University of Southern Queensland
FACULTY OF ENGINEERING AND SURVEYING

CENTRE OF EXCELLENCE IN ENGINEERED FIBRE COMPOSITES

ENVIRONMENTALLY FRIENDLY NATURAL WASTE MATERIALS FOR USE IN CIVIL STRUCTURES

A Dissertation submitted by

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In fulfilment of the requirements of

Bachelor of Engineering (Environmental)

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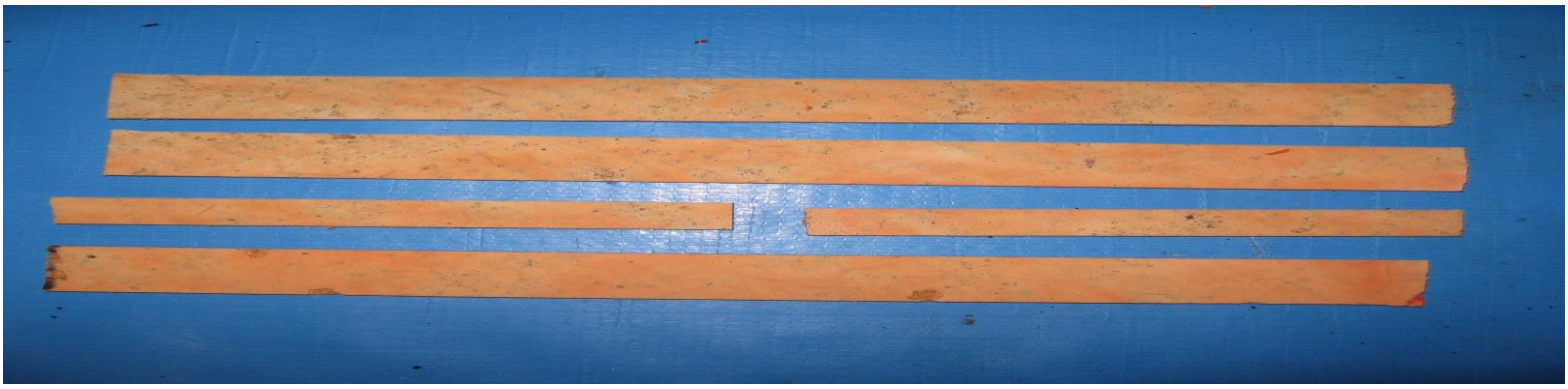

ABSTRACT

By examining past work and conducting a review of available literature the best design and experimentation methodology of investigating environmentally friendly composites using natural waste products could be identified. As examples of these natural waste products, jute and CNSL were used to construct numerous samples of different texture, treatment process of cardanol content.

Flexural, tensile and dynamic mechanical analyse was used to identify the mechanical properties of each sample. These results show quite a high susceptibility to stresses.

Testing also shows that cardanol can be combined with phenol in the phenol-formaldehyde resin in ratios up to 40%, with minimal impact on mechanical properties.

Another significant result of the testing conducted in this project is the proven benefit of treating jute fibre in NaCl solution. Jute and CNSL grow abundantly in some of the poorest region in the world. Coincidently, these areas also show some of the highest rates of deforestation. If jute reinforced composites are used to supplement or replace timber as a building material in these areas, they can be significantly improved by treating the fibres in seawater.

Using seawater to treat jute fibres and supplementing petrochemically derived phenol-formaldehyde resins with CNSL has the potential to create one of the most sustainable fibre composites since mud-brick.

The first principles that allowed us to research and develop composites for use in civil structures came from very basic technology in primitive societies. This research explored ways in which we can further the technology and couple it with sustainable thinking. Through research and experimentation this project investigated how waste materials can be utilised in creating environmentally friendly composites.

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CERTIFICATION

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I would like to also thank Nathan Manthey. Nathan conducted a similar project last year as his thesis and has returned to the CEEFC as a PHD student. I found Nathans advice here and there very useful and his help during my absence from the labs was priceless.

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CONTENTS

1.0 INTRODUCTION

1.1 Background

Social, economic and political demands are increasingly demanding a stronger focus on environmental considerations. In addition to most areas of engineering, this demand has been conveyed to numerous areas of research. One such area of research affected by this drive for sustainability is that of fibre composites for use in civil structures.

Fibre composites are traditionally comprised of petroleum based resins and polymer based fibres. Replacing or substituting these composites with natural, renewable materials increases sustainability. However, if these natural materials can be found as an existing waste product then the economic significance of this research also becomes evident.

Typically, research and production of composites is a luxury that only first-world countries can afford. However, the principle of using fibres to reinforce different materials is extremely old and originated from developing societies. As an evolution of this very basic technology it is necessary to explore more sustainable alternatives. In short, it is now possible to use modern technology and enlightened knowledge to enhance or provide alternatives to older, finite materials.

It falls upon engineers to seek out and develop alternative methods with which to construct fibre-composites in order to ensure the future of the construction industry.

1.2 Aims and objectives

This project is aimed at investigating the use of natural waste products in phenolic resins. There are three primary objectives:

1.2.1 Examine past work and conduct background research into the field This is to include an in depth review of literature

1.2.2 Prepare and test samples

1.2.3 Discuss the results and identify and optimum procedure for the preparation of jute/resin composites.

Secondary objectives are:

1. To examine the material for potential structural use.
2. Investigate factors influencing the properties of test composites

Overall, this project intends to expose the potential for waste products to be used on a more widespread basis in the fibre-composite area.

1.3 Previous work and the 'Peer Group'

Fellow student Nigel Pola is conducting a similar project on a parallel level to this one. Although Nigel is also experimenting with substituting the phenol-formaldehyde resin with a waste product, his scope does not include the use of jute fibre. Nigel has shared useful data developed by testing neat resins.

Past student, Nathan Manthey conducted a similar project using hemp fibre. While this may prove a valuable resource, there are significant differences between hemp fibre and jute fabric and his project omits the potential for supplementing the phenolic resin with a waste product.

This area is one that is only just beginning to be investigated, and while there are a number of resources available, research is certainly still in its infancy. It is

important to note that trying to bond other compounds (such as cardanol) with phenol-formaldehyde compounds is rarely attempted

1.4 Scope

At this stage, this project is limited to investigation into jute as a fabric for use in fibre-composites, and Cardanol (CNSL) as a substitute of phenol in the phenolic resin.

Factors that affect the mechanical properties of jute-phenolic composites will also be investigated. These are coarseness of fabric, pre-treatment of fibres, jute to resin ratio and the amount of waste product in the resin.

As a student of environmental engineering, the author is to impose a strong focus on sustainability and analysis of using low cost fibre-composites in developing countries.

1.5 Conclusion

The first principles that allowed us to research and develop composites for use in civil structures came from very basic technology in primitive societies. The purpose of this research is to explore ways in which we further the technology and couple it with sustainable thinking. Through research and experimentation it is the aim of this project to investigate how waste materials can be utilised in creating environmentally friendly composites.

2.0 LITERATURE REVIEW

2.1 Introduction

Before any kind of experimentation and testing can be conducted an in-depth level of research is required. This is presented as a review of many sources of existing literature that has been analysed for relevance and reliability in order to extract the most accurate and useful information.

The following literature review is structured such that all relevant materials, techniques and fundamentals are discussed broadly, with focus then shifting to those aspects central to the research.

2.2 Introduction to Fibre-Composites

Composites are created by combining multiple materials of different structural behaviour in order to create a singular material, known as the composite, which has optimal properties. For example reinforced concrete is a composite because in creating it we take concrete (which has very high compressive strength but poor tensile strength) and combined it with steel, which has very high tensile strength. The result is a material which is extremely high in compressive strength without significant flaws in tensile strength.

Fibre-composites are comprised of both fibres and a matrix. In the above example steel is the fibre that stiffens and strengthens the composite and concrete is the matrix the spreads the load and provides a medium in which the fibres can be placed.

Composites are highly resistant to corrosion and magnetism and can be designed in a way which locates strength, stiffness or flexibility where it is most needed (DEEDI 2008).

There are numerous other types of composites combined for different reasons, from flint-tipped feather flighted arrows to the fibre reinforced polymers discussed in this paper. Every composite has a different form, is designed for different purposes and is targeted at specific economic brackets. For instance, Aramid fibre composites are both exceptionally strong and exceptionally expensive and are thus produced in very low volumes. At the other end of the spectrum are composites reinforced with Jute fabric which is a flexible, low cost material that, when strengthened with resin, shows similar properties to wood (Razera and Frollini 2003).

As seen below, the earliest composites were made by combining mud and straw or grass to construct dwellings, grain stores or other civil structures. This very basic technology has evolved over the years through modern research and development and led to the production of materials that are optimised for weight and strength, as can be seen in the carbon-fibre based Porsche pictured below.

Figure 1 Mud-brick dwelling and Carbon-fibre Porsche (Yosax.com)

The following topics will discuss a variety of different fibres but will focus on polymer matrices. Typically the majority of fibre-composites fall within these bounds (Kaw 1997).

2.3 Fibres

Fibres are used in composites to strengthen the resin by binding the matrix. Depending on the fibres specific properties this may add flexural strength, tensile strength or improve thermodynamics.

There are many different types and orientation of fibres used in composites, most commonly **nylon, glass and carbon** fibres and **random, unidirectional and fabric** orientations.

Unfortunately these three fibres, despite being extremely effective, are all synthetic and are increasingly causing environmental concerns. The sustainable alternative to synthetic fibre is natural fibre.

2.3.1 Natural Fibres

Natural fibres can be used in composites in the same way synthetic fibres are. Although there are many fibres in nature that can be used to strengthen matrices, from feathers to sawdust, however the main source of natural fibres in modern composites comes from plants. The type and name of fibre is classified based which part of the plant the fibre comes from. These are grouped broadly into leaf, seed, bast, fruit, grass and stalk (Kalia et al. 2009). Examples are shown in table 1, with the most common fibres shown in bold.

Leaf	Seed	**Bast**	Fruit	Grass	Stalk
Abaca	Cotton	**Bast**	Coir	Alfa	Straw
Date palm		**Hemp**	Kapok	Bagasse	Banana
Pineapple		**Jute**	Oil Palm	Bamboo	
Sisal		**Ramie**			

Table 1

Natural fibres are non-abrasive and non-toxic with very low density. Mechanically, these fibres have shown high stiffness and strength and thus proven their value in structural engineering. For example, soft-wood-Kraft and flax fibres have a very close characteristic value to the very popular, but synthetic, E-Glass fibres (Kalia et al. 2009).

As can be seen in figure 2, natural fibres are made up of many layers and walls. Between each layer is an amorphous lignin matrix. And herein lies the first of several downsides of natural fibres. The plant lignin is hydroscopic, flammable and breaks down quickly (Rana and Jayachandran 2000). Tests have shown that the hydroscopic lignin in natural fibres does not bond well with the composite resin, which are typically hydrophobic.

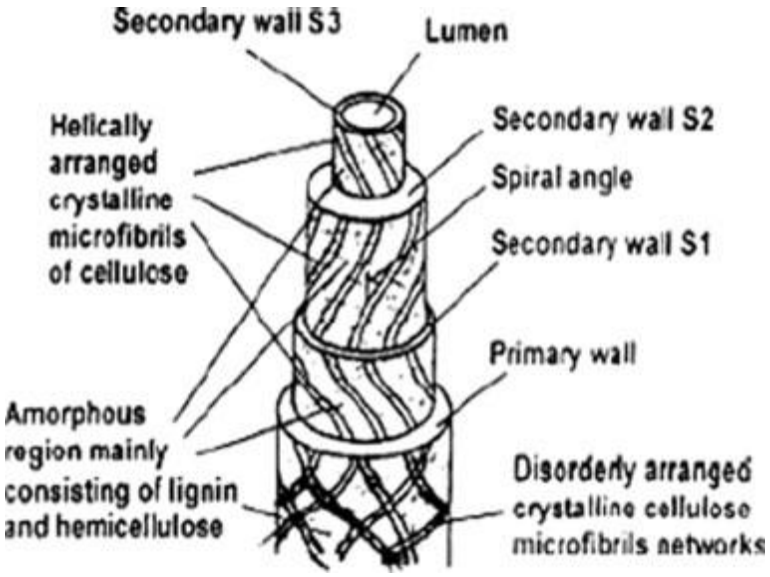


Figure 2 – Structure of a natural fibre (Kalia et al 2009)

Information from Kalia et al. (2009), Das (2010) and Rana and Jayachandran (2000) have been used to tabulate the advantages and disadvantages of natural fibres (table 2). Obviously, every purpose and application requires individual analysis to assess the impact of

each disadvantage and the benefit of each advantage to decide if natural fibres fits the purpose of the intended composite. It must be realised that many of these disadvantages are possible to overcome with fibre treatment (see section 2.2.1.2). Notice heat resistance has been included as both an advantage and disadvantage due to the differing properties between types of natural fibre.

Advantages	Disadvantages
Low cost and readily available	Moisture absorption
Easily formed	Flammability
High tensile strength and elasticity	Biologically susceptible
Thermal and acoustic insulation	Low resistance to UV light
Non Toxic	Lignin hampers bonding with polymers
Sustainable and biodegradable	Low consistency of microstructure

Table 2

2.3.1.1 Jute Fibre

Jute is a natural, bast type fibre from the genus *Chorchorus* and is grown primarily in and around India, China and Bangladesh . Next to cotton, Jute is the second most significant fibre in the world (Rana and Jayachandran 2000).

Figure 3 – Jute in its vegetative state (Wikipedia.com)

Jute is an excellent example of natural fibre for use in composites. It is inexpensive, readily available, safe to work with, flexible and strong.

Jute absorbs CO_2, provides short term habitat for animals, stabilises soil and provides an income and clothing to millions of impoverished people (Sarkar et al. 2001).

Studies by Das 2010 have shown that the lignin problem that disadvantages other natural fibres can be dealt with by bonding jute with Phenolic resins rather than urea or melamine resins. This is turn increases the water resistance of jute fibre composites.

Despite a fair amount of dedicated research, jute is still in its infancy as a fibre for reinforcing composite matrices (Mitra et al. 1997).

2.3.1.2 Jute Fibre Treatment

Because the lignin in jute fibres contain –OH groups, moisture absorption and poor matrix bonding often causes dimensional instability. For this reason, it is important to treat the fibres in order to reduce the –OH content (Das 2010). Typically, this done through alkali treatment with extremely strong chemicals such as sodium hydroxide. A study by Ray et al. 2001 showed that, as a result of NaOH treatment, an improvement of over 20% for flexural strength and modulus can be made.

However, NaOH is an extremely hazardous material. Synthesis, storage and disposal of sodium hydroxide is both hazardous to health and the environment. In researching environmentally friendly composites it seems too ironic that fibres should be treated in such a non-environmentally friendly way. An alternative to this was identified in a source by Oladele et al. 2010 who experimented with various chemical treatments, one of which was NaCl, or salt. Although this source dealt with sisal fibres, it shows significant advantages of treating with sodium chloride. Indeed, this calls for further investigation through experimentation.

If Jute fibre reinforced polymers can be improved by treating the fibre in common seawater, an even more environmentally friendly outcome can

be identified. Environmentally friendly composites made using natural waste materials treated in seawater is an ideal situation in terms of cost effectiveness and sustainability.

2.4 Composite Matrix

Like fibres, there are numerous different types of matrices used in composites. While just about all of these are used for binding and structuring fibres and dispersing loads, nearly all modern composites use a polymer matrix. Polymer matrices can be divided into two groups; thermosets and thermoplastics.

2.4.1 Thermosets

Thermosets are polymer matrices that are liquid at room temperature, hardening when they are cured. Curing can be done with the use of catalyst or with heating devices. Common heating devices include ovens and microwaves. The method of curing depends on specific properties desired of the composite and the type of resin or catalyst used. Curing effectively cross-links the polymer chains and prevents the molecules sliding past one-another (Manthey 2009).

Once cured, thermosets are generally hard and stiff at low temperature. Although they are unable to re-liquefy as they are heated, thermosets become more ductile and eventually reach what is known as the glass transition temperature. This is the temperature at which thermosets go from being hard and brittle to soft and flexible.

2.4.2 Thermoplastics

Unlike thermosets, after glass transition temperature is reached, thermoplastics become so elastic that they can even be reworked and re-formed. This is due to the effect of Van der Wals forces. As they are heated, the molecules in thermoplastics vibrate increasingly causing the Van der Walls forces to decrease significantly. Consequently, viscosity decreases and the polymer becomes plastic (Manthey 2009).

2.4.3 Common types of polymer matrices

- Unsaturated polyester
- Epoxy
- **Phenolic**
- Vinyl ester

2.4.4 Phenolic Resin

The phenolic resin is a thermoset condensation polymer formed by combining phenol with formaldehyde and is possibly the most widespread type of resin in fibre composites. Since 1965, the volume of phenolic resins used commercially has risen from 200 million kg to over a billion kilograms in 1990 (Modern Plastic 1991).

Phenolic resins are classified as either **resol** or **novolac**, depending on the acidity or alkalinity of the catalyst.

As mentioned in section 2.2.1.1, phenolic resins are the best suited polymer matrix to bond with natural fibre.

The process in which condensation polymerisation combines phenol and formaldehyde and produces the phenolic resin can be seen below.

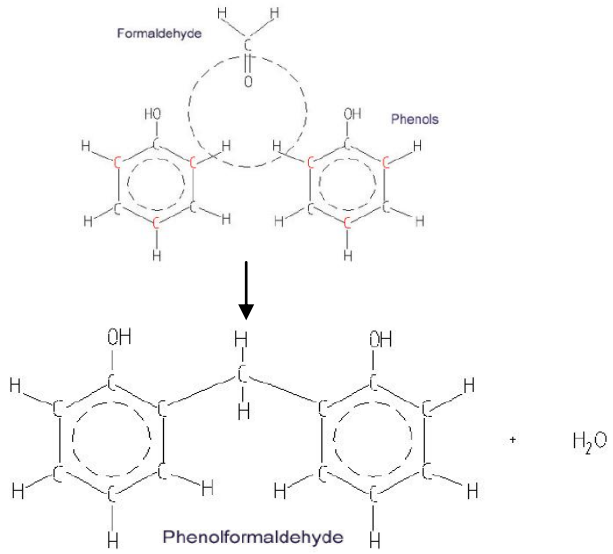


Figure 4 – Synthesis of phenolic resin

2.4.5 Organic Resins

As can be seen in the mud-brick example, composites can be made using naturally derived binding matrices.

2.4.5.1 Cashew Nut Shell Liquid (CNSL)

A by-product of the cashew industry, CNSL is often disposed of as waste without realising the many applications of this important resin.

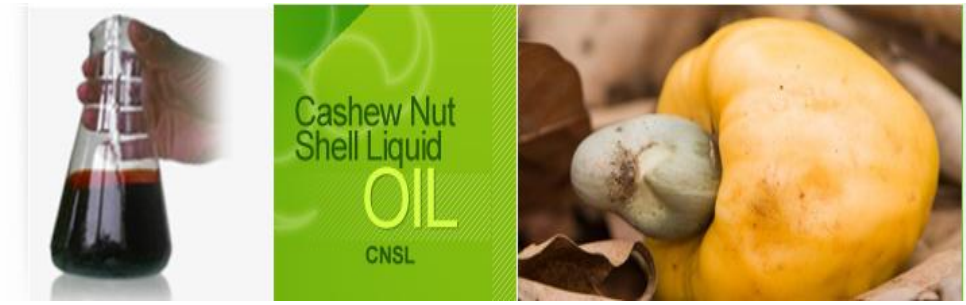
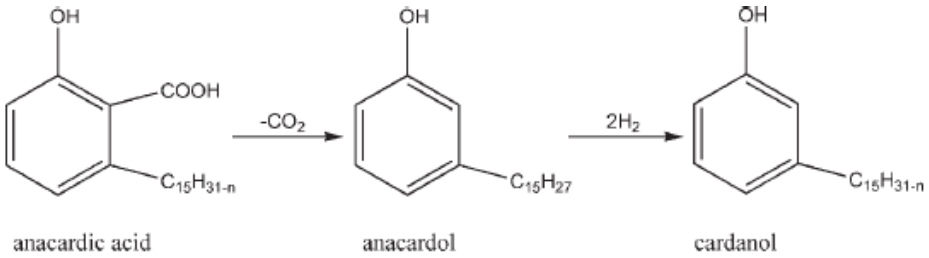


Figure 5 – CNSL in liquid and nut form (http://www.kancoindia.com/)

Cashew nut shell liquid has been found to include many of the same compounds as phenolic resins and can be substituted for phenol in phenol-formaldehyde. Phenol-formaldehyde is usually combined in a 1:2 ratio (P:F). Cardanol can be added to the P quantity effectively up to about 40%.

"*Upon heating, anarcardic acid is decarboxylated to produce anacardol, which, when hydrogenated, yields cardanol*" *(Chauyjulit, Rattanametangkool and Potiyaraj 2006, pp 1)*

As seen in the diagram below, Cardanol can be used in fibre composites because it can react with formaldehyde to produce cardanol-formaldehyde and reduce the need for the petrochemically produced phenol-formaldehyde.



Scheme 2 Conversion of anacardic acid into anacardol and then cardanol.

Figure 6 – production of cardanol *(Chauyjulit, Rattanametangkool and Potiyaraj 2006, pp 1)*

2.5 Mechanical Testing

Like most composites, jute reinforced phenolics are tested for three different properties, tensile strength, flexural strength and dynamic mechanical analysis. Samples were prepared by using cutting tools to shape the composite into standard sizes. These sizes are generally relative to sample thickness and length is based on instrument specification.

2.5.1 Tensile and Flexural Strength

Tensile strength of a material is the degree at which the material can resist forces per unit area applied axially to the specimen (shown in figure 7).

Flexural strength on the other hand deals with forces applied perpendicularly to the material. The most common method of testing flexural strength is the three point bending test. This is shown in figure 8.

Both flexural and tensile strength are measure of the materials resistance to stress and strain.

Figure 7 – Tensile forces

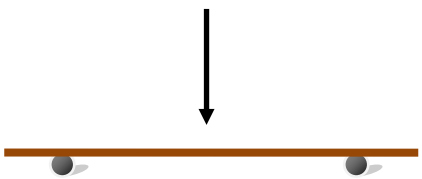


Figure 8 – Flexural test

2.5.2 Stress and Strain

Stress and strain are caused for forces acting on a material. As mentioned in the section above, these can be either flexural or tensile.

Stress σ and strain $\mathcal{E}$ calculations are shown below:

$$\sigma = \frac{3PL}{2bd^2}$$

Where:

$P = Applied\ load\ to\ specimen\ (N)$

$L = Length\ of\ support\ span\ (mm)$

$b = Width\ of\ the\ test\ specimen\ (mm)$

$d = Thickness\ of\ the\ test\ specimen\ (mm)$

$$\mathcal{E} = \frac{6Dd}{L^2} \qquad (4)$$

Where:

$D = Maximum\ deflection\ at\ the\ centre\ of\ the\ specimen\ (mm)$

$L = Length\ of\ support\ span\ (mm)$

$d = Thickness\ of\ the\ test\ specimen\ (mm)$

2.5.3 Flexural Modulus

Flexural modulus, in a similar way to flexural strength is an indication of the stiffness of the material. It is given as a ration of stress over strain (Manthey 2009).

The equation below calculates flexural modulus .

$$E = \frac{L^3 m}{4bd^3}$$

(Ray et al. 2001)

Where:

$m = Gradient\ of\ straight\ line\ portion\ of\ load\ deflection\ curve$

$L = Length\ of\ support\ span\ (mm)$

$d = Thickness\ of\ the\ test\ specimen\ (mm)$

$b = Width\ of\ the\ test\ specimen\ (mm)$

2.5.4 Dynamic Mechanical Analysis (DMA)

Dynamic Mechanical Analysis or DMA is used to investigate the viscoelastic behaviour of polymers. This is done by applying sinusoidal stresses to the material and recording complex moduli (Wikipedia.com).

The most valuable outcome of DMA is glass transition temperature. As aforementioned this is the temperature at which a material goes from hard and stiff, to soft and plastic.

Storage and loss moduli are also determined in DMA. This is indicative of the energy either stored or lost from the material.

DMA also provides information on damping coefficient. However this remains an object for further research at this stage.

2.6 Society, Sustainability and the Environment – Consequential Effects

As both costs and level of environmental concern rises, the use of natural and renewable materials in composites similarly increases.

Although petrochemically derived resins and fibres show excellent mechanical properties they are a finite resource and are toxic to humans and the environment. This means the future of synthetic fibres is unsure. It also means that synthesis and disposal of composites and composite materials is detrimental to our already fragile environment. On local and global scales, the long-term impact of such processes is beginning to be seen. Rising sea levels, increased storm activity, desertification, drought, habitat loss and the endangerment of millions of native flora and fauna us do to, in some part, the production of petrochemical fibres and resins (Sarkar et al. 2001).

Use of natural based composites also has the benefit of reducing deforestation by providing an alternative to the common, unsustainable building materials such as timber (Sarkar et al. 2001).

Jute, for example, is a quick growing crop that absorbs CO_2, provides short term habitat for animals, stabilises soils and provides an alternative to timber in the form of jute reinforced fibre composites.

Because the majority of fibres and natural resins grow well in tropics where a lot of third world countries are situated geographically, they are positioned quite well to pursue this drive towards sustainable composites and building materials. The majority of leaf and bast type fibres grow in countries such as India, Bangladesh and China. These fibres include sisal, jute and hemp, fibres that are already grown in massive quantities to provide fibre for things such as clothing. Resins like those derived from CNSL grow just about anywhere in the world.

The benefits of natural composites are not limited to the environment. Again, using Jute as an example, this fibre covers nearly a million hectares in India alone where it provides a livelihood to around 4 million farmers and 362 workers (Rana and Jayachandran 2000). Adding to this demand, composites made using jute fibre have the capability to enrich the lives of some of the poorest people on earth.

The potential for these countries to use natural waste products is extremely high, and their cost-effectiveness is ideal. No longer are composites a technology that only the rich can afford to take part in.

Sarkar and Adhikari (2001) have reinforced the fact that synthetic materials pose issues with solid waste pollution, poisonous gas generation and carcinogenic chemicals.

This research project is a perfect example of using technical skills and engineering processes in the interest of future generations. By investigating alternatives or supplements to existing petro-chemical based ingredients it is possible to ensure that the numerous benefits of fibre-composites can be enjoyed in the civil-structural field for years to come.

Using natural waste products such as jute and CNSL we are also decreasing waste and the energy used to process it.

Developing societies demand safer infrastructure. Fibre-composites have consistently proven to increase the desirable properties of certain materials while decreasing the gross weight of that required material.

There are addition ways in which waste material can increase the safety of structure. For example, resins reinforced with jute fibre have previously shown

to demonstrate improved dimensional stability against moisture attack and non-vulnerability towards other environmental agents (Singh, 1999).

Aside from those discussed regarding sustainability, there are further ethical considerations behind this project. The use of jute, or waste products in general is an indication that fibre-composites need not always be a luxury that only the wealthy can experiment with. Singh (1999) has identified that jute is often produced in lower socio-economic areas of the world, thereby providing easy accessibility to the resource for natural fibre-reinforcement. Singh (1999) goes on to claim that jute fibre materials can be used effectively in low cost housing and infrastructure as a wood substitute. In this way financially disadvantaged governments can not only supply an excellent structural material to the masses, but also create jobs by increasing demand in local produce (jute).

By promoting interest in this field and conducting valuable research, Engineers are adhering to the strict array of ethics to which we are bound.

2.7 Risk Assessment

Like any work task or environment, there are a number of risks or hazards that need to be assessed and addressed. Although this particular project centres around the laboratory, handling of resins, cutting tools and stress inducing implements means that this workplace poses significant danger.

Risks associated with this project can be identified as:

1. Hazardous materials
2. Sample preparation
3. Sample testing

4. Muscular-skeletal stress

After identifying risks and hazards, it is important to consider both the likelihood of incident and the degree of consequence. In this way, it is possible to determine the ultimate level of risk. The most effective way of implementing this strategy is by using a risk matrix. An example risk matrix can be seen below. The risk matrix works by seeking points of corresponding likelihood and degree of consequence. For example, handling strong acids with bare hands has **major** consequence and is quite **likely**, therefore it can be awarded and **high (H)** risk activity.

Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Severe
Almost certain	M	H	H	E	E
Likely	M	M	H	H	E
Possible	L	M	M	H	E
Unlikely	L	M	M	M	H
Rare	L	L	M	M	H

These risks can be managed in a number of ways.

1. Effective risk assessment
2. Being aware of hazard identification signage such as flamable or toxic signs.
3. Being aware of any material safety data sheets (MSDS's) which are required by law in any environment where hazardous materials are used or stored.
4. Wearing correct PPE ie. Gloves, glasses, earplugs and masks.
5. Wearing appropriate clothing ie. Covered footwear and no loose clothing or jewelry.
6. Being generally aware of surroundings.
7. Keeping the workplace free of trip hazards.

8. Using ergonomic office furniture and correct posture.
9. Use tools as they were designed, with safety guards in place.
10. Identify emergency equipment ie. Fire extinguishers, eye baths.

2.8 Conclusion

The above review of relevant literature gives a background of all materials and methods involved in this research project. Composites are comprised of both fibre and resin and optimised to gain the best mechanical characteristics of both. Fibres are arranged differently in different composites but are generally used to bind the matrix and stiffen the composite. Like resins, they are traditionally petrochemically derived.

Resins support the fibres and disperse the load. They are classified as either thermosets or thermoplastics, depending on their behaviour under heat. One type of thermoset is the phenolic resin, which can either be a resol or novolac, depending on the acidity or alkalinity of the catalyst.

However, there are alternatives to petrochemically derived composites. Natural materials such as jute and CNSL can be used in a way such that sustainability is increased and society bettered.

It was discovered that some natural fibres contain lignin that, without treatment can cause water absorption and matrix bonding problems.

Testing materials for tensile strength, flexural strength and DMA is required in order to determine the mechanical properties of composites as well as their glass transition temperatures.

All this information is necessary if an effective experimental design is to be developed and their results discussed concisely.

3.0 EXPERIMENTAL DESIGN AND METHODOLOGY

3.1 Introduction

In order to investigate the construction of environmentally friendly composites made using natural waste materials, two different materials were selected to focus upon, one a fibre and the other a resin. Jute was selected for its desirable mechanical properties and environmental qualities outlined in section 2. As an environmentally friendly resin, CNSL was chosen because when converted to Cardanol, it becomes a phenolic resin. The process in which this is done is also described in section 2, the literature review.

This project can be broken down into four major components:

i) **RESEARCH**
ii) **CONSTRUCTION**
iii) **TESTING**
iv) **EVALUATION**

Each of these components complement one another and, when combined, provide the basis of an effective research project.

3.2 Research

As identified in the initial literature review included with this assessment, research is the key element behind the project. Research itself is conducted at three stages: **Background, Working and Evaluation**. Even before setting foot in a laboratory it is necessary to gain a general insight into the field of fibre-composites and the potential applications for waste materials. For this reason, background research is crucial to project success.

During construction of composites, research is needed to solve any problems encountered and explore other paths of investigation. Prior to, and during testing, research is important in gaining an understanding of procedures and behaviours exhibited under loading.

In the evaluation stage of the project, research must be used in order to explain results and put forward educated items of discussion

3.3 Construction

From the research discussed in previous section, a general construction procedure could be developed. The Construction Execution Procedure (CEP) for experimentation is shown below. Each CEP is aligned with a specific reference section that will be discussed.

An example of a trial and error sample that was used to develop some of the CEP can be seen in figure 9.

Step	Action	Ref
1	Prepare standardised sample mould	Nil
2	Cut, wash and treat (if required) jute fabric	3.3.1
3	Dry and weigh jute fabric	3.3.1
4	Synthesise catalyst	3.3.2
5	Prepare phenol-formaldehyde and cardanol	2
6	Combine catalyst with phenolic	Nil
7	Combine jute and resin	3.3.3
8	Cover and compress	3.3.4
9	Bench cure	3.3.5
10	Oven cure	3.3.5

Table 3 - CEP

3.3.1 Jute Fabric Preparations

In order to investigate the effect of weave size on the composite, two types of jute were used, a fine weave and a thick, coarser weave.

After these were cut to size, they were washed or washed and treated. To investigate the effect of treating jute fibres in NaCl (see chapter 2), the fabric was washed in a 5% solution for roughly an hour to simulate common seawater. As a control, jute was also left un-treated and simply washed in warm water with detergent to remove any contaminants picked up in manufacturing or transport. Whether treated or un-treated, the fabric was always rinsed thoroughly in fresh, cool water before drying. An example of large weave jute fabric can be seen in figure 15.

Figure 15 – Coarse jute fabric

When the jute fabric was completely dried, it could be weighed. Weighing the fabric was absolutely essential in trying to determine the optimum ratio in which jute is combined with the resin.

Once that ratio was found, weighing the fabric was required in determining how much resin to use.

3.3.2 Catalyst Synthesis

The catalyst of choice in this project was Phencat 10. Phencat 10 is a general purpose catalyst that works well with J2027 Phenolic Resin. The construct was initially found by Nigel Pola, however it was later found on hazards.com where BP chemicals listed the ingredients and amounts.

These are;

50% P-Toluenesl fonic acid (PTSA)
20% Phosphoric acid
30% Water

Experience, and trial and error, led to the discovery that the catalyst was best added to the resin at 3.2% by weight.

3.3.3 Combination of Jute and Resin

After the phenolic J2027L was prepared and Cardanol added where required, it was time to combine the fibre with the resin. From earlier experiments the ratio in which this was best done was 1 gram jute to 6.4 grams resin. The process of physically combining the two proved to be quite difficult and trial and error once again revealed the best method.

Roughly half the mixture should be applied to the bottom of the mould. Lay the fabric and roll thoroughly with a small barrelled roller, taking care to evenly compress and spread the resin beneath the fabric. After the resin fully and equally penetrates the jute, apply the remaining half of the resin on top of the fabric, repeating the process of rolling and spreading.

If the correct amount of resin was added (1:6.4) there should be no excess of resin, however if there is, simply remove excess before continuing.

3.3.4 Cover and Compress

What may be considered such a simple step is actually quite easy to create mistakes.

Without some form of compression, the composite tended to bubble and deform under curing. To rectify the problem a gentle weight needs to be applied uniformly over the surface. However, it is essential that the weight be adequately prevented from binding with or affecting the composite.

An example where this step went wrong can be seen in figure 9.

Figure 9 – Sample with excessive resin without compression during curing

3.3.5 Curing

All samples were bench cured for 1 hour then oven cured for four hours at 80^{o}C in the oven pictured below.

Figure 10 – Curing Oven

3.4 Testing

3.4.1 Tensile

Tensile strength is measured by testing the reaction of the material to tensile stress and strain. By applying a load to the sample we can use instruments to gauge stress and strain. This project uses the Alliance RT/10 for both tensile and flexural testing. As can be seen in the image below, the prepared sample is clamped at both ends. Tensile, or longitudinal stresses are applied while a laser extensometer records extension. This deformation in the y direction is used for strain calculations in the calculations noted in chapter 2. However, software is alone responsible for the calculation of stress and strain using this equipment.

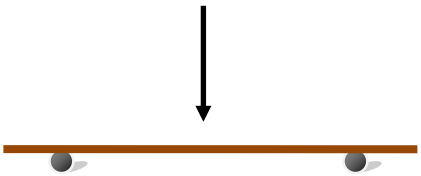
Due to the brittle nature of fibre reinforced polymers such as this, a very slow rate of change was selected. The large clamps therefore were set to pull apart at 2mm/min.

Either 4 or 5 specimens from the one sample were used in testing.

Figure 11 – Tensile testing with laser extensiometer in place.

3.4.2 Flexural

Flexural strength was tested using what is known as a three point test. The principle of this test is shown in the sketch below.



Once again, the Alliance RT/10 was used for testing and calculating stress and strain. Ultimate flexural stress is described as the stress at which the material ruptures.

Again, the machine was set to operate at 2mm/min. The span that separates either end of the bracket is defined as 16 times the thickness of the sample (usually around 4mm).

Either 4 or 5 specimens from the one sample were used in testing.

Figure 12 - Flexural 3 point test

3.4.3 DMA

At this stage of the project DMA has used to investigate the viscoelastic behaviour of polymers. It is most useful in evaluating the glass transition temperature of the material (the temperature at which the material becomes either brittle or elastic.

Storage and loss moduli are also determined in DMA. This is indicative of the energy either stored or lost from the material. DMA also provides information on damping coefficient. However this remains an object for further research at this stage. The Q800 seen in figure 13 from D.M.A. was been used for analysis.

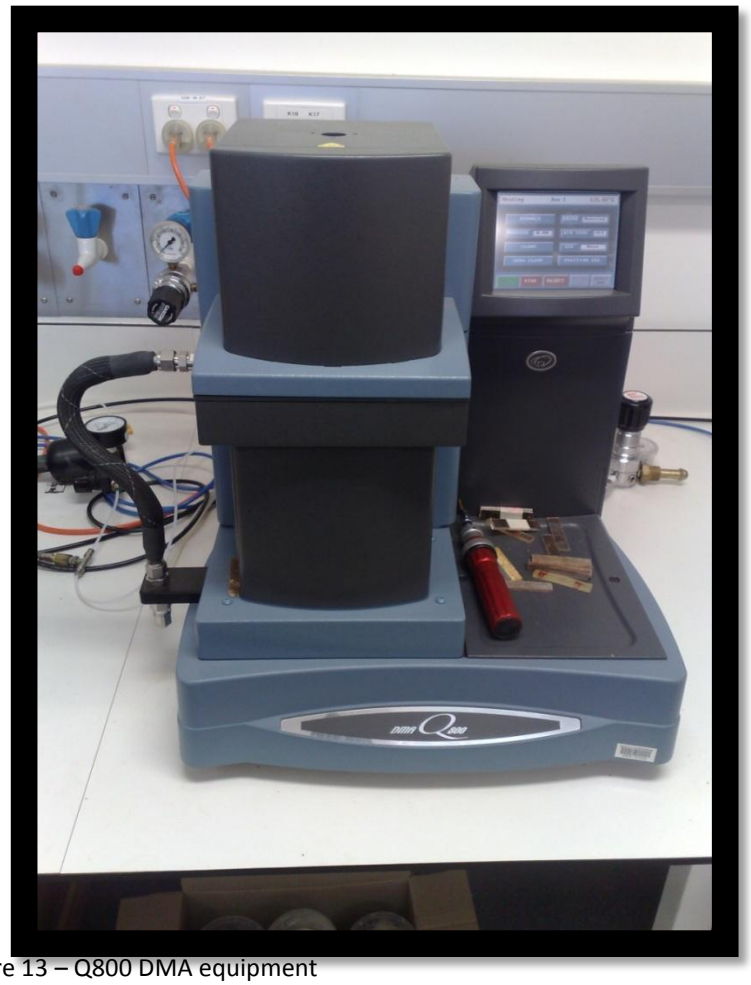


Figure 13 – Q800 DMA equipment

3.5 Evaluation

The final step in experimentation, the evaluation of findings will be discussed in a separate chapter.

3.6 Conclusion

Research, construction, testing and evaluation are the four components of experimental design and methodology that are absolutely essential for success. Background and continual research provided all the knowledge required to start effectively creating composites while trial and error provided the remaining knowledge to define steps of best practice. This lead to samples that were able to be tested for tensile and flexural strength. DMA could then be used to reveal viscoelastic properties. Therefore, the only thing remaining in this experimental design and methodology is to gather and discuss results.

4.0 RESULTS

4.1 Introduction

Various different samples were made and tested to investigate the influence of weave size, cardanol content and fibre treatment on the composites mechanical properties. These samples included:

- Jute reinforced phenolic neat resin, large weave
- Jute reinforced phenolic neat resin, fine weave
- Jute reinforced phenolic resin – 20% Cardanol
- Jute reinforced phenolic resin – 30% Cardanol
- Jute reinforced phenolic resin – 40% Cardanol
- Jute reinforced Phenolic neat resin – large weave - Treated
- Jute reinforced phenolic resin – 20% Cardanol - Treated

4.2 Jute reinforced phenolic neat resin, large weave

Construction and testing began with samples made using large, coarse jute fabric purchased from local markets. Initial testing was used to determine optimum jute to resin ratio. This was found to be 1:6.4. Figure 9 shows a result of initial testing used to determine this ratio. Figure 13 shows a sample constructed satisfactorily.

Figure 14 – Jute phenolic neat sample

Tensile testing of this sample resulting in expected types of failure.

Figure 16 - Tensile testing failure

Of the two samples constructed in this way, a mean peak tensile stress of 11.5 MPa was reached. A complete summary of these results can be seen in the appendices.

Flexural testing of jute reinforced neat resin yielded a average peak stress of 20.3 MPa and a flexural modulus of 1600 MPa.

4.3 Jute reinforced phenolic neat resin, fine weave

The fine weave shown in figure 17 produced no results due to the extreme delicacy of the composite produced. The thin layer could not be extracted from the mould. Obviously, the coarse weave jute is required in producing single layer composite. This said, if resources are available and the sample could be removed from the mould the results would have been interesting. This is an objective for further research.

Figure 17 – Coarse and dine jute fibres

4.4 Jute reinforced phenolic resin, 20% 30% 40% Cardanol content

Peak flexural and tensile stresses of the samples containing 20, 30 and 40 percent cardanol content are shown in figure 18.

As described in chapter 2, the cardanol was combined with phenol in the phenol-formaldehyde. The samples were simply labelled CPF – 20, CPF – 30, CPF – 40.

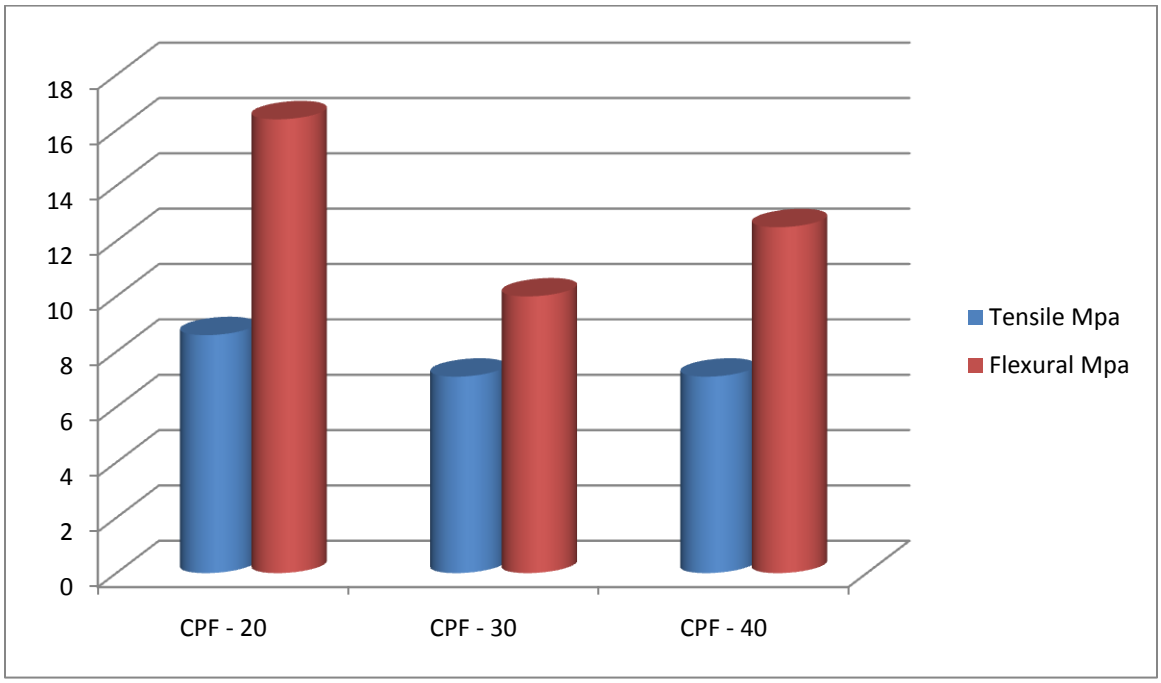


Figure 18 – Peak flexural and tensile stress

Flexural moduli for the samples is shown in figure 19.

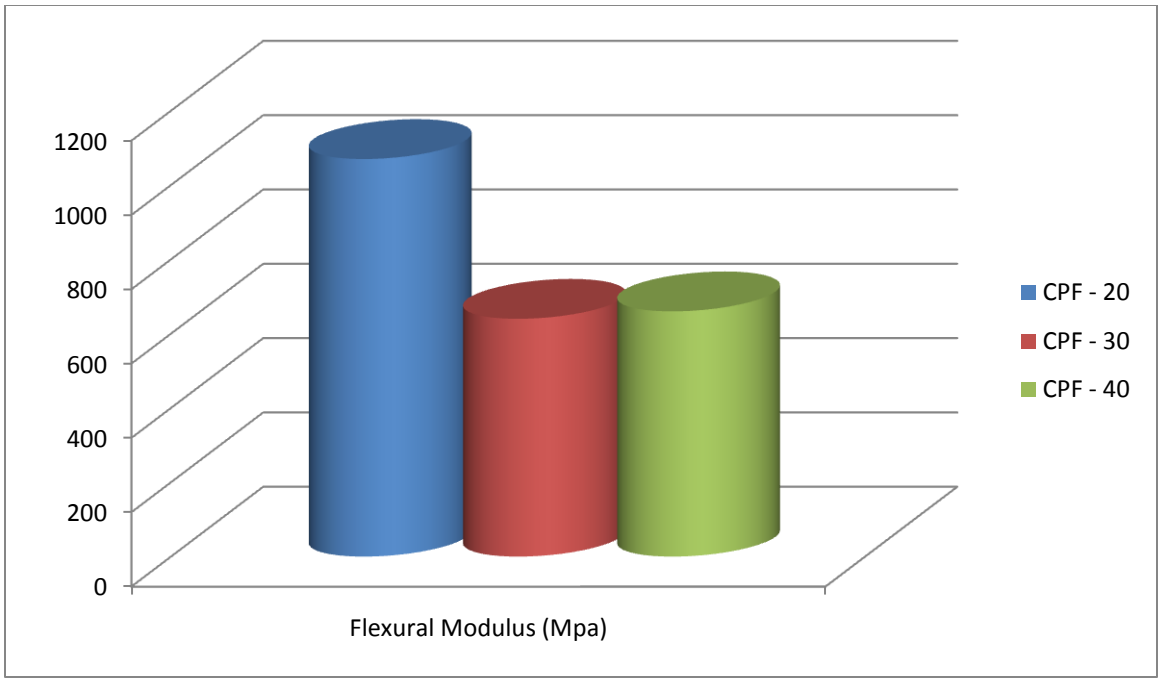


Figure 19 – Flexural Modulus

The image below has been included to give a visual representation of the colours and consistency of a 30% phenol-formaldehyde composite reinforced with coarse jute fibre. The image also shows the differing sizes of tensile (larger) specimens and flexural (smaller) specimens.

Figure 22 – CPF 30 Sample

4.5 Jute reinforced Phenolic neat resin – large weave – Treated

The sample constructed with neat phenolic resin and coarse jute fibre treated in a 5% NaCl seawater solution had a peak tensile stress of 15.21 MPa, peak flexural stress of 20.23 MPa and flexural modulus of 1790 MPa.
Note that treatment of fibres in seawater shows an increase in the tensile and flexural strength of neat phenolic-jute resins.

4.6 Jute reinforced phenolic resin – 20% Cardanol – Treated

The sample constructed of 20% Cardanol-Phenol formaldehyde and coarse jute fibre treated in a 5% NaCl seawater solution had a peak tensile stress of 8.5 MPa, peak flexural stress of 7.8 MPa and flexural modulus of 632 MPa.
Unlike neat phenolic resins, treating fibres in seawater does not seem to increase the strength of Cardonal-Phenol Formaldehyde.

4.7 DMA results

Dynamic mechanical analysis of the neat phenolic yielded the following results.

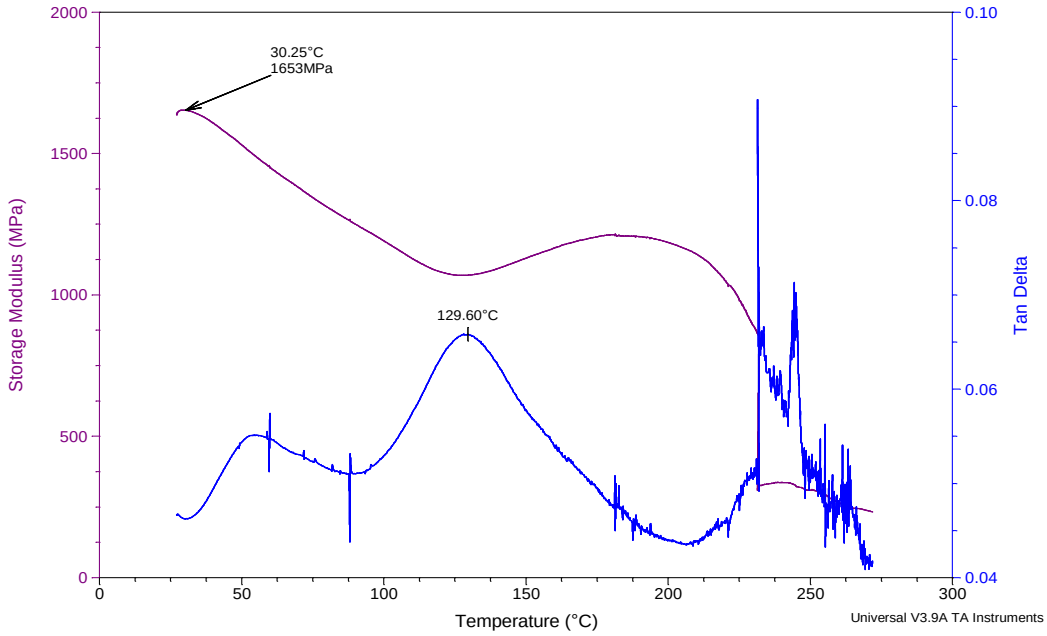


Figure 20 – DMA results neat phenolic

Dynamic Mechanical Analysis showing storage modulus or elasticity of the 20, 30 and 40 percent cardanol contents is shown in the chart below.

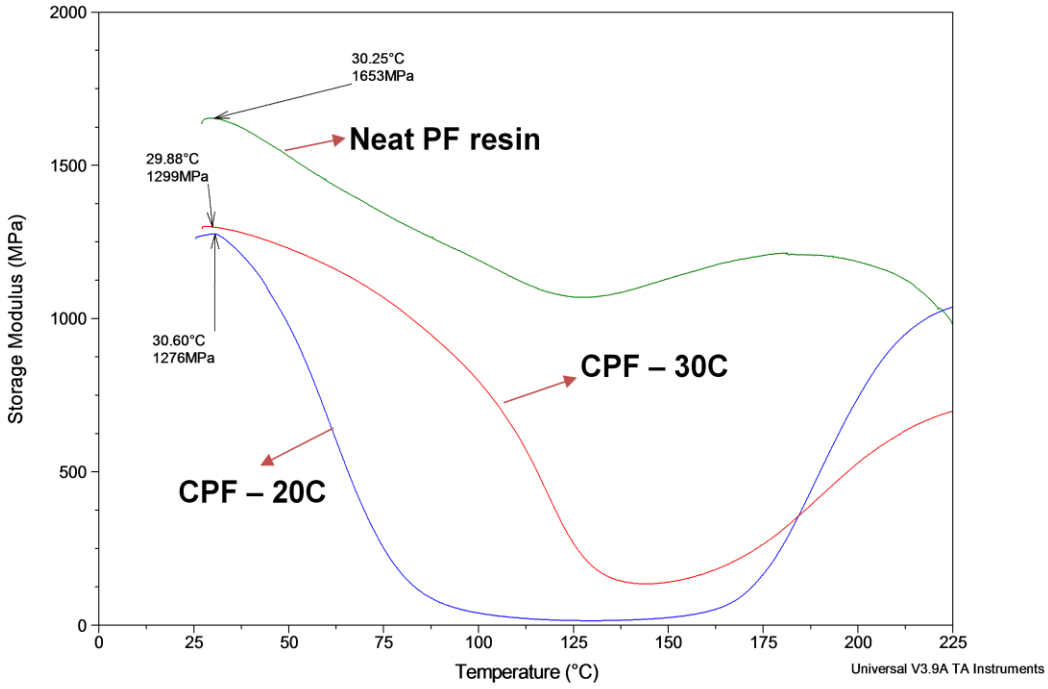


Figure 21 – DMA results for elasticity

5.0 CONCLUSION

By examining past work and conducting a review of available literature the best design and experimentation methodology of investigating environmentally friendly composites using natural waste products could be identified. As examples of these natural waste products, jute and CNSL were used to construct numerous samples of different texture, treatment process of cardanol content.

Flexural, tensile and dynamic mechanical analyse was used to identify the mechanical properties of each sample. These results show quite a high susceptibility to stresses.

Testing also shows that cardanol can be combined with phenol in the phenol-formaldehyde resin in ratios up to 40%, with minimal impact on mechanical properties.

Another significant result of the testing conducted in this project is the proven benefit of treating jute fibre in NaCl solution. Jute and CNSL grow abundantly in some of the poorest region in the world. Coincidently, these areas also show some of the highest rates of deforestation. If jute reinforced composites are used to supplement or replace timber as a building material in these areas, they can be significantly improved by treating the fibres in seawater.

Using seawater to treat jute fibres and supplementing petrochemically derived phenol-formaldehyde resins with CNSL has the potential to create one of the most sustainable fibre composites since mud-brick.

The first principles that allowed us to research and develop composites for use in civil structures came from very basic technology in primitive societies. This research explored ways in which we can further the technology and couple it with sustainable thinking. Through research and experimentation this project investigated how waste materials can be utilised in creating environmentally friendly composites.

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APPENDICES

FLEXURE TESTING REPORT

Test Method: User Specified

Test Date:	**Test Method:**	**Operator:**
7/04/2010	CEEFC - Neat Resin & PFR (ISO 178).msm	Francisco

Sample Information:

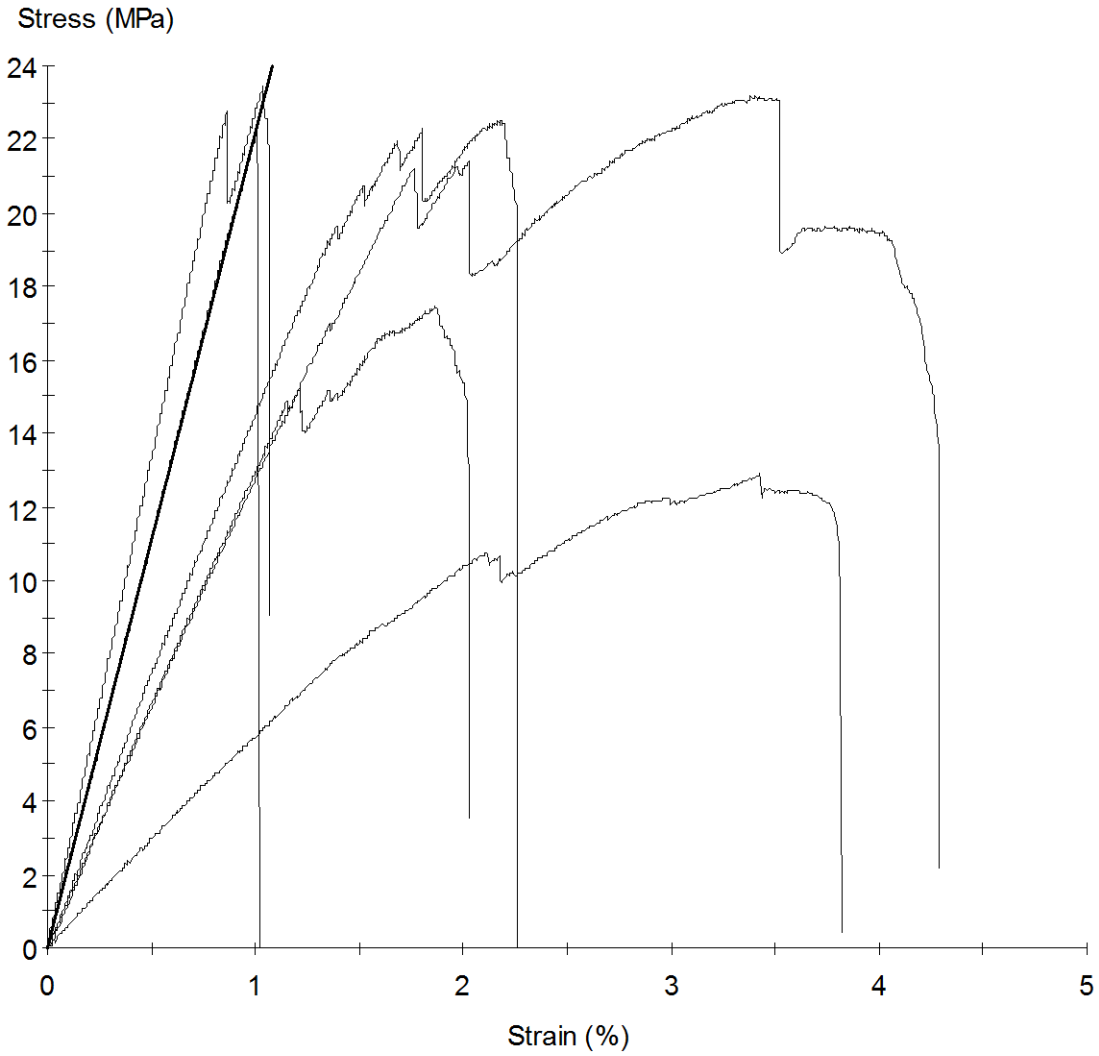
(A) Project Name:	Thomas Bailey
(B) Sample ID:	PF - jute fabric
(C) Resin Name:	PF resin
(D) Curative Name:	postcured 4h- 80 oC
(E) Mix Ratio:	
(F) CastingType:	PFR Casting
(G) Attention:	
(H) Nominal Spec. Dimensions:	200mm x 50mm x 10mm
(I) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(J) Nominal Span (mm):	64
(K) Conditioning Temp. & RH:	N/A
(L) Test Speed (mm/min):	2

Test Equipment Details:

Test Machine:	MTS Alliance RT/10
Location:	P9 110

Specimen Results:

Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	14.95	3.51	34	17.47	2.03	1.86	3.62	3.62	1326
2	14.99	3.80	29	12.89	3.82	3.43	6.16	6.16	611
3	15.01	3.51	45	23.46	1.07	1.04	2.02	2.02	2663
4	15.30	3.10	34	22.51	2.27	2.18	4.81	4.81	1475
5	14.92	3.31	39	23.19	4.29	3.42	7.06	7.06	1301
6	14.92	3.47	42	22.42	1.02	1.02	2.00	2.00	2214
Mean	**15.02**	**3.45**	**37**	**20.32**	**2.42**	**2.16**	**4.28**	**4.28**	**1598**
Std Dev	**0.14**	**0.23**	**6**	**4.26**	**1.37**	**1.08**	**2.11**	**2.11**	**730**


Stress (MPa)
24
22
20
18
16
14
12
10
8
6
4
2
0
0
1
2
3
4
5
Strain (%)

FLEXURE TESTING REPORT

Test Method: User Specified

Test Date:	**Test Method:**	**Operator:**
9/04/2010	CEEFC - Neat Resin & PFR (ISO 178).msm	Francisco

Sample Information:

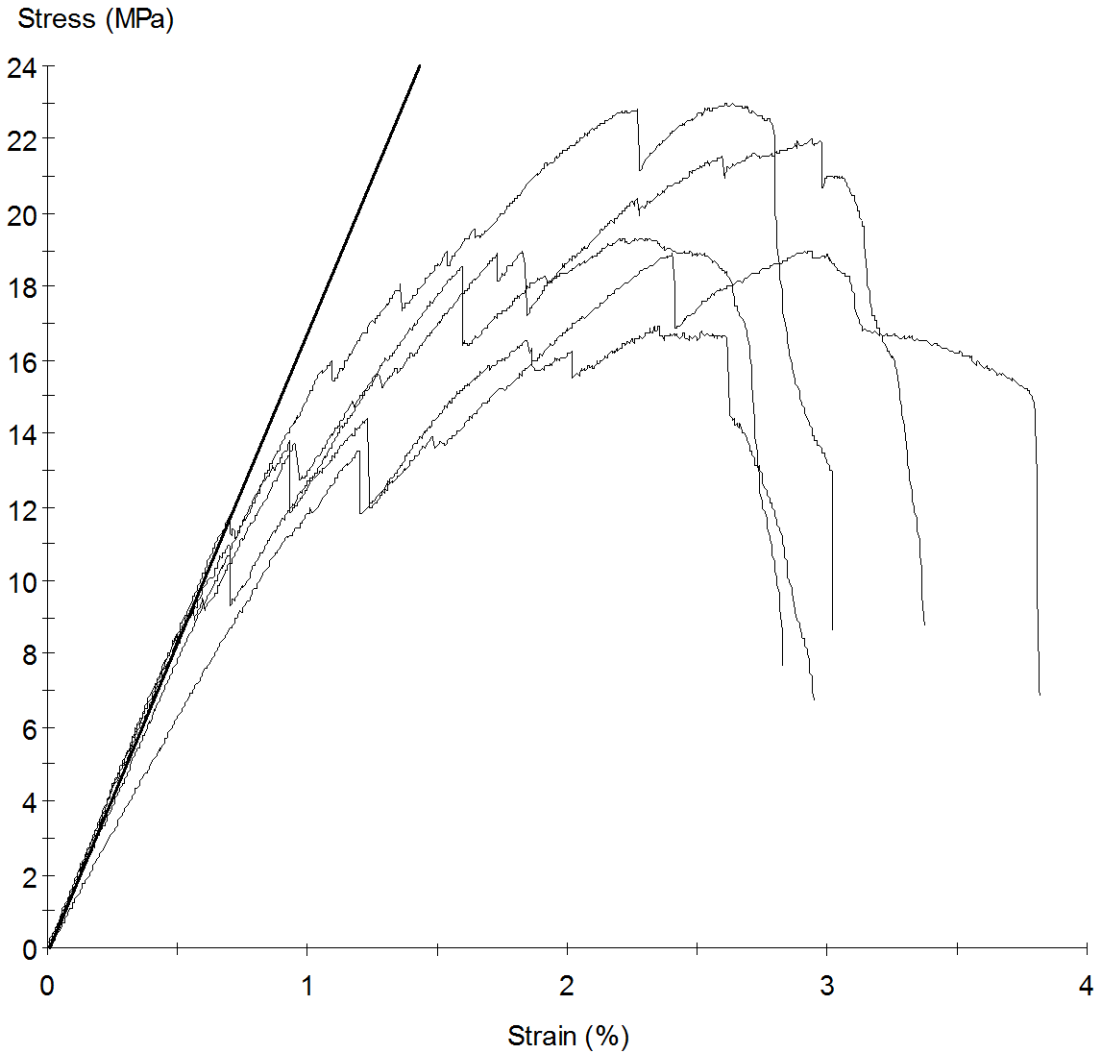
(A) Project Name:	PF + Jute Fabric
(B) Sample ID:	PF - 2
(C) Resin Name:	PF
(D) Curative Name:	
(E) Mix Ratio:	2
(F) CastingType:	Neat Resin Casting
(G) Attention:	
(H) Nominal Spec. Dimensions:	200mm x 50mm x 10mm
(I) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(J) Nominal Span (mm):	64
(K) Conditioning Temp. & RH:	N/A
(L) Test Speed (mm/min):	2

Test Equipment Details:

Test Machine:	MTS Alliance RT/10
Location:	P9 110

Specimen Results:

Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	14.48	3.19	35	23.00	3.02	2.63	5.63	5.63	1712
2	14.40	2.87	21	16.93	2.95	2.33	5.55	5.55	1736
3	14.40	3.61	37	19.00	3.81	2.92	5.53	5.53	1252
4	14.39	3.04	30	22.01	3.37	2.94	6.60	6.60	1559
5	14.47	3.26	31	19.33	2.83	2.28	4.77	4.77	1683
Mean	**14.43**	**3.19**	**31**	**20.06**	**3.20**	**2.62**	**5.62**	**5.62**	**1588**
Std Dev	**0.04**	**0.28**	**6**	**2.44**	**0.40**	**0.31**	**0.65**	**0.65**	**200**


Stress (MPa)
24
22
20
18
16
14
12
10
8
6
4
2
0
0
1
2
3
4
Strain (%)

FLEXURE TESTING REPORT

Test Method: User Specified

Test Date:	**Test Method:**	**Operator:**
28/04/2010	CEEFC - Neat Resin & PFR (ISO 178).msm	Francisco

Sample Information:

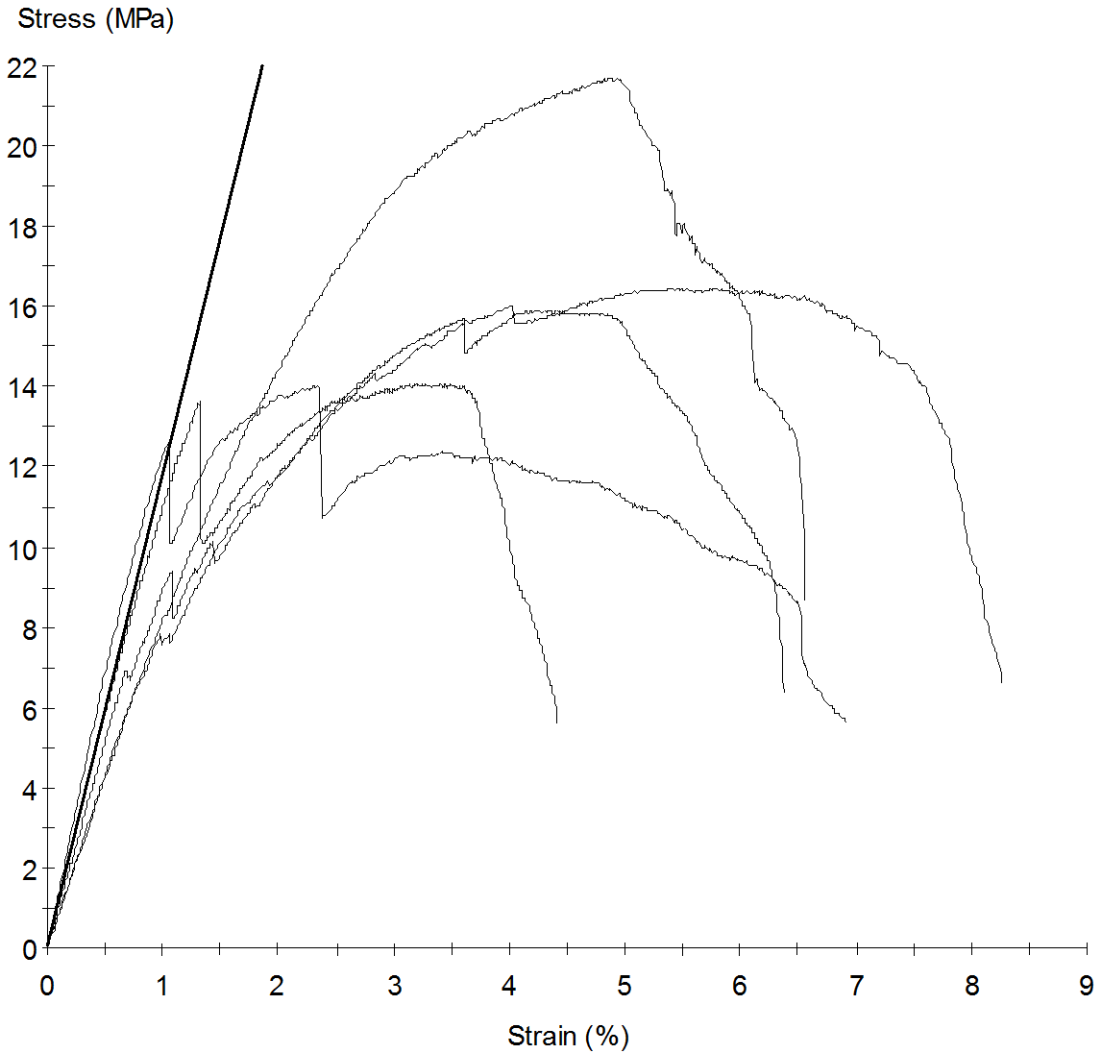
(A) Project Name:	Jute reinforced phenolic - 20% Cardonal
(B) Sample ID:	CPF - C20
(C) Resin Name:	Cardonal-Phenol Formaldahyde
(D) Curative Name:	
(E) Mix Ratio:	
(F) CastingType:	PFR Casting
(G) Attention:	
(H) Nominal Spec. Dimensions:	200mm x 50mm x 10mm
(I) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(J) Nominal Span (mm):	64
(K) Conditioning Temp. & RH:	N/A
(L) Test Speed (mm/min):	2

Test Equipment Details:

Test Machine:	MTS Alliance RT/10
Location:	P9 110

Specimen Results:

Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	14.45	3.62	43	21.71	6.56	5.20	9.17	9.81	850
2	14.50	3.92	33	14.01	6.91	****	4.00	****	1397
3	14.90	4.46	49	15.91	6.38	4.68	6.60	7.17	1030
4	15.00	3.83	38	16.47	8.27	6.71	9.64	11.96	868
5	14.93	3.45	26	14.09	4.42	3.44	6.80	6.80	1207
Mean	**14.76**	**3.86**	**38**	**16.44**	**6.51**	**5.01**	**7.24**	**8.94**	**1070**
Std Dev	**0.26**	**0.38**	**9**	**3.14**	**1.38**	**1.35**	**2.27**	**2.42**	**233**


Stress (MPa)
22
20
18
16
14
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
Strain (%)

FLEXURE TESTING REPORT

Test Method: User Specified

Test Date:	**Test Method:**	**Operator:**
28/04/2010	CEEFC - Neat Resin & PFR (ISO 178).msm	Francisco

Sample Information:

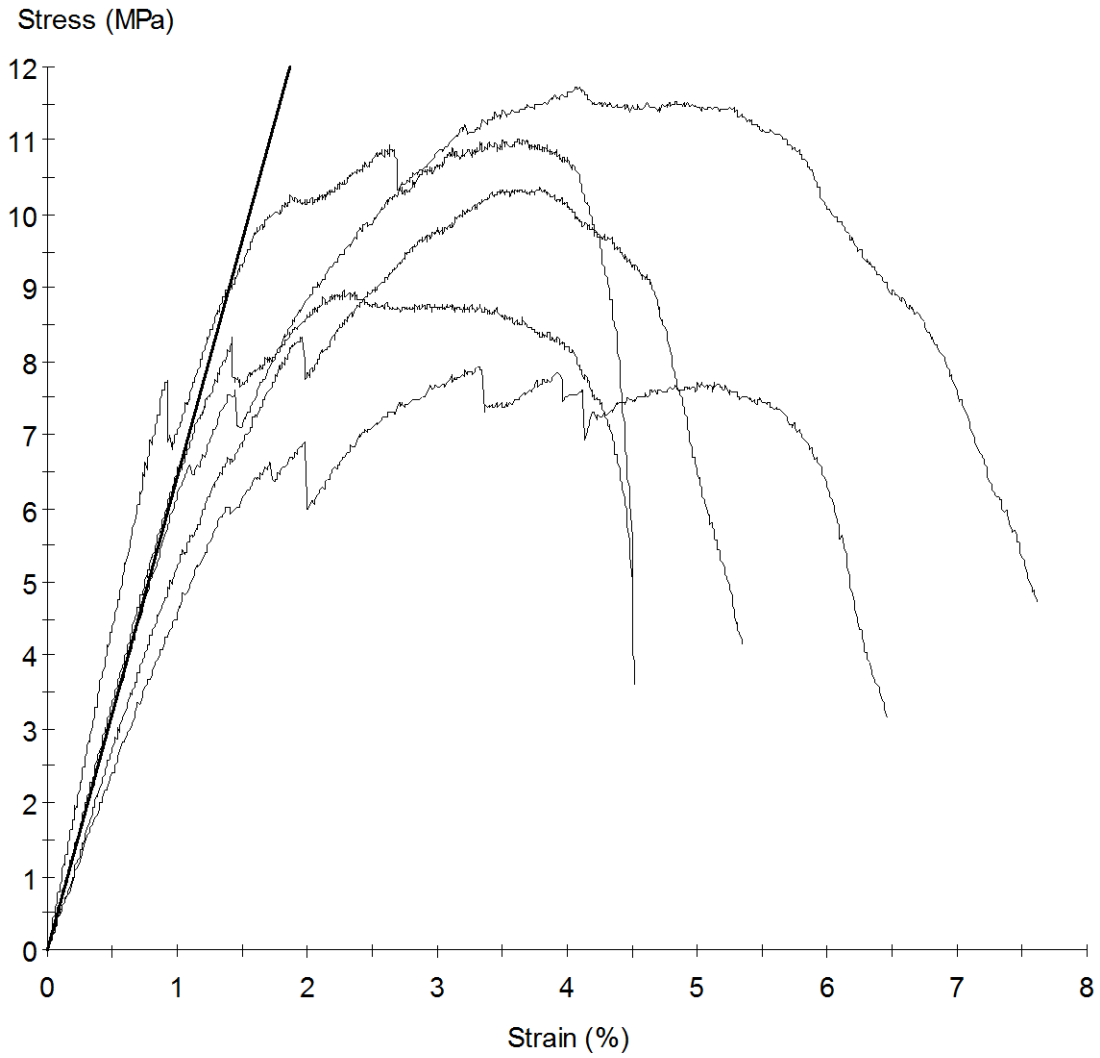
(A) Project Name:	Jute reinforced phenolic - 30% Cardonal
(B) Sample ID:	CPF - C30
(C) Resin Name:	Cardonal-Phenol Formaldahyde
(D) Curative Name:	
(E) Mix Ratio:	
(F) CastingType:	PFR Casting
(G) Attention:	
(H) Nominal Spec. Dimensions:	200mm x 50mm x 10mm
(I) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(J) Nominal Span (mm):	64
(K) Conditioning Temp. & RH:	N/A
(L) Test Speed (mm/min):	2

Test Equipment Details:

Test Machine:	MTS Alliance RT/10
Location:	P9 110

Specimen Results:

Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	15.00	3.77	23	10.37	5.34	3.80	6.87	6.88	512
2	15.07	3.62	18	8.96	4.53	3.16	4.30	5.95	661
3	15.09	3.32	19	11.02	4.50	3.62	7.45	7.45	891
4	14.41	3.58	15	7.93	6.45	5.00	6.31	9.53	487
5	15.01	3.62	24	11.74	7.61	6.27	7.66	11.82	651
Mean	**14.92**	**3.58**	**20**	**10.00**	**5.69**	**4.37**	**6.52**	**8.33**	**640**
Std Dev	**0.29**	**0.16**	**4**	**1.55**	**1.34**	**1.26**	**1.35**	**2.35**	**161**


Stress (MPa)
12
11
10
9
8
7
6
5
4
3
2
1
0
0
1
2
3
4
5
6
7
8
Strain (%)

FLEXURE TESTING REPORT

Test Method: User Specified

Test Date:	**Test Method:**	**Operator:**
28/04/2010	CEEFC - Neat Resin & PFR (ISO 178).msm	Francisco

Sample Information:

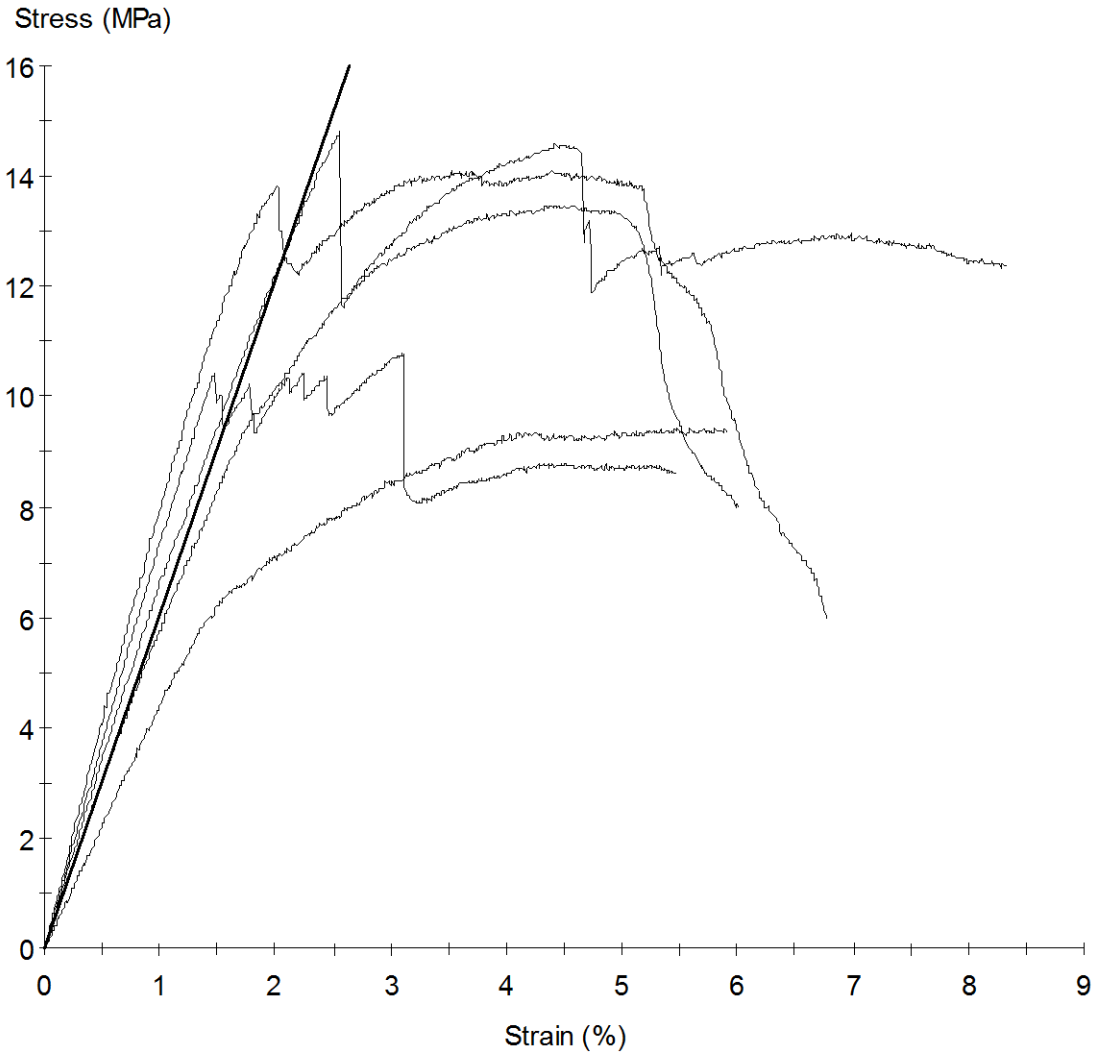
(A) Project Name:	Jute reinforced phenolic - 30% Cardanol
(B) Sample ID:	CPF - C40
(C) Resin Name:	Cardonal-Phenol Formaldahyde
(D) Curative Name:	
(E) Mix Ratio:	
(F) CastingType:	PFR Casting
(G) Attention:	
(H) Nominal Spec. Dimensions:	200mm x 50mm x 10mm
(I) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(J) Nominal Span (mm):	64
(K) Conditioning Temp. & RH:	N/A
(L) Test Speed (mm/min):	2

Test Equipment Details:

Test Machine:	MTS Alliance RT/10
Location:	P9 110

Specimen Results:

Specimen #	Width mm	Thickness mm	Peak Load N	Peak Flexural Stress MPa	Strain At Peak %	Strain at Break %	Deflection At Peak mm	Deflection At Break mm	Flexural Modulus MPa
1	15.13	3.72	32	14.82	8.34	****	4.70	****	697
2	15.06	3.25	23	14.10	6.78	****	9.22	****	815
3	15.06	3.25	16	9.43	5.90	****	12.37	****	433
4	15.15	3.52	26	13.47	6.01	****	8.88	****	740
5	15.05	4.13	29	10.79	5.46	****	5.16	****	615
Mean	**15.09**	**3.57**	**25**	**12.52**	**6.50**	****	**8.07**	****	**660**
Std Dev	**0.05**	**0.37**	**6**	**2.31**	**1.13**	****	**3.17**	****	**146**


Stress (MPa)
16
14
12
10
8
6
4
2
0
0
1
2
3
4
5
6
7
8
9
Strain (%)

TENSILE TESTING REPORT

ISO 527-4/2/2: 1997 Plastics – Determination of Tensile Properties

Test Date:	**Test Method:**	**Operator:**
9/04/2010	STS - Laminate Tension - Biaxial Ext (ISO 527).msm	Atul Sakhiya

Sample Information:

	PF-1
(A) Client Name:	
(B) Mailing Address:	
(C) Mailing Address:	
(D) Mailing Address:	
(E) Attn:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	
(I) STS Job Number:	
(J) Specimen Orientation:	0 Degrees
(K) Sample Description:	
(L) Layup Sequence:	
(M) Principle Dimensions:	
(N) Method of Manufacture:	
(O) Laminate Cure Schedule:	
(P) Test Room Conditions:	
(Q) Conditioning Temp. & RH:	
(R) Clamping Pressure (MPa):	
(S) Testing Speed (mm/min):	2.0
(T) Specimen Prep. Method:	Specimens cut by diamond coated cutting wheel, edges sanded smooth & defect free.

Test Equipment Details:

Test Machine:	MTS 810 Material Test System
Location:	Z104 Test Laboratory, Faculty of Engineering and Surveying, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	15/02/2007
Expiration Date:	15/02/2008
Strain Measurement Device:	MTS Extensometer Model No. 632.85F-14
Extensometer Calibration Date:	15/02/2007
Load Cell Calibration Date:	15/02/2007
Expiration Date:	15/02/2008

Specimen Results:

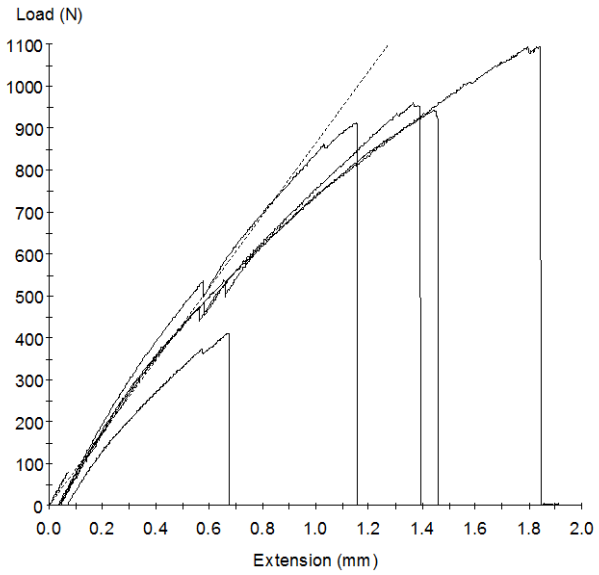
Specimen #	Thickness 1 mm	Thickness 2 mm	Thickness 3 mm	Width 1 mm	Width 2 mm	Width 3 mm	Avg Thick mm	Avg Width mm	Area mm^2
1	2.83	2.83	2.83	25.04	25.04	25.04	2.83	25.04	70.86
2	2.81	2.81	2.81	25.25	25.25	25.25	2.81	25.25	70.95
3	2.81	2.81	2.81	25.25	25.25	25.25	2.81	25.25	70.95
4	3.00	3.00	3.00	25.13	25.13	25.13	3.00	25.13	75.39
5	3.22	3.22	3.22	24.62	24.62	24.62	3.22	24.62	79.28
6	3.13	3.13	3.13	25.18	25.18	25.18	3.13	25.18	78.81
Mean	**3.00**	**3.00**	**3.00**	**25.04**	**25.04**	**25.04**	**3.00**	**25.04**	**75.06**
Std Dev	**0.18**	**0.18**	**0.18**	**0.25**	**0.25**	**0.25**	**0.18**	**0.25**	**4.08**

Specimen Results:

Specimen #	Peak Load N	Peak Stress MPa	Modulus of Elasticity MPa						
1	942	13.30	2227						
2	79	1.12	****						
3	960	13.53	2248						
4	411	5.45	1775						
5	911	11.50	2196						
6	1094	13.89	2263						
Mean	**864**	**11.53**	**2142**						
Std Dev	**263**	**3.52**	**207**						

Specimen Comments:

Specimen #	Failure Status
1	Acceptable
2	Acceptable
3	Acceptable
4	Acceptable
5	Acceptable
6	Acceptable



Load vs Extension Plot

Checked By:

TENSILE TESTING REPORT

ISO 527-4/2/2: 1997 Plastics – Determination of Tensile Properties

Test Date:	**Test Method:**	**Operator:**
9/04/2010	STS - Laminate Tension - Biaxial Ext (ISO 527).msm	Atul Sakhiya

Sample Information:

	PF-2
(A) Client Name:	
(B) Mailing Address:	
(C) Mailing Address:	
(D) Mailing Address:	
(E) Attn:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	
(I) STS Job Number:	
(J) Specimen Orientation:	0 Degrees
(K) Sample Description:	
(L) Layup Sequence:	
(M) Principle Dimensions:	
(N) Method of Manufacture:	
(O) Laminate Cure Schedule:	
(P) Test Room Conditions:	
(Q) Conditioning Temp. & RH:	
(R) Clamping Pressure (MPa):	
(S) Testing Speed (mm/min):	2.0
(T) Specimen Prep. Method:	Specimens cut by diamond coated cutting wheel, edges sanded smooth & defect free.

Test Equipment Details:

Test Machine:	MTS 810 Material Test System
Location:	Z104 Test Laboratory, Faculty of Engineering and Surveying, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	15/02/2007
Expiration Date:	15/02/2008
Strain Measurement Device:	MTS Extensometer Model No. 632.85F-14
Extensometer Calibration Date:	15/02/2007
Load Cell Calibration Date:	15/02/2007
Expiration Date:	15/02/2008

Specimen Results:

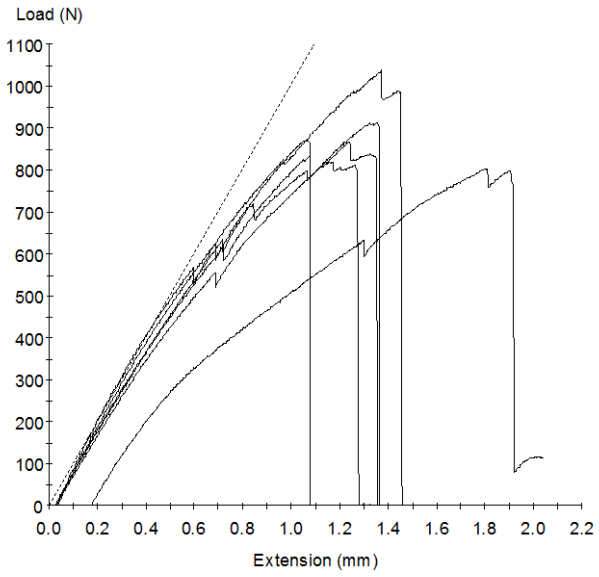
Specimen #	Thickness 1 mm	Thickness 2 mm	Thickness 3 mm	Width 1 mm	Width 2 mm	Width 3 mm	Avg Thick mm	Avg Width mm	Area mm^2
1	3.93	3.93	3.93	24.88	24.88	24.88	3.93	24.88	97.78
2	3.93	3.93	3.93	24.88	24.88	24.88	3.93	24.88	97.78
3	3.55	3.55	3.55	24.78	24.78	24.78	3.55	24.78	87.97
4	3.55	3.55	3.55	24.78	24.78	24.78	3.55	24.78	87.97
5	4.34	4.34	4.34	24.94	24.94	24.94	4.34	24.94	108.24
6	4.10	4.10	4.10	24.98	24.98	24.98	4.10	24.98	102.42
7	3.66	3.66	3.66	25.05	25.05	25.05	3.66	25.05	91.68
Mean	**3.92**	**3.92**	**3.92**	**24.93**	**24.93**	**24.93**	**3.92**	**24.93**	**97.62**
Std Dev	**0.32**	**0.32**	**0.32**	**0.10**	**0.10**	**0.10**	**0.32**	**0.10**	**8.13**

Specimen Results:

Specimen #	Peak Load N	Peak Stress MPa	Modulus of Elasticity MPa						
1	803	8.21	2153						
2	870	8.90	2139						
3	1	0.01	****						
4	868	9.87	2097						
5	821	7.58	1935						
6	913	8.92	2033						
7	1038	11.32	2094						
Mean	**902**	**9.32**	**2060**						
Std Dev	**83**	**1.38**	**79**						

Specimen Comments:

Specimen #	Failure Status
1	Acceptable
2	Acceptable
3	Acceptable
4	Acceptable
5	Acceptable
6	Acceptable
7	Acceptable



TENSILE TESTING REPORT

ISO 527-2/1B/1: 1997 Plastics – Determination of Tensile Properties

Test Date:	**Test Method:**	**Operator:**
13/05/2010	CEEFC - Neat Resin Tension (ISO 527).msm	Student

Sample Information:

(A) Client Name:	CPF– 20-Cardanol
(B) Mailing Address:	
(C) Mailing Address:	
(D) Mailing Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	
(I) FCDD Job Number:	
(J) Specimen Orientation:	
(K) Sample Description:	CPF- C20-T
(L) Initiator Description & Level:	
(M) Principle Dimensions:	
(N) Method of Manufacture:	
(O) Casting Pretreatment:	
(P) Test Room Temp. & RH:	
(Q) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(R) Clamping Pressure (MPa):	1
(S) Test Speed (mm/min):	2
(T) Specimen Preparation Method:	

Test Equipment Details:

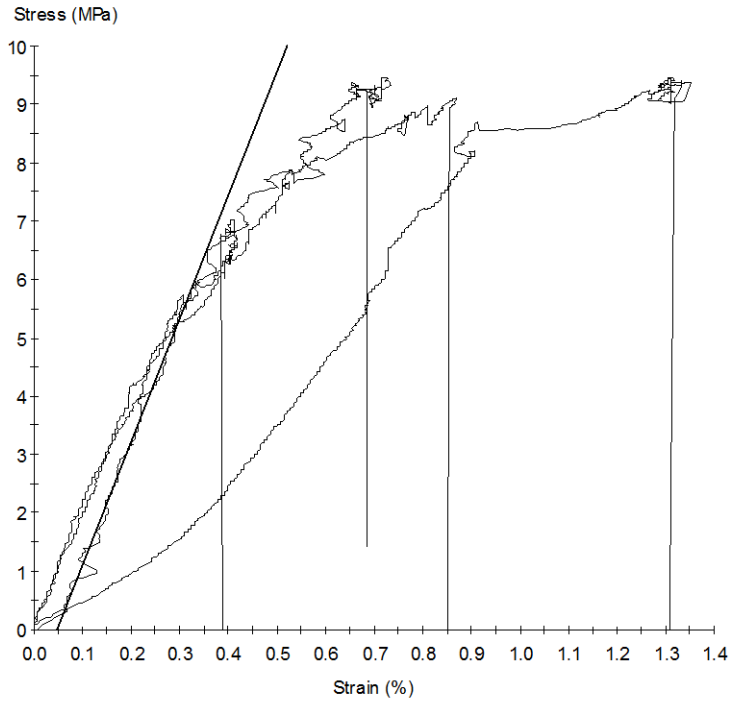
Test Machine:	MTS Alliance RT/10
Location:	Z126 Test Laboratory, Faculty of Engineering and Surveying, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	08/06/2004
Expiration Date:	08/06/2005
Strain Measurement Device:	MTS Extensometer Model No. LX300
Strain Calibration Date:	08/06/2004
Expiration Date:	08/06/2005
Load Cell Calibration Date:	08/06/2004
Expiration Date:	08/06/2005

Specimen Results:

Specimen #	Thick-ness 1 mm	Thick-ness 2 mm	Thick-ness 3 mm	Width 1 mm	Width 2 mm	Width 3 mm	Avg Thick mm	Avg Width mm	Area mm^2
1	3.24	3.24	3.24	25.36	25.36	25.36	3.24	25.36	82.17
2	3.24	3.24	3.24	25.36	25.36	25.36	3.24	25.36	82.17
3	3.56	3.56	3.56	25.10	25.10	25.10	3.56	25.10	89.36
4	3.36	3.36	3.36	24.53	24.53	24.53	3.36	24.53	82.42
5	3.22	3.22	3.22	25.01	25.01	25.01	3.22	25.01	80.53
Mean	**3.32**	**3.32**	**3.32**	**25.07**	**25.07**	**25.07**	**3.32**	**25.07**	**83.33**
Std Dev	**0.14**	**0.14**	**0.14**	**0.34**	**0.34**	**0.34**	**0.14**	**0.34**	**3.45**

Specimen Results:

Specimen #	Peak Load N	Peak Stress MPa	% Strain At Peak %	% Strain At Break %	Elastic Modulus MPa				
1	751	9.14	0.87	0.87	1668				
2	779	9.48	1.31	1.31	1054				
3	697	7.80	-0.42	-0.42	****				
4	580	7.04	0.41	0.41	1944				
5	763	9.47	0.72	0.72	2121				
Mean	**714**	**8.58**	**0.58**	**0.58**	**1697**				
Std Dev	**81**	**1.11**	**0.65**	**0.65**	**467**				



Stress vs Strain Plot

Checked By: _____

TENSILE TESTING REPORT

ISO 527-2/1B/1: 1997 Plastics – Determination of Tensile Properties

Test Date:	**Test Method:**	**Operator:**
13/05/2010	CEEFC - Neat Resin Tension (ISO 527).msm	Student

Sample Information:

(A) Client Name:	CPF – 30Cardanol
(B) Mailing Address:	
(C) Mailing Address:	
(D) Mailing Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	
(I) FCDD Job Number:	
(J) Specimen Orientation:	
(K) Sample Description:	CPF- C20-T
(L) Initiator Description & Level:	
(M) Principle Dimensions:	
(N) Method of Manufacture:	
(O) Casting Pretreatment:	
(P) Test Room Temp. & RH:	
(Q) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(R) Clamping Pressure (MPa):	1
(S) Test Speed (mm/min):	2
(T) Specimen Preparation Method:	

Test Equipment Details:

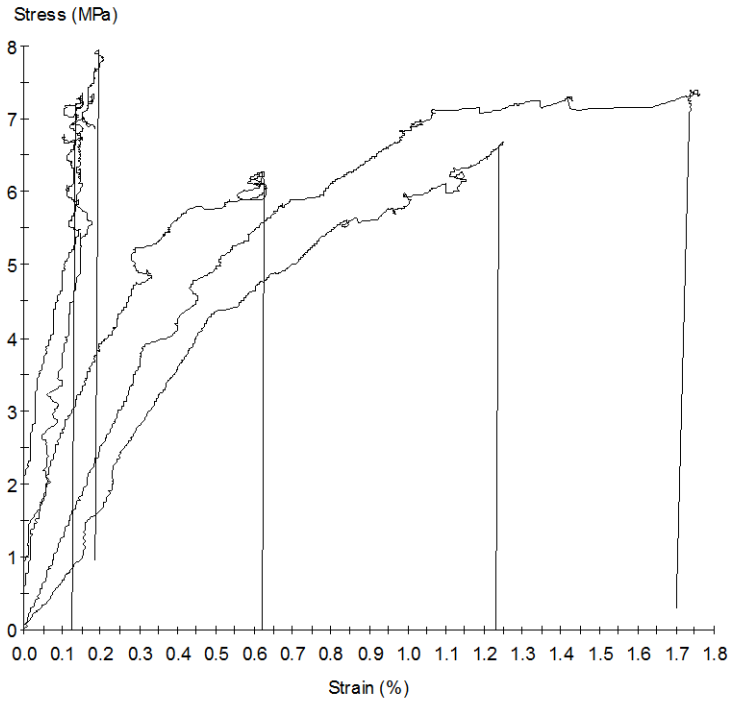
Test Machine:	MTS Alliance RT/10
Location:	Z126 Test Laboratory, Faculty of Engineering and Surveying, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	08/06/2004
Expiration Date:	08/06/2005
Strain Measurement Device:	MTS Extensometer Model No. LX300
Strain Calibration Date:	08/06/2004
Expiration Date:	08/06/2005
Load Cell Calibration Date:	08/06/2004
Expiration Date:	08/06/2005

Specimen Results:

Specimen #	Thick-ness 1 mm	Thick-ness 2 mm	Thick-ness 3 mm	Width 1 mm	Width 2 mm	Width 3 mm	Avg Thick mm	Avg Width mm	Area mm^2
1	4.13	4.13	4.13	24.56	24.56	24.56	4.13	24.56	101.43
2	4.13	4.13	4.13	24.21	24.21	24.21	4.13	24.21	99.99
3	3.66	3.66	3.66	25.11	25.11	25.11	3.66	25.11	91.90
4	4.17	4.17	4.17	24.52	24.52	24.52	4.17	24.52	102.25
5	4.00	4.00	4.00	24.70	24.70	24.70	4.00	24.70	98.80
Mean	**4.02**	**4.02**	**4.02**	**24.62**	**24.62**	**24.62**	**4.02**	**24.62**	**98.87**
Std Dev	**0.21**	**0.21**	**0.21**	**0.33**	**0.33**	**0.33**	**0.21**	**0.33**	**4.12**

Specimen Results:

Specimen #	Peak Load N	Peak Stress MPa	% Strain At Peak %	% Strain At Break %	Elastic Modulus MPa				
1	807	7.96	0.19	0.19	****				
2	739	7.39	1.76	1.76	1199				
3	677	7.37	0.15	0.15	****				
4	642	6.28	0.63	0.63	1203				
5	660	6.68	1.25	1.25	1055				
Mean	**705**	**7.13**	**0.79**	**0.79**	**1152**				
Std Dev	**68**	**0.66**	**0.70**	**0.70**	**84**				



Stress vs Strain Plot

Checked By: _____

TENSILE TESTING REPORT

ISO 527-2/1B/1: 1997 Plastics – Determination of Tensile Properties

Test Date:	**Test Method:**	**Operator:**
13/05/2010	CEEFC - Neat Resin Tension (ISO 527).msm	Student

Sample Information:

(A) Client Name:	CPF – 40Cardanol
(B) Mailing Address:	
(C) Mailing Address:	
(D) Mailing Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	
(I) FCDD Job Number:	
(J) Specimen Orientation:	
(K) Sample Description:	CPF- C20-T
(L) Initiator Description & Level:	
(M) Principle Dimensions:	
(N) Method of Manufacture:	
(O) Casting Pretreatment:	
(P) Test Room Temp. & RH:	
(Q) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(R) Clamping Pressure (MPa):	1
(S) Test Speed (mm/min):	2
(T) Specimen Preparation Method:	

Test Equipment Details:

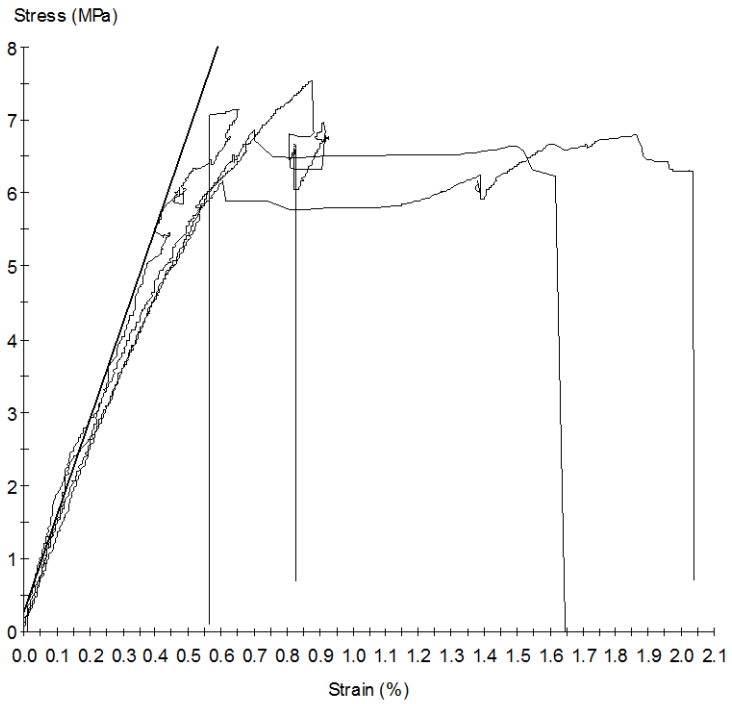
Test Machine:	MTS Alliance RT/10
Location:	Z126 Test Laboratory, Faculty of Engineering and Surveying, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	08/06/2004
Expiration Date:	08/06/2005
Strain Measurement Device:	MTS Extensometer Model No. LX300
Strain Calibration Date:	08/06/2004
Expiration Date:	08/06/2005
Load Cell Calibration Date:	08/06/2004
Expiration Date:	08/06/2005

Specimen Results:

Specimen #	Thick-ness 1 mm	Thick-ness 2 mm	Thick-ness 3 mm	Width 1 mm	Width 2 mm	Width 3 mm	Avg Thick mm	Avg Width mm	Area mm^2
1	4.21	4.21	4.21	25.13	25.13	25.13	4.21	25.13	105.80
2	4.46	4.46	4.46	24.47	24.47	24.47	4.46	24.47	109.14
3	4.54	4.54	4.54	25.19	25.19	25.19	4.54	25.19	114.36
4	4.41	4.41	4.41	24.45	24.45	24.45	4.41	24.45	107.82
Mean	**4.40**	**4.40**	**4.40**	**24.81**	**24.81**	**24.81**	**4.40**	**24.81**	**109.28**
Std Dev	**0.14**	**0.14**	**0.14**	**0.40**	**0.40**	**0.40**	**0.14**	**0.40**	**3.66**

Specimen Results:

Specimen #	Peak Load N	Peak Stress MPa	% Strain At Peak %	% Strain At Break %	Elastic Modulus MPa				
1	727	6.88	0.70	0.70	1122				
2	824	7.55	0.87	0.87	1183				
3	818	7.15	0.66	0.66	1041				
4	733	6.80	1.86	1.86	1312				
Mean	**775**	**7.09**	**1.02**	**1.02**	**1165**				
Std Dev	**52**	**0.34**	**0.57**	**0.57**	**114**				



Stress vs Strain Plot

Checked By: _____

FLEXURE TESTING REPORT

ISO 14125:1998(E)/Method A/Class II
Fibre-Reinforced Plastic Composites - Determination of Flexural Properties

Test Date:	**Test Method:**	**Operator:**
26/10/2010	STS - Laminate Flexure (ISO 14125).msm	Francisco Cardona

Sample Information:

(A) Client Name:	CPF-20 jute x 1h Salt Water
(B) Mailing Address:	
(C) Mailing Address:	
(D) Mailing Address:	
(E) Attn:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	CPF-20 jute x 1h Salt Water
(I) STS Job Number:	CPF-20 jute x 1h Salt Water
(J) Layup Sequence:	Details Not Supplied by Client
(K) Test Orientation:	0 Degrees
(L) Sample Description:	Laminate Test Panel
(M) Laminate Cure Schedule:	Details Not Supplied by Client
(N) Conditioning Temp. & Humidity:	23°C, 50% RH Constant for 24 Hours
(O) Test Room Conditions:	22°C, 37% RH
(P) Nominal Specimen Dimensions (mm):	250 x 30
(Q) Nominal Span (mm):	120
(R) Test Speed (mm/min):	2
(S) Surface in Compression:	Mold Side
(T) Cushion Material:	Not Used
(U) Specimen Preparation Method:	Specimens cut by diamond coated cutting wheel, edges sanded smooth & defect free.
(V) Equations Used:	ISO 14125: 1998(E) Clause 10.1

Test Equipment Details:

Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, Fibre Composites Research Centre, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	17/06/2008
Expiration Date:	17/06/2009
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	17/06/2008
Expiration Date:	17/06/2009
Load Cell Calibration Date:	17/06/2008
Expiration Date:	17/06/2009

Specimen Results:

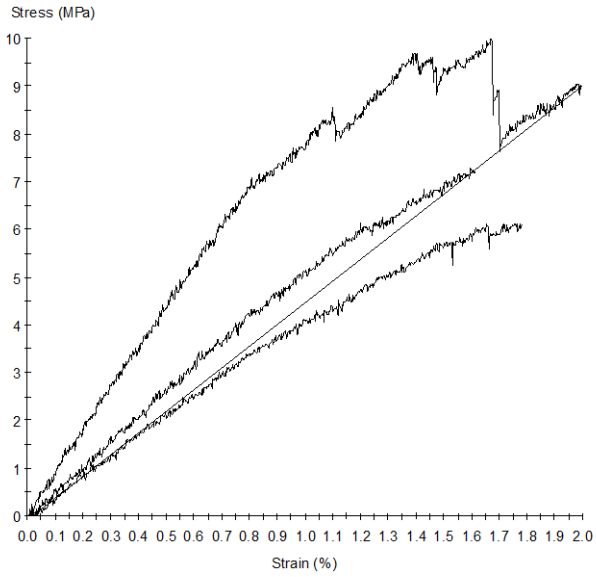
Specimen #	Thickness 1 mm	Thickness 2 mm	Thickness 3 mm	Width 1 mm	Width 2 mm	Width 3 mm	Average Width mm	Average Thickness mm	Peak Load N
1	2.58	2.72	3.14	19.91	19.68	19.81	19.80	2.81	9
2	2.78	2.80	3.06	20.37	20.15	20.39	20.30	2.88	7
3	3.15	2.95	3.45	19.99	19.97	20.30	20.09	3.18	7
Mean	**2.84**	**2.82**	**3.22**	**20.09**	**19.93**	**20.17**	**20.06**	**2.96**	**7**
Std Dev	**0.29**	**0.12**	**0.21**	**0.25**	**0.24**	**0.31**	**0.25**	**0.20**	**1**

Specimen Results:

Specimen #	Peak Flexural Stress MPa	Deflection at Peak mm	Strain at Peak %	Flexural Modulus MPa					
1	10.00	14.25	1.67	895					
2	7.28	13.31	1.60	520					
3	6.13	13.38	1.77	480					
Mean	**7.80**	**13.65**	**1.68**	**632**					
Std Dev	**1.98**	**0.52**	**0.09**	**229**					

Specimen Comments:

Specimen #	Failure Mode
1	Tensile Fracture at Outermost Layer
2	Tensile Fracture at Outermost Layer
3	Tensile Fracture at Outermost Layer



Stress vs Strain Plot

Checked By: _____

Authorised Signature: _____ **Date:** _____

TENSILE TESTING REPORT

ISO 527-4/2/2: 1997 Plastics – Determination of Tensile Properties

Test Date:	**Test Method:**	**Operator:**
26/10/2010	STS - Laminate Tension - Biaxial Ext (ISO 527).msm	Student

Sample Information:

(A) Client Name:	PF-jute x 1h Salt Water
(B) Mailing Address:	
(C) Mailing Address:	
(D) Mailing Address:	
(E) Attn:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	PF-jute x 1h Salt Water
(I) STS Job Number:	PF-jute x 1h Salt Water
(J) Specimen Orientation:	0 Degrees
(K) Sample Description:	Laminate Test Panel
(L) Layup Sequence:	Details Not Supplied by Client
(M) Principle Dimensions:	250mm x 250mm
(N) Method of Manufacture:	Details Not Supplied by Client
(O) Laminate Cure Schedule:	Details Not Supplied by Client
(P) Test Room Conditions:	23°C, 38% RH
(Q) Conditioning Temp. & RH:	23°C, 50% RH Constant for 24 Hours
(R) Clamping Pressure (MPa):	8
(S) Testing Speed (mm/min):	2.0
(T) Specimen Prep. Method:	Specimens cut by diamond coated cutting wheel, edges sanded smooth & defect free.

Test Equipment Details:

Test Machine:	MTS 810 Material Test System
Location:	Z104 Test Laboratory, Faculty of Engineering and Surveying, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	15/02/2007
Expiration Date:	15/02/2008
Strain Measurement Device:	MTS Extensometer Model No. 632.85F-14
Extensometer Calibration Date:	15/02/2007
Load Cell Calibration Date:	15/02/2007
Expiration Date:	15/02/2008

Specimen Results:

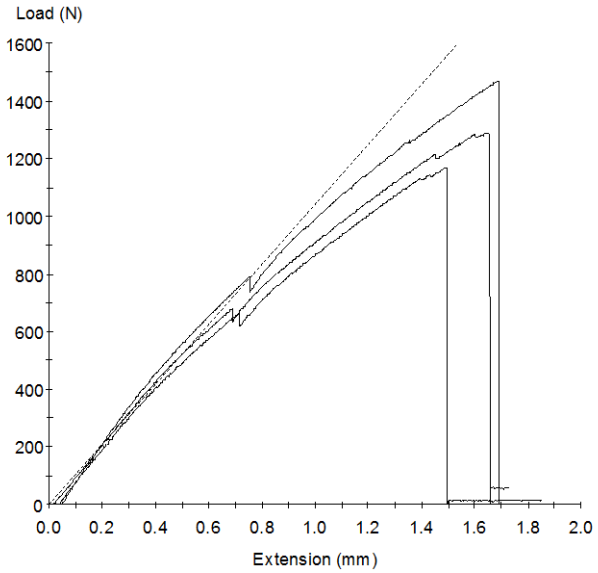
Specimen #	Thickness 1 mm	Thickness 2 mm	Thickness 3 mm	Width 1 mm	Width 2 mm	Width 3 mm	Avg Thick mm	Avg Width mm	Area mm^2
1	3.54	4.02	4.12	24.90	24.97	25.04	3.89	24.97	97.22
2	3.19	3.17	3.18	25.00	24.96	24.84	3.18	24.93	79.29
3	3.13	3.32	3.34	24.97	25.10	25.00	3.26	25.02	81.66
Mean	**3.29**	**3.50**	**3.55**	**24.96**	**25.01**	**24.96**	**3.45**	**24.98**	**86.05**
Std Dev	**0.22**	**0.45**	**0.50**	**0.05**	**0.08**	**0.11**	**0.39**	**0.05**	**9.74**

Specimen Results:

Specimen #	Peak Load N	Peak Stress MPa	Modulus of Elasticity MPa						
1	1468	15.11	2671						
2	1170	14.76	2806						
3	1288	15.78	2801						
Mean	**1309**	**15.21**	**2759**						
Std Dev	**150**	**0.52**	**77**						

Specimen Comments:

Specimen #	Failure Status
1	Acceptable
2	Acceptable
3	Acceptable

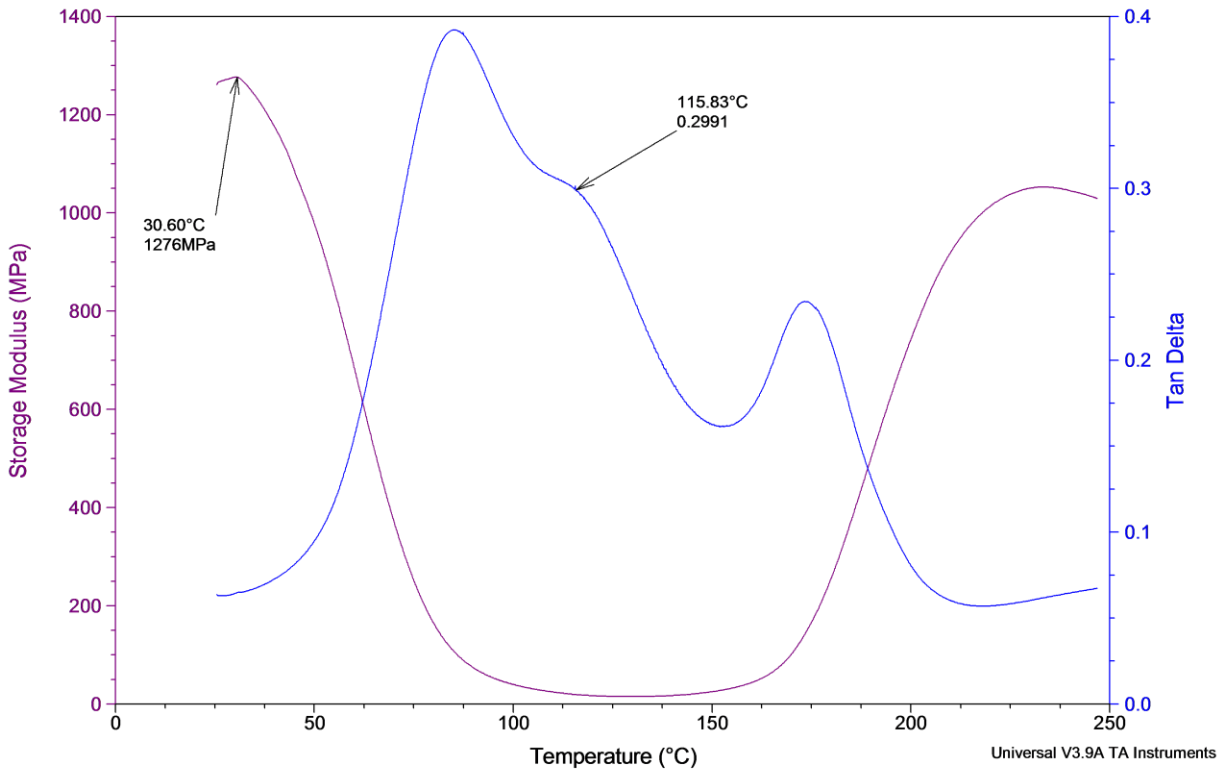


Load vs Extension Plot

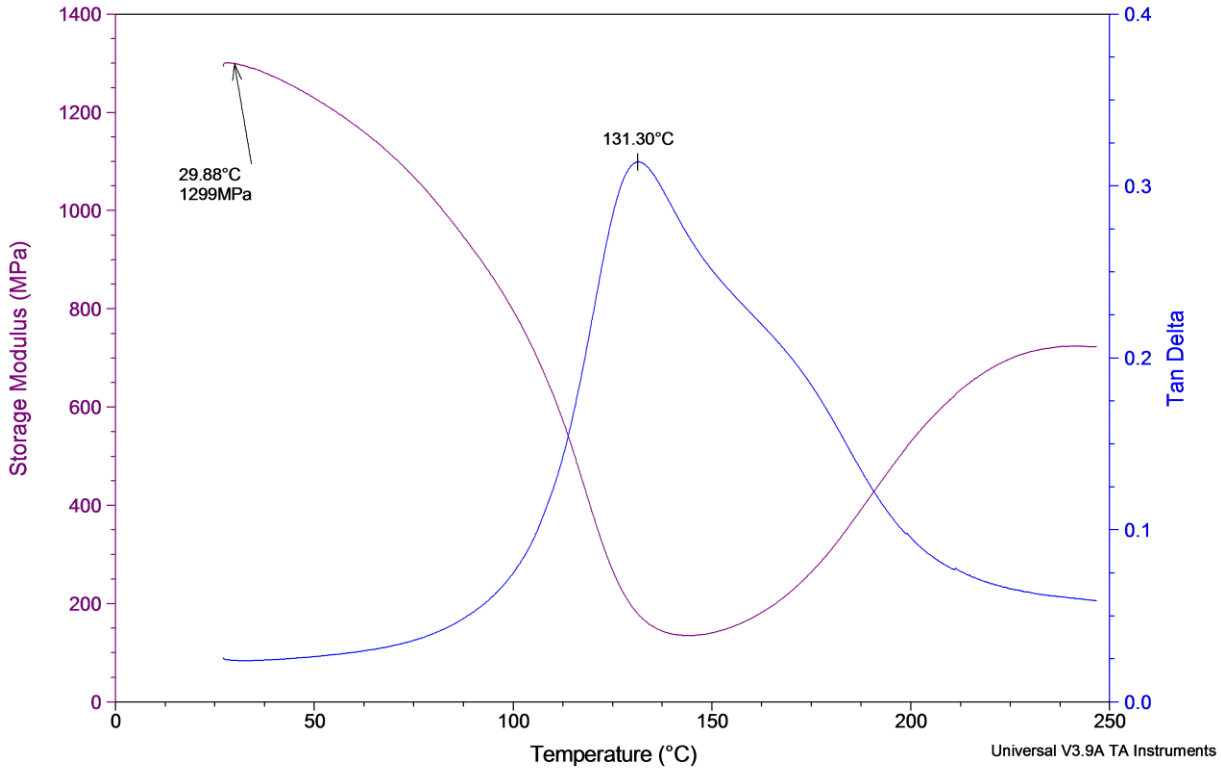
Checked By: _____

Authorised Signature: _____ **Date:** _____

DMA Analysis of Modified Phenolic Resin (CPF)
(20% (wt %) Cardanol content)



DMA Analysis of Modified Phenolic Resin (CPF) (30% (wt %) Cardanol content)



University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

Eng 4111/4112 Research Project
PROJECT SPECIFICATION

For: Tom Bailey (0050040667).

Topic: Environmentally friendly composites made from natural waste materials. Preparation, mechanical properties and their uses in civil engineering structures.

Supervisor: Dr Francisco Cardona

Sponsorship: CEEFC Centre / Faculty of Engineering and Surveying

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AIM: To investigate the use of environmentally friendly composites made from natural waste material, such as jute fabric, cardanol resin, and sawdust.

PROGRAMME: **(issue A, 24 March 2010)**

- Conduct background research into the field of composite materials and their use in civil structures
- Research properties of the waste materials to be used in composite construction (Cardanol resin, jute fabric and sawdust).
- Construct sandwich panels of composites based on different waste material content percentages.
- Test the mechanical properties of the composite samples and determine the effects of waste material in composites. Identify the corresponding optimum content of waste material in the composite.
- Discuss results
- Discuss and research advantages of using waste material to supplement synthetic resins.

AGREED: _____ (student) _____ (supervisor)

Date: 24/03/2010 Date: 24/03/10.

Examiner/Co-examiner: _____