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Flexural testing of sustainable and alternative materials for surfboard construction, in comparison to current industry standard materials

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Abstract

The objective of the project was to test if natural materials were a viable and sustainable alternative to current surfboard materials. The testing was comparative, comparing differing natural fibre laminates (2 differing hemp cloths), an environmentally friendly Bio-Foam and epoxy resin against the industry standard materials of glass fibre, polyurethane foam and polyester resin. The materials were laid up in sandwich construction (dimensions: l=240mm, w=50mm, d=10.3-11.6mm) and tested in three point flexural testing. Four test specimens for each material selection were tested, with the mean result taken.

All the samples failed in indentation, with the core crushing beneath the top skin, underneath the load beam. In comparison to the standard materials, the thin hemp cloth showed decreased flexural strength (-0.055 GPa) and flexural stiffness (-30.9%). The thick hemp cloth showed further decreased flexural strength (-0.0183GPa) and flexural stiffness (-63.2%) in comparison to industry standard materials. The hemp cloths also showed high levels of deviation from the mean (Thin: 23.8 N and Thick: 21.1).

The Bio-Foam sample expressed lower compressive core shear strength in comparison to polyurethane foam, and therefore lower flexural strength and stiffness in comparison to the standard (Flex strength: -0.27 GPa, Stiffness: -39.1%). The epoxy sample was the only specimen to show increased mechanical properties in comparison, with an increase in flexural strength of 0.046 GPa and an increase of 5.2% in flexural stiffness.

The results showed that natural alternatives do not show comparable properties to currently used materials, although by using an epoxy matrix the strength and stiffness of the specimen is increased. This would therefore increase the longevity of a surfboard, leading to decreased waste.

Contents

1. Introduction

Currently In the surf industry the majority of boards are still made by hand, using unsustainable and un-recyclable materials which have been used since the 1960's. These materials consist of a polyurethane core, encased in a glass fibre and polyester resin laminate. Each of these components are harming the environment in their own way, and are difficult to dispose of. Another problem is current board fashion, which are lightweight, thin surfboards, prone to breaking easily. For example, an average high performance surfboards dimensions are 6'2'' (188cm) in length, 2.25 inches (6cm) thick, and 18.5 inches (47cm) wide.

In the current high performance surf board industry, surfboards are regarded to be disposable, with professional surfers breaking between 30-50 boards a year (Factory Media, 2009). This obviously creates the problem of wasted resources and many broken, un-recyclable surfboards in landfill**.** Wallenberger et al (2004) state how if fibreglass is disposed of in landfill sites it can remain un-decomposed for long periods of time, therefore causing serious environmental pollution.

Currently there are some natural alternatives being developed. Materials such as Bio-Foam (45% vegetable oil based instead of petroleum), fibres from hemp, bamboo and jute, as well as natural plant based resins have all been used as substitutes (Martin, 2007.) Other materials with increased structural properties, such as carbon fibre, can sustain the life of a surfboard by strengthening the overall structure. Epoxy resin also shows better mechanical characteristics than polyester. Therefore by using a material with increased mechanical properties, the longevity of a surfboard can be improved.

This project aims to gain quantitative scientific data on the flexural strength and stiffness of currently used materials, as well as natural alternatives in surfboard manufacture. The samples will be manufactured as sandwich structures, with a foam core and laminated skin, therefore emulating surfboard construction, and tested to failure in three point flexural testing.

The testing aims to be comparative; testing the alternative range of materials against the industry standard selection of glass fibre, polyurethane foam and polyester resin. The comparable testing will show quantitative mechanical data on the properties of each specimen, therefore deciding if natural and alternative materials can be a viable and sustainable solution to currently used materials in the surf industry

Qualitative data will also be recorded on the ease of manufacture of each material, determining whether the material is viable for wide scale use in surfboard construction.

2. Background Science Review

2.1 Current Materials

Manning et al (1993) state how in the surf board manufacturing industry, the standard materials used represent a simple sandwich construction. Manning (1993) continues to state that surfboards are conventionally constructed from a pre-shaped low density polyurethane foam core encased in glass fibre and polyester resin. This process and these materials still remain dominant in the surf industry to this day, with over three quarters of a million surfboards being produced each year (Hines, 2004).

This obviously creates a problem for the surf industry as the majority of the materials needed for surfboard construction are based on oil; which is a finite resource, depleting at a rapid rate. This therefore increases in price and the affects the cost of construction materials (Wallenberger et al, 2004). Dave Parmenter (2004), a leading surfboard manufacturer for over 20 years explains that people do not ride surf boards thick enough for the stresses they are put through, therefore resulting in wasted resources. This high volume of broken surfboards causes many surfboards to end up in landfill sites due to their un-recyclability. Fibreglass and other components remain un-decomposed for long periods of time causing severe environmental pollution (Wallenberger et al, 2004.)

Each of the main components used in current surfboard manufacture have their own problematic factors, whether in their production or disposal. Most current foams are made mainly from petro-chemical derivatives with a catalyst and some bubble producing agents (Shaw, 1994.) These chemicals are injected into a mould and form the polyurethane foam.

Currently MDI polyurethane is becoming more widely used in surfboard manufacture. In this foam the problematic ingredient of TDI has been replaced with MDI which decreases the levels of VOC's and is therefore safer to shape with (Martin, 2007.) Despite the fact that health and safety issues may have improved with polyurethane foam, there are still serious waste disposal issues (long decomposition time scale), and scrap foam cannot be satisfactorily used for other products due to its poor physical properties (Freepatentsonline, 2005.) It is stated that 25% of a pre-shaped blank ends up in landfill due to the shaping process (Howard, 2009.)

Glass fibre is the most widely used composite reinforcement in surfboard construction. Wasteonline (2006) states that large amounts of fossil fuels are used to heat and melt the glass, producing high volumes of carbon dioxide. In 2002 the glass industry consumed a total of 8611,000,000 kWh of energy, including electricity and carbon dioxide emissions totalled 1.8 million tonnes from the fossil fuels burnt in the factories. The surf industry has high levels of glass fibre disposal, either from waste material in the building process, or trying to dispose of broken, out of date or damaged boards. Asokana (2009) explains how 55,000 tonnes of glass fibre waste are produced annually in the UK, increasing by 10% each year. The most common form of disposal is landfill or incineration, with 90% of the UK glass fibre waste being sent to landfill. There is very little recycling available.

When looking at varying resins, the flexural modulus of epoxy resin ranges from 2.1 to 5.5 GPa, while polyester resin has slightly lower flexural modulus, ranging from 1.3 to 4.5 GPa (John, 1972). Greene (1999) states that polyester resin is the most widely used resin, while being most economical, with ease of use and good chemical resistance. Despite this, epoxy resins show the best performance and chemical resistance characteristics out of all resins used in the marine industry. This difference in quality does increase the cost of epoxy over polyester.

As these resins will be used in a marine environment, degradation from water ingress is another factor to look at. All resins will absorb some moisture, therefore adding weight to the laminates, although significant amounts of water can be absorbed. This therefore affects the resin/fibre bond, and the long term mechanical properties of the laminate. Polyester resin is prone to water absorption, with a thin polyester laminate retaining 65% of its inter-laminar shear strength after a year of water immersion,

compared to an epoxy laminate which will retain 90% of its inter laminar shear strength (SP Gurit).

The depletion of petroleum resources, coupled with increasing environmental regulations are providing the impetus for new materials compatible with the environment and independent from fossil fuels (Mohanty et al, 2005). Renewable bio-materials can be used for both bio-energy and bio-products, therefore creating an alternative to petroleum-based and synthetic products (Sun, 2005)

2.2 Natural Alternatives

Natural alternatives such as Bio-foam blanks (45% vegetable oil based instead of petroleum based), natural plant based fibres and natural plant based resins have all been used as substitutes in the surf manufacture industry (Martin, 2007). Plants such as cotton, flax, hemp, jute, bamboo, banana, sisal, kenaf, raime and coir are all a source of natural fibres (Wallenberger et al, 2004). The renew ability, availability, low density, good mechanical properties and cost all make them attractive reinforcing fibres in manufacturing composites. Wallenberger et al (2004) states that the natural fibres are completely or partially recyclable and biodegradable, therefore aiding the process of disposal. This makes the idea of using natural fibres as an alternative attractive as it will minimize environmental load.

Creating an eco-cycle using natural fibres in composites may help in reducing levels of carbon dioxide, and increase oxygen supply into the atmosphere (Wallenberger et al, 2004). For example, using bamboo fibres instead of glass fibres will reduce the amount of carbon dioxide released into the atmosphere, and more importantly assimilate carbon dioxide. Natural fibres also show good growth rate. For example, bamboo can grow up to 1m a day if grown in optimum conditions (Farrelly, 2008).

Mohantya et al (2000) state how natural fibres can exhibit large variations in fibre length and diameter of individual filaments, therefore affecting the quality and mechanical properties of the fibres. Other factors can affect this including size of the fibre, and the extraction process. The size of the fibre directly relates to its properties, with the fibre modulus decreasing with the fibre diameter.

Mohantya et al (2000) continues to state that the strength and stiffness of the fibres are related to their internal composition and chemical structure. Plant fibres are characterized by cellular structure with each cell containing crystalline cellulose region (microfibrils). The more parallel the microfibrils are to the fibre axis, the higher the fibre strength will be. Therefore, plants such as flax, jute, bamboo and hemp have increased microfibrils parallel to the fibre axis, which would explain their high strength and modulus (Mohantya et al, 2000). Every technical natural fibre contains numerous individual fibres, which range from 30-70mm in length (Wallenberger et al, 2004).

From Figure 1.1, comparisons can be seen between the mechanical properties of glass fibres and natural fibres, therefore proving their applicability to surfboard manufacture. These natural fibres are all obtained from the stems, known as bast fibres and have found to be particularly suited to composite applications due to their high Young's and specific modulus (Wallenberger et al, 2004). Despite lower tensile strength in the natural fibre, they have similar specific modulus to glass fibre, which consists of the elastic modulus of the fibre in relation to its density (Tomsic, 2000). Figure 1.1 also shows comparable Young's Modulus of hemp, flax and bamboo to glass fibre.

Fibre Type	***Density (g/cm³)***	***Tensile Strength (MPa)***	***Young's Modulus (GPa)***	***Specific Modulus (GPa/kg)***	***Elongation to Break (%)***	***Moisture Absorption (%)***
Glass fibre (E- glass)	2.55	2400	*73*	29	3	-
Flax	1.4	800-1500	*60-80*	26-46	1.2-1.6	7
Hemp	1.48	550-900	*60-70*	47	1.6	8
Bamboo	0.9	400-1000	*48-89*	-	-	-

Figure 1.1: Mechanical Properties of Glass and Natural Fibres (Sourced from Wallenberger and Weston, 2004). Factors affecting varying natural fibre results include plant species, fibre extraction and growing conditions

High stiffness levels are often as important as tensile strength, due to the fact that many engineering structures are limited by their allowable deflection (Lilholt et al, 2000).

Other factors apart from fibre type and mechanical properties need to be taken into account. These include the amount of fibre in the composite ('Fibre Volume Fraction'), the surface interaction of the fibre and resin, and the orientation of the fibres in the composite (SP Gurit.) For example, fibres are designed to be loaded along their length therefore creating design specific properties in the composite, therefore increasing properties if the fibres are place along the main load paths.

The automotive industry is beginning to use natural fibres in replacement of glass fibre reinforcement for manufacturing differing car parts, including door accessories and package trays. (Schloesser 2004). This global commercialisation of natural fibres is driven by the potential of low parts cost and waste, as well as reducing emissions and generally sparing resources.

Polyurethane foam consists of two main components: an isocyanate (e.g. MDI) and a polyol which is normally petroleum based. This is where Bio-Foam differs as the MDI has been bonded with a plant based polyol therefore resulting in foam made up of 45% renewable materials, and its production emits 36% fewer global warming emissions and lowered health risks (Martin, 2007).

To date there has been some development in manufacturing surfboards using some natural materials. The Eden Project (2007) state that they have created the most environmentally friendly surfboards to date, which are performance based and lightweight, consisting of 36% plant based Bio-Foam, glass fibre and 98% plant based resin. These boards have only been tested using qualitative research and feedback from surfers, but there has been no mechanical testing on materials in lay up (Eden Project, 2007).

2.3 Composite Sandwich Construction

When constructing the test samples it's important to note a structural sandwich is a laminated composite utilising a combination of different materials that are bonded together so as to use the properties of each separate component, therefore increasing the structural properties of the whole assembly (Zenkert, 1995.) This sandwich structure consists of two high strength skins, separated by a core material, therefore increasing thickness with minimal weight increase. This therefore causes the core to act like an I-beam; with the load bearing flanges (skins) carrying the majority of the tensile and compressive loads (SP Gurit.)

Equation 1.1 shows Second Moment of Area (I) for a rectangular cross section. Engineering theory and this equation show the flexural stiffness of any panel is proportional to the cube of its thickness; therefore increasing a panel's thickness dramatically increases its stiffness, with little increase in weight (Gordon, 1968). This therefore states the importance of keeping the depth of the panel constant throughout.

$$I = \frac{bd^3}{12}$$

b=Width

d=Depth

Equation 1.1: Second Moment of Area for rectangular cross section (Gordon, 1969)

An example of varying skin thickness against flexural stiffness can be seen by conducting three point flexural tests on a variety of samples with the same materials, but differing dimensions. A specimen with skin thickness 3.2mm failed at a load of 3kN. When this skin thickness was increased by 2.3mm, a load of 6.2kN was needed for the sample to fail (Shuaeib et al, 1997). This therefore states that a small increase in skin thickness dramatically increases load needed to deflect beam.

The SP Gurit Guide to Composites states that flexural loading of a composite sandwich involves a combination of tensile, compression and shear loads, with the upper face being put into compression, the lower face into tension and the central core experiencing shear. By testing composite structures in 3 point flexural testing it is able to replicate the similar stresses and loads applied to a surfboard in reality (Audy et al, 2004). For example, it will emulate the crest of a wave landing on the board.

According to the ASTM C393-62 Standards for Flexural Properties of Sandwich Constructions (1988), the flexural test can be used to calculate the flexural and shear stiffness of the entire panel, the shear modulus and strength of the core, or the compressive or tensile strength of the facings. Borsellino et al (2004) states that carrying out flexural tests to a complete static mechanical characterisation of the sandwich structure, allows for important comparison parameters of the entire structure to be obtained.

To ensure that the results are fair and each sample is being tested comparatively, the dimensions of each test sample must remain constant, and in accordance to the ASTM Standards C393-62 (1988). Equation 1.2 for span length has limitations when sizing samples as assumptions were not always known for allowable facing stress and core shear stress. This therefore affects the applicability and use of the equation.

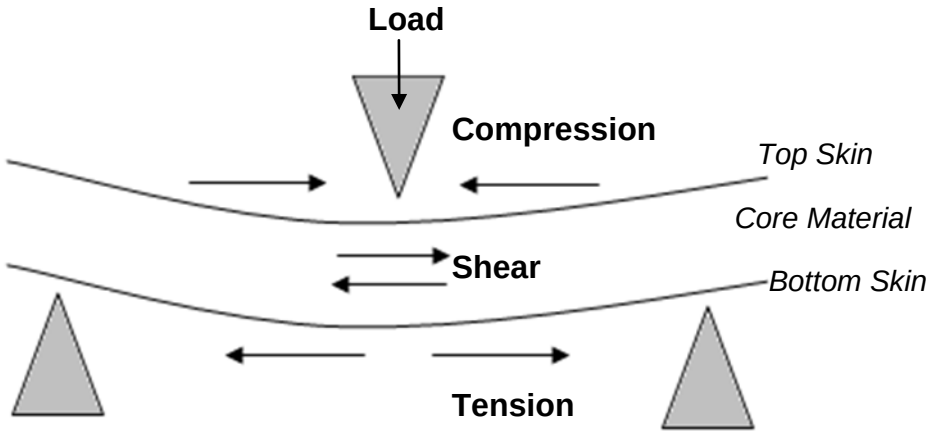


Figure 1.2: Diagram showing simply supported sandwich construction loaded centrally. Loads shown for top skin (compression) core (shear) and tension (bottom skin.)

$$a^1 = \frac{2\int F}{S}$$

a^1= *Span Length*

$\int$= *Facing Thickness*

F= Allowable Facing Stress

S= Allowable Core Shear Stress

Equation 1.2: Span Length (ASTM Standard, 1988)

The properties of the composite sandwich are affected by the method in which the samples are designed and manufactured (SP Gurit.) For example, the sample can be manufactured using Hand Lay-up which consists of resins being impregnated by hand into the fibres (SP Gurit). Any resins and fibres can be used in this process, and it allows simplicity, costs to be kept low and high fibre contents. Despite this, the quality of hand lay-up manufacture can be dependant on the skills of the laminator, with a low skilled laminator creating poor, structurally impaired laminates, with excessive quantities of voids (Piggot, 2006.) Vacuum Bagging is an extension of the hand lay-up, with a plastic film applied over the wet laid up laminate causing a vacuum, creating up to one atmosphere of pressure to be applied to the laminate (SP Gurit.) This allows for higher fibre content, lower void content and better fibre wet out due to pressure and resin flow through structural fibres (Barbero, 1999).Natural fibres are applicable to almost all production techniques (Wallenberger et al, 2004).

The fibre volume fraction is determined by the internal packing geometry of the fibres, as well as the behaviour of the fibre and matrix combined (Carlsson et al, 1987.) This is another important factor when comparing the properties of varying laminates.

$$V_f = \frac{n\ Aw}{\rho_f\ d}$$

n = Correction Factor

Aw = Area Weight

d = Skin depth

ρ_f *= Fibre Density*

Equation 1.3: Fibre Volume Fraction

2.4 Flexural Testing

Flexural testing is conducted on simply supported beams with a constant cross-sectional area, with a flat rectangular specimen being supported close to its ends and loaded centrally (Hodgkinson, 2000). In this case three point flexural testing has been selected as the bending moment increases linearly from zero at the supports to a maximum under the central loading point (Hodgkinson, 2000). Using the three point flexural test machine, the test samples will be tested until failure therefore obtaining results for modulus of elasticity in bending (Chung 2007.)

Stress-strain graphs indicate the materials plastic and elastic regions (Chung, 2007.) Figure 1.3 shows an example of a stress/strain graph. The yield strength is defined as the stress at which the material exhibits a specified deviation from the proportionality of stress to strain (Tosmic, 2000). In areas of elastic deformation the material can return to its original dimensions, with plastic deformation causing permanent change in dimensions.

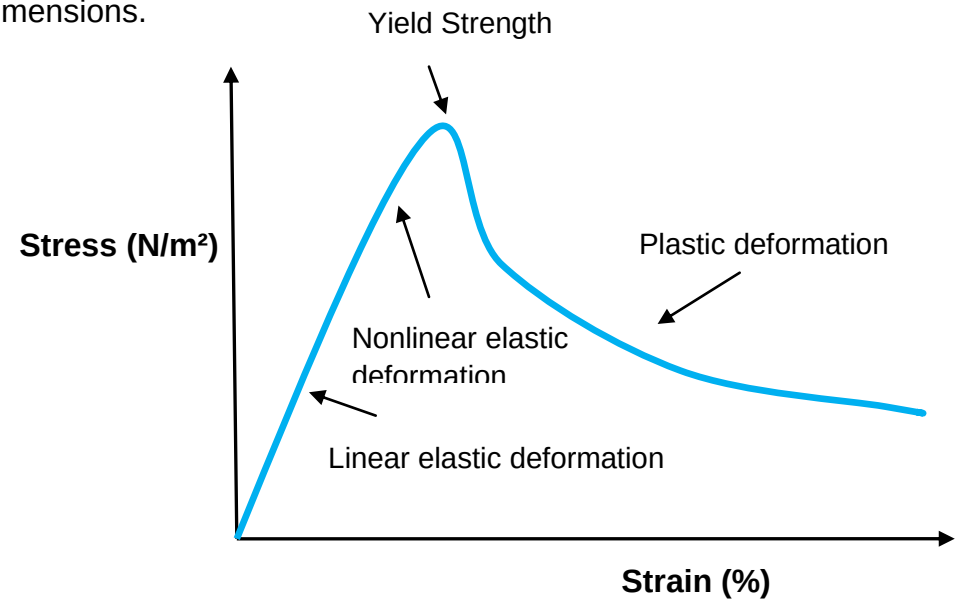


Figure 1.3: Stress-strain curve for composite material in testing, showing differing failure mechanisms throughout testing cycle (Roylance, 1996)

Borsellino et al (2004) identify the mechanical behaviour of composite sandwiches constructed from PU foam, with glass and carbon fibres, when tested in three point flexural bending. The initial part of the stress/strain curve shows linear elastic behaviour. After this point the load/deflection curve plateaus as the cellular structure of the sandwich collapses, with the top area of foam crushing. Further loading leads to a top skin failure under compression, with the bottom skin being put into tension, therefore causing a large decrease in load. Deflection is still high, with a relatively low stress due to the fact that as the top skin completely fractures in compression, the crack propagates through the foam down the centre of the sample (Figure 1.4). The sample then fails as the lower skin fractures in tension causing de-lamination and de-bonding (Figure 1.5) where the skin is attached to the foam.

Figure 1.4: Crack propagating through foam after skin failure

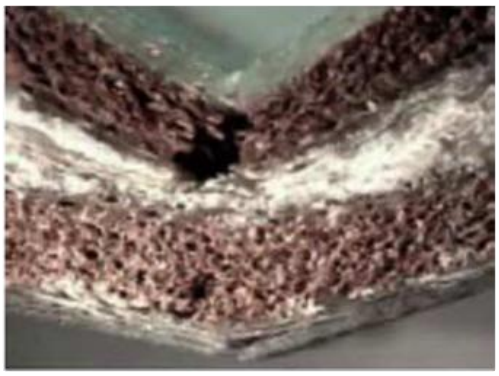


Figure 1.5: Sample failing after de-lamination-de-bonding of lower skin

The bending moment (M) is a function of the measured load and specimen geometry which allows for the full stress/strain behaviour of the beam in bending to be obtained (Hodgkinson, 2000).

$$M = \frac{PL}{4}$$

P= Central Load

L= Span Length

Equation 1.4: Bending Moment (Hodgkinson, 2000)

2.5 Mechanical Properties

Greene (1999) states that failure in composite structures can be classified by strength, or stiffness characteristics. Stiffness failures result when displacement exceed the strain limit of the laminate, and strength limited failures occur when stress exceeds the load carrying capability of the laminate.

Stress is defined as a force per unit area applied to a material to produce a deformation (Tomsic, 2000). John (1972) explains that as a stress is applied to a

material so that a dimensional change (strain) is developed, with the strain being termed elastic if the material returns its original dimensions, or plastic if permanently deformed.

Calculations are needed to determine the allowable skin stress, therefore aiding the design process in determining skin and core thickness (Greene, 1999). As the beam is 'simply supported' the maximum skin stress will occur at the centre of the panel, with the top skin loaded in compression, and the bottom in tension (x-y plane).

$$\sigma_s = \frac{ME_s h}{2D}$$

M = Bending Moment

E_s= Skin Modulus

h = Total Thickness

D = Flexural rigidity of plate

Equation 1.5: Skin Stress (Greene, 1999)

The British Standards (2008) define flexural strain as the nominal fractional change in length of the outer surface of the test specimen at mid-span. Strain (%) is expressed as:

$$\varepsilon_f(\%) = \frac{600sh}{L^2}$$

s = Deflection

h = Total Thickness

L = Span Length

Equation 1.6: Flexural Strain (British Standards, 2008)

The Young's Modulus (E) or stiffness for the component can be calculated using a ratio of stress to strain in the region of linear elasticity (Roylance, 1996). Flexural modulus is defined as the ratio of load on the test specimen in relation to the strain on the outermost fibres (Tosmic, 2000).

$$E_F = \frac{L^3 m}{4wt^3}$$

L = Span Length

m = Gradient of liner load in elastic region (N/mm)

W = Specimen Width

t = Specimen Thickness

Equation 1.7: Flexural Modulus (Curtis, 1988)

The yield is the deformation resulting from a single application in load in a relatively short space of time (Roylance, 1996). The yield strength is the stress at which a material exhibits a specified limiting deviation from the proportionality of stress to strain, referenced at the point of limiting deviation in units of stress. The British Standards (2008) define flexural strength as the maximum flexural stress sustained by the test specimen before plastic failure, during the bend test.

$$f_F = \frac{1.5\ PS}{wt^2}$$

P = Load at failure

S = Span Length

w = Specimen Width

t = Specimen Thickness

Equation 1.8: Flexural Strength (Curtis, 1988)

2.6 Failure Mechanisms

Zenkert (1995) states how sandwich panels can fail in several different ways, depending on the load bearing capacity of the structure, as well as the geometry and loading on the structure. Four main collapse mechanisms have been identified when looking at the failure of a sandwich beam in 3 point bending, with the operative collapse mode taken to be the weakest (Steeves et al, 2004):

Face microbuckling occurs when the axial stress within the compressive face sheet attains the face sheet microbuckling strength, causing the skin under compression to buckle under the central displacement load.

Face wrinkling occurs due to the elastic instability of the faces involving short wavelength elastic buckling of the upper face, resisted by the underlying core.

The core material is primarily subjected to core shear, and carries almost the entire transverse force from the load (Zenkert, 1995.) Greene (1999) defines shear stress as an applied force that causes two contiguous parts of a material to slide past each other, in a direction parallel to their plane of contact.

Indentation is when the core crushes in compression under the top skin. The indentation load is set by the plastic yield of the core, with the face sheets either deforming plastically or elastically. Models assume that the collapse is a local instability of the compressive face sheet, accompanied by the low compressive plastic yield of the core, therefore causing core crushing (Steeves et al, 2004.)

Zenkert (1995) states that that the loads should be applied over a larger surface area, therefore preventing local indentation of the faces. In three point flexural testing the localised load is applied in the upper face, with the two support beams supporting half the load. As indentation occurs at concentrated loads the face will act as a plate on an elastic support, with the face skin bending independently of the opposite skin. If the elastic strength applied to the core exceeds the compressive strength of the core, the core will fail and indentation will occur.

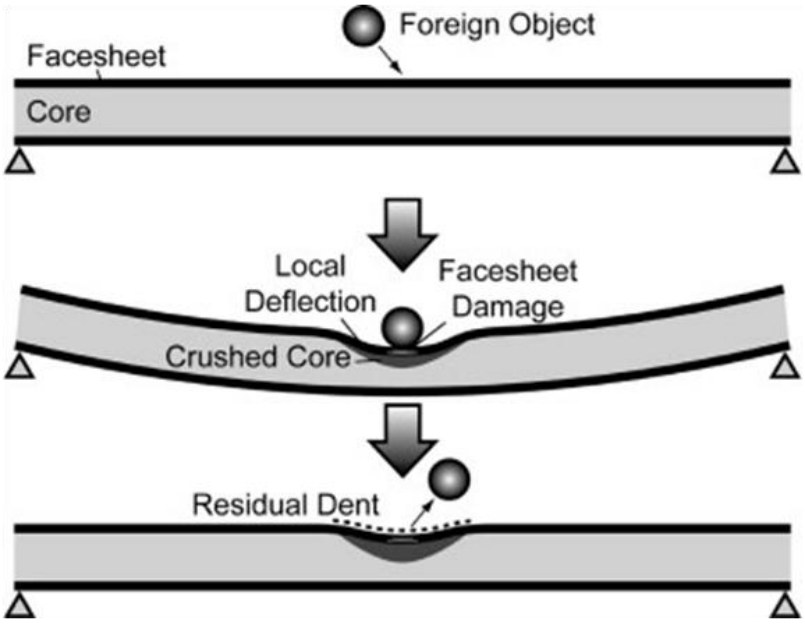


Figure 1.6: Behaviour of sandwich structures when subjected to localised transverse loading (Minakuchia et al, 2007.)

Figure 1.6 shows indentation of a beam, similar to centrally loaded beam in three point flexural testing. Figure 1.6 shows how the entire panel is elastically deformed under localised transverse loading, while the top skin locally defects against the lower skin at the load point, with a deformation of the core. When local deformation surpass elastic limit, core crushing and compressive failure of the top skin occur. This indentation can cause significant deterioration of strength and stiffness properties of the sandwich construction. If load is increased so as the entire panel exceeds its elastic limit, the bottom skin can fail in tension, causing complete failure of the structure *(*Minakuchia *et al, 2007.)* Despite this, failures in tension are relatively rare as filament reinforcements are strongest in tension along their primary axis (Greene, 1999.)

3. Methodology

3.1 Sample Manufacture

It was vital that each of the foam cores were precisely the same dimensions, therefore allowing for rigour and precision throughout the results.

- The initial process involved dissecting the two surfboard blanks to retrieve foam to use for the cores. This was done using a band saw, although the curve throughout the blank made it hard to obtain long flat samples.
- The correct dimensions (Figure 1.7 and 1.9) were set in accordance with ASTM Standard Test Method calculations. The foam core samples were measured using electronic callipers to ensure consistency.
- Each foam section was laminated simultaneously, with the desired dimensions cut from the foam samples at a later point (e.g. Core samples 4 x wider than

final dimensions at ~200mm). This would ensure that the resin mixing and laminate resin quality would remain constant.

- The samples were laminated on a glass laminating plate, with added release agent. The varying cloth types were then cut to size and overlaid onto the foam. One side was laminated at a time so as to ensure that the fibres were wet out sufficiently and an even layer of resin was distributed.
- Resin mixed with 2% catalyst. Well mixed together, therefore no void patches of un-catalysed resin.
- Fibre orientation kept constant throughout each sample. Bi-axial (0/90º) fabric therefore fibres running parallel in the same direction.
- Laminates were then heated in specialised ovens, therefore increasing the curing time.
- After hardening, the samples were sanded to remove any over-hanging laminate or uneven surfaces. During the laminating process, some resin ran off the top surface of the foam to the laminating plate and to the underside of the sample. This excess resin was partially sanded off, although some resin soaked into foam.

- The samples were cut to the correct width (50mm) using a diamond bladed wet saw. Preliminary test samples were cut to ensure accuracy. The dimensions of the saw were set accurately to a width of 50mm, ensuring consistency throughout each sample.

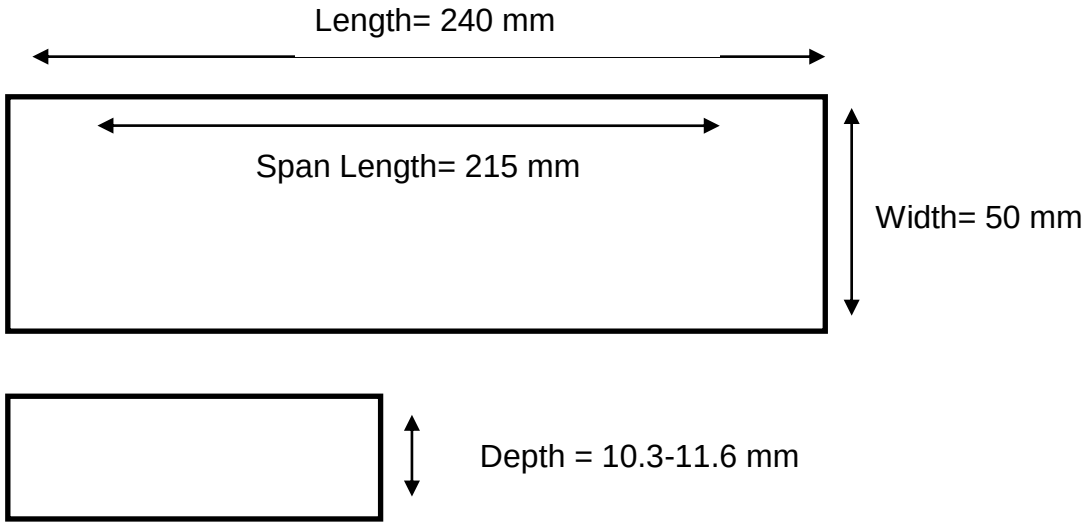


Figure 1.7: Diagram to show sample dimensions (Differing depth due to varying laminate thickness. Core depth kept constant throughout at 9.6mm.)

3.2 Sample Testing

Measurements of each material selection were recorded for evaluation, to ensure accuracy and consistency (Figure 1.9). By recording the depth of the samples, the skin depth could be calculated as all the foam cores were of exact dimensions.

The samples were then tested in three point flexural testing using Instron 5582 (Figure 1.8). The span length was set to 215mm on the support beams, and the dimensions of the test samples were input to the computer. A test rate of 10mm extension per minute

was set, with a maximum extension rate of 100mm. The samples were tested until failure, or until the maximum extension rate was reached. Results were recorded in the form of load/extension graphs.

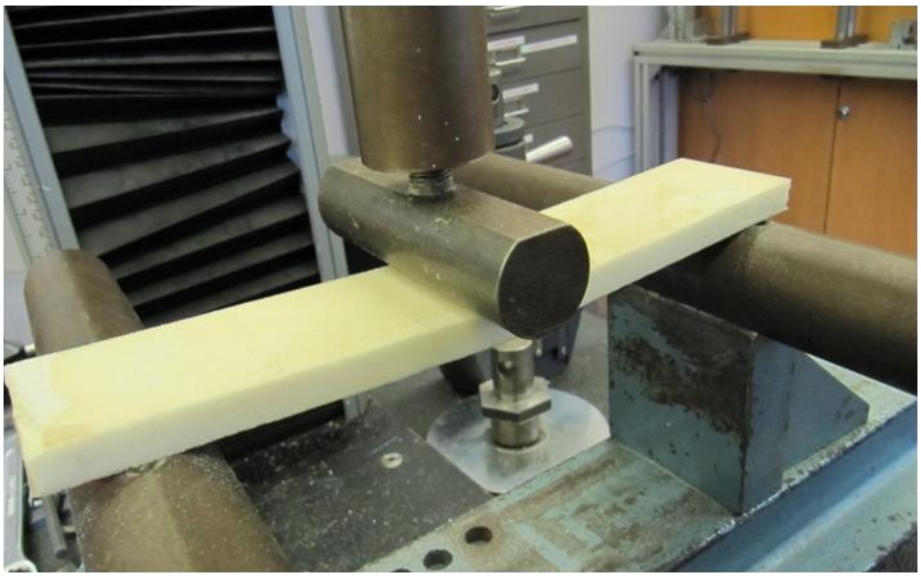


Figure 1.8: Flexural Testing equipment used. Picture shows the beam supported at either end, with a span length of 215 mm and the beam loaded centrally.

3.3 Safety Considerations

There are some potential issues and dangers with varying materials and equipment, therefore appropriate safety precautions were necessary (Johnson, 2005.):

- Polyurethane foam produces high levels of air polluting volatile organic compounds (VOC's). Therefore a respirator or dust mask and goggles should be used when hand shaping with polyurethane. It's also important to shape in a well ventilated area.
- Glass fibres are an irritant; with Individual fibres causing painful itching and skin irritation. Some very small fibres can also be inhaled causing irritation to the lungs and throat. Gloves and a dust mask should be worn.
- Polyester and Epoxy resin cause irritation and possible burning if in contact with skin, therefore gloves are needed when handling. A good respirator is also needed so as to avoid inhalation of any fumes, and goggles should be worn so as no resin comes in contact with the eyes. Polyester resin is also flammable so there should be no smoking or naked flames close by.

Sample Type	Dimensions (mm)	Skin Depth (mm)	Core Depth (mm)	Weight (g)
Glass Fibre, Polyurethane Foam, Polyester Resin	240 x 50 x 10.3	0.77	9.6	19
Thin Hemp Cloth, Polyurethane Foam, Polyester Resin	240 x 50 x 10.7	1.15	9.6	30.5
Thin Hemp Cloth, Polyurethane Foam, Polyester Resin	240 x 50 x 11.6	2	9.6	40
Epoxy Resin, Glass Fibre, Polyurethane Foam	240 x 50 x 10.4	0.82	9.6	20.5
Bio-Foam, Glass Fibre, Polyester Resin	240 x 50 x 10.6	1	9.6	19.7

Figure 1.9: Differing samples, with dimensions and weight. Skin depth varies due to differing laminates and fibre thickness. 4 samples of each material type were manufactured.

4. Results

Figure 2.1 shows skin stress against flexural strain for the mean results of each sample type. These figures were calculated from the load/extension results gained from the flexural testing, using the equations stated earlier in the literature review (Equation 1.5 and 1.6).

From the results it can be seen how each of the samples behave in three point bending. The *standard* materials results represents the industry standard (glass, polyester, polyurethane), as well as the bench-mark for mechanical properties against the other materials. The differing materials are tested in comparison to this industry standard.

In Figure 2.1 each of the samples undergo similar failure mechanicsms : The initial linear line from the zero point states the linear elastic zone of the beam. In this area the beam is deforming only elastically. The beam is subjected to non-linear elastic deformation before reaching its maximum yield strength. This point can seen as the skin stress level peaks, then begins decreasing dramatically.

After the sample has peaked and maximum flexural/yeild strength has occurred the skin stress decreases dramatiacally. In this area of the graph the component is experiencing plastic deformation. Some residual skin stress remains. Flexural stiffness is determined by the gradient of the linear elastic region.

Figure 2.1 and 2.2 show the comparitive properties and figures of the materials against the indusrtry standard:

The Epoxy sample shows increased skin stress at failure in comparison to the Standard materials at 8.4 MPa (+ 0.8 MPa than the standard), with a maximum flexural strength of 0.499 GPa. Figure 2.2 show a 5.2% increase in stiffness compared to the standard. After yeild strength point, skin stress decreases, and until leveling out at a level of ~2 MPa .This residual skin stress remains low.

The thin hemp sample shows a decreased skin stress in comparison, at 7.1 MPa (-0.50 MPa than the standard materials), with a flexural strength of 0.398 GPa. The flexural stiffness can also noted to be 30.9% lower than the standard materials. The plastic deformation after the max yield strength point remains at a higher skin stress, dropping to a similar stress to the standard materials at a strain of ~3.6%.

The thick hemp sample shows lower skin stress at failure at 5.6 MPa (-2 MPa in comparison to the industry standard) and a maximum flexural strength of 0.27 GPa. The stiffness of the thick hemp component is 63.2% lower in comparison. In the area of platic deformation skin stress remains high, decreasing at a slower rate, reaching comparable levels to industry standard at a strain of ~4.4%.

The Bio-Foam sample shows decreased skin stress load at failure, at 3.9 MPa (3.7 MPa less than skin stress of standard materials), with a flexural strength of 0.183 GPa. Flexural stiffness is also decreased, -39.1% on the industry standard materials. Plastic deformation after the max yield strength remains at a low level of skin stress, dropping to beneath 1 MPa after the the component experience's 2% strain.

Figure 2.3 to 2.7 show results aquired directly from the testing machine, comparing the flexural load against flexural extension. These results show the raw data, before the the figures had been calculated to show skin stress, against flexural strain, therefore explaing the varying loads.

These figures represent the five different sample types, and show the results for each of the four test specimins for each sample type, as well as the mean result, therefore indicating wether the materials show repeatable charecteristics. Figure 2.8 shows the average deviation from the mean for each of the sample types.

Figure 2.3 shows the industry standard results. It can be seen that each of the four test specimin results are clustered around the mean result, with an average deviation from the mean at 5.1 N.

Figure 2.4 shows the results for the thick hemp sample. The graph shows the specimen results scattered sporadically, with deviation from the mean 21 N. The maximum difference between flexural loads, at its highest point, shows a 36 N difference. The majority of deviation from the mean occurs after the sample has failed, in the area of plastic deformation, with the linear elastic areas of the samples remaining relatively consistent.

Figure 2.5 shows the Bio-Foam sample. This sample shows high average deviation from the mean, at 20.2 N. The majority of this deviation occurs in the area of plastic deformation, with the results in the linear elastic region remaining relatively constant.

Figure 2.6 show the Epoxy sample. Results are concentrated around the mean results, with an average deviation from the mean at 8.61 N.

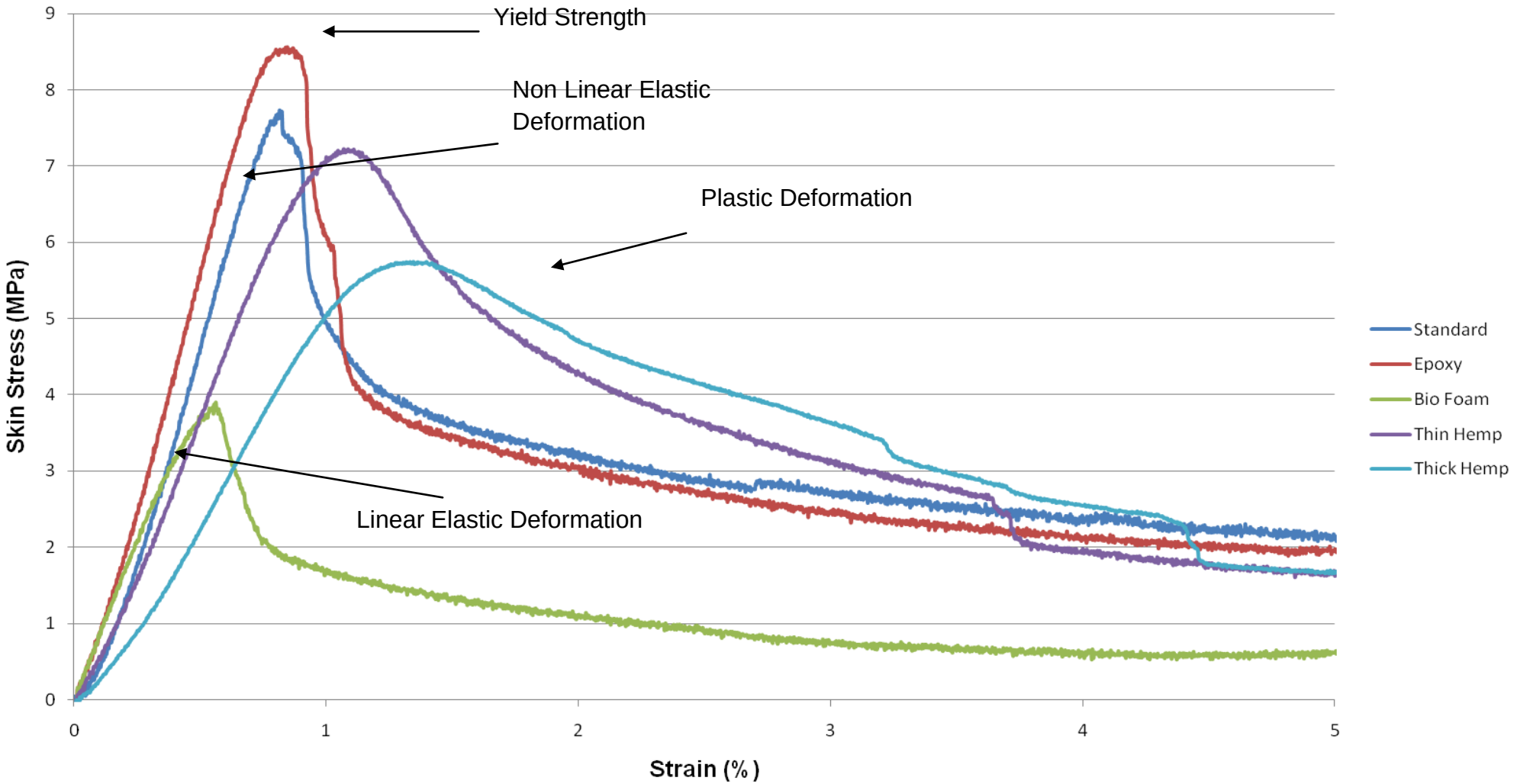
Figure 2.7 shows the load/extension results for the thin hemp sample. This figure shows the thin hemp to have high standard deviation from the mean, at 23.6 N, with a maximum difference between yield strength points at ~23 N. It shows consistent results in the linear elastic region, with the area of plastic deformation becoming more erratic with higher deviation.

Figure 2.2 also shows statistical analysis between the variants. From the P-Values it can be seen that the thick hemp cloth (P: .008) and the bio-foam sample (P: .002) show a strong significant difference at a 99% confidence level when in comparison to the max flexural strength of the standard materials.

The max flexural strength of the epoxy and thin hemp sample do not show a significant difference, with P-Values of .231 and .139 respectively. This test was done a 95% confidence level.

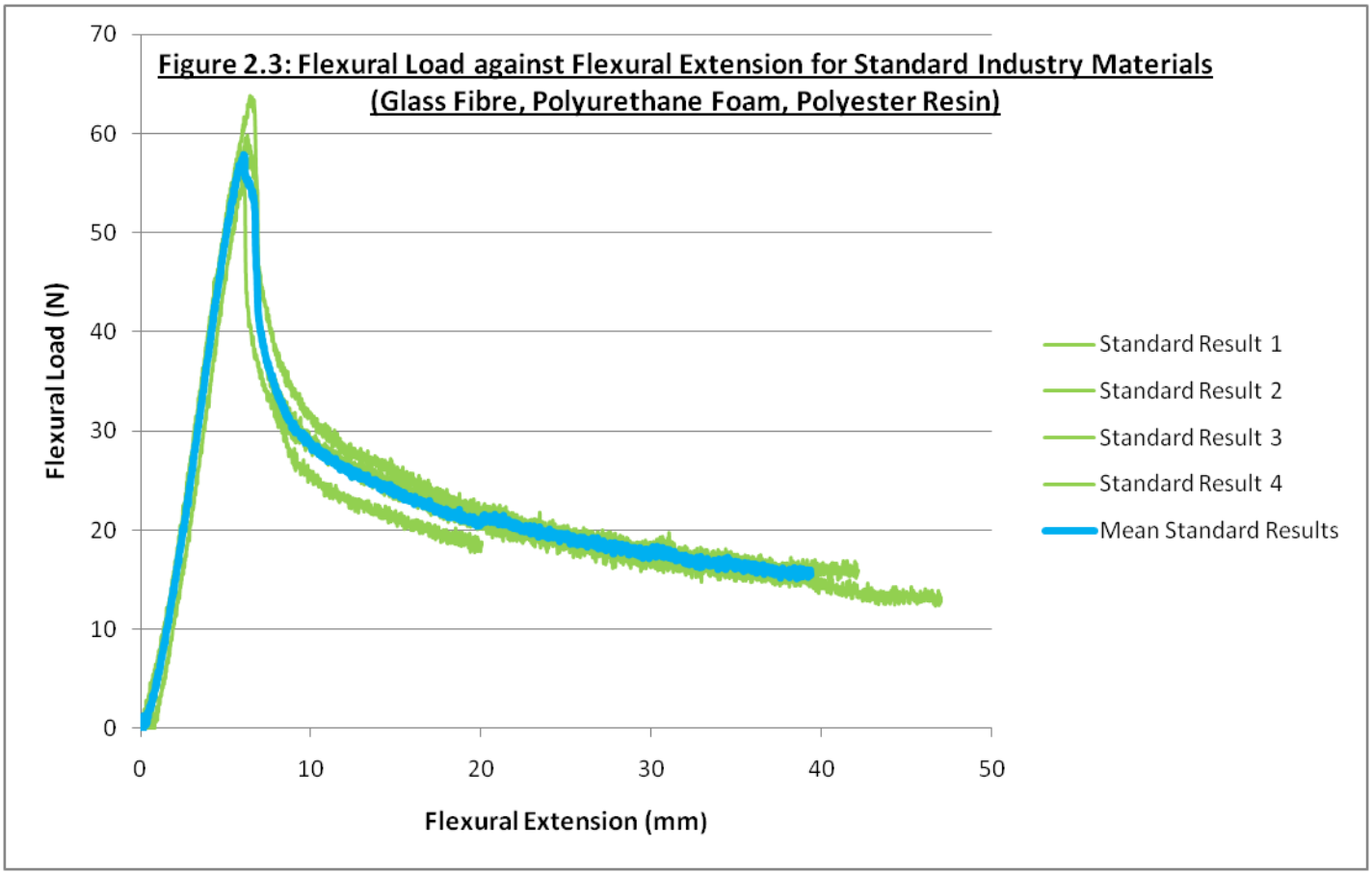
Figure 2.9 shows the qualitative results table, displaying observations on the manufacturing issues with each material, as well as their relative costs.

Figure 2.1: Mean Skin Stress (MPa) Against Strain (%) for each Material Selection



Material Type	Skin Stress at Fail (MPa)	FLEXURAL STRENGTH (GPa)	Significant Difference of Max Flexural Strength from Standard: P-Value	% Difference in Stiffness from Standard
Standard	7.6	0.453	-	-
Epoxy	8.4	0.499	.231	5.2
Thin Hemp	7.1	0.398	.139	-30.9
Thick Hemp	5.6	0.27	.008	-63.2
Bio-Foam	3.9	0.183	.002	-39.1

Figure 2.2: Table of results for mean values of Flexural strength of each sample type, as well as P-Value for significant difference from max strength in comparison to standard results. Table also shows Mean % difference in stiffness in comparison to mean results and skin stress at failure.



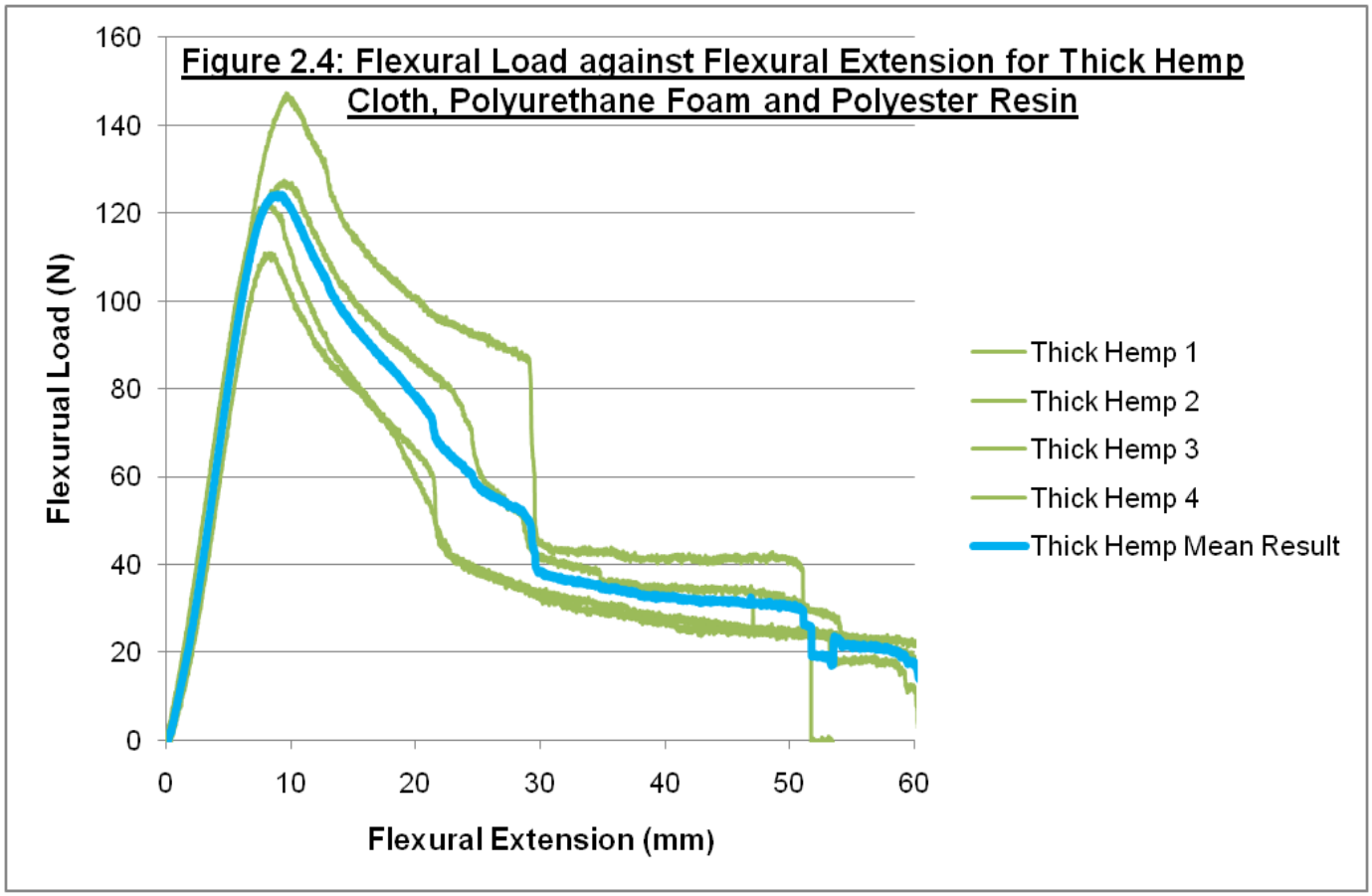


Figure 2.4: Flexural Load against Flexural Extension for Thick Hemp Cloth, Polyurethane Foam and Polyester Resin
Flexurual Load (N)
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
Flexural Extension (mm)
Thick Hemp 1
Thick Hemp 2
Thick Hemp 3
Thick Hemp 4
Thick Hemp Mean Result

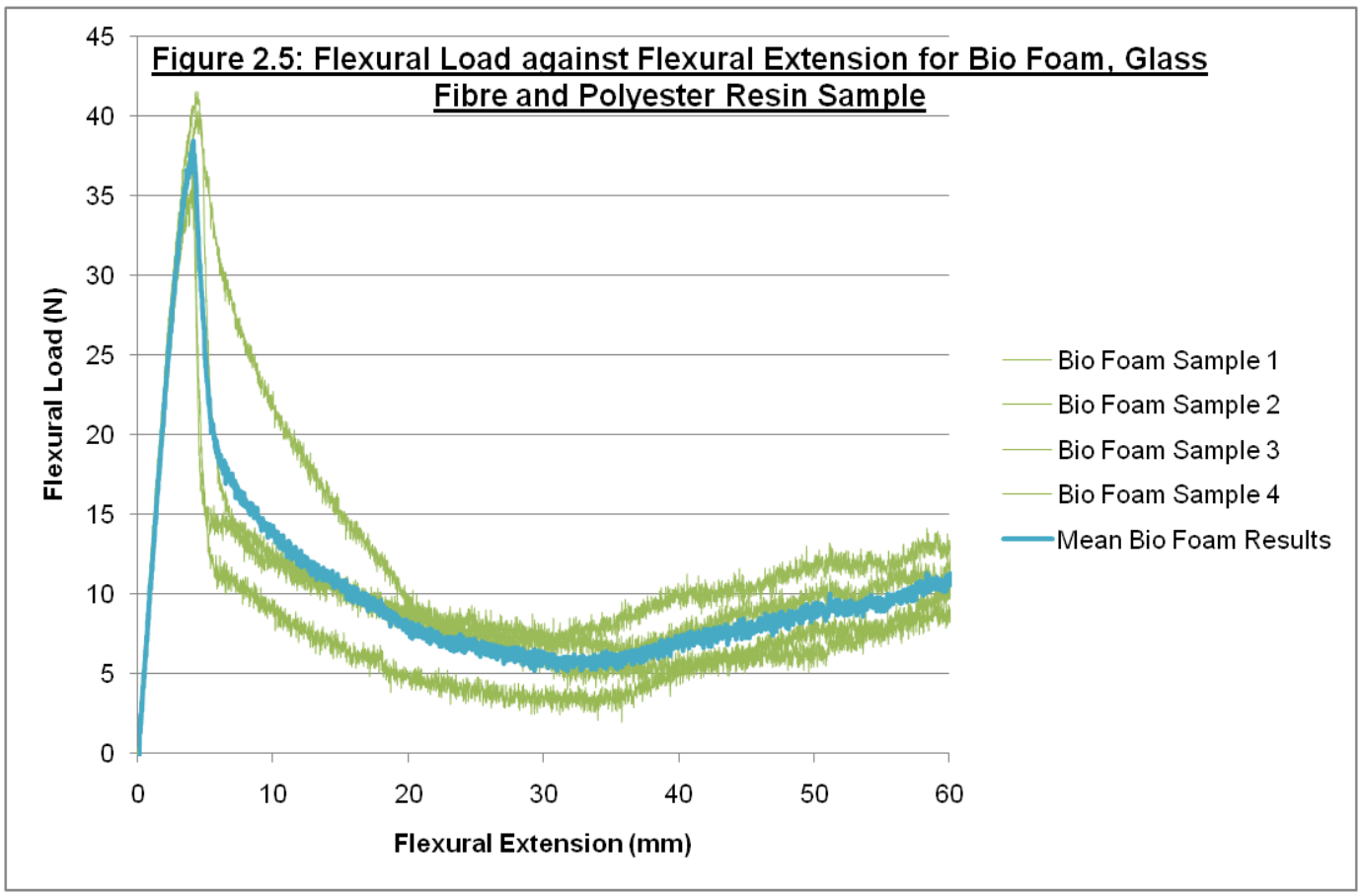


Figure 2.5: Flexural Load against Flexural Extension for Bio Foam, Glass Fibre and Polyester Resin Sample
Flexural Load (N)
45
40
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
Flexural Extension (mm)
Bio Foam Sample 1
Bio Foam Sample 2
Bio Foam Sample 3
Bio Foam Sample 4
Mean Bio Foam Results

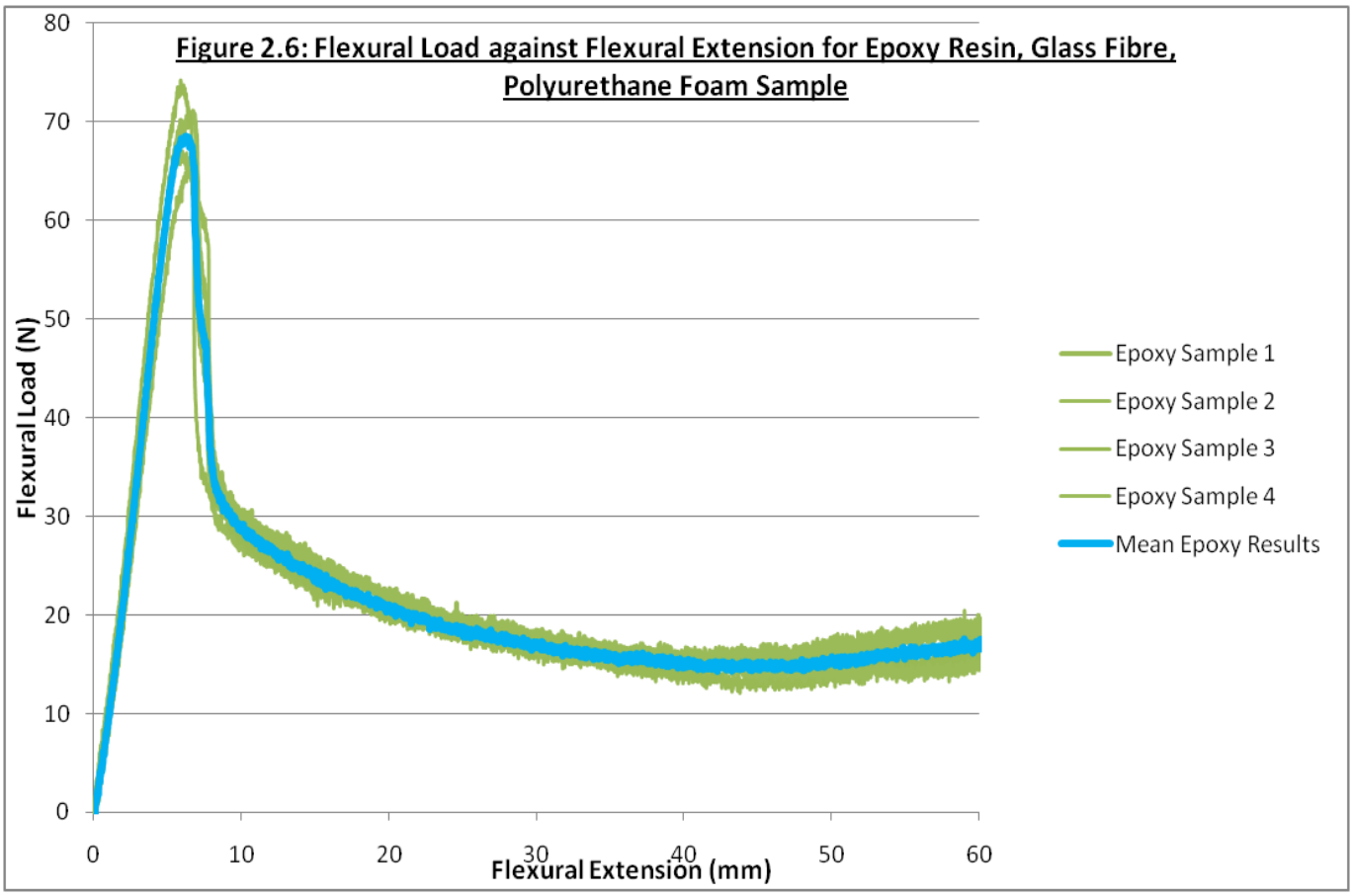


Figure 2.6: Flexural Load against Flexural Extension for Epoxy Resin, Glass Fibre, Polyurethane Foam Sample
Flexural Load (N)
Flexural Extension (mm)
0
10
20
30
40
50
60
70
80
Epoxy Sample 1
Epoxy Sample 2
Epoxy Sample 3
Epoxy Sample 4
Mean Epoxy Results

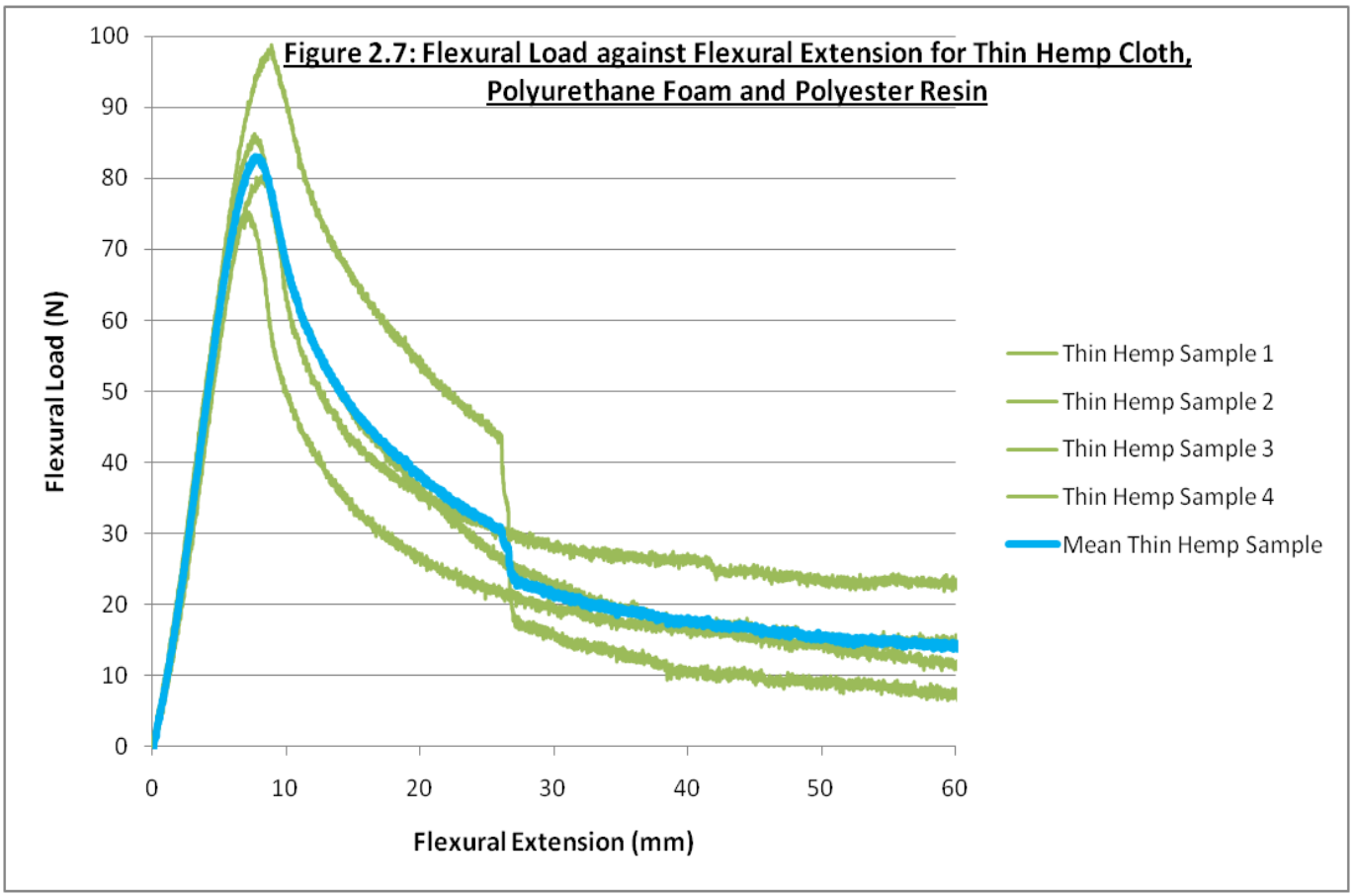


Figure 2.7: Flexural Load against Flexural Extension for Thin Hemp Cloth, Polyurethane Foam and Polyester Resin
Flexural Load (N)
Flexural Extension (mm)
0
10
20
30
40
50
60
70
80
90
100
Thin Hemp Sample 1
Thin Hemp Sample 2
Thin Hemp Sample 3
Thin Hemp Sample 4
Mean Thin Hemp Sample

Material Selection	Average Deviation from the Mean (N)
Glass Fibre, Polyurethane Foam, Polyester Resin	5.1
Thick Hemp Cloth, Polyurethane Foam and Polyester Resin	21.1
Bio Foam, Glass Fibre and Polyester Resin Sample	20.2
Epoxy Resin, Glass Fibre, Polyurethane Foam Sample	8.6
Thin Hemp Cloth, Polyurethane Foam and Polyester Resin	23.8

Figure 2.8: Table to show Average Deviation from mean for each sample selection

MATERIAL TYPE	COST	EASE OF USE/MANUFUCTURE
LAMINATE		
Glass Fibre	£3.58 (per m²)	-Easy to work with, flexible cloth. -Resin easily absorbed, and cloth wet-out quickly with ease. Absorbed ~10g of resin for each sample (e.g. standard size: 240mm x 50mm x ~10.6mm). -Few visible voids, even distribution of resin. -Fibres cut and sand evenly, no fraying.
Thin Hemp Cloth	£7 (per m²)	-Higher resin absorption at ~19g for each sample. -Fibre feels inflexible (0/90º weave), although bonds to foam with relative ease. -Higher visible void content. -Fibres cut easily and cleanly, although fraying occurs when sanded.
Thick Hemp Cloth	£5.25 (per m²)	-High levels of resin absorption ~27g for each sample. -Very inflexible cloth, difficult to laminate. Poor bond to foam, weight needed during curing process to compress laminate to foam. -High levels of visible voids in laminate. -Stiff, thick fibres very difficult to cut. During the cutting and sanding process there were high levels of frayed/split fibres.
FOAM		
Polyurethane	£45 (per 6'3'' blank)	-Easy to cut, sand and shape. No tears or rips in foam. -Standard consistency and density throughout whole blank. -No resin absorbed. -Clean white in colour.
Bio- Foam	£45 (per 6'3'' blank)	-Weak, soft properties. Little resistance (feels soft) when pressed. -Foam seems to absorb resin, causing the first sample manufacture attempt to fail due to huge voids in laminate. -Off white, yellowish colour
RESIN		
Polyester	£9 (for 1kg)	-Viscous: Easy to mix and apply to laminate. -Catalyst mixture (2%), samples hardened in oven to increase cure time.
Epoxy	£23 (for 1kg)	-Similar application properties to polyester.

Figure 2.9: Qualitative Table of results and observations throughout the manufacturing process. Costing figures from Homeblown (2006).

5. Discussion

5.1 Failure Mechanisms

In Figure 2.1 each of the samples go through similar failure mechanisms. Throughout the testing, the top skin is subjected to compression, with the bottom skin skin subject to tension, and the foam core to shear stress, as can be seen in Figure 1.2 .The most important analysis of the graph/samples occur in the initial elastic region, up to the point of top skin failure, in which the flexural stiffness and strength of the component can be calculated. The samples follow the same failure mechnisms seen in Figure 1.3 (Roylance, 1996). After top skin failure, analysis of plastic deformation area relatively un-important.

In each of the samples indentation failure occurred, in which the core was crushed under the top skin, with the top skin plastically deforming in compression (Rizov et al, 2005). This was noted by viewing the samples in testing, as it was clear the top skin elastically flexed in compression until core crushing occurred. Cracking noises could be heard after this point as the top skin failed in compression. This point can be seen on Figure 2.1 as each of the specimens reach their yield strength. Each of the five samples underwent these same failure mechanisms.

This indentation is localised in the top skin and occurs under the load beam, with the two support beams only supporting half the load each. The top skin bends elastically in compression, independently from the opposite skin, with the entire component bending elastically. In this case the load applied to the top skin surpassed the compressive strength of the core, therefore causing indentation of the core, and with further load, the top skin to failing in compression (Zenkert, 1995). This could therefore indicate that the both the Polyurethane foam core and the Bio-Foam have low allowable core shear stress, crushing before the skin laminate reaches its plastic yield point.

At this point the maximum flexural/yield strength is reached, followed by a drop in skin stress, due to a large fall in the structural rigidity of the beam. Greene (1999) states that indentation causes significant deterioration of the strength and stiffness properties of the sandwich construction, therefore explaining the dramatic drop in skin stress at this point.

5.2 Results

Hemp Cloth

By looking at Figure 2.1 and 2.2 it can be seen out of the natural fibres, the thin hemp cloth showed the most comparable properties to the industry standard. The flexural strength is 0.055 GPa lower than the standard materials, with a 30.9% decrease in flexural stiffness. The flexural strength of this sample is not significantly different to the standard materials (P: .139).

This pattern was also continued throughout the thick hemp results, which was a thicker, more un-refined hemp cloth. In this case the thick hemp showed a dramatic decrease of 63.2% in flexural stiffness compared to the industry standard, as well as 0.183 GPa decrease in flexural strength. This flexural strength is significantly different to the standard at a 99% confidence level (P: .008).

These test figures do not correlate to numerical data shown in Figure 1.1, which show only a 10.96% decrease in hemp Young's Modulus compared to glass fibre (Wallenberger et al, 2004). The strength figures stated are also not in relation with the literature, with Figure 2.1 showing a large difference (+≤0.183 GPa) between the hemp samples and glass fibre.

Therefore in both hemp cloth samples it can be seen that the flexural stiffness and strength is not comparable to that of the industry standard. By changing the laminate type (e.g. E-glass to hemp) the mechanical properties of the entire beam can be decreased. Reasons for this decrease in properties relate to the inconsistency in the natural fibres. Many factors affect their properties in testing, including individual fibre size, fibre extraction, the internal chemical composition as well as the fibre volume fraction (Equation 1.3.) (Mohantya et al, 2000).

The consistency and reliability of both the thin hemp and thick hemp samples can be seen in Figures 2.4 and 2.7. In both of these figures the results are sporadically spread away from the mean result. The thin hemp sample has a 23.8 N deviation from the mean, and the thick hemp with an average deviation at 21.1 N from the mean. This high level of deviation occurs amongst the natural hemp fibres due to the varying extraction methods and differing fibre types, as well as difficulties in laminating with the natural fibres (e.g. High void content). These inconsistencies make the hemp cloth unreliable to use in wide scale surfboard manufacture.

Figure 2.9 shows qualitative results. It should be noted that both the thin and thick hemp cloth are more expensive than standard glass fibre, with the thin refined hemp cloth costing £3.42 more per m^2, and the thick hemp costing £1.67 more per m^2, compared to standard glass fibre (Homeblown, 2006). This is due to the fact glass fibre is produced on such a large scale worldwide, therefore achieving vast economies of scale, and low costs (Wasteonline, 2006).

Figure 2.9 shows that the two hemp laminates actually absorbed higher amounts of resin, therefore adding to the weight of the samples. For example, the thin hemp sample absorbed ~9g more resin than the standard of glass fibre, with the thick hemp sample absorbing ~17g more resin. The increased weight is due to the fact that both hemp cloths are thicker than the glass fibre, with more resin needed to saturate the fibres. Hemp fibres also have moisture absorption of 8% (Figure 1.1). These factors therefore lead to weight increase, affecting the applicability of hemp as replacement to glass fibre, as keeping weight minimum is vital in surfboard construction.

It also states that the two hemp cloths were inflexible and difficult to laminate with, especially the thick hemp cloth which was difficult to bond to the foam, therefore needing to be weighted to aid the bonding process. Both hemp cloths also showed levels of visible voids compared to the glass fibres, possibly due to the level of moisture absorption in hemp (*Figure 1.1*: 8%). These higher levels of voids in the hemp samples could explain the inconsistency in results, as the voids cause weakness in the laminates due to the fibres not being wet out.

Other conditions to affect manufacturing issues include difficulties to cut and sand the hemp fibres. Overall these factors make using hemp cloth very difficult and labour intensive, especially on a large scale, decreasing their applicability for board manufacture.

Despite this there may be some use for hemp cloths as laminates in surfboard construction, especially in the surfboards with denser, stiffer cores such as balsa wood. In this case the surfboard would be gaining most of its rigidity from the dense core, therefore allowing for the environmentally friendly hemp laminate to be used to seal the balsa core, as well as adding some structural strength. This could be beneficial on non performance based surfboards, where keeping minimum weight is not a priority.

Using natural fibres in the surf industry is still relatively new and undeveloped. Schloesser (2004) states that the use and versatility of natural fibres in replacement of glass reinforcement is new, and global commercialisation of natural fibres will continue as benefits in low cost, low waste and reduced emissions is realised. As industries invest more time and money into the manufacture of natural fibres, fibre type and extraction quality will improve therefore improving the consistency and repeatability of the mechanical properties.

Bio-Foam

The Bio-Foam sample seen in Figure 2.1 can be seen to have dramatically decreased maximum flexural strength, and fails at a skin stress of 3.7 MPa lower than the industry standard, as well as a decrease in stiffness of 39.1%. The Bio-Foam sample showed a strong significant difference at a 99% confidence level from the flexural strength of standard materials (P: .002)

These decreased mechanical properties can be explained by the fact that Bio-Foam has a low compressive core shear strength compared to the polyurethane foam, which was used throughout the other samples. The Bio-Foam sample was laminated with the same glass fibre and polyester resin as the industry standard sample; therefore the decreased mechanical properties are a direct result of the low compressive strength of the core.

The decreased stiffness of the component is also a result of the low compressive strength of the core. By looking at Figure 2.1 it can be seen that the non-linear elastic region of the Bio-Foam sample begins at a lower skin stress. This therefore states that as load is applied, it exceeds the compressive strength of the core at an early stage, causing indentation and the top skin to bend elastically in compression. This therefore specifies why the stiffness of the Bio-foam component shows a 30.1% decrease, despite being laminated using the same glass fibre and polyester matrix as the industry standard.

Figure 2.5 shows the Bio-foam and its deviation from the mean. In this case the Bio-foam had an average deviation from the mean at 20.2N, therefore indicating a high level of unreliability. Despite this, most of this deviation occurred after the sample had failed, therefore not being relevant to the structural properties of the beam. In the elastic region, up to the yield point, the deviation remains relatively consistent, similar to the industry standard.

Figure 2.9 states that in comparison to the industry standard the Bio-foam shows un-desirable construction properties. It describes the foam feeling soft, with little resistance to pressure. These properties caused the foam to absorb resin, creating large voids, and unsaturated fibres in the laminate, therefore weakening the structure. This could be explained by the fact the petroleum based polyol, which makes up 45%

of the blank, has been replaced by a plant-based polyol, therefore dramatically decreasing the compressive core strength (Manning, 2007).

It can be seen by looking at the qualitative and quantitative results from the Bio-foam test specimen that it does not show comparable characteristics to the industry standard of polyurethane. The mechanical properties of the beam are dramatically deteriorated when the polyurethane foam is replaced with Bio-foam, and issues with resin absorption would make the foam un-usable on a wide scale surfboard manufacture. For this reason the Bio-foam could not act as a viable alternative to polyurethane, despite the environmental benefits.

Epoxy Resin

The test sample laminated with epoxy resin was the only sample to show improved mechanical characteristics compared to the industry standard. Figures 2.1 and 2.2 indicate that the epoxy laminate showed an increase in stiffness of 5.23%, and an increase of 0.046 GPa in flexural strength. The flexural strength of the epoxy laminate showed no significant difference to standard materials (P: .231).

This therefore states that by replacing the polyester resin used in standard surfboard manufacture, the mechanical properties of the entire structure can be improved. This correlates with numerical data from John (1972) which states that epoxy resin has higher flexural modulus of 2.1-5.5 GPa, compared to polyester resin with a flexural modulus ranging from 1.3-4.5 GPa. As well as this, epoxy resin retains 90% of it's inter laminar shear strength after one year in water immersion, where as polyester retains only 65% (SP Gurit). This is an important factor when looking at the environmental impact of surfboards, as it shows the epoxy resin will increase the longevity of a surfboard as less salt water degradation will occur over time.

Figure 2.9 that states that polyester costs £9 per kg, compared to epoxy which costs £23 per kg. Homeblown (2006) states that 5 kg's of resin is needed to laminate a standard 6'2'' (183cm) surfboard, therefore laminating a surfboard using epoxy resin would increase the cost by ~£70. This potential increase in cost could affect the potential use of epoxy resin in the surfboard manufacturing industry, due to the cost competitive nature of the surfboard industry.

Epoxy resin shows similar environmental properties to the industry standard of polyester, with poor environmental characteristics in relation to its production and disposal. Despite the fact epoxy resin is not an environmentally friendly alternative to polyester resin; its mechanical properties make it an attractive alternative. Epoxy resin improves the stiffness and flexural strength of sandwich panel, as well as its resistance to salt water corrosion. This will therefore increase the longevity of surfboards, therefore leading to a decreased amount of broken/damaged surfboards, and less waste in the long term.

As well as this it can be seen in Figure 2.9 that there were no comparable or noticeable differences between the polyester and epoxy resin in the manufacturing process. This therefore indicates that based purely on ease of use, epoxy resin could become an alternative to polyester resin. Figure 2.6 and 2.8 also show low average deviation from the mean (-8.6N), with most deviation occurring after failure, therefore indicating high level of repeatability and consistency, which is a vital attribute when looking at wide scale manufacture.

5.3 Sample Manufacture and Quality

As stated in the methodology, some problems occurred in the laminating process due to excess resin bonding to the samples underside on the laminating plate, which can be seen in *Figure 3.1*. The thicker level of resin would potentially increase the thickness, and therefore stiffness (second moment of area) of varying areas of the component. This could therefore increase the mechanical properties of the structure, accounting for random higher levels of deviation from the mean throughout the results.

Figure 3.1: Area of excess resin on laminate.

In this case hand lay was used to manufacture the samples, although this technique is inconsistent and can produce poor, structurally impaired samples with a high void content (Piggot, 2006). To ensure higher levels of accuracy vacuum bagging could be used, therefore applying higher fibre content, lower void content and better fibre wet out (Barbero, 1999). This in turn would ensure higher level of accuracy in the results. As well as this, vacuum bagging would have prevented issues such as the areas of excess resin seen in Figure 3.1.

The ASTM Standards for flexural testing state that span length must be calculated using *Equation 1.2,* therefore ensuring the specimens fail in the correct fashion. This proved to be difficult as assumptions and figures were not always known about allowable stresses for every material, therefore affecting the validity of the equation. As the testing was comparative between different materials it was deemed that span length was not the most important factor, and keeping the core dimensions constant was vital.

The bend or ‘rocker’ in the surfboard cores also restricted the amount of straight core material available. Due to this lack of material, only four samples for each material type were manufactured, instead of the ASTM recommendation of 5 samples. To ensure higher levels of accuracy more materials could be acquired, therefore increasing the number of test specimens, and the span lengths of the samples.

Another factor to take into account was the varying skin depths. As the samples were being laminated with differing materials, the thickness varied, with the thick hemp cloth at 2 mm thick, the thin hemp at 1.15 mm and the glass fibre at 0.77 mm. This varying skin depth affected the properties of the specimen in bending, with the thickest

samples showing the stiffest and strongest characteristics due to increased second moment of area (*Equation 1.1*). This was not proportional to the characteristics of the materials; therefore the flexural load/extension results gained from the flexural testing machine were calculated in skin stress/strain results using Equations 1.5 and 1.6. The skin stress equation allowed each of the components to be to be compared to each other (Figure 2.1) as the skin stress equation takes into account other factors, including the skin modulus and flexural rigidity of the plate.

6. Conclusion

This project aimed to test a variety of different materials against the standard industry surfboard materials, to a find natural or sustainable alternative which could be manufactured on a wide scale. From the research conducted, quantitative figures on the mechanical properties of materials were calculated, as well as qualitative results regarding the ease of use and manufacture, costs and consistency/reliability. These individual factors, when combined, could determine whether any of the materials tested were a viable alternative to the standard materials.

From both the flexural tests, and the qualitative results, it was seen that neither of the two hemp cloths had comparable properties to glass fibre. In both cases the flexural stiffness and strength of the hemp were dramatically lower than glass fibre. The thin and thick hemp also showed undesirable properties in manufacture, relating to the increase in weight and difficulties in lamination.

The Bio-Foam sample also showed detrimental characteristics by dramatically reducing the flexural strength and stiffness of the specimen. This showed the Bio-Foam to have a lower compressive core shear strength in comparison to polyurethane foam, and therefore not a viable alternative. These natural materials consequently offered a sustainable alternative to standard materials, but due to their mechanical and manufacturing properties, were not a realistic or viable alternative to either glass fibre or polyurethane foam.

By using an epoxy matrix instead of polyester, the stiffness and the flexural strength of the specimen was improved, as well as improving its resistance to chemical corrosion. Despite the fact that epoxy shows no environmental benefits over polyester, it would be a more environmentally friendly alternative to polyester as it increases the longevity of a surfboard. This therefore decreases board turnover and waste, resulting in fewer surfboards in landfill and less environmental pollution.

From the results it can be seen that these natural alternatives do not show good enough properties to replace industry standard materials. To ensure more thorough results a wider selection of natural and alternative materials could be tested. In this case, the material selection was reliant on materials available from free donations, although many other natural fibres and materials show good comparable properties to current standard materials.

As well as this, the use of natural alternatives in surfboard manufacture is relatively new. As more time and money is invested into the development of natural materials, their properties and consistency will improve leading to increased applicability in surfboard construction.

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