Engineered Composite Materials and Natural Fibres: Design and Manufacture (A Review)

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Abstract: *This paper looks into the engineering act of designing and developing new materials for sustainable applications through natural fibre reinforcements and green composites. Composites or composite materials are extending the horizons of designers in all branches of engineering, and yet the degree to which this is happening can easily pass unperceived, consequence being that these materials still need to be engineered to perfection. Natural fibres have recently become attractive to researchers, engineers and scientists as an alternative reinforcement for fibre reinforced polymer (FRP) composites, due to their low cost, fairly good mechanical properties, high specific strength, non-abrasive, eco-friendly and bio-degradable characteristics. The engineering approach to the design and manufacture of these materials is to overcome the shortfalls of the natural fibre reinforced polymer composites which are basically the hydrophilic nature of natural fibres and the incompatibility between them (fibres) and their matrices (polymers).*

Keywords: *Composites, Engineering, Fibre Reinforced Polymer, Hydrophilic, Hydrophobic, Natural Fibre,*

I. Introduction

The use of composite materials dates from centuries ago, and it all started with natural fibres. In ancient Egypt some 3000 years ago, clay was reinforced by straw to build walls. Later on, the natural fibre lost much of its interest. Other more durable construction materials like metals were introduced (Brouwer, 2012). In the sixties of the 20th century, the rise of composite materials began when glass fibres in combination with tough rigid resins could be produced in large scale. At the past decade of the 21st century there has been a renewed interest in the natural fibre as a substitute for glass, motivated by potential advantages of weight saving, lower raw material price, and 'thermal recycling' or the ecological advantages of using resources which are renewable. The need for renewable fibre reinforced composites has never been as prevalent as it currently is. A major goal of natural fibre composites is to alleviate the need to use expensive glass fibre ($3.25/kg) which has a relative high density of $2.5g/cm^3$ and is dependent on nonrenewable sources (Holberty and Houston, 2006; Mohantya, et al 2000). Therefore, emphatically, natural fibres have become attractive to researchers, engineers and scientists as an alternative reinforcement for fibre reinforced polymer (FRP) composites. They are exploited as a replacement for the conventional inorganic fibres, such as glass, aramid and carbon (Ku, et al 2011).

Natural fibres primarily consist of Cellulose, Hemicelluloses, Pectin and Lignin, with a small quantity of extractives (Sabu and Pothan, 2009; Xiao, et al 2003; Westman, et al 2010; Mwaikambo, 2006).The individual percentage of these components varies with the different types of fibres. This variation can also be affected by growing and harvesting conditions. Cellulose is a semicrystalline polysaccharide and is responsible for the hydrophilic nature of natural fibres (Westman, et al 2010). Hemicellulose is a fully amorphous polysaccharide with a lower molecular weight compared to cellulose. The amorphous nature of hemicelluloses results in it being partially soluble in water and alkaline solutions (Bledzki and Gassan, 1999). Pectin, whose function is to hold the fibre together, is a polysaccharide like cellulose and hemicelluloses. Lignin is an amorphous polymer but unlike hemicelluloses, lignin is comprised mainly of aromatics, and has little effect on water absorption (Saheb and Jog, 1999; Li, et al 2007). Table 1 shows these chemical compositions of some natural fibres (Mwaikambo, 2006).

Nevertheless, compared with conventional inorganic fillers like glass and carbon fibres, natural fibres provide the following advantages; (i) abundance and therefore low cost (ii) biodegradability (iii)flexibility in processing and less machine wear (iv) minimal health hazard (v) low density (vi) desirable fibre aspect ratio (vii) relatively high tensile and flexural modulus. Incorporating the tough and light weight natural fibres into polymer (thermoplastic and thermoset) matrices produces composites with a high specific stiffness and strength (Wambua, et al 2003). The renewable and biodegradable characteristics of natural fibres facilitate their ultimate disposal by compositing or incineration options not possible with most industrial fibres.

Two factors currently limit the large scale production of natural fibre composites. First, the strength of natural fibre composites is very low compared with glass. This is often as a result of the incompatibility between the fibre and the resin matrix. The wettabilty of these fibres is greatly reduced compared to glass and this constitutes a challenge for scale up production. The second factor is the water absorption ability of natural fibres. This absorption deforms the surface of the composited by swelling and creating voids. These factors are usually due to the inherent low compatibility between polar fibres and non-polar matrices especially hydrocarbon matrices such as Polypropylene (PP) and Polyethylene (PE) (Bledzki and Gassan, 1998; Cantero, et al 2003). This incompatibility may not be an issue when using polar polymers such as unsaturated polyester (UP) and epoxy resin as matrices.

The treatment of fibres is currently an area of research receiving significant attention. The absorption of water is commonly thought to occur at the free hydroxyl groups on the cellulose chains. With a ratio of 3 hydroxyl groups per glucose repeat until the amount of ware that can be absorbed is substantial. By capping the hydroxyl groups this ratio can be reduced. There are several promising techniques that have been studied by various groups. Among these treatments; mercerization (alkaline) treatment has had the most reviews. Utilizing silanes as coupling agents is a treatment commonly used in glass composite production and it also has been found useful in the area of natural fibre composites. Acetylation is another treatment that is common with cellulose to form a hydrophobic thermoplastic and has the potential to have the same results on natural fibres (Rowell, 1998; George, et al 2001; Singh, et al 1998; Yan Li, et al 2000; Khalil, et al 2001).

II.   Composites (composite materials) and Classification

The 'composite' concept is not a human invention. Wood is a natural composite material consisting of one species of polymer-cellulose fibres with good strength and stiffness in a resinous matrix of another polymer, the polysaccharide lignin. Bone, teeth and mollusk shells are other natural composites, combining hard ceramic reinforcing phases in natural organic polymer matrices (Harris, 1999). A composite (composite material) in engineering sense is any material that has been physically blended to form a homogenous material (Pichai, 2005). The resulting material would still have components identifiable as the constituent of the different materials. One advantage of composites is that two or more materials could be combined to take advantage of the good characteristics of each of the materials.

Traditional engineering materials like steel, aluminum, etc., contain impurities that can represent different phases of the same material and fit the broad definition of a composite, but are not considered composites because the elastic modulus or strength of the impurity phase is nearly identical to that of pure material. The definition of a composite material is flexible and can be augmented to fit specific requirements (Ashby, 1990). Usually, composites will consist of two separate components, the matrix and the filler. The matrix is the component that holds the filler together to form the bulk material. The composites generally used in structural applications are best classified as high performance. They are typically made from synthetic materials have high strength-to-weight ratios, and require controlled manufacturing environments for optimum performance. Although composite material technology has grown rapidly, it is not yet fully developed. New combinations of fibre/resin systems and even new materials (bio-composites) are constantly being developed. The best one can hope to do is identify the types of composites that exist through broad characterization and classification. Fig, 1 depicts the relationship between three major classes of engineering materials and composite formation.
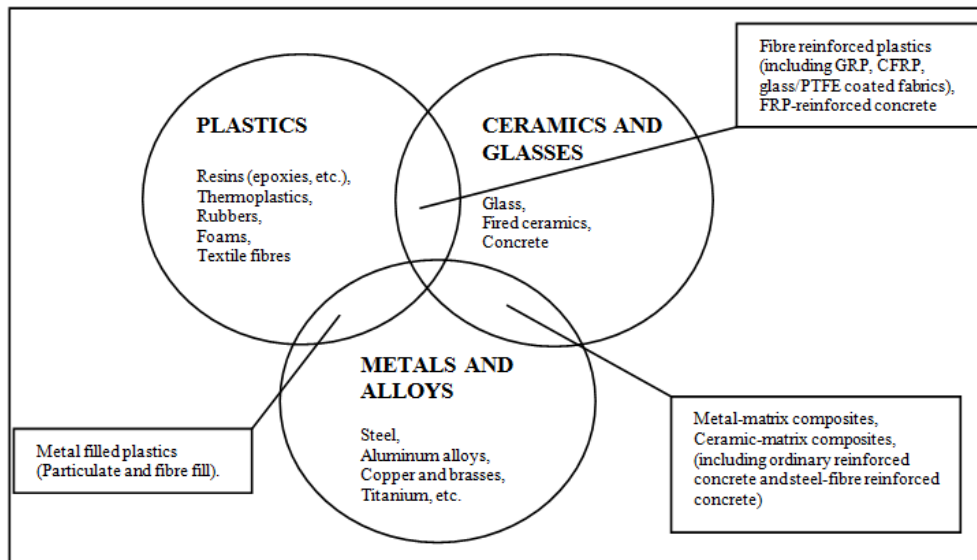
Fig 1: Relationships between Classes of Engineering Materials, Showing the Evolution of Composite

2.1 Classification of Composites

The constituents of a composite are generally arranged so that one or more discontinuous phases are embedded in a continuous phase. The discontinuous phase is termed the 'reinforcement' and the continuous phase is the 'matrix'. Composites can be classified in two ways according to; (1) type of reinforcement/filler (2) type of matrix.

2.1.1 Type of Filler/Reinforcement

Under this classification, composites are classified into roughly four types namely (i) particulate fillers (ii) discontinuous fillers (uni-directional short fibres and random short fibres 'quasi-isotropic') (iii) continuous fillers (iv) laminate fillers.

(i) Particulate filler composite consists of the composite materials in which the filler materials are roughly round. Example is the unreinforced concrete, where the cement is the matrix and the sand serves as the filler. Cermet is a metal matrix composite with ceramic filler.

(ii) Discontinuous (short) filler composites are composites in which the filler material has a length to diameter ratio, l/d, greater than one. Short fibre composites are generally takento have l/d ~ 100. Fibre glass filler for boat panel is an example of short fibre composite. With recent innovations in composite technology, discontinuous fibre composites now include fibres in Nano scale.

(iii) Continuous (long) filler composites consist of a matrix reinforced by a dispersed phase in form of continuous fibres. The filler material has a length to diameter ratio l/d ~ ∞. Carbon fibre, Aramid fibre, Kevlar fibre are some of the filler material used in the long fibre type.

(iv) Laminate is the type of composite that uses the filler material in form of sheet instead of particles or fibre. A laminate is fabricated by stacking a number of laminae in the thickness direction. These laminates can have uni-directional or bi-directional orientation of the fibre reinforcement according to end use of the composite.

2.1.2 Type of Matrix

Composites can be classified based on the type of matrices bonding them. Based on this matrix material which forms the continuous phase, composites are broadly classified into (1) polymer matrix composites (PMC), (2) metal matrix composites (MMC), (3) ceramic matrix composites (CMP), and (4) bio matrix composites (BMC).

(1) Polymer Matrix Composites (PMC):

Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. It follows, therefore, that high temperature resins are extensively used in aeronautical application. Two main types of polymers are (a) thermosets and (b) thermoplastics.

Thermosets have qualities such as a well bonded three dimensional molecular structure after curing. They decompose instead of melting on hardening. Merely changing the basic composition of the resin is enough to alter the conditions suitably and determine its other characteristics. They can be retained in a partially cured condition too, over prolonged period of time, rendering thermosets very flexible. Thus they are the most suited

as matrix bases for advanced conditions fibre reinforced composite (Ashby, 1992).Major and commonly used thermoset materials in composite engineering include, epoxy, polyester, phenolic polyamide resins.

Thermoplastics have one or two-dimensional molecular structure and they tend to at an elevated temperature and show exaggerated melting point. Another advantage is that the process of softening at elevated temperatures can be reversed to region its properties during cooling, facilitating applications of conventional compress techniques to mould the compounds. Resins reinforced with thermoplastics now comprise an emerging group of composites. The theme of most experiments in this area is to improve the base properties of the resins and extract the greatest functional advantages from them in new avenues, including attempts to replace metals in die-casting processes (Ashby, 1992). When crystalline or amorphous, thermoplastics possess the facility to alter their creep over an extensive range of temperature.Common kinds of thermoplastics are polyethylene, polystyrene, polyamides, nylons, and polypropylene.

(2) Metal Matrix Composites (MMC):

Metal matrix composites at present though generating a wide interest in research, are not as widely in use as their plastic counter parts. High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites. Most metals and alloys could be used as matrices and they require reinforcement materials which need to be stable over a range of temperature and also non-reactive. Titanium, Aluminum, and Magnesium are particularly useful for aircraft applications. The melting point, physical and mechanical properties of these composites at various temperatures determine the service temperature of the composites.

(3) Ceramic Matrix Composites(CMC):

Ceramics can be described as solid materials which exhibit very strong ionic bonding in general and few cases covalent bonding. High melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength, make ceramic based matrix materials a favourite for application requiring a structural material that does not give way at temperatures above 1500^0C. High modulus of elasticity and low tensile strength which most ceramics possess have combine to cause the failure of attempts to add reinforcements to obtain strength improvement. This is because at the stress levels at which ceramics rupture, there is insufficient elongation of the matrix which keeps composites from transferring an effective quantum of load to the reinforcement and the composite may fail unless the percentage or volume fraction of fibre is high enough. A material is reinforced to utilize the higher tensile strength of the fibre to produce an increase in load bearing capacity of the matrix.

(4) Bio Matrix Composites (BMC):

Bio based resins in other words matrices for composites consist partially or completely of renewable raw materials but can no longer be melted down after a single hardening step. Several developments of bio-based resins using natural oils (epoxy), carbohydrates (thermosets and thermoplastics), and natural phenolics (tannin and lignin) have been carried out. Attempts have been made to produce bio-based versions of unsaturated polyester (UP), epoxy and tannin resins (Bakare, 2015; Schuster, et al, 2014). Combining these bio-based matrices with natural fibres results in composites made only from renewable resources, which are called bio-composites or green composites. According to Bakare (2015), synthesis of bio-based thermoset resins involve the epoxidation of vegetable oils for epoxy, phenols from lignin for phenol formaldehyde resins, or sugar derivatives such as polyol in polyurethane resins, etc.

However, it is important to note that as these matrices are mostly reinforced with macro and micro sized fibres to form composites, likewise these matrices are used in classifying composites formed with their reinforcements in nano-scale as follows; Polymer Matrix Nanocomposites, Metal Matrix Nanocomposites, and Ceramic Matrix Nanocomposites (Carmago et al 2009).

III. Engineered Composites (Natural Fibres)

As it has been stated in the introductory part of this paper, the certain drawback of natural fibres/polymers composites is the incompatibility between the hydrophilic (polar) natural fibres and the hydrophobic (non-polar) polymer matrices (Malkapuram et al 2008; Wambua et al 2003). This leads to undesirable properties of the fibre surface by employing chemical modifications to improve the adhesion between fibre and matrix.

There are many factors that can influence the performance of natural fibre reinforced composites. Besides the hydrophilic nature of the natural fibre, the properties of the natural fibre reinforced composites can also be influenced by fibre content/amount of filler. In general, high fibre content is required to achieve high performance of composites and it is often observed that the increase in fibre loading leads to an increase in

tensile properties (Ahmad et al 2006). Another important factor that significantly influences the properties and interfacial characteristics of the composites is the processing parameters used. Therefore, suitable processing techniques and parameters must be careful selected I order to yield the optimum composite products.

3.1 Engineered Fibre Surfaces

In order to improve and develop natural fibre reinforced polymer composites with better tensile properties, it is necessary to increase fibre hydrophobicity by introducing the natural fibres to surface chemical modification (surface treatment). The fibre modification is attempted to improve fibre hydrophobic, interfacial bonding between matrix and fibre, roughness and wettability, and also decrease moisture absorption, leading to the enhancement of tensile properties of the composites (Lee et al 2009; Li et al 2009; Panigrahy et al 2006; Santos et al 2009). Different surface chemical modifications, such as chemical treatments, coupling agents and graft co-polymerization of natural fibres aimed at improving the tensile properties of the composites were performed by a number of researchers. Chemical treatments like alkali (NaOH) treatment known as mercerization is used to remove the hydrogen bonding in the network structure of the fibres' cellulose, thereby increasing fibres surface roughness, some quantity of lignin, wax and oils covering the external surface of the fibre cell wall, depolymerises the native cellulose structure and exposes the short length crystallites (Li et al 2009).

Hu and Lim (2007) investigated that alkali treatment significantly improves the tensile properties of hemp fibre reinforced polylactic acid (PLA) compare to those of untreated. The tensile strength and tensile modulus of the composites with 40% treated fibre are 54.6MPa and 85GPa respectively, which are much higher than neat PLA, especially the modulus which is twice that of neat PLA (35GPa). Li et al (2009) studied bio-composite containing 58wt% of flax shives used in the reinforcement of high-density polyethylene (HDPE) and linear-low density polyethylene (LLDPE)). In their surface modification; alkali, silane, potassium permanganate, acrylic acid and sodium chlorite treatments were employed to improve the interfacial bonding between fibres and matrix. They reported that the bio-composites tensile strengths were increased after surface modifications. Among these surface modification techniques, acrylic acid was found to be a relatively good method in enhancing tensile properties of both flax/HDPE and flax/LLDPE bio-composites.

3.2 Engineered Composites Fibre Content

Many researches have been carried out to buttress the fact that the tensile properties of composites are markedly improved by adding fibres to a polymer matrix since fibres have much higher strength and stiffness values than those of the matrices. Consider the tensile strength of S-glass from Table 2 and that of polypropylene (PP) from Table 3 and that of polyester resins from Table 4, it can be found that the tensile strength of the fibre (S-glass) is 75 – 150 times higher than those of the matrices (PP and polyester resin). It can also be found that the Young's modulus of the fibre (S-glass) is 80 – 100 times higher than those of the matrices (Nabi and Jog, 1999; Tabil et al 2009; Holbery and Houston, 2006).

TABLE 2: Properties of Selected Natural and Manmade Fibres

Fibre	Density (g/cm^3)	Elongation (%)	Tensile Strength (MPa)	Elastic Modulus (GPa)
Cotton	1.5-1.6	7.0-8.0	400	5.5-12.6
Jute	1.3	1.5-1.8	393-773	26.5
Flax	1.5	2.7-3.2	500-1500	27.6
Hemp	1.47	2-4	690	70
Banana	1.35	1-3.5	430-760	8-20
Sisal	1.5	2.0-2.5	511-635	9.4-22
Coir	1.2	30	593	4.0-6.0
Softwood kraft pulp	1.5	4.4	1000	40
E-glass	2.5	0.5	2000-3500	70
S-glass	2.5	2.8	4570	86
Aramid	1.4	3.3-3.7	3000-3150	63.0-67.0
Carbon	1.4	1.4-1.8	4000	230-240

Table 3: Properties of Typical Thermoplastic Polymers used in Natural fibre Composite Fabrication

Property	PP	LDPE	HDPE	PS	Nylon 6	Nylon 6.6
Density (g/cm^3)	0.899-0.920	0.915-0.925	0.54-0.96	10.4-10.6	1.12-1.14	1.13-1.15
Water absorption-24h (%)	0.01-0.02	<0.015	0.01-0.2	0.03-0.10	1.3-1.8	1.0-1.6
T_g (^{0}C)	-10 to -27	-125	-133 to -100	N/A	48	80
T_m (^{0}C)	100-176	105-116	120-140	110-135	215	250-269
Heat deflection Temp (^{0}C)	50-63	32-50	43-60	Max. 220	56-80	75-90
Coeff. Of thermal expansion (mm/mm/^{0}Cx10^5)	6.5-13.5	10	12-13	6-8	8-8.86	7.2-9
Tensile strength (MPa)	26-41.4	40-78	14.5-38	25-69	43-79	12.4-94

Elastic modulus (GPa)	0.95-1.77	0.055-0.38	0.4-1.5	4-5	2.9	2.5-3.9
Elongation (%)	15-700	90-800	2.0-130	1-2.5	20-150	35->300
Load impact strength (J/m)	21.4-267	>854	26.7-1068	1.1	42.7-160	16-654

PP – polypropylene, LDPE – low density polyethylene, HDPE – high density polyethylene, and PS – polystylene

Table 4: Properties of Typical Thermoset Polymers used in Natural Fibre Composites

Properties	Polyester Resin	Vinyl ester Resin	Epoxy
Density (g/cm^3)	1.2-1.5	1.2-1.4	1.1-1.4
Elastic modulus (GPa)	2-4.5	3.1-3.8	3 - 6
Tensile strength (MPa)	40-90	69-83	35-100
Compressive strength (MPa)	50-250	100	100-200
Elongation (%)	2	4-7	1-6
Cure shrinkage (%)	4-8	N/A	1-2
Water absorption (24h @ 20^{0}C)	0.1-0.3	0.1	0.1-0.4
Load impact strength (J/m)	0.15-3.2	2.5	0.3

Hajnaika, et al (2008) investigated the tensile properties of hemp fibre and polypropylene matrix composite in terms of volume of fibre content. The tensile strength with fibres in perpendicular direction, tended to decrease with increase in hemp fibre content (a maximum decrease of 34% at 70% of hemp). Whereas, the tensile strength, with fibres in the parallel direction, showed a different trend and a maximum value was found with increasing fibre loading. It was also found that the Young's modulus was almost two and a half times higher at 50% hemp fibre loading than that of 0% fibre content (i.e. pure PP) for the parallel fibre orientation.

The dependence of tensile properties of micro winceyette fibre reinforced thermoplastic corn starch composite on fibre content was studied by Ma et al (2005). An increase in fibre content from 0% to 20wt%, showed that the tensile strength was approximately trebled to 150 MPa. This is just to mention but a few of researches that supported that increase in fibre content is proportional to the increase in tensile strength of composite materials.

3.3 Engineering the Composites' Processing Parameters

Another important factor that significantly influences the properties and interfacial characteristics of the composites is processing techniques and parameters used. Common methods for manufacturing natural fibre reinforced thermoplastic composites are extrusion injection moulding and compression moulding. Li et al (2009) determined the appropriate value of injection temperature and pressure for flax fibre reinforced high-density polyethylene bio-composites. The results showed that higher fibre content in composites led to higher mechanical strength. Injection temperature of more than 160^{0}C but less than 192^{0}C was recommended for better composite quality because at higher temperature, fibre degradation might have occurred, therefore, lead to inferior tensile properties. However, higher injection pressure is preferred to obtain better tensile strength.

The optimum pressure was determined for the natural fibre mat (hemp and kenaf) reinforced acrylic resin manufactured by high-tech vacuum compression process (Mechria et al 2009).The optimum pressure for the composites was 60MPa,above this value, there was a decrease in tensile properties of the composites due to the damage of the fibre structure. Also it was found that one of the advantages of using vacuum technology was to allow a reduction of the press time to a minimum without decreasing the performance of the cured materials. Joseph et al (1999) studied the effect of the melting-mixing technique parameters on the tensile properties of sisal fibre reinforced polypropylene composites, which were optimized by varying the mixing time, rotor speed, and mixing temperature. They found out that the mixing time of 10 mins., rotor speed of 50 rpm and a mixing temperature of 170^{0}C is the optimum mixing condition. Saravanan and Dhurai (2012), produced composite boards using compression molding technique, where they discovered that the combination of a temperature of 160^{0}C, pressure of 8.13bar and a compression time of 3mins produced the material with best impact strength. Muthuraj, et al, (2015) studied the influence of processing parameters on the impact strength of biocomposites. Likewise, hosts of researchers (Raju, et al, 2015; Reddy, et al, 2013; Oumer and Mamat, 2013 etc.) have studied the effect of processing parameters on different biocomposites and natural fibre reinforced composites.

IV.　Composite Design and Manufacture

To optimally design and manufacture a composite material, first, we must identify the numerous materials related variables that contribute to the mechanical and physical properties of the composite material. Secondly, the appropriate physical and mathematical models that describe how the properties of the individual components of the composite are combined to produce the properties of the composite material itself must be derived. So, it is possible to design a composite material such that it has the attributes desired for a specific application. Those attributes might be as simple has having a specified stiffness and strength, a desired thermal conductivity, or have a minimum specified stiffness at the cheapest possible cost per unit volume. Whatever the

specifications it should be possible to design a suitable composite material. As in all design processes, it may not be possible to meet all the specifications exactly and compromise and tradeoffs will be required, but by understanding the physical origin of the required properties and developing an appropriate mathematical description, a suitable composite can be designed. We should also keep in mind that there may be an exisitng conventional material that is more suitable for the application than a composite. So the composite must offer a specific advantage in terms of cost or performance than conventional alternatives.

Perhaps the easiest way to demonstrate how the design process required to develop a composite material is implemented is to start with a familiar composite material and examine just what factors control its properties. By looking at the range of fibreglass products available and by seeking clarification on the structure and composition of the fibreglass we have begun to identify the micro structural variables that will control the properties of the composite. These may be summarised as

- The properties of the fibre reinforcement
- The properties of the matrix in which the reinforcement is placed
- The amount of reinforcement in the matrix.
- The orientation of the reinforcement
- The size and shape of the reinforcement.

The development of the advanced composite technology is an engineer's dream for innovative design and application. The characteristics of a composite can be tailored and designed to meet any desired specifications. The challenge in applying composites is for one to understand the behavior of not only the constituents in the composites but also the completed end product in the way they respond to an applied condition of operation. Depending on the area of application of the composite, one could start by considering those parameters of the composite constituents that he needs to adjust in order to achieve the required properties, these alterable parameters are known as "control factors". These factors include but not limited to the following; (1) Type of fibre (classification) (2) Fibre orientation and aspect ratio (3) Fibre content and volume fraction (4) Amount/type of surface modification (5) Fibre dispersion mechanism (6) Type of matrix (7) Matrix curing temperature (8) Compounding technique (9) Machine parameters (in situations like injection or extrusion moulding) (10) Pressure on compounding etc.

Besides these factors that can be controlled during the process of designing and formation of composites, there are those factors (mostly environmental) which affect the formed composites during application (degradation). They are basically known as " noise factors" in Taguchi design method. Inevitably, the degradation of composite materials by various environmental factors is better understood so that corrective measures can be taken while designing the material, in order to realize the true potential of such materials. The apparent causes of degradation may involve several factors:

1. Loss of strength of the reinforcing fibers by a stress-corrosion mechanism.
2. Degradation of the fiber-matrix interface resulting in loss of adhesion and interfacial bond strength.
3. Permeability of the material to corrosive agents, such as water.
4. Normal viscoelastic dependence of matrix modulus and strength on time and temperature.
5. Accelerated degradation from the combined action of temperature and moisture.

Furthermore, the experiments for manufacturing of these engineering materials have to be designed to aligned with expectations of the material during application. There are different approaches to design of experiment (DOE) such as; full factorial, fractional factorial (Taguchi orthogonal array and Plackett Burman design), screening experiment, response surface analysis, EVOP (evolutionary operations), and mixture experiment.

V.   Conclusion

In the engineering of composite materials it is very important to achieve wettability or compatibility between the two components of composites (fibre and matrix). In order to improve the fibre-matrix interfacial bonding and enhance the mechanical properties especially the tensile properties of the composites, different processing techniques, chemical and physical modification methods were reviewed. However, the experimental procedures that can lead to achieving this goal have to be properly designed, most importantly by putting into the design all controllable and uncontrollable factors (noise factors) that affect the composites during fabrication and field application.

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