1	8.04	5.98	7.13	5.41	60.13		47.54	58.50
2	8.14	7.51	4.32	0.28	55.19		59.96	56.03
3	8.14	7.59	6.31	3.92	60.97		53.25	59.94
4	8.00	6.09	3.13	4.40	56.34		44.51	57.11
Mean	8.08	6.79	5.22	3.50	58.16		51.32	57.90
Std Dev	0.07	0.88	1.83	2.24	2.82		6.81	1.70

Table 1: Peak Flexural Stress

4.4.1 Flexural Stress

lists the Peak flexural stress recorded during the flexural testing and the average for each composition. The LDPE shows a marked decrease in strength with the increase of fibre content. This is consistent with the non-homogeneous nature of the samples, as the areas of un-wet bagasse reduce the cross sectional area of the sample that is load bearing, and the problem increases with a higher fibre content. An increase in the standard deviation is also observed once again demonstrating the inconsistency of the samples mixture.

Figure 10 shows the braking of a sample during the flexural test at the site of un-wet bagasse fibre.



Figure 10: Flexural testing - breakage at fibre clump

The LLDPE samples show a twelve percent difference between the neat and the 20% fibre content and less than one percent difference between the neat and 30% content.

4.4.2 Flexural Modulus

The flexural modulus represents the slope of the flexural stress versus strain graph and indicates the materials tendency to bend. Figures 11,12,13 show the stress strain curve for the LLDPE compositions. A progressive reduction in the peak strain can be observed as the fibre content increases. Figure 11: LLDPE 30% bagasse stress strain curve is the stress strain curve of the thirty percent bagasse in LLDPE composite. It demonstrates consistent peak and shape for all the samples indicating a consistent material mixture.

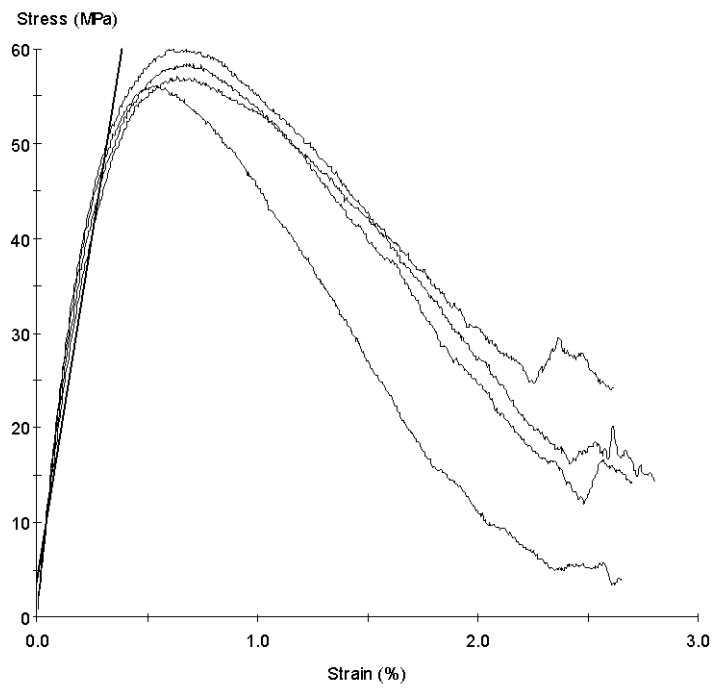


Figure 11: LLDPE 30% bagasse stress strain curve

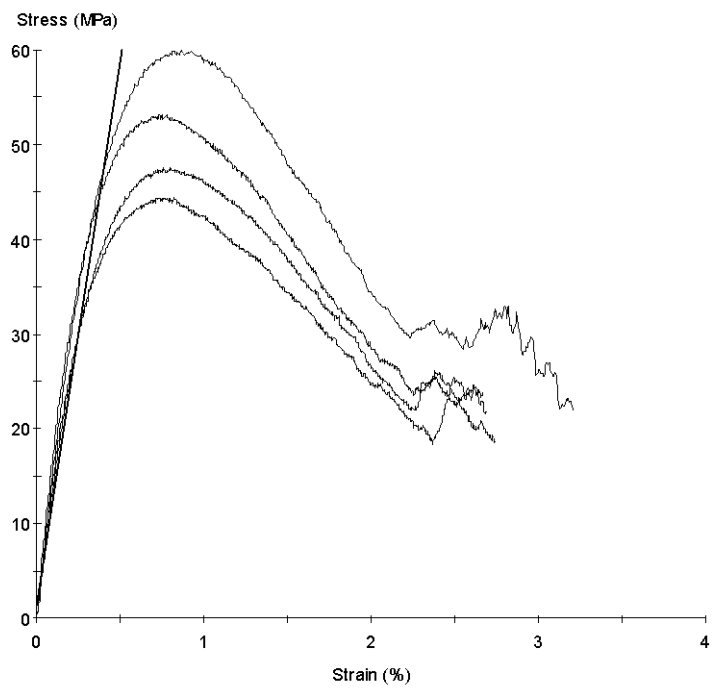


Figure 12: LLDPE 20% bagasse stress strain curve

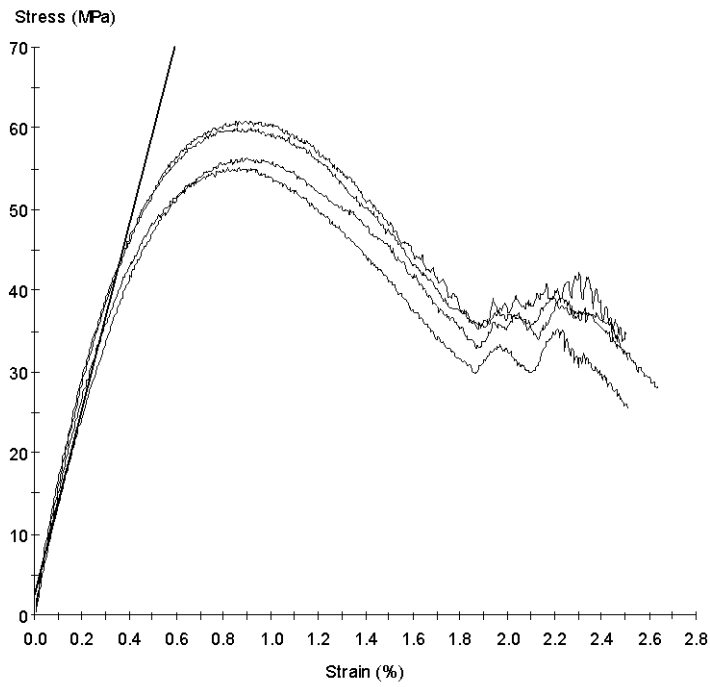


Figure 13: LLDPE neat stress strain curve

Flexural Modulus (MPa)								
Specimen #	Neat LDPE	10% Bagasse	20% Bagasse	30% Bagasse	Neat LDPE	10% Bagasse	20% Bagasse	30% Bagasse
1	153	159	149	196	11354		11273	15822
2	153	156	83	37	11675		13157	16392
3	252	169	125	197	11919		12814	15819
4	155	144	93	165	10944		10890	14587
Mean	153	157	113	149	11473		12033	15655
Std Dev	1	11	30	76	421		1119	761

Table 2: Flexural Modulus

From the results listed in Table 2 a clear pattern of increase in flexural modulus with fibre content for the LLDPE is observable.

4.5 Tensile test

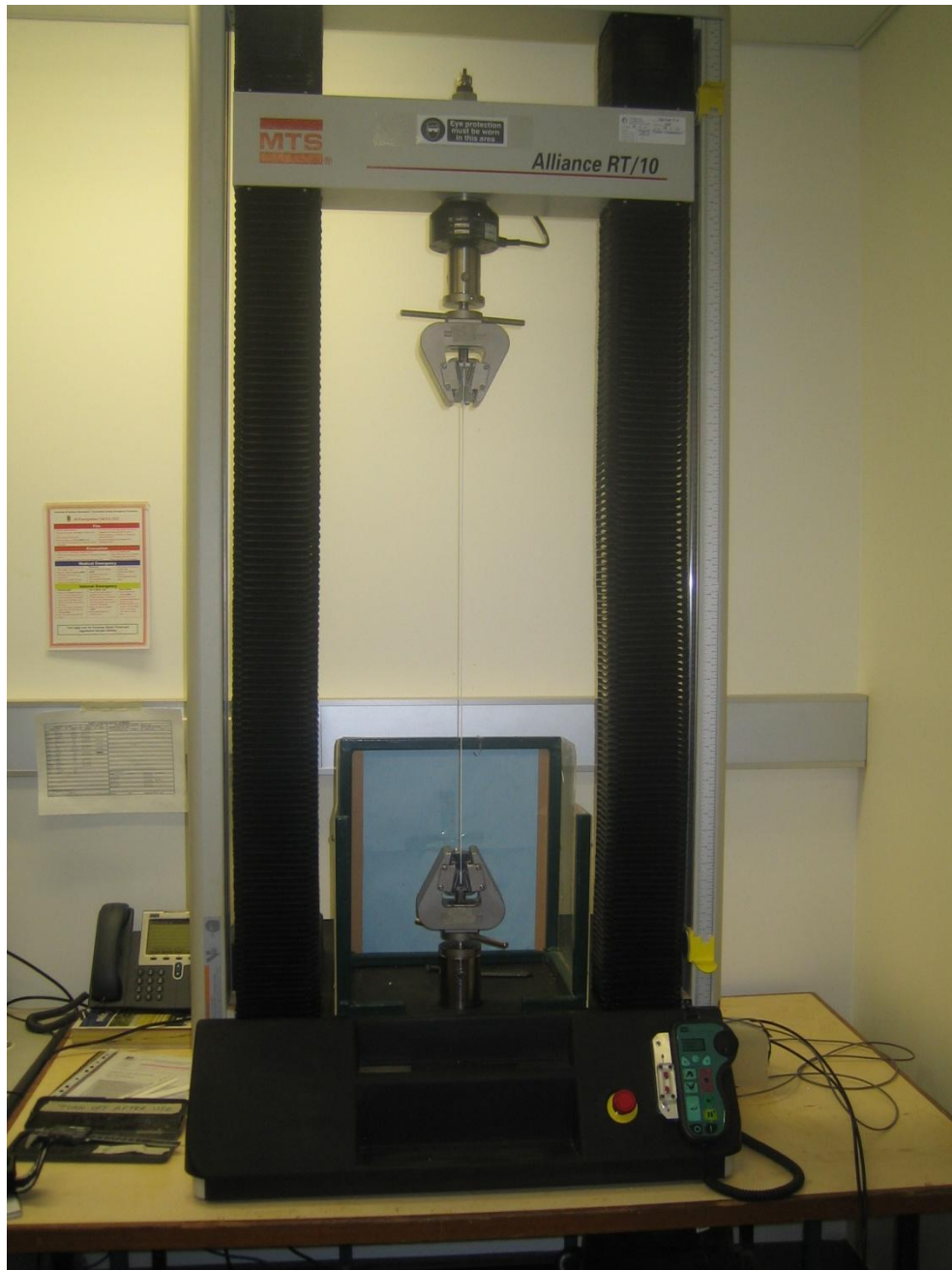


Figure 14: Tensile test neat LLDPE - machine at full extension

Figure 14 shows a neat sample of LLDPE elongating over six times its original length.

Peak Stress (MPa)								
Specimen #	Neat LDPE	10% Bagasse	20% Bagasse	30% Bagasse	Neat LLDPE	10% Bagasse	20% Bagasse	30% Bagasse
1		5.17	1.94	1.28	16.75		9.70	8.37
2		4.32	2.11	1.07	18.69		10.23	9.14
3		4.44	2.31	2.31	18.97		10.27	9.33
4		5.04	3.91	1.57	19.07		10.29	12.21
Mean		4.74	2.57	1.56	18.37		10.12	9.76
Std Dev		0.43	0.91	0.54	1.09		0.29	1.69

Table 3: Peak Stress

4.5.1 Strain

Strain has been calculated from the elongation data (table 7 Appendix D) and the formula for strain:

$$\varepsilon = \frac{\text{change in length}}{\text{Original length}} = \frac{\Delta l}{l_0}$$

The original length measurement of the LDPE sample was 40mm and the LLDPE samples 38mm. Results have been recorded and presented in Table4.

The results of the LDPE testing were greatly affected by the inhomogeneous nature of the composite. For all the samples breakages were observed where there was a large clump of un-wet bagasse creating a smaller cross sectional area of the polymer matrix to carry the load (testing observations Appendix C). The forth samples of both the 10% and 20% bagasse content demonstrate a strain greater than double of the other samples, this arose due to two breaks occurring on opposite sides of the sample simultaneously, requiring extra elongation to occur for one crack to fully separate.

The 30% bagasse sample contained such large areas of un-wet bagasse that breakages occurred at an unrealistic strain.

Peak Strain								
Specimen #	Neat LDPE	10% Bagasse	20% Bagasse	30% Bagasse	Neat LLDPE	10% Bagasse	20% Bagasse	30% Bagasse
1		0.0485	0.03075	0.03425	0.22368		0.03894	0.02342
2		0.04925	0.0185	0.0055	0.20342		0.04632	0.02473
3		0.05475	0.03675	0.01675	0.20289		0.05237	0.03394
4		0.0665	0.06625	0.01225	0.20631		0.04316	0.04237
Mean		0.055	0.038	0.017	0.209		0.045	0.031
Std Dev		0.01	0.02	0.01	0.01		0.006	0.01

Table 4: Peak Strain

From the recorded peak stress data and calculated peak strain the modulus of elasticity has been determined from Hooke's Law:

$$E = \frac{\delta}{\varepsilon}$$

This represents the slope of the stress strain curve and is a measure of the stiffness of a material.

Young's Modulus, E, (MPa)								
Specimen #	Neat LDPE	10% Bagasse	20% Bagasse	30% Bagasse	Neat LLDPE	10% Bagasse	20% Bagasse	30% Bagasse
1		106.6	63.1	37.4	74.9		249.1	357.4
2		87.7	114.1	194.5	91.9		220.9	369.5
3		81.1	62.9	137.9	93.5		196.1	274.8
4		75.8	59.0	128.2	92.4		238.4	288.9
Mean		87.8	74.8	124.5	88.2		226.1	322.5
Std Dev		13.4	26.3	65.0	8.89		23.1	47.9

Table 5: Modulus of Elasticity

A dramatic increase in the Young's modulus can be seen for the LLDPE composites with the increasing fibre content.

4.6 DMA

4.6.1 Storage Modulus

Figure 14 shows the comparative results of the dynamic mechanical analysis of the LDPE bagasse composite. A small increase in the storage modulus is seen with the 10% and 30% over the temperature range compared with the neat LDPE. The 20% bagasse composite exhibits an approximate 13% drop in storage modulus for the majority of the temperature range. It is once again difficult though to draw a definitive conclusion from this analysis due to the inconsistent nature of the samples. The sample size used for DMA is very comparative to the clump size of un-wet bagasse, and also at this size sample it is even less certain of the percentage composition of the sample.

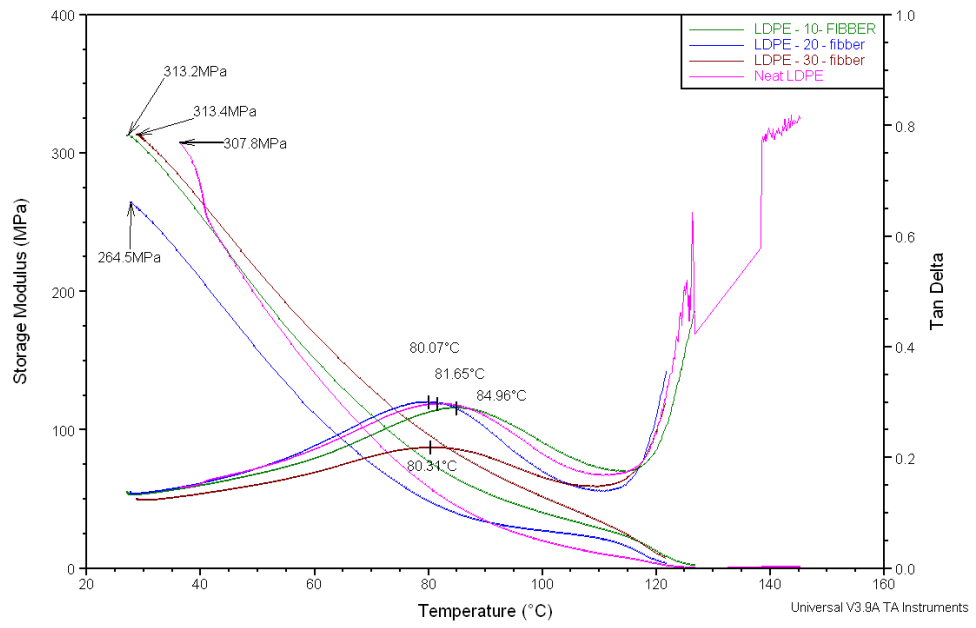


Figure 15: Dynamic mechanical analysis LDPE composites

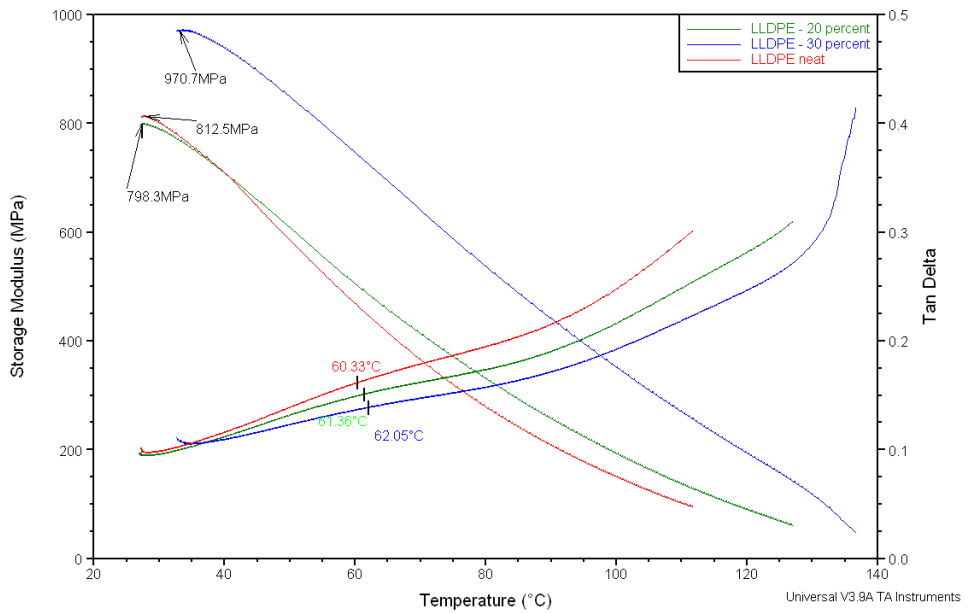


Figure 16: Dynamic mechanical analysis LLDPE composites

4.6.2 Glass Transition Temperature and Loss Modulus

The temperature indicators in Figure 15 mark the sub-glass transition (sub- T_g) loss peak. The bagasse containing samples lie to the left and right of the neat sample, with the ten percent and twenty percent content having a very similar curve and position to the neat. The 30% sample has a smoother line with less of an abrupt change during the sub- T_g , indicating a real affect to the sub- T_g . This may also be seen with the decrease respectively with increased bagasse content of the main T_g .

The impact of the fibre content on the, $\tan \delta$, and storage modulus is much more evident in the LLDPE composites. A 19% increase in the storage modulus is seen for the thirty percent bagasse composite. Although the twenty percent bagasse sample has a lower max point the general form of the line also shows an increase in storage modulus over the investigated temperature range.

A progressive increase in the sub- T_g point and decrease in $\tan \delta$ corresponding with increased fibre content is evident. The sub- T_g point is less clear in the LLDPE samples compared with the LDPE, this is due to the linear nature of the LLDPE.

4.7 Results

It is difficult to draw conclusions from the results of this investigation because of the limit sample size and missing compositions. However information can be derived from the general trends of the results.

The flexural testing and tensile testing both indicate an increase in the modulus of elasticity with an increase in the fibre content for the LLDPE compositions.

4.8 Recommendations

The accuracy of the results of this report has been greatly hindered by the small sampling size.

Australian and international standards call for a minimum of 6 repetitions to be performed per test. The availability of samples impeded this research to just four repeats.

Trends in the results would be made clearer by reducing the step size in percentage fibre content. The initial plan for testing in this project was to produce compositions in five percent increments. This would provide a clearer image of the trends for property changes in the varying compositions.

5 Conclusion

5.1 Introduction

The results pertaining to the LDPE samples were greatly affected by the lack of assimilation between fibre and matrix. The results of these tests can only be used to conclude that the manufacturing process requires either, consistency in material size or further investigation into mixing processes.

The following results refer to the LLDPE and bagasse composites from which information about the viability of sugarcane bagasse as a fibre additive can be drawn.

5.2 Flexural Modulus

Although there is a very limited sample range a clear increase in the Flexural Modulus can be link to an increase in sugarcane bagasse fibre content in the composite.

5.3 Young's Modulus

Tensile testing showed an even greater increase in the modulus of elasticity that is clearly related to the addition of sugarcane bagasse fibres.

5.4 Conclusion

Sugarcane bagasse has a controllable affect on the mechanical properties of LLDPE when used in composite moulded form. It is a viable option for further investigation for the use of producing a sustainable alternative product for hardwoods.

5.5 Further Research and Recommendations

The main objective is to produce a material that is cost effective, eco-friendly and sustainable. Further research should be directed towards using a matrix material that comes from a sustainable and recyclable source.

Repetition on the testing undertaken thus far, with the inclusion of 5% increments would provide greater detail of the effects and suitability of the bagasse.

6 References

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Appendix A

Project Specification

University of Southern Queensland
Faculty of Engineering and Surveying

ENG411/4112 Research Project

PROJECT SPECIFICATION

For: Simone KILIAN - 00050062296

Topic: **Wood fibre reinforced thermoplastic composite**

Supervisor: Dr. Harry Ku

Sponsorship: David Rogers, Technical Manager of Leisure Pools

Enrolment: ENG 4111 – S1, D, 2011
ENG 4112 – S2, D, 2011-03-17

Project Synopsis:

There is a continued high demand by domestic and commercial consumers for hardwood timber products. However a continued viably supply from logging old growth forests is unsustainable. Investigations into alternative products have and continue to be done. One such product is “wood plastic”, a composite of wood fibre and thermoplastic resins. Many products being produced and investigated are created from recycled petroleum based plastics such as drink bottles. I am to investigate the properties of wood plastics produced from non-petroleum based thermoplastics such as polylactic acid (PLA) and locally-sourced wood flour such as bamboo and sugarcane bagasse. This aims to find a product that is more sustainable and environmentally friendly.

This project will cover an investigation into the effects on the properties, including structural from:

- type of wood flour used
- processing parameters
- bio-based thermoplastic compared with traditional recycled thermoplastics

Microscopy and dynamic mechanical analysis (DMA) will be used to investigate the adhesion between wood and plastic.

Appendix B

LDPE Specifications

Alkathene®
Polyethylene

Qenos

Grade
LDH210

Major End Use
FILM EXTRUSION - MEDIUM GAUGE UP TO 80 MICRON

Description
LDH210 is a low density polyethylene designed for the production of bundle shrink films as well as a variety of medium gauge (40 - 80µm) general purpose film applications. LDH210 is formulated with a process stabilisation additive package but contains no antiblock or slip additives.

Application
LDH210 is intended for use in bundle shrink films as well as a variety of medium gauge (40 - 80µm) applications including produce bags, carry bags and blending into other film grades.

Specifications
If this product is used for food contact applications, then the user needs to ensure compliance with the requirements of AS2070-1999 and relevant FDA regulations. When used in accordance with FDA application guidelines, this product meets the requirements of FDA 21 CFR 177.1520 (c) 2.1 and AS2070-1999 section 4.1.1(a). This product should not be used in applications for holding food during cooking without the required compliance testing. This information is only for the Major End Use described on this Product Data sheet. For further information, please contact your primary Qenos contact.

Safety
Material Safety Data Sheets are available for all Qenos polyethylene grades from Qenos.



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Qenos Pty Ltd ACN 054 196 771

Grade
LDH210

Physical Properties				
		Test Method based on ¹	Value ²	Units
Base Polymer Properties				
Melt Index @190°C, 2.16kg		ASTM D1238	1.0	g/10 min
Density		ASTM D1505	0.922	g/cm ³
Typical Film Properties (50µm; Blow-up Ratio 2.0 to 1)				
Haze		ASTM D1003	6	%
Gloss, 45°		ASTM D2457	73	GU
Dart Drop Impact (F ₅₀)		ASTM D1709	120	g
Tear Strength	MD	ASTM D1922	5.1	N
	TD		3.2	N
Tensile Strength at Yield	MD	ASTM D882	11	MPa
	TD		10	MPa
Tensile Strength at Break	MD	ASTM D882	23	MPa
	TD		18	MPa
Elongation at Break	MD	ASTM D882	360	%
	TD		770	%
2% Secant Modulus	MD	ASTM D882	140	MPa
	TD		170	MPa

1. Test procedures may be modified to accommodate operating conditions or facility limitations.
2. Typical values - not to be construed as specifications.

For up to date information, refer to www.qenos.com

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Issue date: 14/11/2008 Refer to web site for latest version.	Version number: v 1.0
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Appendix C

Flexural testing

Table 6: FLexural testing observations

*all samples were placed with the top side up	
Neat LDPE	
	All samples bent without visual signs of damage. Returned to original shape a short period after being removed from machine
10% Bagasse	
1	Sample showed no visible damage, small amount of residual strain after removal from machine
2	“
3	Approximately ½ depth tear looks like due to un-wet bagasse clump
4	“
20% Bagasse	
1	Crack where large un-wet clump of bagasse present
2	No crack observed
3	“
4	Turned off-centre in machine during testing, probably due diagonal split in underside of sample
30% Bagasse	
1	Split
2	98% split – large area un-wet bagasse
3	“
4	2 cracks – 60% across sample
Neat LLDPE	
	All samples bent without visual signs of damage. Returned to original shape a short period after being removed from machine
10% Bagasse	
	NIL
20% Bagasse	
1	Small tear 4mm x 1mm tension side
2	No break
3	Small tear 5mm x 1mm stringy
4	“
30% Bagasse	
1	Stringy tear full width 2/3 depth
2	Stringy tear full width 3/4depth
3	Stringy tear full width 1/2 depth
4	Stringy tear very small 1/2mm depth

Appendix D

Tensile testing

Table 7: Tensile testing elongation and observations

Elongation (mm) at peak stress		
Specimen #	Neat LDPE	
1	>600	Sample elongated in excess of machines capacity, test was stop before breakage. Sample necked several times and material was elongated out of the clamping area.
	10% Bagasse	
1	1.94	Broke along area of clumped un-wet bagasse, small elongation of unmixed polymer
2	1.97	"
3	2.19	"
4	2.66	Broke two places, opposite sides making zigzag shape.
	20% Bagasse	
1	1.23	Broke along area of clumped un-wet bagasse, small elongation of unmixed polymer
2	0.74	"
3	1.47	"
4	2.65	Broke two places, opposite sides making zigzag shape.
	30% Bagasse	
1	1.37	Broke as soon as tension applied
2	0.22	Broke along area of clumped un-wet bagasse, small elongation of unmixed polymer
3	0.67	"
4	0.49	Broke as soon as tension applied
	Neat LLDPE	
1	8.50	Sample elongated in excess of machines capacity, test was stop before breakage. Sample necked several times and material was elongated out of the clamping area.
2	7.73	Sample necked several times and material was elongated out of the clamping area.
3	7.71	Sample necked several times and material was elongated out of the clamping area.
4	7.84	Sample necked several times and material was elongated out of the clamping area.
	10% Bagasse	
		NIL
	20% Bagasse	
1	1.48	
2	1.76	
3	1.99	
4	1.64	
	30% Bagasse	
1	0.89	
2	0.94	
3	1.29	
4	1.61	

Appendix E

DMA Testing Results

Sample: Neat LDPE
Size: 35.0000 x 10.0600 x 3.2000 mm
Method: Temperature Ramp
Comment: Neat LDPE

DMA

File: C:\...\Students\SIMONE 2011\Neat LDPE.001

Run Date: 19-Sep-11 14:14
Instrument: DMA Q800 V5.1 Build 92

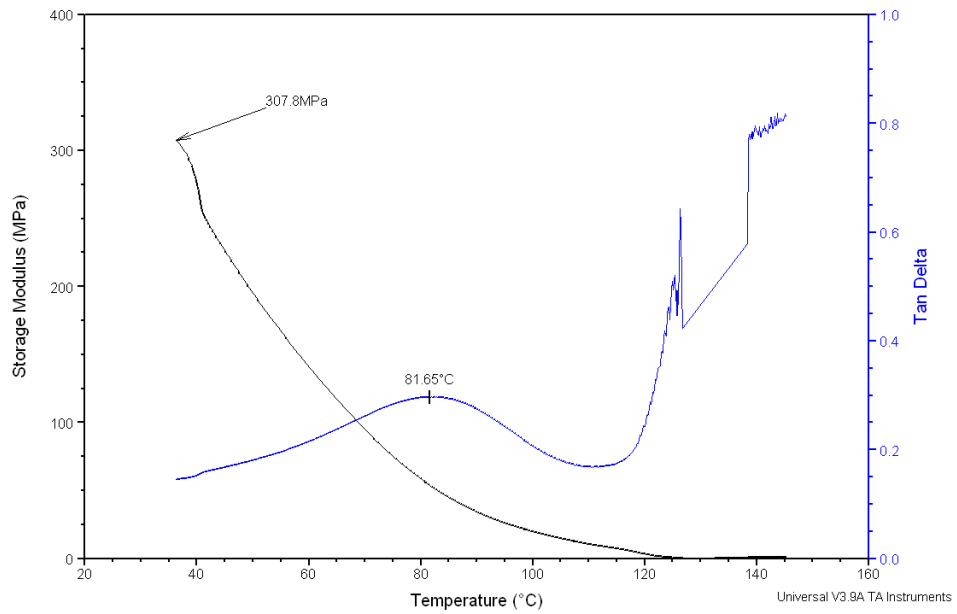


Figure 17: DMA results LDPE neat

Sample: LDPE - 10- FIBBER
Size: 35.0000 x 10.0500 x 2.9700 mm
Method: Temperature Ramp
Comment: LDPE - 10- FIBBER

DMA

File: C:\...\SIMONE 2011\LDPE - 10- FIBBER.001

Run Date: 19-Sep-11 14:14
Instrument: DMA Q800 V5.1 Build 92

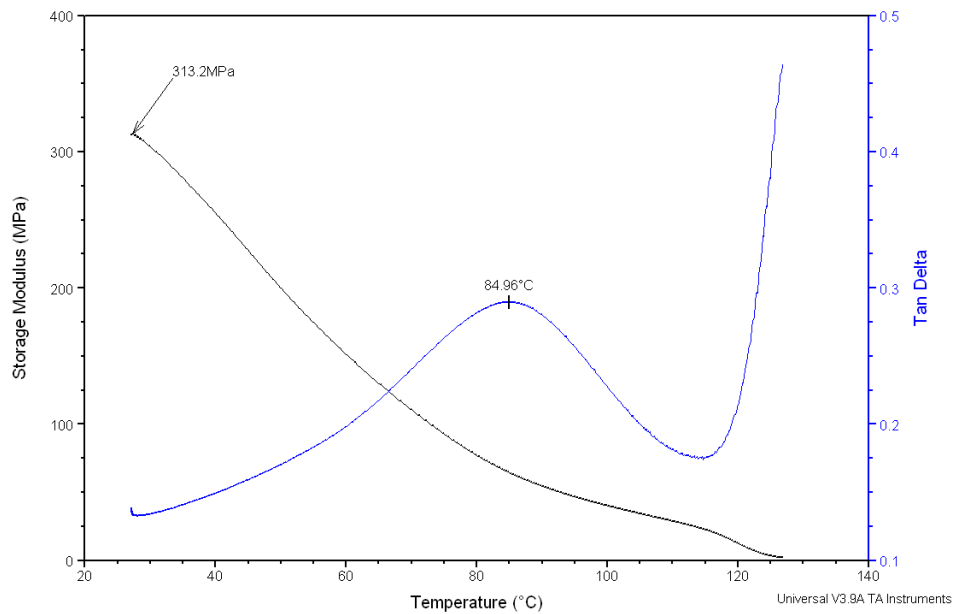


Figure 18: DMA results LDPE 10% bagasse

Sample: LDPE - 20 - fibber
Size: 35.0000 x 10.0300 x 3.0300 mm
Method: Temperature Ramp
Comment: LDPE - 20 - fibber

DMA

File: C:\...SIMONE 2011\LDPE - 20- FIBBER.001

Run Date: 19-Sep-11 14:14
Instrument: DMA Q800 V5.1 Build 92

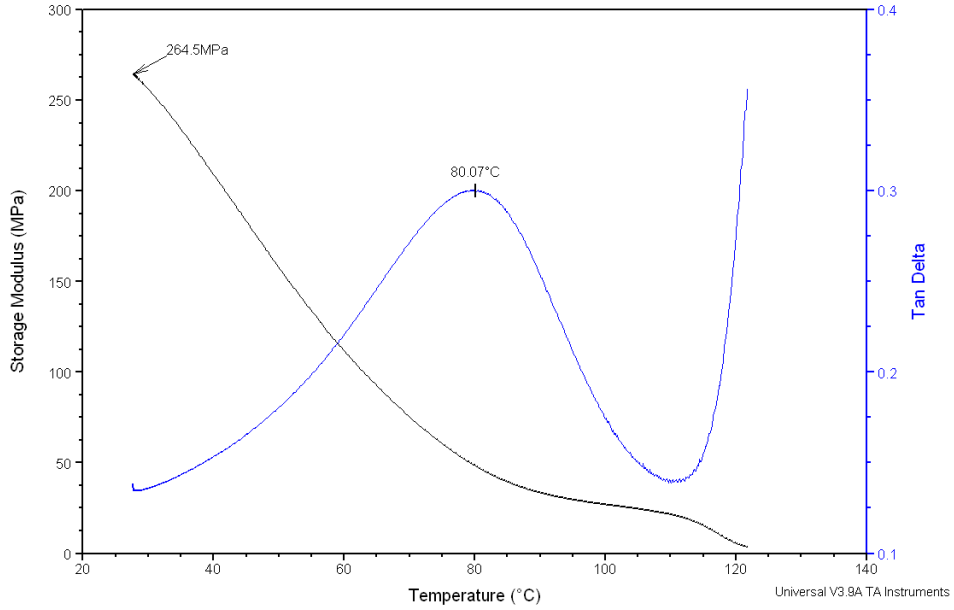


Figure 19: DMA results LDPE 20% bagasse

Sample: LDPE - 30 - fibber
Size: 35.0000 x 10.0800 x 3.3400 mm
Method: Temperature Ramp
Comment: LDPE - 30 - fibber

DMA

File: C:\...SIMONE 2011\LDPE - 30- FIBBER.001

Run Date: 19-Sep-11 14:14
Instrument: DMA Q800 V5.1 Build 92

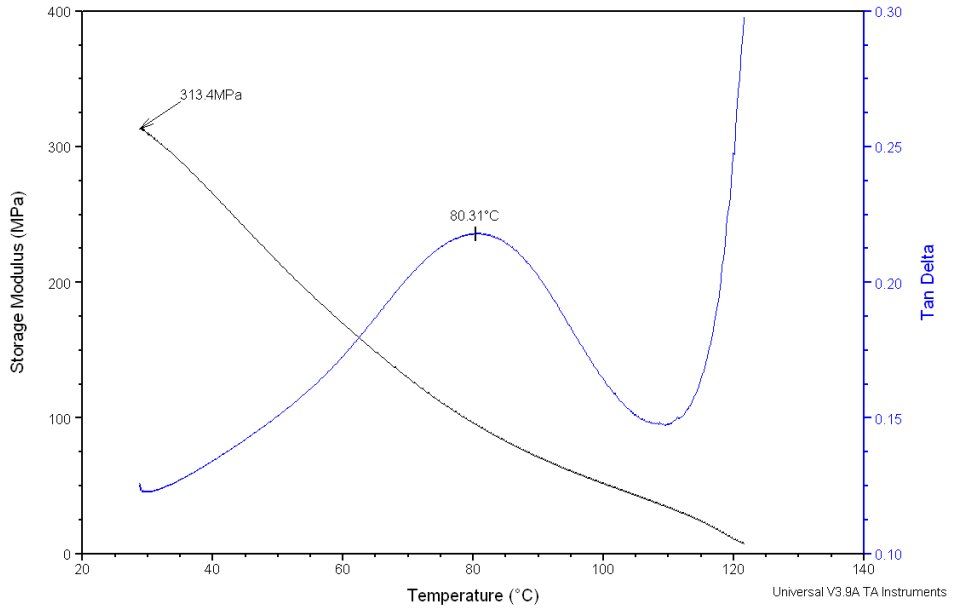


Figure 20: DMA results LDPE 30% bagasse

Sample: LLDPE neat
Size: 35.0000 x 10.2000 x 2.9200 mm
Method: Temperature Ramp
Comment: LLDPE neat

DMA

File: C:\...SIMONE 2011\LLDPE neat.001

Run Date: 14-Oct-11 10:51
Instrument: DMA Q800 V5.1 Build 92

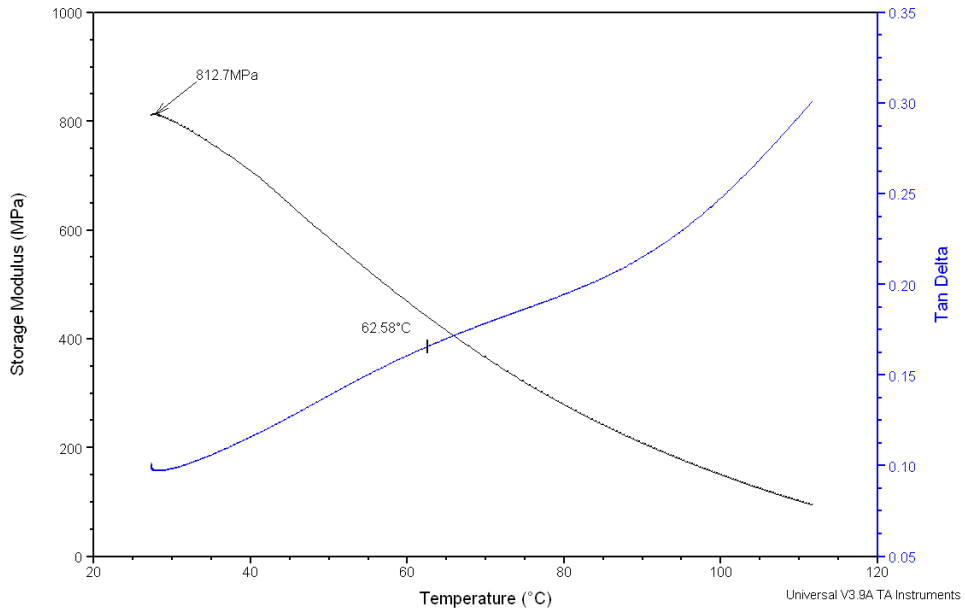


Figure 21: DMA results LLDPE neat

Sample: LLDPE - 20 percent
Size: 35.0000 x 10.6600 x 3.0700 mm
Method: Temperature Ramp
Comment: LLDPE - 20 percent

DMA

File: C:\...SIMONE 2011\LLDPE - 20 percent.001

Run Date: 14-Oct-11 10:51
Instrument: DMA Q800 V5.1 Build 92

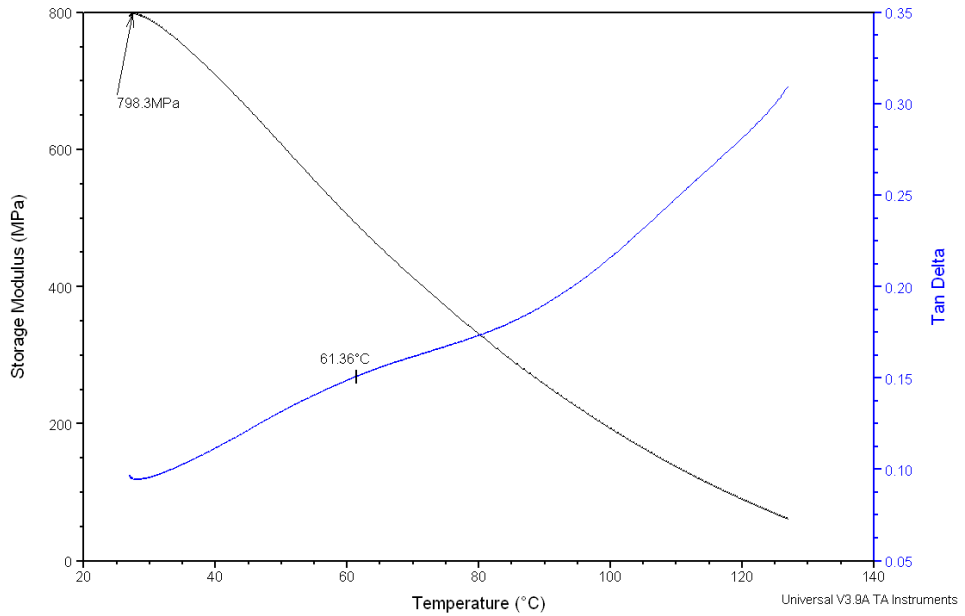


Figure 22: DMA results LLDPE 20% bagasse

Sample: LLDPE - 30 percent
Size: 35.0000 x 10.2500 x 3.0700 mm
Method: Temperature Ramp
Comment: LLDPE - 30 percent

DMA

File: C:\...SIMONE 2011\LLDPE - 30 percent.001
Run Date: 14-Oct-11 10:51
Instrument: DMA Q800 V5.1 Build 92

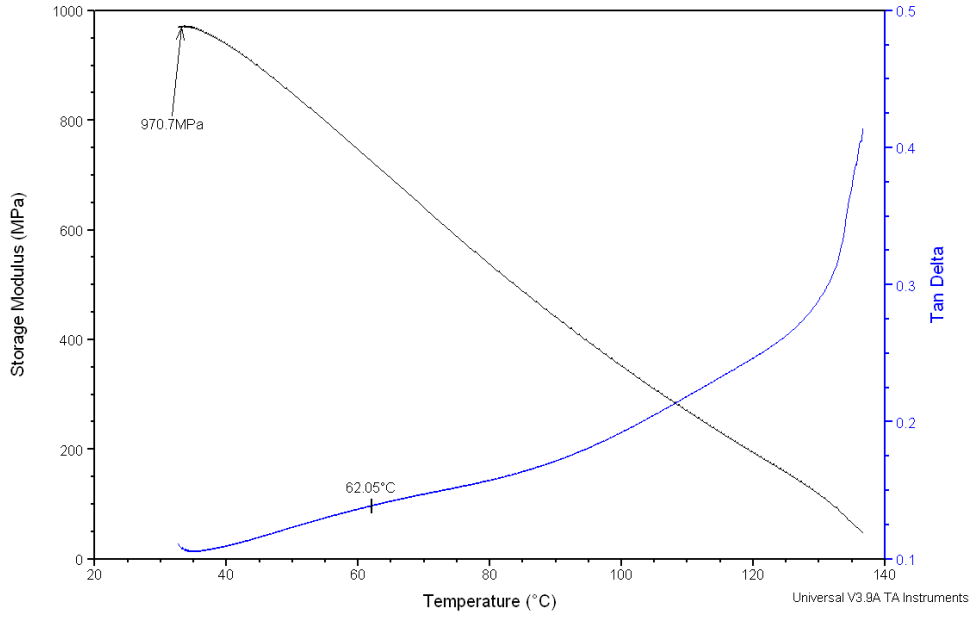


Figure 23: DMA results LLDPE 30% bagasse