A Systematic Review and Investigation on Mechanical Properties and Finite Element Modelling of Reinforced Polymer Based Fiber Composites

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***Abstract*—throughout the preceding epoch's fibre reinforced polymer composites (FRPC) have been evidenced as very valued substantial and apposite to be a new-fangled construction material. Even though at the present time, natural fibres have acknowledged plentiful more consideration from the structural scientist and engineers all over the world and manipulation of natural fibres as reinforcement in polymer composite for making the stumpy cost construction materials has been budding very eclectic interest. Due to the disadvantage of the synthetic and fibre glass as reinforcement, the use of fibre reinforced composite augmented the curiosity of the researcher or the scientist. Natural fibres have assisted numerous convenient purposes but the demand for exploitation of it as fortification in polymer matrix is growing in recent years. In current days the use of natural fibre reinforced polymer composites in automobile, aerospace and other industrial applications become increased due to light weight, less cost, bio degradability and easy to manufacture. This review article investigates the use of various fibres as reinforcement in composites. We present a systematic review of work done by previous researchers especially in analysing mechanical and finite element properties of banana fibre composites. Influence of Fibre on Matrix Properties and various Mechanical Properties of Hybrid Composites are also surveyed.**

I. INTRODUCTION

Fiber resources are getting exhausted constantly while demand for material is ever growing. According to the literature, by the creation of the subsequent century the wood will be limited for the entire world (Singh, 1982) [1]. This condition has led to the progress of another material. Between the numerous synthetic materials that have been discovered & advocated, plastics claim a main share as wood alternatives. Plastics are used for nearly everything from articles of daily use to components of complex engineering structures & dense industrial applications (Rai & Jai Singh, 1986) [2]. Plastics find a widespread application in the buildings as flooring the material because they are resistant to scrape, have a low heat conductivity & low water absorption, adequate hardness & strength. They fail to swell when moistened, readily take on varnishes & paints. Hardware objects like door & window frames, flushing cisterns, overhead water storage tanks & water fittings are commercially obtainable & are finding receipt in the building industry. Plastics are used to manufacture numerous sanitary wares, which comprise wash basins, bathtubs, sinks, shower cabins, washing racks & others. Plastic pipes are extensively used in the installation of numerous industrial devotions, water source etc.

However, during the previous decade, the study of the filled plastic composites has simulated immense interest in the meeting future shortage of the plastic materials (*Lightsey*, 1983) [3]. In fact, synthetic fibers such as nylon, rayon, aramid, glass, polyester & carbon are widely used for reinforcement of the plastics (Erich et al., 1984 [4]; Lawrence et al., 1995) [5]. Nonetheless, these materials are costly & are non-renewable resources. Because of the uncertainties fundamental in the source & price of petroleum based products, there is every requirement to use naturally occurring alternatives. In many portions of the world, further for the agricultural purposes, dissimilar portions of plants & fruits of numerous crops have been found to be possible sources of raw material for industrial determination.

In current years, polymer composites comprising vegetable fibers have received significant devotion both in the literature & in industry. The interest in the natural fibre reinforced polymer composites is increasing rapidly due to high performance in the mechanical properties, important processing benefits, low cost & low density (Satya Narayana et al., 1990) [6] [7]. Natural fibers are renewable resources in numerous emerging countries of the world; they are inexpensive, pose no health hazards &, lastly, offer a solution to environmental pollution by finding novel uses for waste materials. Additionally, natural fibre reinforced polymer composites form a novel class of materials which seem to have decent potential in the future as an additional for unusual wood & wood based materials in structural applications. Fibres acquired from the many parts of plants are known as the vegetable fibres. These fibres are categorized into 3 categories depending on the part of plant from which they are removed.

- Bast or the Stem fibres (Mesta, jute, banana etc.)

- Leaf fibres (pineapple, sisal, screw pine etc.)
- The fruit fibres (cotton, coir, oil palm etc.)

Several of the plant fibres like coir, jute, sisal, banana, Palmyra, pineapple, *talipot*, hemp, etc. find applications as resource for the industrial materials (*Satyanarayana* et al., 1990b [7]; Thomas & Udo, 1997 [8]; Rowell et al., 1997) [9]. Table 1 offerings the properties of various plant fibres. Properties of plant fibres depend generally on nature of plant, locality in which it is developed, age of the plant, & the extraction technique used. For instance, coir is a hard & tough the multicellular fibre with central portion called "lacuna". Sisal is a significant leaf fibre & is very strong. Pineapple leaf fibre is soft & has high cellulose satisfied. Oil palm fibres are hard & tough, & display comparison to coir fibres in cellular structure. The fundamental unit of cellulose macromolecule is the *anhydro*-d-glucose, which comprises 3 alcohol hydroxyls (-OH) (*Bledzki et al.,* 1996) [10]. These hydroxyls form the hydrogen bonds inside macromolecule itself (i.e. intramolecular) & among further cellulose macromolecules (i.e. Intermolecular) as well as with the hydroxyl groups from the air. Therefore, all the plant fibres are of hydrophilic nature; their moisture content spreads 8-13%.

Additionally, to cellulose, plant fibres comprise different natural substances. The most significant of them is lignin. The separate cells of hard plant fibres are merged together by lignin, acting as a cementing material. The lignin content of plant fibres effects its structure, properties & morphology. A significant characteristic of the vegetable fibre is their degree of the polymerization (DP). The cellulose molecules of every fibre fluctuate in their DP & subsequently, the fibre is a difficult combination of polymer homologue $(C6H10O5)_n$. Bast fibres usually display the highest DP among all plant fibres (~10,000). Typically, these fibres have been used for making twines, ropes, cords, as packaging material in sacks & gunny bags, as carpet-backing & more recently, as a geotextile material.

The vegetable fibres can be considered as naturally happening composites consisting generally of cellulose fibrils fixed in lignin matrix. These cellulose fibrils are associated along the length of the fibre, regardless of its origin, i.e. whether it is removed from stem, leaf or fruit. It performs that such an arrangement renders maximum tensile & flexural strengths, additionally to providing inflexibility in that direction of the fibre as perceived in the case of bamboo. Further, these fibres show the high electrical resistance in addition to being the thermally & acoustically insulating. It can therefore be predictable that when these fibres are combined in low modulus polymer matrices, they would yield materials with improved properties appropriate for numerous applications.

Since vegetable fibres are strong, light in weight, abundant, non-abrasive, non-hazardous & reasonable, they can assist as an outstanding reinforcing agent for plastics. Numerous cellulosic products & wastes such as shell flour, wood flour & pulp have been used as plasters in polymers, primarily to attain cost savings & also to convey certain necessary properties like reducing shrinkage after molding, growing elastic modulus & creep resistance (*Lightsey*, 1983 [3]; *Prasad* et al. 1983 [11]; *Kokta*, 1988 [12]; *Maldas & Kokta*, 1991 [13]). Cotton-polymer composites are described to be first fiber reinforced plastics used by military for the radar aircraft (*Piggot*, 1980 [14]; *Lubin*, 1982 [15]). However, over ancient decade, the cellulosic fillers of the fibrous nature have been of the greater interest as they would give the composites with enhanced mechanical properties compared to those comprising non-fibrous fillers (*Paramasivam & Abdulkalam*, 1974 [16]; Joseph et al., 1993 [17] [18]; *Carvalho*, 1997 [19]; *Pavithran* et al., 1987 [20], 1988) [21].

Vegetable fibres possess moderately high definite strength & difficulty & can be used as the reinforcing materials in the polymeric resin matrices to make the useful structural composites materials. *Ligno* cellulosic fibres like jute, sisal, coir, & pineapple have been used as helps in the polymer matrices. Between these fibres, sisal is of specific interest in that its composites have highly influence strength besides having reasonable tensile & flexural properties associated to other lingo cellulosic fibres (*Pavithran* et al., 1987) [20]. However, a huge amount of the renewable resource is being the under-utilized. The sisal fibre is primarily used for the production of ropes for use in marine industry & agriculture, for creating twines, cords, padding, mat making, fishing nets, fancy objects such as purses, wall hangings, table mats etc. Use of the sisal fibre as textile fibre by mankind initiated with *Weindling's* effort for the period of forties (*Weindling*, 1947) [23]. Along with the reading of agronomic & industrial features, a systematic & significant study on sisal fibre was carried out by Wilson (1971) [24].

TABLE 1. Properties of some natural fibers (*Mukherjee & Satyanarayana*, 1984) [22]

Fiber type	**Diameter (μm)**	**Density (gcm^{-3})**	**Cellulose (%)**	**Lignin (%)**	**l/d ratio***	**Cell Wall Thickness (μm**	**Microfibrillar Angle (deg)**
sisal	100-300	1.450	70	12	100	12.5	20-25
Banana	50-250	1.350	83	5	150	1.25	11-12
Coir	100-450	1.150	37	42	35	8.00	30-45

He also paid attention to the probability of chemically changing the fibre & put forward arguments for refusing the impression due to the disadvantages that have to be permitted for the loss in strength as an outcome of chemical actions. Over past few decades, numerous studies have been described on use of the sisal fibres as reinforcements in the polymer matrices (*Barkakaty*, 1976 [25]; *Bisanda* & Ansell, 1991 [26]; Joseph et al., 1992 [27], 1993 [17] [18], 1994 [28]; *Mattoso* et al., 1997) [29]. Therefore, comprehensive & the organized survey has been carried out on use of the sisal fibre as reinforcement in polymer composites

II. TYPES OF POLYMER COMPOSITES

Broadly, polymer composites can be classified into three groups on the basis of reinforcing material. They are:

1. Fiber reinforced polymer (FRP)
2. Particle reinforced polymer (PRP)

1. *Fiber reinforced polymer*

Okra Fiber reinforced polymer composite [30] is useful for the preparation of doors for house hold purposes with light weight. Tensile modulus of okra woven chemical treatment fiber reinforced polymer composite shown linear increase in its value with increase in percentage volume fraction of fiber.

A study [31] on the synthesis & mechanical properties of new series of green composites involving Hibiscus sabdariffa fiber as a reinforcing material in urea formaldehyde (UF) resin was carried out. It revealed that mechanical properties such as tensile strength, compressive strength and wear resistance of the UF resin increased to considerable extent when reinforced with fiber. Groundnut shell properties shell particles reinforced polymer composite (GSPC) were prepared [32] with different weight percentage of particles in polymer matrix. It was observed that the addition of particles improved the mechanical properties up to some weight % & further decreased with increased particle content in the sample.

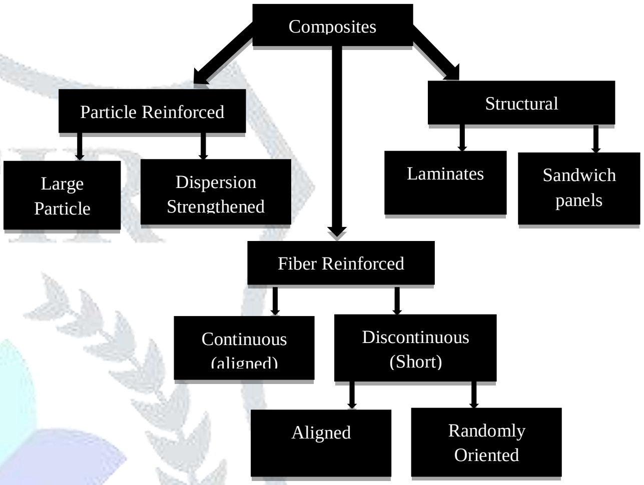

Fig. 1: Classification of composites based on reinforcement type

Natural fibrous material used as reinforcement in the polymer composite [33] was pine needles collected from local resource. It had been observed that polymer composite obtained by particle reinforcement exhibit better mechanical properties as compared to short & long fiber reinforcement.

Starch [34] is a natural polymer which possesses many unique properties. By combining the individual advantage of starch & synthetic polymers, starch based biodegradable polymers found to be potential due to the wide variety of available manufacturing process; each resulted in their own characteristic products. Development in the field of biopolymer materials is promising because of its environmental friendly behavior. The common used fibres are glass, carbon, or aramid, while other fibres such as paper or wood or asbestos can also be used.

2. *Particle reinforced polymer*

Particulate composites have an additive constituent which is essentially one or two dimensionally & macroscopic /microscopic. In some composites however, the additive constituent is macroscopically non-dimensionally, i.e., conceptually a point, as opposed to a line or an area. Only on the microscopic scales does it become dimensional, i.e., a particle, & thus the concept of composite must come down to the microscopic level if it is to encompass all the composite of interest of engineers. Particulate composites differ from the fiber flake types in that distribution of the additive constituent is usually random rather than controlled. Particulate composite are therefore usually isotropic. This family of composites includes dispersion-hardened alloy & cermet.

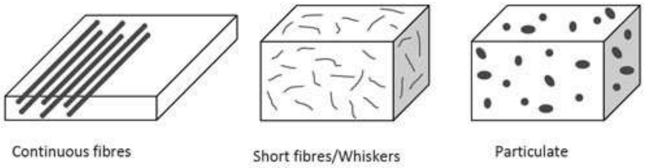

Fig. 2: Different types of composites

III. FINITE ELEMENT ANALYSIS

The finite element concept is derived from the stiffness matrix for the triangular element based on the displacement & this triangular element is named as mesh (Martin & Carey, 1973). The development of FEA was greatly aided by developments in the computer industry, provides larger storage capacities for larger problem to run & modeling more accurate physical situation. It is not reasonable to expect designers to calculate those complex interactions & solutions using manual methods.

There are many journal papers worldwide using of FE analysis to predict the behavior of the products they are going to design, such as *Qiao et al*. (1998) using of finite element model to predict the response of the composite reinforced wood crosstie; Mahdi et al. (2002) using of FEA modeling to predict the mechanical performance of repaired stiffened panels. However, in this paper, the failure displacement from modeling was calculated to be 28% lower than experiment, they explained that the current finite element (FE) model which do not take into account the interaction of the repair plugs & the wall of the cut-out, & lead to the poor prediction when compared to experimental results.

Besides, finite element analysis of impact damage response of composite motorcycle safety helmets was done (*Kostopoulos et al.*, 2002). In this research, they presented a basic shell structure comprising of a woven fabric & a glass mat ply with three different woven fabric reinforcement materials & the shell structure was analyzed using FE simulation of drop tests. This is one of the advantages from finite element analysis where various composites can be used in computer modeling without involving fabrication of many different prototypes, hence reducing the total cost & time saving in testing & manufacturing of new products.

According to *Wu et al.* (2002), use of finite element method to predict the performance of the fiber reinforced polymer (FRP) sandwich composite could lower cost & have accurate prediction of structural behavior of FRP. However, several assumptions were made in the model in order to achieve an agreement with finite element, such as that the material is homogeneous & linearly elastic in each layer & displacement in z direction is small & interfacial layer is under anti-plane shear & shear stress throughout the plate thickness is uniform.

Experimental work done by *Lim et al*. (2003) in experimental & finite element analysis of the static deformation of natural fiber reinforced composite beam had revealed the assumptions like plastic & reinforcing agent are acted together & the matrices & fiber are equally mixed & the composite is obeying Hooke’s law. He also revealed that many heterogeneous composite materials are having non-linear & anisotropic material properties & these materials sometime have to be treated as homogeneous as well in order to simplify the analysis.

In another work carried out by *Van Paepegem* et al. (2001) to investigate the fatigue behavior of reinforced composite materials, FEA simulation was used to compare against the results of fatigue experiments on plain-woven glass / epoxy specimens with a [#45°] stacking sequence. They established a FE model that is incorporated in commercial FEA code which is able to deal with two conflicting demands: The first one is that the continuous stress redistribution requires the simulation to follow the complete path of damage states & simulation should be fast & efficient in order to save time in the stage of composite components designing.

IV. TYPES OF NATURAL FIBER

Natural fibres can be divided into animal fibres & plant cellulose fibres. Plants that produce natural fibres are categorized into primary & secondary depending on the utilization. Primary plants are grown for their fibres while secondary plants are plants where the fibres are extracted from the waste product. There are 6 major types of fibres namely; Bast fibres, leaf fibres, fruit fibres, grass fibres, straw fibres & other types (wood & roots etc.). There are thousands of natural fibres available & therefore there are many research interests in utilization of natural fibres to improve the properties of composites [35]. Recycled cellulose fibres are obtained from cellulosic waste products such as paper, newspaper, cardboard & magazine. Fig 3 shows the classification of natural fibres.

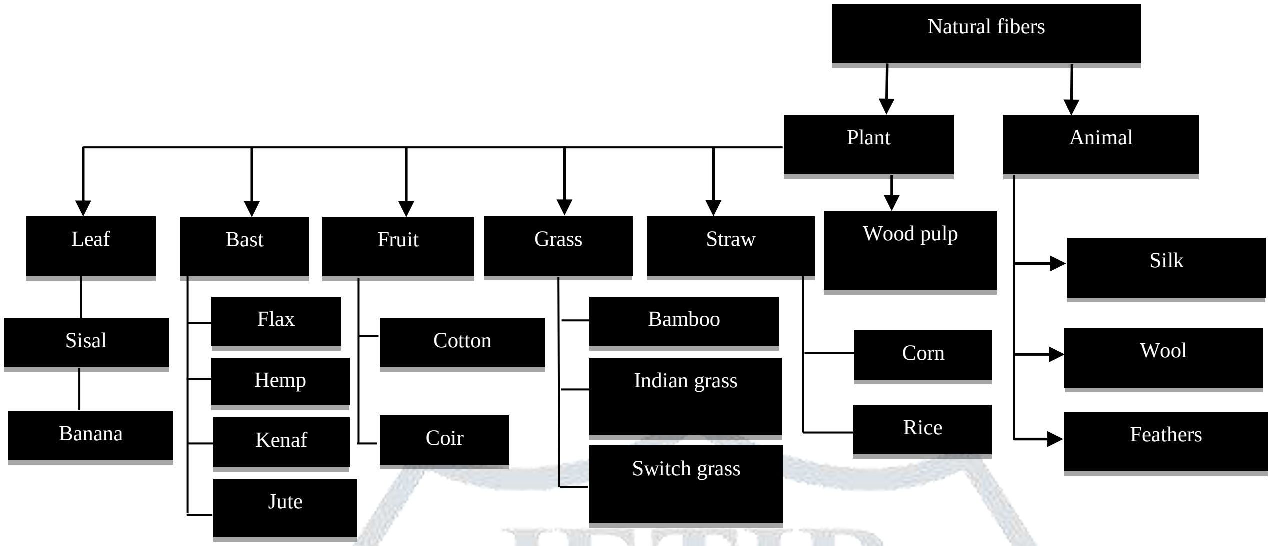

Fig. 3: Classification of natural fibres [36]

V. BANANA FIBER REINFORCED EPOXY COMPOSITES

The mechanical properties of a natural-reinforced composite depend on many parameters, such as fiber strength, modulus, fiber length & orientation, in addition to the fiber-matrix interfacial bond strength. A strong fiber-matrix interface bond is critical for high mechanical properties of composites. A good interface bond is required for effective stress transfer from the matrix to the fiber where by maximum utilization of the fiber strength in the composite is achieved [37]. Modification to the fiber also improves resistance to moisture induced degradation of the interface & the composite properties [38]. Mechanical properties of natural fibers, especially flax, hemp, jute, banana & very good & many complete with glass fiber in specific strength & modulus [39]. A number of the investigations have been conducted on numerous kinds of the natural fibers like Kenaf, hemp, flax, bamboo, banana & jute to study the effects of these fibers on mechanical properties of the composite materials [40]. Information on usage of the banana fibers in reinforcing the polymers is limited in literature. In dynamic mechanical analysis, *Laly et al* [41] have investigated banana fiber reinforced polyester composites & found that optimum content of the banana fiber is 40%. Mechanical properties of banana-fiber-cement composites were investigated physically & mechanically by *Corbiere – Nicollier et al* [42]. It was reported that the Kraft pulped banana fiber composite has the good flexural strength, In addition, short banana fiber reinforced polyester composite was studied by *Pothan et al.* [43]. Study concentrated on effect of the fiber length & the fiber content. Maximum tensile strength was observed at the 30 mm fiber length while the maximum impact strength was observed at the 40 mm fiber length. Incorporation of the 40% untreated fibers provides 20% increase in tensile strength & a 34% increase in impact strength Joseph et al [44] tested banana fiber & glass fiber with varying fiber length & fiber content as well as Luo & Netravali [45]. The Compressive properties of the composites were assessed before & after moisture absorption. The subsequent banana fiber/epoxy composites were originate to produce a flexural Strength of 34.99 MPa & compressive strength of 122.11 MPa when alkaline pre-treated with amended environmental exposure resistance. While the non-alkaline pre-treated banana fiber/epoxy composites were found to produce a flexural strength of 40.16 *Mpa* & compressive strength of 123.28 MPa, with hypothermal resistance than pre-treated fiber composites with the similar matrix. Flexural Modulus, Flexural Strength, Compressive strength for 55% pre-treated & non-pre-treated banana fiber reinforced polyester & epoxy values are recorded [46]. Carried out comparative study of mechanical properties of the phenol formaldehyde composites reinforced with the banana fibres & glass fibres. In this work composites were invented using banana fibre & glass fibre with variable fibre length & fibre loading.


a) Banana woven fiber b) Banana fiber immersed in 6% NaOH solution

Fig. 4: Banana woven fiber.

The study of tensile, flexural & influence properties of the composites exposed that the finest length of fibre essential for banana fibre & glass fibre are dissimilar in phenol formaldehyde resole matrix. Both fibres display a consistent development of growth in properties with the fibre loading, the interfacial shear strength values acquired from single fibre pull out examination, which also revealed that the banana fibre & phenol formaldehyde resin [47].

Pothan et al. [48] investigated the influence of chemical modification on dynamic mechanical properties of banana fiber-reinforced polyester composites. A number of silane coupling agents were used to modify the banana fibers. The damping peaks were found to be dependent on the nature of chemical treatment. Joseph et al. [49] studied the environmental durability of chemically modified banana-fiber-reinforced phenol formaldehyde (PF) composites. The authors observed that silane, NaOH, & acetylation treatments improved the resistance of the banana/PF composites on outdoor exposure & soil burial. *Idicula et al.* [50] investigated the thermos physical properties of banana-sisal hybrid-reinforced composites as a function of chemical modification.

Sisal & banana fibers were subjected to mercerization & polystyrene maleic anhydride (MA) treatments. The authors observed that chemical modification resulted in an increase of 43% in thermal conductivity when compared with untreated composites. In recent years; the natural fiber woven fabrics are attractive as reinforcements since they provide excellent integrity & conformability for advanced structural applications. When comparing the woven fabrics composites with non-woven composites, they have excellent drape ability, reduced manufacturing costs & increased mechanical properties, especially the interlinear or interfacial strength. Several researchers has been investigated the mechanical properties of the woven fabrics polymer composite [51].

VI. FIBRE REINFORCED THERMOSET COMPOSITES

Incorporation of the sisal fibre into the thermosetting plastics have been conveyed by numerous workers (*Paramasivam* & *Abdulkalam*, 1974 [16]; *Pavithran* et al., [20], [21]; *Joseph* et al., 1996a) [52]. *Paramasivam & Abdulkalam* (1974) [16] have explored possibility of emerging the polymer based composites using sisal fibres due to the small cost of production of composites & amenability of these fibres to winding, laminating & other fabrication procedures. It was found that fabrication of these composites was equally easy & cost of production was fairly low.

Winding of cylinders with longitudinal or helical & hoop strengthening was effectively carried out. Tensile strength of the sisal epoxy composites was originate to be 250-300 MPa, which was nearly half strength of the fibre glass-epoxy composites of similar composition. Because of low density of sisal fibre, however, the exact strength of sisal composites was similar with that of glass composites.

Unidirectional modulus of the sisal-epoxy composites was originating to be about 8.5 GPA. This study indicated the possibility of evolving composites incorporating one of the abundantly obtainable natural fibres, to be used in the field of customer goods, low cost housing & civil engineering constructions.

Satyanarayana et al. (1984) [53] have calculated the mechanical properties of severed sisal fibre – polyester composites. Chopped sisal fibre-polyester composites were organized by the compression molding method. It was found that the detailed modulus of the composite was 1.90 compared with 2.71 for glass fibre reinforced plastics, while the specific strength was of the similar order as that of polyester resins (34 - 41 MPa). The influencing strength was 30 J m-2, which is 3 times higher than that of polyester & 30% less than glass fibre reinforced plastics. Accelerated testing exposed slight modification in initial modulus, & reductions of 5% in crucial tensile strength, 16% in flexural strength & 5.4% in water absorption.

Pavithran et al. (1987, 1988) [20] [21] have described on the influence properties of oriented sisal fibre-polyester composites. Unidirectional aligned sisal fibre-polyester composites comprising @ 0.5 volume fraction of sisal fibre were organized from unsaturated polyester pre-*pregs*. *Pavithran et al.* (1988) [21] have compared influence properties of the *Unidirectionlly* oriented sisal fibre-polyester composites with those of the composites having the ultra-high-density polyethylene [UHDPE] & the glass fibres.

It was detected that sisal composites displays work of fracture equal with that of the ultra-high-modulus polyethylene composites & toughness of the sisal fibre composites is only 25% less than that of the glass fibre composites when density of latter is taken into account.

Bisanda & Ansell (1991) [25] have considered the outcome of silane action & alkali action on the mechanical & physical properties of sisal-epoxy composites. They have described that combination of sisal fibres in an epoxy resin yields stiff & strong composite materials. The action of the sisal fibres with silane, preceded by mercerization, delivers enhanced wettability, mechanical properties & water resistance.

Joseph et al. (1996a) [52] have considered the effect of interfacial adhesion on the mechanical & fracture performance of small sisal fibre reinforced polymer composites of numerous thermoset resin matrices (polyester, epoxy, phenol formaldehyde) & the thermoplastic matrix (i.e. low density polyethylene) with respect to the fibre length & fibre loading. They perceived that all the composites presented a universal movement of increasing properties with fibre loading. However, the finest length of the fibre essential to acquire an increase in properties mixed with the type of matrix.

A novel composite material of the tamarind seed gum & the cellulosic rich sisal plant fibre was organized & methods were established to rise the strength of the organized composite material by a procedure of humidification & compression (*Veluraja* et al., 1997) [54]. It was described that organized composite material have the potential industrial applications like false roofing & room dividing. Sisal fibre reinforced rigid foam scheme based on plant polyols has been established by *Dahlke* et al. (1998) [55]. They have described that properties of polyurethane-sisal fibre scheme were similar to polyether-based standard systems. Gupta et al. (1998) [56] have considered the nature of interfacial adhesion among chemically improved sisal fibre & polyester resin in composites.

In recent times Bai et al. (1999) [57] have calculated failure mechanisms of the continuous sisal fibre reinforced epoxy matrix composites. They have observed the micro-failure performance & interfacial *debonding* of the sisal fibre bundle/epoxy matrix using the scanning electron microscopy after 4 points bend examinations. It was described that the sisal fibre bundle-epoxy interface had enough high strength, but the adhesive strength among the micro-tubular fibre & the bonding material performed to be small.

VII. FIBRE REINFORCED THERMOPLASTIC COMPOSITES

Thermoplastic polymers establish a significant class of materials with an extensive variation of applications. Because of its growing use of mutual with the high demand, the cost of the polymer has improved quickly over the past decade. This condition made it required to use the low cost fillers as means of decreasing the cost of the end product. However, the generally used inorganic fillers, such as glass fibre & mica are very costly related to wood fibres.

Numerous cellulosic products & wastes such as shell flour, wood flour & the pulp have been used as fillers in the thermoplastics (*Lightsey*, 1983 [3]; *Kokta*, 1988 [12]; *Maldas* & *Kokta*, 1991) [13]. The effect of wood flour on mechanical properties of the polypropylene was considered by Raj et al. (1989) [58] & they found that cost of material could be condensed without too much loss of elastic modulus. However, fibrous fillers are now gaining more significance over the particulate fillers due to their high performance in the mechanical properties.

Available data display that numerous commercial wood fibres have noble potential as reinforcements in the thermoplastics. The wood fibres are nonabrasive so that moderately huge concentrations of fibres can be combined into polyolefin without causing serious machine wear through mixing & handling. *Raj* & *Kokta* (1989) [58] have considered mechanical properties of the wood fibre filled the Medium Density Polyethylene composites. They perceived an important growth in modulus with development in filler content. However, incomplete studies have been described in literature on use of the sisal fibre as a reinforcing proxy in thermoplastic matrices.

Joseph et al. [17,18,26,27] have examined the mechanical, rheological, electrical & the viscoelastic properties of the short sisal fibre reinforced the LDPE composites as function of processing technique, fibre content, fibre length & fibre orientation. They have described that the fibre harm generally occurs during combination of fibre & the polymer by the melt mixing technique can be evaded by accepting a solution mixing process.

They have also described that unidirectional alignment of the short fibres completed by an extrusion procedure improved the tensile strength & modulus of composites along axis of fibre alignment by more than 2 fold related to randomly oriented fibre composites. They have compared the experimentally detected tensile properties (tensile strength & modulus) of the short sisal fibre reinforced-LDPE composites with present theories of reinforcement such & Parallel & Series, *Hiesch*, Cox, *Halpin*-Tsai, Modified Halpin-Tsai & improved Bowyer & Bader models *Kalaprasad* et al. (1997a). [59]

The viscoelastic properties, & rheological properties of the LDPE filled with the short sisal fibre as function fibre length, fibre content & fibre orientation have been examined by Joseph et al. [18,26,27] They have described that longitudinally oriented composites presented maximum storage moduli & a critical fibre length of 6 mm is essential to acquire maximum dynamic moduli. The electrical properties of coir fibre & sisal fibre reinforced LDPE composites have been considered by Paul & Thomas (1997) [60] & Paul et al. (1997) [61].

Main disadvantages related with use of natural fibres as reinforcements in the thermoplastics matrix to attain composite material with enhanced mechanical properties & dimensional stability are the reduced wettability & the weak interfacial bonding with polymer due to fundamentally poor compatibility as well as *dispersability* of hydrophilic cellulose fibres with hydrophobic thermoplastics (*Carvalho*, 1997 [19]; *Marcovich* et al., 1997) [62]. So in order to increase fibre-matrix adhesion the pre-treatment of fibre surface or incorporation of the surface converter during handling is essential.

Numerous studies have been described based on the effect of numerous type of chemical variation on the physical & mechanical properties of the sisal fibre filled the thermoplastic composites (*Bisanda* & *Ansell*, 1991 [25]; Paul et al., 1997; Joseph et al., [63, 64]) [61]. The graft copolymerization of the methyl methacrylate onto the sisal fibres using the potassium persulfate initiator was considered by *Sabaa* et al. (1995) [65]. They have studied the effect of the initiator concentration, monomer concentration, reaction time, reaction temperature & pH, oil grafting percentage, grafting efficiency & total alteration. The surface topology, as well as x-ray diffraction patterns of improved fibres were also considered.

VIII. FIBRE REINFORCED RUBBER COMPOSITES

In recent years, short fibre reinforced elastomers have gained extensive position due to the benefits in processing & low cost coupled with high strength. Numerous investigators have used the short glass fibres for reinforcing the rubbers because of their high modulus, high strength & low creep.

A significant extent of study effort has been described on the plant fibre reinforced elastomer composites (*Bhagavan* et al., 1987 [66]; Varghese et al., [67] [68]; *Geethamma* et al., 1995 [69]. Coran et al. (1974) [70] have considered the properties of cellulosic fibre-elastomer composites & found that the aspect ratio of fibre has a main role on composite properties. Properties of the particulate fillers on these composites have also been described.

O'Conor (1977) [71] linked mechanical properties of the composites reinforced with 5 types of fibres & found that their mechanical properties depend on type, volume loading, aspect ratio, orientation & dispersion of fibre & fibre-matrix adhesion. He also described that for cellulosic fibres, a *dicomponent* dry bonding scheme containing of *hexamethylene tetramine* & resorcinol is adequate for receiving good fibre - rubber adhesion, in its place of the usual *tricomponent* dry bonding scheme containing of *hexa*, resorcinol & silica. *Geethamma* et al. (1995) [69] have considered the belongings of fibre length, orientation & alkali treatment on the short coir fibre reinforced natural rubber composites. Vulcanization parameters, procedure capability features & stress-strain properties of these composites were studied.

Varghese et al. (1992) [67] have considered the mechanical properties of acetylated & the untreated short sisal fibre reinforced the natural rubber composites & found that acetylation increases the adhesion among the rubber & the fibre. They have considered the result of changed bonding agents on the physical & the mechanical properties of the sisal fibre reinforced natural rubber composites. The actions employed comprised alkali immersion at high temperature & use of the bonding agent based on the phenol-formaldehyde & resorcinol formaldehyde precipitated silica at dissimilar focusses.

IX. INFLUENCE OF FIBRE ON MATRIX PROPERTIES

Woven fabric composites, in particular, are constructed by weaving two fiber tows into each other to form a layer. These layers are then impregnated with a resin or matrix material, stacked in a desired orientation, & cured to obtain a composite laminate. The interlacing of fiber bundles has several advantages such as increasing the strength of the lamina, greater damage tolerance, as well as providing a possibility to produce near net shape structural components [72]. However, these advantages come at the expense of some loss in the in-plane stiffness & strength, which depends upon the weave architecture.

In this research, two types of natural fibers, woven -banana & *pandanus* (Kenaf) were utilized as reinforcement is studied. These two types of natural fibers are taken for study is because of their ability to be produced in a continuous form, & hence able to produce into a woven mat form. Woven composite is known to be complex systems, which have additional features such as, interlace spacing or gap, interlace point & unit cell (Lai et al., [73]). There are very few reports on woven fabric composites reported so far. The popularity of woven composites is increasing due to simple processing & acceptable mechanical properties (*Jekabsons & Bystrom*, [74]). Woven fabric composites provide more balanced properties in the fabric plane than unidirectional laminas.

S.M.Sapuan et.al [75] investigated the Mechanical properties of woven banana fiber reinforced with epoxy composites. From the result of tensile test, it is found that maximum value of the stress in x-direction is 14.14 MN/m2 & in y-direction is 3.398 MN/m2. The results of three-point bending test predict that the maximum load applied is 36.25 N to get the deflection of 0.5 mm.

Boisse P.H et al. [76] discussed the principal deformation mode of woven fabrics is the plane shear & could be estimated by measurement of angle between yarns, during the process. *Ala Tabiei* et al. [77] reviewed modeling of Process Induced Residual Stresses in Resin Transfer Molded Composites with Woven Fiber Mats. Significant change in the elastic properties is observed as a result of the scissoring effect & fiber reorientation in woven fabric composites.

L.A.Pothan et al. [378] studied composites of woven sisal in polyester matrix using three different weave architectures: (plain, twill, & matt) were prepared using a resin transfer molding technique with special reference to the effect of resin viscosity, applied pressure, weave architecture, & fiber surface modification. His study provides the information that weaving architecture & the fiber content were both found to have an effect on the composite mechanical properties.

W. L. Lai et al. [79] investigated betel palm woven hybrid composite characteristics & testing features. It is found that the alkaline treatment of fibers effectively cleans the fiber surface & increases the= fiber surface roughness. In general, mechanical properties of the woven composites made from alkali treated fibers were superior to the untreated fibers.

X. MECHANICAL PROPERTIES OF HYBRID COMPOSITES

The next sections review the collected data on mechanical properties of hybrid composites & provide an extensive discussion on which configurations yield the best properties. The investigated mechanical properties are tensile, flexural, impact & fatigue resistance. Other properties, such as shear or compression, will not be investigated, as those remain smaller sub-fields within hybrid composite research.

1. *Tensile properties*

A. *Tensile modulus*

The longitudinal tensile modulus of hybrid composites has been shown to obey a linear rule of mixtures, according to many researchers [89, 90, 91, 92, 93, 94, & 95]. Values deviating from this behavior can in most cases be attributed to variations in the fibre volume fraction or fibre orientation. This is for example the case in Ren et al. [96], who reported a higher modulus for intralayer than for interlayer unidirectional carbon fibre/carbon fibre hybrids. It can be probable that the unimportant described deviations are due to crease, fibre misorientations or measurement incorrectness in the fibre volume fraction.

Instead, as described by Phillips [97, 98], certain deviations can also be explicated by an improper use of the rule of combinations [97, 98]. The relative volume fractions of both basic fibres should be used as composition factor, but these are often tough to measure distinctly in hybrid composites. Estimates based on ply fraction or tow fraction are easier to obtain, but they do not necessarily depend linearly on the fibre volume fraction, meaning that the rule of mixtures would not be linear either.

Hybrid effects may not be expected for the longitudinal tensile modulus, but can still occur in the transverse direction, where rule of mixtures are not linear & often less accurate. In his PhD. thesis, Taketa [99] demonstrated that the tensile modulus in the transverse direction of unidirectional carbon fibre-reinforced polypropylene (PP) hybridized with woven self-reinforced PP displays a positive hybrid effect. This is explained based on the high Poisson's ratio of the self-reinforced PP, which means it has a high tendency to shrink in the transverse direction during a tensile test. This transverse direction coincides with the stiff carbon fibers, which counteract the Poisson's contraction. As a consequence of the additional constraints, the composite as a whole behaves stiffer than expected from the linear rule of mixtures.

B. *Failure strain*

In a review paper, Kretsis [89] analyzed literature data prior to 1987 & clearly demonstrated that the hybrid effect increased with decreasing LE fibre content. An overview of the hybrid effect reported in literature can be found in Fig. 5. A typical range of the hybrid effect for failure strain is 10–50%, although some outliers have been reported. Based on the data reported in Chamis et al. [100], Kretsis [89] calculated negative hybrid effects down to -66%. These results were discarded as unrealistic values. Aveston & Sillwood [101] reported a hybrid effect of + 116% in carbon/glass interlayer hybrids, but this is mainly due to an unreasonably low failure strain for their carbon fibre reference composite.

A vital caveat for interpreting the literature data that Kretsis [89] gathered is that this data is more than 25 years old. At that time, carbon fibre had a lower failure strain, sometimes even below 1% [90, 101], & a higher scatter on the fibre strength [102]. Influencing parameters both these changes in carbon fibre properties have an influence on the hybrid effect. Firstly, a lower failure strain for the LE fibres results in a higher ratio of the composite failure strains & will increase the hybrid effect. Secondly, Fukunaga et al. [103] proved that the scatter on the LE fibre strength, or equivalently LE fibre failure strain, is a vital parameter for the hybrid effect.

If the fibre strength was a deterministic value, then the hybrid effect would be zero. Therefore, even though this remains unproven, it seems to be reasonable to conclude that a larger scatter on fibre strength results in a larger hybrid effect. The low cost carbon fibres that are expected to come on the market for automotive applications in the next years [104] will most likely have a larger scatter on fibre strength than the current state-of-the-art carbon fibres. Hence, they are expected to bear potential for a large hybrid effect.

Based on the previous arguments, it can be expected that the hybrid effect in hybrid composites with the current carbon fibres is smaller than in the early reports. Diao et al. [105] recently reported a failure strain decrease of 8% in co-mingled T700-IM7 carbon fibre/carbon fibre hybrid composite compared to the reference IM7 carbon fibre composite. This decrease was attributed to surface damage introduced by the co-mingling process. The small difference in the failure strains of both fibre types may explain the lack of a positive hybrid effect.

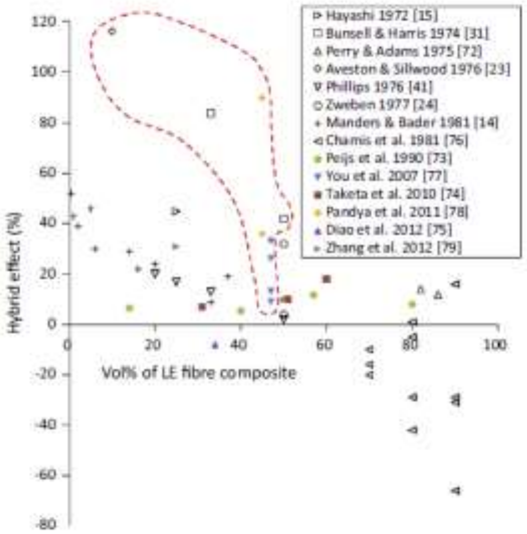

Fig. 5. The hybrid effect for tensile failure strain as a function of the volume percentage of the LE fibre composite. Data from before *Kretsis'* review in 1987 are in black, while the others are colored. Data which has to be interpreted with care can be found within the red dashed region. (For explanation of the positions to color in this figure legend, the reader is mentioned to the web form of this object.)

Pandya et al. [106] reports a hybrid effect of +36% & +90% for a carbon/glass hybrid composite. Since the relative content of carbon fibre was 47% & the degree of dispersion was low, these results are surprisingly higher than the trends predicted by *Kretsis* [89]. Moreover, the hybrid effect was increased from +36% to +90% by putting the carbon fibre layers as inner plies rather than outer supplies. Their tensile diagrams do not display a vertical drop, which would coincide with failure of the carbon fibre plies. Instead, Pandya et al. [106] achieved a gradual failure, but still used the ultimate failure strain to calculate the hybrid effect. This does not conform to the definition of hybrid effect based on the apparent failure strain enhancement of the LE fibre composite. From their data, it was not possible to deduce the hybrid effect using the proper definition.

You et al. [107] reported a hybrid effect of 9–33% in unidirectional carbon/glass hybrids. The highest hybrid effect was achieved when the fibres were well dispersed. You et al. obtained a failure strain of only 1.25% for unidirectional T700 carbon fibre composites. In our opinion, this surprisingly low failure strain for their reference T700 composites might be partially due to the testing conditions. This would mean that the reported effect may be partially caused by the fact that the hybrid composite is less sensitive to the testing conditions. Their results therefore need to be interpreted with care. Moreover, You et al. used the ultimate failure strain to calculate the hybrid effect & do not mention whether this coincides with failure of the carbon fibres. Again, it was not possible to deduce the hybrid effect according to the proper definition.

Zhang et al. [108] hybridized woven glass & carbon fibre & found improvements in failure strain, ranging between 10% & 31%. The failure of the carbon fibre layers coincided with final failure of the hybrid composite & no further load carrying by the glass fibre layers was observed. This remaining load carrying capacity was observed by several other authors, e.g. [109, 90, & 94]. It is unclear which parameters are exactly required to maintain this load carrying capacity after the carbon fibre failure, though *interlaminar* bonding [94] & dispersion [109] have been proven to play a crucial role.1.

In general, most of the reported values are positive. The values of *Bunsell & Harris* [94], *Aveston & Sillwood* [101], Pandya et al. [106], You et al. [107] are found within the red dashed line in Fig. 5. These values have to be interpreted with care, as they may be affected by improper testing of the reference composites or an improper definition of the hybrid effect. From Fig. 5, it cannot be concluded that the hybrid effect has decreased compared to before 1987, even though this was expected based on theoretical considerations.

C. Tensile strength

According to many authors, the hybrid effect for tensile strength is based on a bilinear rule of mixtures, see Fig. 6a [89, 110, 111, 112]. This prediction is based on a displacement controlled test, in which *iso − strain* is assumed for both the LE & HE fibres. For simplicity of this explanation, the contribution of the matrix is neglected.

Based on their failure strains, the LE fibres fail first, followed by the HE fibres. After the LE fibres have failed, they are assumed to fully *debond* or delaminate from the HE fibres. The LE fibre hence stop carrying stress, leaving only the HE fibres as load-carrying elements. As would be the case in a regular tensile test, the initial cross-sectional area would still be used to convert load into stress. Depending on whether the fraction of HE fibres is high or low, two possibilities arise after the LE fibre failure. At high fractions of HE fibres, the stress is able to reach levels higher than the stress at the failure strain of the LE fibres, as illustrated in Fig. 6b. The strength will hence be dominated by the stress contribution of HE fibres at their failure strain, which is represented by the line ACE. At low fractions of HE fibres, these fibres also continue to carry stress, but in this case, the stress at HE failure does not exceed the stress at the failure strain of the LE fibres. This is illustrated in Fig. 8d. The strength in this region is hence determined by the line BCD, which represents the stress in the hybrid when the LE fibres break. The minimum in this bi-linear rule of mixtures occurs when both peaks in the tensile diagram have the same height, as displayed in Fig. 6c.

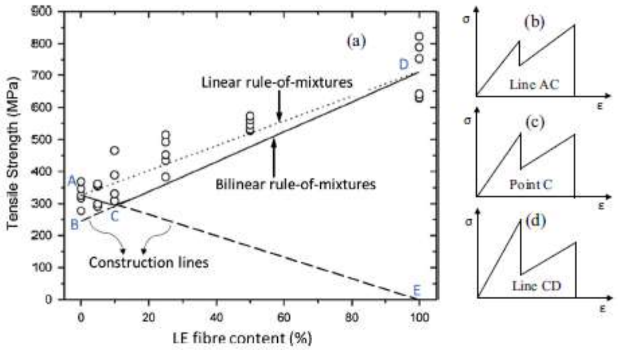

Fig. 6. (a) Illustration of the bilinear rule of mixtures for the tensile strength of carbon/glass hybrid composites (adapted from Shan & Liao [113], with permission from Elsevier), & corresponding tensile diagrams of hybrid composites for (b) line AC, (c) point C, & (d) line CD. (For explanation of the positions to color in this figure legend, the reader is mentioned to the web form of this object.)

Fig. 6 also contains experimental data points for carbon/glass hybrid composites from Shan & Liao [113], showing that the bilinear rule of mixtures does not yield a satisfactory prediction. A similar positive deviation from the bilinear rule of mixtures was found in *Peijs et al.* [114].

If both fibres are linearly elastic, then the tensile modulus follows a linear rule of mixtures in the fibre direction. If one observes experimentally that the failure strain is enhanced, then the tensile strength should also be enhanced. This is not as straightforward as it seems. The reason for the failure strain enhancement is often a more gradual failure, meaning that the last part of the tensile diagram is not linear anymore. In some cases, the tensile diagram even has a plateau near the end [109, 105].

Zhang et al. [95] found that the ultimate tensile strength of unidirectional glass/flax composites increased by 15% if the dispersion was improved. Ren et al. [96] observed a small but negative hybrid effect by combining two different types of carbon fibres in a single composite. The tensile strength for *intralayer* hybrids was slightly higher than for interlayer hybrids, demonstrating that increased dispersion leads to better mechanical performance in hybrid composites.

2. *Flexural properties*

Flexural properties of hybrid composites are highly dependent on the layup, as the longitudinal stress at the neutral line is zero, but increases when moving away from that line. Hybrid composites yield additional possibilities to optimize the mechanical performance by not only changing the ply angles, but also by changing the material type of each ply.

This also makes the flexural properties of hybrid composites more difficult to interpret than the tensile properties. Just like the tensile modulus, the flexural modulus can be predicted rather well. While simple rule of mixtures apply to tensile moduli, the classical laminate theory is commonly used to predict flexural moduli. This part of the review will therefore focus on flexural strength rather than modulus.

Basic effects

The ratio of compressive strength over tensile strength is different for carbon & glass fibre composites. *Wonderly* et al. [115] for example reported this ratio as 0.73 for glass fibre composites, while it was only 0.34 for carbon fibre composites due to the anisotropic nature of carbon fibres. These values may not be generally applicable though. They are known to strongly depend on the carbon fibre type [116] & how well the fibres are supported against buckling. Nevertheless, it may be possible to increase the flexural strength of a composite by replacing carbon fibres in the outer ply on the compressive side by glass fibres. This can potentially lead to large hybrid effects.

Flexural tests do have the advantage over tensile tests that they are not influenced by gripping artefacts. Flexural strength may however be affected by other artefacts, such as stress concentrations at the rollers & difficulties in accurately measuring stresses [117, 118]. Size effects are also known to be significant in flexural strength of non-hybrid composites [119, 102]. *Wisnom* et al. [119] pointed out that the strain or stress gradients may be the main contributor to the size effect in flexure.

The underlying assumption is that large stress or strain gradients provide larger support of the outer layers by the inner layers. The distribution of stress gradients in hybrid composites can be rather complex in hybrid composites due to the different stiffness of the layers. The literature on hybrid composites has not given any attention to these phenomena. It is therefore unclear how important they are in determining the hybrid effect.

XI. CONCLUSION

Natural polymer composites are more environmental friendly compared to polymer composites with synthetic fibres reinforced. The natural fiber-reinforced polymer composite is rapidly growing both in terms of their industrial applications & fundamental research. They are renewable, cheap, completely or partially recyclable & biodegradable. These composites are having low density & cost as well as satisfactory mechanical properties make them an attractive due to easy availability & renewability of raw materials. Natural fibers have been proven alternative to synthetic fiber in transportation such as automobiles, railway coaches & aerospace. The present review focuses on the progress of natural fiber reinforced composites. Industries are in constant search of new materials to lower costs & profit margins. Due to the challenges of petroleum based products & the need to find renewable resources. Natural fibers have cost & energy advantages over traditional reinforcing fibers such glass & carbon. Now a day's research is going on development of bio-composites to replace traditional materials. The combination of different natural fibers found to give better mechanical & physical properties. It can be concluded that with methodical & constant research there will be a good possibility & better expectation for natural fibre polymer composites in the future.

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