

## Development of Plastic-biofiber Composite

Emmanuel Baffour-Awuah<sup>1, 2\*</sup>; Stephen Akinlabi<sup>3</sup>, Tien-Chien Jen<sup>4</sup>

1. PhD Student, Department of Mechanical Engineering Science, Faculty of Engineering and the Built Environment, University of Johannesburg, P. O. Box 524, Auckland Park, 2006, South Africa.
2. Department of Mechanical Engineering, School of Engineering, Cape Coast Technical University, P. O. Box, AD 50, Cape Coast, Ghana.
3. Department of Mechanical & Industrial Engineering Technology, Faculty of Engineering and the Built Environment, University of Johannesburg, P. O. Box 524, Auckland Park, 2006, South Africa.
4. Department of Mechanical Engineering Science, Faculty of Engineering and the Built Environment, University of Johannesburg, P. O. Box 524, Auckland Park, 2006, South Africa.

### Abstract

The use and applications of plastics have brought in its wake unpredictable and undesirable trail of waste and consequential sanitation and waste management and sanitation challenges. Polyethylene has not been spared of this conundrum considering the fact that it is the material used to package water, popularly referred as 'pure water' in most West African counties, including Ghana. Substantially large amounts of palm fruit fiber waste find their way into landfills and incinerators also creating waste management problems. To help reduce the environmental, sanitation and waste management challenges associated with waste sachet water polyethylene and palm fruit fiber there is the need to strategically deal with the situation from long term perspective. This paper proposes a technique for developing composite material using waste polyethylene and palm fruit fiber. It is expected that, generally, characterized composites so designed using the proposed technique will find invaluable applications in the materials and manufacturing industries. Specifically, it is expected that the wood and furniture, packaging, automobile and building and construction sectors of the economy will find applications of the composites so developed very useful.

**Keywords:** Composite, Biofiber, Mesocarp, Plastic

### 1. Introduction

The diminutive degree of consideration that has been given to the impact of the scale of plastic consumption and disposal resulting from mass production has largely contributed to the health and environmental predicament of human societies today (Gunter, 2007). However, the use of plastics has facilitated major technological and economic advances globally and its applications cut across states, nations and continents thus, contributing to global applications of engineering materials (King County Linkup, 2010; King County Linkup, 2009). Globally, over 25 different major types of plastics are used for various applications (Association of Plastic Manufacturers in Europe, 2006). Though the benefits of plastics are undeniably manifest in their use and

applications in various sectors of economies, human health and the environment have been of great concern (Halden, 2010; Gunter, 2007). For example bisphenol A (BPA) and di-(2-ethylhexyl) phthalate (DEHP) found in plastics could be dangerous when exposed to humans.

Plastics have many benefits, and the amount of energy required to produce plastics is relatively lower. In addition, plastics are light in weight and are very cost effective and finally, biocompatible. Besides, plastics are transparent, soft and flexible. Since plastics are of different types, applications and its usage are found in various industrial fields such as automobile, medicine, hydrology and water, among others. In the water industry, polyethylene has been grossly used as a packaging material in various economies. It is estimated that over 300 million metric tons of plastics are produced for annual global consumption (Halden, 2010) while approximately 50% (Souhrada, 1988) of this quantity is disposed of every year after content is being consumed.

Plastic disposal could be achieved in four major ways. These include biodegradation, incineration, and land filling and recycling. Generally, plastics do not degrade easily in the raw state. However biodegradable plastics are designed so that degradation could be relatively faster in order to reduce the period of harm to the environment. In spite of the purpose design, biodegradable plastics may not degrade under ambient conditions, cause continuous accumulation and thus disrupt and pollute the recycling process within the environment. Though incineration is another option, its negative impact on health and the environment are well documented (Dube, Nandan, & Dua, 2014; Balkan, 2012; Hopewell, Dvovak, & Kosior, 2009).

Land filling as a plastic waste disposal technique has its share of disadvantages. For example, land filling requires a relatively larger space. Besides, the energy and chemical components, which are toxic, are ingested by the environment in the process (Shah, Hasan, Hameed, & Ahmed, 2008). Plastic recycling has therefore become the most desirable method of disposing off the waste (Hopewell et al., 2009). This is because in the long term, the incineration and land filling techniques of plastic waste disposal is unsustainable. While incineration results in the release of toxins and pollutants into the atmosphere, land filling pollutes water, soil and vegetative systems (Dube, et al., 2014; Chintan Environmental Research and Action Group, 2011; Tyndall, 1861). For example, incinerated plastics could release greenhouse gases such as carbon dioxide, dioxins (Yasuhara, Katami & Shibamoto, 2005) and carcinogenic polycyclic aromatic hydrocarbons (PAHs) (Shemwell, 2011).

One way of recycling plastic waste, such as polyethylene, used in packaging sachet water is to form a composite with a bio-material such as palm fruit fiber to form a composite material (Olusunmade, Adetan & Ogunnigbo, 2016). The availability and accessibility of biomaterial for the production of plastic-biofibre composite from general garbage encounter market and quantity challenges due to the challenges associated with localized and centralized sorting procedures besides the challenges of consumer involvement in waste collection. Producing a composite material for engineering purposes from polyethylene and palm fruit fiber has many advantages. Apart from decaying rapidly and therefore being environmentally friendly as well as preventing irreparable damage to the environment, such a composite could have benefits to specific applications (Olusunmade et al., 2016; Temitope, Abayomi, Ruth & Adeola, 2015; Eng, Ibrahim, Zainuddin, Ariffin & Yunus, 2014; Hassan, Tesfamichael & Nor, 2014; Jawaid, Khalil & Bakar, 2010; Salema, Hassan, Ani & Bakar, 2010;) such as in medicine, automobile, construction, aviation and hydrology. Palm fruit fiber is produced as a homogeneous waste product. Sorting

sachet water alone from general garbage or on household basis has been found to be relatively easier and less laborious. Thus, the challenges of availability and accessibility of the raw materials for the composite are easily surmountable. In a country like Ghana where sachet water consumption has been increasing at an average rate of 9% (Stoler, 2012) and palm fruit produced in commercial quantities as an agricultural product (MoFA, 2011), developing composite engineering materials based on these waste materials will go a long way to reduce the impact of plastic waste on both human health and the environment.

## **2. Research motivation and justification**

Palm fruit fiber-plastic composites are potential material for bio fiber-plastic boards, medium density bio fiber-plastic boards and bio fiber-plastic mats as complement or substitute for synthetic fiber-plastic. Nevertheless, studies have shown that the use of palm fruit fiber-plastic composites as substitute for synthetic fiber-plastic has a long way to go in terms of commercial and industrial competitiveness. Their applicability and relevance to the consumer thus, demands that both primary and applied research is required in terms of candidate composite characterization data. There is therefore a gap in the study area that needs to be filled. One major motivation of this study is to fill this gap. Nevertheless, available literature with regards to studies into the development of composite materials based on waste sachet water polyethylene and palm fruit fiber appears to be scanty (Olusunmade et al., 2016; Temitope et al., 2015; Salema et al., 2010).

Out of the 200 journal papers reviewed on the subject, only a couple of papers deal directly to studies relating waste sachet water polyethylene and palm fruit fiber composites (Olusunmade et al., 2016). This study is therefore also motivated by the fact that in the absence of commitments to waste sachet water polyethylene recycling there will be no future as to how sachet water, which has become the best alternative source of drinking water in Ghana, could enhance sustainable availability and accessibility to potable and healthy drinking water in the country (Stoler, 2012). Another motivational factor is that the private sector involvement in managing sachet water polyethylene waste through collection appears to improve (Little, 2015) thus, making its availability and accessibility easy to come by. Finally, the present study is encouraged by the fact that palm fruit fiber waste is readily available both at domestic levels and industrial settings in the production of palm oil and palm kernel oil in the country.

Since synthetic polyethylene is not degradable, it takes many years in the natural environment before decomposition. When disposed of in landfills, it constitutes nuisance to the soil, affect plant growth physically, produce health risk through breeding of insect vectors and contribute to toxic leachate streams and underground water. When incinerated, noxious fumes; particulates; and gases such as fumes; particulates; and gases such as carbon dioxide; carbon monoxide; nitrogen oxides and sulfur oxides; ecological and environmental impacts need much to be desired (Ezeokpube et al., 2014). Available recycling programs and introduction of biodegradable materials have also failed to achieve the desired result. The acknowledgement of local governments to ban sachet water without a more plausible option would be a milieu for humanitarian detriment (Stoler, 2012). The hope of dealing with the environmental, ecological and humanitarian menace arising from the use of sachet water therefore lie in recycling the waste into composite materials. With palm fruit fiber being abundant in Ghana a composite material from these two sources could deal with the environmental, ecological and humanitarian challenges that the Ghanaian populace is contending and grappling with

The primary objective of the study is, therefore, to develop a composite engineering material from polyethylene and waste palm fruit fiber. The research therefore aims at developing engineering material composites, using water polyethylene and palm fruit fiber, suitable for engineering applications. The objectives are however to determine the physical properties of waste polyethylene-palm fruit fiber composites; identify the mechanical properties; and determine the thermal properties. The rest are to identify the suitable engineering applications of the composites; and suggest recommendations pertaining to the recycling of sachet water polyethylene waste as a composite material with palm fruit fiber.

### **3. Uses, benefits and applications of plastics and palm fruit fiber**

Various concepts have been related to plastic-biofiber composite development. Specifically among these are the uses, benefits of applications of plastics and palm fruit fiber; challenges associated with the use of plastics; recycling of plastics; and advances in plastic-biofiber composites. The use of plastics as an engineering material has been astonishing due to the degree of diversity in its applications (Samotu, Dauda, Anafi & Obada, 2015; Andrady & Neal, 2009; Vert, 2011; Prausnitz, 2004). In various manufacturing engineering sectors, plastics have taken the place of wood, metals, fibers and glass ceramic in the production of numerous products including automobile parts, aviation components dishware, clothing, personal care products and medical products among others (Andrady & Neal 2009). Three distinguished properties that have given this advantage are lightweight, variety and low cost (Homgren, 1974). The three most important industries where plastics have gained immense applications are the automotive, building and construction and packaging industries (Plastics, 2015).

In the automobile industry the lightweight nature of plastics has inured to its widespread application. Other properties, which are beneficial to the application of plastics in the industry, include resistance to corrosion, prolonging vehicle life, flexibility that allows for component integration, freedom in design, provides adequate advancement in creativity and innovation, and recyclability, and allowing sustainability. Plastic products also provide safety, comfort and greater economy. For every 10% reduction in vehicle weight, fuel consumption of vehicles could be reduced by 5% to 7 % (Gerard, 2014). Gerard (2014) is of the view that there are 13 topmost high performance plastics including polypropylene (PP), a thermoplastic polymer which is usually resistant to many chemicals. It is used to manufacture automotive bumpers and carpets, gas containers, chemical tanks and cable insulation. Solid polyurethane (PUR), an elastomeric material is tough, flexible, and resistant to temperature and abrasion. It also has high load-bearing capacity, resistant to weather, ozone, radiation, oil, gasoline and most solvents. In the automobile manufacturing industry, polyurethane (PUR) is therefore used in manufacturing components such as suspension bushings, elastomeric wheels and tires, flexible foam seating, electrical potting compounds, foam insulation panels and other hard plastic components.

Poly-Vinyl-Chloride (PVC) has good thermal stability, flame retardant properties good flexibility and moldable. It is used in the industry in the production of sheathing and electrical cables, automobile instrument panels and doors. Similarly, Acryl Nitrite Butadiene Styrene (ABS), a polymer, is high in impact resistance, heat resistant automotive body parts, wheel covers and dashboards. General purpose nylon (Polyamide, PA) also has good mechanical and wear strength though high water absorbent properties. However, nylon is used in the application of gear, cam, bush and weather proof coating production. Polystyrene (PS) is a naturally clear

material. It has excellent electrical and chemical resistant properties; some types exhibiting high gloss and high impact grade characteristics though low resistant to ultraviolet rays. Applications of polystyrene are therefore found in car fittings, equipment housings, buttons and vehicle display bases. Polyethylene (PE) has high impact resistance, low density and portrays high toughness. As a thermoplastic material, it is resistant to moisture and low in cost. Polyethylene is used in the automotive industry in the manufacture of car bodies (glass reinforced) and electrical insulation. Other plastics used in the automotive industry include Polyoxymethylene (POM), polycarbonate (PC), acrylic (PMMA), polybutylene terephthalate (PBT), polyethylene terephthalate (PET) and acrylonitrile styrene acrylate (ASA). These materials are used in variegated applications including, interior and exterior trims, small gears, fuel systems, bumpers, headlamps, windows, displays, screens, others include door handles, bumpers, carburetor components, wiper arm, and engine cover, among others (Plastics, 2015).

In the building and construction industry factors that aid in the choice of plastics include durability, cost effectiveness, and safety, ease of installation, energy savings and recyclability. Applications include roofing, flooring, walling, doors, windows, insulation pipes. Plastic materials applicable include PVC, PE, PUR, structural insulated panel (SIP), PVC, ABS, polycarbonate (PC) and fiber reinforced plastics (FRP). In the packaging industry low-density polyethylene is used to manufacture plastic bags and films (Whitley, 2011). Further literature reveals that oil palm bunches fiber is used in manufacturing fire log. Fire log is a manufactured log using wood fuel. In Ghana the raw bunch is used for heating in palm oil manufacturing industries. At household levels, palm fruit fiber waste may be used for heating purposes. Literature shows that palm fruit fiber is scarcely used in Ghana but rather allowed to decompose at the vagaries of atmospheric conditions (Sosu, Hasford & Dadson, 2011).

#### **4. Challenges of plastic applications**

Generally, the challenges associated with the use of plastics are in two-fold which are health and environmental in nature. Except when plastics are ingested accidentally, their potential to bio-accumulate in human organs and tissues are not significant. However, biomedical research indicates a continuous balance of perpetual exposure, metabolism and excretion of plastics in humans indicating a steady-state concentration of plastic biological organs and tissues (Calafat, Kuklenky, Reidy, Condill, Ekong & Needham, 2005). Thus, at any point in time the human and physical environment, to some degree, is being exposed to the negative effects of plastics from cradle to grave. When exposed to the environment, for example, BPA and DEHP plastic constituents have been found to potentially accumulate in humans with associated harmful impacts on early sexual maturation, aggressive behavior, health and reproduction, and reduction in male fertility among others (Halden, 2010; Diamanti-Kandarakis, Bourguignon, Giudice, Hauser, Prins, Soto et al., 2007; Richter, Birnbaum, Farabollini, Newbold, Rubin, Talsness et al., 2007; Safe, 2000).

Unlike the health effects of plastics that is flagrant with some uncertainties, the problems associated with plastic waste is quite obvious of which quick response by all and sundry is required. Since the use of plastics began in the early 40s, the swiftness and alacrity with which its use and applications spread into nations and industries was to an extent that its effects became oblivious to be observed by stakeholders (Halden, 2010). The automotive plastics market for passenger cars only is estimated to grow from 10.9% between 2015 and 2020 with a market size of 40.1 billion US dollars by 2020 and 8.3% by volume within the same period, that is, 2015 to



2020 (Columbia University Earth Engineering Center, 2011). In the United States for example 12-15 vehicles are recycled with 30% of non-metallic materials being plastics (Benefits of Recycling Car Bodies, 2012), while between 7% and 9% of vehicle components by weight is made of plastics (Standinger & Keolelan, 2001). About 34 million tons of plastic is disposed of in the United States in 2008 (Columbia University Earth Engineering Center, 2011).

Waste plastics may be disposed of through incineration. Though plastic incineration has the benefits of preventing transmission of diseases, reduction of waste mass and volume and energy recovery in an appropriate incineration may yield significant human health risk, specifically through Dioxin toxins, which are carcinogenic (reference). In most developing countries and developed countries, plastics are commonly burnt in the open releasing toxins such as Dibenzop-dioxins/ polychlorinated dibenzofurans (PCDD/PCDF) into the atmosphere. Plastic incineration may also release metal-containing ashes that can pollute streams and leach to underground water reservoirs (Lisk, 1988)

Plastic waste may also be abandoned in landfills as a means of waste disposal technique. Though this is an ideal means of carbon sequestration, preventing 100% release of carbon into the atmosphere, there are challenges bereft with this procedure. Discarding plastics in landfills implies both mass and energy in the plastic have been stored, perhaps permanently (U.S Environmental protection Agency 2010). This means that in the United States alone, 329 million barrels of feedstock and 2 million barrels of fuel which constitute 4.6% of annual petroleum consumption in the manufacture of plastics would be buried for good. All over the world, particularly smaller – sized developed nations, such as Japan and Denmark, land is increasingly becoming a scarce community. Even in developing nations such as Ghana, urbanization and population increase have had negative consequences in the land market. If landfills are continuously used as plastic waste disposal technique, in the near future, the competition between landfill and other infrastructure would have to be contended with (Hopewell, Dvorak & Kosior, 2009). Biodegradable plastics may also be designed as a means of preventing plastic pollution to the environment. Though bio plastics decompose easily when found in the environment, the raw materials, which are edible agricultural produce, tend to compete with direct human consumption (Chanprateep, 2010). It therefore appears recycling is the most appropriate means by which the menace of plastics can be dealt with.

## 5. Recycling of plastics

Since the days of Plato, around 400 BC, recycling has been practiced. Literature shows that recycling has been practiced during pre- industrial times as well as during and after the 1<sup>st</sup> and 2<sup>nd</sup> world wars. However, it was during the 1970s as a result of rising energy costs, that recycling became very popular after the 2<sup>nd</sup> world war (with emphasis of recycling of aluminum) (*Black Cleveland, & Morris, 2013; The Economist, 2007; Dog Publishing, 2006*). The recycling process begins with the collection of recyclate (a raw material for recycling); sorting; rinsing and processing (production). Four types of collection methods are available. These include curbside collections, buy – back centers, drop – off centers and distributed recycling. Various curbside systems include mixed waste collection, commingled recyclates and source separation. Generally, waste is picked by waste collection vehicle. For buy-back centers, the waste materials is cleaned and sold to be processed by the recycling producer. The amount received serves as an incentive for steady raw materials for processing. In the U.S. for example, a ton of waste material may cost an average of US \$50 at a government subsidized cost of \$20 (Trucost, 2016; *Dog*

*Publishing, 2006*). Drop off centers require that the waste producer carries the recyclates and deposit them at the collection center, may be mobile or stationary. Distributed recycling, as a means of recyclate collection, is a recent technology.

Sorting is the separation of the plastics into homogeneous materials. Homogeneity of material may be in terms of color, chemical composition or otherwise. If plastics are commingled with other non – plastic material, sorting separates all materials into homogeneous units. Sorting is done after recyclates have been collected and delivered to a central collection station. It may be manual, automatic mechanical or hybrid. Rinsing of material is done to get rid of organic and non-organic contamination. This may include food products, dirt, oils, grease, and lubricants, among others. Various chemicals and detergents and water at high temperature may be used in the rinsing process. Processing involves shredding, mixing and heating. Processing techniques include thermal de-polymerization, chemical pyrolysis, heat compression, distributed recycling and compatibility. Plastic waste recyclate may also be used as a carbon source in the recycling of scrap steel and other metal recovery processes from the ore (Darkwa, 2012).

## **6. Empirical studies**

The applications of natural fibers for reinforcement of plastic composites have been getting popularity among industrialists, environmentalists and researchers (Obasi, 2013). The benefits of such composites include low tool wear (Wambua, Ivens & Verprest, 2003); and low cost, availability, low density and high biodegradability as compared to pure synthetic plastics (Nishino, Hirao, Kotera, Nakamae & Inagaki, 2003). Though many natural fibers can be applied in composite development most are used in low stress applications (Bullions, Hoffman, & Gillerpie, Price, O'Brien & Loos, 2006). Natural fiber composites are also deficient in good compatibility (between natural fiber and synthetic polymer matrix); heterogeneity of fiber dispersion and poor moisture resistance thereby reducing their applications (Praalla, Haque & Alvarez, 2010). Nevertheless, natural fiber composites are biodegradable, renewable, low in density, low cost, lower energy consumption during production, and have specific mechanical properties thus, supporting their application in the packaging, construction, biomaterial and automobile industry (Samotu, Dauda, Anafi & Obada, 2015; Gerard, 2014).

Natural fibers may be obtained through the processing of consumer, agricultural and industrial waste (Bullions et al., 2006). Currently, various types of natural fibers have been researched into as composite materials for composite material development. Common amongst are wood, flax hemp, bamboo, jute straw, sisal, rice husk, wheat husk, bagasse, kenaf, raphia, banana fiber, pineapple leaf and oil palm empty fruit bunch (Bledzki & Gassan, 1999), raphia palm fiber (Obasi, 2013) and palm fruit fiber (Olusunmade et al., 2016; Yousif, 2010; Columbia University Earth Engineering Center, 2011). Natural fiber applications could be a means of solving waste management problems specifically in plastic waste management and agro waste disposal administration. It is therefore of no surprise that a new door of research has been opened to overcome the use of carbon, aramid, glass, and other traditional composites in the area of research. Though several natural fibers in the application of composites have been studied, it appears very little has been done in the literature involving palm fruit fiber composite. Palm fruit fiber, as it is usually referred, is available in large quantities in Ghana. It is a by-product in the processing of oil palm fruits into palm oil. The fiber is low in density, non-abrasive and biodegradable. The application of natural palm fruit fiber will have positive environmental advantages in terms of waste management and offer better use as raw material (Singha and

Thakur, 2008). The use of palm fruit fiber will also enable developing countries, particularly Ghana the opportunity to make use of its own natural resources in industries engaged in materials technology and development. Such a material may be suitable for applications in furniture such as windows, ceiling boards, doors, door and window frames, and automobile interior and table boards among others. This study also seeks to bridge the gap between studies involving composite material development in Africa and West Africa in general and besides open a new arena of research in Ghana.

## 7. Materials and experimentation

Palm fruit fiber shall be obtained from the Twifu Praso traditional area, in the Central Region of Ghana. Waste sachet water polyethylene shall also be obtained in the Cape Coast Metropolis. Composites shall be developed and tested at the laboratory. Applying the Taguchi method of partial factorial with its assumptions, experiments shall be designed and performed to determine the properties of different composites in terms of proportions of waste polyethylene, and palm fruit fiber by weight and size. Two factors shall therefore be considered. Fiber weight loadings varying from 0 to 50% at 5% interval shall be analyzed (Olusunmade et al., 2016).

The present study shall therefore optimize the two properties based on fiber weight as recommended by Olusunmade, et al., (2016) and fiber size as employed by Sosu, et al., (2011). Accordingly, there shall be five factor levels for weight and three factor levels for fiber size. Both tables and graphs shall be used to display data. Descriptive parameters such as frequencies, percentages, means and standard deviations shall be adopted.

Waste palm fruit fiber shall be processed by washing with detergent and water in order to remove the remaining palm oil that shall be present in the raw material. The fibers shall then be sun dried, cut into smaller sizes and pulverized using grinding machine. The resulting product will then be sieved to appropriate size. Fibers shall be multi-chemically treated (and coupling agents added to the mixture) to improve upon the interfacial adhesion of the composite material as recommended by Olusunmade et al (2016).

Studies have shown that methacrylate silane and alkaline solutions when used to treat palm fruit fiber for plastic composite development improves impact and flexural properties of the composite and by enhancing water adsorption characteristics (Eng, Ibrahim, Zainuddin, Ariffin, & Yunus, 2014<sup>a</sup>; Eng, Ibrahim, Zainuddin, Ariffin, & Yunus, 2014<sup>b</sup>; Eng, Ibrahim, Zainuddin, Ariffin, Yunus, 2013). Other chemicals shall also be explored and applied which may probably enhance the properties of the composites.

The waste sachet water polyethylene shall also be cut into small ( $d \leq 0.8\text{mm}$ ); medium ( $0.8 \leq d \leq 1.1\text{mm}$ ); and large ( $1.1 \leq d \leq 4.8$ ) sizes. Both raw materials shall then be mixed at appropriate proportions by weight and sizes. Hand lay-up method shall be adopted to prepare the composites. Mixed fiber and plastic shall then be heated to a temperature of between  $130^{\circ}\text{C}$  and  $170^{\circ}\text{C}$  for 20 minutes during which it is expected to be thoroughly mixed to form a homogeneous material (Olusunmade et al., 2016; Samotu, et al., 2015; Eng et al., 2014<sup>a</sup>). The resulting composite molten material shall then be molded to suitable sizes. Physical properties that shall be tested include water absorption properties; resistance to biodegradation; microstructure and density (specific gravity). Flame propagations rate, thermo-gravimetric strength, insulation (thermal conductivity) as thermal properties shall also be tested. Table 1 present the experiments,



including those that aim at determining the mechanical properties of the developed composites, that shall be performed and the corresponding instruments/methods which shall be employed.

Table 1: Property of composite and corresponding instrument (or method) for experimentation

Property	Instrument/Method
Tensile strength	Universal testing machine
Hardness	Brinell hardness testing machine
Impact strength	Izodimpact testing machine
Flexural strength	Universal testing machine
Compressive strength	Universal testing machine
Torsional strength	Universal testing machine
Water resistance	Water absorption test (immersion Test)
Micro structure	SEM micrograph Test (Scanning Electron Microscope)
Specific gravity	Immersion test
Biodegradation resistance	Burial method
Flame propagation rate	A STM D 792
Thermo-gravimetric strength	TGA 7 (Perkin Elmer) Testing machine
Thermal conductivity	ISO 1180

Source: Author's construct (January, 2017)

## 8. Conclusion

The main objective of the study is to design composite materials using waste polyethylene and waste palm fruit fiber. The secondary objectives are to determine the physical, mechanical, thermal and biodegradable properties of the composites. Other objectives are to determine the palm fruit fiber weight and size that will produce the optimum characteristics of the composite for potential engineering applications. Various studies have shown that palm fruit fiber used to impregnate plastics into composites may enhance most of the physical, mechanical and thermal properties of the plastics. Formulation of composites shall be done using the Taguchi (partial

factorial) method of experimentation. Two factors, weight and size of palm fruit fiber shall be considered; five factor level for weight and three factor level for fiber size shall be experimented. Weight factor level shall range between 30% - 50%, increasing by 5%; while size factor levels shall be small ( $d \leq 0.8\text{mm}$ ); medium ( $0.8 \leq d \leq 1.1\text{mm}$ ); and large ( $1.1 \leq d \leq 4.8$ ). Temperature of experiment shall range between  $130^{\circ}\text{C}$  and  $170^{\circ}\text{C}$ , depending on the properties of the matrices. Various chemicals apart from methacrylate silane and sodium hydroxide solutions, for instance, shall be explored to treat the palm fruit fiber.

It is the expectation of the study that after characterization, both palm fruit fiber weight and size and fiber chemical treatment would enhance some, if not all the physical, mechanical, thermal and biodegradable properties of polyethylene. It is especially envisaged that impact and flexural strength, hardness, stress/strain properties; torsion, tensile and compressive strengths and specific gravity of polyethylene shall be improved. It is further envisaged that thermal conductivity and thermo-gravimetric strength of polyethylene shall be enhanced with palm fruit fiber presence. Lastly, it is expected that the biodegradable characteristics of polyethylene shall also be improved with the presence of palm fruit fiber. Finally, the study envisages that composites so developed shall find applications, particularly in the wood and furniture, automobile, packaging, and building and construction industries after characterization.

## References

Andrady, A. L. & Neal, M. A. (2009). Applications and societal benefits of plastics. *Phil Trans R Soc B*. 364(1526), 1977-1984 [PMC free article] [Pub Med].

Association of Plastic Manufacturers in Europe (2006). An analysis of plastics production demand and recovery in Europe, *APME*, 2006.

Balkan, E. (2012, July 4). The dirty truth about China's incinerators. *The Guardian*, Wednesday 4 July 2012. Retrieved from: <https://www.theguardian.com/environment/2012/jul/04/dirty-truth-chinas-incinerators>.

*Black Dog Publishing (2006). Recycle : a source book. London, UK: Black Dog Publishing.*

Bledzki, A. K. & Gassan, J. (1999). Composites reinforced with cellulose based fibers. *Progress in Polymer Science*, 24(2), 221-274.

Bullions, T. A., Hoffman, D., Gillespie, R. A., Price, O'Brien, J. & Loss, A. C. (2006). Contributions of feather fibers and various cellulose fibers to the mechanical properties of polypropylene matrix composites. *Science and Technology*, 66(1), 102 -114.

Calafat, A. M., Kuklenky, Z., Reidy, J. A., Candill, S. P., Ekong, J. & Needham, L. L. (2005). Urinary concentrations of bisphenol A and 4-nonylphenol in a human reference population. *Environment Health Perspect*, 113(4), 391-385. [PMC free article] [Pub Med].

Chanprateep, S. (2010). Current trends in biodegradable poly-hydroxyalkanoates. *J Biosci & Bioeng*. 110(Bioeng.110 (6), 621 -632. [PubMed].

Chintan Environmental Research and Action Group (2011). *Waste to energy or waste of energy: Social and economic impact assessment of WTE projects on wastepickers near Ghazipur and Okhla landfills in Delhi*. <http://www.indiaenvironmentportal.org.in/content/345374/waste-to-energy-or-waste-of-energy-social-and-economic-impact-assessment-of-waste-to-energy-projects-in-wastepickers-near-ghazipur-and-okhla-landfills-in-delhi/>

Cleveland, C. J. & Morris, C. G. (November 15, 2013). Handbook of Energy: Chronologies, Top Ten Lists, and Word Clouds. Elsevier. p. 461.

Columbia University Earth Engineering Center (2011). *Energy and economic value of non recycled non-recycled plastic (NRP) and municipal solid wastes (MSW) that are currently landfilled in the fifty states*. Retrieved from [http://jrnetserver.shorensteincen.netdna-cdn.com/wp-content/uploads/2011/11/report\\_from-Columbia-University's-Earth-Engineering-Center.pdf](http://jrnetserver.shorensteincen.netdna-cdn.com/wp-content/uploads/2011/11/report_from-Columbia-University's-Earth-Engineering-Center.pdf).

Darkwa, J. R. (2012). *Utilization of end-of-life plastics/rubber tires and their blends with metallurgical coke in EAF steelmaking: Reduction of iron oxide*. PhD Thesis, School of Materials Science and Engineering, University of New South Wales, Sydney, Australia.

Diamanti-Knadarakis, E., Bourguignon, J. Guidice, L. C. Hauser, R., Prins, G. S. Soto, A. M. et al. (2007). Endocrine-disrupting chemicals: An Endocrine Society scientific Statement. *Endocr Re*, 30 (4), 293-342. [PMC free article] [PubMed].

Dube, R., Nandan, V. & Dua, S. (2014). Waste incineration for urban India: valuable contribution to sustainable MSWM or inappropriate high-tech solution affecting livelihoods and public health? *Int. J. Environmental Technology and Management*, 17(2/3/4), 199-214.

Eng, C. C., Ibrahim, N. A., Zainuddin, N. J., Ariffin, H. & Yunus, W. M. Z. W. (2014b). Compositional and morphological changes of chemical modified oil palm mesocarp fiber by alkaline bleaching and silane coupling agents, *Bio resources*, 9(3), 5290-5301.

Eng, C. C., Ibrahim, N. A., Zainuddin, N. J., Ariffin, H. & Yunus, W. M. Z. W. (2014a). Impact strength and flexural properties enhancement of methacrylate silane treated oil palm mesocarp fiber reinforced biodegradable hybrid composites. *The Scientific World Journal*. Retrieved from <http://dx.doi.org/10.1155/2014/213180>.

Eng, C. C., Ibrahim, N. A., Zainuddin, N., Ariffin, H. & Yunus, W. M. Z. W. (2013). *Modification of oil palm mesocarp fiber by methacrylate silane effect on morphology, thermal and mechanical properties of bio-nanocomposites*: In Proceedings of Malaysia Polymer International of Conference, 97, 2013.

Ezeokpube, N. D., Obiora, C. J. & Phil- Eze, P. O. (2014). Environmental problems of sachet water waste disposal in Nsukka Urban, Enugu State, Nigeria. *Civil and Environmental Research*, 6(1), 105-113.

Gerard, K (2014). *13 High performance plastics used in the automotive industry*. Craftech Industries, New York. Retrieved from: [www.craftechind.com](http://www.craftechind.com)

- Halden, R. U. (2010). Plastics and health risks. *Annu Rev Public Health*, 31(1), 179 – 194. [PubMed].
- Hassan, S., Testa-Michael, A. & Nor, M. F. M. (2014). Comparison study of thermal insulation characteristics from oil palm fibre. *MATEC Web of Conferences 13*, 02016. DOI: 10.1051/mateconf/2014 1302016
- Holmgren, J. H. (1974). Advantages of disposables safety, cost convenience. *Med Hosp*. 122(1), 35 [PubMed].
- Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: Challenges and opportunities. *Phill. Trans. R Soc. B* 304 (1526), 2115 -2126 [Pub Med] [PMC free article].
- Jawaid, M., Khalil, H. P. S. & Bakar, A. A. (2010). Mechanical performance of oil palm empty fruit bunches/jute fibers reinforced epoxy hybrid composites. *Material Science and Engineering*.doi: 10 – 1016. Mesa. 2010.09.005.
- King County Linkup (2009). *Surviving the ups and downs of the recycled materials markets*. Retrieved from: [https://your.kingcounty.gov/solidwaste/linkup/eNewslink/eNewslink\\_2009-winter.asp](https://your.kingcounty.gov/solidwaste/linkup/eNewslink/eNewslink_2009-winter.asp).**
- King County Linkup (2010). *Updates in Urban Wood*. Retrieved from: [https://your.kingcounty.gov/solidwaste/linkup/eNewslink/eNewslink\\_2010-fall.asp](https://your.kingcounty.gov/solidwaste/linkup/eNewslink/eNewslink_2010-fall.asp).
- Lisk, D.J. (1988). Environmental implications of incineration of municipal solid-waste and ash disposal. *Sci Total Environ*, (74), 39 -66. [PubMed]
- Little, R. J. (2015). *The state of sachets: Ghana's private sector solution to a public infrastructure problem*. Pitzer Senior theses, Paper 62. Retrieved from: <http://scholarship.claremont.edu/pitzer-theses/62>.
- Nishino, T., Hirao, K., Kotera, M., Nakamae, K. & Ignaaki, H. (2003). Kenaf reinforced biodegradable composite. *Composites Science and Technology*, 63(9), 1281-1286.
- Obasi, H. C. (2013). Properties of raphia palm interspersed fibre filled high density polyethylene.
- Olusunmade, O. F., Adetan, D. A., & Ogunnigbo, C. O. (2016). A study on the mechanical properties of oil palm mesocarp fibre reinforced thermoplastic. *Journal of Composites*, Vol 2016, 1-7. Retrieved from: <http://dx.doi.org/10.1155/2016/3137243>.
- Plastics (2015). *The facts 2014/2015: An analysis of European plastics production, demand and waste data*. Retrieved from: [www.plasticseurope.org/PDF](http://www.plasticseurope.org/PDF).
- Pracella, M., Haque, M. M. U. & Alvarez, V. (2010). Functionalization, compatibilization and properties of polyolefin composites with natural fibres fibers. *Polymers* 2(4), 554-574.
- Prausnitz, M. R. (2004). Microneedles for transdermal drug delivery. *Adv Drug Deliver Rev*, 56(5), 581 -587 [PubMed].

Ritchter, C. A., Birnbaum, L. S., Farabollin, F., Newbold, R. R., Rubin, B. S. & Talsness, C. E. et al (2007). In vivo effects of bisphenol A in laboratory rodent studies. *Reprod Toxicol*, 24(2), 199-224. [PMC free article][PubMed].

Safe, S. H. (2000). Endocrine disruptors and human health - is there a problem? An update. *Environ Health Perspect*. 108(6), 487-493. [PMC free article] [ PubMed].

Salema, A., Hassan, Ani. F. N. & Bakar, A. A. (2010). Oil palm fiber as natural reinforcement for polymer composite s. *Plastics Research Online* .10.1002/spepro.003052.

Samotu, I. A., Dauda, M., Anafi, F. O. & Obada, D. O. (2015). Suitability of recycled polyethylene/palm kernel shell- iron – fillings composite for automobile applications. *Tribology in industry*. 37(2) 142-153.

Shah, A. A., Hasan, F., Hameed, A. & Ahmed, S. (2008). Biodegradation of plastics: A comprehensive review. *Biotechnol Adv*. 26 (3), 246-265. [PubMed].

Shemwell, B. E. & Levendis, Y. A. (2011). Particulates generated from combustion of polymers. *JAPCA J Air Waste Ma*.50(1), 94- 102. [PubMed].

Singha, A. S. & Thakur, V. K. (2008). Fabrication of hibiscus sabadariffa fiber reinforced polymer composites. *Iranian Polymer Journal*, 17(7), 541 -553.

Sosu, E. K., Harsford, F. & Dadson, A. B. C. (2011). Study of mechanical properties of composite materials made from palm fruit fiber and sawdust. *Research Journal of Applied Sciences, Engineering and Technology*, 3 (12), 1441-1444

Souhrad, L. (1988). Re-usables revisited as medical waste adds up. *Hospitals* 62(20), 82. [Pub Med].

Standinger, J. & Keolelan, G. A. (2001). *Management of end of life vehicles (ELVS) in the USA*. Centre for sustainable systems, Report No.CSS01- 01, March, 2001.

Stoler, F., Fink, G., Weeks, J. R., Appiah, O. R., Ampofo, J. A. & Hill, A. G. (2012). When urban taps run dry: Sachet water consumption and health effects in low income neighborhoods of Accra – Ghana. *Health and Place* 18, 250-262.

Stoler, J. (2012). Improved but unsustainable: Accounting for sachet water in post – 2015 goals for global safe water. *Tropical medicine and International Health*, 17(12), 1506-1508

Temitope, A. K., Abayomi, O. O., Ruth, A. O, & Adeola, A. P. (2015). A pilot recycling plastic pure water sachets/bottles into composite floor tiles: A case study from selected dumping site in Ogbomoso. *Material science and Engineering*. Retrieved from: <http://dx.doi.org/10.4172/216-0022.1000201>

*The Economist* (2007). *The truth about recycling*. *The Economist*. June 7, 2007.

The Price of Virtue (2007, June 7). *The Economist*. *CRC History*, Computer Recycling Center. Retrieved from: <http://www.crc.org>.



Trucost, (2016). *Plastics and Sustainability: A Valuation of Environmental Benefits, Costs and Opportunities for Continuous Improvement*. American Chemistry Council.

Tyndall, J. (1861). On the absorption and radiation of heat by gases and vapors, and on the physical connexion of radiation, absorption, conduction. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, 7(22), 273-285.

US Environmental Protection Agency (2011). *Municipal Solid waste generation, recycling and disposal in the United States: tables and figures for 2010*. Retrieved from: <http://www.epa.gov/epawaste/nonhaz/municipal/pubs/2010-MSW-Tables-and-figures-508.Pdf>.

Vasuhara, A., Katami, T. & Shibamoto, T. (2005). Dioxine formation during combustion of nonchloride plastic, polystyrene and its product. *Bull Environ Contam Toxicol*, 74(5), 899-903. [PubMed]

Vert, M. (2011). Not any new functional polymer can be for medicine: What about artificial biopolymers? *Macromol Biosc*. 11(12): 1653-1661. [PubMed]

Wambia, P., Ivens, J. & Verpoest, I. (2003). Natural fibers: can they replace glass in fiber reinforced plastics? *Composites Science and Technology*, 63(9), 1259-1264.

Whitely, K. S. (2011). *Polyethylene*. Ulmanris Encyclopedia of Industrial Chemistry. doi:10.1002/14356007.A21-487.pub2.