Natural Fibre Composites with Epoxidized Vegetable Oil (EVO) Resins: A Review

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Abstract—**This paper presents an overview of natural fibre composites that contain epoxidized vegetable oil (EVO) based resins. An introduction to fibre composites is given covering both the fibre reinforcement and polymer matrix. Natural fibre composites are discussed in detail with regards to the natural fibres themselves and the structure and composition of plant based fibres. The synthesis of EVO based bioresins and the technical background of vegetable oils, in particular Australian based vegetable oils is presented. Performance limiting factors of natural fibre composites have been identified and outlined. Key areas of concern such as fibre-matrix interfacial bonding, biodegradation of natural fibres, fibre separation and dispersion and thermal instability of fibres are covered. Current state-of-the-art research into natural fibre/EVO composites is reviewed with particular emphasis being placed on structural natural fibre/EVO composites. Areas for future research such as a focus on the synthesis and characterisation of EVO made from novel vegetable oils is discussed.**

Keywords-Natural fibre; Composite; Epoxidized vegetable oil; EVO;

I. INTRODUCTION

Over the last several decades synthetic fibre composites have emerged as an important engineering material and are being used in numerous applications ranging from sports equipment, automotive, residential construction, aerospace and recently large scale civil engineering projects such as bridges [1]. These fibre composites have predominantly been produced from non-renewable, petro-chemical based materials. However, currently there is an emergence in the support of producing natural fibre composites that offer sustainability, reduced energy consumption, low cost and comparable performance to synthetic fibre composites. This shift in attitude has arisen primarily due to an increase in the levels of environmental awareness, health concerns and the likelihood of cost increases due to petro-chemical dependence of synthetic fibre composite resins.

Due to the requirement to develop sustainable fibre composites for use in civil engineering applications, the Centre for Excellence in Engineered Fibre Composites (CEEFC) is currently involved in numerous research projects regarding natural fibre composites. Particular research is focused on improving the interfacial adhesion between the fibre and resin,

development of epoxidized hemp oil (EHO) based resins and the evaluation of the application of natural fibre composites as structural components. It is envisioned by the author that natural fibre composites manufactured with plant derived natural fibres or a natural/synthetic hybrid fibre blend in a complete bio-resin matrix or a bio-resin/synthetic epoxy blend have the potential to be used as an alternative to glass fibre composites in entry-level structural engineering applications. This paper presents an overview of plant based natural fibre composites that contain epoxidized vegetable oil (EVO) based bio-resins.

II. COMPOSITES

Mainstream implementation of composites is often perceived to be a relatively new occurrence. However the reality is that the utilization of composite materials has been in existence for centuries. Some of the earliest evidence of the existence of composite materials can be traced back to biblical times with the book of Exodus describing the Israelites being forced to find their own straw to make clay bricks.

Composites consist of two main components whereby one component (fibre) structurally reinforces the other component (matrix). The material constitutes are selected in order to design a material with specifically desired material properties. It is the synergy of the combined material constituents that ensures the final composite material has superior material properties for the required application than each of the individual material elements alone. The primary phase is generally the reinforcing fibres such as glass, carbon or natural 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 [2] that is petro-chemical based. Composites can be broken down into two main groups; fibre reinforced composites and particulate composites.

A. Fibres and Particulates (Fillers)

The ultimate material properties of fibre composites are primarily governed by the reinforcing supplied to the matrix in the form of fibres. Therefore the performance of the end composite is ultimately governed by the inherent properties of

the selected fibre type [3]. Fibres differ from particular reinforcements (fillers) in that they display a length of a much greater magnitude than their cross section [4]. Fillers are generally used for cost reduction purposes as by nature they do not provide any significant increase in the mechanical properties of the composite. The fibre/filler content can be characterised in terms of weight fraction (Wf) and volume fraction (Vf) [4] which are ratios of weight and volume respectively compared with the weight and volume of the final composite.

Fibres can be categorised as being synthetic, natural, or regenerated, with natural fibres also being subcategorized as being plant, animal, or mineral fibres [5]. Synthetic fibres consist of fibres such as nylon, glass and carbon. Examples of natural fibres are flax, bagasse, sisal 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 [5]. Common types of fillers being used are silica, aluminium, calcium carbonate. Waste products such as flyash and wood flour can also be used as fillers.

An important aspect regarding the material properties of the composite is the degree of adhesion between the fibre and the matrix. From the literature, numerous studies [6, 58-61] indicate that the quality of the fibre matrix bond has an effect on the compression strength, flexural strength, transverse tensile strength, in-plane shear strength and fracture toughness. The quality of the fibre matrix bond is related to the Wf and Vf with the determination of an upper limit in order to prevent fibre-fibre contact and ultimately fibre damage [4] and composite failure. This was further confirmed by Manthey et al. [7] where it was found that above an optimum Wf the composite mechanical performance started to decrease. It is the need to balance performance versus cost that research has been conducted on numerous fibre types.

B. Polymer Resins

Modern commercially produced composites use petro-chemical based 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. There are two main categories of polymer resins, these being thermoplastics and thermosets.

Thermosetting polymers are the most common type of resin used in the civil engineering composite industry as they have the required mechanical properties for use in structural components. Some of the most common types of thermosetting polymers used throughout industry are unsaturated polyesters, epoxies, phenolics and vinyl esters.

Thermosetting polymers are liquid at room temperature, which enables the easy addition of fibres and or other additives before curing. Curing of thermoset polymers is achieved by the addition of a hardener followed by post-curing in an oven. 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 permanently increases the viscosity of the polymer, even upon reheating.

III. NATURAL FIBRE COMPOSITESS

Natural fibre composites are similar to synthetic fibre composites except that the materials that compromise one or more phases are of biological instead of synthetic origin. The polymer matrix may be derived from EVO or starches instead of synthetic epoxies or polyesters for example. The reinforcing phase may be hemp, flax or jute fibres instead of glass, carbon or aramid fibres. Fillers may be in the form of wood flour, or waste products such flyash.

A. Natural Fibres

Natural fibres can be subcategorised as being plant, animal, or mineral fibres [5]. Plant based natural fibres can be further classified as leaf, bast, fruit, seed [8], wood, cereal straw, and other grass fibres [9]. These plant based natural fibres demonstrate numerous advantages over synthetic fibres. They signify an inexpensive, easy to process, renewable fibre that exhibits high specific material properties with end of life cycle recyclability [8, 10, 11]. Other advantageous properties of plant based natural fibres are a reduced carbon footprint from the growing of the plants, and enhanced energy recovery at the end of their lifecycle [12]. However there are also disadvantages associated with these fibres. Saherb & Jog [13] reported that they may have the propensity to form aggregates during processing and also exhibit a low resistance to moisture absorption. This hydrophilic characteristic may lead to poor matrix-fibre compatibility and therefore compromise overall material performance. Chemical treatments, such as alkali treatment aim to overcome this problem by modifying the structure and the surface properties of the fibres, thereby allowing enhanced fibre-matrix compatibility. Table 1 provides the mechanical properties of some common nature fibres compared with E-Glass as a reference. It can be seen that natural fibres compare favourably to E-Glass in terms of specific properties.

Table 1. Mechanical properties of natural fibres compared with E-glass [56, 57].

Fibre	Specific gravity	Tensile Strength (MPa)	Young's Modulus (GPa)	Specific Strength (MPa)	Specific Modulus (GPa)
Sisal	1.20	600-700	38	500-583	32
Flax	1.20	800-1500	60-80	667-1250	50-67
Jute	1.46	600-1100	10-30	411-753	7-21
Hemp	1.14	550-900	50-70	482-790	44-62
E-Glass	2.60	3400	75	1308	29

1) Structure and Composition of Plant 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 [9]. The basic structure of a plant fibril is a primary cell wall surrounding a secondary wall. The primary cell wall is responsible for providing structural and mechanical support, controlling growth rate and direction and cell-cell interactions. The secondary wall consists of three layers that provide the bulk of the mechanical strength of the fibre [9]. The outmost layer of the fibre is called the middle lamella and it serves to provide stability by fixing adjacent cells together. The structure of a plant fibre can be seen in Fig. 1.

The components of common plant based fibres are displayed in table 2 with the three main components shown to be, cellulose, hemi-cellulose and lignin respectively. Cellulose is a naturally occurring polysaccharide that consists of a linear chain of D-anhydroglucose connected by β(1-4)-D-glycosidic links in ^{4}C1 formation [9]. 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 [9]. Hemi-cellulose is comprised of 5 and 6 carbon ring sugars that support the cellulose microfibrils through a matrix arrangement [9]. 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 [9] lignin is a thermoplastic polymer with a glass transitional temperature of 90°C and a melting temperature of 170°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.
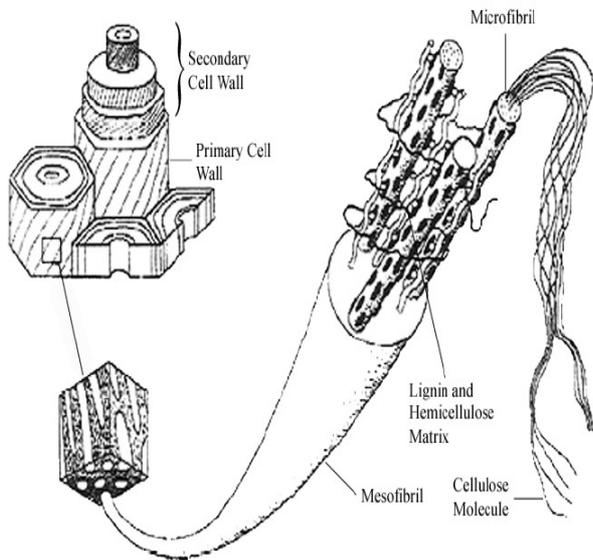

Figure 1. Structure of a plant fibre [14].

B. EVO Based Bio-Resins

The majority of polymer resins used in engineering applications are currently derived from non renewable, petro-chemical based resources. The production of genuine natural fibre composites requires that the matrix be manufactured predominately from renewable materials. Due to the performance limitations of thermoplastics in structural applications, there is sizeable need for research and development into the synthesis and optimisation of thermosetting bio-resins made from renewable resources.

Bio-resins which are derived from natural sources, particularly vegetable oil based resins, offer a viable alternative to petro-chemical based resins as the required feedstocks are readily available in most of the world [15]. There are indications [16] that the Darling Downs region of Queensland, Australia is suitable for the production of vegetable oil based resin feedstocks, although the successful implementation of these crops will depend on both the profitability and the manufacturing properties of the oil produced.

Plant oil feedstocks are converted into bio-resins through the process of epoxidation and are termed, EVO. EVO based bio-resins are inexpensive and are easily incorporated into epoxy resins and are currently, primarily used as a plasticiser or toughening additive for epoxy resins. However with further research it is anticipated that EVO based resins can be developed and used as complete resins systems in civil engineering applications.

1) Australian based vegetable oils

Australia is a major world producer of oilseed crops of which Queensland (QLD) is a large contributor. The annual production of oilseed crops in Australia is 2-3 million tonnes, of which over 90% is canola and cotton seed. Sunflower and soybean make up the majority of the remaining 10% with minor contributions being from safflower, peanut, linseed and industrial hemp [17]. Table 3 outlines the annual production of oilseeds in Australia. QLD produces several main types of oilseed crops, namely soybeans (48000 tonnes/annum) and sunflowers (31700 tonnes/annum) [17]. Other oilseed crops such as cottonseed, peanut and industrial hemp are produced in smaller quantities. The majority of oilseed production is used for food products and is used in cooking oils, livestock meal, shortening and edible products. The problem posed by using vegetable oils for bio-polymer uses is the fact that it diminishes the supply for food sources. As the demand increases in the polymer industry the price of the oils is expected to rise due to increased competition. A focus on using non-food crops, such as hemp for use in bio-polymers is required so as not to influence the price of food oils. Current QLD legislation does not allow the use of hemp in food products thereby making it a suitable candidate for a bio-polymer feedstock. Although the production of industrial hemp is still in its infancy after being previously banned it is currently being grown in southern QLD with oilseed yields of 250-500kg per hectare [18].

Table 2. Composition of some common plant fibres [19].

Fibre	Cellulose (%)	Hemi-Cellulose (%)	Lignin (%)	Pectin (%)	Other (%)
Jute	61-71	13.6-20.4	12-13	0.2	0.5
Flax	71-78	18.6-20.6	2.2	2.2	5.5
Hemp	70.2-74.4	17.9-22.4	3.7-5.7	0.9	7
Kenaf	53-57	15-19	5.9-9.3	-	7.9
Sisal	67-78	10-14.2	8-11	10	3
Cotton	82.7	5.7	-	-	0.6

Table 3. Annual production of oilseeds in Australia ('000 tonnes) [17].

Oilseed crop	07/08	06/07	05/06	04/05	03/04
Canola	1069	512	1440	1531	1622
Sunflower	75	20	95	61	29
Soybean	35	30	56	54	74
Cottonseed	200	350	800	850	420
Other	10	10	20	7	10
Total	1985	922	2411	2503	2165

2) Technical Background of Vegetable Oil

Vegetable oils are composed of triglyceride molecules which can be categorised as consisting of a glycerol molecule which consists of a chain of three carbon atoms that are connected to three hydroxyl groups. The glycerol molecule is in turn attached to three fatty acid chains which comprise of unsaturated and saturated fatty acids [20]. Fig. 2 displays a typical triglyceride molecule. Saturated fatty acids exhibit only single carbon-carbon bonds (C-C) and no carbon-carbon double bonds, whereas unsaturated fatty acids may contain numerous double or triple carbon-carbon double bonds. This is typically designated in the literature as C=C and C≡C respectively. A fatty acid chain contains a long carbon chain that is connected to a carboxylic acid group at one end. Fatty acid chains are constructed from the elements carbon, oxygen and hydrogen. According to Wool [15] 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 carbon-carbon double bonds per fatty acid chain. Vegetable oils are predominately composed of the following unsaturated fatty acids; oleic acid, linoleic acid and linolenic acid. A variation in the number and the type of triglycerides differs relative to the type of oil in question due to differing fatty acid compositions.

The C=C 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 C=C 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 [15].

Vegetable oils composing of a high level of C=C and/or C≡C provide superior mechanical and thermal characteristics because of the higher crosslink density attributed to the higher number of unsaturated groups in the oil. Table 4 shows the fatty acid profiles of some common vegetable oils.
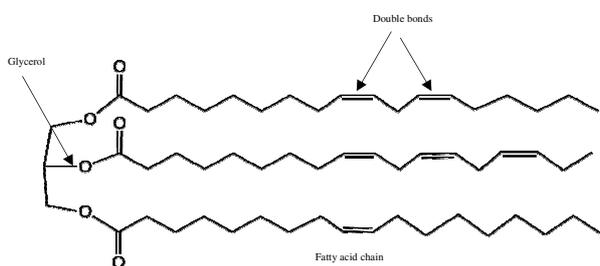

Figure 2. Triglyceride molecule.

3) Synthesis of EVO Based Resins

There are four established techniques acknowledged in the literature regarding the conversion of plant oils into epoxidized polymer resins. These are epoxidation with organic and inorganic peroxides using a transition metal catalyst, epoxidation using halohydrines, epoxidation via molecular oxygen and epoxidation *in situ* with percarboxylic acid. Epoxidation with organic and inorganic peroxides involves a transition metal catalyst such as nitrile hydrogen peroxide. A common inorganic catalyst is nitrile hydrogen peroxide [21]. Epoxidation using halohydrines is environmentally unfriendly and involves the use of hypohalous acids (HOX) and salts as reagents [22]. Epoxidation via molecular oxygen is most environmentally friendly and economically viable when catalysed with silver. However it produces low levels of double bond conversion and is only suited to simple ethylenic substrates such as ethylene and butadiene [23]. Goud et al. [24] states that the use of oxygen as a catalyst may lead to vegetable oil degradation. The most suitable technique for clean and efficient epoxidation of vegetable oils is epoxidation *in situ* with percarboxylic acid using Acidic Ion Exchange Resin (AIER) as the catalyst.

It is possible to use either acetic acid or formic acid as the carboxylic acid in the epoxidation process. Acetic acid represents an inexpensive acid that is readily available and has high epoxidation efficiency. Predominately the role of acetic acid is as a catalyst in the formation of the oxirane ring [25] and as an oxygen carrier from the aqueous phase to the oil phase [23]. Mungroo et al. [26] found that the use of acetic acid resulted in a 10% increase in the conversion of ethylenic unsaturation to oxirane than that formed by formic acid. Furthermore Dinda et al. [23] identified that acetic acid resulted in a higher ultimate conversion to oxirane with fewer undesired products formed. The increased formation of undesired products may be attributed to the decomposition of some hydrogen peroxide. This is a result of the active temperament of the formic acid thereby resulting in early onset oxygen depletion of the system [27].

Peroxyacetic acid is created by the reaction between the hydrogen peroxide and the acetic acid. This peroxyacetic acid interacts with the catalyst by way of entering the pores of the catalyst. After the AIER is implemented into the reactor the pores of the resin are filled with peroxyacetic acid. This action results in low oxirane degradation due to the non-admittance of triglycerides into the resin as a result of the gel type structure of the AIER [15]. There is an extensive body of literature regarding the synthesis of oils by way of epoxidation *in situ* with percarboxylic acid, hydrogen peroxide and AIER.

AIER is the most frequently used catalyst with acids such as sulphuric acid [25] and enzymes [23] less frequently being used. According to Vlcek and Petrovic [27] the use of strong acids such as sulphuric and phosphoric acid as catalysts can lead to undesirable oxirane ring-open reactions with water thereby creating secondary hydroxyl groups on the fatty acid backbone. AIER is an insoluble gel type catalyst in the form of small yellowish organic polymer beads. Situated on the surface of the AIER are pores which serve to trap and release ions. The catalyst works by carrying a surplus electrical charge and is made electrically neutral by carrying counter-ions. The counter-ions are not fixed and are able to leave the structure of the catalyst provided they are replaced by other ions of the same charge. Table 5 provides examples of the research into some epoxidised vegetable oils.

Table 4. Research into EVO.

Oil type	Reference
Soybean	31, 27, 49, 50, 55
Canola	26, 51
Jatropha	25, 31
Karanja	21, 52
Hemp	53, 54

IV. PERFOMANCE LIMITING FACTORS

Although natural fibre composites present numerous advantageous properties there are some key problems that need to be solved in order for commercial success. The main performance limiting factors pertain more to the natural fibres as the problems seem to be mainly independent of resin type.

A. Fibre-Matrix Interfacial Bonding

Incorporating hydrophilic natural fibres into largely hydrophobic resins often results in a final composite exhibiting inferior mechanical properties due to heterogeneity. This heterogeneity can be attributed to poor fibre-matrix interfacial bonding. Fibre-matrix interfacial bonding is primarily dependent on the degree of adhesion between the fibre and the matrix. This adhesion serves as an important aspect of the ultimate performance of the final composite as it acts as a means of stress transfer from the matrix to the fibre.

Therefore to fully realise the mechanical properties of the reinforcing fibres and ultimately improve the properties of the final composite, it is necessary to improve the fibre-matrix interfacial bonding. Improvements to the fibre-matrix interfacial bonding can be realised by modifying the surface of the fibres to make them more compatible with the matrix, with treatments such as; bleaching, alkali, silane, acetylene, benzoylation and acrylation. It is also possible to improve fibre-matrix interfacial bonding by modifying the matrix with the addition of coupling agents. Of these methods, possibly the most common and simply implemented method is alkali treatment of the fibres with a solution of sodium hydroxide (NaOH). Alkali treatment enhances the fibre-matrix interface through increased surface roughness and removal of numerous impurities and waxy substances. Ultimately this results in superior mechanical interlocking of the fibres with the resin.

B. Biodegradabilty of Natural Fibres

When exposed to biological organisms, natural fibres have the propensity to biodegrade. This biodegradation is primarily facilitated by interactions of the organisms with cell wall constituents, primarily hemicelluloses. It is imperative to reduce or ideally prevent this biodegradation in order to produce high quality composites. One possible solution is to use chemical treatments to effectively block the hydroxyl groups (-OH) thereby reducing organism-cell wall interactions [28]. Natural fibres are also prone to photochemical degradation. Photochemical degradation of natural fibres occurs as a result of exposure to ultraviolet (UV) light. The degradation primarily involves the lignins within the fibre and the severity ranges from mere surface discolouration through to a discernible reduction in mechanical performance [29, 30].

Table 5. Fatty acid percent composition of vegetable oils [21, 31, 32].

Fatty acid	Canola	Soybean	Linseed	Sunflower	Hemp
Palmitic	4.1	11.0	5.0	4.8	6.0
Stearic	1.8	4.0	4.0	5.7	2.0
Palmitoleic	0.3	0.1	-	0.8	-
Oleic	60.9	23.4	19.0	20.6	12.0
Linoleic	21.0	53.2	14.0	66.2	57.0
Linolenic	8.8	7.8	58.0	0.8	20.7
Other	3.1	0.5	-	1.1	2.3

C. Fibre Separation and Dispertion

The integration of natural fibres into polymer resin matrices often leads to poor dispersion of fibres due to the strong inter-molecular hydrogen bonds of the fibres and differences in polarity between fibre and matrix [13, 33]. Mechanical properties of the end composite are reduced due to an increased susceptibility to micro-cracking as a result of poor fibre dispersion which is a result of fibre clumps and fibreless areas within the composite structure. In order to obtain satisfactory end composite performance it is imperative to ensure adequate fibre dispersion within the matrix. The implication is that the fibres should be completely separated from each other and entirely surrounded by the matrix [34]. Separation of fibres can be achieved by dissolving the pectins and lignins present within the fibre with an alkali solution [35].

D. Thermal Instability of Fibres

Natural fibres exhibit low thermal stability characteristics. Thermal degradation of the natural fibres is a two-stage process with the initial thermal degradation occurring at 200°C due to degradation of hemicelluloses. The second stage occurs at approximately 280-300°C and is due to the degradation of lignins. Owing to the occurrence of thermal degradation of the natural fibres processing conditions, namely curing temperature in thermosets and extrusion temperature in thermoplastics has to be monitored. It has also been suggested by several authors [36-38] that alkali treatment may result in an improvement in thermal degradation.

V. CURRENT STATE OF THE ART: NATURAL FIBRE/EVO COMPOSITES

Natural fibre composites manufactured with natural plant fibres or natural/synthetic hybrid fibre blends in a complete EVO matrix or a EVO/synthetic epoxy blends have shown the potential to be used as an alternative to glass fibre composites in entry-level structural engineering applications. Large scale natural fibre composite 'unit beams' of sandwich construction were successfully manufactured at the University of Delaware (UD) from flax mat, chicken feathers, recycled paper and structural foam using epoxidized soy-bean oil (ESO) and a modified vacuum assisted resin transfer moulding (VARTM) process [39, 40]. Fig. 3 shows a completed unit beam after debagging. Similar work undertaken at UD focused on the development of natural fibre composite bridges using recycled paper, sisal and jute twine, jute fabric and ESO and VARTM [41]. The overall goal of this study at UD is the development of an all-natural monolithic roof system for residential construction [42].

Other researchers have undertaken research into natural fibres with synthetic resins and/or glass fibres with EVO based resins. Chandrashekhara et al. [43] and Zhu et al. [44] from the University of Missouri-Rolla have conducted research into

pultruded composite structural beams using ESO based resins and glass fibres. They demonstrated that ESO resins showed significant promise for use in structural composite applications. A body of work from Burgueno et al. [45-48] has primarily focused on developing structural hierarchical natural fibre composite beams and panels. Numerous materials were used ranging from chopped hemp, flax mat, E-glass and jute mat with unsaturated polyester resins (UPE). Results from these studies found that hierarchical designs can improve the performance of natural fibre composite beams and plates thereby allowing them to potentially compete with synthetic fibre composites.

Figure 3. Natural fibre composite unit beam [42].

VI. POSSIBLE FUTURE RESEARCH DIRECTIONS

A considerable amount of research been conducted on natural fibre composites. However the majority of this work tends to focus on using natural fibres with synthetic resins. For natural fibre composites to be truly sustainable the matrix must also be predominately of a biological origin. Throughout the world vegetable oils have been used as renewable feedstocks from which to produce epoxy resins. The most commonly used vegetable oils are soybean oil, linseed oil, palm oil and to a lesser degree canola oil. Soybean oil currently enjoys the largest market share out of all of the oils and extensive research and development has been performed throughout the world involving natural fibre composites made from soybean oil based resins. However for vegetable oil based polymer resins to compete with petrochemical based resins different types of vegetable oils must be investigated. Due to the numerous different fatty acid structures of different types of vegetable oils it is possible to find superior alternatives to soybean oil. Research needs to be conducted on the synthesis and characterisation of novel vegetable oils. Currently there is limited research into the characterisation of EVO based resins in terms of curing behaviour and moisture absorption. Further functionalization of novel vegetable oils also needs to be examined.

VII. CONCLUSIONS

The potential of natural fibre/EVO composites has begun to be realised in engineering applications with leading researchers demonstrating that it is possible to develop low cost structural components such as beams and panels that can compete with glass fibre composites in entry level structural applications.

The possible combinations of biocomposites are almost infinite. In order to better understand the potential for natural fibre/EVO composites to be used in structural or construction applications, different types of composites made from different types of fibre and matrices should be studied. Further research needs to be conducted on the development of EVO based bioresins using novel vegetable oils. These new bioresins must be characterised in terms of curing behaviour moisture absorbance and mechanical properties.

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