Chapter 8

Oil Palm Biomass Fibres and Recent Advancement in Oil Palm Biomass Fibres Based Hybrid Biocomposites

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1. Introduction

Worldwide 42 countries cultivate *Elaeis guineensis* (oil palm tree) on about 27 million acres. Oil palm is one of the most valuable plants in Malaysia, Indonesia and Thailand. Oil palm tree (**Figure 1**) generally has an economic life span of about 25 years, and it contributes to a high amount of agricultural waste in Malaysia. The oil palm tree is ≈ 7–13m in height and 45–65 cm in diameter, measuring 1.5m above the ground level (Abdul Khalil et al. 2010d) and one of the commercial crop in Malaysia. Malaysia is the world's largest producer and exporter of the oil palm, accounting for approximately 60% of the world's oil and fat production. The oil palm industry in Malaysia, with its 6 million hectares of plantation, produced over 11.9 million tons of oil and 100 million tons of biomass (Abdul Khalil et al. 2010b). The amount of biomass produced by an oil palm tree, inclusive of the oil and lignocellulosic materials, is on the average of 231.5 kg dry weight/year (Abdul Khalil et al. 2010c**).** An estimation based on a planted area of 4.69 million ha (MPOB 2009) and a production rate of dry oil palm biomass of 20.34 tonnes per ha per year (Lim 1998) show that the Malaysian palm oil industry produced approximately 95.3 million tonnes of dry lignocellulosic biomass in 2009. This figure expected to increase substantially when the total planted hectarage of oil palm in Malaysia could reach 4.74 million ha in 2015 (Basiron and Simeh 2005), while the projected hectarage in Indonesia is 4.5 million ha.Oil palm production has nearly doubled in the last decade, and oil palm has been the world's foremost fruit crop, in terms of production, for almost 20 years (Abdul Khalil et al. 2010c**).** Oil palm industries generate abundant amount of biomass say in million of tons per year (Rozman et al. 2005) which when properly used will not only be able to solve the disposal problem but also can create value added products from this biomass.

OPB is an agricultural by-product periodically left in the field during the replanting, pruning, and milling processes of oil palm. Oil palm biomass (OPB) is classified as lignocellulosic residues that typically contain 50% cellulose, 25% hemicellulose, and 25% lignin in their cell wall(Alam et al. 2009).The biomass from oil palm residue include the oil palm trunk (OPT), oil palm frond (OPF), kernel shell, empty fruit bunch (EFB), presses fruit fibre (PFF), and palm oil mill effluent (POME). Oil palm fronds accounts for 70% of the total oil palm biomass produced, while the EFB accounts for 10% and OPT accounts for only about 5% of the total biomass produced (Ratnasingam 2011). They also stated that 89% of the total oil palm biomass produced annually used as fuel, mulch and fertilizer. In 2006, Malaysia alone produced about 70 million tonnes of oil palm biomass, including trunks, fronds, and empty fruit bunches (Yacob 2007). Despite this enormous production, oil comprises only a small fraction of the total biomass produced by the plantation. The remaining biomass is an immense amount of lignocellulosic materials in the form of fronds, trunks and empty fruit bunch. As such, the oil palm industry must be prepared to take advantage of the situation and utilize the available biomass in the best possible manner (Basiron 2007). Oil palm biomass waste can create substantial environmental problems when simply left on the plantation fields. Presently, EFB mainly used as mulch, but the economic are marginal due to the high transport cost. It is seldom burnt as fuel, as the shell and fruit fibres are sufficient for oil palm mills (Abdul Khalil 2004). It reported that oil palm biomass burnt as fuel in the boiler to produce steam for electricity generation in the processing of oil palm (Nasrin et al. 2008). Researchers stated that a large amount of oil palm residues resulting from the harvest can be utilized as by–products, and it can also help to reduce environmental hazards (Sulaiman et al. 2011). Researchers carried out an extensive study on utilization of OPB as a source of renewable materials (Sumathi et al. 2008). Oil palm biomass fibres offer excellent specific properties and have potential as outstanding reinforcing fillers in the matrix and can be used as an alternative material for bio-composites, hybrid composites, pulp, and paper industries (Abdul Khalil et al. 2010d; Abdul Khalil et al. 2009).

Natural fibres such as hemp, kenaf, jute, sisal, banana, flax, oil palm etc. have been in considerable demand in recent years due to their eco-friendly and renewable nature. Natural fibres received considerable attention as potential reinforcements in polymer composites (Wong et al. 2010; Wan Nadirah et al. 2011; Bledzki and Gassan 1999). The attraction towards utilization of natural fibres as a reinforcement of polymer-based composites is mainly due to their various advantages over synthetic fibres such as are low density, lower cost, light weight, high strength to weight ratio, biodegradability, acceptable specific properties, better thermal and insulating properties (Rout et al. 2001; Rana et al. 2003; Joshi et al. 2004; Nayak et al. 2009). Natural fibre are also less wear and tear in processing, lower energy requirements for processing, wide availability and relative non abrasiveness over traditional reinforcing fibres such as glass and carbon. Natural fibre based polymer composites made of jute, oil palm, flex, hemp, kenaf have a low market cost, attractive with respect to global sustainability and find increasing commercial use in different applications (Jawaid et al. 2011b). Despite the advantages, use of natural fibre reinforced composites has been restricted due to its high moisture absorption tendency, poor wettability, and low thermal stability during processing and poor adhesion with the synthetic counterparts (Demir et al. 2006; Son et al. 2001). Natural fibres are not suitable for high performance military and aerospace applications due to its low strength, environmental sensitivity, and poor moisture resistance which results in degradation in strength and stiffness of natural fibre reinforced composites. Most of the drawbacks that have been identified can be overcome by effective hybridization of natural fibre with synthetic fibre or natural fibre.

Figure 1. Oil palm Tree

Hybrid composites are these systems in which one kind of reinforcing material incorporated in a mixture of different matrices (blends) (Thwe and Liao 2003), or two or more reinforcing and filling materials are present in a single matrix (Karger-Kocsis 2000; Fu et al. 2002) or both approaches are combined. Hybrid composite which contain two or more types of fibre in a single matrix, the advantages of one type of fibre could complement with what are lacking in the other. Hybrid composites fabrication by proper material design could help in achieve balance in cost and performance (John and Thomas 2008). Various researchers have tried blending of two fibres in order to achieve the best utilization of the positive attributes of one fibre and to reduce its negative attributes as far as practicable(Abdul Khalil et al. 2009; Abu Bakar et al. 2005; Jawaid et al. 2012; Jacob et al. 2004a; Akil et al. 2009). One another reasons for blending of one fibre with other natural fibres are to impart fancy effect, reduce cost of the end product, and find out suitable admixture of natural origin to mitigate the gap between demand and supply

(Basu and Roy 2007). It is possible to combine two or more existing materials and allow a superposition of their properties—in short, to create a *hybrid* (Figure 2)(Ashby and Brechet 2003). Hybrid composites reinforced with natural fibres, well often combined with synthetic fibres such as glass/Carbon fibres, can demonstrate exemplary mechanical performance (Abu Bakar et al. 2005; Wan Busu et al. 2010; Noorunnisa Khanam et al. 2010). Sisal/oil palm fibres and jute/oil palm fibres appear to be promising materials because of the high tensile strength of sisal and jute fibres and the toughness of oil palm fibre (Jacob et al. 2004b; Jawaid et al. 2010). Therefore, any composite comprised of these two fibres will exhibit the desirable properties of the individual constituents. The primary advantages of using oil palm fibres in hybrid composites are its low densities, non abrasiveness and biodegradability. Mixing natural fibres like hemp and kenaf with thermoplastics put Flex Form Technologies (Jon Fox-Rubin 2010) on the map and in the door panels of Chrysler's Sebring convertible. However, the combination of rising oil prices and exterior applications could drive its utilization even higher. Flex Form is also looking to produce vehicle load floors, headliners, seatbacks, instrument panel top covers, knee bolsters, and trunk liners.

2. Oil palm fibres

Oil palm industries generates massive quantities of oil palm biomass such as oil palm trunk (OPT), oil palm frond (OPF) and oil palm empty fruit bunch (EFB) as shown in **Figure 3**. The OPF and OPT generated from oil palm plantation while the oil palm EFB from oil palm processing. In Malaysia, oil palm EFB is one of the biomass materials, which is a by-product from the palm oil industry. EFB are left behind after the fruit of the oil palm harvested for the oil refining process. EFB amounting to 12.4 million tonnes/year (fresh weight) are regularly discharged from palm oil refineries (Abdul Khalil et al. 2010c). This oil palm EFB has high cellulose content and has potential as natural fiber resources, but their applications account for a small % of the total biomass productions. Several studies showed that oil palm fibres have the potential to be an effective reinforcement in thermoplastics and thermosetting materials (Khalil et al. 2008; Hassan et al. 2010; Shinoj et al. 2011). In order to develop other applications for oil palm fibres they need to be extracted from the waste using a retting process (Shuit2009). Oil palm frond (OPF) is one of the most abundant by-products of oil palm plantation in Malaysia. Oil palm fronds are available daily throughout the year when the palms are pruned during the harvesting of fresh fruit bunches for the production of oil. OPF contains carbohydrates as well as lignocellulose and it amounting to 24 million tons/year discharged from oil palm mills. Oil palm frond, consisting of leaflets and petioles, is a by-product of the oil palm industry in Malaysia and their abundance has resulted in major interest in their potential use for livestock feed (Dahlan 2000). OPF are left rotting between the rows of palm trees, mainly for soil conservation, erosion control and ultimately the long-term benefit of nutrient recycling (Abu Hassan 1994). The large quantity of fronds produced by a plantation each year makes these a very promising source of roughage feed for ruminants.

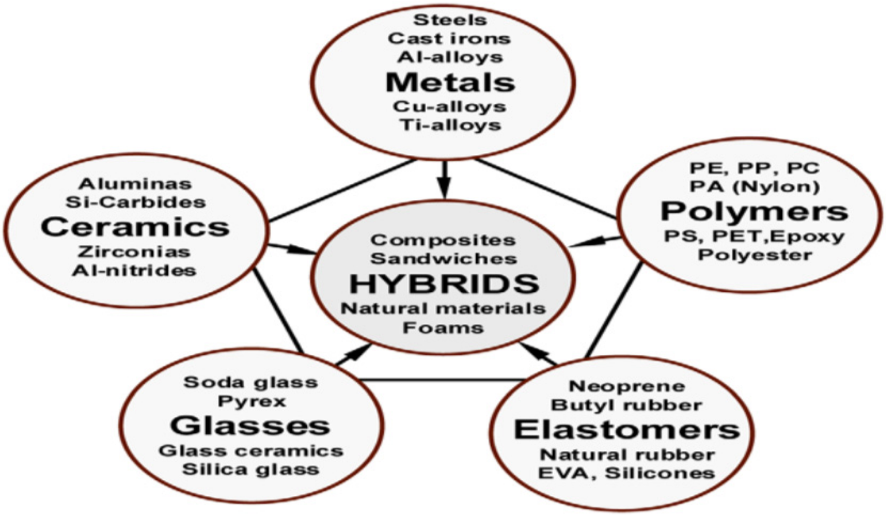

Figure 2. Hybrid materials combine the properties of two (or more) monolithic materials, or of one material and space. They include fibrous and particulate composites, foams and lattices, sandwiches and almost all natural materials. One might imagine two further dimension: those of shape and scale (Ashby and Brechet 2003 with permission).

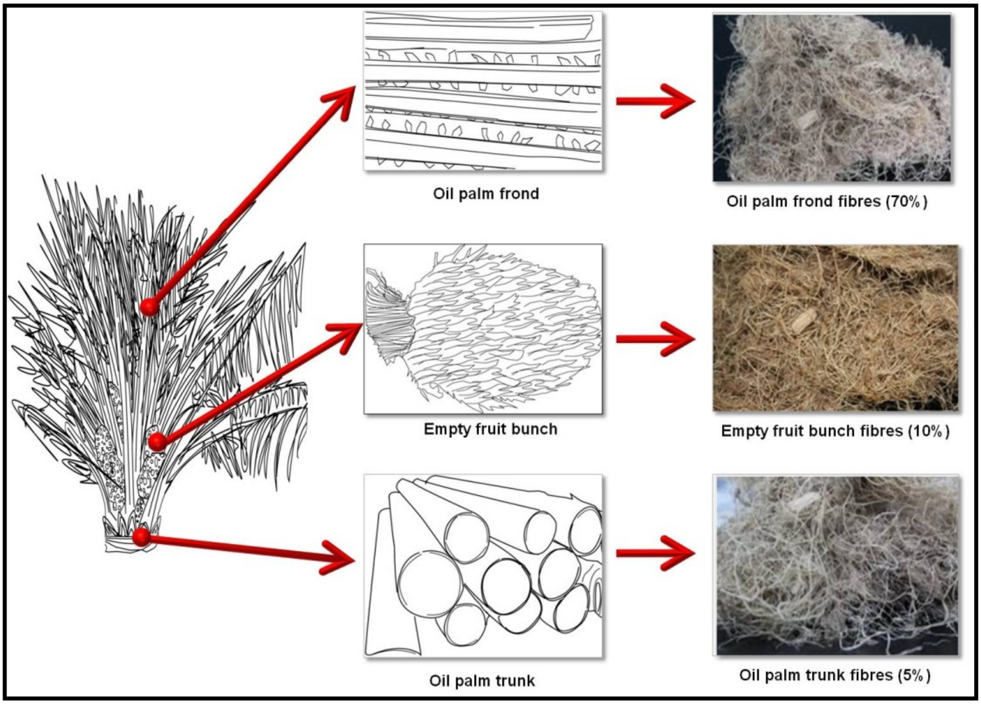

Figure 3. Oil palm biomass and oil palm biomass fibres from oil palm tree

Oil palm tree discarded for replantation after 25~30 years of oil production. Related to the large production of main products from oil palm in Malaysia, there is abundance of oil palm trunk. A large quantity of cellulosic raw material generated in the form of felled trunks during replanting can be utilized. Oil palm trunk obtained from oil palm tree and it consists of vascular bundles and parenchayma. Oil palm trunk amounted to approx 3 million tonnes/year. Up to now, there is no economical value of oil palm trunk from the structural point of view and ultimately it becomes a hazardous material to farmers. To increase the added value of these residues, several investigations have been carried out to produce hybrid plywood, MDF, polymer composites, particle boards, paper, pulp, furniture, bio fuels etc. from oil palm biomass. Many studies have been carried out on the utilization of the oil palm EFB fibres such as in particleboard, pulp, medium density fibreboard, and composites (Rozman et al. 2005). For non-structural applications, works are continuing to look into the possibilities of using OPT as furniture and particleboard raw material (Chew 1985). At present, most of the oil palm biomass are disposed off at the oil palm plantation or burned at the mills to produce oil palm ash. Thus, finding useful utilization of the oil palm biomass in fabrication of natural fibre based composites/hybrid composites will surely alleviate environmental problems related to the disposal of oil palm wastes. Application of oil palm biomass fibre in different sector is shown in **Table 1**.

Oil palm biomass	Products	References
Oil palm EFB fibres	Plywood	Abdul Khalil et al. 2010c
	MDF	Abdul Khalil et al. 2008; Abdul et al. 2010b
	Polymer biocomposite	Chai et al. 2009
	Hybrid composite	Jawaid et al. 2010
	Particle boards	Zaidon et al. 2007
	Biofuel	Shuit et al. 2009
Oil palm frond fibres	Pulp, Paper	Wan Rosli et al. 2004; Abu Hassan 1994
	Nutrient recycling	Abu Hassan 1994
	Fibreboard	Abu Hassan 1994
	Biodegradable film	Noor Haliza 2006
	Animal feed	Hassim et al. 2010; Dahlan 2000
	Downdraft gasifier	Sulaiman 2011
Oil palm trunk fibres	Lignin	Xiao et al. 2001
	Plywood, Furniture	Abdul Khalil et al. 2010c; Abdul Khalil et al. 2010a; Chew 1985

Table 1. Application of oil palm fibres

2.1. Chemical composition of oil palm fibres

It is well know that chemical constituents of oil palm biomass significantly vary due to their diverse origins and types (Chew and Bhatia 2008). Oil palm biomass is lignocellulosic residues composed of cellulose, hemicellulose, lignin and ash (Raveendran et al.1995). **Table 2** shows the chemical composition of different oil palm biomass. All the oil palm biomass are rich in lignin, cellulose and hemicellulose (Meier and Faix 1999; Demirbaş 2000). Oil palm EFB fibres are lignocellulosic fibres where the cellulose and hemicellulose are reinforced in a lignin matrix similar to that of other natural fibres. These oil palm empty fruit bunch consist of high cellulose content and is a potential natural fibre resources, but its applications account for a small percentage of the total biomass productions. High cellulose content and high toughness value of oil palm EFB fibres make it suitable for application in polymer composites (Sreekala et al., 2004; John et al., 2008). The cell wall of OPF also consists of cellulose, hemicellulose and lignin. In addition to these main components, ash, glucose and xylose are also present in cell wall of oil palm fibres. It was revealed that oil palm fibre from oil palm frond contain highest composition of hemicellulose compared to coir, pineapple, banana, and even soft and hardwood fibres (Abdul Khalil et al. 2006). Cellulose, hemicellulose, and lignin that form major constituents of the oil palm EFB fibre might differ depending on plant age, environment, soil condition, weather effect, and testing methods used (**Table 3**). Researchers reported that chemical composition of EFB and OPF are quite comparable with coir but lower in cellulose content as compared to jute and flax fibres (Khalil et al. 2000). Oil palm trunk fibre is strong and high content of lignin (23%) as lignified cellulose fibres retain their strength better than delignified fibres. The chemical compositions of a lignocellulosic fibre vary according to the species, growing conditions, method of fibre preparations and many other factors (Bledzki and Gassan 1999).

	Oil Palm biomass chemical composition (wt%)		
Composition	**Oil Palm EFB**	**Oil palm Frond**	**Oil Palm Trunk**
Cellulose	43-65	40-50	29-37
Hemicellulose	17-33	34-38	12-17
Holocellulose	68-86	80-83	42-45
Lignin	13-37	20-21	18-23
Xylose	29-33	26-29	15-18
Glucose	60-66	62-67	30-32
Ash	1-6	2-3	2-3

Sources: Law et al., 2007; Abdul Khalil 2006;Punsuvon 2005); Shinoj et al. 2011; Chew and Bhatia 2008.Mohamad and Abdul Halim 1985;Abdul Khalil 2004);Law and Jiang 2001); Sreekala et al. 2001

Table 2. Chemical composition of oil palm biomass

Hemicellulose (%)	Cellulose (%)	Lignin (%)	Location	References
22	48	25	Malaysia	Hill and Abdul Khalil 2000
30	36	22	Indonesia	Minowa et al.1998
30	50	18	Malaysia	Khalil et al. 2008
28	65	19	India	Sreekala et al.1997; Law et al. 2007

Table 3. Chemical composition of oil palm EFB fibres from different researchers

2.2. Physical properties of oil palm fibres

Table 4 provides data on physical properties of different oil palm biomass fibres. Fibre strength is a crucial factor to choose fibre that is specific for certain usage. Fibre length is an vital factor in determining bonding and stress distribution (Khalil et al. 2008). Oil palm EFB fibre length values between hardwood and softwood fibre length (Hassan et al. 2010). Researchers also reported that aspect ratio (l/d) of fibre has a significant effect on the properties of final composite materials. Researchers also reported that OPF fibres are shorter and thicker as compared with EFB and OPT fibres. Fibre with thicker cell wall resists collapse and do not contribute to interfibre bonding to the same extent (Reddy and Yang 2005). The microfibril angle, cell dimensions, and the chemical composition of fibres are the essential variables that determine the over all properties of the fibres (John and Thomas 2008). OPT fibres show high density which also indicates that fibre is strong. Researchers reported that fibers with higher lignin content, lower l/d ratio and higher microfibrillar angle show lower strength and modulus but have higher extensibility (Reddy and Yang 2005). The shape and size of cell lumen depends on the cell wall thickness, source of the fibres and it affect the bulk density of fibres (Reddy and Yang 2005). The physical properties such as length, diameter, lumen width, density and microfibril angle of oil palm fibres have revealed momentous changes in the physical and mechanical properties of the composite materials (Hassan et al. 2010; Shinoj et al. 2011; Jawaid and Abdul Khalil 2011a). Owing to their low specific gravity, which is about 1.25–1.50 g/cm^3 as compared to glass fibers which is about 2.6 g/cm^3, the lignocellulosic fibers are able to provide a high strength-to-weight ratio in plastic materials (Abu Bakar et al. 2005).

Fibre	Fibre length (mm)	Fibre Dia (μm)	Lumen width (μm)	Density (g/cm^3)	Fibril Angle (^{0})	Ref
Oil Palm EFB	0.89-142	8 –300	8	0.7-1.55	46	Mohamad and Abdul Halim 1985; Law and Jiang 2001; Bismarck 2005; Amar 2005),Zulkifli et al. 2009),Khalil et al. 2008,Hassan et al. 2010
Oil Palm Frond	0.59 -1.59	11-19.7	8.20-11.66	0.6-1.2	40	Mohamad and Abdul Halim 1985; Law and Jiang 2001; Amar 2005, Khalil et al. 2008, Law and Jiang 2001
Oil Palm Trunk	0.60 -1.22	29.6 –35.3	17.60	0.5-1.1	42	Mohamad and Abdul Halim 1985; Khoo 1985; Amar 2005;Khalil et al. 2008;Ahmad et al.2010

Table 4. Physical properties of oil palm biomass fibres

2.3. Mechanical properties of oil palm biomass fibres

Table 5 gives the data for mechanical properties of oil palm biomass fibres. Mechanical properties such as tensile strength and modulus related to the composition and internal structure of the fibers. It reported that generally the tensile strength and young's modulus of plant fibre increases with increasing cellulose content of the fibres (Aji et al. 2009). Oil palm trunk fibre found to be suitable as reinforcement because it possesses high tensile strength (300-600 MPa) which is considered high when compared with other natural fibre. The properties of cellulosic fibers are strongly influenced by chemical composition, fibre structure, microfibril angle, cell dimensions and defects, it differs from different parts of a plant as well as from different plants (Dufresne 2008). The thicker walled fibre tend to produce an open and bulky sheet with low burst/tensile strength and high tearing resistant (Mishra et al. 2004). The mechanical properties of natural fibers also depend on their own cellulose and its crystalline organization, which can determine the mechanical properties (Bledzki and Gassan 1999). Oil palm fibres are hard and tough and found to be a potential reinforcement in polymer composites (Jawaid and Abdul Khalil 2011a).

Fibres	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Ref
Oil Palm EFB	50-400	0.57-9	2.5-18	(Sreekala et al. 2004; Bismarck 2005; Kalam et al. 2005; Bakar et al. 2006)
Oil Palm Frond	20-200	2-8	3-16	Lab sources
Oil Palm Trunk	300-600	8-45	5-25	Ahmad et al. 2010; Killman and Hong 1989; Lim and Khoo 1986

Table 5. Mechanical properties of oil palm fibre

3. Oil Palm Fibre based hybrid composites

The oil palm fibres have been focus of study in Malaysia and around the world but still oil palm fibres have not found a solid economic value. Oil palm fibres are abundant in nature and due to its low density, non abrasiveness and biodegradability can be used in hybrid composites. In order to take full advantage of the oil palm fibres, it can be combined with other high strength fibres in the same matrix to produce hybrid composites, and thereby an economically viable composite can be obtained. Researchers reported that fibre content, fibre length, orientation, extent of intermingling of fibres, fibre/matrix interface and arrangement of both the fibres mainly affect the over all properties of a hybrid composite (Munikenche Gowda et al. 1999; Sreekala et al. 2002). Hybrid effect is defined as a positive or negative deviation of a certain mechanical property from the rule of mixture behaviour (Kickelbick 2007). Researchers explained that the rule of mixture defines a composite property as weighted average of the properties of its constituents. For example, if two fibres of different properties such as oil palm fibres and jute fibres are incorporated in the polymer, the resulting hybrid composite would most probably exhibit properties which are some sort of an average between those individual fibre components. Reported work on oil palm fibre based hybrid composites are shown in **Table 6**.

3.1. Physical and mechanical properties of oil palm fibre based hybrid composites

The physical properties are used to calculate the product weight, which relates to manufacturing costs, injection molding machine melt capacity (machine size), and the product dimensional control (mold shrinkage). The mechanical properties of natural fibre composites depends on fibre properties, surface character of material, types of matrix, fibre-matrix bonding, volume fraction of fibre and alignment of fibers etc. Mechanical properties of natural fibre composite also depend on composite processing method and effectiveness of the coupling between the fibre and matrix phases. Most of the studies on natural fibre hybrid composite involve study of mechanical properties as a function of fibre length, fibre loading, extent of intermingling of fibres, fibre to matrix bonding and arrangement of both the fibres, effect of various chemical treatments of fibers, and use of coupling agents.

Hybrid	Matrix	References
Oil Palm/Glass	Polyester	Kumar et al. 1997;Agrawal et al. 2000;Abdul Khalil et al. 2007; Karina et al. 2008; Wong et al. 2010)
	Polypropylene(PP)	Rozman et al.2001a,b
	Phenol Formaldehyde(PF)	Sreekala et al. 2002a,b; Sreekala et al. 2004; Sreekala et al. 2005)
	Epoxy	Hariharan et al. 2004; Abu Bakar et al. 2005; Mridha et al. 2007
	Vinyl Ester	Abdul Khalil et al. 2009
	Natural rubber	Anuar et al. 2006
Oil palm/Sisal	Natural rubber	Jacob et al. 2004a,b; Jacob et al., 2005;Jacob et al. 2006a,b,c,d;Jacob et al. 2007; John et al. 2008
Oil Palm/Jute	Epoxy	Jawaid et al., 2010;2011a-g; Khalil et al., 2011
Oil Palm/Kalonite	Polyurethane	Anuar and Badri, 2007

Table 6. Reported works on Oil Palm Fibre based Polymer Hybrid Composites

3.1.1. Oil palm/Glass fibres reinforced hybrid composites

Hybridization of oil palm fibres with glass fibres carried out by several researchers in Malaysia, India and Indonesia. It's clear from the literature review that first time oil palm/glass hybrid composites fabricated and researchers developed fire resistant sheet moulding hybrid composites by measuring fire retardancy through limiting oxygen index (Kumar et al. 1997). After initiative from Kumar et al. (1997), another researchers carried out non-isothermal crystallization kinetics of oil palm/glass hybrid composites and analyzed it in the light of Ozawa's Theory (Agrawal et al. 2000). Preliminary study on mechanical properties of oil palm/glass fibres as reinforcing agents in polypropylene (PP) matrix was carried out (Rozman et al. 2001a,b). Results indicated that the incorporation of oil palm and glass fibres into PP matrix resulted in the reduction of tensile and flexural strength (Rozman et al. 2001a). They also studies the effect of coupling agents on tensile and flexural properties of hybrid composites and concluded that only slight improvements in some cases were shown for those composites treated with polymethylenepolyphenyl isocyanate. In another interesting research, they reported that effect of extraction of the oil palm EFB fibres show significant improvement in flexural and tensile strength and toughness, with a slight increase in the flexural and tensile modulus and elongation at break of oil palm/glass hybrid composites (Rozman et al. 2001b).

Researchers reported extensive study on effect of glass fibre loading on tensile, flexural and impact response of oil palm EFB fibre/phenol formaldehyde(PF) composite (Sreekala et al. 2002a). The over all mechanical performance of the hybrid composite was improved except impact strength and density of the hybrid composite decreases as volume fraction of oil palm EFB fibre increases while hardness of the hybrid composite also showed a slight decrease on an increased volume fraction of oil palm EFB fibre in hybrid composites. Similar study carried out on the influence of glass fibre loading, relative volume fraction of fibres in hybrid composites, and surface modification of fibres on water sorption kinetics in oil palm/glass fibres reinforced PF hybrid composites (Sreekala et al. 2002b). Results out put indicated that Hybridization of oil palm fibre with glass fibre considerably decreased the water sorption of oil palm composite. Accelerated weathering studies of untreated and treated oil palm/glass reinforced PF composites conducted and observed biodegradation and irradiation effects in light of variations in tensile and impact properties (Sreekala et al. 2004). Results indicated that mechanical performance of hybrid composites decreased with thermal and radiation ageing. Researchers studied physical and mechanical properties of the oil palm/glass fibres reinforced epoxy resin bi-layer and tri-layer hybrid composites (Hariharan et al. 2004; Abu Bakar et al. 2005). They observed that hybridization of oil palm with glass fibres increased impact strength of the hybrid composites but tensile strength and young's modulus show negative hybrid effect while positive hybrid effect was observed for the elongation at break of the hybrid composites.

In 2006, one researchers studied tensile and impact properties of thermoplastic natural rubber hybrid composite with short glass fibre and oil palm EFB fibres for the first time (Anuar et al. 2006). Researchers focused on the effect of treatment of glass and oil palm fibres with coupling agent such as silane, and maleic anhydride grafted polypropylene (MAgPP). Obtained results show that hybrid composites containing 10% EFB and 10% glass fibre gave an optimum tensile and impact strength for treated and untreated hybrid composites and tensile properties increased with addition of coupling agent. In another study on physical (density and water absorption), and mechanical (tensile, flexural and impact) properties of oil palm EFB/glass fibres reinforced polyester hybrid composites investigated with increasing loading of both oil palm EFB and glass fibres (Abdul Khalil et al. 2007). Hybridization of glass fibres with oil palm EFB fibres improved mechanical and physical properties of hybrid polyester composite as compared to oil palm EFB/Polyester composites due to the high strength and modulus value of glass fibre than the inferior EFB fibre. In 2007, first type researchers hybridized oil palm wood flour particle (Size < 250μm) with woven glass fibre reinforced epoxy composite and fabricate hybrid composites by hand lay-up method (Mridha et al. 2007). They reported that impact strength reduced with increasing the filler content and also several damages found in specimens at higher filler content resulting higher energy absorption during impact. Similar work reported by Indonesian researchers who studied physical and mechanical properties of oil palm/glass fibre reinforced polyester hybrid composites related to EFB fibre specimen length and fibre loading (Karina et al. 2008). Results show that oil palm fibre length did not show any significance effect on the flexural strength and density of hybrid composites but shorter EFB fibre show low dimensional stability as compared to longer

Until now only one research paper reported on mechanical and physical properties of the oil palm EFB/glass fibre reinforced vinyl ester hybrid composites at a different layer arrangement (Abdul Khalil et al. 2009). Mechanical and physical properties of hybrid composites were found higher than that of mechanical and chemical treated oil palm fibres reinforced composites. It also clear from the results that layering pattern of oil palm EFB and glass fibres within hybrid composites affect dimensional stability and decrease by the incorporation of glass fibre as compared to mechanical and chemical treated composites. Recently conducted a study on impact behaviour of E-glass/oil palm fibres reinforced polyester hybrid composites showed that impact strength improved with increasing number of glass fibre layer and increment in fibre length (Wong et al. 2010).

3.1.2. Oil palm/Sisal fibres reinforced hybrid composites

In 2004, Ist time any researchers try to fabricate oil palm based hybrid biocomposites by hybridization of oil palm fibres with other natural fibres by the unique combination of sisal and oil palm fibres reinforced rubber composites (Jacob et al. 2004a,b). Researchers studied the effect of fibre loading, fibre ratio, and treatment of fibres on mechanical properties of sisal/oil palm fibre reinforced hybrid composites (Jacob et al. 2004a). Results indicated that increasing the concentration of fibres reduced tensile and tear strength, but enhanced tensile modulus of the hybrid composites. They also reported that 21g sisal and 9 g oil palm based hybrid composite show maximum tensile strength and concluded that tensile strength of hybrid composites depend on weight of sisal fibres rather than oil palm fibres due to high tensile strength of sisal fibres. It also seen that treatments of both sisal and oil palm fibres causes better fibre/matrix interfacial adhesion and resulted in enhanced mechanical properties. Similar studies carried out on the influence of fibre length on the mechanical properties of untreated sisal/oil palm fibre based hybrid composites and reported that increase in fibre length decreases the mechanical properties of hybrid composites due to fibre entanglements (Jacob et al. 2004b).

Researchers also studied water sorption characteristics of the oil palm/sisal hybrid composites with reference to fibre loading, chemical modification and influence of temperature (Jacob et al. 2005). Mercerization and silanation treatment of sisal and oil palm fibres decreased the water uptake in the hybrid composites and moisture uptake found to be dependent on the properties of the biofibres. In an interesting study, researchers reported durability and ageing characteristics of oil palm/sisal hybrid composites (Jacob et al. 2007). Researchers again fabricated oil palm /sisal hybrid composites by using surface treated oil palm and sisal fibre with varying concentration of NaOH solution and different coupling agents (John et al. 2008). They compared fibre reinforcing efficiency of the chemically treated biocomposites with that of untreated composites. Results demonstrated that chemical treatment of sisal and oil palm fibres enhanced mechanical properties of hybrid composites and 4% NaOH show superior tensile properties due to better fibre/matrix interaction. Hybrid composites prepared from fluorosilane treated fibres exhibited better mechanical properties as compared to other silane treated hybrid composites. They also investigated anisotropic swelling studies of hybrid composites and revealed that fluorosilane treated fibres based hybrid composites has the highest degree of fibre alignment.

3.1.3. Oil palm/Jute fibre reinforced hybrid composites

Recently we carried out an extensive study on mechanical and physical properties of oil palm/jute fibres reinforced epoxy hybrid composites in our laboratory. Research output show that dimensional stability, density, void content, and chemical resistance of oil palm EFB fibres reinforced epoxy composite improved with hybridization of oil palm EFB fibres with non woven/woven jute fibres (Jawaid et al. 2011d,f,g; Abdul Khalil et al. 2011). Hybridization of oil palm EFB composites with jute fibres improved physical properties of oil palm/jute hybrid composites due to packed and hybrid arrangement of fibre, less hydrophilic nature of jute fibres, better jute/epoxy interaction. It also observed that woven hybrid composites display poor dimensional stability, density and chemical resistant due to high void content of woven jute fabrics as compared to non woven fibres.

Mechanical performance of oil palm EFB fibres with non woven/woven jute fibres reinforced hybrid composites were also carried out (Jawaid et al. 2010;2011b,c,e). Results indicated that oil palm/non woven jute fibre based hybrid composites has higher tensile and flexural properties due to high tensile strength of jute fibres and better jute/epoxy matrix interaction. Hybrid composite show less impact strength as compared to oil palm EFB composite because oil palm EFB fibre has high fracture toughness as compared to jute fibres (Jawaid et al. 2010; 2011c,g). It observed that mechanical properties of woven hybrid composites significant improved work as compared to non woven hybrid composites due to woven fibres are tightly bonded, low deformation at break, stretching nature of fabrics or fabrics mats have higher fibre count than chopped strand (non woven) mat (Jawaid et al. 2011b,e).

3.1.4. Oil palm/Kaolinite hybrid composites

Mechanical and water sorption properties of oil palm empty fruit bunch fibres and kaolinite reinforced polyurethane hybrid bio-composites were studied (Amin and Badri 2007). Hybrid bio-composites showed maximum flexural and impact strengths were at 15% kaolinite loading. It observed that oil palm fibre hybridization with kaolinite improved stiffness, strength, and display better water resistance to extent. Mechanical properties of oil palm/Kaolinite hybrid enhanced due to interaction between kaolinite with PU matrix and EFB fibres.

3.2. Electrical properties of oil palm fibre based hybrid composites

In the field of natural fibre reinforced polymer composites, extremely limited research has been reported on the electrical properties. In 1981, Ist time researchers reported electrical resistivity and dielectric constant of some natural fibre (Coir, banana, sisal pineapple leaf, and palmyra fibres) and results indicated that natural fibre has high electric resistivity and dielectric strength (Kulkarni et al. 1981). They also suggested that natural fibre can be used as a replacement for wood in insulating applications. Further study reported by another researcher on electrical resistivity of various part of the coconut tree and confirm that it can used as good insulators (Satyanarayana et al. 1982). Recently electrical properties of oil palm fibres reported and concluded that dielectric constant value of oil palm fibre is in agreement with the values reported earlier (Chand 1992) for other natural fibres (Shinoj et al. 2010). Results obtained by researchers also clear that fibre size reduction caused an increase in dielectric constant, while alkali treatment on fibres caused a decrease in dielectric constant. Several researchers worked on electrical properties of natural fibre reinforced polymer composites (Reid et al.1986; Paul and Thomas 1997; Datta et al.1984; Jayamol et al.1998; Chand and Jain 2005). Researchers studied electrical properties of untreated and treated oil-palm fibre reinforced polymer composites by using transient plane source technique at room temperature. Results indicated that all the silane and alkali treated fibres shows enhancement in thermal conductivity and diffusivity of the composites as compared to acetylated composite (Agrawal et al. 2000). In this work, the dielectric properties of oil palm/natural rubber composite materials of untreated and treated oil palm fibres were characterized. It noticeable that oil palm fibre reinforced in rubber matrix affects the dielectric properties of composites and treatment of fibres increase the loss factor. They also reported that low fibre content (20%) show less significant effect on the dielectric properties of composites (Marzinotto et al. 2007). Recently, another researchers investigate the influence of the fibre orientation in the dielectric properties of the oil palm tree fibre reinforced polyester composite by using a dielectric spectroscopy (Ben Amor et al. 2010). Results demonstrated that orientation of the fibre can strongly influence the dielectrical properties and interfacial polarization processes in composites and this technique can be used to probe the composite interphase and investigate the effect of fibre orientation on the evolution of composite interfacial properties.

In an attractive research work carried out on thermal conductivity and diffusion of banana/glass fibres reinforced rubber hybrid composites in relation to fibre loading, fibre ratio, frequency, chemical modification of fibres and the presence of a bonding agent (Agarwal et al. 2003). Electrical strength and volume resistivity of jute/wheat and jute/jamun fibres reinforced bispheniol-c-formaldehyde has been evaluated (Mehta and Parsania 2006). Researchers reported that there is no much difference in dielectric breakdown strength between hybrid composites but volume resistivity of hybrid composites increased by 197-437% as compared to jute fibres reinforced bispheniol-c-formaldehyde composite. Researchers investigated dielectric behaviours of glass and jute fibres reinforced polyester hybrid composites and later on electrical properties of banana/glass hybrid fibre reinforced composites with varying hybrid ratios and layering patterns were analyzed (Fraga et al. 2006; Joseph and Thomas 2008). In 2006, Ist time dielectric characteristics and volume resistivity of sisal-oil palm hybrid biocomposites investigated (Jacob et al. 2006). Results obtained show that dielectric constant increases with fibre loading at all frequencies, and volume resistivity decreases with frequency, and fibre loading, this implies that the conductivity increases upon addition of lignocellulosic fibres. Researchers also reported that chemical modification of fibres resulted in a decrease in dielectric constant and increase in volume resistivity due to increase in hydrophobicity of fibres. It also observed that addition of a two-component dry bonding agent consisting of hexamethylene tetramine and resorcinol, used for the improvement of interfacial adhesion between the matrix and fibres reduced the dielectric constant of the hybrid composites. They also reported that dissipation factor was seen to increase with fibre loading which indicates that the electrical charges can be retained over a longer period of time. Researchers studied dielectric constant and volume resistivity values of sisal/coir hybrid composites and reported similar results to oil palm/sisal hybrid composites (Haseena et al. 2007).

3.3. Thermal and dynamic mechanical properties of oil palm fibre based hybrid composites

Thermal stability of natural fibres and natural fibre based composites can be analyzed by two techniques viz., thermogravimetric analysis (TGA) and differential scanning calorimeter (DSC). Weight and energy loss with heating is common phenomena for natural fibre reinforced polymer composites due to degradation and loss of residual solvents and monomers. Weight loss on heating is studied by TGA and measurement of relative changes in temperature and heat or energy either under isothermal or adiabatic conditions studied by DSC. Dynamic mechanical analysis (DMA) is a technique for measuring the modulus and damping factor of a sample. The modulus is a measure of how stiff or flimsy sample is, and amount of damping a material can provide is related to energy it can absorb (Duncan 2008). DMA is generally used for thermoplastics, thermosets, composites and biomaterials. DMA is one of the most powerful tools to study the behaviour of polymer composite materials and it allows for a quick and easy measurement of material properties (Swaminathan and Shivakumar 2009). Previously thermal properties of hybrid composites such as banana/glass, sisal/glass, bamboo/glass, hemp/glass, etc. were studied by researchers and observed that addition of glass fibre improved thermal properties of natural fibre based composites. Researchers reported that hybridization of banana fibre reinforced polymer composites with glass fibres enhanced melting point, crystallization temperature and onset thermal degradation temperature of maleic anhydride grafted polypropylene (MAPP) treated banana/glass hybrid composites (Samal et al. 2009a). It is due to SiO groups in glass fibre which interlinks with anhydride group of MAPP, providing synergism between glass and banana fibres. Similar study on thermal stability of banana/glass hybrid composites carried out by TGA and DSC and revealed that MAPP treated banana and glass fibres enhanced thermal stability of polypropylene (Nayak et al. 2010a). Dynamic mechanical properties of banana/glass hybrid composites have been analyzed to investigate the interfacial properties (Samal et al. 2009a; Nayak et al. 2010a). Results show that the storage modulus and loss modulus of MAPP treated hybrid composites improved over the whole temperature range, indicating better adhesion between fibre/matrix. Dynamic mechanical properties of banana/glass hybrid composites also studied over a range of temperature and three different frequencies (Pothan et al. 2010). Storage modulus values of hybrid composite decreases above the glass transition temperature (Tg) where glass is the core material.

Researchers studied thermal properties of sisal/glass hybrid composites and confirm that addition of glass fibre improved thermal properties of sisal/PP composites (Jarukumjorn and Suppakarn 2009; Nayak and Mohanty 2010b). In an interesting study on thermal properties such as crystallization, melting behaviour and thermal stability of bamboo/glass hybrid composites and obtained results indicate an increase in thermal stability of bamboo composites due to the higher thermal stability of glass fibre than bamboo fibre (Samal et al. 2009b; Nayak and Mohanty 2010b; Lee and Wang 2006). Hybridization of hemp fibre composites with glass fibres shifts the temperature of degradation to a higher value indicating an increased thermal stability of the hybrid composites (Panthapulakkal and Sain 2007). Effect of glass fibre loading and MAPP treatment on dynamic mechanical properties of sisal/glass hybrid composites carried out and reported improvement in storage modulus and loss modulus of hybrid composites with hybridization of sisal/pp composite with glass fibres and treatment with MAPP (Ornaghi Jr et al. 2010; Nayak and Mohanty 2010b). Dynamic mechanical properties of bamboo/glass fibre hybrid composites were also studied and observed results indicate an increase in storage modulus and decrease in damping properties due to hybridization and treatment of fibres with MAPP as compared to untreated composites and pure matrix (Nayak et al. 2009,2010c; Samal et al. 2009b). Until now, there is no any researcher work carried out on thermal stability of banana/sisal and pineapple leaf/glass reinforced hybrid composites but few work reported on dynamic mechanical properties of these hybrid composites. They concluded that storage modulus and damping factor of banana/sisal and pineapple leaf/glass hybrid composites also enhanced due to hybridization with natural and synthetic fibres (Idicula et al. 2005a,b; Uma Devi et al. 2010).

Literature review indicated that particularly limiting work reported on thermal and dynamic mechanical properties of oil palm based hybrid composites. In 2006, Ist time any researchers studied thermal properties of sisal/oil palm fibres reinforced natural rubber hybrid composites and observed that sisal fibre loading and chemical modification of fibres enhanced thermal stability of the oil palm composites (Jacob et al. 2006b). In case of oil palm/sisal hybrid composite, the peak temperatures have decreased to 356.3^{0}C, and a new peak has come at 489.9^{0}C due to hemicellulose and alpha-cellulose degradation and addition of fibers results in an increase of thermal stability as indicated by the higher peak temperatures. Chemical modification of fibres results in a further increase of thermal stability as evident from the peak temperatures of 524^{0}C and 518.3^{0}C of 4%NaOH and aminosilane treated composites.

They also carried out an extensive study on dynamic mechanical properties of oil palm/sisal fibre reinforced natural rubber hybrid composites as a function of temperature (Jacob et al. 2006c). The storage modulus of hybrid composites increased with sisal fibre loading while the damping factor found to decrease due to the increased stiffness imparted by oil palm and sisal fibres. Treatment of fibres with NaOH also enhanced the storage modulus value of hybrid composites while chemically treated composites show decreased in damping factor value as compared to untreated composites. Similar study on dynamic mechanical properties of oil palm/sisal hybrid composites with reference to the role of coupling agents were carried out (Jacob et al. 2006d). It observed that storage and loss modulus of treated hybrid composites increased while damping properties decreased due to better interfacial interface between fibre and matrix. The dynamic mechanical properties of oil palm fibre/glass fibre reinforced phenol formaldehyde hybrid composites as a function of fibre content, and hybrid fibre ratio was investigated (Sreekala et al. 2005). The glass transition temperature of the hybrid composites found to be lower than that of the unhybridized composites. Storage modulus of the hybrid composites was also found to be lower than that of unhybridized oil palm fibre/PF composite. Loss modulus of hybrid composites increased with increase in glass fibres, and gradual decrease in loss modulus is observed with the increase in frequency. It also noted that the activation energy decreases with incorporation of glass fibres in hybrid composites.

In our laboratory, we carried out research work on thermal and dynamic mechanical properties of oil palm/jute fibre reinforced epoxy hybrid composites (Jawaid and Abdul Khalil 2011e; Jawaid et al. 2012). The thermal behaviour of the oil palm/jute based hybrid composites were determined (**Figure 4**), and it noticed that initial degradation temperature of hybrid composites shifted to a higher temperature well over 268-271°C as compared with the EFB composite (260°C), which indicate higher thermal stabilities of the hybrid composites (Jawaid and Abdul Khalil 2011e). Final degradation temperature of hybrid composites also shifted between 441 to 443°C due to complex reaction. Hybridization of oil palm EFB fibres with jute fibres, the final decomposition temperature and ash content of the hybrid composite shifted slightly towards higher temperature as a result of the high thermal stability of jute fibre which acts as barriers to prevent the degradation of oil palm EFB fibres. Similar study carried out on thermal stability of oil palm/woven jute fibre reinforced epoxy hybrid composites and results indicated that woven hybrid composites initial and final decomposition temperature higher than oil palm/jute hybrid composites (Jawaid et al. 2012). It clear from **Figure 4** that oil palm EFB/woven jute hybrid composites are more thermal stable as compared to oil palm EFB composite which is possibly due to the higher thermal stability of woven jute fibre than oil palm EFB fibre.

Dynamic mechanical properties of oil palm/jute and woven hybrid composites also carried out in our laboratory (Jawaid and Abdul Khalil 2011e; Jawaid et al. 2012). Figure 5 shows storage modulus values of hybrid composites at a frequency of 1 Hz. On investigating the variation of storage modulus with temperature, storage modulus was found to be decreased with the increase in temperature in all cases at low temperature because fibre do not contribute much to imparting stiffness to the material. As temperature increases, the components become more mobile and lose their mobility and lose their close packing arrangement. The high stiffness of hybrid composites is in agreement with their tensile property reported in our previous research (Jawaid et al. 2011g). In particular the composite stiffness is substantially increased with woven jute and EFB fibre incorporation, and it causes a drop in the modulus above T_g and comparatively less than epoxy matrix (Jawaid et al. 2012). The stiffness of the oil palm EFB composite increases with hybridization with woven jute fibres, resulting in high storage modulus **(Figure 5)**.Moreover, the addition of woven jute fibres allows greater stress transfer at the interface and ultimately increases the storage modulus.

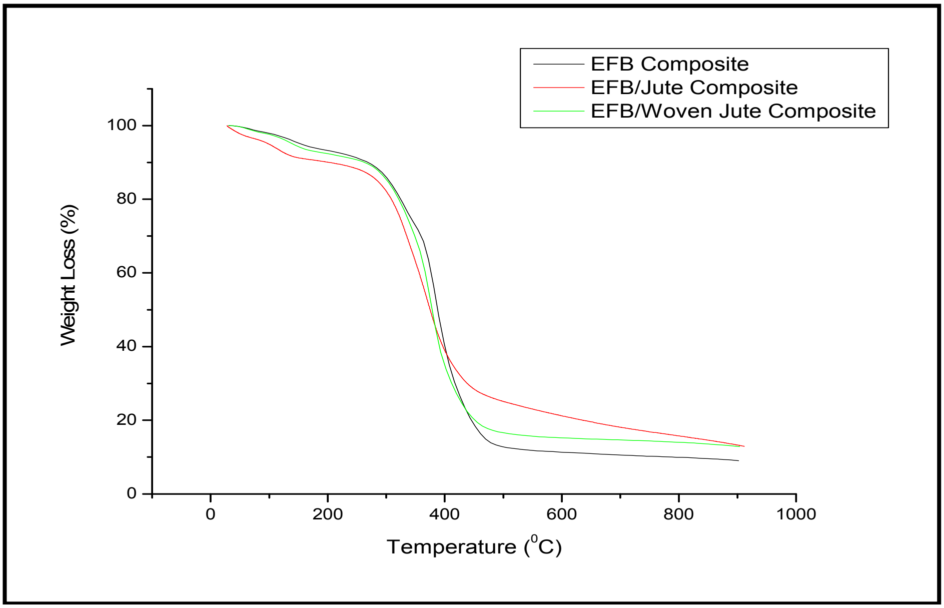

Figure 4. Thermogravimetric analysis curve of Oil Palm EFB, oil palm EFB/jute, and Oil Palm EFB/Woven Jute Hybrid Composites.

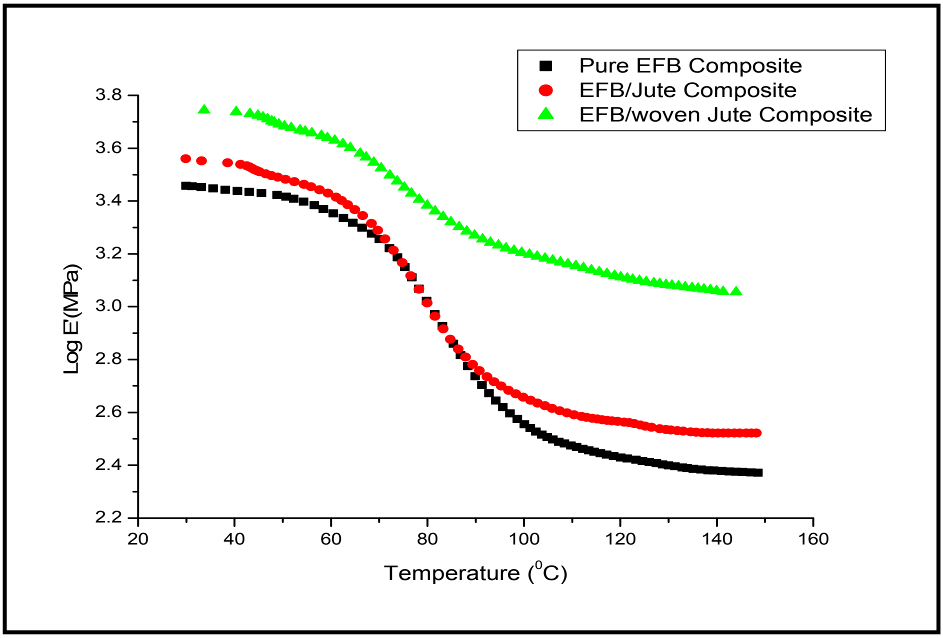

Figure 5. Storage modulus of oil palm EFB, oil palm EFB/jute, and oil palm EFB/woven jute hybrid compossites

Trends of change in the damping factor of the hybrid composites with temperature are shown in Figure 6. Damping factor of oil palm/non woven jute hybrid composite indicate that incorporation of the small amount of jute fibre to oil palm EFB/epoxy composite enhances the damping characteristics of the hybrid composites (Jawaid and Abdul khalil 2011e). With incorporation of oil palm EFB and woven jute fibres, the Tan δ peak was lowered as expected (Jawaid et al. 2012). Reinforcement of fabrics results in the formation of barriers that restrict the mobility of polymer chain, leading to lower flexibility, lower degree of molecular motion and hence lower damping characteristics (Jacob et al. 2006).

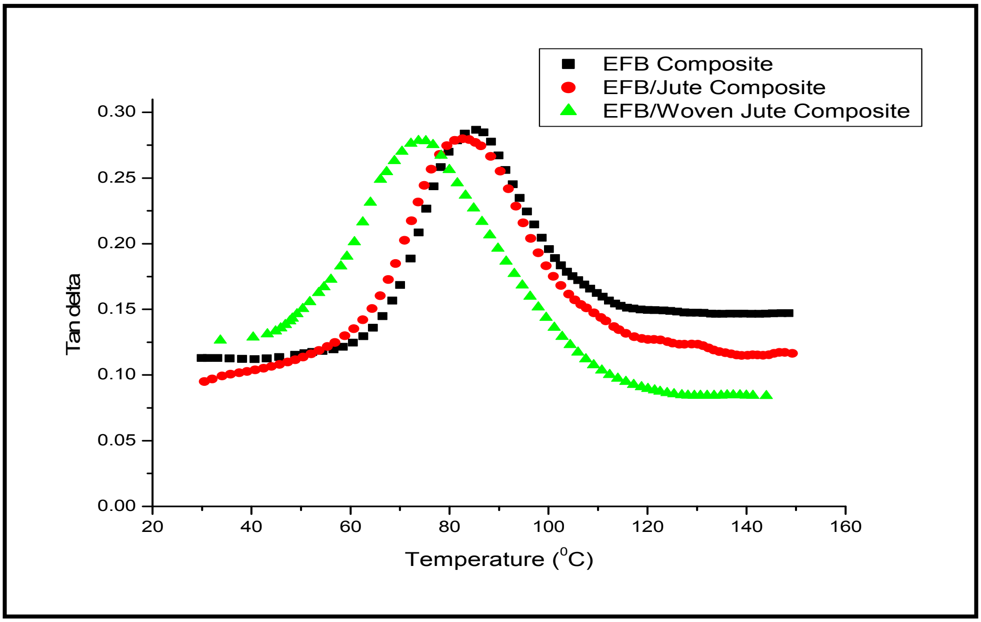

Figure 6. Damping factor of oil palm EFB, oil palm EFB/jute, and oil palm EFB/woven jute hybrid composites

4. Application of oil palm fibres based composites

The use of bio-fibres for composite applications is being investigated throughout the world (Bledzi et al, 2006). Biocomposites have received increasing attention from both of the academic world and industries as building, automotive, packaging, and so on. Green composites or biocomposites based on natural fibres and resins are increasingly used for various applications as replacements for non-degradable materials. Green composites made entirely from renewable agricultural resources could offer a unique alternative for building, construction, furniture and automotive application (Gupta 2009). Biocomposites find applications in a number of fields viz., automotive industry and construction industry such as for panels, frames, ceilings, and partition boards (Abu Bakar et al. 2005), structural applications, aerospace, sports, recreation equipment, boats, office products, machinery, etc.

(Sreekala et al. 2002a), and structural and non structural components such as window, door, siding, fencing, roofing, decking, etc. (Yatim et al. 2011). Bledzki et al. (2006) point out the importance of natural fibres and natural fibres composites in the automotive industry. Researchers already developed many automotive components (interior and exterior) from bio-fibre reinforced composite materials and designed Eco car which is built from bio fibre composite panels that incorporate biodegradable resins as the matrix material. (Bledzi et al, 2006). A modern automobile requires recyclable or biodegradable parts because of the increasing demand for a clean environment (Gupta 2009). Composites are also finding application in electrical and electronic industries.

Recently trends developed in the automotive industry to use natural and recycled materials to fulfil "The End of Life Vehicle (ELV) Directive", which came into force in October 2000, requires all member states to de-pollute all scrapped vehicles, avoid hazardous waste and reduce the amount of waste placed in landfill sites to a maximum of five per cent per car by 2015. Ford automotive stated to develop one million Lincoln and Mercury vehicles that feature recycled plastic bottles and even worn-out jeans in their seat cushions and backs by the end of the year, while French carmaker Citroën has turned to natural materials derived from hemp, bamboo and kenaf for the door linings of its 'premium' models. A team at Baylor University in the USA has made trunk liners, floorboards and car-door interior covers using fibres from the outer husks of coconuts, replacing the synthetic polyester fibres typically used. So, the main driving force to use natural fibres or recycled materials to develop cost effective, low weight and sustainable car to fulfil ELV directive and reduce hazardous waste.

Oil palm fibres can be used as fillers in thermoplastics and thermoset composites. These composites have wide applications in furniture and automobile components. Malaysian Palm Oil Board (MPOB) has developed a series of technologies on manufacturing thermo-formable plastic composites through compression or extrusion process for car components such as bumbers, trimmings, rear parcel shell, spare wheel cover and splash shield and also plastic pellets. Blending of oil palm fibres with polyols can produce cost effective lighter products such as packaging materials and roof insulators, which only require low compressive hardness. Oil palm fibre-filled automotive upholstery parts, dampening sheets for automotive industry using oil palm fibres, moulded particleboard, pulp and paper from oil palm fibres also developed. Researchers developed composite plastic fiber for automotive application by using oil palm biomass (Viva 2011). Progress in utilization of oil palm fibre finally reached to commercialization stage when PROTON (Malaysian National Carmaker) entered into an agreement with PORIM (Palm Oil Research Institute of Malaysia) to develop the thermoplastic and thermoset composites and used it in PROTON car (Panigrahi 2010). Sheffield University (UK) research team started to work with a producer of palm oil fibre and show interest in sustainable car production by replacing traditional materials and say that once the research will be in a later stage they will try to motive car manufacturers to use new materials and they hope that once the regulations become more stringent, this will force to do the change. In an interesting research, oil palm EFB fibre reinforced concrete roof slates produced, and preliminary results suggest that oil palm EFBs have a potential to be a material component of reinforced mortar roofing slates with the appropriate water cement ratio and concrete mix (Kaliwon 2010).

Researcher have developed, manufactured and assembled a small prototype car with all body panels made from jute fibre reinforced composite and hybrid composite. It also reported that door panels manufactured from flax/sisal hybrid epoxy composite shown remarkable weight reduction of about 20% (Schuh 2004). In 2000, Audi launched the A2 midrange car in which door trim panels were made of polyurethane reinforced with mixed flax/sisal mat. Researcher developed bamboo/glass fibre biocomposites for applications in wall panels, roofing panels, floors (Van Rijswijk et al. 2001). From literature view, we unable to find any application of oil palm fibres based hybrid composites which is required to explore the application in automobile, construction, packaging, etc sectors.

5. Conclusions

Oil palm biomass is an agricultural by-product periodically left in the field after oil extraction and considers as hazardous material creating environmental problems. The oil palm biomass residue include the oil palm trunks, oil palm fronds, kernel shell, empty fruit bunch, presses fruit fibre, and palm oil mill effluent. Oil palm fronds accounts for 70%, EFB accounts for 10%, and OPT accounts for only about 5% of the total biomass produced. Oil palm biomass residues can be utilized as by–products, and it can also help to reduce environmental hazards. Oil palm biomass fibres consist of cellulose, hemicelluose, and lignin while oil palm empty fruit bunch consist of high cellulose content and is a potential natural fibre resource, but its applications account for a small percentage of the total biomass productions. The properties of oil palm fibres are strongly influenced by chemical composition, fibre structure, microfibril angle, cell dimensions and defects, it differs from different parts of a plant as well as from different areas. Oil palm biomass fibres offer excellent specific properties and have potential as outstanding reinforcing fillers in the matrix and can be used as an alternative material for bio-composites, hybrid composites, pulp, and paper industries. Natural fibres such as oil palm biomass fibres are not suitable for high performance applications due to its low strength, environmental sensitivity, and poor moisture resistance which results in degradation in strength and stiffness of natural fibre reinforced composites. Most of the drawbacks that have been identified can be overcome by effective hybridization of oil palm fibres fibre with glass fibre or natural fibres (jute/sisal).

The primary advantages of using oil palm fibres in hybrid composites are its low densities, non abrasiveness and biodegradability. Oil palm fibres with jute/sisal fibres appear to be promising materials because of the high tensile strength of jute and sisal fibres and the toughness of oil palm fibre. Now most of automobile manufacturer try to replace synthetic fibres with natural fibres, but it’s not comparable in properties while fabricating hybrid composites by the combination of two natural fibres give them advantage to replace synthetic fibres. Hybridization of oil palm EFB fibres with glass/jute/sisal fibres enhanced physical and mechanical properties of oil palm EFB composites. It would appear that a wide variety of work carried out worldwide on physical and mechanical properties of oil palm/glass, oil palm /sisal, and oil palm/jute hybrid composites but still not fully explore electrical, thermal, and dynamic mechanical properties of oil palm based hybrid composites. Over all conclusions is that hybrid composites fabrication by using oil palm fibres will help in development of unique cost effective advanced composites possessing superior mechanical properties, dimensional stability, appropriate stiffness, damping behaviour and thermal stability.

Extensive research still required to do on oil palm based hybrid composite while exploring compatible of oil palm fibres with other natural fibres by compounded with several other polymers in the line of previous work. Microstructure of the interface between the oil palm fibre with other natural fibres, and matrix needs to be investigated and the interfacial properties should be studied with single fibre pull out, micro-bond test and single fibre fragmentation test. Complementary techniques such as X-ray photoelectron spectroscopy, time-of-flight secondary ion mass spectrometry may be studied to get more information about the chemical composition of the surface, its wetting behaviour, etc., that, coupled with the mechanical assessment of the interface, can shed more light on the structural characteristics of the interface. Future research on oil palm fibre based hybrid composites not only limited to its automotive applications but it also required to explore its application in aircraft components, construction industry, rural housing and biomedical applications.

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