University of Southern Queensland
FACULTY OF ENGINEERING AND SURVEYING

ENVIRONMENTALLY FRIENDLY NATURAL FIBRE COMPOSITES WITH QLD BASED VEGETABLE OILS

A Dissertation submitted by

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Abstract

In modern times there has been a growing focus towards environmental awareness and sustainability which has entered the fibre composite industry. This attitude has seen an emergence in the occurrence of environmentally friendly, sustainable materials.

Traditional synthetic composites are predominately constructed from petro-chemical based resins and synthetic fibres. These traditional petro-chemical based composites have benefited society in many different ways. Recently there has been increasing concerns over the finite nature and the unsustainably of these resources. A genuine concern is the increase of costs as the availability of the resource reduces. There is a requirement to find a sustainable replacement material for use in industry, and this is where natural fibre composites are being positioned.

This project has compared natural fibre composites made from epoxidized vegetable oils and hemp fibres with traditional glass fibre composites through the investigation of mechanical and thermal properties. An understanding of the benefits of making the composites has been gained throughout this project. Traditional glass fibre composites were manufactured using the hand layup technique and the microstructure, thermal and mechanical properties were characterised through flexural tests, impact tests, DMA and microscopic analysis. Natural fibre composites were manufactured from different types of hemp fibre (short bleached and raw long) and different types and quantities of EVO using randomly orientated short hemp fibres and also unidirectional hand laid hemp fibres. The effects of fibre content and alkali treatment of the hemp fibre were analysed through mechanical, thermal and microscopic analysis. Natural fibre composites were compared with traditional glass fibre composites through mechanical, thermal and microscopic analysis.

This study has confirmed the ability of natural fibres and plant-oil based resins as feasible resources from which to manufacture fibre composites. Improvements were realised through the use of alkali treatment of the fibres. In terms of cost and specific material properties, natural composites represent an alternative to traditional synthetic fibre composites in certain applications.

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Date

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Nomenclature

CEEFC = Centre of Excellence in Engineering Fibre Composites

DMA = Dynamic Mechanical Analysis

EHO = Epoxidised Hemp Oil

EHO = Epoxidised Hemp Oil – Tyson Cooney

ELO = Epoxidised Linseed Oil – Tyson Cooney

ESFO = Epoxidised Sunflower Oil – Tyson Cooney

EVO = Epoxidised Vegetable Oil

HDT = Heat Distortion Temperature

JSA = Job Safety Assessment

NaOH = Sodium Hydroxide

PAN = Polyacrylonitrile

PPE = Personal Protective Equipment

SEM = Scanning Electron Microscope

T_g = Glass Transition Temperature

1 Introduction

This chapter describes the project outline and the research objectives of the project. The primary purpose of this project is to investigate and characterise natural fibre composites made with Queensland based vegetable oils through the investigation of mechanical and thermal properties.

1.1 Project Topic

Environmentally friendly natural fibre composites with QLD based vegetable oils

1.2 Project Background

In recent times there has been an increasing focus towards environmental awareness which has crossed over into the fibre composite industry. This attitude has seen an emergence in the prevalence of environmentally friendly, sustainable materials. Traditional synthetic composites are predominately constructed from petro-chemical based resins and synthetic fibres.

These traditional petro-chemical based composites have benefited society in many different ways. Recently there has been increasing concerns over the finite nature and the unsustainably of these resources. A genuine concern is the increase of costs as the availability of the resource reduces. There is a requirement to find a sustainable replacement material for use in industry, and this is where natural fibre composites are being positioned.

Natural fibre composites exhibit numerous advantages over traditional synthetic composites. They represent an inexpensive, easy to process composite that exhibits high specific properties, with end of life cycle recyclability and are made from renewable resources (*O'Donnell, Dweib & Wool 2004, Agrawal et al. 2000, Canché-Escamilla et al. 1999*). Other advantageous properties of natural fibre composites are; reduced carbon footprint from the growing of the natural fibres, and enhanced energy recovery (*Joshi et al. 2004*). Saherb and Jog (*1999*) theorised that there are

also disadvantages with natural fibre composites such as the propensity to form aggregates during processing and a low resistance to moisture absorption.

With increased demand and applications for composites, pressure is being placed on the viability of these non-renewable synthetic composites. Therefore there is a focus on developing less expensive sustainable composites with superior or comparable material properties.

1.3 Research Aim and Objectives

The aim of this project is to compare environmentally friendly composites made from natural polymer resins (such as epoxidized vegetable oils) and natural fibres (such as bagasse and hemp fibres) with traditional glass fibre composites through the investigation of mechanical and thermal properties.

The research objectives of this project are characterised below:

- Understand the mechanisms and benefits of making the composite
- Prepare traditional fibre composites and characterise them in terms of microstructure, thermal and mechanical properties
- Prepare environmentally friendly natural fibre composites and characterise them in terms of microstructure, thermal and mechanical properties
- Study the effects of the fibre selection (type, volume and size) and processing conditions (temperature, pressure and fibre treatment) on the material properties
- Compare the environmentally friendly natural fibre composite with traditional glass fibre composites in terms of material properties

1.4 Justification

The justification of this project stems from the requirement to derive an alternative to non-renewable fibre composites that satisfy the requirements of industry. With further research, natural fibre composites represent a renewable alternative with the potential to be widely used throughout numerous industries such as, automobile,

furniture and household construction, sports equipment and various civil engineering applications.

Europe has an end of life vehicle (ELV) initiative currently in existence that requires all vehicles to be constructed of a minimum of 95% recyclable materials by 2015. This ELV includes a further requirement for the recovery of 85% of the material by mechanical means and 10% through thermal recycling or energy recover techniques (*Maya Jacob John & Sabu Thomas 2008*).

Numerous automobile manufactures in Germany are utilising natural fibre composites for applications ranging from door panels, under floor protection and dashboards (*Maya Jacob John & Sabu Thomas 2008*). Figure 1 displays the natural fibre composite components of Mercedes-Benz E Class sedan.

Figure 1 - Natural fibre composite components of Mercedes-Benz E Class (*www.ncn-uk.co.uk*)

Initiatives such as the ELV highlight the increasing demand for natural fibre composites in just the automobile industry alone. Figure 2 demonstrates the use of natural fibres for automotive composites in Germany and Austria for the period 1996 – 2002. From figure 2 the growth rate displays a linear trend and the annual increase in the use of natural fibres being approximate 22%.

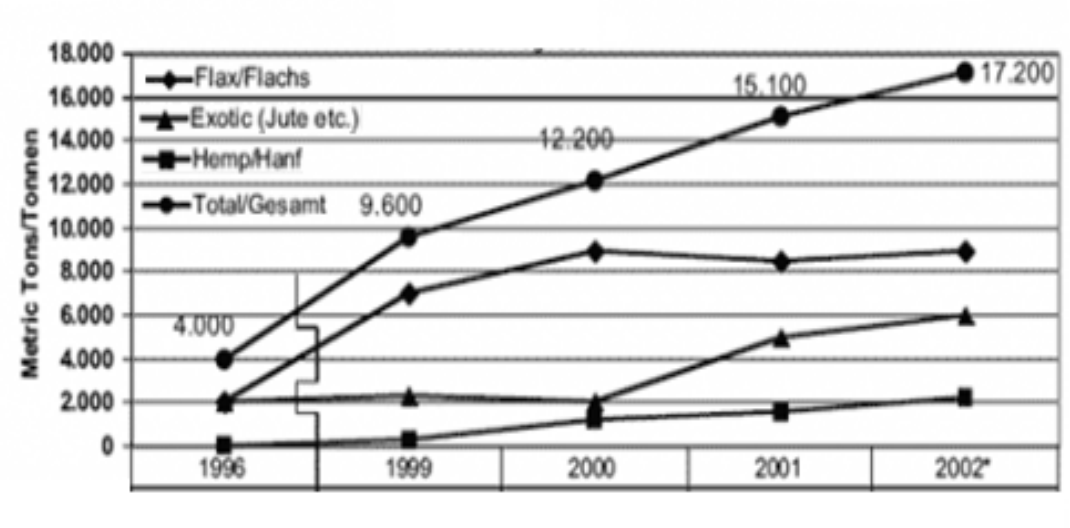


Figure 2 – Use of natural fibres for automotive composites in Germany and Austria for the period 1996 – 2002 (*www.chanvre-inf.ch*)

Current applications in the automobile industry primarily utilise natural/synthetic hybrid composites as a transition material. With further research it is hoped that completely environmentally friendly natural fibre composites will replace transition composites and traditional non-renewable composites.

1.5 Scope

The testing undertaken throughout this project will focus on investigating and characterising the material properties of natural fibre composites made from epoxidised vegetable oils (EVO) and hemp fibres. Samples were manufactured using two different processes. The majority of the samples were made from randomly orientated short bleached hemp fibre and EVO. Other samples were made from unidirectional long hemp fibre and glass fibre using the hand layup technique.

The manufactured samples were produced from epoxy (GY-191) and hardener (Aradur 250) with varying quantities and types of EVO with hemp fibre. The EVO used ranged from values of 10% to 40% and the types used were epoxidised linseed oil (ELO), epoxidised sunflower oil (ESFO), and epoxidised hemp oil (EHO). The hemp fibres were also subjected to alkali treatment.

Mechanical testing was performed in the form of flexural and impact tests with the primary parameters analysed being peak flexural stress, flexural modulus, strain at break and total impact energy. Dynamic Mechanical Analysis (DMA) was performed to characterise and compare the viscoelastic behaviour of the composite materials at a predetermined temperature range. This comparison was achieved by measuring values such as loss modulus, storage modulus and the glass transition temperature. Microscopic analysis was used to establish the fibre dispersion and to identify any voids within the composite.

1.6 Conclusion

This project aims to investigate and characterise natural fibre composites made with Queensland based vegetable oils through the examination of mechanical and thermal properties. A literature review will be conducted to provide the background for the methods used in the preparation and testing of the composites. It will also provide the basis for limitations and expected outcomes for this project.

2 Literature Review

2.1 Introduction

This chapter will review the previous studies and the current literature that has been published regarding environmentally friendly natural fibre composites. Information regarding the various subject matters has also been obtained from unpublished information sources and through correspondence with supervisors and colleagues. A historical background of fibre composites with sub categories associated with polymers and fillers pertaining to their places in engineering will be provided. This will be used in part to quantify the materials used throughout the project. Catalysts will be described along with the curing procedure, specimen production and the testing procedures. Finally the consequential effects of the project will be assessed.

2.2 Fibre Composites

Composites are a type of material made from two or more different types of phases, generally each with different material properties. The material constitutes are selected in order to design a material with specific desired material properties (*Mano 1991*). Synergy of the combined materials usually ensures that the final composite material has superior material properties than each individual material constituent.

Although seemingly prevalent in regards to current high technological applications such as the aerospace industry and motorsports, composite material has been in existence for centuries. Some of the earliest evidence of the existence of composite materials can be traced back to biblical times. The book of Exodus (*Exodus 5: 6-9*) tells of the Israelites being forced to find their own straw to make clay bricks.

Fibre composites consist of two or main components whereby one component (fibre) structurally reinforces the other component (matrix). The primary phase is generally the reinforcing fibres such as glass or hemp fibres however it can also be a filler material such as glass powder or sawdust. The secondary phase or polymer matrix is used to ensure that the primary phase remains in position and also acts as a means of

load dispersion. Most commercially derived composites use a form of polymer matrix or resin (*Kaw 1997*).

Fibre composites are traditionally made from non-renewable petro-chemical based materials and have served industry well for a long period of time. However as petroleum is a non-renewable resource with supplies diminishing, there has been an increasing focus on natural fibre composites that are sustainable and provide similar or superior properties to traditional synthetic composites.

2.2.1 Background of Polymer Resins

Modern commercially produced fibre composites use polymer resins as the matrix phase in the composite material. The functions of the polymer matrix are to transfer load, secure the fibre reinforcement and to prevent any mechanical or environmental damage to the fibres (*www.mdacomposites.org*). Specific material properties can be achieved with the addition of various different types of fibres to the polymer matrix. There are two main categories of polymer resins, these being thermoplastics and thermosets.

Thermoplastics

Thermoplastics display an ability to become elastic and flexible when heated to a temperature above the specific glass transition temperature (T_g). This increase in elasticity and flexibility can be attributed to the fact that thermoplastic polymers are characterised as possessing weak Van de Wall forces. When the temperature of the polymer increases, the vibration of the molecules increases. This creates further separation of the molecules and therefore decreases the strength of the Van de Walls forces. When heated, thermoplastic polymers display a decrease in viscosity without a subsequent phase change, thereby enabling remoulding of the polymers.

Thermosets

Thermoset polymers are liquid at room temperature, which enables the easy addition of fibres and or other additives before being set. Curing of the thermoset polymers is achieved by the addition of a catalyst/hardener, curing in an oven or by a combination of the two methods. Once the polymers have been cured, they remain in the solid phase and are unable to return to a liquid phase. This phenomenon can

be attributed to cross linking of the molecules whereby the molecules lose the ability to slide past each other. The cross linking permanent increases the viscosity of the polymer, even upon reheating. When heated the cured thermoset polymers will soften and when cooled the polymers will become stiff and brittle. The glass transition temperature and the heat distortion temperature (HDT) are used as a measurement of the differing phases of the cured polymer.

Thermosetting polymers are the most common type of resin used in the composite industry and are also the type used in this project. Some of the most common types of thermosetting polymers used throughout industry are unsaturated polyesters, epoxies, phenolics and vinyl esters. These polymers are described below.

Unsaturated Polyester Resin

One of the most widely used resins in the fibre composites industry is unsaturated polyester resin. Unsaturated polyester resins can be categorised as being thermosetting polymers. Styrene is added to the resins thereby enabling the curing of the resin by cross linking. The addition of styrene also serves to lower the viscosity of the resin which aides in production of moulds by making the resin easier to handle. Catalysts are also added to unsaturated polyester resins to initiate the curing process. Figure 3 depicts a common representation of a cured unsaturated polyester resin. The styrene molecules can be seen cross linking with the polymer chains at each of the reaction sites.

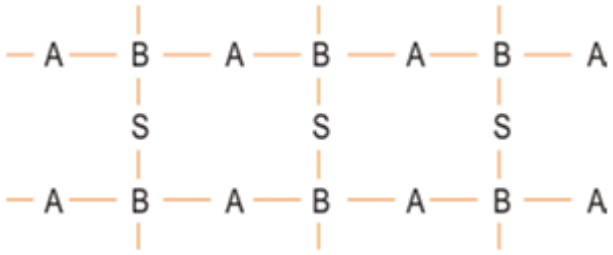


Figure 3 – Common representation of a cured unsaturated polyester resin (*www.azom.com*)

Epoxy Resin

Epoxy resin is a high performance resin that is commonly used in aerospace and marine applications. Epoxies are polymers that belong to a chemical group that consists of three members situated on the ends of the polymer chains. These three member groups contain an oxygen atom bonded to two carbon atoms. Curing of epoxy resin is obtained at temperatures ranging from $5^{\circ}C - 150^{\circ}C$. The epoxy resin consists of long molecular chains with reaction sites situated at each end. Figure 4 displays a typical chemical structure of an epoxy group.

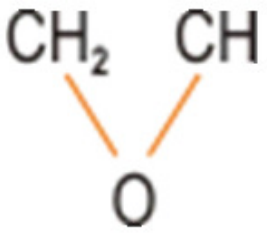


Figure 4 – Typical chemical structure of an epoxy group (*www.azom.com*)

Epoxy resins are cured with the addition of a hardener rather than with a catalyst. The curing process is achieved by way of an addition reaction which generally creates two reaction sites (*www.azom.com*).

Phenolic Resin

Phenolic resin is obtained by a condensation reaction process involving phenol and formaldehyde. This reaction process generates cross linking of methylene between the phenol molecules and can be seen in figure 5. Phenolic resins are highly temperature resistant and are hard and rigid (*Kopf & Little 1991, Knop & Pilato 1985*).

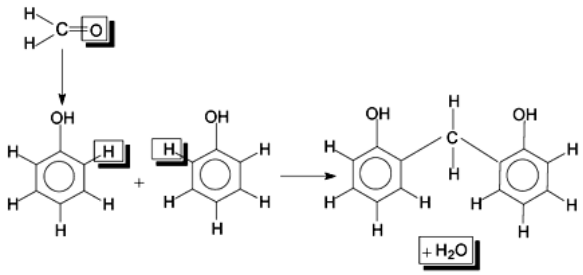


Figure 5 – Condensation reaction for the formation of phenolformaldehyde (*Leite et al. 2004*)

The cross linking in phenolic resins involve the formation of a three dimensional network that provides the desired material properties.

Vinyl Ester Resin

Vinyl ester resins are created through a reaction process involving epoxy resin and methacrylic acid being mixed with styrene which acts as a reaction solvent. Although similar in structure to polyesters vinyl ester have reaction sites only at the end of the molecular chains (*www.azom.com*). Figure 6 displays the chemical structure of an epoxy based vinyl resin.

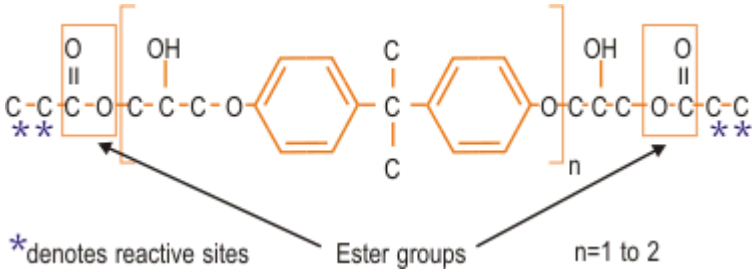


Figure 6 – chemical structure of an epoxy based vinyl resin (*www.azom.com*)

Toughness and high corrosion resistance are some of the material properties that vinyl ester resins display without the requirement for complex processing that are more common in epoxies (*www.mdacomposites.org*).

Bio-based Resins

The majority of polymer resins used in engineering applications are currently derived from non renewable petro-chemical based resources (*www.dpi.qld.gov.au*). Plant-oil based resins, which are derived from natural sources, are a viable alternative to petro-chemical based resins as they are readily available in most of the world (*Wool 2005*). There are indications (*Van Erp & Rogers 2003*) that the Darling Downs region of Queensland, Australia is suitable for the production of plant-oil based resin feedstocks, although the successful implementation of these crops will depend on the profitability of the crops and the manufacturing properties of the oil produced (*www.dpi.qld.gov.au*). The focus of this project lies in using epoxidized plant based oils and therefore these will be examined in detail.

The primary use for plant-oil based resins is as a plasticiser or toughening additive. They are inexpensive and are easily incorporated into epoxy resins. Plant-oil based resins consist of triglyceride molecules, which exhibit the structure shown below in figure 7. The triglycerides can be categorised as consisting of unsaturated and saturated fatty acids (*Lligadas et al. 2006*). Saturated fatty acids exhibit no double bonds, whereas unsaturated fatty acids display one to three double bonds. A variation in the number and the type of triglycerides is apparent relative to the type of oil in question (*www.dpi.qld.gov.au*). The triglyceride molecules consist of three fatty acid chains and a glycerol join which can also be seen below.

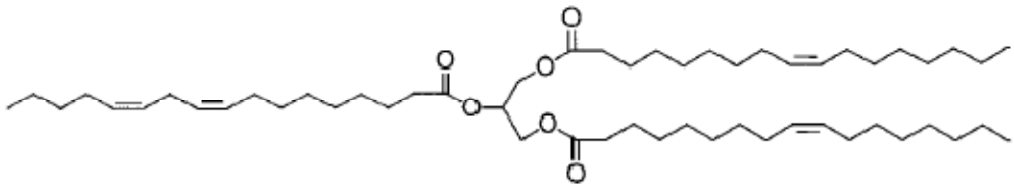


Figure 7 – Triglyceride molecule, the primary component of plant based oils (*Wool 2005*)

According to Wool (*2005*) the fatty acids contained in the most commonly used oils display a variation in length of between 14 to 22 carbon atoms with 0 to 3 double bonds per fatty acid chain. The double bonds that are present in unsaturated fatty acids are used as reaction sites in the formation of cross linking. Cross linking may be achieved by a functional reaction of the carbon-carbon double bonds to enable use in high-molecular weight products. The material properties of the resin are dependent on the degree of cross linking with materials that have a high crosslink density displaying good mechanical and thermal properties (*Van Erp & Rogers 2003*).

Khot et al (*2001*) states that there are numerous chemical pathways of ensuring functionalisation of the triglycerides. Functionalisation of the triglycerides can be achieved by ring opening or by polycondensation polymerisation related to the conversion of unsaturated fatty acids to epoxies (*Hodakowski et al. 1975*) or hydroxyls (*Trecker et al. 1976*), and the attachment of maleates (*Cunningham & Yapp 1974*). In the case of this project the focus is on using epoxidised vegetable oil resins derived from the conversion of the unsaturated fatty acids to epoxies.

2.2.2 Background of Fibres

Fibre composites derive their material properties from the reinforcing supplied to the matrix in the form of fibres. Fibres differ from particular reinforcements or fillers in that they display a length of a much greater magnitude than their cross section (*Matthews & Rawlings 1999*). The two main reasons for using fibres in fibre composites are to achieve specific material properties and for cost reduction purposes. Specific material properties are able to be obtained by combining two different phases, each with differing material properties into a composite. The addition of fibres to the polymer matrix of the composite serves to decrease the overall cost of the composite, as the fibres are less expensive than the polymer matrix.

Fibres can be categorised as being synthetic, natural, or regenerated, with natural fibres also being subcategorised as being plant, animal, or mineral fibres (*Bunsell & Renard 2005*). Synthetic fibres consist of fibres such as nylon, glass and carbon. Examples of natural fibres are flax, bagasse and hemp from plants, wool and silk from animals and asbestos from minerals. Regenerated fibres are based on the molecular structure of plants and are processed to form continuous filaments, such as Rayon (*Bunsell & Renard 2005*). Further classification of fibre composites is also possible in terms of composite type (fibre or filler) and fibre orientation. Figure 8 displays examples of composites characterised by different types and fibre orientations.

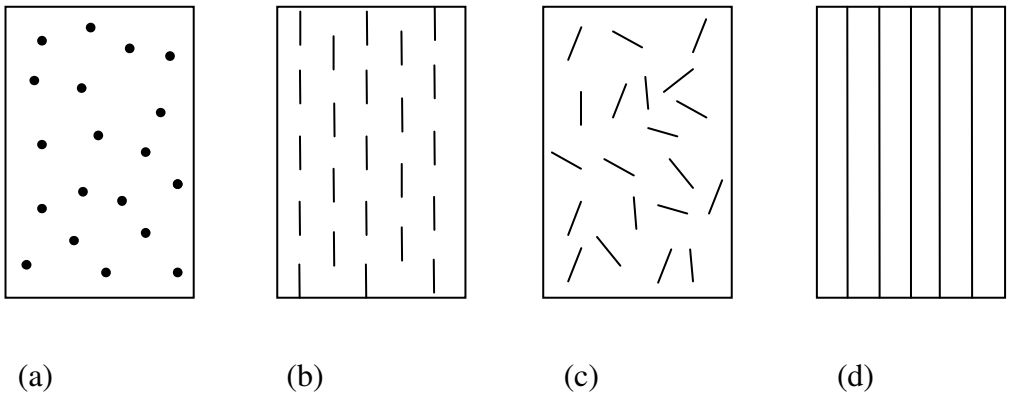


Figure 8 – Examples of composites: (a) particulate, random; (b) discontinuous fibres, unidirectional; (c) short fibres, random; (d) continuous fibres, unidirectional (*Matthews & Rawlings 1999*)

The ultimate properties of the composite are closely associated with the properties and content of the fibre reinforcement in the matrix. This project characterised the fibre content in terms of weight fraction (*w*), which has relevance in composite fabrication as opposed to volume fraction (*v*), which is used in property calculations (*Matthews & Rawlings 1999*). The weight and volume fractions are ratios of weight and volume respectively compared with the weight and volume of the composite. The relations are defined below in equations 1 and 2.

Weight fraction:

$$w_f = \frac{W_f}{W_c} \tag{1}$$

Volume fraction:

$$v_f = \frac{V_f}{V_c} \tag{2}$$

An important aspect regarding the material properties of the composite is the degree of adhesion between the fibre and the matrix. In reports in the literature, Juska and Puckett (*1997*) indicate that the quality of the fibre matrix bond has an effect on the compression strength, flexural strength, traverse tensile strength, in-plane shear strength and fracture toughness. The quality of the fibre matrix bond is related to the weight and volume fractions with the determination of an upper limit in order to prevent fibre-fibre contact and ultimately fibre damage (*Matthews & Rawlings 1999*) and composite failure. It is the need to balance performance versus cost that research has been conducted on numerous fibre types.

Traditional Synthetic Fibres

Traditional synthetic fibre reinforcements that are commonly used in engineering applications can be categorised into three main groups.

- Glass fibres
- Carbon fibres
- Aramid fibres

Each of these classes of fibre reinforcements are commonly used in advanced industry applications and will therefore be discussed further in the following sections. It can be seen in figure 9 that these three different fibre groups make up a significant value of approximately 31% of the fibre composite market.

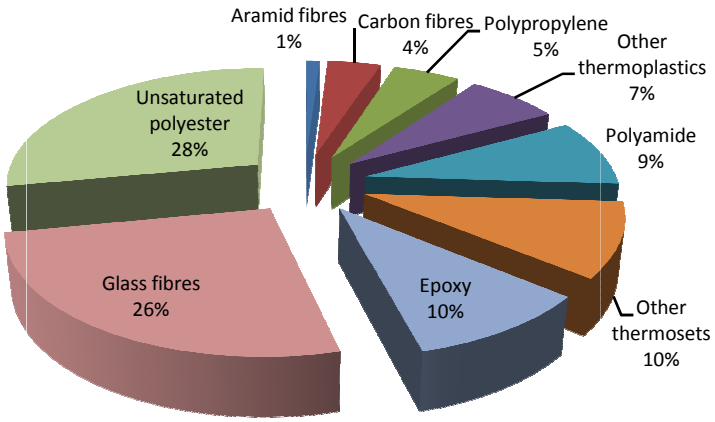


Figure 9 - Percentage value of fibre reinforced fibre composite market (*Bunsell & Renard 2005*)

Glass Fibres

Glass fibres have been in use since the 1940's and are the most widely used reinforcements in the current fibre composite industry. The uses of glass fibre reinforced composites are wide ranging and encompass civil to military applications.

The glass fibres are produced by an extrusion process whereby the molten glass is heated to temperatures of up to 1200°C and extruded through fine spinnerets. The filaments are then drawn to produce fine uniform fibres with diameters of between 5 and 15μm (*Bunsell & Renard 2005*).

There are numerous different types of glass fibres throughout the glass category with silica (SiO_2) being the most common base. The composition of the most common types of glass, along with their associated mechanical properties is shown in table 1.

Table 1 - Composition and mechanical properties of the most common types of glass (Bunsell & Renard 2005)

Glass type	E	S	R	C	D
SiO_2	54	65	60	65	74
Al_2O_3	15	25	25	4	
CaO	18		9	14	0.2
MgO	4	10	6	3	0.2
B_2O_3	8			5.5	23
F	0.3				
Fe_2O_3	0.3				
TiO_2					0.1
Na_2O				8	1.2
K_2O	0.4			0.5	1.3
Density	2.54	2.49	2.49	2.49	2.16
Strength ($20^{\circ}C$) (GPa)	3.5	4.65	4.65	2.8	2.45
Elastic modulus ($20^{\circ}C$) (GPa)	73.5	86.5	86.5	70	52.5
Failure strain ($20^{\circ}C$) ()	4.5	5.3	5.3	4.0	4.5

From the five different types of glass fibre listed in table 1, the most common form is E-glass. E-glass was developed for electrical applications as it displays high electrical resistance (*Mechanics of technology and fibre composites Study Book 2009*), S and R glass fibres are known to display superior mechanical properties. Glass fibres can be used as short fibres or can be woven into a mat or made into a non-woven mat depending on the application.

Glass fibres exhibit several properties that make them advantageous for use in composites. They are inexpensive compared to other fibres (*Bunsell & Renard 2005*, *Mechanics of technology and fibre composites Study Book 2009*), they are easy to manufacture as there is a base of existing knowledge (*Bunsell & Renard 2005*, *Mechanics of technology and fibre composites Study Book 2009*) and they are compatible with a range of various different materials (*Mechanics of technology and fibre composites Study Book 2009*).

The main disadvantages with glass fibres are their low elastic modulus compared with other fibres (*Bunsell & Renard 2005*, *Mechanics of technology and fibre composites Study Book 2009*) and their potential to be a health risk with regards to skin irritation. Although these health risks can be minimised through the use of the correct personal protective equipment (PPE) such as long sleeve shirts and eye protection when machining or cutting the fibres.

The typical price for E-glass fibre is approximately $2 to $4 per kilogram, with the price of R and S-glass fibre being approximately $24 to $40 per kilogram (*www.azom.com*).

Carbon Fibres

Carbon fibres are often associated with high performance fibre composites such as aerospace and motorsport applications. They are a lightweight fibre that exhibits high stiffness and high strength (*Mechanics of technology and fibre composites Study Book 2009*) that is due in part to the strongest covalent bond in nature (carbon-carbon bond) (*Bunsell & Renard 2005*). Carbon has two different crystalline forms (diamond and graphite), with graphite being the most important form for use in fibre composites (*Matthews & Rawlings 1999*).

Carbon fibres are manufactured from several different precursors with the majority being made from polyacrylonitrile (PAN) precursors (*Bunsell & Renard 2005*). The process involves the PAN fibres being heated to approximately $250^{\circ}C$ while being held under tension. The structure is made infusible due to the presence of cross linking and is further heated to approximately $1000^{\circ}C$ in a nitrogen rich atmosphere so that the nitrogen level decreases. The fibres are then reheated to around 1500 - $1600^{\circ}C$ so that a carbon structure remains (*Bunsell & Renard 2005*).

Ultimate strengths of PAN precursor based carbon fibres range from 3000MPa to above 6000MPa (*Mechanics of technology and fibre composites Study Book 2009*).

Carbon fibres offer advantages such as (*Mechanics of technology and fibre composites Study Book 2009*):

- High fibre stiffness
- High fibre strength
- Low density
- High public marketability

However there are disadvantages such as (*Mechanics of technology and fibre composites Study Book 2009*):

- High cost
- Resin incompatibility
- Fibre availability

The typical price for high strength carbon fibre is approximately $30 to $80 per kilogram (*www.azom.com*).

Aramid Fibres

Aramid fibres are a type of organic fibre that is used in a range of diverse applications ranging from military, aerospace and transport infrastructure. They are an aromatic polyamide that is typically manufactured by spinning a solid fibre from a liquid chemical blend (*www.azom.com*). Aramid fibres are more widely known by their trademarked names such as Kevlar and to a lesser extent Twaron.

Aramid fibres are used in continuous reinforcement applications such as bullet proof vests because of their high impact strength characteristics. They are also suitable for applications such as gaskets due to their high temperature properties (*Mechanics of technology and fibre composites Study Book 2009*). A disadvantage of aramid fibres is that some forms of the fibre have a propensity to degrade after being exposed to ultraviolet light (*www.azom.com*).

The typical price for high quality aramid fibre is approximately $30 to $50 per kilogram (*www.azom.com*).

Natural Fibres

Natural fibres can be subcategorised as being plant, animal, or mineral fibres (*Bunsell & Renard 2005*). Plant based fibres can be further classified as leaf, bast, fruit, seed (*O'Donnell, Dweib & Wool 2004*), wood, cereal straw, and other grass fibres (*John & Thomas 2008*). This project focuses on the use of plant fibres; specifically natural hemp fibres that can be classified as being randomly orientated short bleached hemp fibres, and raw long hemp fibres, therefore the focus of this dissertation will be on plant based fibres. Figure 8c displays an example randomly orientated short fibres.

Natural fibres offer various advantages over traditional synthetic composites. They signify an inexpensive fibre with high specific properties that is easy to process, has

end of life cycle recyclability and are made from renewable resources (*O'Donnell, Dweib & Wool 2004, Agrawal et al. 2000, Canché-Escamilla et al. 1999*). Other advantageous properties of natural fibre composites are reduced carbon footprint from the growing of the natural fibres, and enhanced energy recovery (*Joshi et al. 2004*).

There are also disadvantages with natural fibre composites such as the propensity to form aggregates during processing and a low resistance to moisture absorption (*Saherb & Jog 1999*). Wool (*2004*) writes that one of the main disadvantages is that the natural fibre properties are dependent on factors such as locality, what part of the plant the fibres are harvested from, the maturity of the plant and the production process. Table 2 displays a comparison of the mechanical properties of some common natural fibres and traditional fibres.

Table 2 - Mechanical properties of some common natural fibres and traditional fibres (Bogoeva-Gaceva et al. 2007).

Fibre	Specific gravity (g/cm^3)	Tensile Strength (GPa)	Tensile modulus (GPa)	Specific strength (g/cm^3)	Specific Modulus ($GPa/g.cm^3$)	Cost ratio
Sisal	1.20	0.08-0.5	3-98	0.07-0.42	3-82	1
Flax	1.20	2.00	85	1.60	71	1.5
E-Glass	2.60	3.50	72	1.35	28	3
Aramid	1.44	3.90	131	2.71	91	18
Carbon	1.75	3.00	235	1.71	134	30

It is worth noting the advantageous cost ratio of the natural fibres compared to the traditional synthetic fibres. This characteristic coupled with the relatively high specific strength makes natural fibres a favourable alternative to traditional fibres in certain applications.

Structure of Natural Fibres

Plant fibres can be thought of as being a natural form of composite material with the main constitutes being cellulose fibres secured in a lignin and hemi-cellulose matrix (*John & Thomas 2008*). The basic structure of a plant fibril is a primary cell wall surrounding a secondary wall (*John & Thomas 2008, www.ccrc.uga.edu*). The primary cell wall is responsible for providing structural and mechanical support,

controlling growth rate and direction and cell-cell interactions (*www.ccrc.uga.edu*). The secondary wall consists of three layers that provide the bulk of the mechanical strength of the fibre (*John & Thomas 2008, www.ccrc.uga.edu*). The outmost layer of the fibre is called the middle lamella (*www.ccrc.uga.edu*) and it serves to provide stability by fixing adjacent cells together. The structure of a plant fibre can be seen below in figure 10.

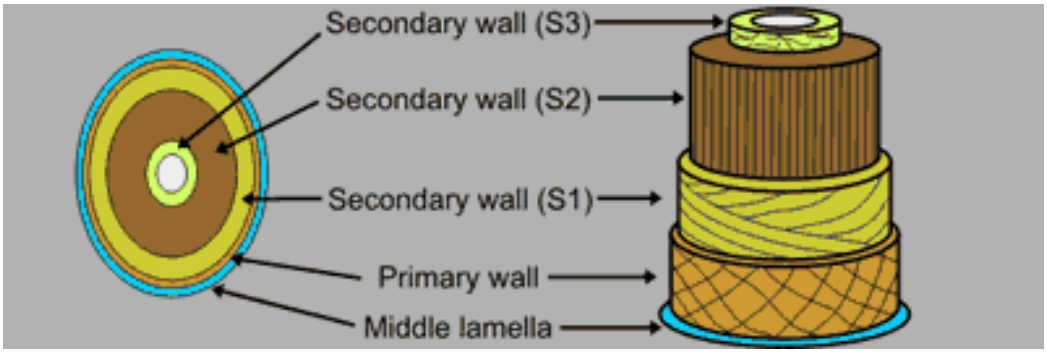


Figure 10 – Structure of a plant fibre (*www.ccrc.uga.edu*)

Composition of Natural Fibres

The components of common plant based fibres are displayed in table 3 with the three main components shown in table 3 to be, cellulose, hemi-cellulose and lignin respectively.

Table 3 - Components of common plant based fibres (Bogoeva-Gaceva et al. 2007)

Fibre	Cellulose (%)	Hemi-cellulose (%)	Lignin (%)	Extractives (%)	Ash (%)	Pectin (%)	Wax (%)
Jute	61-71	13.6-20.4	12-13	-	-	0.2	0.5
Flax	71-78	18.6-20.6	2.2	2.3	1.5	2.2	1.7
Hemp	70.2-74.4	17.9-22.4	3.7-5.7	3.6	2.6	0.9	0.8
Kenaf	53-57	15-19	5.9-9.3	3.2	4.7	-	-
Sisal	67-78	10-14.2	8-11	-	1	10	2.0
Cotton	82.7	5.7	-	-	-	-	0.6

Cellulose is a naturally occurring polysaccharide (*www.molecular-biology.suite101.com*) that consists of a linear chain of D-anhydroglucose ($C_6H_{11}O_5$) connected by $\beta(1-4)$-D-glycosidic links in ${}^4C_1$ formation (*John & Thomas 2008, www.lsbu.ac.uk*). Figure 11 displays the chemical structure unit of cellulose.

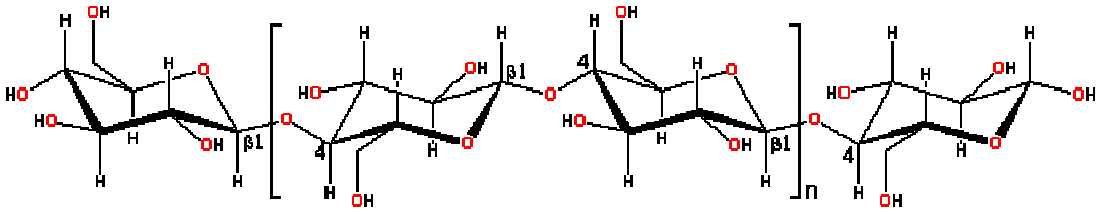


Figure 11 – Chemical structure unit of cellulose (*www.chemistry.oregonstate.edu*).

Cellulose is directly related to the reinforcing ability of the natural fibre whereby an increase in cellulose content can be correlated with an increase in tensile strength and Young's modulus (*John & Thomas 2008*).

Hemi-cellulose is comprised of 5 and 6 carbon ring sugars that support the cellulose microfibrils through a matrix arrangement (*John & Thomas 2008*). The cell walls of all plants contain hemi-cellulose.

Lignin is a chemical compound located in the secondary cell wall of plants. According to Maya & Thomas (*2008*) lignin is a thermoplastic polymer with a glass transitional temperature of $90^{\circ}C$ and a melting temperature of $170^{\circ}C$. The mechanical strength of the plant fibre is related to the distribution of lignin between hemi-cellulose and cellulose, causing binding and stiffening of the plant fibres to occur (*www.mrw.interscience.wiley.com*). A cut-away view of a plant fibre in figure 12 enables the various components and constitutes to be seen.

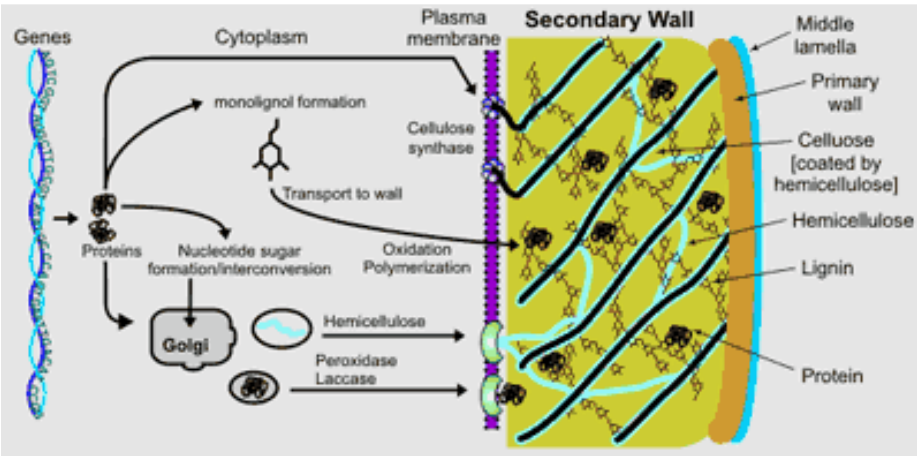


Figure 12 – Cut-away view of a plant fibre showing the various components and constitutes (*www.ccrc.uga.edu*)

Treatment of Natural Fibres

Plant based fibres can be further classified as leaf, bast, fruit, seed (*O'Donnell, Dweib & Wool 2004*), wood, cereal straw, and other grass fibres (*John & Thomas 2008*). The hemp fibres used in this project can be classified as bast fibres. Owing to the numerous different classifications of fibres there are numerous different methods of processing the plants to obtain a useful form of fibre. The most common method of fibre extraction entails stripping the outer fibre from the hurd by mechanical means and converting the fibre into the desired textile product. Different forms of fibre products such as short and long fibres, yarn and woven mats are produced.

Although natural fibres have numerous advantages over traditional fibres they tend to exhibit hydrophilic characteristics which may lead to poor matrix-fibre compatibility (*Li, Tabil & Panigraphi 2007, Mehta et al. 2006*). Chemical treatments aim to overcome this problem by modifying the structure and the surface properties of the fibres thereby allowing superior fibre-matrix compatibility. The chemical treatments may also serve to increase the strength of the fibres.

In order to overcome the fibre-matrix compatibility problems and to further the development of natural fibre composites it is necessary to appreciate the surface bonding characteristics and the chemical composition of natural fibres (*Li, Tabil & Panigraphi 2007*). A review on numerous different chemical treatments was completed by Li, Tabil & Panigraphi (*2007*).

The chemical treatments examined by Li, Tabil & Panigraphi (*2007*) included alkali, silane, acetylene, benzoylation, acrylation, maleated coupling agents, permanganates, isoyanates and other treatments. Mehta et al (*2006*) also examined the effects of fibre surface treatment, specifically alkali, silane, and acrylonitrile treatments on the properties of biocomposites. Li, Tabil & Panigraphi (*2007*), and Mehta et al. (*2006*) concluded an increase in fibre-matrix adhesion and increased mechanical and thermal properties as a result of chemical treatments of the fibres.

The chemical treatment undertaken in this project is the alkali treatment with sodium hydroxide (NaOH). This treatment was chosen due to the availability of the required chemicals, the ease of the process and because of the encouraging results obtained in examination of previous work documented in the literature. From Weyenberg et al,

Li, Tabil & Panigraphi (*2007*) details a 30% increase in the tensile properties of alkali treated flax fibres.

Li, Tabil & Panigraphi (*2007*) reports that alkali chemical treatment creates an increase in fibre surface roughness and the quantity of exposed cellulose on the fibre surface. This results in enhanced mechanical locking and an enlarged number of potential reaction sites respectively.

2.3 Microstructure and Mechanical Testing of Natural Fibre Composites

2.3.1 Curing

Curing of the fibre composites can be characterised as being an exothermic reaction which results in the fibre composites becoming rigid. The fibre composites are cured by the addition of a hardener, curing in an oven or by a combination of the two. The fibre composites are initially cured at room temperature and are then post cured at a specified temperature and period of time dependant on the type of resin and hardener used. The curing conditions may vary depending on the resin and hardener used. In a study conducted by Mwaikambo, Tucker & Clark (*2007*) on hemp fibre reinforced composites; the composites were post cured at $60^{\circ}C$ for 10 hours. Williams and Wool (*2004*) cured natural fibre composites made from hemp and flax fibres, for an hour at $90^{\circ}C$ and then post cured the composites at $110^{\circ}C$ for a further hour.

The fibre composites become rigid as a result of cross linking of the molecules which causes the molecules to lose the ability to slide past each other. As a result of a thermosetting resin being used in this project, the fibre composites that have been cured remain in a solid state and are unable to return to a liquid state.

2.3.2 Testing

The testing of fibre composites is important in order to establish material property data so as to be able to compare various different composites. The testing from the literature commonly incorporates mechanical testing such as tensile, compressive, flexural, shear, and impact tests. Dynamic mechanical analysis (DMA) is often

undertaken and is used as a comparison with the results of the mechanical testing. Further investigation in the form of microscopic analysis is often used, particular in analysing fibre-matrix adhesion and the dispersion of the fibres throughout the matrix.

Mechanical Testing

Mechanical testing is often performed in the form of tensile, compressive, flexural, shear, and impact tests. There is a variety of literature available regarding the different forms of mechanical testing of natural fibre composites although the majority of these tests focus on the use of natural fibre matting which was unable to be obtained by the author. O'Donnell, Dweib & Wool (*2004*) performed flexural tests on different natural fibre mats. Mwaikambo, Tucker & Clark (*2007*) performed tensile, shear and impact tests on treated and untreated hemp mats. Flexural and impact testing were the mechanical testing used to quantify and compare the mechanical properties of the fibre composites in this project.

Flexural Tests

The three-point bending flexural test was chosen due to the ease of specimen preparation and because of the importance of the material properties it is able to accurately quantify. However care must be taken in setting up the test and in specimen preparation in order to achieve accurate test results. The flexural test consists of a three point bending test which ascertains the peak flexural stress (σ_f), strain at break (ε_f), and flexural modulus (E).

Peak Flexural Stress

The peak flexural stress of the specimen signifies the maximum flexural stress experienced at the moment of failure. In a three point bending test the specimen will experience maximum stress at the surface whereby compressive stress will be experienced on the top surface and a tensile stress on the bottom surface.

Flexural stress (flexural strength) is measured in Pascals (N/m^2) or more commonly megapascals (N/mm^2). It is calculated by using equation 3, which is derived from the maximum bending moment equation relating to the failure load.

Peak Flexural Stress:

$$\sigma_f = \frac{3PL}{2bd^2} \tag{3}$$

Where:

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

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

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

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

Strain at Break

Strain at Break is a measure of the geometrical deformation of the specimen as a result of the applied loading. It is a direct measurement of the difference in displacement from an initial state to a deformed state. Flexural strain is dimensionless and can be calculated from equation 4.

Strain at Break:

$$\varepsilon_f = \frac{6Dd}{L^2} \tag{4}$$

Where:

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

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

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

Flexural Modulus

Flexural modulus is used to quantify the stiffness of a material. It is a ratio of the stress over the strain and can be used to determine the behaviour of a material whilst

subjected to load. Equation 5 shows the relationship of stress and strain in relation to modulus of elasticity.

Flexural Modulus:

$$E = \frac{L^3 m}{4bd^3} \tag{5}$$

Where:

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

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

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

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

Impact Tests

Impact tests are used to quantify the impact properties of the composite. The data obtained from the impact tests was total impact energy, which is expressed in Joules (J). To calculate total impact energy, integration is used to obtain the area under the force-deflection curve by using equation 6.

Impact energy:

$$W_j = \int_0^{s_j} F(s)ds \tag{6}$$

Where:

$j = Either\ the\ break\ B\ or\ maximum\ points\ (M) on\ the\ \ force - deflection\ curve$

$s = Deflection\ in\ metres\ (m)$

$F = Force\ in\ Newtons\ (N)$

2.3.3 Dynamic Mechanical Analysis

Dynamic mechanical analysis (DMA) is used to quantify the mechanical properties of materials, particularly polymers that behave in a viscoelastic manner. The specimen may be tested either using dynamic oscillatory or transient tests.

Dynamic oscillatory tests involve a sinusoidal stress or strain being applied to the specimen. The test outputs resultant sinusoidal stress or strain, and phase difference between the two sine waves (δ). Transient tests may be either stress relaxation or creep orientated. Stress relaxation involves the sample being deformed and then held constant, with the stress to maintain the deformation being measured against time. Creep tests involve the measurement of the specimen recovery in terms of stress, after being held in a deformed state for a period of time.

The useful outputs obtained from performing DMA are loss modulus, storage modulus and damping coefficient (tan δ) which is more commonly referred to as the glass transition temperature (T_g). The T_g indicates the point at which the material becomes brittle on cooling and or soft on heating. The loss modulus and the storage modulus are referred to as dynamic moduli and represent the dissipated energy and the stored energy of the material respectively. The storage modulus can be correlated to flexural stress values obtained in mechanical testing.

An example output of DMA is shown below in figure 13. The T_g which in this case is $70.52^{\circ}C$ can be seen to be at the peak of the (tan δ) line. The (tan δ) line is indicated as the blue line, the loss modulus as the red line, and the storage modulus as the purple line. The test results obtained by DMA are used as a comparison with the results obtained by the mechanical tests.

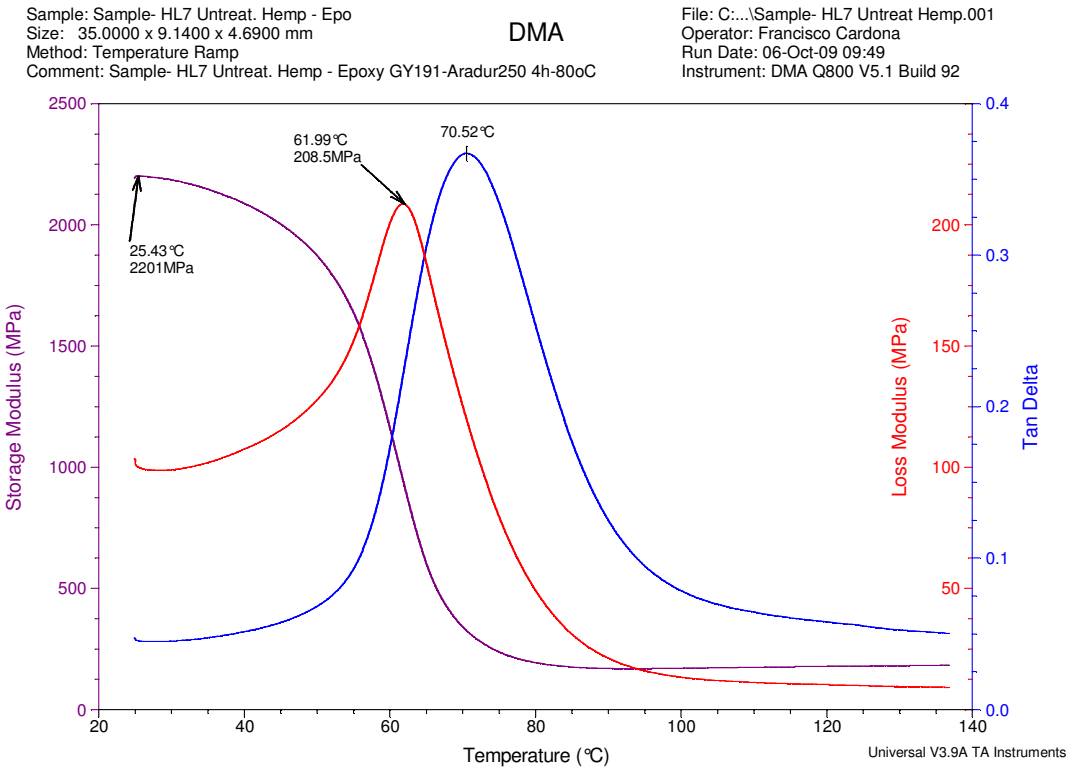


Figure 13 – Example output of DMA

2.3.4 Microscopic Analysis

Microscopic analysis is used to study the fibre-matrix adhesion and the fibre dispersion throughout the matrix. Mwaikambo, Tucker & Clark (*2007*), M Mosiewicki, Borrajo & Aranguren (*2005*) used scanning electron microscopes (SEM) to analyse the fractured surfaces of test specimens and there are many other cases throughout the literature where SEM is used to study various macrostructural characteristics. Microscopic analysis with an optical microscope (Olympus BX41M) will be conducted to characterise the microstructure as having and defects and to quantify the fibre dispersion throughout the matrix. The fibre-matrix interface will also be examined.

2.4 Risk Management in Natural Fibre Composites

2.4.1 Introduction

The consequential effects of this project involve conducting a risk assessment whereby all of the associated risks and safe guards are documented. Risks are encountered throughout and beyond the execution of the project therefore it is important to establish a level of continuing responsibility.

2.4.2 Risk Identification

The primary risks associated with this project can be characterised as sample production, sample shaping, sample testing, housekeeping, and project sustainability. Risks associated with sample preparation entail the handling of natural and glass fibres, epoxy and natural resin, hardeners, and NaOH for chemical treatments.

Sample shaping poses the greatest risk as the samples are cut and polished to size. Throughout this process the operator is subjected to spinning blades and discs, airborne dust particles and high noise levels. Each of these hazards can potentially cause operator injury, both in the short and the long term. The injuries may range from, skin irritation and/or breathing difficulties to lose of appendages.

The testing stage produces risks in the form of operator error and injuries as a result of airborne fragments released as part of the testing process. If the operator is not confident and is not trained in the use of the testing machine, injuries may occur. For example a limb, hand may be crushed due to depressing the wrong button on the machine.

General risks associated with housekeeping are risks involving areas such as slippery floors from spills, clean work areas, trip hazards, and correctly labelled chemicals and equipment.

Project sustainability relates to risks involving the environment and future direct users of this project. Risks to the environment may relate to disposal of chemicals, resin, fibre, and samples. Power usage and particle emissions from testing also are

important and need to be considered. Future direct users of this project are not expected to be exposed to any risks.

2.4.3 Risk Evaluation

The majority of the risks described above represent a low level of risk to any associated persons involved. Sample preparation risks can be characterised as being low risk with the materials used being relatively harmless to the operator if handled correctly. If the materials are handled incorrectly there is a greater potential for injuries to occur.

The highest probability for injury may be encountered throughout the sample shaping stages. The risks associated with mechanical devices such as saws and sander/polishers can be characterised as being minor to moderate. There are possibilities of irreversible injuries to the operator if the machines are incorrectly used. These injuries may be due to breakages of the blades and polishing discs which may cause serious injuries in the form of cuts and amputations of fingers for example. There is a moderate risk of lung damage associated with the high level of dust produced from the polishing process. Eye injuries also represent a minor/moderate risks with regards to flying debris associated with the cutting and polishing of samples.

The testing stage provides a minor probability of injury to the operator as the operator is situated a distance away from the testing machine. The likelihood of injury associated with crushing is unlikely as the testing machine is predominately remotely controlled from a computer station. Injuries associated with flying debris from test samples is also an unlikely event as there are shields in place around the operational components of the testing machine.

Risks associated with housekeeping are also unlikely as the labs are cleaned on a regular basis. Spills are cleaned when they occur and the benches are wiped down once experiments are completed.

Environmental risks are also low as the majority of the materials used for this project are naturally occurring. For example hemp fibres, hemp, linseed and sunflower oils are used. The only materials that may not be able to be recycled are the glass fibres

and the epoxy resins, but the small quantities used throughout the project are unlikely to pose a serious environmental threat.

2.4.4 Risk Control

The risks associated with this project are controlled by utilising the following risk action plan.

1. Do I understand the task that I am about to conduct?
2. Have I been trained to undertake the task?
3. What hazards may be associated with performing this task?
4. What controls can I implement to reduce the risks associated with performing this task?

Once these four questions have been satisfactorily answered the operator is able to safely perform the associated task. All tasks were explained in detail by my supervisors and laboratory technicians before performing the tasks. Training was provided in the form of demonstrations and safety inductions regarding all aspects of the project, such as materials handling, machine operation and the location of fire exits and other associated safety actions.

Before undertaking any task an informal job safety assessment (JSA) was conducted to identify any risks. Controls were then implemented in order to minimise any risks associated with the current task. These controls may consist of wearing appropriate personal protective equipment (PPE) or removing trip hazards for example.

3 Research Design and Methodology

3.1 Introduction

This chapter has been separated into three main sections which describe in detail the materials used, manufacturing and shaping of the test specimens, and mechanical testing and microstructural observations. Manufacturing of the specimens describes in detail, the mixing of the resin, hardener and fibres, chemical treatments of the fibres and the curing process. The sections regarding specimen shaping encompass machining operations, dimensions of test specimens and any expected or encountered specimen defects. The final section regarding testing encompasses the mechanical testing process, DMA and microscopic analysis. The methods used in the manufacturing of the composites were adopted from Dr Francisco Cardona and his associated experience in this field and the CEEFC.

Three main types of samples were manufactured:

1. EVO blends - ELO, ESFO and EHO
    a. with different percentage blends – 0%, 10%, 20%, 30%, 40%
2. Fibre weight % – 1% to 7%
3. Fibre treatment – Alkali treatment

3.2 Materials

This project used materials that were directly relevant to the materials and processes reviewed in the literature. Epoxidised vegetable resins, synthetic epoxies and hardeners were used in conjunction with glass fibres and natural fibres and NaOH.

3.2.1 Resins Used in Project

Both commercially available and laboratory synthesised epoxidised plant-oil based resins are used and compared in this project. The three types of resins are all manufactured from renewable plant oils, specifically, Linseed oil, Sunflower oil, and Hemp oil. These oils were chosen because they are easily obtainable and the

feedstocks are currently being grown in QLD or are able to be grown in QLD in the future.

The commercial epoxidised Linseed oil (ELO) used in this project was manufactured by Pasthall and it displayed a degree of epoxidisation of 82.5%. The epoxidised Sunflower oil (ESFO) and the epoxidised Hemp oil (EHO) were manufactured and optimised at the Centre of Excellence in Engineering Fibre Composites (CEEFC) by Mr Tyson Cooney. The QLD based oils were synthesised by an epoxidisation reactor (Mettler Toleda Labmax). The epoxidised oil resins provided for use in the project were of varying degrees of epoxidisation as they were being optimised constantly throughout the lifecycle of this project. The reactor used in the synthesis of the resin for this project can be seen in figure 14.

Figure 14 - Mettler Toleda Labmax used in synthesis of resin

A commercial petro-chemical based epoxy resin in the form of Araldite GY-191 was used throughout this project as both a control sample and in blended form with the bio-resin. Araldite GY-191 is a modified epoxy resin that is a light yellow clear liquid with a density of 1.10-1.15 g/cm^3 and a dynamic viscosity of 600-900 *MPa.s*.

3.2.2 Catalyst/Hardener

The hardeners used in this project are Hyrez-B and Aradur 250. Hyrez-B is a mixture of different hardeners that was developed at the Centre of Excellence in Engineered Fibre Composites (CEEFC). It exhibits a higher degree of cross linking and reaction sites compared with Aradur 250. Aradur 250 is a low viscosity polyamidoamine hardener that is a clear coloured liquid. It exhibits a density of 0.95 g/cm^3 and a dynamic viscosity of 400-700 *MPa.s*.

3.2.3 Fibres

Hemp fibre was used throughout this project and was sourced from Ecofibre. Two types of hemp fibre were used, short hemp fibres (figure 15) and raw long hemp fibres (figure 16).

Figure 15 - Short hemp fibre

Figure 16 - Long raw hemp fibre

The short hemp fibre was bleached and was used for the randomly orientated samples and the long raw hemp fibre was used in the unidirectional hand laid composite samples to enable a comparison with unidirectional glass fibre composites to be conducted.

3.2.4 Cost of Materials

The costs of the most utilised materials are provided in table 4 below. It can be seen from table 4 that using naturally occurring ingredients is less expensive than using traditional synthetic constituents.

Table 4 - Costs of the most utilised materials

Material	Cost
Hemp Oil	$5/L
Linseed Oil	$5/L
GY-191	$10/L
Aradur 250	$14/L
Hyrez-B	$12/L
Hemp Fibre	$2/kg
Glass Fibre Mat	$24/kg

3.3 Manufacture of Test Specimens

The manufacture of the fibre composite specimens for use in testing consists of mixing the resin, hardener and fibres in various quantities to obtain the desired composite. Some composites used untreated hemp fibres and others used hemp fibres that had been alkali treated. All of the fibre composites used in stage one of the testing process were random, discontinuous hemp fibres. Stage two samples involved the manufacturing of unidirectional long hemp and glass fibre composites.

3.3.1 Mixing of Resin, Hardener and Fibre

The fibre composites are created by mixing specific quantities of resin, hardener and hemp fibre to obtain the desired composite. Appendix B contains the tables associated with the different quantities and types of resin, hardener and fibre used in the manufacturing of the different samples.

To accurately ensure the correct quantities of the constituents are used an empty plastic container is placed on the scales and the scales are then tared. The epoxy resin and EVO if required is then added to the container by a plastic spoon. The plastic spoon is used to allow precise control of the quantity added to the container. If using an epoxy and EVO mix, the epoxy was added first and the EVO added afterwards. After the epoxy/EVO was added the hardener in the form of either Hyrez-B or Aradur was added to the mixture. Once again a plastic spoon was used to transfer the hardener accurately to the mixture. The scales were tared after each constituent was added, thereby ensuring accuracy.

For the randomly orientated short fibre composite samples after all of the ingredients had been added, the mixture was hand mixed by using a plastic spoon. The mixture was thoroughly mixed for a period of three minutes to ensure uniformity and to remove any air bubbles. The weight of fibres required for each mixture was measured and then added and stirred through the mixture.

The mixture in the plastic container was then lightly compressed by the addition of another plastic container on top of the mixture. This was necessary to compact the fibres and to ensure a superior product. PPE was worn at all times during the mixing process in the form of glasses, gloves and a mask.

The mould utilised for the manufacture of the randomly orientated short fibre composites was a simple polypropylene plastic container. These containers were used as they are inexpensive, readily available and can be subjected to the necessary curing temperatures without degradation occurring. The type of container used as the mould can be seen below in figure 17.

Figure 17 - Mould used for sample manufacture

The unidirectional hand laid fibre composites were made by separating the fibre bundles into individual fibres and aligning in a unidirectional manner. The fibres were weighed to be 21.5g for the hemp fibre and 30g for the glass fibre samples. The resin/EVO was prepared in the same method as the randomly orientated short fibre samples. Sheet metal trays were used as the moulds of the composite and a top was used to compress the composite. One layer of fibre (10.5g hemp and 15g for glass) was laid in the mould on top of a small layer of resin. Resin was added to the layer of fibre and the layer was hand rolled with a roller to achieve sufficient resin coverage of the fibre. The process was then repeated with the final layer of fibres. The top was then placed on the mould to provide compaction of the composite. Two unidirectional hand laid fibre composite samples in moulds can be observed below in figure 18.

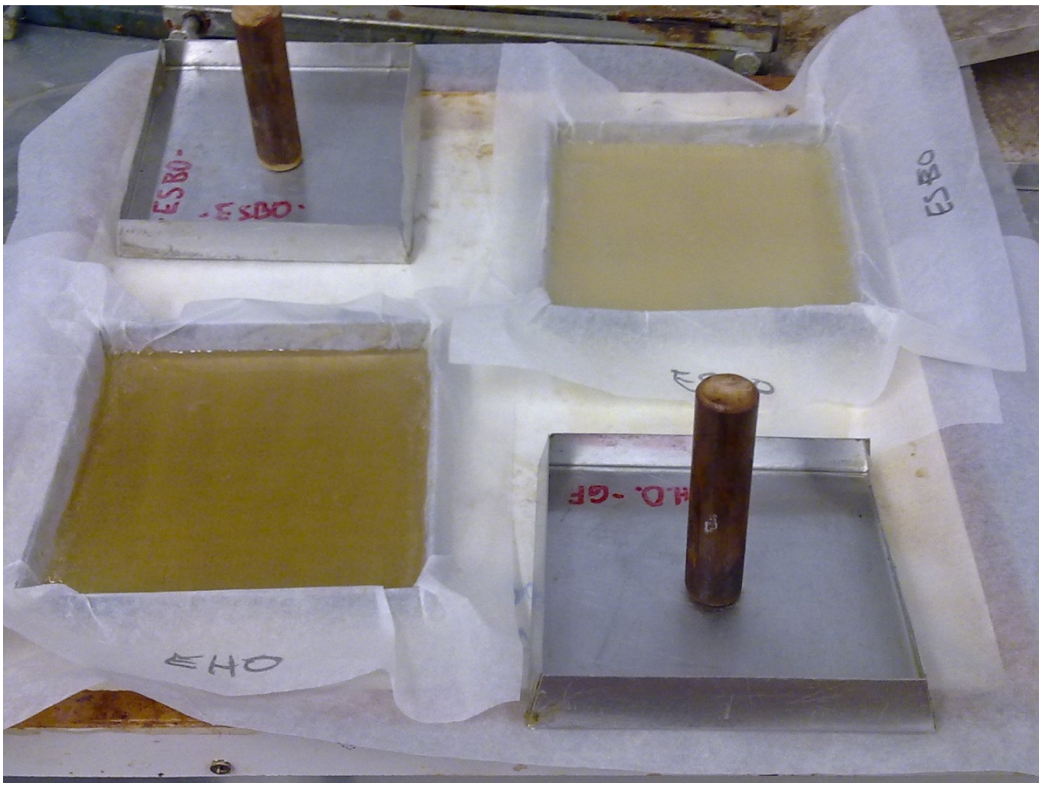


Figure 18 - Unidirectional hand laid fibre composite samples

3.3.2 Chemical Treatment of Fibre

Investigation of the performance of chemical modification of the hemp fibres was performed. The chemically modified fibres were compared with unmodified hemp fibres. The chemical modification chosen for this experiment was an alkali treatment using NaOH. Testing also focused on comparing the affect of different concentrations of the alkali treatment on the material properties of the samples.

To perform the alkali treatment, fibres at a specific weight were placed into individual plastic containers. NaOH powder was carefully weighed and placed into a clean glass beaker. Water was weighed depending on the required concentration of the alkali solution. The water was added to the alkali powder and was mixed together to ensure the NaOH was completely dissolved. The NaOH solution was then added to the fibres and then mixed together to ensure complete coverage of the fibres. The fibres were then left to sit for one hour to allow the chemical treatment to occur. The fibres were then drained of the NaOH solution and were thoroughly washed with water three times. This ensures that the chemical reaction ceases by

way of neutralising the reaction. To ensure the fibres were completely dried they were left to air dry for six hours and then placed into a oven at $80^{\circ}C$ for four hours.

3.3.3 Curing

Curing of the fibre composites was performed in two stages, initial curing and post curing. Once the manufacturing of the fibre composite samples was complete initial curing was undertaking at room temperature for a period that was adequate for the exothermic reaction to occur. This initial curing was performed for a period of 3-5 hours. The fibre composites were then post cured in an oven. The samples were post cured at $80^{\circ}C$ for 4 hours. Figure 19 displays the oven used in the curing process.

Figure 19 - Oven used for post curing

3.3.4 Specimen Shaping

The randomly orientated short fibre composite samples were removed from the moulds and samples for testing were cut using a wet saw and polished using a rotating sander. The bottom of the fibre composites were polished to ensure a flat, smooth surface. The fibre composite was then placed into position on the wet saw and cuts were performed. Figure 20 depicts the top view of a fibre composite with the performed cuts visible.

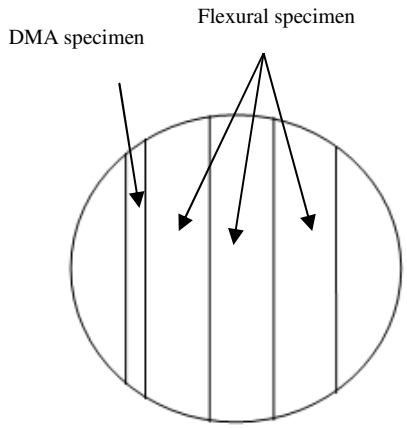


Figure 20 –Top view of a fibre composite with the performed cuts visible

The cuts produce one DMA specimen with a width of approximately 4*mm* – 4.5*mm* and three flexural test specimens with an approximate width of 10.6*mm* – 11*mm*. After the cutting procedure the specimens were dried and wiped down for the sanding/polishing process.

The specimens were then polished on a rotating sander to the final approximate dimensions. The approximate dimensions of the samples can be seen below in figure 21.

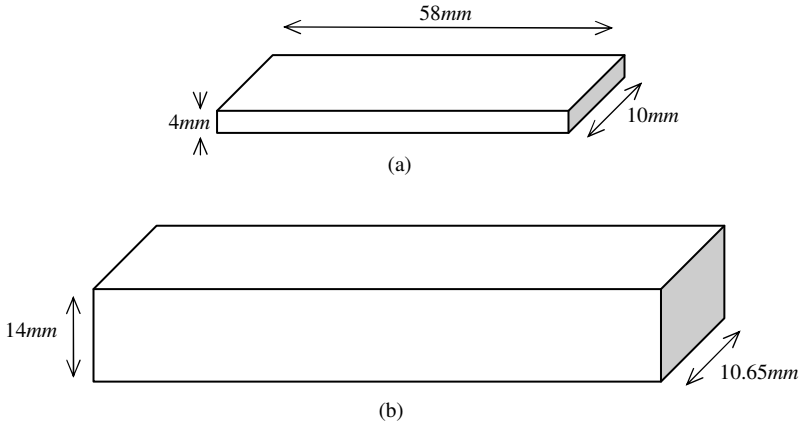


Figure 21 – Dimensions of the samples (a) DMA sample, (b) Flexural sample

Appropriate PPE was worn in the form of safety glasses, dust mask, earmuffs and safety boots. Barter cream was also applied before any cutting or polishing operations to prevent skin irritation. It was also necessary to use the dust extraction system to alleviate any airborne particles.

The unidirectional hand laid fibre composites were cut in the same manner with the same equipment to the same dimensions; however impact testing samples were cut to the standard size.

3.3.5 Defects

There were several defects encountered with the specimens throughout the various manufacturing phases. A problem was initially experienced with the first batch of fibre composites whereby the author was inexperienced with regards to the mixing process. This problem can be attributed to the fibre composite mixture not having the air bubbles removed satisfactorily.

Defects also occurred throughout the shaping process. The DMA samples were sometimes cut to an inadequate width and subsequently had to be recut. Some DMA samples, particular samples with high levels of EVO were difficult to polish as they were soft and ductile due to the plasticising affect of EVO. This lead to some samples being damaged during the sanding process. Once again the samples had to be remade.

3.4 Testing

The testing for this project consisted of flexural testing, impact testing and DMA. Results from the tests were analysed. Further investigation in the form of microscopic analysis was used to study the microstructure of the composites by studying the fibre dispersion throughout the matrix.

3.4.1Flexural Testing

The flexural tests are conducted at CEEFC using a universal testing machine MTS RT/10 at a 10kN couple. TESTWORK 4 is the software used to control the testing. Tests were performed at room temperature, at a crosshead speed of *4mm/min* using the three-point bending setting of the MTS RT/10. Figure 22 displays the MTS RT/10 testing machine and the computer control station.

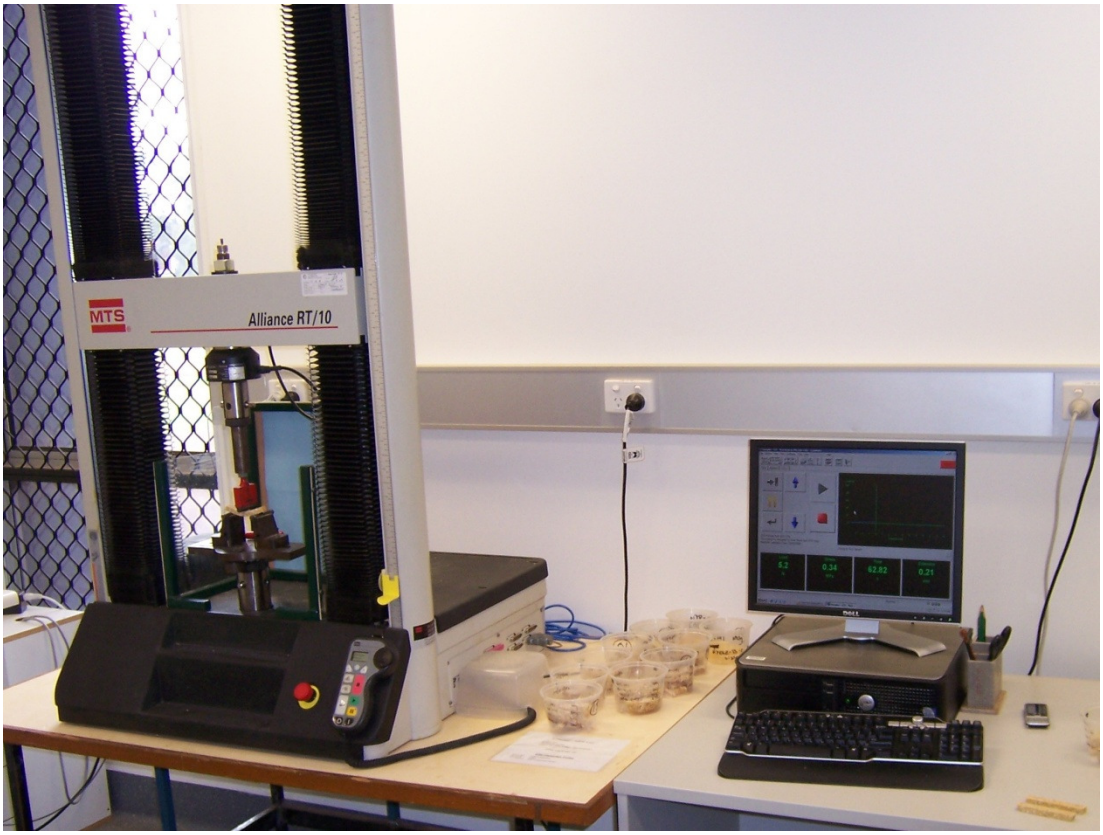


Figure 22 – MTS R/10 testing machine and computer control station

Testing Procedure

The testing procedure for conducting the flexural tests involves setting up the MTS RT/10 for flexural testing. ISO 178 is used as the basis for the flexural tests; this standard is selected from the testing options in the testing software. A support span of 64*mm* is used for the flexural tests. Inputs such as specimen dimensions, crosshead speed, were then entered into the testing program. The test specimen is then positioned parallel onto the supports of the machine. The crosshead is then lowered to a position that is approximately 1*mm* above the test specimen. After the specimen and the crosshead are in position the test is started. A specimen undergoing testing can be seen below in figure 23.

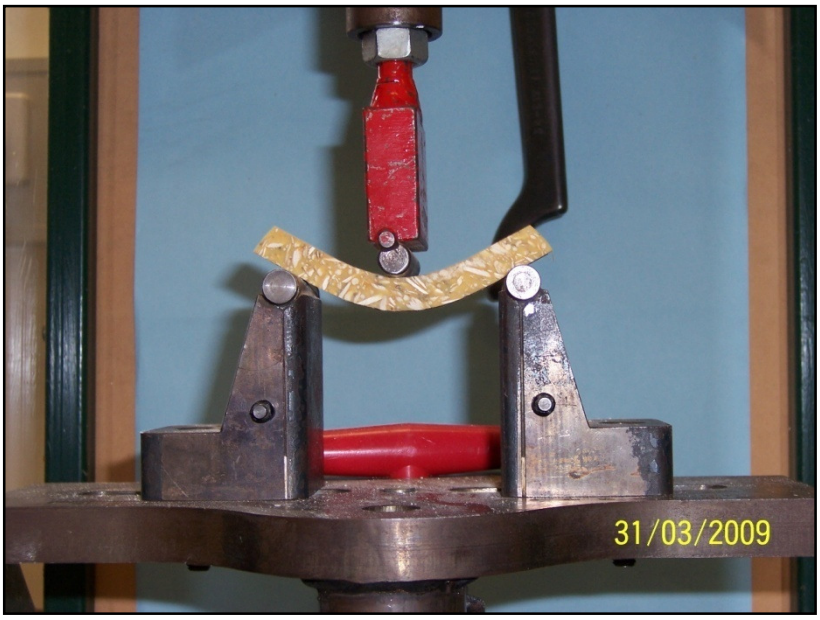


Figure 23 – Specimen undergoing testing

Data Output

Data is outputted in the form a stress strain plot and tabulated results. The tabulated results contain information such as flexural modulus, flexural strain, and flexural stress. Please refer to appendix C for the data output from flexural testing.

3.4.2 Impact Testing

Charpy impact tests were used to quantify the total impact energy of the unidirectional hand laid composites. International standard ISO 179-2 was used as

the basis for testing procedure. The machine used for testing is an Instron Dynatup M14-15162 Impulse Impact Testing System. Figure 24 shows the impact testing machine.

Figure 24 - Instron Dynatup M14-15162 Impulse Impact Testing System used in impact tests

Figure 25 displays a sample plot of an impact test. From the figure the yellow line can be seen to correspond with impact energy. The complete data output including plots can be seen in appendix D.

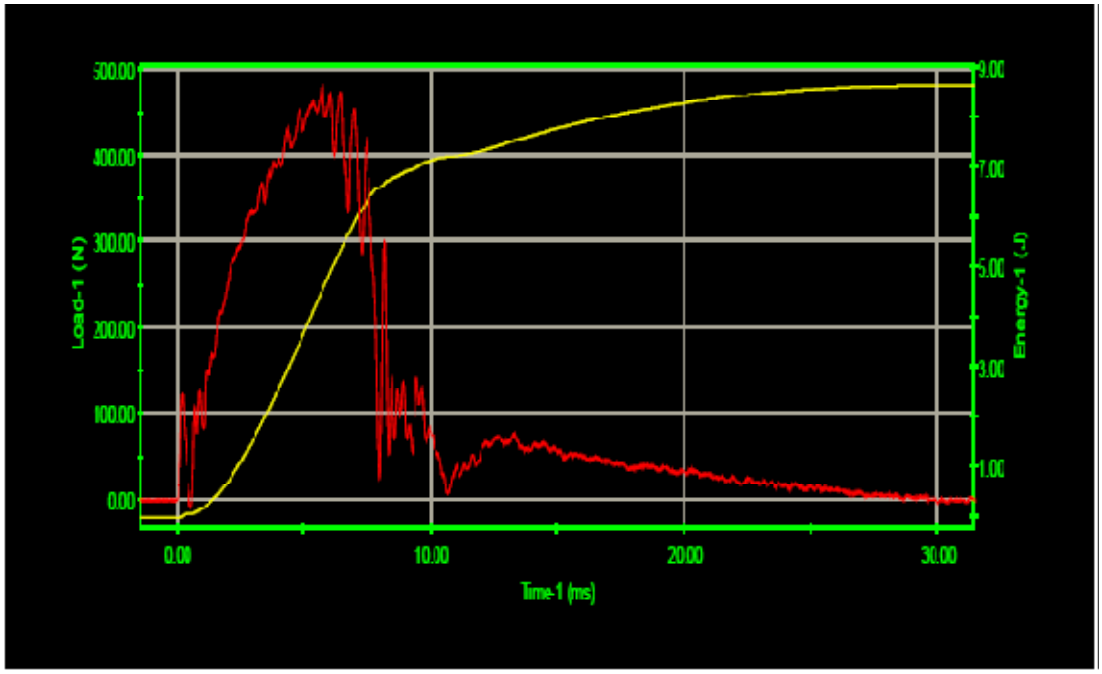
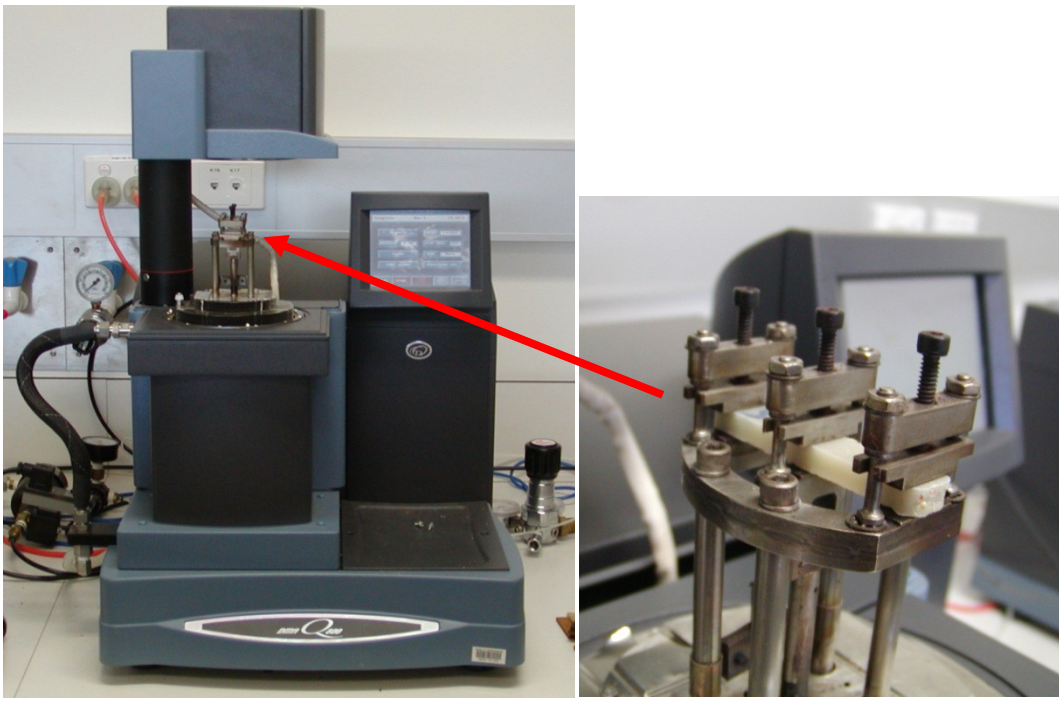


Figure 25 - Sample plot of an impact test

3.4.3 Dynamic Mechanical Analysis

DMA is used to ascertain the thermal and mechanical properties of the fibre composite specimens. The DMA machine used throughout the testing is a TA instruments Q800 which can be seen below in figure 26 (a) and 26 (b). Specimens for the test were cut and polished to approximate size of $58mm \times 10mm \times 4mm$. Tests were performed using the dual cantilever mode with a temperature change of $3^{\circ}C\ /m$ with a fixed frequency of $1Hz$. The sample was mounted into position and secured at both ends and flexed in the middle. The test was then started and the mechanical properties of the specimen were recorded. Please refer to appendix E for the data output from DMA.



(a) (b)

Figure 26 - (a) TA Instruments Q800 DMA machine (b) Test specimen positioned in dual cantilever arrangement

3.4.4 Optical Microscope Sample Preparation

Samples were prepared for the optical microscopy by sectioning and polishing with different grades of polishing paper. Course polishing was initially performed followed by finer grade polishing to achieve a flat reflective surface. Samples were examined with an Olympus BX41M optical microscope with image recording capabilities. The fibre-matrix interface was examined to determine the effect of alkali treatment on the fibre-matrix adhesion. Magnification from 50X to 200X was used to obtain the images. Figure 27 shows the microscope used in the analysis.

Figure 27 - Olympus BX41M optical microscope used in analysis

3.5 Resource Analysis

All required resources for the successful completion of this project are available for use at the CEEFC facilities. CEEFC is a commercial research centre with ties to USQ and therefore the facilities are more than satisfactory for the successful completion of this project.

4 Results and Discussion

4.1 Introduction

This chapter analyses and discusses the results obtained from the associated flexural, impact, DMA, and microscopic testing. The presentation of these results will commence with randomly orientated short fibre composites which consists of flexural properties (stress, modulus, and strain at break,) as a function of EVO percentage, fibre weight and NaOH concentration. The flexural and impact properties of hand laid unidirectional long fibre composites will then be analysed. The final sections will focus on the results of DMA and microscopic analysis.

4.2 Random Short Fibre Composites

4.2.1 Effect of EVO Blending on Flexural Properties

The following table and graphs display the relationship between peak flexural stress, flexural modulus and flexural strain as a function of EVO percentage. The flexural properties are important because they identify the flexibility and the bending resistance of the fibre composites. Table 5 displays the peak flexural stress, flexural modulus and flexural strain of fibre composites with different types and percentages of EVO with 4% wt hemp fibre. Figure 28 below shows an example stress strain output from flexural testing.

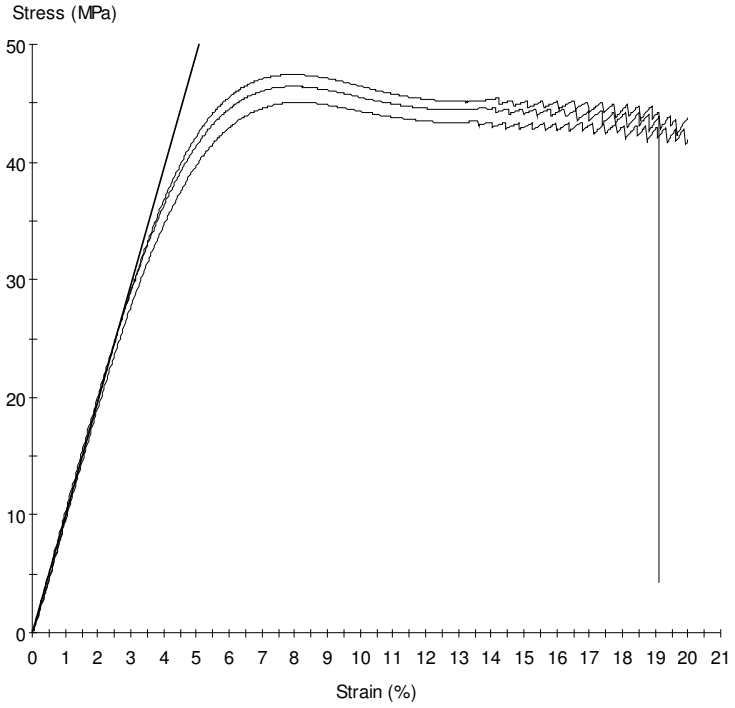


Figure 28 - Example flexural test output

Table 5 - Flexural properties of randomly orientated short fibre composites vs. % EVO

Type of Fibre Composite	**Peak flexural stress (MPa)**					**Flexural modulus (MPa)**					**Flexural strain (%)**				
	% EVO					**% EVO**					**% EVO**				
	0	10	20	30	40	0	10	20	30	40	0	10	20	30	40
Neat Epoxy	46.3	-	-	-	-	970	-	-	-	-	19.1	-	-	-	-
Hemp Fibre/Epoxy	-	38.1	-	-	-	-	1150	-	-	-	-	4.1	-	-	-
Hemp Fibre/Epoxy + ELO	-	24.7	10.23	3.6	3.7	-	594	138	34	40	-	13.5	-	-	-
Hemp Fibre/Epoxy + ESFO	-	26.7	23.1	21.0	18.1	-	655	548	511	439	-	11.2	12.2	12.2	10.4
Hemp Fibre/Epoxy + EHO	-	30.3	11.8	4.0	1.2	-	747	206	42	9	-	9.7	-	-	-

The data for the flexural properties of the randomly orientated short hemp fibre composites as a function of EVO percentage from table 5 has been summarised and the relationship can be seen more clearly in figures 29, 30 and 31 below.

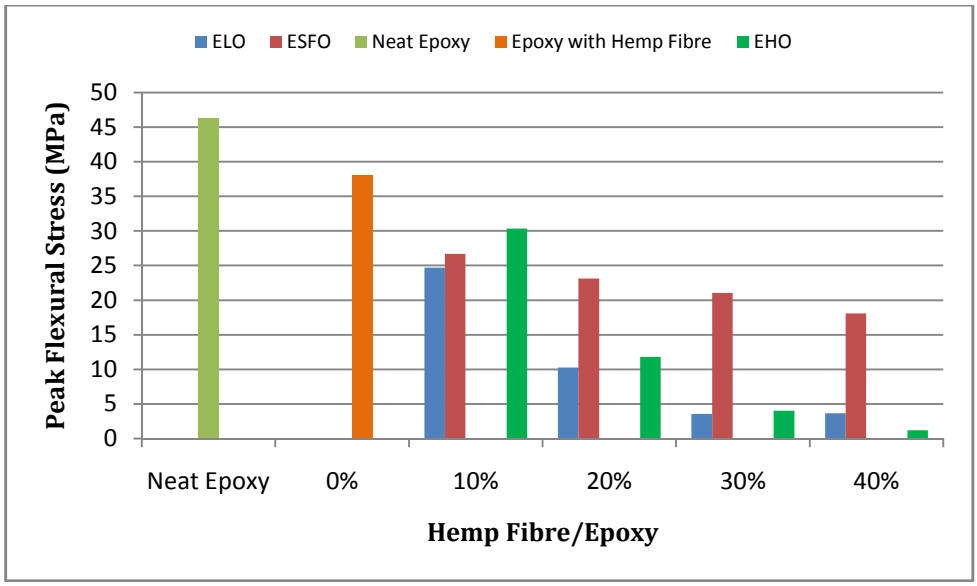


Figure 29 - Peak flexural stress vs. % EVO

The peak flexural stress represents the highest stress experienced by the fibre composite sample at the moment of rupture. From figure 29 the neat epoxy displayed the highest peak flexural stress of 46.31MPa with the epoxy containing hemp fibre displaying a value of 38.06MPa. A decrease in peak flexural stress is observed with the addition of the short hemp fibre to the epoxy. This decrease is due to the non-uniform nature of the hemp fibre dispersion throughout the matrix causing areas of high strength offset by regions of low strength throughout the composite.

When EVO is blended into the epoxy there is a noticeable decrease in peak flexural stress as the EVO percentage increases. Peak flexural stress reduction is summarised below in table 6. A reduction in the peak flexural stress of the fibre composites was observed with results ranging from 20% for the 10% EHO to 97% for the 40% EHO compared to the epoxy composite. The ESFO displayed values that were consistently higher than both the ELO and the EHO.

Table 6 - Flexural stress/modulus reduction vs. % EVO

Type of Fibre Composite	**Peak flexural stress (MPa)**				**Flexural modulus (MPa)**			
	% EVO				**% EVO**			
	10	**20**	**30**	**40**	**10**	**20**	**30**	**40**
Hemp Fibre/Epoxy +ELO	35	73	91	90	48	88	97	97
Hemp Fibre/Epoxy + ESFO	30	39	45	52	43	52	56	62
Hemp Fibre/Epoxy +EHO	20	69	89	97	35	82	96	99

The relationship between the flexural modulus and the EVO percentage can be seen below in figure 30. Flexural modulus describes the stiffness of the material and is an important characteristic when flexibility is required in the composite design. From figure 30 the epoxy containing hemp fibre displayed the highest flexural modulus of 1150MPa. As the EVO percentage increases the flexural modulus decreases for all three EVO composites. This decrease in flexural modulus is due to the plasticising effect through the addition of the EVO. The flexural modulus of the fibre composites showed a reduction ranging from 35% for the 10% EHO to 99% for the 40% EHO. The ESFO displayed values that were consistently higher than both the ELO and the EHO. Flexural modulus reduction values are summarised above in table 6.

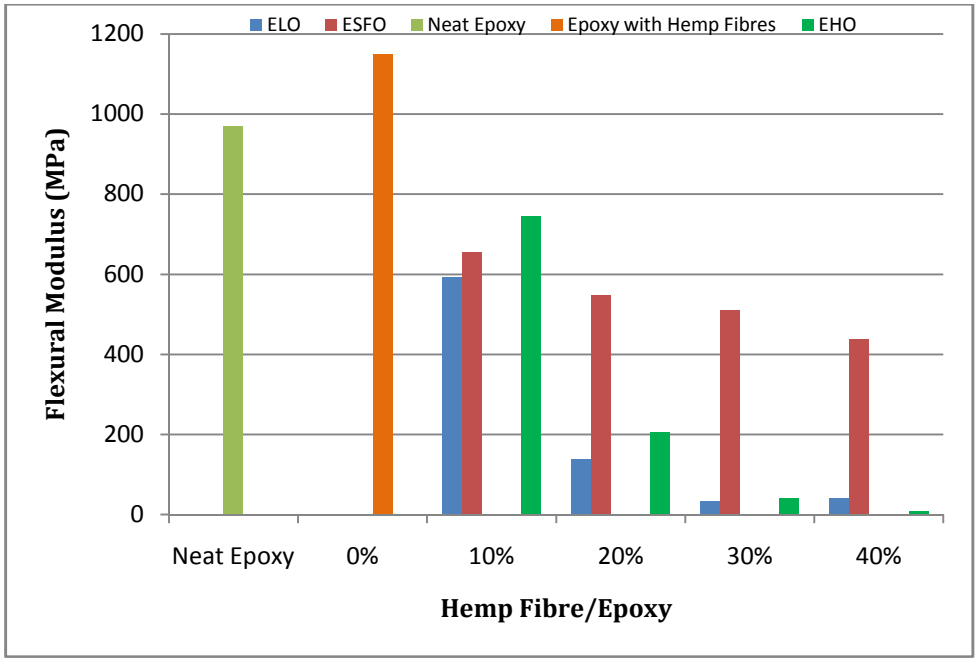


Figure 30 - Flexural modulus vs. % EVO

The strain at break characteristics of the fibre composites with different quantities and types of EVO can be seen below in figure 31. There is limited data available due to the low flexural modulus of the samples containing EVO. The ESFO was the only composite type with consistent strain at break results.

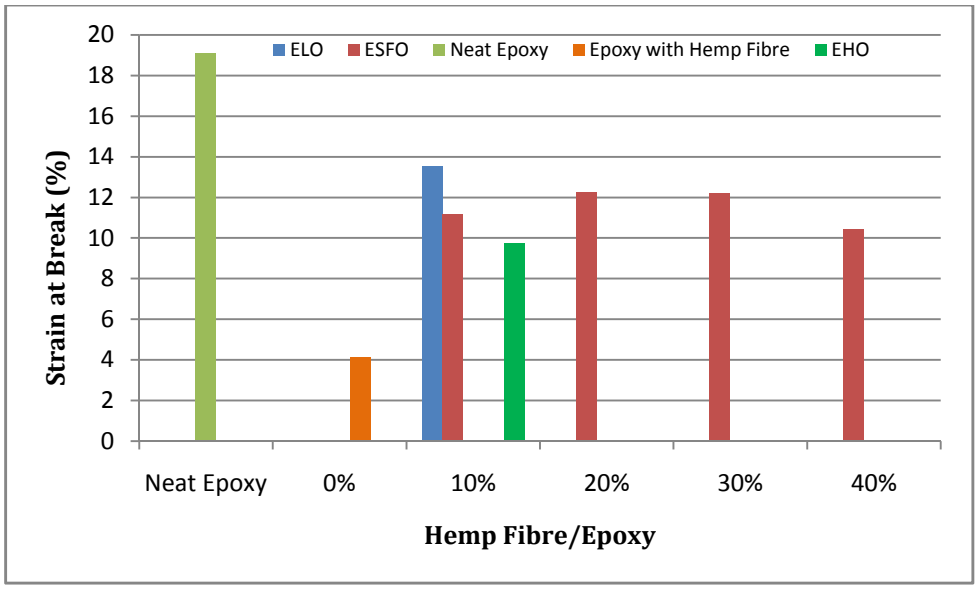


Figure 31 - Strain at break vs. % EVO

4.2.2 Effect of Fibre Weight on Flexural Properties

The flexural properties, in particular peak flexural stress and flexural modulus as a function of fibre weight were analysed. Samples were made using epoxy containing 20% EHO with varying quantities of randomly orientated short hemp fibre. The results can be seen below in table 7 and figures 32 and 33.

Table 7 - Flexural properties as a function of fibre weight

Flexural Property (MPa)	**Fibre Weight (wt%)**					
	0.5	1	2	3	4	5
Peak Flexural Stress	9.46	9.98	11.49	11.81	11.79	9.92
Flexural Modulus	100	107	139	145	206	143

From figures 32 and 33 below a trend can be seen whereby the flexural properties increase with fibre weight and then decrease after reaching 4 or 5% of fibre weight. The peak flexural stress increases from 9.46MPa at 0.5 wt% of hemp fibre to a maximum value of 11.81MPa at 3 wt% of hemp fibre. It begins to decrease to a value of 9.92MPa obtained at the maximum fibre weight of 5 wt%. The flexural modulus shows a similar trend to the peak flexural stress whereby an increase is observed from a minimum value of 100MPa at 0.5 wt% of hemp fibre through to a maximum value of 206MPa at 4 wt% of hemp fibre. The flexural modulus then

begins to steadily decrease to a value of 143MPa at the maximum 5 wt%. This decrease in flexural properties after 4 wt% of hemp fibre is attributed to the fibre matrix interactions whereby the wettability of the fibre is being compromised leading to a formation of voids at the fibre-matrix interface and ultimately a more porous composite with lower mechanical properties.

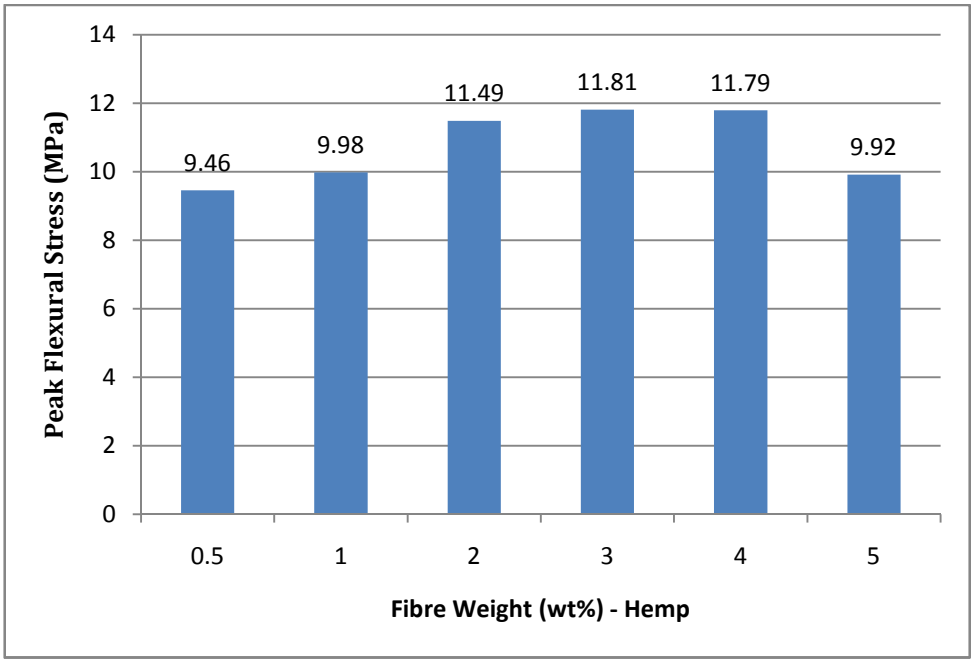


Figure 32 - Peak flexural stress as a function of fibre weight (20% EHO-TC)

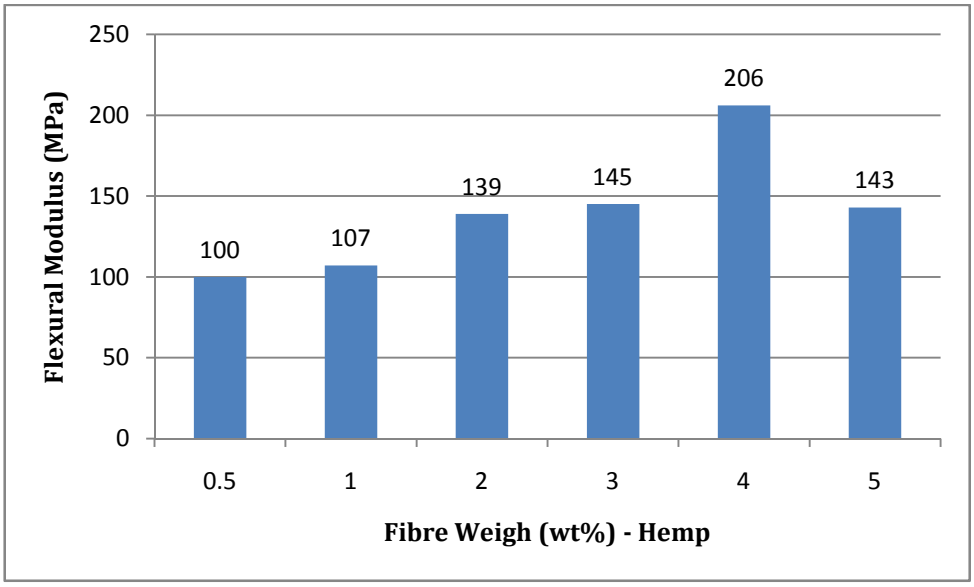


Figure 33 - Flexural modulus as a function of fibre weight

Strain at break was not included in the results as the fibre composite samples were made with 20% EHO which resulted samples with low flexural moduli. Consequently this meant that the strain at break was not present in the samples.

4.2.3 Effect of Alkali Treatment on Flexural Properties

Peak flexural stress, flexural modulus and strain at break as a function of NaOH concentration were analysed. Samples were made using GY-191 epoxy with Aradur 250 as the hardener. The composites contained 5 grams of randomly orientated bleached short hemp fibre. The results can be seen below in table 8 and figures 34, 35 and 36.

Table 8 - Flexural properties as a function of NaOH concentration

Mechanical Property	**NaOH %**				
	0	5	10	15	20
Peak flexural stress (MPa)	38.06	43.59	46.47	47.15	51.03
Flexural modulus (MPa)	1150	1377	1423	1435	1366
Strain at break (%)	4.12	3.59	3.8	3.68	4.52

Figure 34 displays the peak flexural stress as a function of NaOH %. It can be seen that the peak flexural stress increases as the NaOH concentration increases. The lowest value of peak flexural stress of 38.06MPa occurs with the untreated hemp composite and the highest value of 51.03MPa is displayed at the highest NaOH concentration of 20%. This shows an improvement in the peak flexural stress of 34% when compared with the untreated hemp sample.

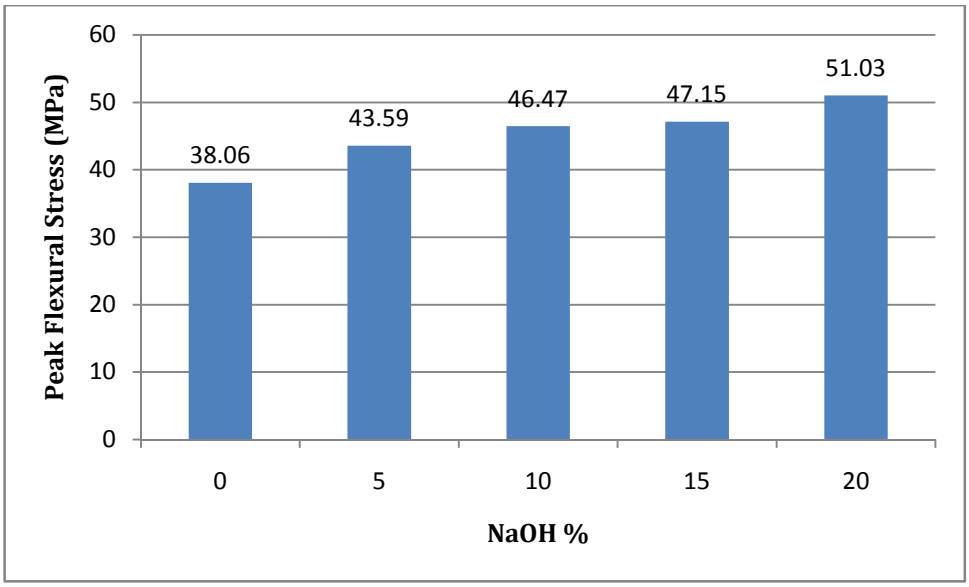


Figure 34 – Peak flexural stress as a function of NaOH concentration

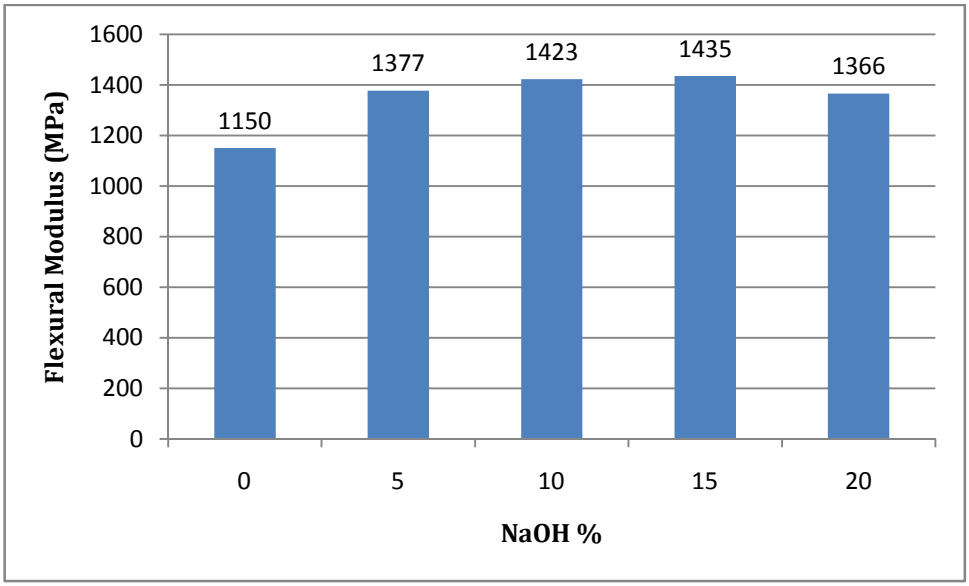


Figure 35 – Flexural modulus as a function of NaOH concentration

The flexural modulus as a function of NaOH concentration can be seen in figure 35. A trend can be seen whereby the flexural modulus increases from 1150MPa at the untreated hemp sample to a maximum value of 1435MPa at a 15% NaOH concentration whereby it then decreases to 1366MPa at 20 % NaOH concentration.

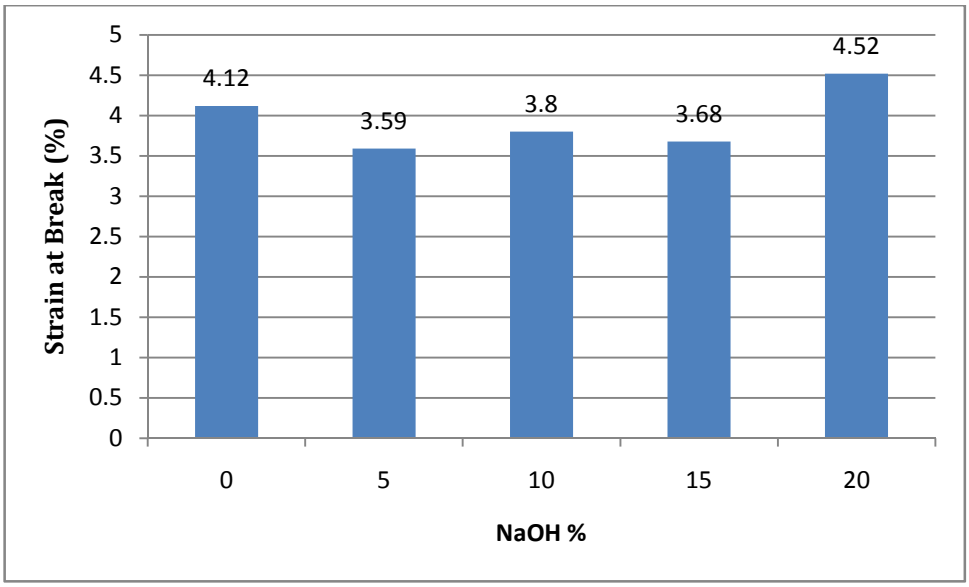


Figure 36 – Strain at break as a function of NaOH concentration

The strain at break characteristics are shown above in figure 36. The untreated hemp sample displays a strain at break value of 4.12%. Alkali treated samples show values ranging from 3.59% at 5% NaOH concentration through to a maximum value of 4.52% at 20% NaOH concentration. The maximum variation in the results is approximately 13% and the minimum variation is approximately 9%.

The improvement in the flexural properties of the composites can be attributed to the alkali treatment. Alkali treatment has improved the fibre-matrix interface and has increased the surface roughness and removed numerous impurities and waxy substances which have in turn resulted in superior mechanical interlocking.

4.3 Unidirectional Long Fibre Composites

4.3.1 Flexural Properties

The flexural properties of unidirectional hand laid hemp fibre composites will be analysed and discussed in this section. The hemp fibres used were untreated, 5% and 10% NaOH treated in a GY-191 epoxy matrix with Aradur 250 being used as the hardener. These were compared with neat resin and glass fibre composites. Table 9 displays the results obtained from flexural testing.

Table 9 - Flexural properties of hand laid UD composites

Composite Type	**Mechanical Property**		
	Peak flexural stress (MPa)	Flexural modulus (MPa)	Strain at break (%)
Neat epoxy	42.5	944	-
Glass fibre	144.4	4230	4.3
UT Hemp fibre	45.2	1693	3.2
5% NaOH	33.7	2000	1.7
10% NaOH	32.5	1263	4

Figures 37 and 38 below, display the peak flexural stress and the flexural modulus respectively for the unidirectional composites. The highest peak flexural stress of 144.38MPa is exhibited by the glass fibre reinforced composite. The untreated hemp fibre composite displays a peak flexural stress of 45.24MPa which is an increase of approximately 6% compared with the neat epoxy sample. The alkali treated hemp fibre composites displayed a reduction of about 25% in peak flexural stress compared with the untreated hemp fibre composite. This result is unexpected as the alkali treatment should increase the flexural properties of the composite by improving the fibre-matrix adhesion at the interface. This demonstrates that the fibre is reinforcing the composite and not simply acting as a filler as is the case for the randomly orientated short fibres. The glass fibre composites displayed a peak flexural stress that is a minimum of 3.2 times larger than the hemp fibre composites.

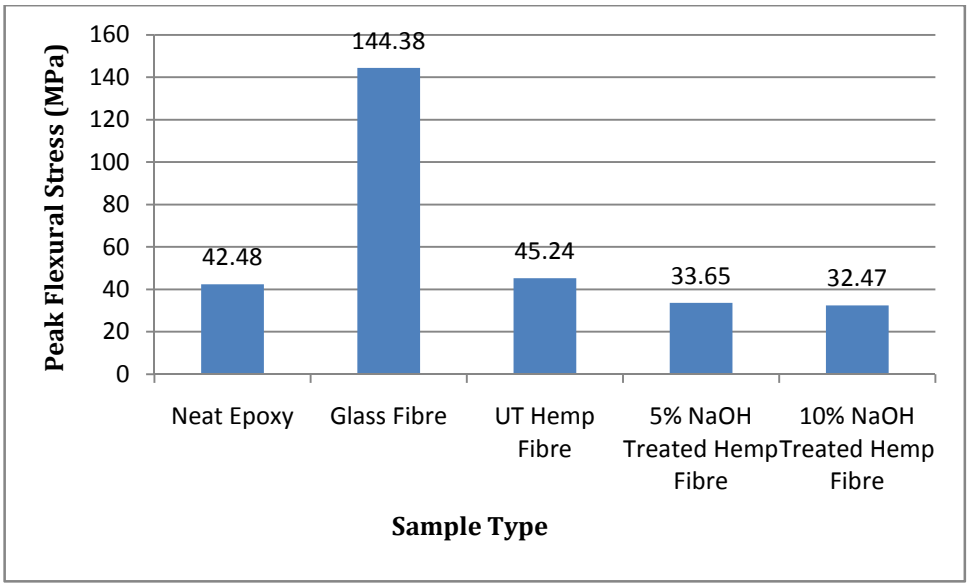


Figure 37 – Peak flexural stress of hand laid UD composites

Fig 38 below, displays the flexural modulus of the unidirectional hand laid composites. The untreated hemp fibre displays a flexural modulus of 1693MPa in comparison with the neat epoxy sample which has a flexural modulus of 944MPa, which represents an increase in flexural modulus of 79%. The alkali treated hemp fibre samples exhibit an increase of 18% (2000MPa) at 5% NaOH concentration and a decrease of 25% (1263MPa) at 10% NaOH concentration. The glass fibre composites displayed a flexural modulus that is a minimum of 2.1 times larger than the hemp fibre composites.

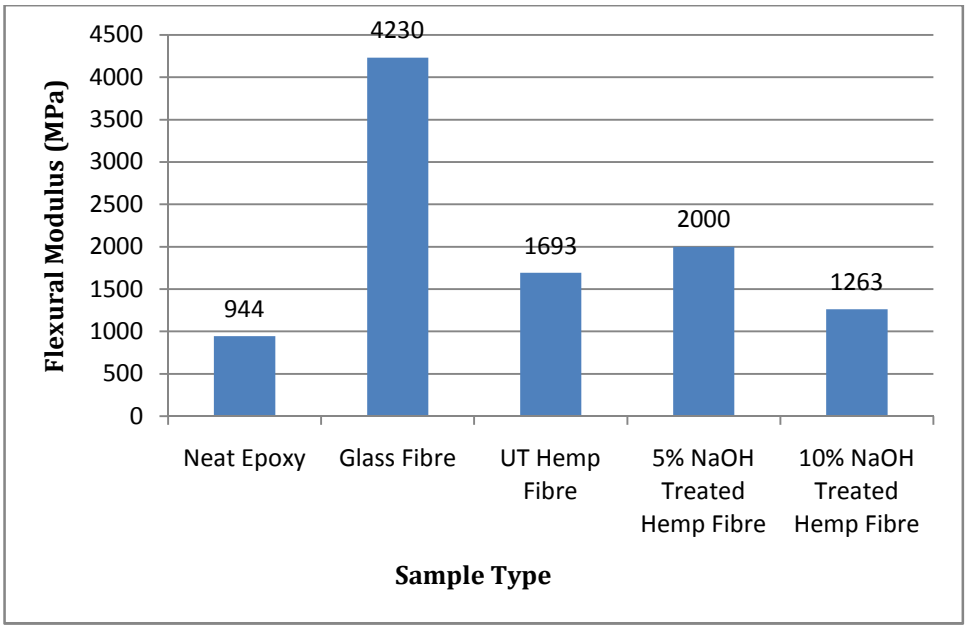


Figure 38 - Flexural modulus of hand laid UD composites

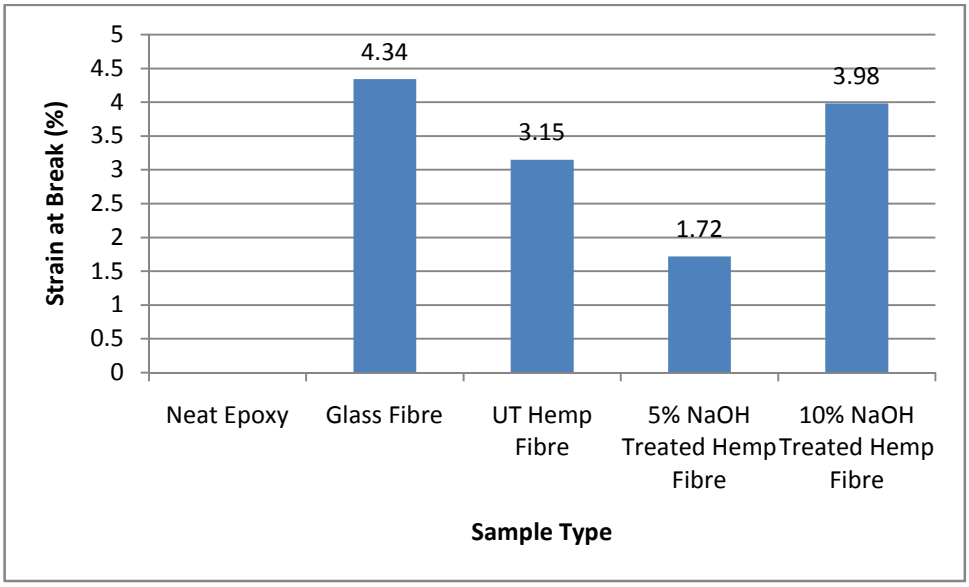


Figure 39 – Stain at break of hand laid UD composites

The strain at break can be observed above in figure 39. From the figure it be seen that there is a difference in the samples of between 8% and 60%. A strain at break of 1.72% was observed for the 5% NaOH treated composite which represented the lowest value aside from the neat epoxy which did not display any strain at break. 3.98% strain at break was also observed for the 10% NaOH treated hemp composite.

It is difficult to quantify any meaningful data from this plot as no real trend can be determined from the results.

4.3.2 Impact Strength

Impact tests were performed on unidirectional hand laid hemp and glass fibre composites and this section analyses the data. The hemp fibres used were untreated, 5% and 10% NaOH treated in a GY-191 epoxy matrix with Aradur 250 being used as the hardener, which are the same parameters as for the flexural tests. Table 10 displays the results obtained from the impact tests.

Table 10 - Impact properties of unidirectional hand laid hemp fibre composites

Composite Type	**Maximum Load (N)**	**Total Impact Energy (J)**
Glass fibre	481.8	8.6242
UT hemp fibre	946.1	1.3705
5% NaOH treated hemp fibre	339.8	1.2451
10% NaOH treated hemp fibre	624.1	0.6608

Figure 40 below shows the results of table 10 in a more easily interpreted way. The lowest value of impact energy of 0.66J occurs at 10% NaOH and the highest value is 8.62J which is displayed by the glass fibre control sample. From the figure it can be seen that there is a reduction in total impact energy for the treated hemp samples of between approximately 9% for the 5% NaOH treated sample to 52% for the 10% NaOH treated sample. These results are consistent with those found in the literature. The glass fibre composites displayed a total impact energy value that is a minimum of 6.3 times larger than the hemp fibre composites.

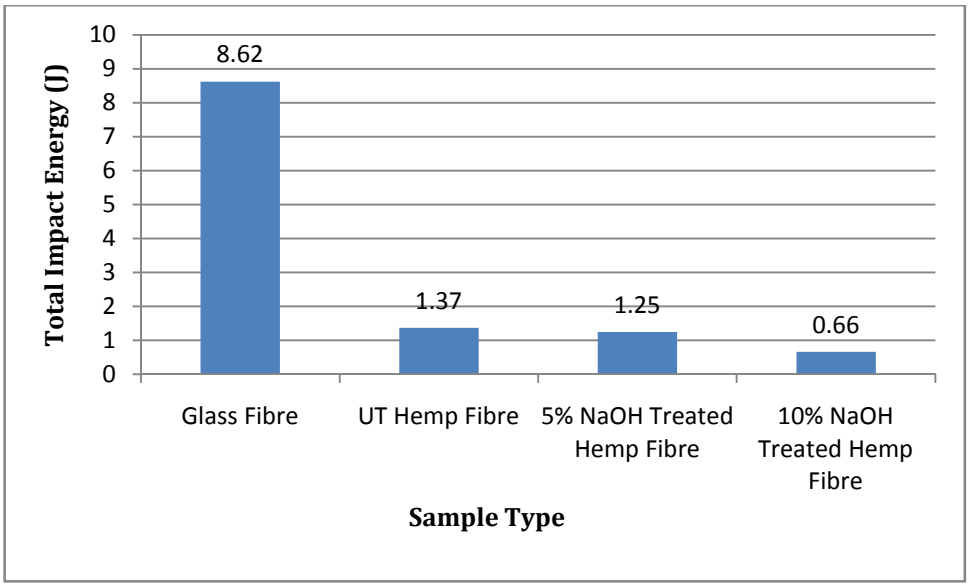


Figure 40 – Total impact energy of hand laid UD hemp composites

4.4 Dynamic Mechanical Analysis (DMA)

The behaviour of the manufactured composite samples under elevated temperatures from DMA will be investigated and analysed within this section. The storage modulus, loss modulus and the glass transition temperatures of the manufactured samples will be the material properties focused on in detail.

4.4.1 Random Short Fibre Composites

The Effect of EVO Blending on DMA

The viscoelastic properties as a function of fibre weight were analysed using DMA. Figure 41 displays a sample DMA plot with the storage modulus shown in purple, loss modulus in red and the glass transition temperature (tan delta) in blue. From the figure the peak storage modulus (2201MPa), peak loss modulus (208.5MPa) and the glass transition temperature ($70.52^{\circ}C$) can be observed. The storage modulus value is associated with the flexural modulus values obtained in the mechanical tests.

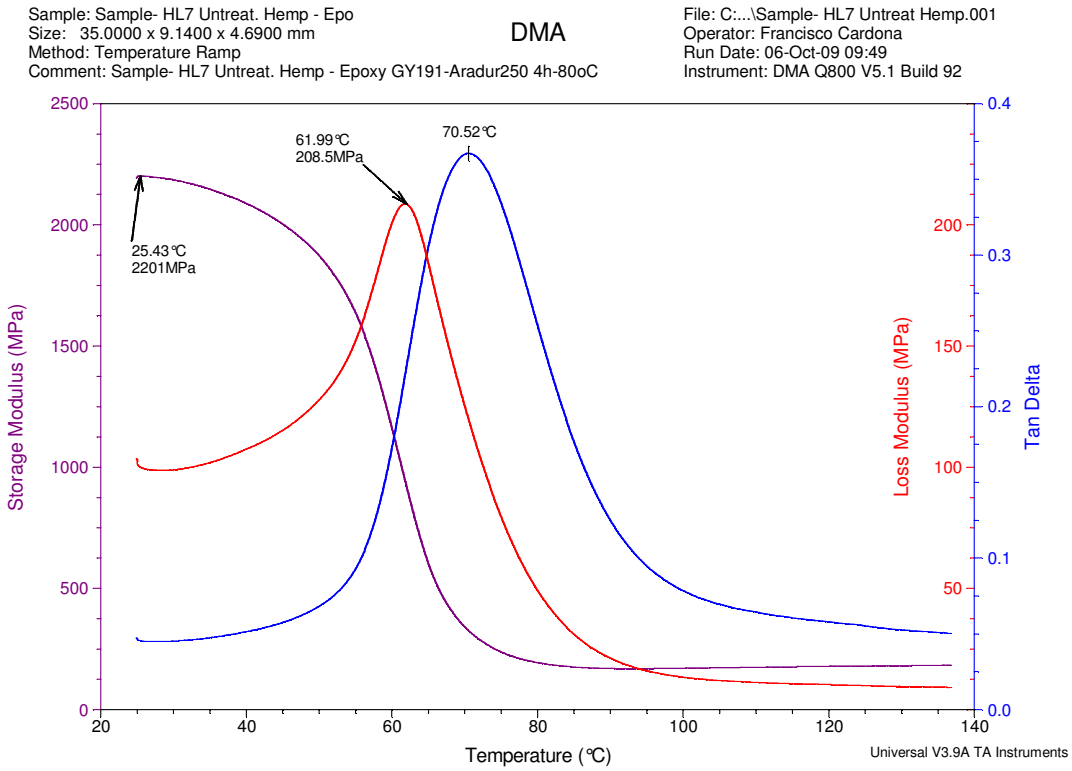


Figure 41 - Sample DMA plot showing storage modulus, loss modulus and glass transition temperature (tan delta)

The following table 11 summarises the results obtained from the DMA. The type of composite is listed with the obtained values of storage modulus, loss modulus, and glass transition temperature. The actual DMA plots are displayed in appendix E. Table 11 illustrates that the maximum storage modulus was 941MPa from the 10% EHO. The minimum storage modulus value occurred at 30% ELO and was 39.45MPa. Samples manufactured from ELO displayed the greatest range of results with the range being 39.45MPa to 904.5MPa. This represents a difference in values of 856.05MPa. ESFO showed the smallest range in values of 565.3MPa to 935.2MPa.

Table 11 - DMA summary from different EVO and % EVO

EVO Type	Storage Modulus (MPa)	Loss Modulus (MPa)	Tan δ (°C)
ELO (%)			
10	904.5	131	58.51
20	309.5	100.8	49.61
30	39.45	26.5	37.83
40	108	51.6	42.56
ESFO (%)			
10	935.2	124.2	61.01
20	575.7	112.5	32.96
30	709.7	89.54	63.14
40	565.3	71.09	64.16
EHO (%)			
10	941	941	60.31
20	301.9	301.9	53.15
30	133	133	44.42
40	60.37	60.37	36.24

A trend was observed whereby the storage modulus decreased when the percentage of EVO increased with the exception of 30% ELO and 30% EHO. This trend can be seen below in figure 42.

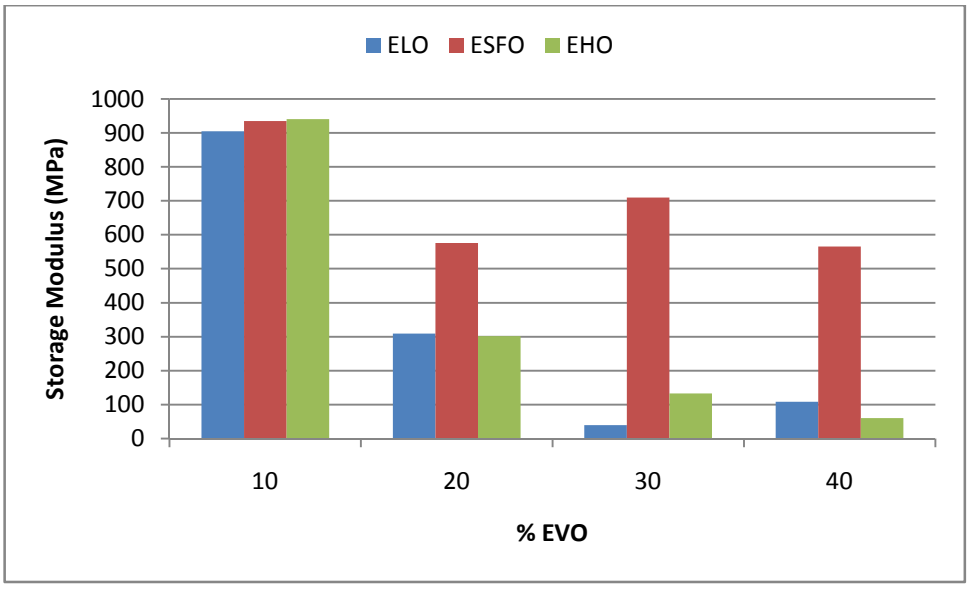


Figure 42 - Storage Modulus as a function of % EVO

Table 11 shows the maximum loss modulus to be 301.9MPa from the 20% EHO with the minimum storage modulus value of 26.5MPa occurring at 30% ELO. Samples manufactured from ELO displayed the highest range of results with the range being 60.37MPa to 301.9MPa. This represents a difference in values of 241.53MPa. The lowest range in values was observed from the ESFO with a range of 124.2MPa to 71.9MPa. A trend was observed whereby the loss modulus decreased when the percentage of EVO increased with the exception of 40% ELO. This trend can be observed more easily below in figure 43. It can be observed that there is a marked reduction in storage modulus for both the ELO and EHO. This is in contrast with the ESFO which has displayed unexpected results whereby the reduction is minimal.

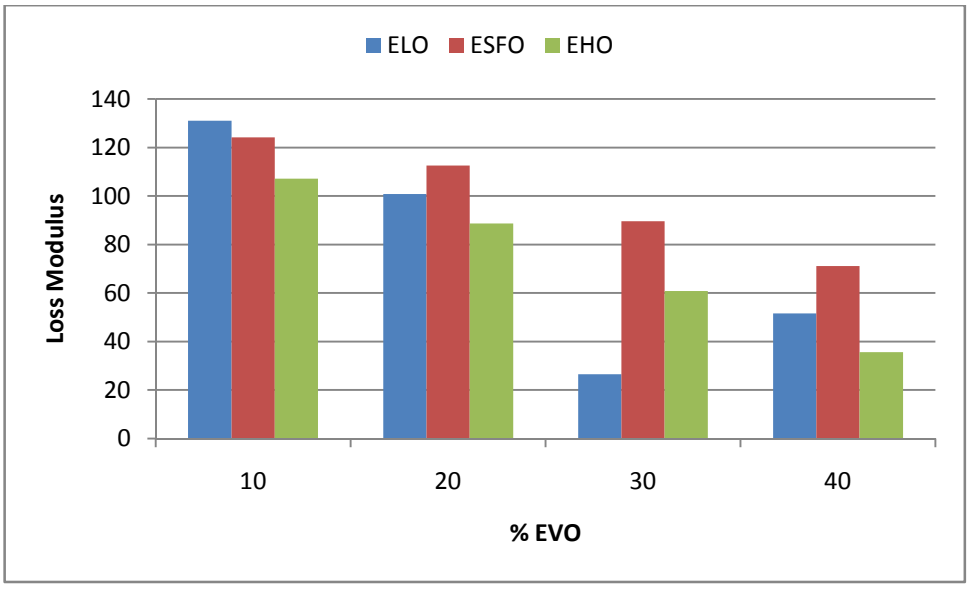


Figure 43 - Loss modulus as a function of % EVO

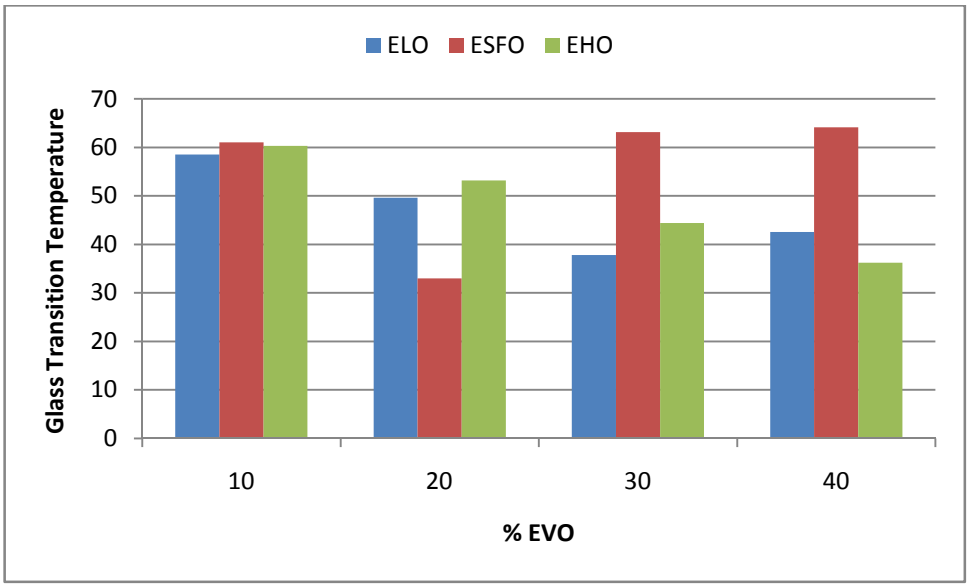


Figure 44 - Glass transition temperature as a function of % EVO

Table 11 and figure 44 shows the glass transition temperature as a function of % EVO. The highest glass transition temperature was 64.16$^{\circ}C$ at 40% ESFO. The lowest glass transition temperature was 32.96$^{\circ}C$ at 20% ESFO. Samples manufactured from ELO displayed the highest range of results with the range being 32.96$^{\circ}C$ to 64.16$^{\circ}C$. This represents a temperature difference of 31.2$^{\circ}C$. The lowest range in values (observed from the ELO) ranged from 37.83$^{\circ}C$ to 58.51$^{\circ}C$.

The average glass transition temperatures were 47.1°C , 55.3°C , and 48.5°C for the ELO, ESFO and the EHO respectively.

Effect of Fibre Weight on DMA

The viscoelastic properties as a function of fibre weight were analysed using DMA. Samples were made using epoxy containing 20% EHO with varying quantities of randomly orientated short bleached hemp fibre. The results can be seen below in table 12.

Table 12 - Viscoelastic properties of samples as a function of fibre weight

Hemp Fibre (wt%)	**Storage Modulus (MPa)**	**Loss Modulus (MPa)**	**Tan δ (°C)**
0.5	284.7	90.72	52.22
1	262.3	87.94	52.27
2	335.6	99.65	52
3	350.2	100.1	52.12
4	301.9	88.73	53.15
5	312.3	90.01	52.14

Storage modulus values ranged from a minimum of 262.3MPa for the sample made with 1 wt% of hemp fibre through to a maximum value of 350.2MPa at 3 wt% of fibre. Figure 45 depicts the obtained results for storage modulus as a function of fibre weight. Storage modulus increases from 284.7MPa at 0.5 wt% of fibre through to the maximum value at 3 wt% of fibre. The storage modulus then decreases to 312.3MPa at 4 wt% of fibre whereby a slight increase in storage modulus is observed at 5 wt% of fibre.

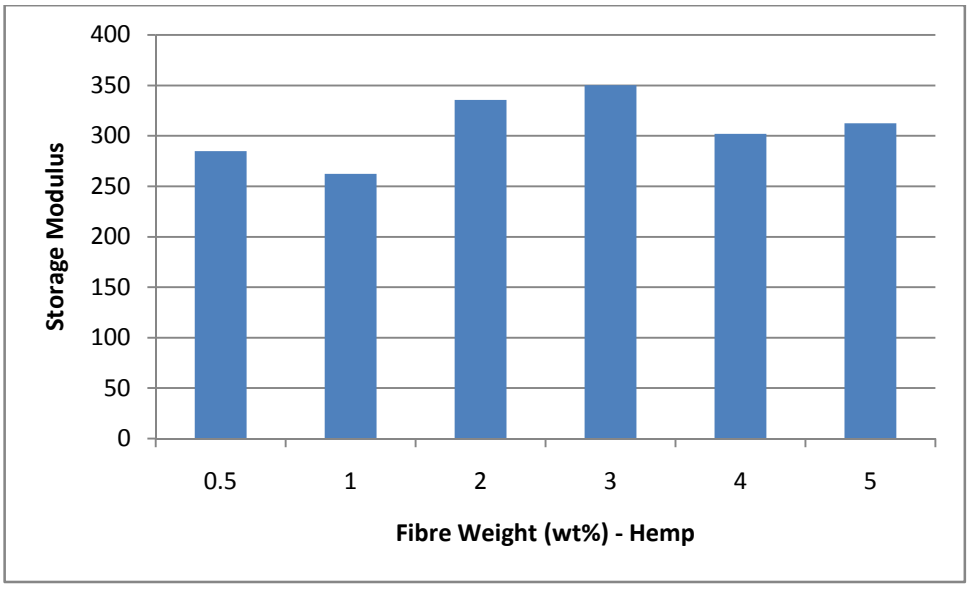


Figure 45 - Storage modulus as a function of fibre weight

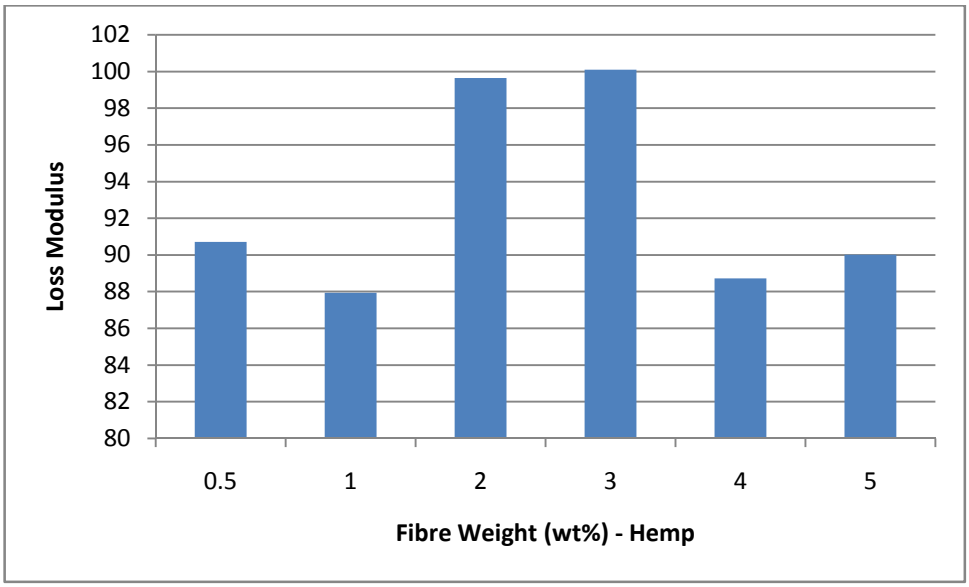


Figure 46 - Loss modulus as a function of fibre weight

Figure 46 depicts the obtained results for the loss modulus as a function of fibre weight. Loss modulus increases from 90.72MPa at 0.5 wt% of fibre through to the maximum value of 100.1MPa at 3 wt% of fibre. There is a discernible decrease in the loss modulus to 88.73MPa at 4 wt% of fibre whereby a slight increase in storage modulus to 90.01MPa is observed at 5 wt% of fibre.

Loss modulus values ranged from a minimum of 262.3MPa for the sample made with 1 wt% of hemp fibre through to a maximum value of 350.2MPa at 3 wt% of fibre.

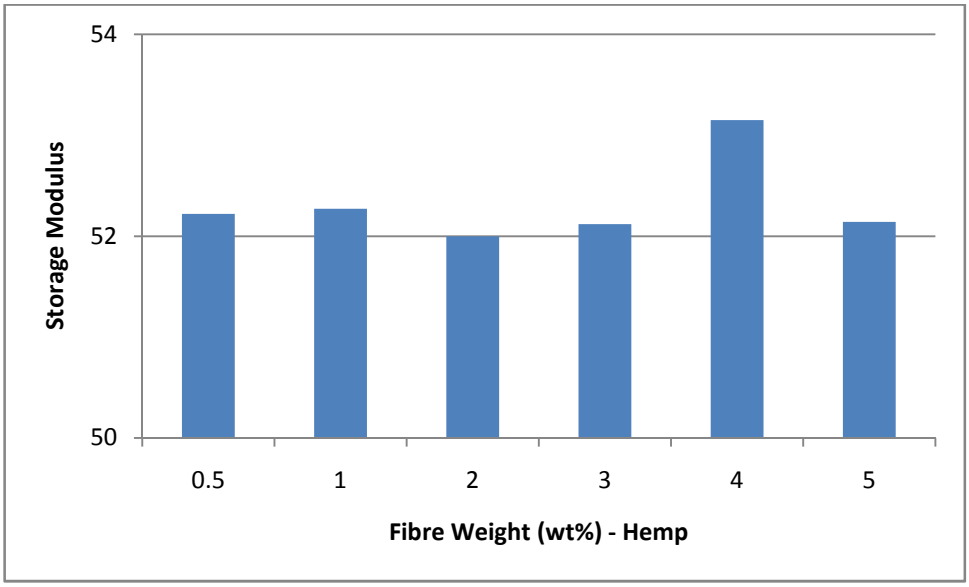


Figure 47 - Glass transition temperature as a function of fibre weight

From figure 47 the glass transition temperature can be observed. There is only a minor variation of 1.15°C between the minimum and maximum values throughout the range. The average glass transition temperature for the samples was 52.3°C. The minimum value was 52°C and the maximum value was 53.15°C.

Effect of Alkali Treatment on DMA

The viscoelastic properties as a function of NaOH concentration were analysed using DMA. Samples contained GY-191 and Aradur 250 with 5g of randomly orientated bleached short hemp fibre treated with different alkali concentrations. The results can be seen below in table 13 and figures 48, 49 and 50.

Table 13 - Viscoelastic properties of alkali treated samples as a function of NaOH concentration

NaOH (%)	Storage Modulus (MPa)	Loss Modulus (MPa)	Tan δ (°C)
0	1453	166.0	65.03
5	1434	143.7	70.8
10	1280	132.4	70.06
15	1343	127.2	70.54
20	1350	131.3	70.37

Storage modulus values ranged from a minimum of 1280MPa for the 10% NaOH treated sample through to a maximum value of 1453MPa for the untreated sample. The storage modulus decreases from 1453MPa at the untreated sample through to the minimum value of 1280MPa at the 10% NaOH treated sample. The storage modulus then increases to a final value of 1350MPa at 20% NaOH. Figure 48 depicts the obtained results for storage modulus as a function of NaOH concentration.

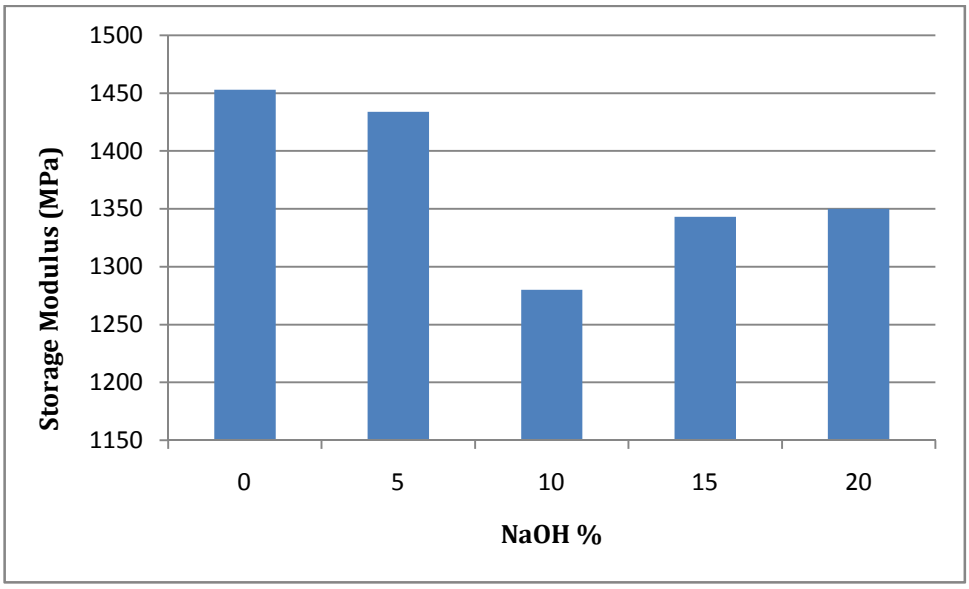


Figure 48 - Storage modulus as a function of NaOH concentration

Figure 49 illustrates the maximum loss modulus to be 166MPa at the untreated sample with the minimum storage modulus of 127.2MPa value occurring at the 15% NaOH treated sample. A trend was observed whereby the loss modulus decreased

when the alkali concentration increased with the exception of 20% NaOH treated sample. This trend can be observed more easily below in figure 49.

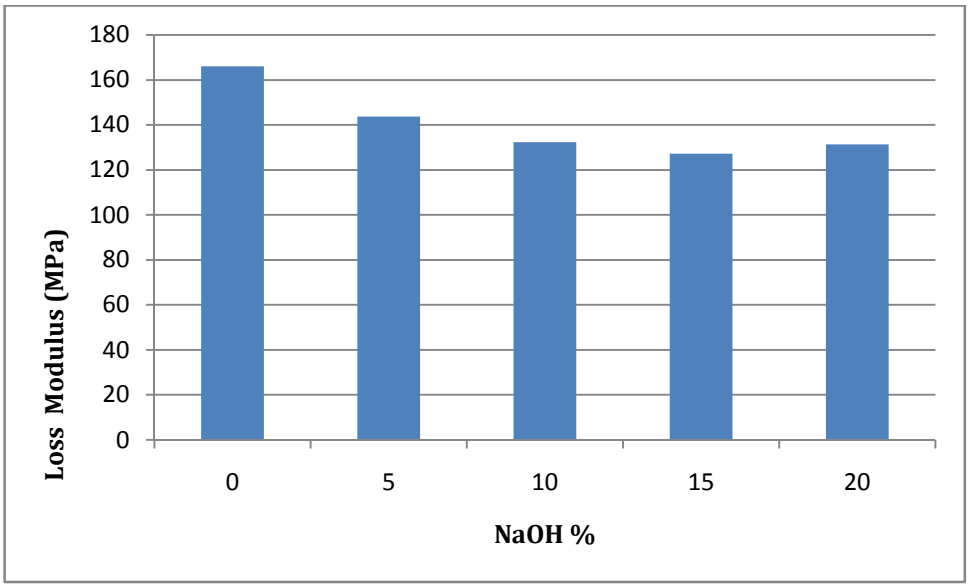


Figure 49 - Loss modulus as a function of NaOH concentration

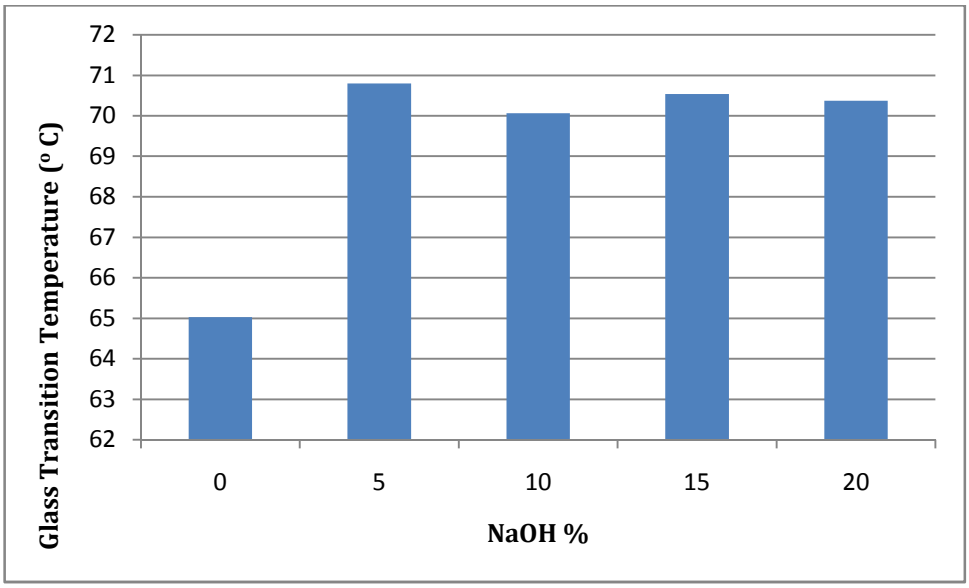


Figure 50 - Glass transition temperature a function of NaOH concentration

Table 13 and figure 50 display the glass transition temperature as a function of NaOH concentration. The highest glass transition temperature was $70.54^{\circ}C$ at the 15% NaOH treated sample. The lowest glass transition temperature was observed to

be 65.03°C at the untreated sample. The average glass transition temperature of the samples was 69.4°C .

4.4.2 Unidirectional Long Fibre Composites

Effect of Alkali Treatment on DMA

The viscoelastic properties as a function of NaOH concentration were analysed for the hand laid unidirectional long fibre samples using DMA. Samples contained GY-191 and Aradur 250 with 21.5g (7 wt%) of randomly raw long hemp fibre treated with different alkali concentrations and samples with 30g (10 wt%) unidirectional glass fibre. The results can be seen below in table 14 and figures 51, 52 and 53.

Table 14 - The viscoelastic properties as for the hand laid unidirectional long fibre samples

Sample Type	Storage Modulus (MPa)	Loss Modulus (MPa)	Tan δ (°C)
Glass Fibre	1766	200.7	68.67
UT Hemp Fibre	2194	208.5	70.52
5% NaOH Treated Hemp Fibre	1340	127.8	71.05
10% NaOH Treated Hemp Fibre	1578	142.3	72.66

Storage modulus values ranged from a minimum of 1340MPa for the 5% NaOH treated sample through to a maximum value of 2194MPa for the unidirectional glass fibre sample. The storage modulus decreases from 2194MPa for the untreated sample through to the minimum value of 1340MPa at the 5% NaOH treated sample. The storage modulus then increases to a final value of 1578MPa at 10% NaOH. Figure 51 depicts the obtained results for storage modulus hand laid unidirectional long fibre samples.

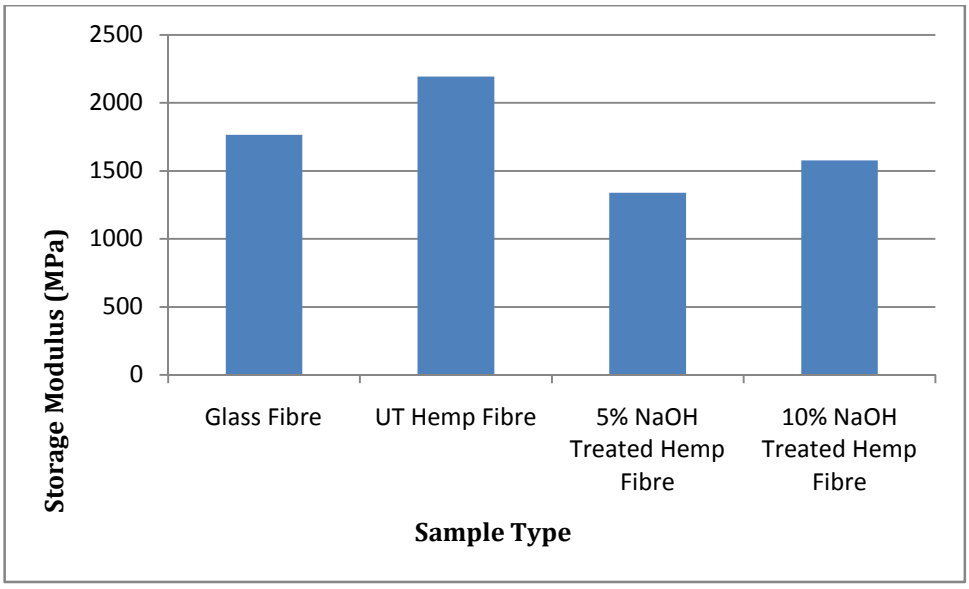


Figure 51 – Storage modulus for the hand laid unidirectional long fibre samples

Figure 51 illustrates the obtained results for storage modulus hand laid unidirectional long fibre samples. Figure 52 depicts the maximum loss modulus to be 208.5MPa at the untreated sample with the minimum storage modulus of 127.8MPa value occurring at the 5% NaOH treated sample. The loss modulus decreases from 208.5MPa for the untreated sample through to the minimum value of 127.8MPa at the 5% NaOH treated sample. The loss modulus then increases to a final value of 142.3MPa at 10% NaOH.

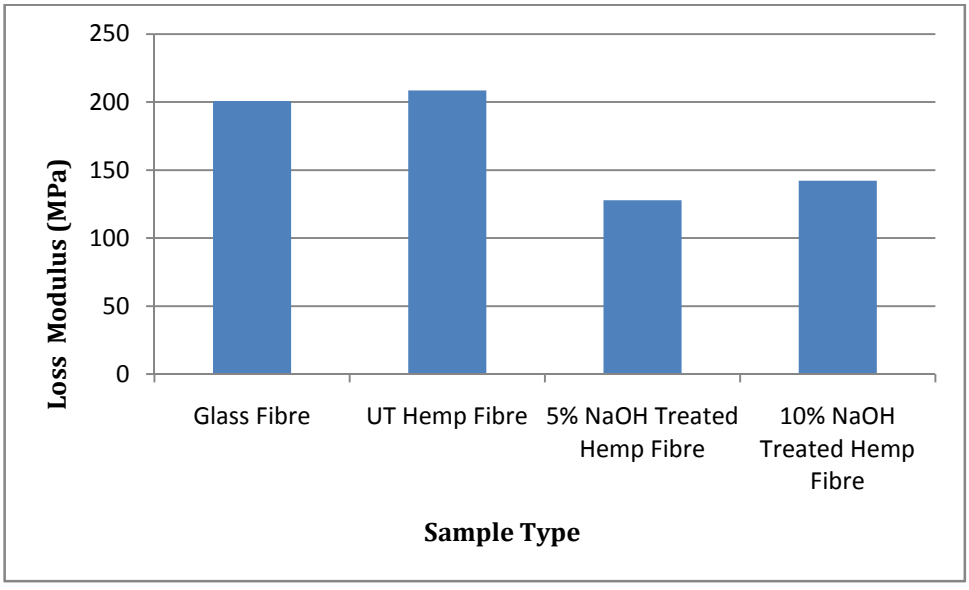


Figure 52 – Loss modulus for the hand laid unidirectional long fibre samples

The glass transition temperature for the hand laid unidirectional long fibre samples is displayed below in figure 53. The highest observed glass transition temperature was 70.54°C at the 15% NaOH treated sample. The lowest glass transition temperature was observed to be 68.67°C for the unidirectional glass fibre sample. The average glass transition temperature of the samples was 70.7°C. A trend was observed whereby the glass transition temperature increased when the alkali concentration increased.

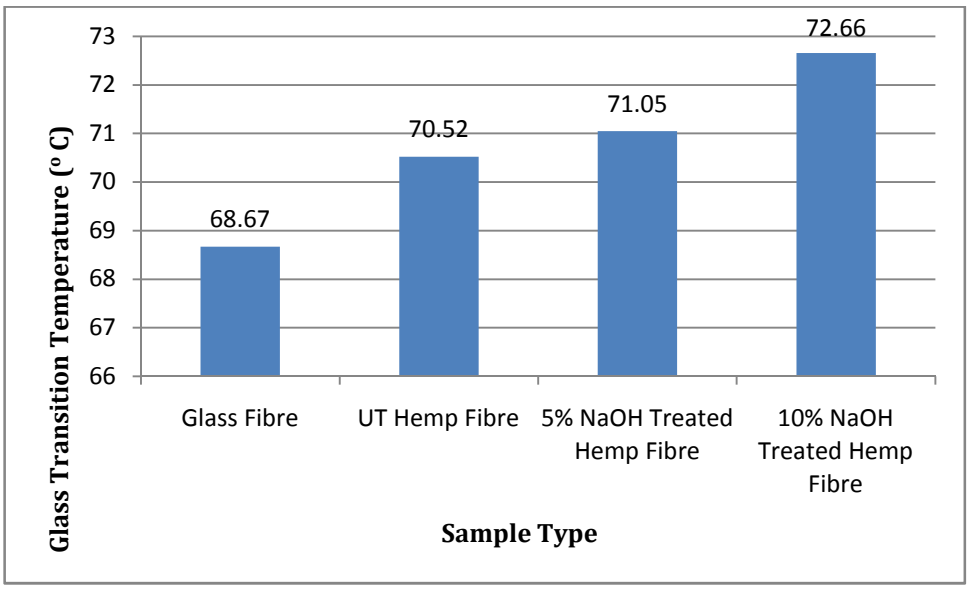


Figure 53 – Glass transition temperature for the hand laid unidirectional long fibre samples

4.5 Microscopic Analysis

Microscopic analysis was performed on different samples to determine the effect of alkali treatment on the fibre-matrix interface. Untreated randomly orientated short hemp fibre composites were compared with 20% NaOH treated randomly orientated short hemp fibre composites. Unidirectional glass fibre and treated hemp composites were also examined.

4.5.1 Random Short Fibre Composites

Composite with Untreated Fibre

Figure 54 and 55 below show untreated randomly orientated short hemp fibre composites at 100X and 200X magnification respectively. The cross sectional view of a hemp fibre can be seen with visible voids between the fibre and the matrix as indicated by the arrows. This is a common problem with natural fibre and can be improved with the use of chemical treatments such as alkali.

Figure 54 and 55 display 20% NaOH treated randomly orientated short hemp fibre composites at 100X and 200X magnification respectively.

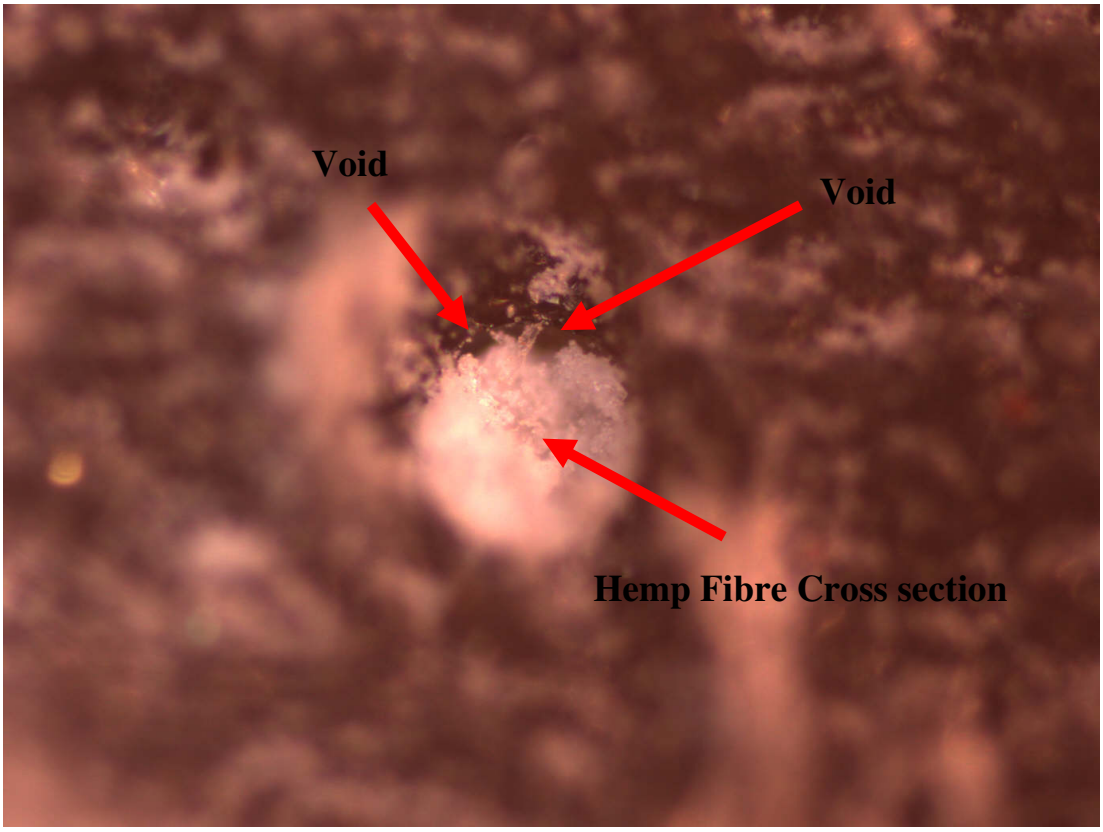


Figure 54 - Untreated randomly orientated short hemp fibre composites at 100X

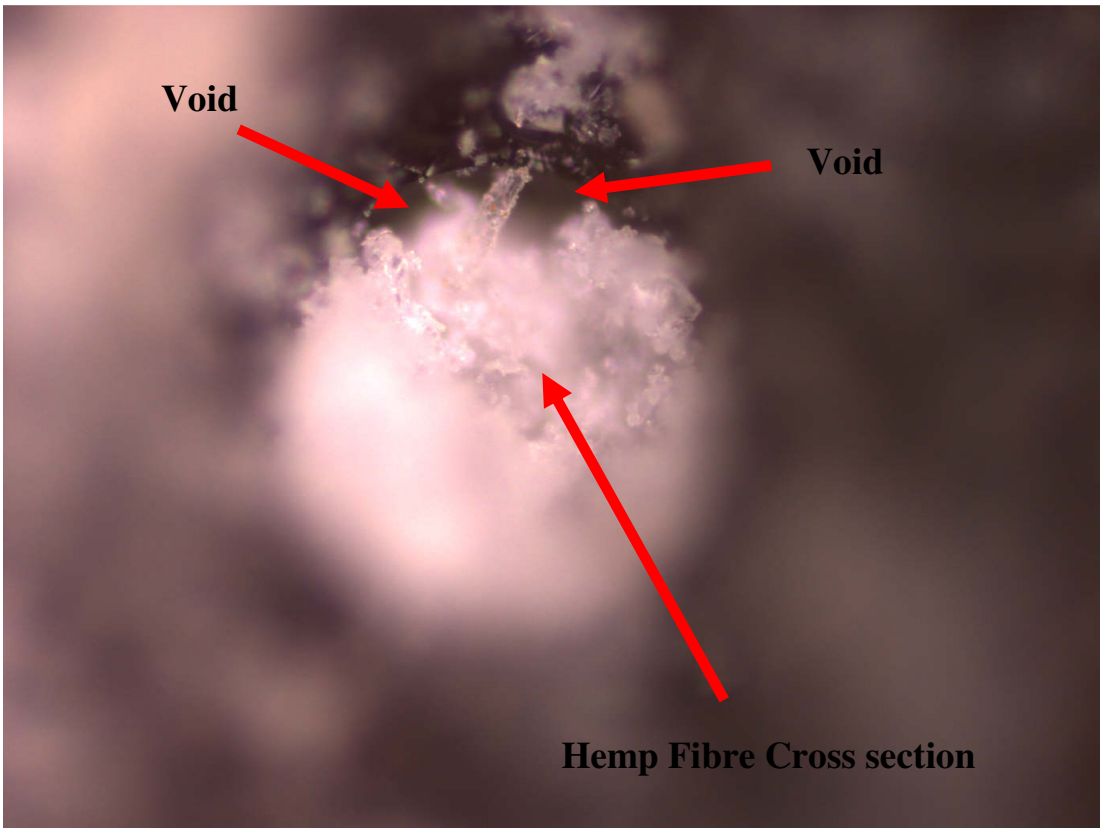


Figure 55 - Untreated randomly orientated short hemp fibre composites at 200X

Composite with Treated Fibre

It can be seen from figures 56 and 57 that there is a marked reduction in void size with the only presence of voids being the particularly miniature void as indicated by the arrow. This suggests that the alkali treatment has improved fibre-matrix adhesion and thereby improving the mechanical properties of the composite.

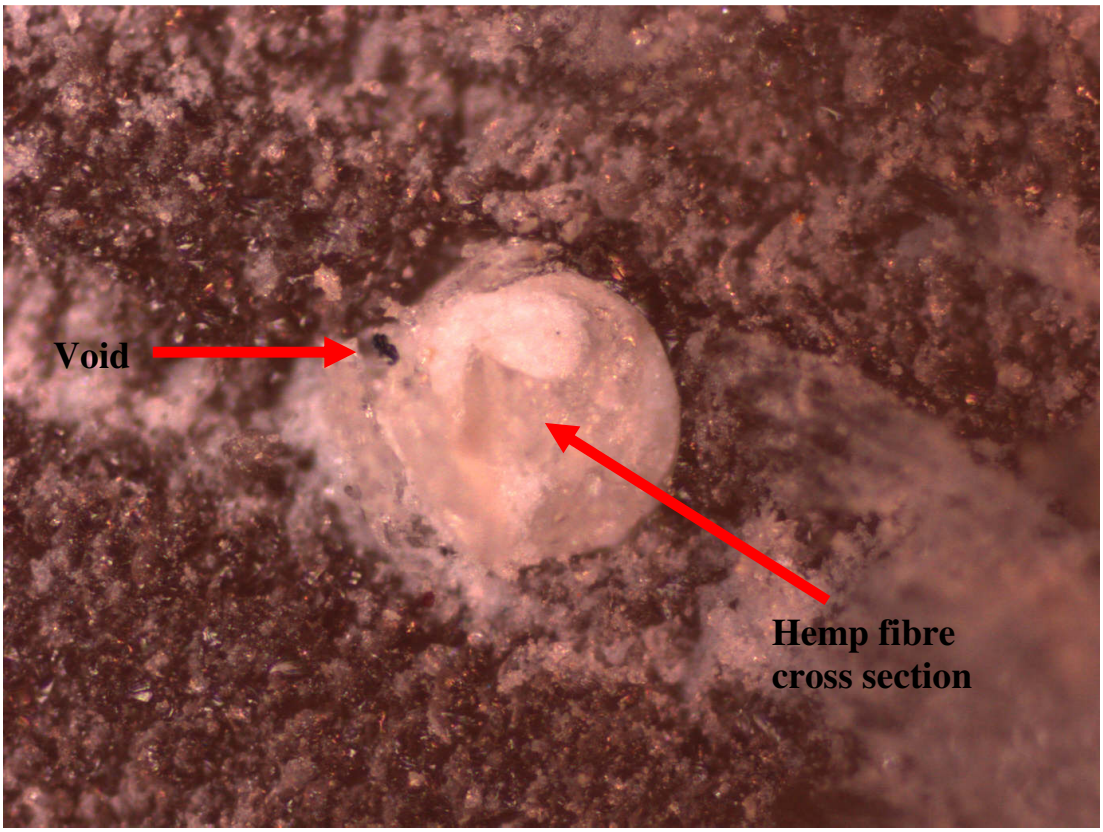


Figure 56 - 20% NaOH treated randomly orientated short hemp fibre composites at 100X

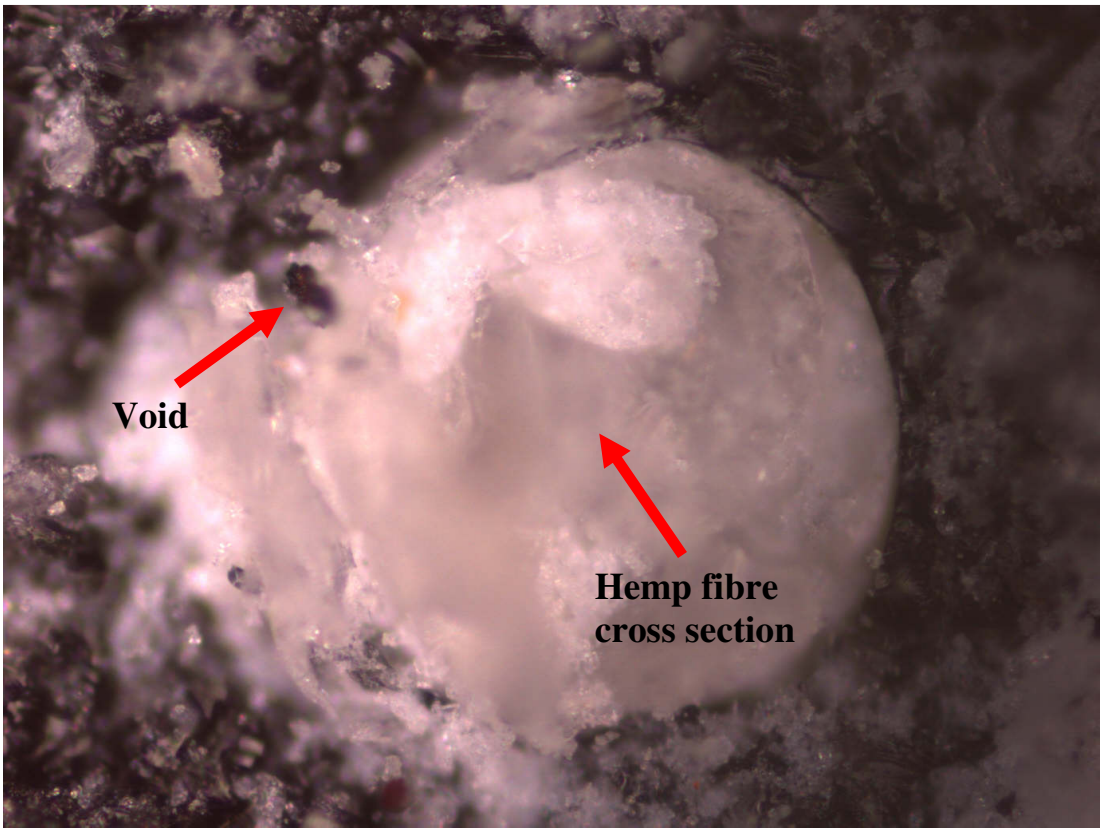


Figure 57 - 20% NaOH treated randomly orientated short hemp fibre composites at 200X

4.5.2 Unidirectional Long Fibre Composites

Unidirectional hemp composites were also examined. Alkali treated and untreated samples were examined with little difference apparent in regards to fibre-matrix adhesion. Wettability of the fibre was problematic and therefore all examined samples showed high void presence. Figure 58 displays an untreated sample at 100X magnification. Figure 59 displays a 5% NaOH treated sample at 100X magnification. Numerous voids are apparent from both figures. The alkali treatment seemed to reduce the voids to a certain extent however the fibre-matrix interface is still compromised.

It is concluded that the main difficulty with achieving satisfactory fibre-matrix interface results stems from the manufacturing process whereby the fibres are difficult to position correctly. This results in the composite having voids at the fibre-matrix interface due to problems with wettability regardless of alkali treatment. A porous composite is the consequence with lower than expected mechanical properties being observed.

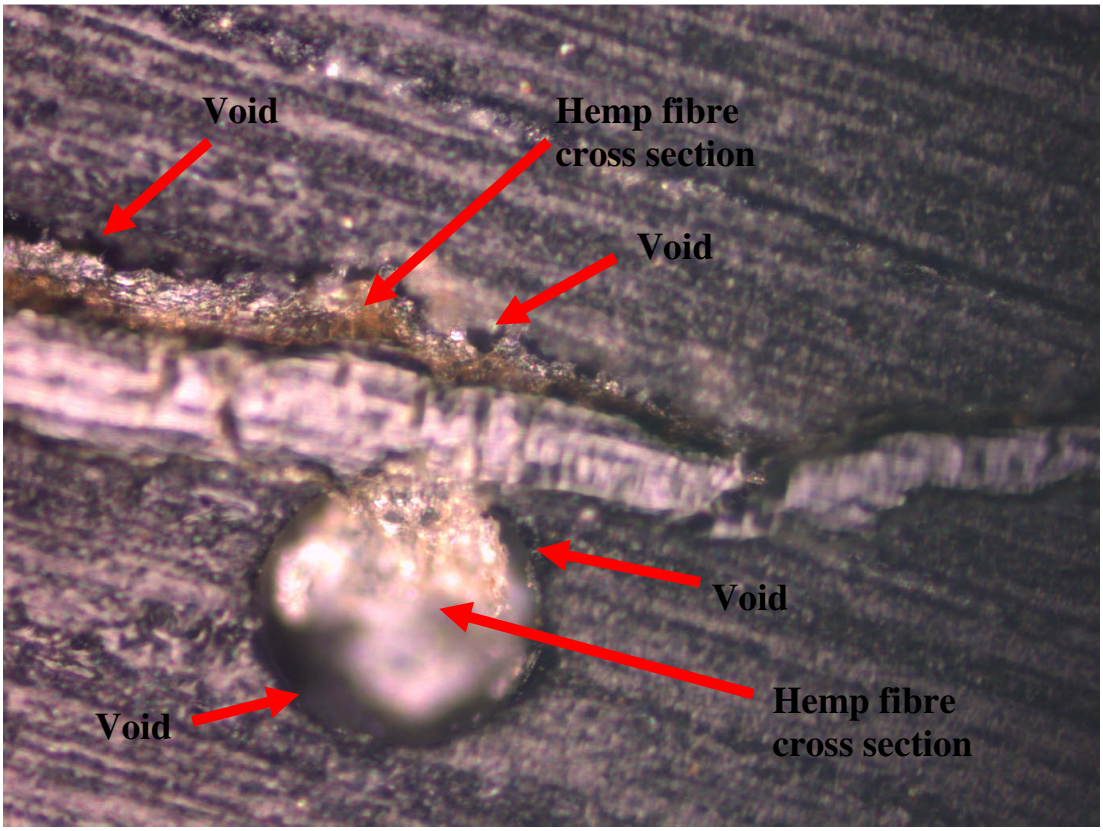


Figure 58 - Untreated unidirectional hemp fibre sample at 100X magnification

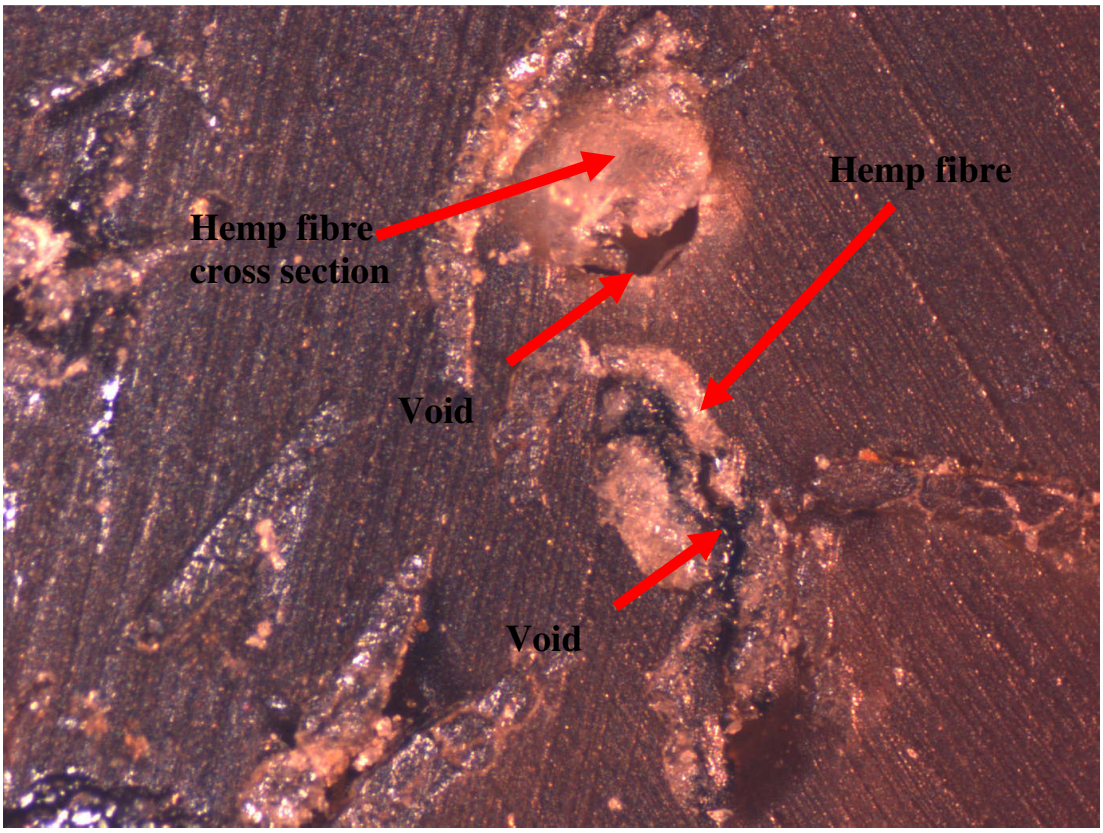


Figure 59 – 20% NaOH unidirectional hemp fibre sample at 100X magnification

4.6 Conclusion

This chapter has analysed and discussed the results obtained from flexural, impact, DMA and microscopic analysis for both randomly orientated short fibre composites and hand laid unidirectional long fibre composites. Peak flexural stress, flexural modulus, strain at break, storage modulus, loss modulus and glass transition temperature as functions of EVO%, EVO type, fibre weight and NaOH concentration were analysed for the randomly orientated short fibre composites. Peak flexural stress, flexural modulus, strain at break, total impact energy, storage modulus, loss modulus and glass transition temperature for unidirectional glass fibre composites and NaOH treated unidirectional long hemp fibre composites were analysed. Microscopic analysis was performed on both randomly orientated and unidirectional fibre composite samples with focus on the fibre-matrix interface to identify the effect of alkali treatment.

5 Conclusions

5.1 Introduction

This project has compared natural fibre composites made from natural polymer resins (such as epoxidized vegetable oils) and natural fibres (hemp fibres) with traditional glass fibre composites through the investigation of mechanical and thermal properties. An understanding of the benefits of making the composites has been gained throughout this project.

Traditional glass fibre composites were manufactured using the hand layup technique and the microstructure, thermal and mechanical properties were characterised through flexural tests, impact tests, DMA and microscopic analysis. Natural fibre composites were manufactured from different types of hemp fibre (short bleached and raw long) and different types and quantities of EVO using randomly orientated short hemp fibres and also unidirectional hand laid hemp fibres.

The effects of fibre content and alkali treatment of the hemp fibre were analysed through mechanical, thermal and microscopic analysis. Natural fibre composites were compared with traditional glass fibre composites through mechanical, thermal and microscopic analysis.

5.1.1 Random Short Fibre Composites

A reduction in peak flexural stress coinciding with an increase in %EVO was observed. The reduction in the peak flexural stress ranged from 20% for the 10% EHO to 97% for the 40% EHO compared to the epoxy containing hemp fibre. Due to the plasticising effect of EVO addition a decrease in flexural modulus corresponding with an increase in EVO % was observed. A reduction ranging from 35% for the 10% EHO to 99% for the 40% EHO in the flexural modulus of the fibre composites was observed. The ESFO displayed values that were consistently higher than both the ELO and the EHO. The ESFO was the only composite type with consistent strain at break results.

Samples manufactured using ESFO gave the highest values of peak flexural stress, flexural modulus and strain at break on average. The higher values of flexural modulus indicate a higher degree of stiffness. DMA showed that samples made using ESFO exhibit a higher glass transition temperature and both storage and loss modulus this suggests a higher degree of curing due to more pronounced crosslinking.

The maximum values of peak flexural stress (9.46MPa) and flexural modulus (206MPa) were achieved at fibre weights of 3 wt% and 4 wt% respectively. This indicates that from the test range of 1g to 7.5 g the optimal amount was between 3 wt% and 4 wt% of short bleached hemp fibre.

From analysis of the results it was found that alkali treatment had a positive effect on the mechanical properties of the composite. Peak flexural stress was found to increase with an increase in NaOH concentration up to a maximum value suggesting increased fibre-matrix adhesion due to the alkali treatment. Flexural modulus reached a maximum value of 1435MPa at 15% NaOH concentration whereby it decreases to 1366MPa at 20% NaOH concentration thereby suggesting a more flexible sample. Strain at break ranged from a minimum value of 3.59% through to 4.52% at the 20% NaOH concentration a due the increased flexibility of the sample.

Optical microscopic analysis showed that alkali treatment (20% NaOH) resulted in a marked reduction in void size with the only presence of voids being the particularly miniature void. This suggests that the alkali treatment has improved fibre-matrix adhesion and thereby improving the mechanical properties of the composite.

5.1.2 Unidirectional Long Fibre Composites

Unexpected results were obtained from the hand laid unidirectional alkali treatment long hemp fibre composites. A reduction in peak flexural stress was observed for the alkali treated samples. The untreated hemp fibre samples displayed a minor increase in peak flexural stress indicating that the hemp is acting as a reinforcement and not simply as a filler. An 18% increase in flexural modulus was observed using the 5% NaOH treated fibres compared with the untreated hemp fibre. The glass fibre composites displayed a peak flexural stress and flexural modulus that is a minimum of 3.2 and 2.1 times larger than the hemp fibre composites respectively.

The alkali treatment displayed the propensity to decrease flexural properties which is in contrast with results found in the literature. It is concluded that the main difficulty with achieving satisfactory results stems from the manufacturing process whereby the fibres are difficult to position correctly. This may result in the composite having voids at the fibre-matrix interface due to problems with wettability. A more porous composite is the consequence with lower than expected mechanical properties being observed. From DMA a trend was observed whereby the glass transition temperature increased when the alkali concentration increased.

The glass fibre composites displayed a total impact energy value that is a minimum of 6.3 times larger than the hemp fibre composites. Alkali treatment of the hemp fibre provided no increase in impact properties. A decrease in total impact energy as a result of increased NaOH concentration was observed. This trend of reduced impact energy is consistent with results found in the literature whereby the alkali treated hemp displays the tendency to exhibit plasticisation of the cell wall of the hemp fibre thereby decreasing the total impact energy that is able to be absorbed before failure.

Optical microscopic analysis showed that numerous voids are apparent for both untreated and treated samples. The alkali treatment seemed to reduce the voids to a certain extent however the fibre-matrix interface is still compromised.

It is concluded that the main difficulty with achieving satisfactory fibre-matrix interface results stems from the manufacturing process whereby the fibres are difficult to position correctly. This results in the composite having voids at the fibre-matrix interface due to problems with wettability regardless of alkali treatment. A porous composite is the consequence with lower than expected mechanical properties being observed.

5.2 Conclusion

This study has demonstrated the ability of natural fibres and plant-oil based resins as viable materials from which to construct fibre composites. Improvements were realised through the use of alkali treatment of the fibres. In terms of cost and specific

material properties, natural composites represent an alternative to traditional synthetic fibre composites in certain applications.

6 Recommendations

6.1 Introduction

The results obtained and the lessons learnt throughout this project have brought to the fore certain limitations and challenges regarding the use of natural fibres in composites. These lessons will aide in the pursuit of further research within this exciting field of study.

6.2 Limitations and Challenges

Throughout the project there were certain limitations and challenges faced by the author. These are listed below:

- Difficulty in sourcing natural fibre mat
- Processing difficulties resulting from type of available fibres used
- Length of fibres
- Damage to fibres through manufacturing processes
- Difficulty achieving uniform fibre dispersion
- Moisture uptake of natural fibres
- Poor surface compatibility between the fibre and the matrix coupled with the high moisture absorption of natural fibres present difficulties for use as fibres.

6.3 Recommendations for future work

Numerous different questions pertaining to natural fibre composites have arisen throughout this journey relating to future work recommendations. Some of these are listed below:

- Investigation into how the manufacturing process affects the properties of the composite
- Investigation of natural fibre modifications instead of chemical modification, perhaps through the use of enzymes or fungi

- Alternative manufacturing methods such as press moulding, resin transfer moulding if mating can be sourced to enable greater consistency of samples or alternatively an improved method of hand layup technique to facilitate improved quality control and fibre wetting

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Appendix A: Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

EBG4111/4112 Research Project
PROJECT SPECIFICATION

FOR:	**NATHAN W MANTHEY – 0050021928**
TOPIC:	ENVIRONMENTALLY FRIENDLY NATURAL FIBRE COMPOSITES WITH QLD BASED VEGETABLE OILS
SUPERVISOR(S):	Dr Hao Wang, Dr Francisco Cardona
SPONSORSHIP:	CEEFC Centre/ Faculty of Engineering and Surveying
PROJECT AIM:	This project seeks to compare environmentally friendly composites made from natural polymer resins (such as epoxidized vegetable oils) and natural fibres (such as bagasse and hemp fibres) with traditional glass fibre composites through the investigation of mechanical and thermal properties.
PROGRAMME:	**Issue A. 23rd March 2009**

1. Understand the mechanisms and benefits of making the composite.
2. Prepare traditional fibre composites and characterise them in terms of microstructure, thermal and mechanical properties.
3. Prepare environmentally friendly natural fibre composites and characterise them in terms of microstructure, thermal and mechanical properties.
4. Study the effects of the fibre selection (type, volume and size) and processing conditions (temperature, pressure and fibre treatment) on the properties.
5. Compare the environmentally friendly natural fibre composite with traditional glass fibre composites.

AGREED:

Nathan W Manthey (Student): _____ Date: ___/___/2009

Dr Hao Wang (Supervisor): _____ Date: ___/___/2009

Dr Francisco Cardona (Supervisor): _____ Date: ___/___/2009

Examiner/Co-examiner: _____ Date: ___/___/2009

Appendix B: Summary of Manufactured Samples

Sample	Epoxy		EVO			Hardener		Fibre			Manufacture Method	Post Curing
#	Type	(g)	Type	D.Epox (%)	(g)	Type	(g)	Type	(g)	Treatment		
1	GY-191	90	ELO (Commercial)	82.5	10	Hyrez-B	21.2	-	-	-	Hand mixed	4h@80.C
2	GY-191	80	ELO (Commercial)	82.5	20	Hyrez-B	20.4	-	-	-	Hand mixed	4h@80.C
3	GY-191	70	ELO (Commercial)	82.5	30	Hyrez-B	19.6	-	-	-	Hand mixed	4h@80.C
4	GY-191	50	ELO (Commercial)	82.5	50	Hyrez-B	17	-	-	-	Hand mixed	4h@80.C
5	GY-191	90	ELO (Commercial)	82.5	10	Hyrez-B	22	Hemp (Hurd chips)	10	-	Hand mixed	4h@80.C
6	GY-191	80	ELO (Commercial)	82.5	20	Hyrez-B	22	Hemp (Hurd chips)	10	-	Hand mixed	4h@80.C
7	GY-191	70	ELO (Commercial)	82.5	30	Hyrez-B	22	Hemp (Hurd chips)	10	-	Hand mixed	4h@80.C
8	GY-191	50	ELO (Commercial)	82.5	50	Hyrez-B	21	Hemp (Hurd chips)	10	-	Hand mixed	4h@80.C
9a	GY-191	90	ELO (Commercial)	82.5	10	Hyrez-B	22	Hemp (Hurd chips)	20	-	Hand mixed	4h@80.C
10a	GY-191	80	ELO (Commercial)	82.5	20	Hyrez-B	22	Hemp (Hurd chips)	20	-	Hand mixed	4h@80.C
11a	GY-191	70	ELO (Commercial)	82.5	30	Hyrez-B	22	Hemp (Hurd chips)	20	-	Hand mixed	4h@80.C
12a	GY-191	50	ELO (Commercial)	82.5	50	Hyrez-B	21	Hemp (Hurd chips)	20	-	Hand mixed	4h@80.C
9	GY-191	90	ELO (Commercial)	82.5	10	Aradur-250	48.7	Hemp (Hurd chips)	10	-	Hand mixed	4h@80.C
10	GY-	80	ELO	82.5	20	Aradur-	47.4	Hemp (Hurd chips)	10	-	Hand mixed	4h@80.C

	191		(Commercial)			250						
11	GY-191	70	ELO (Commercial)	82.5	30	Aradur-250	46.2	Hemp (Hurd chips)	10	-	Hand mixed	4h@80.C
12	GY-191	50	ELO (Commercial)	82.5	50	Aradur-250	43.6	Hemp (Hurd chips)	10	-	Hand mixed	4h@80.C
13	GY-191	90	ELO (Commercial)	82.5	10	Aradur-250	48.7	Hemp (Hurd chips)	20	-	Hand mixed	4h@80.C
14	GY-191	80	ELO (Commercial)	82.5	20	Aradur-250	47.4	Hemp (Hurd chips)	20	-	Hand mixed	4h@80.C
15	GY-191	70	ELO (Commercial)	82.5	30	Aradur-250	46.2	Hemp (Hurd chips)	20	-	Hand mixed	4h@80.C
16	GY-191	50	ELO (Commercial)	82.5	50	Aradur-250	43.6	Hemp (Hurd chips)	20	-	Hand mixed	4h@80.C
17	GY-191	90	ESFO (Tyson)	44	10	Aradur-250	46.1	Hemp (Hurd chips)	10	-	Hand mixed	4h@80.C
18	GY-191	80	ESFO (Tyson)	44	20	Aradur-250	42.3	Hemp (Hurd chips)	10	-	Hand mixed	4h@80.C
19	GY-191	70	ESFO (Tyson)	44	30	Aradur-250	38.4	Hemp (Hurd chips)	10	-	Hand mixed	4h@80.C
20	GY-191	50	ESFO (Tyson)	44	50	Aradur-250	31.6	Hemp (Hurd chips)	10	-	Hand mixed	4h@80.C
21	GY-191	90	ESFO (Tyson)	44	10	Aradur-250	46.1	Hemp (Hurd chips)	20	-	Hand mixed	4h@80.C
22	GY-191	80	ESFO (Tyson)	44	20	Aradur-250	42.3	Hemp (Hurd chips)	20	-	Hand mixed	4h@80.C
23	GY-191	70	ESFO (Tyson)	44	30	Aradur-250	38.4	Hemp (Hurd chips)	20	-	Hand mixed	4h@80.C
24	GY-191	50	ESFO (Tyson)	44	50	Aradur-250	31.6	Hemp (Hurd chips)	20	-	Hand mixed	4h@80.C
25	GY-191	90	ELO (Commercial)	82.5	10	Aradur-250	48.7	Hemp (Bleached Short)	5	-	Hand mixed	4h@80.C
26	GY-191	80	ELO (Commercial)	82.5	20	Aradur-250	47.4	Hemp (Bleached Short)	5	-	Hand mixed	4h@80.C
27	GY-	70	ELO	82.5	30	Aradur-	46.2	Hemp (Bleached Short)	5	-	Hand mixed	4h@80.C

	191		(Commercial)			250						
28	GY-191	60	ELO (Commercial)	82.5	40	Aradur-250	44.8	Hemp (Bleached Short)	5	-	Hand mixed	4h@80.C
29	GY-191	90	ESFO (Tyson)	44	10	Aradur-250	46.1	Hemp (Bleached Short)	5	-	Hand mixed	4h@80.C
30	GY-191	80	ESFO (Tyson)	44	20	Aradur-250	42.3	Hemp (Bleached Short)	5	-	Hand mixed	4h@80.C
31	GY-191	70	ESFO (Tyson)	44	30	Aradur-250	38.4	Hemp (Bleached Short)	5	-	Hand mixed	4h@80.C
32	GY-191	60	ESFO (Tyson)	44	40	Aradur-250	34.5	Hemp (Bleached Short)	5	-	Hand mixed	4h@80.C
33	GY-191	90	EHO (Tyson)	99	10	Aradur-250	49.4	Hemp (Bleached Short)	5	-	Hand mixed	4h@80.C
34	GY-191	80	EHO (Tyson)	99	20	Aradur-250	48.7	Hemp (Bleached Short)	5	-	Hand mixed	4h@80.C
35	GY-191	70	EHO (Tyson)	99	30	Aradur-250	48	Hemp (Bleached Short)	5	-	Hand mixed	4h@80.C
36	GY-191	60	EHO (Tyson)	99	40	Aradur-250	47.4	Hemp (Bleached Short)	5	-	Hand mixed	4h@80.C
37	GY-191	80	-	-	-	Aradur-250	40	Hemp (Bleached Short)	5	-	Hand mixed	4h@80.C
38	-	-	-	-	-	-	-	-	-	-	-	-
39	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-
41	GY-191	80	-	-	-	Aradur-250	40	Hemp (Bleached Short)	5	20% NaOH	Hand mixed	4h@80.C
42	GY-191	80	-	-	-	Aradur-250	40	Hemp (Bleached Short)	5	15% NaOH	Hand mixed	4h@80.C
43	GY-191	80	-	-	-	Aradur-250	40	Hemp (Bleached Short)	5	10% NaOH	Hand mixed	4h@80.C
44	GY-191	80	-	-	-	Aradur-250	40	Hemp (Bleached Short)	5	5% NaOH	Hand mixed	4h@80.C
45	-	-	-	-	-	-	-	-	-	-	-	-

46	-	-	-	-	-	-	-	-	-	-	-	-
47	GY-191	80	EHO (Tyson)	99	20	Aradur-250	48.7	Hemp (Bleached Short)	1	-	Hand mixed	4h@80.C
48	GY-191	80	EHO (Tyson)	99	20	Aradur-250	48.7	Hemp (Bleached Short)	2	-	Hand mixed	4h@80.C
49	GY-191	80	EHO (Tyson)	99	20	Aradur-250	48.7	Hemp (Bleached Short)	3	-	Hand mixed	4h@80.C
50	GY-191	80	EHO (Tyson)	99	20	Aradur-250	48.7	Hemp (Bleached Short)	4	-	Hand mixed	4h@80.C
51	GY-191	80	EHO (Tyson)	99	20	Aradur-250	48.7	Hemp (Bleached Short)	7.5	-	Hand mixed	4h@80.C
HL1	GY-191	100	-	-	-	Hyrez-B	50	-	-	-	Hand laid	4h@80.C
HL2	GY-191	100	-	-	-	Hyrez-B	50	GF Mat	-	-	Hand laid	4h@80.C
HL3	-		EHO (Tyson)	99	100	Hyrez-B	45	GF Mat	-	-	Hand laid	2h@150.C
HL4	-		ESBO (Tyson)	98	100	Hyrez-B	43	GF Mat	-	-	Hand laid	2h@150.C
HL5	GY-191	100	-	-	-	Aradur-250	50	-	-	-	Hand laid	4h@80.C
HL6	GY-191	100	-	-	-	Aradur-250	50	GF UD	30	-	Hand laid	4h@80.C
HL7	GY-191	200	-	-	-	Aradur-250	100	Hemp (Long Field Retted) UD	21.5	-	Hand laid	4h@80.C
HL8	GY-191	200	-	-	-	Aradur-250	100	Hemp (Long Field Retted) UD	21.5	5% NaOH	Hand laid	4h@80.C
HL9	GY-191	200	-	-	-	Aradur-250	100	Hemp (Long Field Retted) UD	21.5	10% NaOH	Hand laid	4h@80.C

Appendix C: Flexural Testing Results

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-25
(I) STS Job Number:	ELO-PL 10g Hemp Long Fibre 5g 48.7 ARARDUR
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 16 Hours @ 40°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4

(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

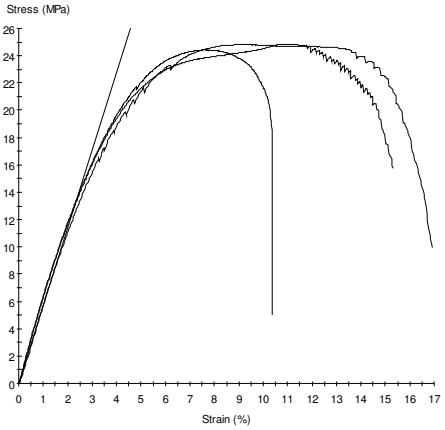
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	15.71	8.96	326	24.82	10.78	****	8.21	****	571
2	16.01	10.28	431	24.43	7.69	10.37	5.11	6.89	619
3	16.14	9.97	415	24.81	9.19	16.70	6.29	11.43	592
Mean	**15.95**	**9.74**	**390**	**24.69**	**9.22**	**13.53**	**6.54**	**9.16**	**594**
Std Dev	**0.22**	**0.69**	**56**	**0.23**	**1.54**	**4.47**	**1.57**	**3.21**	**24**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-26
(I) STS Job Number:	ELO-PL 20g Hemp Long Fibre 5g 47.4 ARARDUR
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 16 Hours @ 40°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

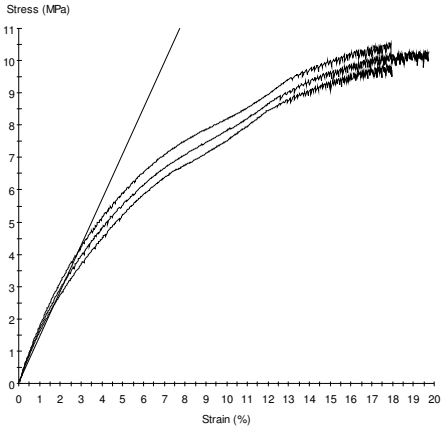
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	15.21	10.03	168	10.56	17.83	****	12.14	****	138
2	15.04	9.91	158	10.30	19.54	****	13.46	****	139
3	16.00	9.84	159	9.88	17.74	****	12.31	****	136
Mean	**15.42**	**9.93**	**162**	**10.25**	**18.37**	****	**12.64**	****	**138**
Std Dev	**0.51**	**0.10**	**5**	**0.34**	**1.01**	****	**0.72**	****	**1**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-27
(I) STS Job Number:	ELO-PL 30g Hemp Long Fibre 5g 46.2 ARARDUR
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 16 Hours @ 40°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

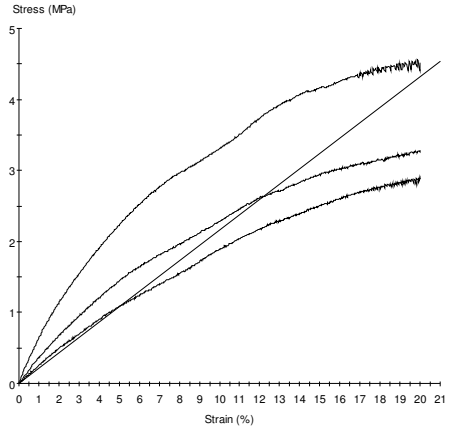
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	15.35	9.93	72	4.56	19.86	****	13.65	****	50
2	14.54	9.87	48	3.28	20.00	****	13.83	****	31
3	14.46	9.10	36	2.89	19.82	****	14.87	****	21
Mean	**14.78**	**9.63**	**52**	**3.58**	**19.89**	****	**14.12**	****	**34**
Std Dev	**0.49**	**0.46**	**18**	**0.87**	**0.10**	****	**0.66**	****	**15**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-28
(I) STS Job Number:	ELO-PL 40g Hemp Long Fibre 5g 44.8 ARARDUR
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 16 Hours @ 40°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

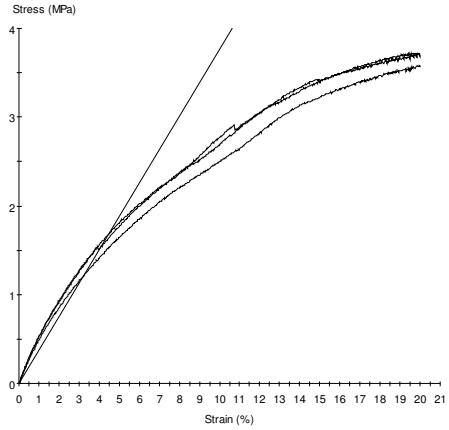
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	15.44	10.00	58	3.58	19.97	****	13.63	****	37
2	15.23	9.89	58	3.72	19.99	****	13.80	****	44
3	16.12	9.39	55	3.71	19.92	****	14.48	****	41
Mean	**15.60**	**9.76**	**57**	**3.67**	**19.96**	****	**13.97**	****	**40**
Std Dev	**0.47**	**0.33**	**2**	**0.08**	**0.04**	****	**0.45**	****	**4**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-29
(I) STS Job Number:	ESFO-TC 10g Hemp Long Fibre 5g 46.1 ARARDUR
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 16 Hours @ 40°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

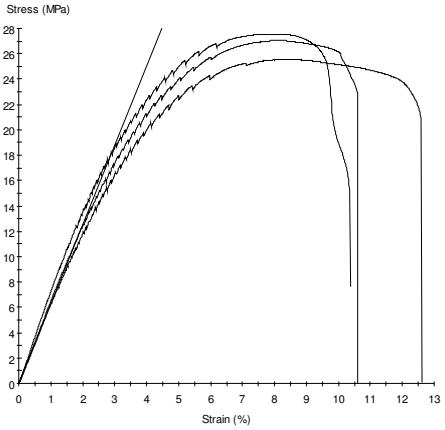
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	14.25	9.92	395	27.05	8.18	10.60	5.63	7.29	632
2	14.66	10.01	422	27.56	7.80	10.37	5.32	7.07	734
3	14.36	9.88	373	25.54	8.41	12.60	5.81	8.70	600
Mean	**14.42**	**9.94**	**397**	**26.71**	**8.13**	**11.19**	**5.59**	**7.69**	**655**
Std Dev	**0.21**	**0.07**	**24**	**1.05**	**0.31**	**1.22**	**0.25**	**0.88**	**70**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-30
(I) STS Job Number:	ESFO-TC 20g Hemp Long Fibre 5g 46.1 ARARDUR
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 16 Hours @ 40°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

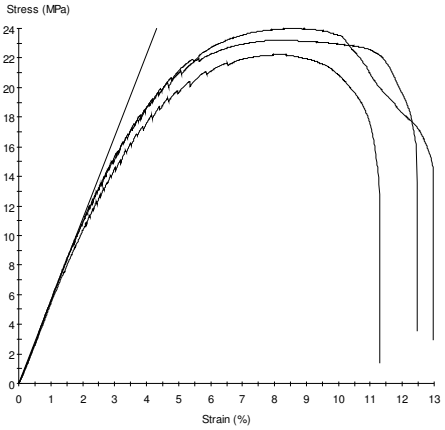
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	15.50	9.70	365	24.00	8.53	12.95	6.00	9.12	567
2	14.82	9.94	339	22.22	8.15	11.29	5.60	7.75	530
3	16.14	9.85	378	23.19	8.06	12.45	5.59	8.63	547
Mean	**15.49**	**9.83**	**361**	**23.13**	**8.25**	**12.23**	**5.73**	**8.50**	**548**
Std Dev	**0.66**	**0.12**	**20**	**0.89**	**0.25**	**0.85**	**0.24**	**0.69**	**19**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-31
(I) STS Job Number:	ESFO-TC 30g Hemp Long Fibre 5g 38 ARARDUR
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 16 Hours @ 40°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

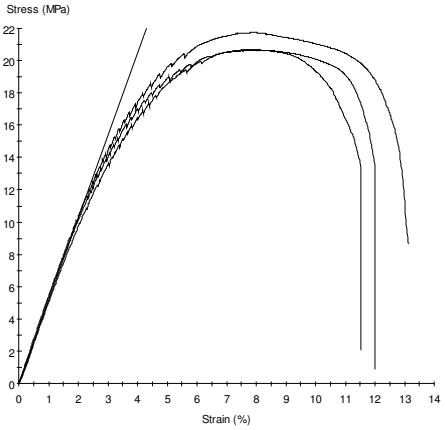
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	16.37	9.85	360	21.74	7.95	13.02	5.51	9.02	535
2	16.51	9.93	351	20.70	7.82	11.51	5.37	7.91	487
3	15.08	10.03	326	20.65	8.02	12.00	5.46	8.17	509
Mean	**15.99**	**9.94**	**346**	**21.03**	**7.93**	**12.18**	**5.45**	**8.37**	**511**
Std Dev	**0.79**	**0.09**	**17**	**0.62**	**0.11**	**0.77**	**0.07**	**0.58**	**24**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-32
(I) STS Job Number:	ESFO-TC 40g Hemp Long Fibre 5g 35 ARARDUR
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 16 Hours @ 40°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

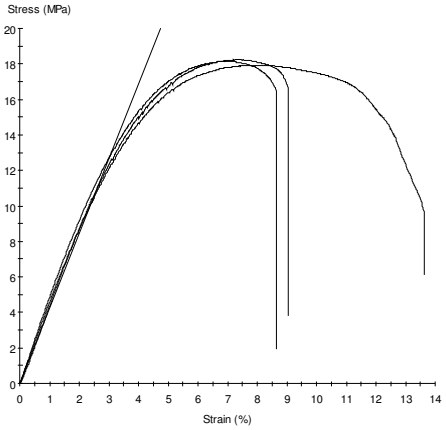
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	14.79	9.92	272	17.92	8.12	13.64	5.59	9.38	425
2	14.53	9.88	268	18.14	6.88	8.64	4.76	5.97	462
3	15.50	9.96	292	18.23	7.33	9.05	5.02	6.20	432
Mean	**14.94**	**9.92**	**277**	**18.10**	**7.44**	**10.44**	**5.12**	**7.19**	**439**
Std Dev	**0.50**	**0.04**	**13**	**0.16**	**0.63**	**2.77**	**0.42**	**1.91**	**20**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-33 90-10 EHO-TC
(I) STS Job Number:	10-EHO-TC
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

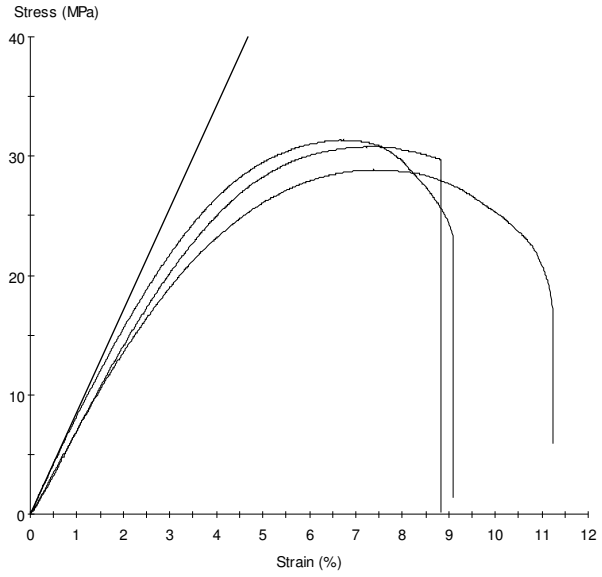
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	17.90	9.93	530	28.84	7.38	11.25	5.08	7.73	657
2	18.04	9.97	575	30.78	7.26	8.83	4.97	6.05	726
3	17.49	9.86	555	31.34	6.73	9.10	4.66	6.30	859
Mean	**17.81**	**9.92**	**553**	**30.32**	**7.12**	**9.73**	**4.90**	**6.69**	**747**
Std Dev	**0.29**	**0.06**	**22**	**1.31**	**0.35**	**1.32**	**0.22**	**0.91**	**103**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-34 80-20 EHO-TC
(I) STS Job Number:	20-EHO-TC
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

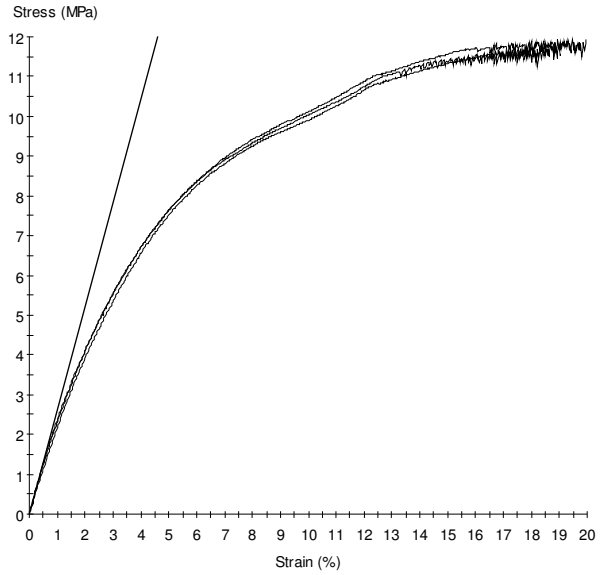
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	16.00	9.83	192	11.93	18.95	****	13.16	****	183
2	15.42	9.99	189	11.77	18.76	****	12.82	****	175
3	15.61	9.98	189	11.65	17.90	****	12.24	****	260
Mean	**15.68**	**9.93**	**190**	**11.79**	**18.54**	****	**12.74**	****	**206**
Std Dev	**0.30**	**0.09**	**2**	**0.14**	**0.56**	****	**0.46**	****	**47**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-35 80-20 EHO-TC
(I) STS Job Number:	30-EHO-TC
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

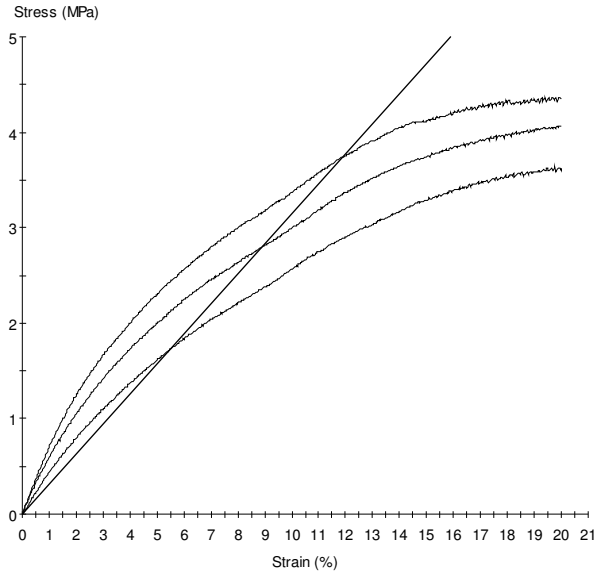
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	15.84	9.94	71	4.37	19.69	****	13.52	****	51
2	15.41	9.83	63	4.07	19.94	****	13.84	****	46
3	15.65	9.76	56	3.63	19.76	****	13.82	****	31
Mean	**15.63**	**9.84**	**64**	**4.02**	**19.80**	****	**13.73**	****	**42**
Std Dev	**0.22**	**0.09**	**7**	**0.37**	**0.13**	****	**0.18**	****	**10**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-36 60-400 EHO-TC
(I) STS Job Number:	40-EHO-TC
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

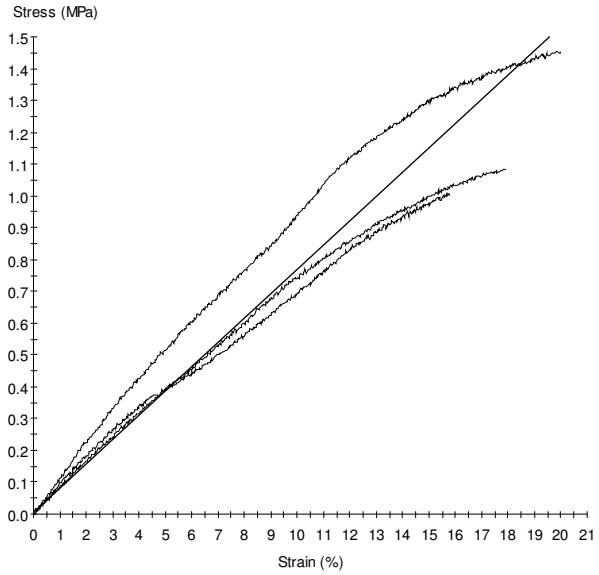
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	15.01	9.96	16	1.01	15.75	****	10.79	****	8
2	15.95	9.99	24	1.45	19.82	****	13.55	****	10
3	15.53	10.01	18	1.09	17.90	****	12.21	****	8
Mean	**15.50**	**9.99**	**19**	**1.18**	**17.82**	****	**12.18**	****	**9**
Std Dev	**0.47**	**0.03**	**4**	**0.24**	**2.04**	****	**1.38**	****	**1**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-37
(I) STS Job Number:	Hemp Long Fibre 5g 40 ARARDUR
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 16 Hours @ 40°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

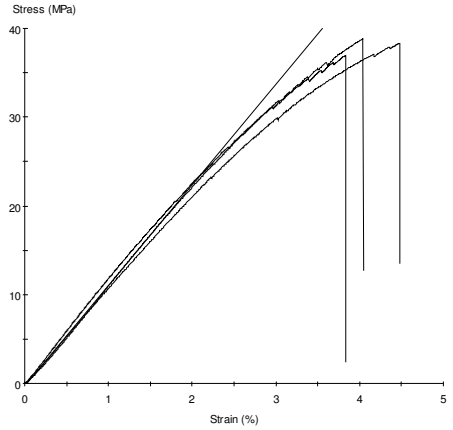
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	13.50	9.92	538	38.84	4.04	4.04	2.78	2.78	1153
2	13.36	9.84	498	36.98	3.83	3.84	2.66	2.66	1209
3	13.54	9.64	503	38.34	4.48	4.48	3.17	3.17	1090
Mean	**13.47**	**9.80**	**513**	**38.06**	**4.12**	**4.12**	**2.87**	**2.87**	**1150**
Std Dev	**0.09**	**0.14**	**22**	**0.96**	**0.33**	**0.33**	**0.27**	**0.27**	**60**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-41 80 GY-191 40 Aradur 250
(I) STS Job Number:	20% NaOH
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

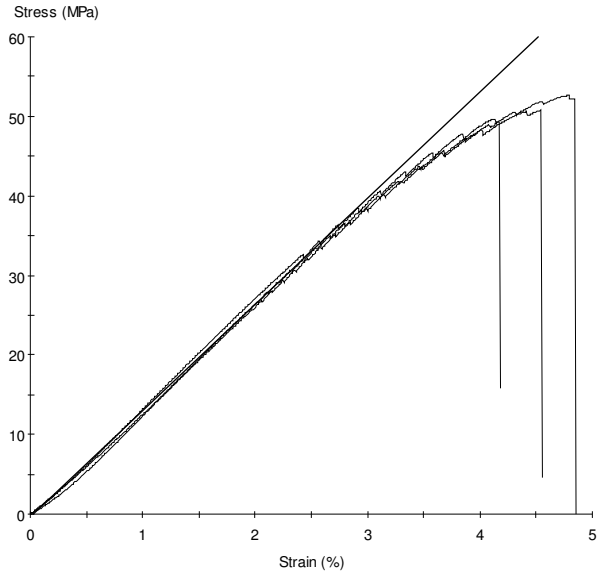
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	13.91	10.53	798	49.68	4.14	4.18	2.68	2.71	1390
2	13.48	10.47	810	52.62	4.79	4.85	3.12	3.16	1327
3	13.81	10.74	842	50.77	4.54	4.54	2.89	2.89	1380
Mean	**13.73**	**10.58**	**817**	**51.03**	**4.49**	**4.52**	**2.90**	**2.92**	**1366**
Std Dev	**0.23**	**0.14**	**23**	**1.49**	**0.33**	**0.34**	**0.22**	**0.23**	**34**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-42 80 GY-191 40 Aradur 250
(I) STS Job Number:	15% NaOH
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

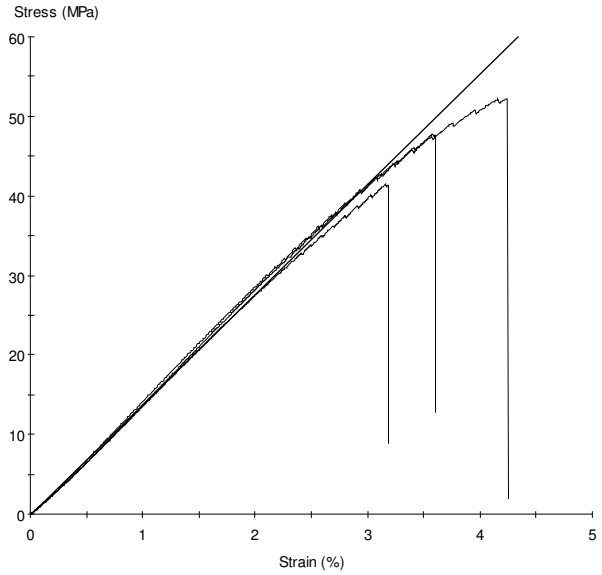
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	13.60	10.35	725	47.78	3.58	3.61	2.36	2.38	1438
2	13.51	10.62	829	52.23	4.25	4.25	2.73	2.73	1462
3	14.02	10.58	677	41.43	3.16	3.19	2.04	2.06	1406
Mean	**13.71**	**10.52**	**744**	**47.15**	**3.66**	**3.68**	**2.38**	**2.39**	**1435**
Std Dev	**0.27**	**0.15**	**78**	**5.43**	**0.55**	**0.53**	**0.34**	**0.34**	**28**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-43 80 GY-191 40 Aradur 250
(I) STS Job Number:	10% NaOH
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

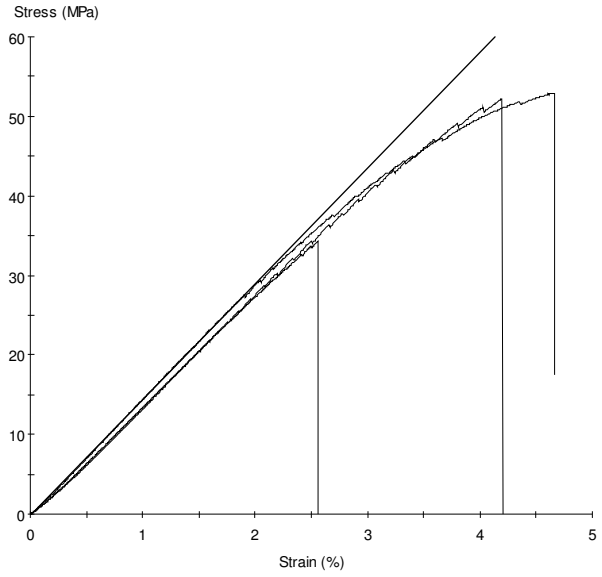
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	13.70	10.71	561	34.27	2.55	2.56	1.63	1.63	1387
2	13.29	10.54	803	52.20	4.20	4.20	2.72	2.72	1412
3	13.09	8.26	492	52.93	4.66	4.66	3.85	3.85	1471
Mean	**13.36**	**9.84**	**619**	**46.47**	**3.80**	**3.80**	**2.73**	**2.73**	**1423**
Std Dev	**0.31**	**1.37**	**163**	**10.57**	**1.11**	**1.10**	**1.11**	**1.11**	**44**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-44 80 GY-191 40 Aradur 250
(I) STS Job Number:	5% NaOH
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

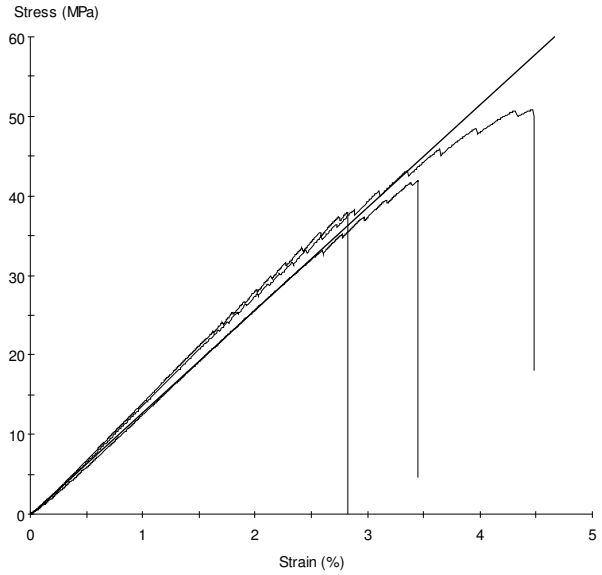
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	14.10	10.54	619	37.94	2.82	2.82	1.83	1.83	1435
2	14.12	10.52	828	50.89	4.48	4.48	2.90	2.91	1387
3	13.76	10.67	684	41.94	3.45	3.45	2.21	2.21	1310
Mean	**13.99**	**10.58**	**711**	**43.59**	**3.58**	**3.59**	**2.31**	**2.31**	**1377**
Std Dev	**0.20**	**0.08**	**107**	**6.63**	**0.84**	**0.84**	**0.55**	**0.55**	**63**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-47 80-20 EHO-TC
(I) STS Job Number:	1g Hemp Fibre
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

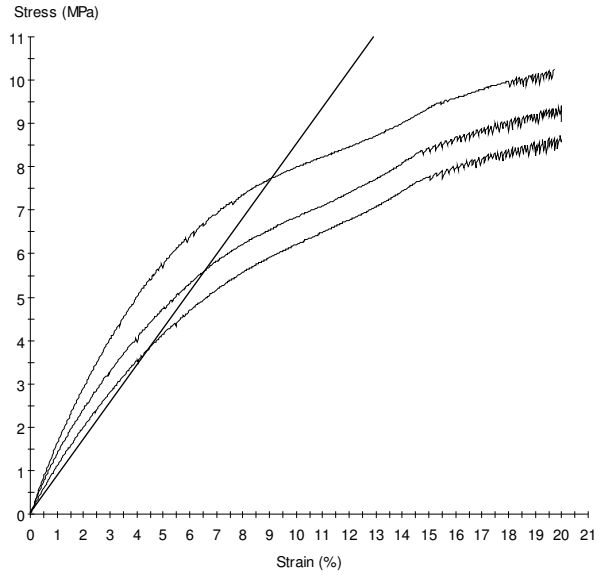
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	13.83	10.56	165	10.25	19.73	****	12.75	****	124
2	13.71	10.44	146	9.40	20.00	****	13.08	****	93
3	13.38	10.48	134	8.73	19.94	****	12.99	****	84
Mean	**13.64**	**10.49**	**148**	**9.46**	**19.89**	****	**12.94**	****	**100**
Std Dev	**0.23**	**0.06**	**16**	**0.76**	**0.14**	****	**0.17**	****	**21**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-48 80-20 EHO-TC
(I) STS Job Number:	2g Hemp Fibre
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

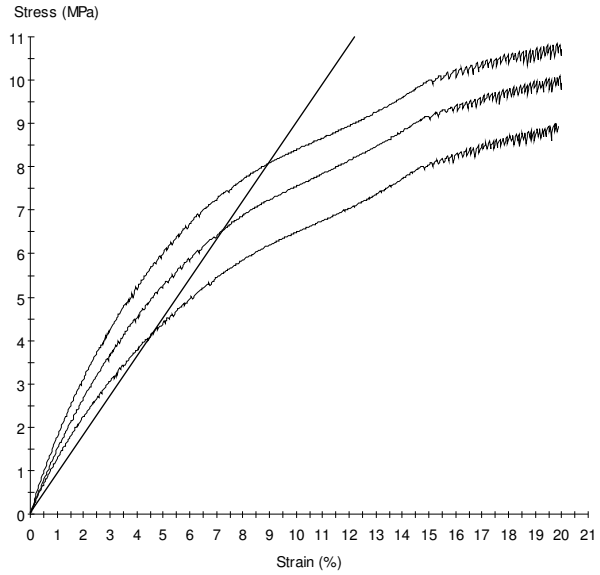
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	14.31	10.56	180	10.84	19.83	****	12.82	****	135
2	13.52	10.53	157	10.09	19.94	****	12.93	****	99
3	13.72	10.46	141	9.00	19.80	****	12.92	****	88
Mean	**13.85**	**10.52**	**159**	**9.98**	**19.86**	****	**12.89**	****	**107**
Std Dev	**0.41**	**0.05**	**20**	**0.93**	**0.07**	****	**0.06**	****	**24**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-49 80-20 EHO-TC
(I) STS Job Number:	3g Hemp Fibre
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

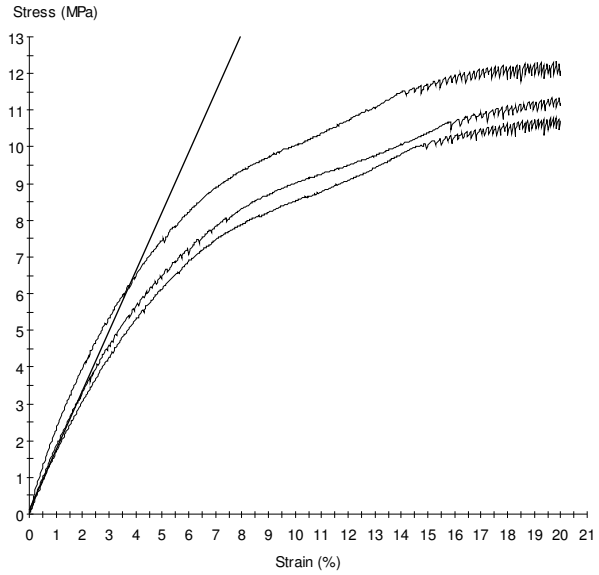
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	13.20	10.55	174	11.34	19.94	****	12.90	****	145
2	14.54	10.43	178	10.80	19.62	****	12.84	****	128
3	13.97	10.43	195	12.32	19.85	****	12.99	****	161
Mean	**13.90**	**10.47**	**182**	**11.49**	**19.80**	****	**12.91**	****	**145**
Std Dev	**0.67**	**0.07**	**11**	**0.77**	**0.17**	****	**0.08**	****	**17**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-50 80-20 EHO-TC
(I) STS Job Number:	4g Hemp Fibre
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

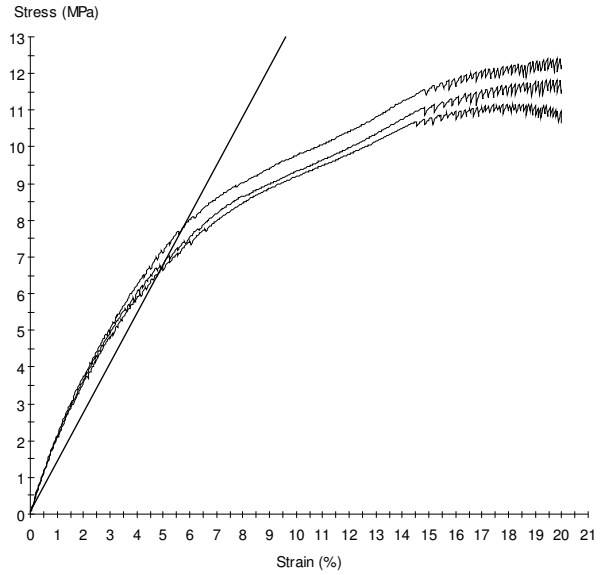
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	14.97	10.52	193	11.17	18.54	****	12.03	****	138
2	14.06	10.50	201	12.43	19.95	****	12.97	****	148
3	15.06	10.52	205	11.84	19.82	****	12.86	****	131
Mean	**14.70**	**10.51**	**200**	**11.81**	**19.43**	****	**12.62**	****	**139**
Std Dev	**0.55**	**0.01**	**6**	**0.63**	**0.78**	****	**0.51**	****	**8**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	S-51 80-20 EHO-TC
(I) STS Job Number:	7.5g Hemp Fibre
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 4 Hours @ 80°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

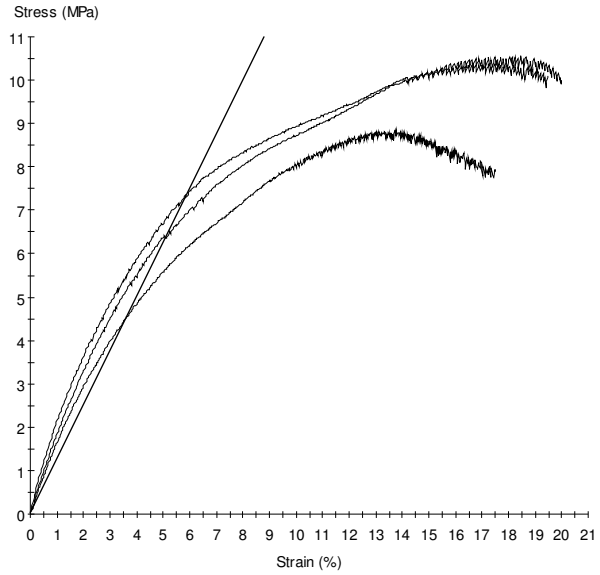
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	14.73	10.50	179	10.56	18.47	****	12.01	****	141
2	14.81	10.56	178	10.37	17.62	****	11.39	****	167
3	15.26	8.82	109	8.84	13.72	****	10.62	****	123
Mean	**14.93**	**9.96**	**155**	**9.92**	**16.60**	****	**11.34**	****	**143**
Std Dev	**0.29**	**0.99**	**40**	**0.94**	**2.53**	****	**0.70**	****	**22**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	Hand Laid Neat EPOXY - Control
(I) STS Job Number:	HL 5
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 16 Hours @ 40°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

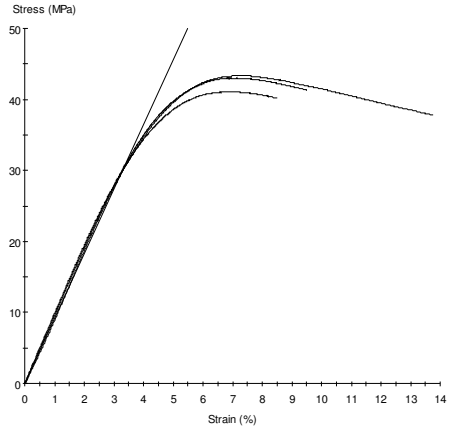
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	15.22	6.85	322	43.34	7.26	****	7.23	****	936
2	15.29	6.05	240	41.08	6.90	****	7.78	****	956
3	15.24	6.38	278	43.02	6.91	****	7.39	****	940
Mean	**15.25**	**6.43**	**280**	**42.48**	**7.02**	****	**7.47**	****	**944**
Std Dev	**0.04**	**0.40**	**41**	**1.22**	**0.20**	****	**0.28**	****	**11**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	Hand Laid UD Glass Fibres EPOXY
(I) STS Job Number:	HL 6
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 16 Hours @ 40°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

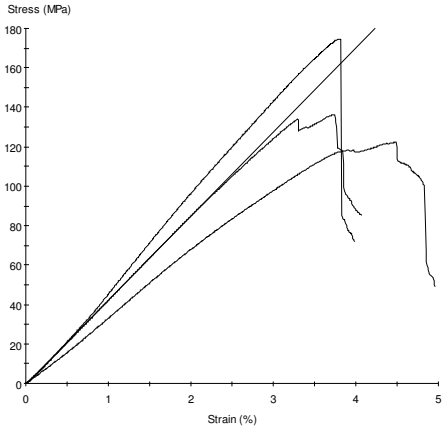
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	15.38	5.18	586	136.37	3.74	****	4.92	****	4291
2	15.24	4.89	464	122.19	4.49	4.86	6.27	6.78	3429
3	15.22	4.38	531	174.58	3.80	3.82	5.92	5.96	4970
Mean	**15.28**	**4.82**	**527**	**144.38**	**4.01**	**4.34**	**5.70**	**6.37**	**4230**
Std Dev	**0.09**	**0.41**	**61**	**27.10**	**0.42**	**0.73**	**0.70**	**0.58**	**772**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	Hand Laid Untreated Hemp EPOXY
(I) STS Job Number:	HL 7
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 16 Hours @ 40°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

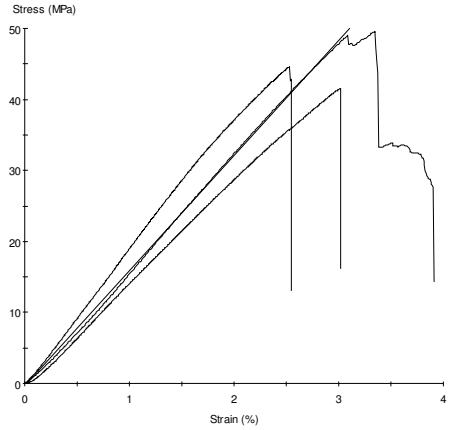
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	15.33	9.58	726	49.53	3.35	3.90	2.39	2.78	1642
2	15.28	10.11	676	41.52	3.01	3.01	2.04	2.04	1508
3	15.28	10.62	802	44.67	2.53	2.55	1.63	1.64	1929
Mean	**15.30**	**10.10**	**734**	**45.24**	**2.97**	**3.15**	**2.02**	**2.15**	**1693**
Std Dev	**0.03**	**0.52**	**64**	**4.04**	**0.41**	**0.69**	**0.38**	**0.58**	**215**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	Hand Laid 5% NaOH Treated Hemp EPOXY
(I) STS Job Number:	HL 8
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 16 Hours @ 40°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

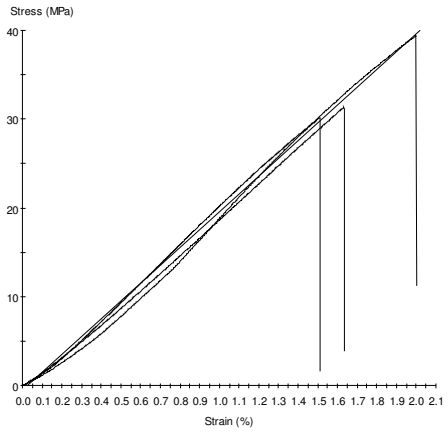
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	15.96	9.29	433	30.19	1.51	1.51	1.11	1.11	2050
2	15.65	8.61	476	39.41	2.00	2.00	1.59	1.59	2045
3	15.02	8.01	315	31.35	1.63	1.63	1.39	1.39	1905
Mean	**15.54**	**8.64**	**408**	**33.65**	**1.71**	**1.72**	**1.36**	**1.36**	**2000**
Std Dev	**0.48**	**0.64**	**84**	**5.02**	**0.25**	**0.25**	**0.24**	**0.24**	**83**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None



Stress vs Strain Plot

Sample Information:

(A) Client Name:	Nathan Manthey
(B) Address:	
(C) Address:	
(D) Address:	
(E) Attention:	
(F) Phone:	
(G) Fax:	
(H) Client Job ID:	Hand Laid 10% NaOH Treated Hemp EPOXY
(I) STS Job Number:	HL 9
(J) Sample Description:	Neat Resin Casting
(K) Principle Dimensions:	250mm x 250mm x 4mm
(L) Method of Manufacture:	Resin Cast into Glass Mould
(M) Nominal Specimen Dimensions:	80mm x 10mm x 4mm
(N) Casting Cure Schedule:	24 Hours @ Ambient, Post Cured 16 Hours @ 40°C
(O) Surface of Force Application:	N/A
(P) Nominal Span (mm):	64
(Q) Test Room Conditions:	24°C, 28% RH
(R) Conditioning Temp. & RH:	23°C, 50% RH Constant for 88 Hours
(S) Test Speed (mm/min):	4
(T) Specimen Preparation Method:	Specimen cut by diamond coated cutting wheel, edges sanded smooth & defect free

Test Equipment Details:

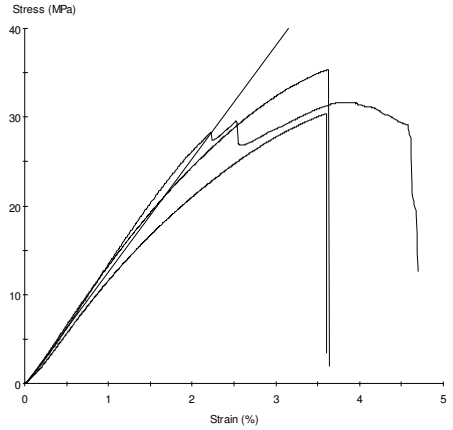
Test Machine:	MTS Alliance RT/10
Location:	P9 110 Test Laboratory, CEEFC, USQ
Accuracy Grading:	Grade A
Machine Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Strain Measurement Device:	Axial Displacement of Crosshead
Strain Calibration Date:	01/06/2007
Expiration Date:	01/06/2008
Load Cell Calibration Date:	01/06/2007
Expiration Date:	01/06/2008

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	15.84	9.48	525	35.40	3.63	3.63	2.62	2.62	1301
2	15.84	9.47	450	30.40	3.61	3.61	2.60	2.60	1104
3	15.84	9.39	460	31.62	3.93	4.68	2.86	3.41	1384
Mean	**15.84**	**9.45**	**478**	**32.47**	**3.72**	**3.98**	**2.69**	**2.87**	**1263**
Std Dev	**0.00**	**0.05**	**41**	**2.61**	**0.18**	**0.61**	**0.14**	**0.46**	**144**

Specimen Comments:

Specimen #	Failure Mode
1	None
2	None
3	None

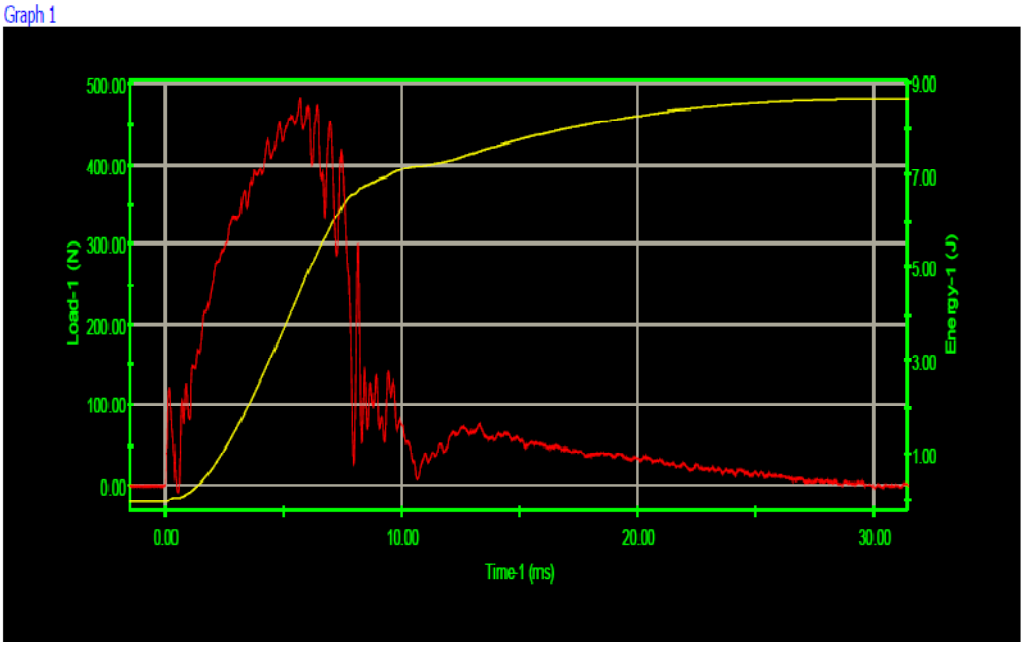


Stress vs Strain Plot

Appendix D: Impact Test Results

HL-6

Graph 1

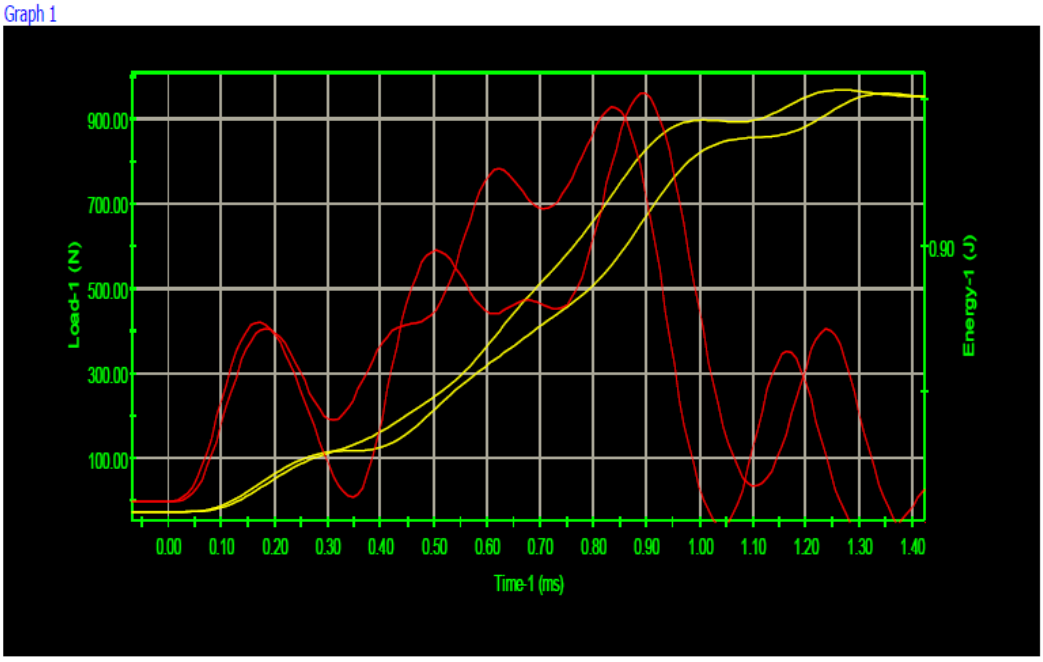


Results Table

Test no	Time to max load-1 (ms)	Maximum load-1 (N)	Impact velocity-1 (m/s)	Total energy-1 (J)	Total time-1 (ms)
1	5.7037	481.8	2.9152	8.6242	29.9194
Average	5.7037	481.8077	2.9152	8.6242	29.9194
Median	5.7037	481.8077	2.9152	8.6242	29.9194
Minimum	5.7037	481.8077	2.9152	8.6242	29.9194
Maximum	5.7037	481.8077	2.9152	8.6242	29.9194
Coef. of Var.	0.0000	0.0000	0.0000	0.0000	0.0000
Std. Dev.	0.0000	0.0000	0.0000	0.0000	0.0000

HL-7

Graph 1

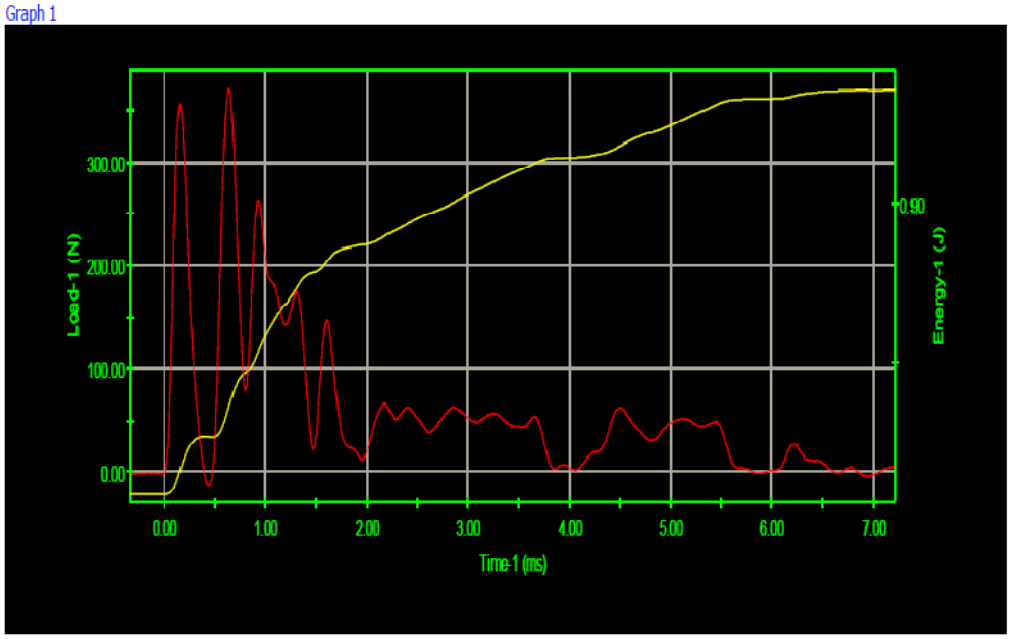


Results Table

Test no	Time to max load-1 (ms)	Maximum load-1 (N)	Impact velocity-1 (m/s)	Total energy-1 (J)	Total time-1 (ms)
1	0.8331	929.5	2.8852	1.3255	1.0162
2	0.8881	962.7	2.8926	1.4154	1.3550
Average	0.8606	946.0965	2.8889	1.3705	1.1856
Median	0.8606	946.0965	2.8889	1.3705	1.1856
Minimum	0.8331	929.4983	2.8852	1.3255	1.0162
Maximum	0.8881	962.6947	2.8926	1.4154	1.3550
Coef. of Var.	0.0000	0.0000	0.0000	0.0000	0.0000
Std. Dev.	0.0000	0.0000	0.0000	0.0000	0.0000

HL-8

Graph 1

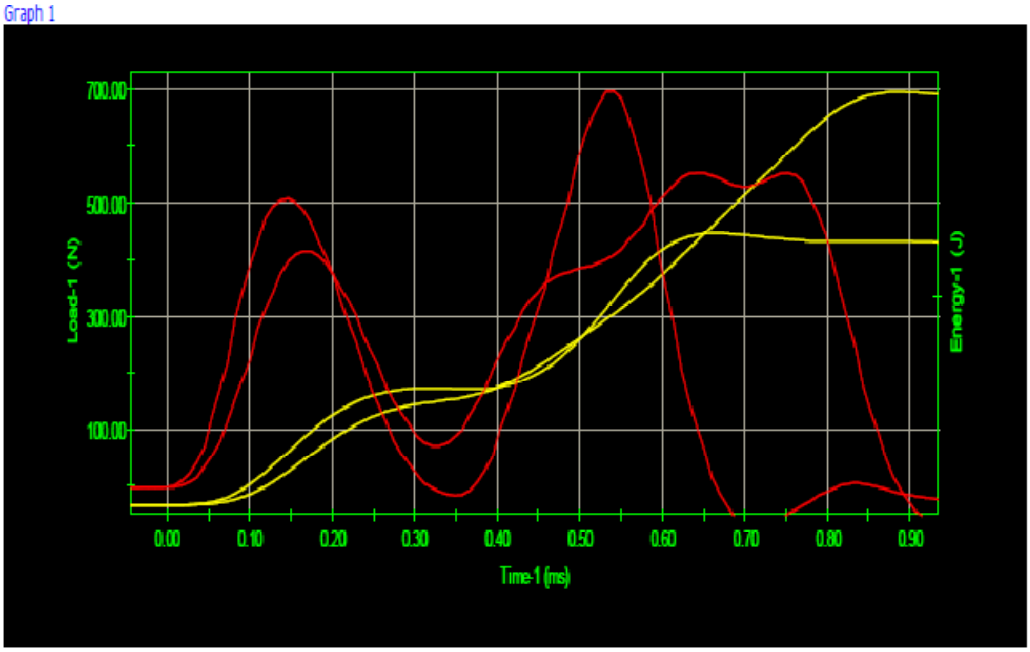


Results Table

Test no	Time to max load-1 (ms)	Maximum load-1 (N)	Impact velocity-1 (m/s)	Total energy-1 (J)	Total time-1 (ms)
1	0.6409	369.8	2.9034	1.2451	6.8756
Average	0.6409	369.8075	2.9034	1.2451	6.8756
Median	0.6409	369.8075	2.9034	1.2451	6.8756
Minimum	0.6409	369.8075	2.9034	1.2451	6.8756
Maximum	0.6409	369.8075	2.9034	1.2451	6.8756
Coef. of Var.	0.0000	0.0000	0.0000	0.0000	0.0000
Std. Dev.	0.0000	0.0000	0.0000	0.0000	0.0000

HL-9

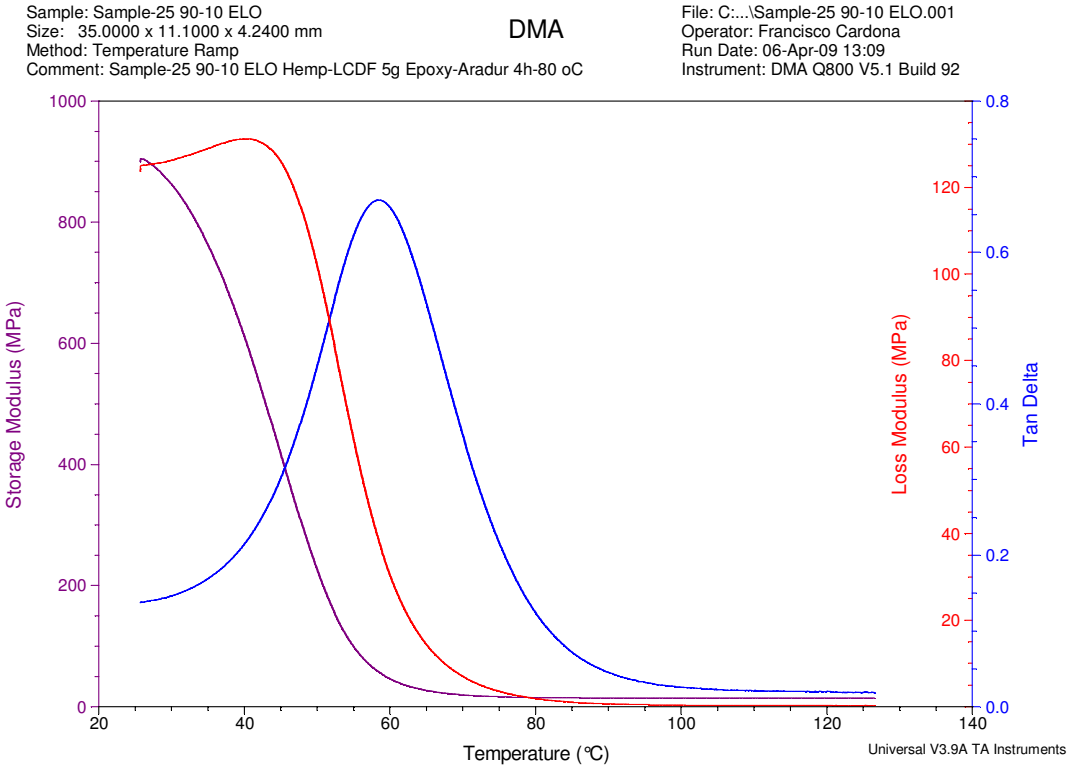
Graph 1

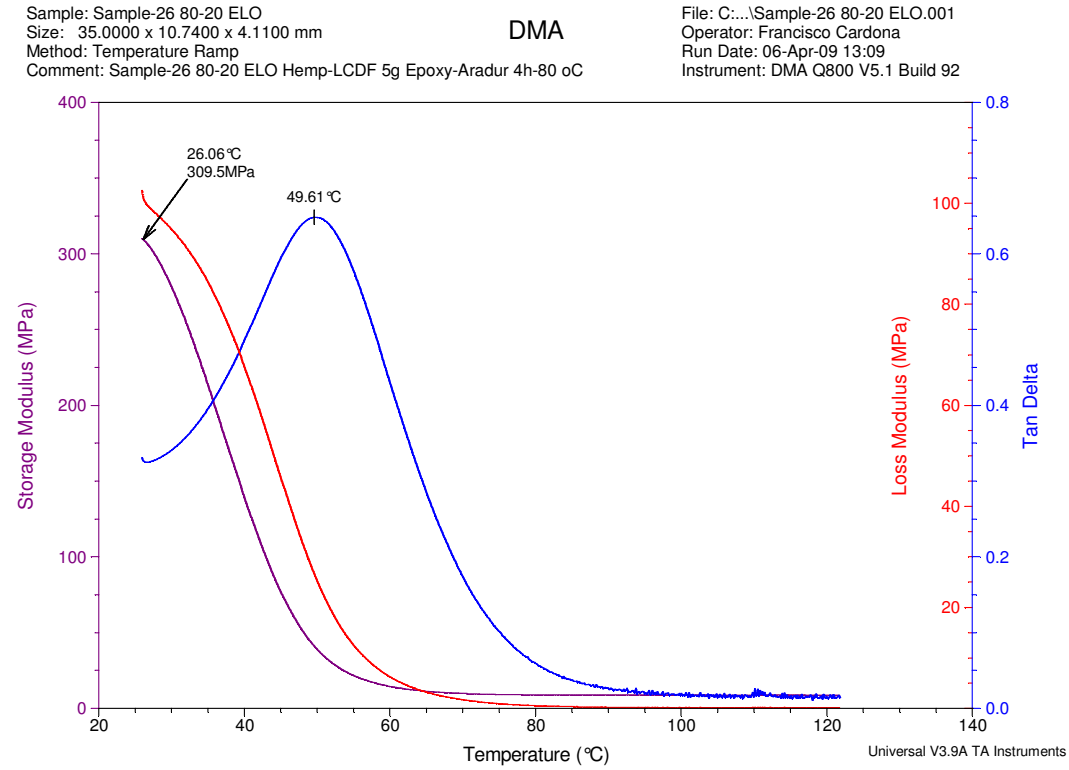


Results Table

Test no	Time to max load-1 (ms)	Maximum load-1 (N)	Impact velocity-1 (m/s)	Total energy-1 (J)	Total time-1 (ms)
1	0.5402	696.1	2.8902	0.5248	0.6683
2	0.6409	552.1	2.8985	0.7968	0.8881
Average	0.5905	624.1261	2.8943	0.6608	0.7782
Median	0.5905	624.1261	2.8943	0.6608	0.7782
Minimum	0.5402	552.1238	2.8902	0.5248	0.6683
Maximum	0.6409	696.1285	2.8985	0.7968	0.8881
Coef. of Var.	0.0000	0.0000	0.0000	0.0000	0.0000
Std. Dev.	0.0000	0.0000	0.0000	0.0000	0.0000

Appendix E: DMA Results

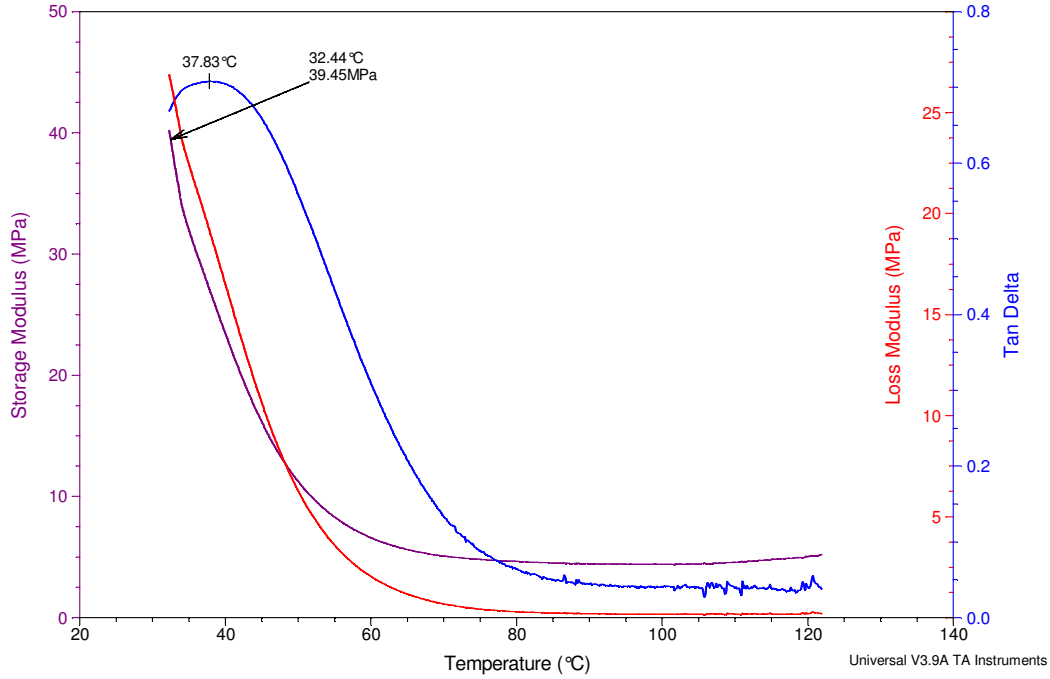




Sample: Sample-27 70-30 ELO
Size: 35.0000 x 10.5100 x 3.7600 mm
Method: Temperature Ramp
Comment: Sample-27 70-30 ELO Hemp-LCDF 5g Epoxy-Aradur 4h-80 oC

DMA

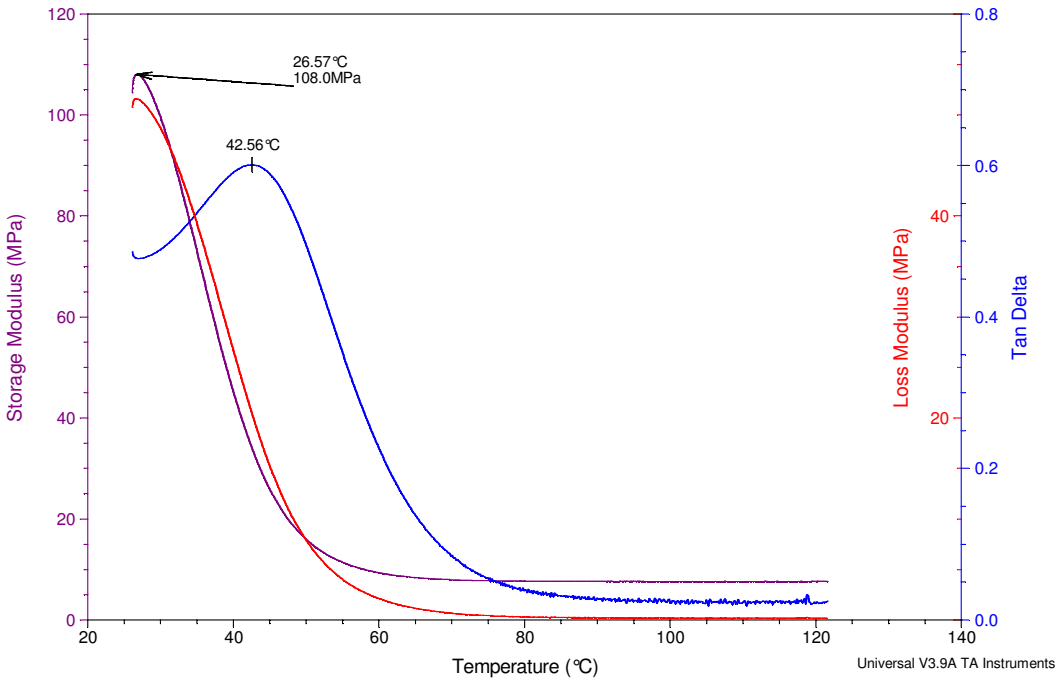
File: C:...\Sample-27 70-30 ELO.001
Operator: Francisco Cardona
Run Date: 06-Apr-09 13:09
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample-28 60-40 ELO
Size: 35.0000 x 12.7700 x 4.2600 mm
Method: Temperature Ramp
Comment: Sample-28 60-40 ELO Hemp-LCDF 5g Epoxy-Aradur 4h-80 oC

DMA

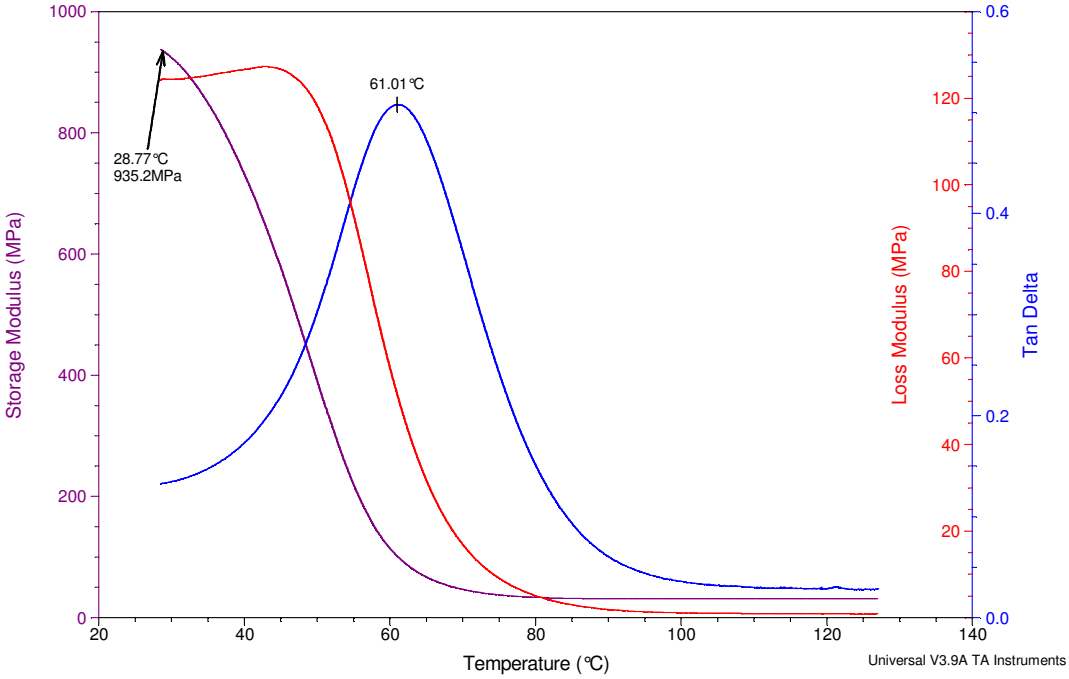
File: C:...\Sample-28 60-40 ELO.001
Operator: Francisco Cardona
Run Date: 06-Apr-09 13:09
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample 29 90-10 ESFO Tyson
Size: 35.0000 x 9.7000 x 4.3000 mm
Method: Temperature Ramp
Comment: Sample 29 90-10 ESFO Tyson Aradur HEMP-LCDC 5g 4h-80 oC

DMA

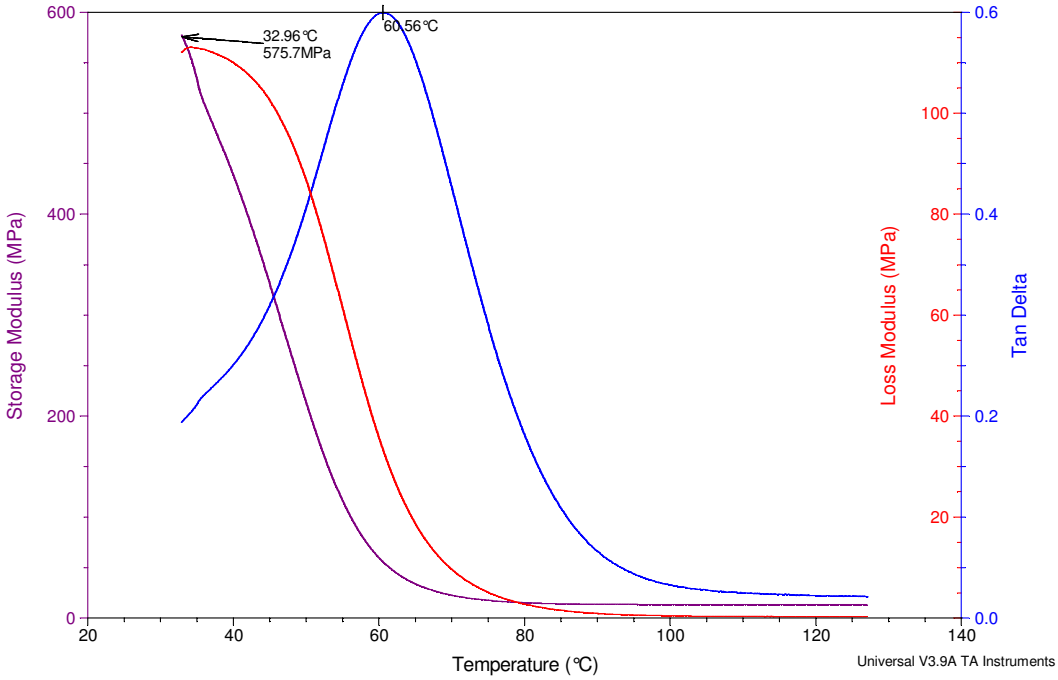
File: C:...\Sample 29 90-10 ESFO Tyson.001
Operator: Francisco Cardona
Run Date: 06-Apr-09 13:09
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample 30 80-20 ESFO Tyson
Size: 35.0000 x 11.3500 x 4.0800 mm
Method: Temperature Ramp
Comment: Sample 30 80-20 ESFO Tyson Aradur HEMP-LCDC 5g 4h-80 oC

DMA

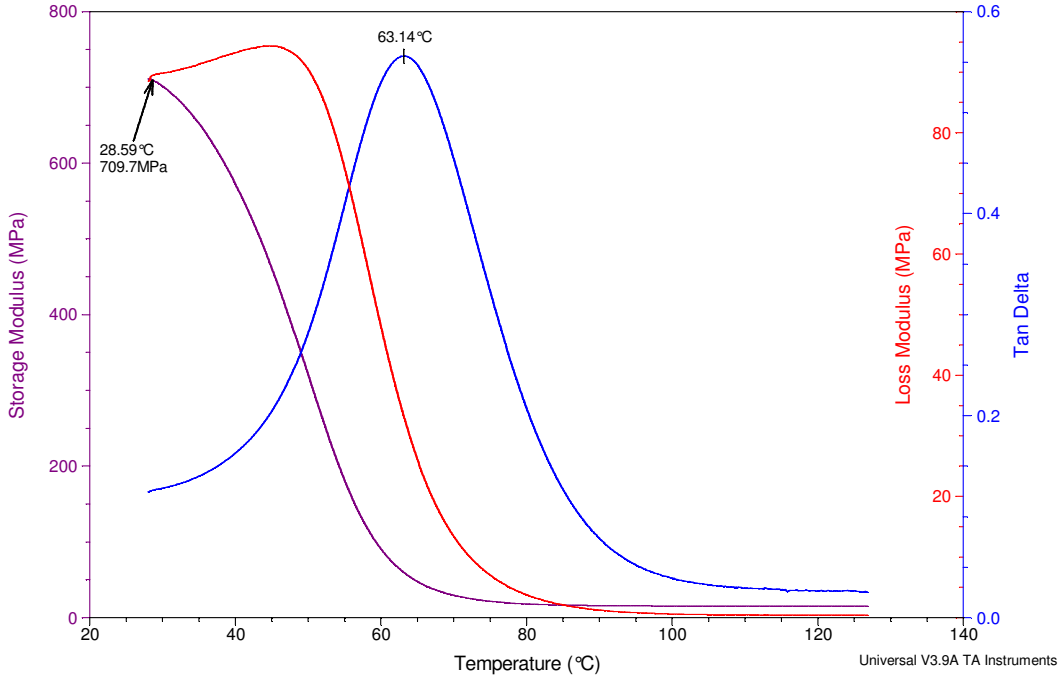
File: C:...\Sample 30 80-20 ESFO Tyson.001
Operator: Francisco Cardona
Run Date: 06-Apr-09 13:09
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample 31 70-30 ESFO Tyson
Size: 35.0000 x 12.1400 x 4.0500 mm
Method: Temperature Ramp
Comment: Sample 31 ESFO-Tyson Hemp-LCDF 5g 4h-80 oC

DMA

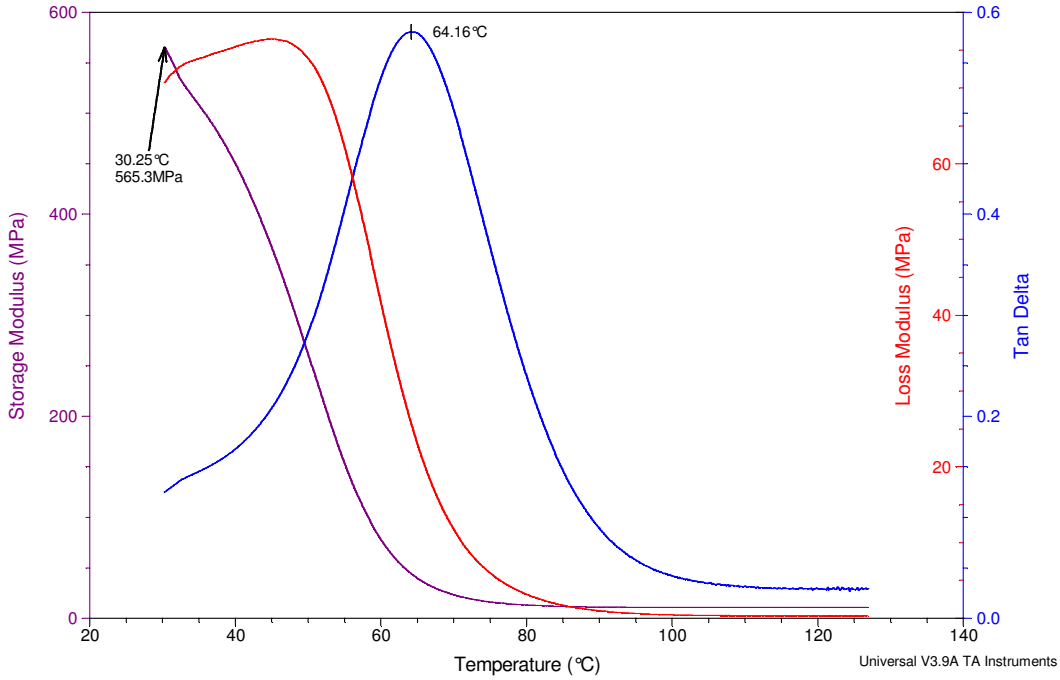
File: C:...\Sample 31 70-30 ESFO Tyson.001
Operator: Francisco Cardona
Run Date: 06-Apr-09 13:09
Instrument: DMA Q800 V5.1 Build 92

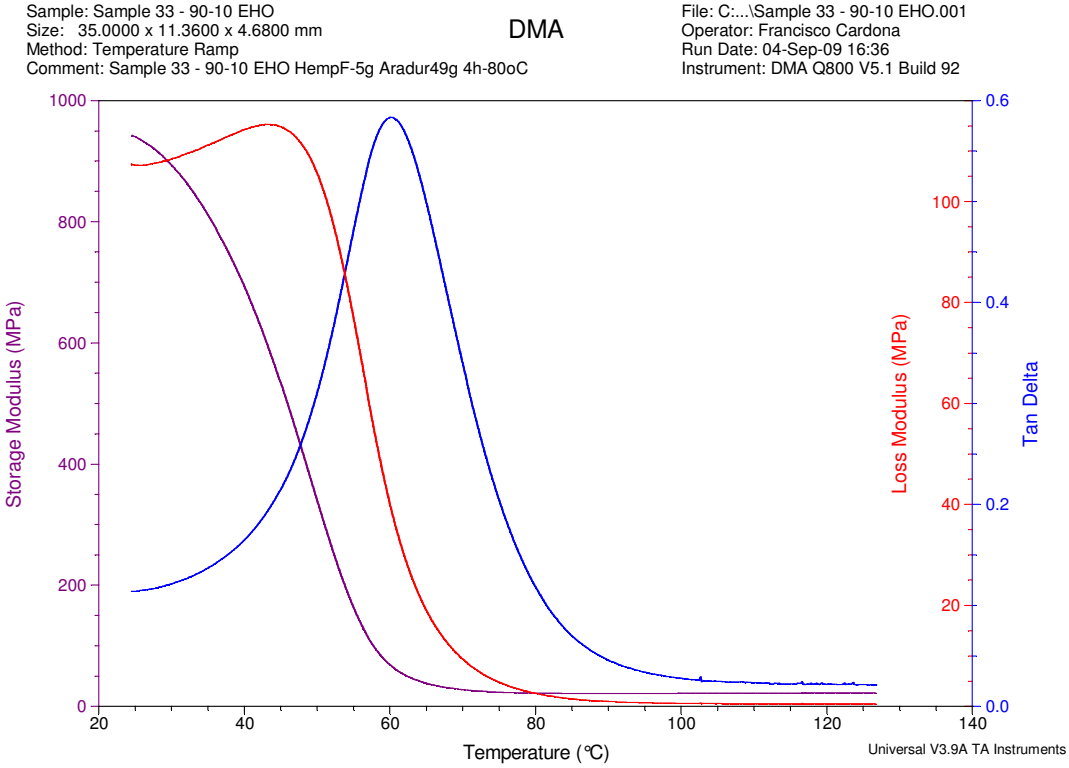


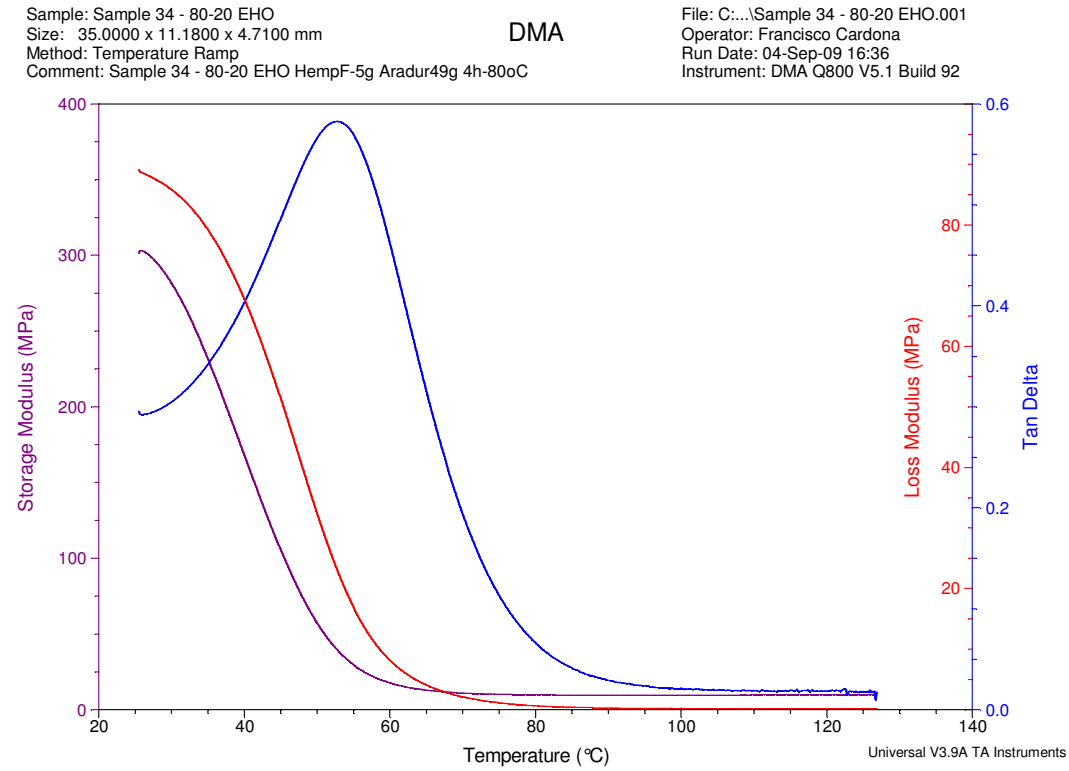
Sample: Sample 32 60-40 ESFO Tyson
Size: 35.0000 x 12.0400 x 4.2200 mm
Method: Temperature Ramp
Comment: Sample 32 60-40 ESFO-Tyson Hemp-LCDF 5g 4h-80 oC

DMA

File: C:...\Sample 32 60-40 ESFO Tyson.001
Operator: Francisco Cardona
Run Date: 06-Apr-09 13:09
Instrument: DMA Q800 V5.1 Build 92



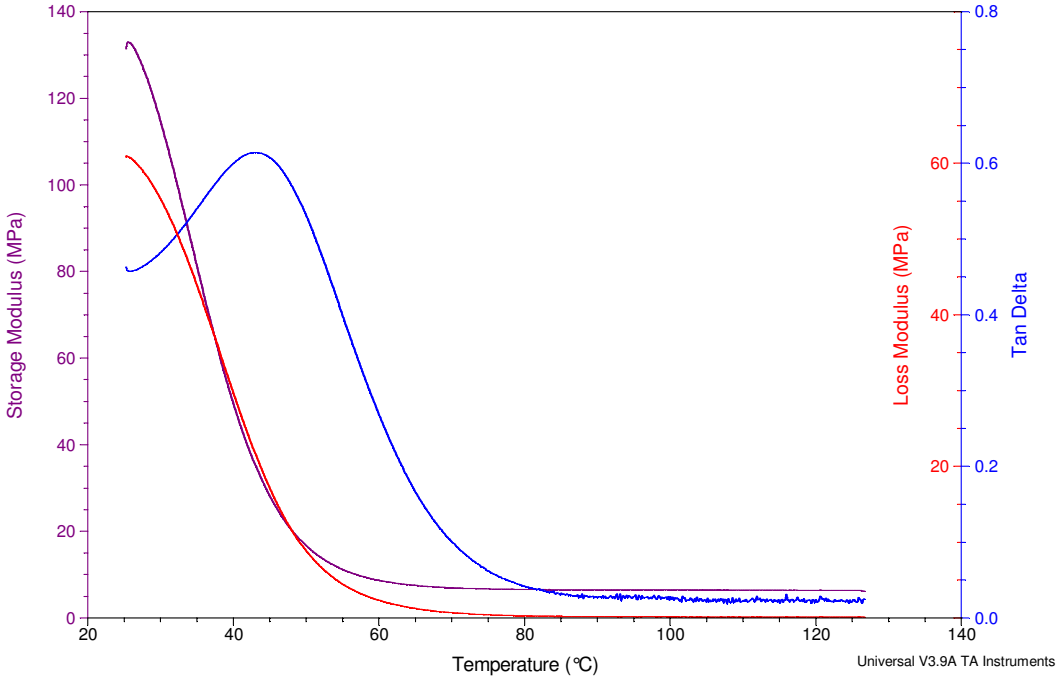

Sample: Sample 33 - 90-10 EHO
Size: 35.0000 x 11.3600 x 4.6800 mm
Method: Temperature Ramp
Comment: Sample 33 - 90-10 EHO HempF-5g Aradur49g 4h-80oC
DMA
File: C:...\Sample 33 - 90-10 EHO.001
Operator: Francisco Cardona
Run Date: 04-Sep-09 16:36
Instrument: DMA Q800 V5.1 Build 92
Storage Modulus (MPa)
Loss Modulus (MPa)
Tan Delta
Temperature (°C)
Universal V3.9A TA Instruments


Sample: Sample 34 - 80-20 EHO
Size: 35.0000 x 11.1800 x 4.7100 mm
Method: Temperature Ramp
Comment: Sample 34 - 80-20 EHO HempF-5g Aradur49g 4h-80oC
DMA
File: C:...\Sample 34 - 80-20 EHO.001
Operator: Francisco Cardona
Run Date: 04-Sep-09 16:36
Instrument: DMA Q800 V5.1 Build 92
Storage Modulus (MPa)
Loss Modulus (MPa)
Tan Delta
Temperature (°C)
Universal V3.9A TA Instruments

Sample: Sample 35 - 70-30 ELO
Size: 35.0000 x 11.4000 x 4.1600 mm
Method: Temperature Ramp
Comment: Sample 35 - 70-30 ELO HempF-5g Aradur49g 4h-80oC

DMA

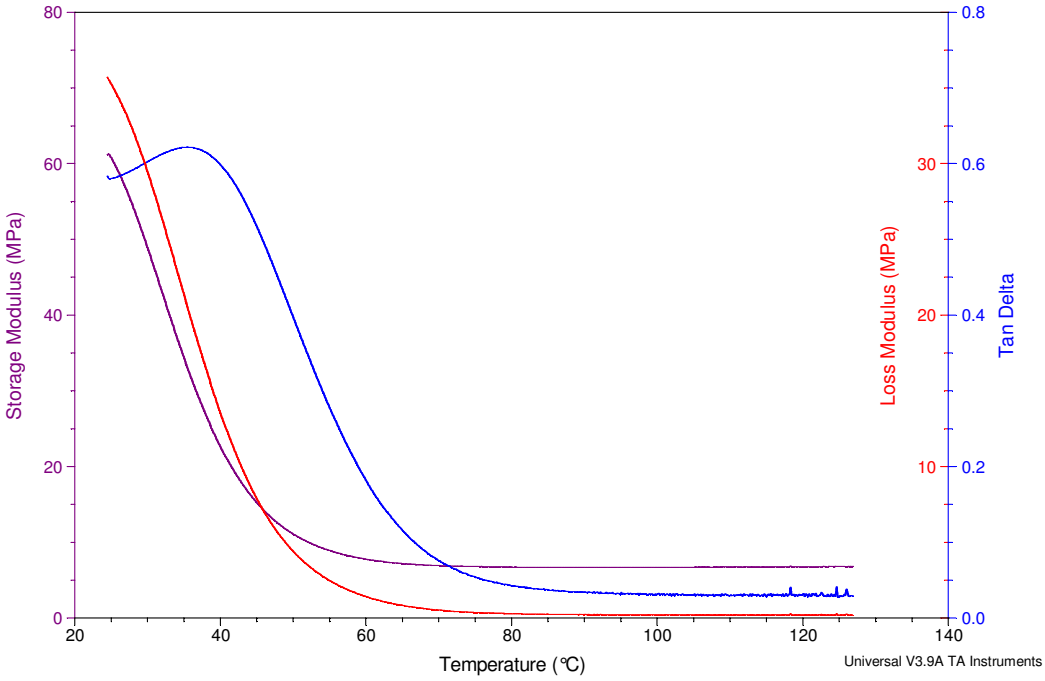
File: C:...\Sample 35 - 70-30 ELO.001
Operator: Francisco Cardona
Run Date: 04-Sep-09 16:36
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample 36 - 60-40 ELO
Size: 35.0000 x 11.5400 x 5.0000 mm
Method: Temperature Ramp
Comment: Sample 36 - 60-40 ELO HempF-5g Aradur49g 4h-80oC

DMA

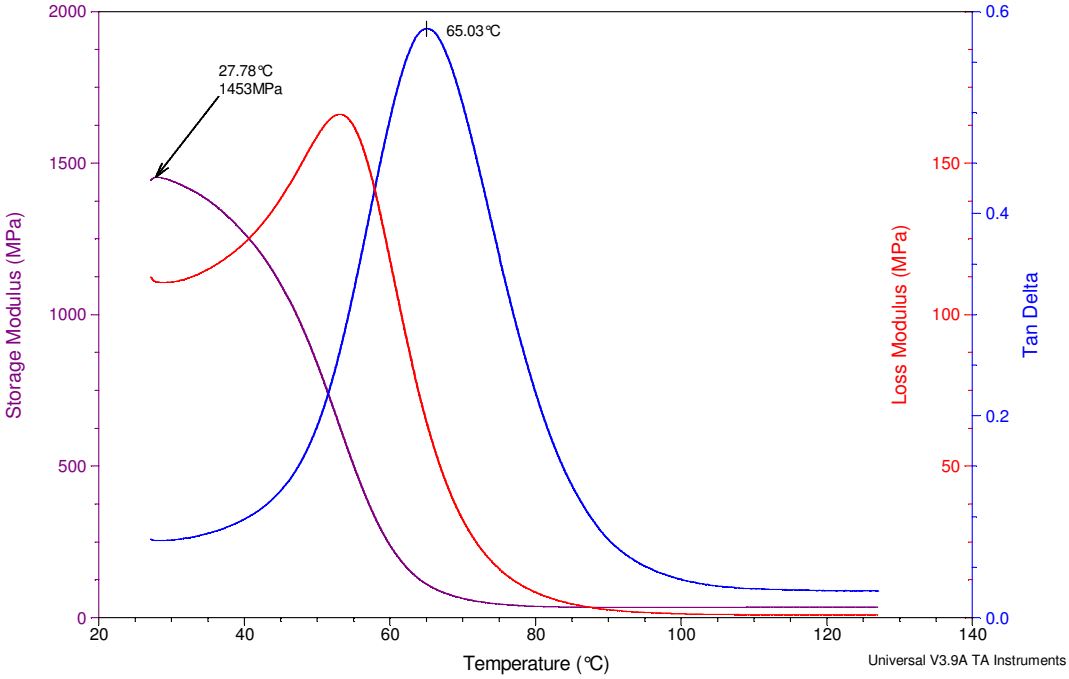
File: C:...\Sample 36 - 60-40 ELO.001
Operator: Francisco Cardona
Run Date: 04-Sep-09 16:36
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample 37 neat Epoxy Hemp-LCDF
Size: 35.0000 x 11.2500 x 3.9900 mm
Method: Temperature Ramp
Comment: Sample 37 neat Epoxy Aradur HEMP-LCDC 5g 4h-80 oC

DMA

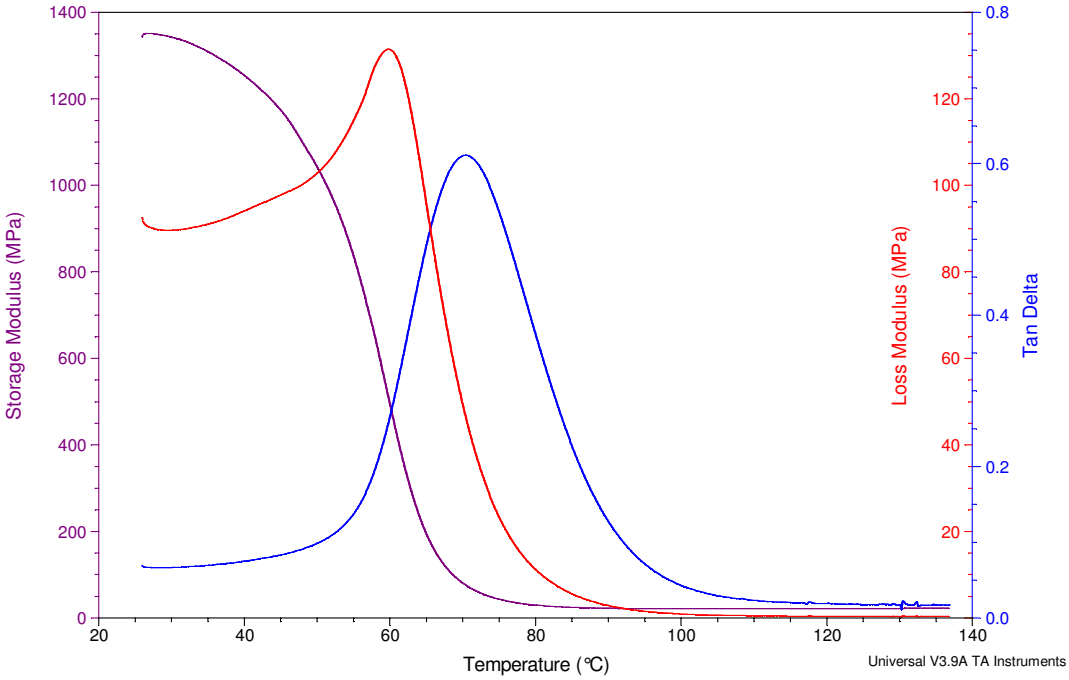
File: C:...\Sample 37 neat Epoxy Hemp-LCDC.001
Operator: Francisco Cardona
Run Date: 06-Apr-09 13:09
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample 41 -Neat Epoxy
Size: 35.0000 x 9.6700 x 5.0200 mm
Method: Temperature Ramp
Comment: Sample 41 -Neat EpoxyGY-191 HempF-5g Aradur40g 4h-80oC

DMA

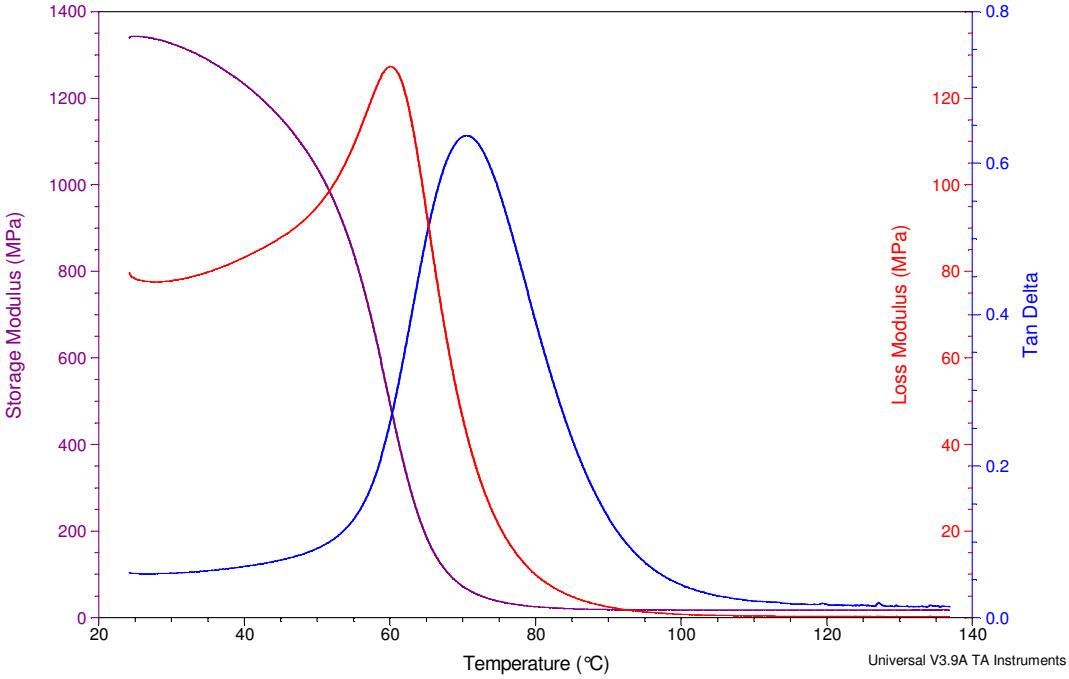
File: C:...\Sample 41 -Neat Epoxy.001
Operator: Francisco Cardona
Run Date: 04-Sep-09 16:36
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample 42 -Neat Epoxy
Size: 35.0000 x 9.6700 x 5.0500 mm
Method: Temperature Ramp
Comment: Sample 42 -Neat EpoxyGY-191 HempF-5g Aradur40g 4h-80oC

DMA

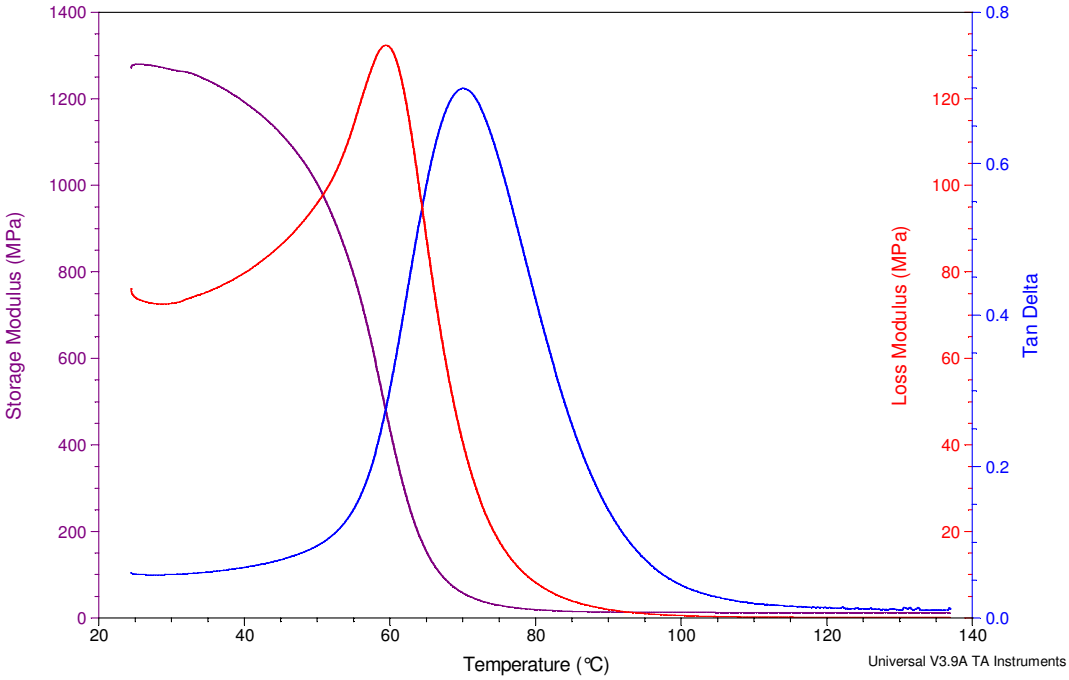
File: C:...\Sample 42 -Neat Epoxy.001
Operator: Francisco Cardona
Run Date: 04-Sep-09 16:36
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample 43 neat Epoxy-GY191
Size: 35.0000 x 9.3100 x 4.9800 mm
Method: Temperature Ramp
Comment: Sample 43 neat Epoxy-GY191 Arzdur250 + 5g-HempF treated 10%-NaO

DMA

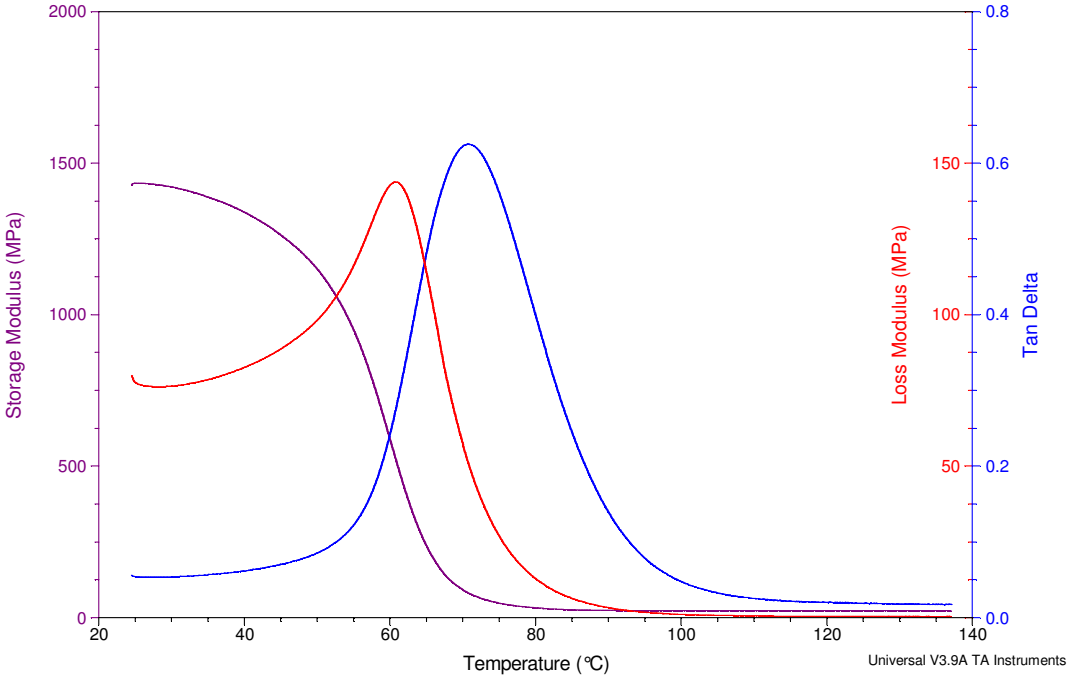
File: C:...\Sample 43 neat Epoxy-GY191.001
Operator: Francisco Cardona
Run Date: 04-Sep-09 16:36
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample 44 neat Epoxy-GY191
Size: 35.0000 x 8.3500 x 4.9800 mm
Method: Temperature Ramp
Comment: Sample 44 neat Epoxy-GY191 Arzdur250 + 5g-HempF treated 5%-NaO

DMA

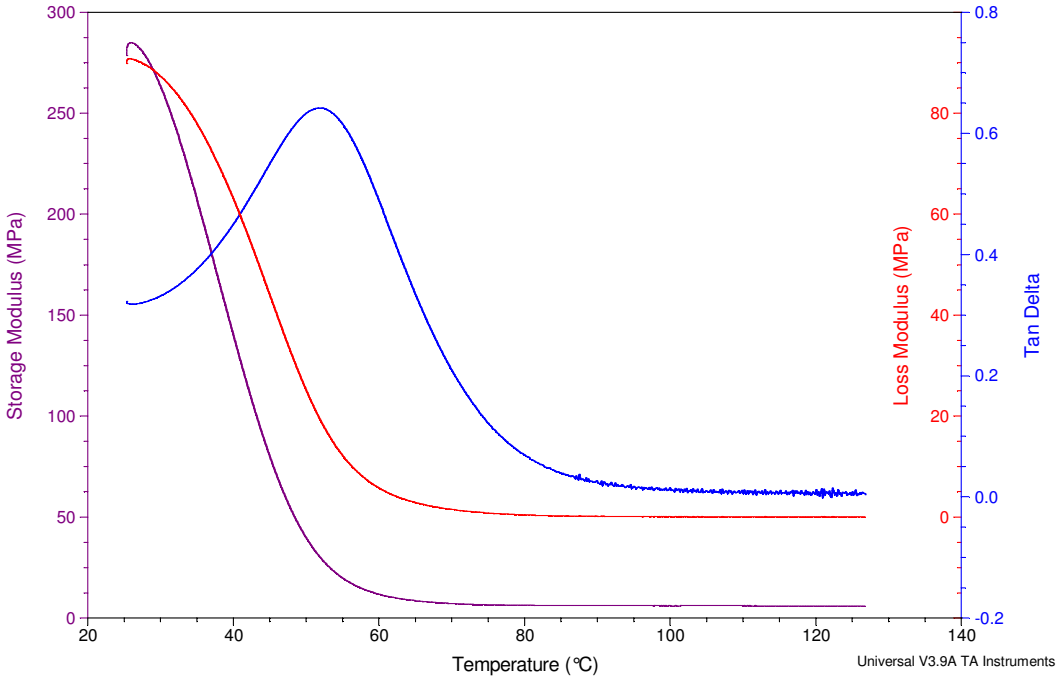
File: C:...\Sample 44 neat Epoxy-GY191.001
Operator: Francisco Cardona
Run Date: 04-Sep-09 16:36
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample 47 80-20 EHO-TC
Size: 35.0000 x 8.0000 x 4.9100 mm
Method: Temperature Ramp
Comment: Sample 47 80-20 EHO-TC Arzdur250 + 5g-HempF

DMA

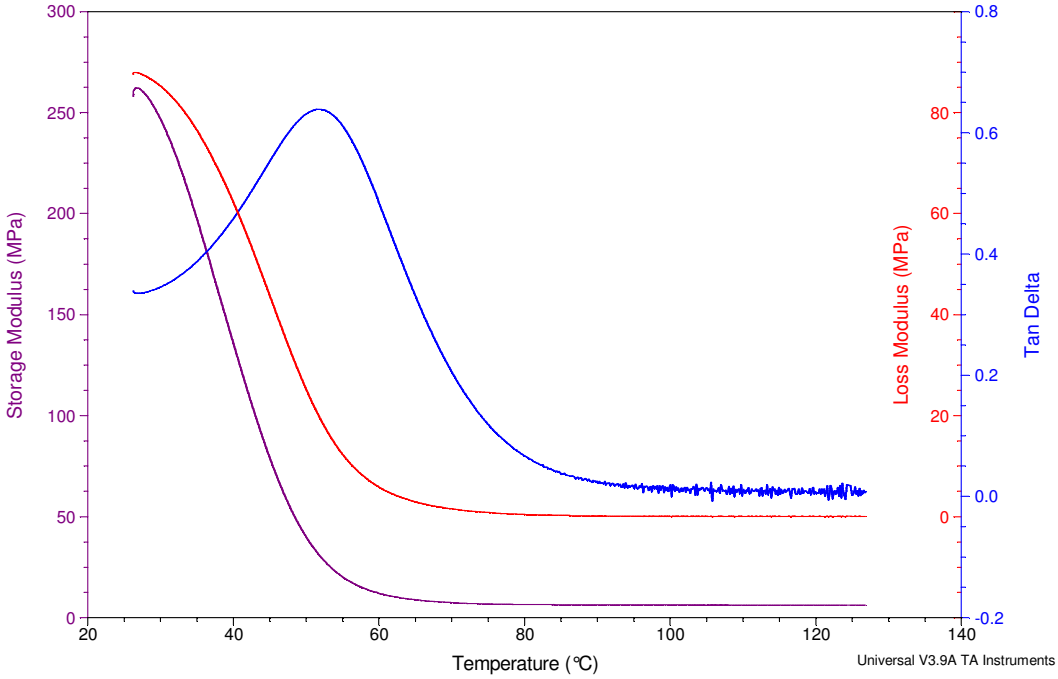
File: C:...\Sample 47 80-20 EHO-TC.001
Operator: Francisco Cardona
Run Date: 04-Sep-09 16:36
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample 48 80-20 EHO-TC
Size: 35.0000 x 9.0100 x 4.8200 mm
Method: Temperature Ramp
Comment: Sample 48 80-20 EHO-TC Arzdur250 + 2g-HempF

DMA

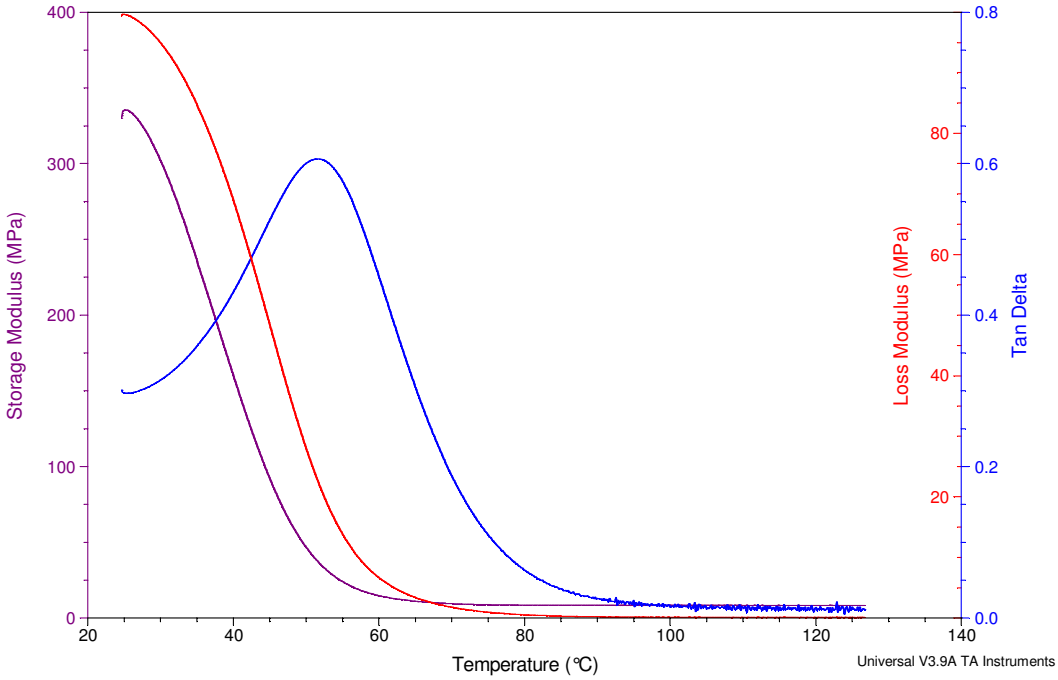
File: C:...\Sample 48 80-20 EHO-TC.001
Operator: Francisco Cardona
Run Date: 04-Sep-09 16:36
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample 49 80-20 EHO-TC
Size: 35.0000 x 8.7300 x 4.7200 mm
Method: Temperature Ramp
Comment: Sample 49 80-20 EHO-TC Arzdur250 + 3g-HempF

DMA

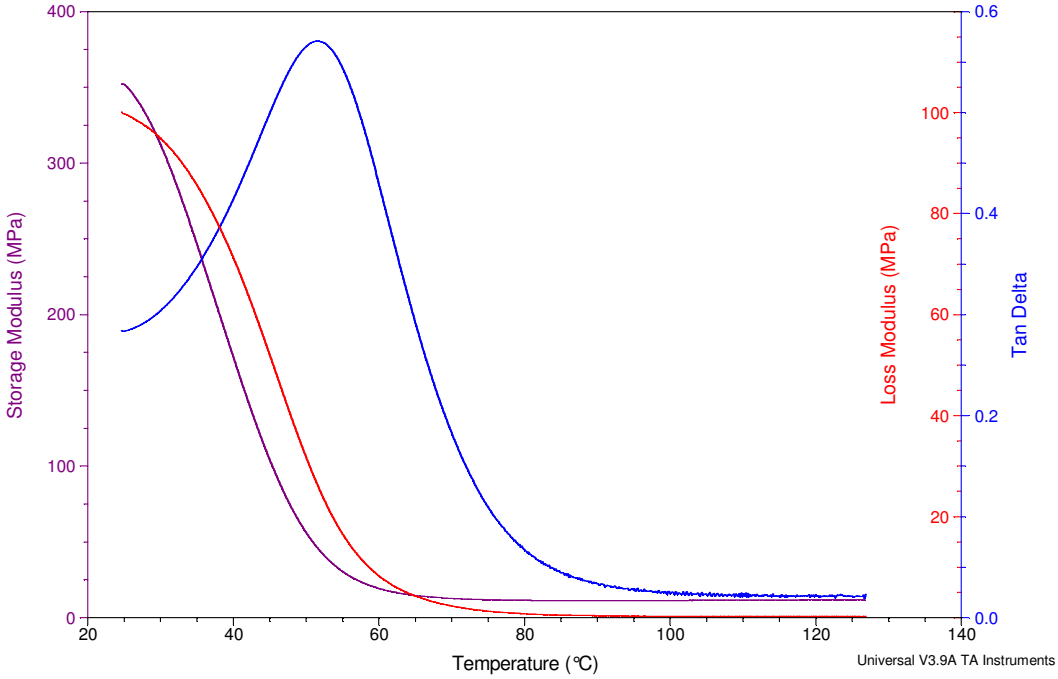
File: C:...\Sample 49 80-20 EHO-TC.001
Operator: Francisco Cardona
Run Date: 04-Sep-09 16:36
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample 50 80-20 EHO-TC
Size: 35.0000 x 8.7300 x 4.7600 mm
Method: Temperature Ramp
Comment: Sample 50 80-20 EHO-TC Arzdur250 + 4g-HempF

DMA

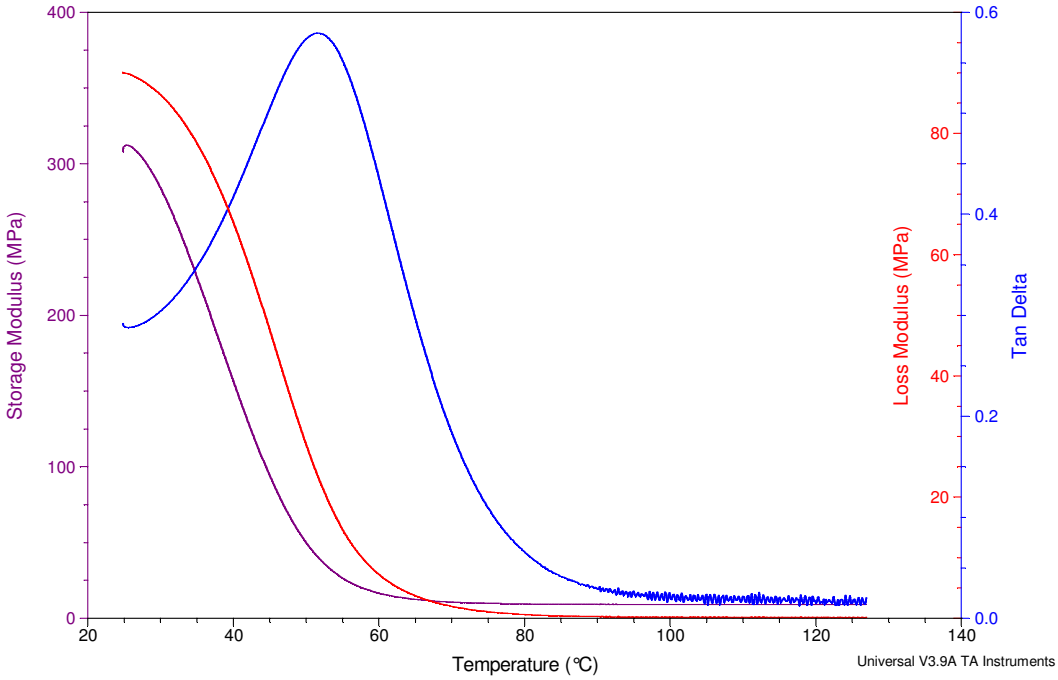
File: C:...\Sample 50 80-20 EHO-TC.001
Operator: Francisco Cardona
Run Date: 04-Sep-09 16:36
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample 51 80-20 EHO-TC
Size: 35.0000 x 8.4100 x 4.8700 mm
Method: Temperature Ramp
Comment: Sample 51 80-20 EHO-TC Arzdur250 + 7.5g-HempF

DMA

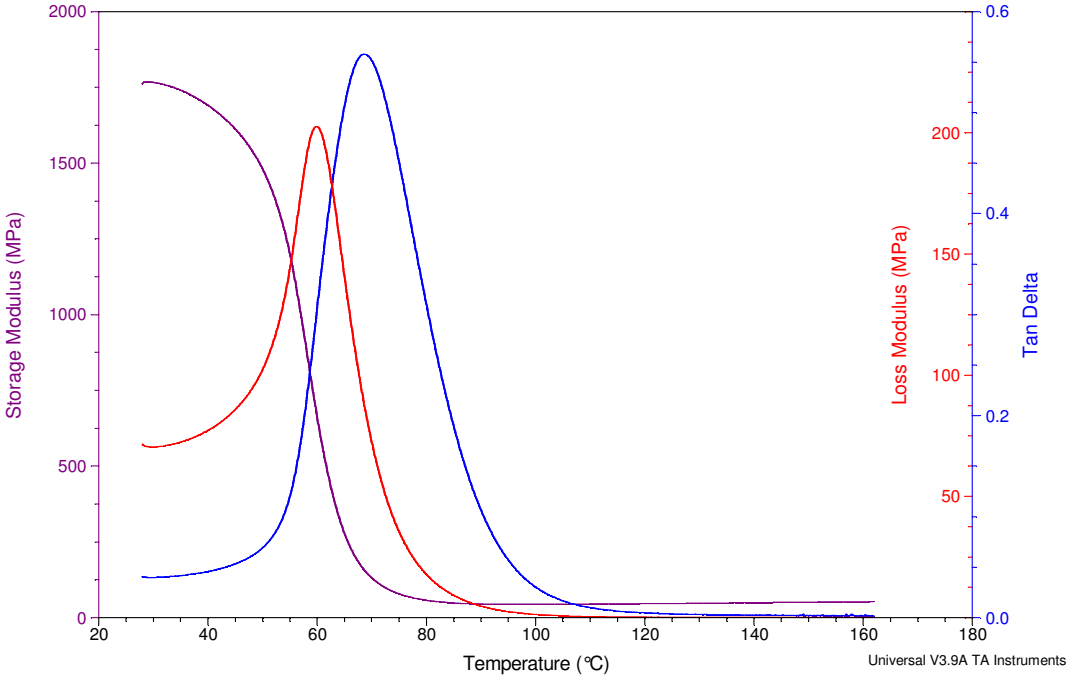
File: C:...\Sample 51 80-20 EHO-TC.001
Operator: Francisco Cardona
Run Date: 04-Sep-09 16:36
Instrument: DMA Q800 V5.1 Build 92



Sample: Sample- HL6 UD GlassF
Size: 35.0000 x 5.3800 x 5.6900 mm
Method: Temperature Ramp
Comment: Sample- HL6 UD GlassF- Epoxy GY191-Aradur250 4h-80oC

DMA

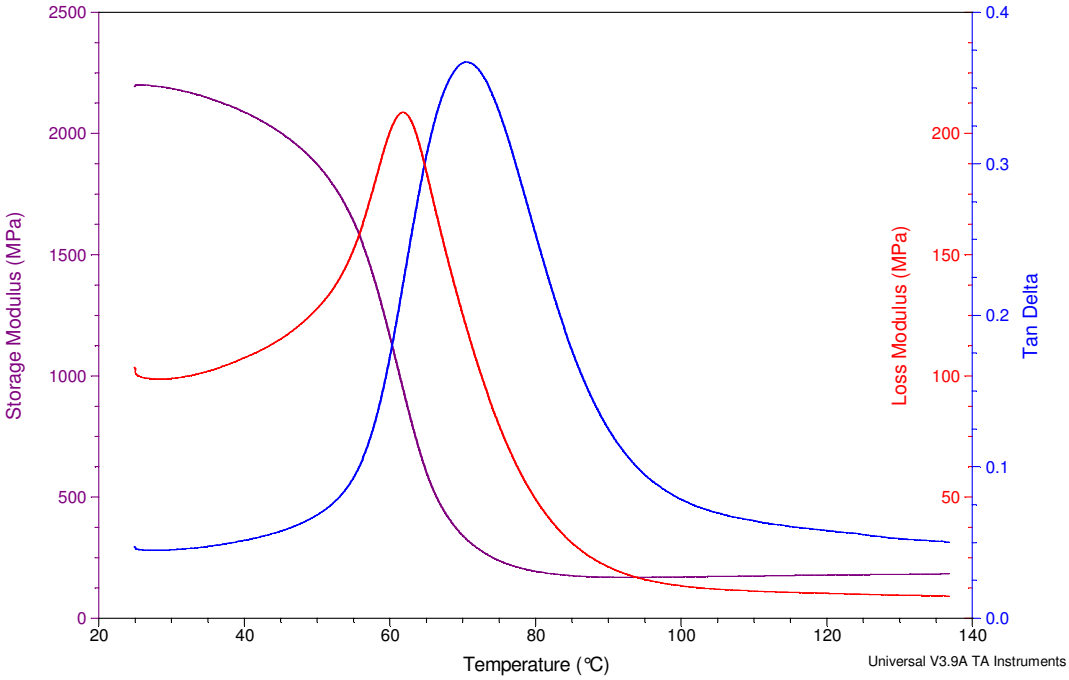
File: C:...\Sample- HL6 UD GlassF.001
Operator: Francisco Cardona
Run Date: 06-Oct-09 09:49
Instrument: DMA Q800 V5.1 Build 92

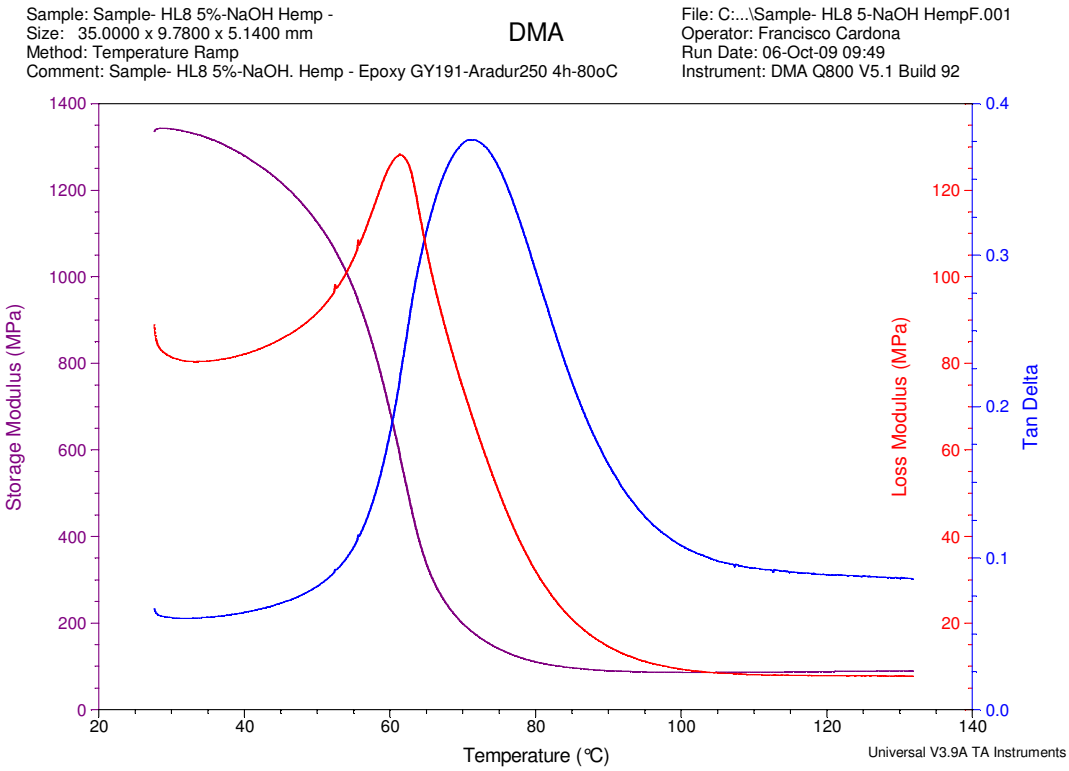


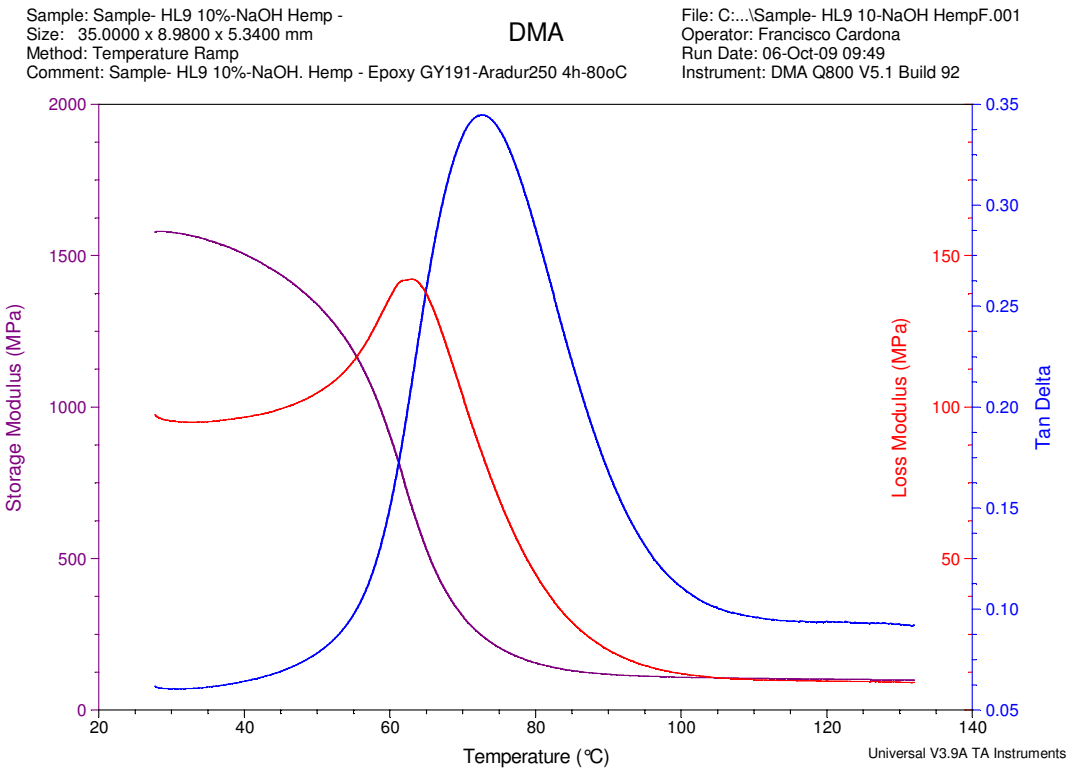
Sample: Sample- HL7 Untreat. Hemp - Epo
Size: 35.0000 x 9.1400 x 4.6900 mm
Method: Temperature Ramp
Comment: Sample- HL7 Untreat. Hemp - Epoxy GY191-Aradur250 4h-80oC

DMA

File: C:...\Sample- HL7 Untreat Hemp.001
Operator: Francisco Cardona
Run Date: 06-Oct-09 09:49
Instrument: DMA Q800 V5.1 Build 92




Sample: Sample- HL8 5%-NaOH Hemp -
Size: 35.0000 x 9.7800 x 5.1400 mm
Method: Temperature Ramp
Comment: Sample- HL8 5%-NaOH. Hemp - Epoxy GY191-Aradur250 4h-80oC
DMA
File: C:...\Sample- HL8 5-NaOH HempF.001
Operator: Francisco Cardona
Run Date: 06-Oct-09 09:49
Instrument: DMA Q800 V5.1 Build 92
Storage Modulus (MPa)
Loss Modulus (MPa)
Tan Delta
Temperature (°C)
Universal V3.9A TA Instruments


Sample: Sample- HL9 10%-NaOH Hemp -
Size: 35.0000 x 8.9800 x 5.3400 mm
Method: Temperature Ramp
Comment: Sample- HL9 10%-NaOH. Hemp - Epoxy GY191-Aradur250 4h-80oC
DMA
File: C:...\Sample- HL9 10-NaOH HempF.001
Operator: Francisco Cardona
Run Date: 06-Oct-09 09:49
Instrument: DMA Q800 V5.1 Build 92
Storage Modulus (MPa)
Loss Modulus (MPa)
Tan Delta
Temperature (°C)
Universal V3.9A TA Instruments