DEVELOPING COMPOSITES FROM WASTE PLASTIC AND SAWDUST

A Project Report

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By

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DECLARATION

I hereby declare that this submission is my own work towards the MPhil and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.



ABSTRACT

The project proposes a key measure to prevent indiscriminate disposal of waste plastic sachet by investigation into the formulation of composite materials from the waste plastic using coconut oil as coupling agent and sawdust as filler. Composites were made by melting the plastics and the sawdust added. Hot-press mouldings of the composites with varying formulations of plastic: sawdust: coupling agent was made. The physical and mechanical properties of the composites were investigated. Porosity (24 h immersion), density (displacement method) as well as three-point flexural yield were examined. Scanning Electron Microscopy (SEM) with JEOL JSM-6390LV was performed on the fractured sample surfaces after flexural strength tests had been carried out. This work demonstrates that formulating composite using LDPE plastic with Ceiba pentandra sawdust and coconut oil produces composites with good physical and mechanical properties. Blending LDPE plastic with wood dust at 50:50 ratios and particle size 90-355 µm with coconut oil forming 10 wt % gives good formulation. The flexural strength was found to increase from 6.11 MPa to 3.94 MPa with increasing plastic loading of 30, 35, 40, 45, 50, 55 wt %. Increasing fiber content of 60 wt % and 30 wt % plastic improved the stiffness of the composites Water absorption increased with increasing fiber content and particle size. The SEM analysis revealed that, samples with 10wt % coconut oil had comparatively no sign of fiber pullout and fewer voids. There were small discontinuities and a reasonably uniform distribution of saw dust particles in the LDPE matrix with samples containing 90-355 µm particles. Increasing plastic loading in the composite showed increase in compatibility and lesser voids as percentage of plastic loading increases. Therefore, composite based on formulating LPDE plastic and sawdust could have potential to use as construction panel for partitioning rooms.

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(b) 35 % (c) 40 % (d) 45 % (e) 50 % (f) 35 %	5 %
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CHAPTER ONE

1.0 Introduction

1.1 Background

Increasing production and consumption of plastics is currently contributing to municipal solid wastes worldwide (Hannequart, 2004). In US, waste plastics accounts for 11.8 % of the 246 million tonnes of municipal solid waste generated (USEPA, (2005). 8.25 million tonnes (39%) of plastics were recorded in Western Europe (plastic 2004). In New Zealand, 35,000 tonnes representing 13.48 % of the total imported virgin plastics (Plastics, 2005). In UK, approximately 500,000 tonnes of waste plastics from 2.8 million tonnes of waste plastics are recycled each year (Optimat Ltd et al, 2003). Similarly, large amounts of wood waste generated at different stages in the wood processing industries are mainly destined for landfill. During 2002, approximately 63 million tonnes of wood waste was generated in the US (Falk, 2004). In the UK, about 0.8 million tonnes of waste wood are Recycled every year although 5 to 7.5 million tonnes of waste wood are produced (Optimat Ltd et al, 2003) Researchers across the world have pursued waste plastic reinforced wood waste in order to reduce the environmental impact and its consumption. Past studies have demonstrated that the recycled plastics possessed similar mechanical properties to the virgin plastics. Composite products have cost-competitive advantage in the markets. It was reported that waste wood in the form of wood flour, are suitable for reinforcement in composites (Woodhams et al, 1984). Pinus radiata wood fibers were found to possess physical and mechanical properties suitable for the reinforcement of plastics (Miller, 1994). Hence, increased usage of the recycled plastics and the waste wood for composite offers the prospect of lessening waste disposal problems.

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Recycled plastics possessed similar mechanical properties but are much cheaper than their virgin form. WPC products will have cost-competitive advantage in the markets.

Composites are one of the most significant proportions of engineering materials ranging from sophisticated to everyday products. It is growing into a material of choice to complement timber products in the building construction industry. Composites are used for decking, fencing, siding, garden furniture, exterior windows and doors (Optimat Ltd et al, 2003). Other applications can also be found in marine structures, railroad crossties, automobile parts and highway structures such as highway signs, guardrail posts, and fence posts (Youngquist et al, 1994).

It is therefore, expected that developing plastic waste composite with sawdust is one of the innovative means of addressing the plastic menace in Ghana.

1.2 Statement of problem.

The non-biodegradable nature of the plastic products coupled with indiscriminate disposal and management practices make the city centres inundated with huge volumes of plastic waste that has overwhelmed waste management authorities.

The waste plastics constitute about 18 % of 1500 tonnes of solid waste generated in Accra, Ghana's capital daily. (Weinaah, 2007). Most of these plastics tend to be low density polyethylene (LDPE).

The large majority of these wastes are being dumped into open areas and existing drains. The clogging of drains has further exacerbated sewage and sanitation problems, leading to subsequent flooding and pollution problems and introducing public health hazards.

Similarly, large amount of wood waste generated at different wood processing industries also mainly end up on landfill. Ghana, in the West Africa sub region, is a major exporter of timber products and at present has a forest cover of 49,400 km² which is a little over 21.7 % of total the land mass. (World Bank indicators, 2010).

Ghana realized 7,187,938 from the export of 21,020m³ wood product in December 2010 (Ghana Forestry Commission, 2012). Currently, the contribution of the timber/lumbering industry to Gross Domestic Product accounts for 5 % GDP and 11 % of National export revenue (Ghana Budget, 2013). The continuous rise in demand both in domestic and international market places has a lot of strain on the nations forest cover. Also, the activities of most saw mills in Ghana generate an average annual wood residue of 33.3 %. (Sekyere and Okyere, .2007). The management of this biomass waste is a source of worry for both industries and local assemblies

The problem is that not much work has been done in the country to develop sawdust reinforced composite products in the country. To ensure sustainable consumption and production patterns in the timber industry, processing of downstream waste to profitable wood products is of essence both economically and environmentally.

1.3 Objective

The objectives of the study were identified as:

- 1) To develop optimum composition of cellulose-plastic composite material from plastic waste, sawdust and coconut oil as coupling agent
- To determine the material strength and physico-chemical parameters of the composite material produced.

3) To determine the micro structure of the composite through microscopic

studies 1.4 Justification /Significance

This thesis is to help address some of the pertinent issues relating to industrial and urban waste management in Ghana. The project proposes a key measure to prevent indiscriminate disposal of these principal wastes, apart from punitive enforcement of legislature. This is to develop technological solutions by providing alternative use for these waste materials which will place a value on them. Identifying the potential use of waste to create job and inadvertently help in shaping public attitude towards its disposal and create job in the long term.



CHAPTER TWO

2.0 Literature Review

This chapter describes varieties of cellulose fibers that can be used to reinforce thermoplastics. These include wood fibers, coir, pineapple leaf (palf), rice husk, and sugarcane bagasse. These fibers are abundantly available throughout the world.

2.1 Cellulose fibers for reinforced composites

Cellulose fibers, often refers to as vegetable fibers come from a renewable resource. The production of these fibers requires little energy with the consumption CO₂. Oxygen is given back the environment. The fibers are light in weight which results in higher specific strength and stiffness than glass. Production is at low cost, which makes the material an interesting product for low-wage countries. Its processing is not harsh on the tooling equipment thus resulting in little wear, no skin irritation and also that thermal recycling is possible. These fibers are now used to reinforce plastic waste composites.(Mukherjee et al,1986).

The following are the disadvantages of cellulose fiber as reinforcement in composites: lower strength properties particularly its impact strength, variable quality, restricted maximum processing temperature, lower durability and poor fire resistance.

2.1.1 Pineapple leaf (Palf)

Pineapple is a tropical plant. Its leaf fiber is rich in cellulose, relatively inexpensive and abundantly available. Furthermore, it exhibits excellent mechanical properties.

These fibers are extracted from the leaf of the plant, Ananas cosomus belonging to Bromeliaceae family. Physical properties, mechanical and dielectric properties, tensile behaviour, surface, and fracture morphology of palf have been reported by many researchers (Muherjee et al, 1986 and Bhattacharrya et al, 1986). It has the potential for polymer reinforcement. At present pineapple leaf fibers which are waste product of pineapple cultivation and therefore relatively inexpensive can be obtained for industrial purposes.

2.1.2 Rice husk

Rice is one of the large groups of cereal grains that can be used to produce hull fibers. Currently, wheat, corn, husk, oats and other cereal crops are used to produce fibers and investigations carried out in the area of reinforced composites. Ismail et al, (2001) studied the mechanical properties of rice husk filled polymer composites and their relation to fiber loading, coupling agent, processability, hygrothermal aging, and hybridization effect. Other studies have focused on: flame retardant properties of rice husk and polyethylene composites (Zhao et al, 2009 and Kim, et al 2004).

2.1.3 Coconut fiber (Coir)

Coconut fiber is a by-product obtained from the husk of the fruit of the coconut palm. It is found between the hard, internal shell and the outer coat of a coconut. The individual fiber cells are narrow and hollow, with thick walls made of cellulose. They are pale when immature, but later become hardened and yellowed as a layer of lignin is deposited on their walls. Each cell is about 1 mm long and 10 to 20 µm. Fibers are typically 10 to 30 cm long (Hindu, 2009). The two varieties of coir are brown and white. Brown coir harvested from fully ripened coconuts is thick, strong and has high abrasion resistance. It is typically used in mats, brushes and sacking. Mature brown coir fiber contain more lignin and less cellulose than fiber such as flax and cotton. They are also stronger but less flexible. Coir is in abundance and its fiber used for making a wide

variety of products (Satynarayana et al, 1982). Coir has also been tested as a filler or a reinforcement in different composite materials (Choudhbury et al, 2007).

2.1.4 Sugar cane fiber (Bagasse)

Bagasse is the fibrous residue which remains after sugarcane stalks are crushed to extract their juice. It is currently used as a renewable cellulose fiber for the manufacture of composites materials. Monteiro et al, (1998) studied the possible uses of bagasse waste as reinforcement in polyester matrix composites. Preliminary results have attested to this possibility. Composites with homogeneous microstructures can be fabricated and enhance the levels of their mechanical properties to enable them have practical applications. Vazquez et al, (1999) reported processing and properties of bagasse fiber-polypropylene composites. Vegetable fibers were with the thermoplastic matrix. The fibers were washed with alkaline solution. The effects of the treatment reactions on the chemical structure of the fibers were analysed by infrared spectroscopy. Optical photomicrographs indicate that a highly fibrillated surface is achieved when fibers are mercerized.

2.1.5 Saw dust from ceiba pentandra

Wood fiber is a plant fiber composed of elongated cells oriented in the longitudinal direction of the stem. The stem consists of cellulose, hemicellulose, and lignin. Cellulose comprises of crystalline structure, while hemicelluloses has a semicrystalline structure. The lignin is an amorphous polymer. The use of wood-based material, such as sawdust and wood fibers, as reinforcement for thermoplastics has gained significant interest. Wood fibers offer a number of advantages over conventional reinforcing materials in the form of abundancy, renewability, low specific gravity, high specific strength stiffness, and relatively low cost (Zadorecki, 1989 and Bledzki et al, 1998).

According to Hagan, (1999) the activities of the timber and wood processing industries generate an estimated 61,000 metric tons of wood waste annually. These wastes are not normally properly disposed off and therefore end up in landfills. To help put this byproduct to good use, it is being incorporated into the project as one of the reinforcements.

Ceiba pentandra is native to the American tropics, Mexico, Peru, Bolivia and Brazil, and West Africa. It is however known by these other common names such as Pochota, Yaxché (Mexico), Bonga, Ceiba de lana (Colombia), Sumaúma (Brazil), Toborochi (Bolivia) (Martin, 1980), Onyina (Ghana). The wood is soft and very light varying in colour from white to light brown. The components of wood are cellulose 40-55 %, lignin 15-35 %, and hemicelluloses 20-35 % (Kenneth, 2002).

The hemicelluloses of wood consist of several types of amorphous polymeric carbohydrates that occur through the woody structure of plants (Word, 1973). The lignin gives the structural rigidity, stiffening and holding the fibers together. Currently, the main use of Ceiba pentandra is as a source of timber as well as for plywood manufacture, packaging composites, and lightweight construction materials.

It is also used locally for carving canoes.

2.2 Plastics

Plastic materials are the most widely used group of synthetic polymers. They include the following: polyethylene, polypropylene, poly (vinyl chloride), polystyrene, fluorocarbons, epoxy, phenolics, and polyesters but the most extensively used in

Ghana are polyethylene, polypropylene, polystyrene, nylon, and polyesters. Plastics are organic polymers of high molecular mass, but contain other substances. They are usually synthetic and are most commonly derived from petrochemicals. Plastics are durable and

degrade very slowly because they have chemical bonds that make plastics resistant to the cellulose processes of degradation. Since the 1950s, one billion tonnes of plastics have been discarded and may persist for hundreds or even thousands of years (Alan, 2010). Processing of plastic polymers is normally accomplished by shaping the material in molten form at an elevated temperature, using at least one of several different moulding techniques, such as compression, transfer injection, blowing, extrusion and casting. (Callister, 2007).

There are two types of plastics: thermoplastics and thermosetting polymers. Thermoplastics are the plastics that do not undergo chemical change in their composition when heated and can be recycled. Examples include polyethylene, polypropylene, polystyrene, polyvinyl chloride, and polytetrafluoroethylene (PTFE) (Alan, 2010). Thermoplastics are made up of many repeating molecular units, known as repeat units, derived from monomers. Thermoplastic polymers are distinguished by their ability to be reshaped upon the addition of heat (above the glass transition temperature of the amorphous phase or the melting temperature of the crystalline phase). This cycle can be carried out repeatedly. Most linear polymers are thermoplastics.

Thermosetting polymers, on the other hand, undergo chemical reactions during curing which crosslink the polymer molecules. Once crosslinked, thermosets become permanently hard and simply undergo chemical decomposition under the application of excessive heat. Thermosetting polymers typically have greater abrasion resistance and dimensional stability over that of thermoplastic polymers, which typically have better flexural strength properties. Thermoset polymers are generally harder and stronger than thermoplastics and have better dimensional stability. Most of the crosslinked and network polymers, which include vulcanized rubbers, epoxies, phenolics and polyester resins, are thermosetting in nature (Callister, 2007).

2.2.1 Polyethylene

Polyethylene is a wax-like thermoplastic material which softens at about 80-130°C with a density less than that of water. It is tough but has moderate tensile strength. It is an excellent electrical insulator and has very good chemical resistance. It is translucent or opaque but thin films may be transparent. Polyethylene (PE) or polythene is the most common plastic in the world. Its primary use is within the packaging industry (plastic bag, plastic films, containers including bottles, etc.).

Polyethylene is a plastic consisting of long hydrocarbon chains. They are known by their chemical formula $(C_2H_4)_nH_2$ which is, resistant to heat distortion; excellent electrical properties and fatigue strength; chemically inert; relatively inexpensive; and poor resistance to UV light. Different temperatures, pressures and catalysts during the polymerization reaction can have drastic effects on the branching of PE molecules. Branching is the formation of side chains off the basic polymer backbone. These side chains are formed when the hydrogen-carbon bond is broken during the polymerization reaction (Strong et al, 2000). With a significant amount of branching on a PE molecule, the structure will become more amorphous and have longer, uniform chains.

Polyethylene is classified into several different categories based mostly on its density and branching. Examples are High density polyethylene (HDPE), linear low density polyethylene (LLDPE), medium density polyethylene (MDPE), and low density polyethylene (LDPE). Depending on the crystallinity and molecular weight, a melting point and glass transition may be observable in its physical properties. The temperature at which these occur varies strongly with the type of polyethylene. For common commercial grades of medium- and high-density polyethylene the melting point is typically in the range of 120 °C to 130 °C

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Most LDPE, MDPE and HDPE grades have excellent chemical resistance, meaning that it is not attacked by strong acids or strong bases. It is also resistant to gentle oxidants and reducing agents. Polyethylene burns slowly with a blue flame having a yellow tip and gives off an odour of paraffin. The material continues burning on removal of the flame source and produces a drip (Boedeker, 2012). Most of the plastics used as plastic bottles, grocery bags; wrappers and water sachets are low density polyethylene (LDPE) from petroleum and are relatively easy to recycle into new product by re-melting. According to Khattab and El-Zoghby (1998), there is only a slight change in mechanical properties of recycled polyethylene. High density polyethylene (HDPE)



Figure 2.1: A schematic representation of a high density polyethylene structure showing few branching leading to closer packing and denser structure

Figure 2.1 shows the chemical structure of a high density polyethylene polymer. HDPE is

the most rigid among the four common PE's and has a density ranging from

0.935-0.960 g/cm³. HDPE can be produced with the aid of chromium/silica catalysts,

Ziegler-Natta catalysts or metallocene catalysts (Strong et al, 2000). HDPE is the product of limited branching that occurs when the polymerization is at low temperatures and low pressure. The limited branching makes HDPE more crystalline leading to the increased density. HDPE can be processed in three different ways: slurry particle reactor, gas phase and metallocene catalyst. It has a very tight cell structure, making it very difficult for other molecules to pass through its structure on a microscopic level (Campo et al, 2006). HDPE is the plastic that is used in making fuel tanks because of its low permeability and superb chemical resistance.

Low density polyethylene (LDPE)



Figure 2.2: A schematic representation of the chemical structure of a low density polyethylene polymer showing a more extended branching leading to low density property

Waste LDPE can provide a suitable matrix for making composites with saw dust and coir fiber. This is one of the most abundant plastics worldwide due to its low cost, ease at processing and other desirable properties (Gómez et al, 2005). Since it is used mainly for disposable packaging, it often finds itself in waste streams. This makes it a good candidate for recycling.

Low-density polyethylene (LDPE) is a thermoplastic polymer made from the monomer ethylene. It was the first grade of polyethylene, produced in 1933 by Imperial Chemical Industries (ICI) using a high pressure process through free radical polymerization (Dennis, 2010) It is defined by a density range of 0.910 -0.940 g/cm³.

It has a high degree of short and long chain branching as shown in Figure 2.2 which means that the chains do not pack in a crystal-like structure. It has therefore, weaker intermolecular bonds compared to HDPE and MDPE. Though more new polymers are competing with it, LDPE continues to be an important plastic grade.

LDPE has more branching of carbon atoms than HDPE, so its intermolecular forces (instantaneous-dipole induced-dipole attraction) are weaker, its tensile strength is lower, and its resilience is higher. Also, its density is lower since its molecules are less tightly packed and less crystalline. LDPE possesses the following characteristics: very tough, weatherproof, good chemical resistance, low water absorption, semi-rigid and translucent (Ratzlaff, 2004).

LDPE Properties	Values		
Tensile Strength	0.20-0.40 N/mm ²		
Notched impact strength	No break		
Thermal coefficient of expansion	100-220		
Melting point	110 °C		
Glass transition temperature	125 °C		
Density	0.910-0.940 g/cm ³		

Table 2.1: Properties of LDPE

Polyethylene is a plastic material of choice for the composites It is one of the urban wastes which are non degradable. Statistics gathered by Ghana Landfill Guidelines, (2002) stated that waste plastics constitute about 18 % of the about 1500 tonnes/day solid waste generated in Accra, Ghana's capital. Most of these plastics tend to be low density polyethylene (LDPE) which is used as plastic bottles, grocery bags, wrappers and water sachets.

Linear Low Density Polyethylene (LLDPE)



Figure 2.3: A schematic representation of a linear low density polyethylene structure

LLDPE is a blended form of HDPE and LDPE. It is created by a low pressure polymerization process much like HDPE, but has more branches much like LDPE. These branches as shown in Figure 2.3 are long enough to prevent the molecules from being closely packed together. This results in a linear molecular structure like HDPE, but also having a low density like LDPE. The density of LLDPE will typically range from 0 .918-0.940 g/cm³. The LLDPE features can be achieved by adding a comonomer during the polymerization process; usually hexene, butene or octene. The comonomer increases chain entanglement, which results in improved physical properties as well as stronger secondary bonding. The downsides to LLDPE are higher melt processing temperatures, 8 % greater shrinkage, less clarity (optically) and less flexibility (Strong et al, 2000). It is "softer" and good for an application like a selfadhesive carpet protection. The molecules all line up and strongly hold together as the film is stretched to give the structure much more strength and elongation than LDPE. Flexible plastic sheeting of LLDPE is most commonly in the thickness range of 0.0125mm to 1mm.

Medium Density Polyethylene (MDPE) has branching which is less than that of the HDPE.

It is less notch sensitive than HDPE and has better stress cracking resistance.

It is defined by a density range of 0.926-0.940 g/cm³ and can be produced by chromium/silica catalysts, Ziegler-Natta catalysts or metallocene catalysts which are the least commonly used form of catalyst. It is used for flexible plastic sheeting. It is stronger than LDPE, a little more chemical resistant, and has a tighter cell structure and tear resistance.

2.2.2 Polystyrene

Polystyrene is a hard, rigid transparent thermoplastic which has a chemical formula (C_8H_8) . It contains the chemical elements carbon and hydrogen and it is one of the most widely used plastics. The scale of its production is several billion kilograms per year (Maul et al, 2007). As a thermoplastic polymer, polystyrene is in a solid glassy state at room temperature but flows when heated above its glass transition temperature (about 100°C). It becomes rigid again when cooled. It is free from odour and taste and burns with a sooty flame. Other valuable qualities are that it is low cost, has good mouldability, low moisture absorption, good dimensional stability, good electric

insulation properties, colourability and reasonable chemical resistance. It is widely used as an injection moulding and vacuum forming material (Brydson, 1999). The principal limitations of the polymer are its brittleness and inability to withstand the temperature of boiling water. Discarded polystyrene does not biodegrade for hundreds of years and is resistant to photolysis (Bandyopadhyay et al, 2007). The mechanical properties of polystyrene depend on the nature of the polymer (e.g. its molecular weight), on the method of preparation of the sample for testing and on the method of test, as is the case with all plastic materials.

2.2.3 Polyethylene terephthalate

Polyethylene terephthalate includes naturally occurring chemicals, such as in the cutin of plant cuticles, as well as synthetics prepared through step-growth polymerization. Depending on the chemical structure, polyester can be a thermoplastic or thermoset; however, the most common polyesters are thermoplastics (Rosato, 2004).

They are highly crystalline and exhibit high toughness, strength, abrasion resistance, low friction, chemical resistance and low moisture absorption. PET has been available for many years but mainly as a fiber (e.g. Terylene). As a moulding material it was less attractive, due to processing difficulties but these were overcome with the introduction of polybutylene terephthalate (PBT). PET is now renowned for its success as a replacement for glass in beverage bottles (Crawdford, 1998). The polar nature of the ester group leads to the resin having a higher power factor and dielectric constant than the hydrocarbon polymers and this limits their use as highfrequency electrical insulators. Many mechanical properties are dependent on the density of cross-links and on the rigidity of the molecules between cross-links.

2.2.4 Polyamides (Nylon)

Polyamides, or nylon polymer compose of long, multiple-unit molecules in which the repeating units in the molecular chain are linked together by amide groups. Amide groups have the general chemical formula CO-NH. There are several different types of nylon (e.g. nylon 6, nylon 66, and nylon 11) but as a family their characteristics of strength, stiffness and toughness have earned them a reputation as engineering plastics (Crawdford, 1998). Typical applications for nylon include small gears, bearings, bushings, sprockets, housing for power tools, terminal blocks and slide roller. Another major application of nylon is in fiber which is strong (Crawdford, 1998).

An important design consideration is that nylon absorbs moisture which can affect its properties and dimensional stability. Glass reinforcement reduces this problem and produces an extremely strong, impact resistant material. Another major application of nylon is in fibers which are notoriously strong (Callister, 2007).

2.3 Coupling agent

Most polymers, especially thermoplastics, are non-polar and therefore hydrophobic substances, which are not compatible with polar (hydrophilic) substances such as wood fibers. This therefore results in poor adhesion between the polymer and wood fiber in the wood fiber plastic composite (WFPC) (Geottler, 1983, Klason et al, 1984). In order to improve the affinity and adhesion between wood fibers and thermoplastic matrices, chemical coupling agents have been employed (Chun et al

1984, Woodhams et al, 1984)

According to Dalväg et al, (1985), Schneider et al (1985) coupling agents are substances that are used in small quantities to treat a surface so that bonding occurs between it and other surfaces. Coupling agents are classified into organic, inorganic, and organic-inorganic groups. Organic agents include isocyanates, anhydrides, amides, imides, acrylates, chlorotriazines, epoxides, and organic acids. Only a few inorganic coupling agents, such as silicates, are used in WFPC. Organic-inorganic agents include silanes and titanates. Coupling agents can be directly mixed with wood fiber and polymer in the melt-blending formation, such as injection moulding, extrusion, and transfer moulding. They can also be coated or grafted on the surface of wood fiber and polymer or both. Then the pretreated and untreated wood fiber and polymer are kneaded. Usually, pretreatment of wood fiber and polymer is by coating or grafting to enhance the mechanical properties.

Some of the important considerations in choosing coupling treatments are concentration and chemical structure of coupling agents, choice of wood fiber and matrix (e.g. shape, size and species), ratio of wood fiber to total matrix weight, formation methods, and end-user requirements of the finished product.

2.3.1 Coconut oil as coupling agent in composites.

Coconut oil is an oil extracted from the kernel or meat of matured coconuts fruit. Melting Point is at 25°C. Smoking Point is at 177°C and it is insoluble in water at room temperature and has a density of 0 924.27 g/cm.3 Chemical properties of coconut oil is predominantly composed of saturated fatty acids and a high proportion of glycerides of lower chain fatty acids. The oil is highly stable towards atmospheric oxidation. It is characterized by a low iodine value, high saponification value, and high saturated fatty acids content and is a liquid at room temperatures of 27°C. It has various applications in food, medicine, and industry.



Figure 2.4: The chemical structure of a typical triglyceride showing the polar and non polar moiety in the same structure.



Figure 2.5: Schematic representation of the coupling effect of a triglyceride molecule with cellulose fiber and plastic matrix

Coconut oil contains a high percentage of glycerides which chemical structure consists

of a polar and non polar end as shown in Figure 2.24 just like other coupling agents.

This characteristic makes it possible to blend with the fibers which are polar and the

LDPE plastics which are non polar.

Compound	Percentage composition
Lauric acid	45 % - 52 %
Myristic acid	16 % -10 %
Caprilic	5 % -10 %
Capric	4 % - 8 %
Caproic	0.5 % - 1 %

Table 2.2 Chemical Composition of coconut oil

Palmitic	7 % - 10 %
Oleic	5 % - 8 %
Palmitioleic	In traces
Linoleic	1 % - 3 %
Linoleric	Up to -0.2

Izyan et al, (2008) have worked on the effect of coconut oil as a coupling agent on the physical properties, swelling behaviour and morphology of silica-filled polypropylene composites. The incorporation of coconut oil coupling agent (COCA) in silica-filled polypropylene (PP) composites gave positive effect by improving tensile strength, elongation at break and Young's modulus but reduced the water absorption resistance. Micrographs of tensile fracture surfaces of silica filled with PP exhibit that silica was covered by PP matrix as a result of better adhesion.

2.4 Cellulose fiber-reinforced plastic waste composites.

This section outlines some of the recent reports published in literature on the mechanical behaviour of some common plastics reinforced with cellulose fibers

(wood dust and coir) to form composites through the action of coupling agents. Cellulose fiber-reinforced waste plastic composites have been used to develop new value-added products such as floor carpets, flower vases, waste paper baskets, park benches, picnic tables and plastic lumber as a way of recycling wastes.

Generally, cellulose fiber-reinforced waste plastic composites are made of a blend of plastics (high density polyethylene and polypropylene) and wood fiber, coir or other agricultural wastes as reinforcing filler. Many researchers like Chen et al, (2006),and Lee et al, (2010), have worked on various wood-plastic ratios which typically range between 50 to 80 % of sawdust or fiber either as filler or reinforcements (Clemons, 2002). The higher strength and aspect ratio of natural fibers offers good reinforcing

potential in composite matrix compared to the artificial fibers (Abdul et al, 2014 and Clemons, 2008).

The interface between the non-polar plastics and the polar cellulose fiber waste is improved to ensure the transfer of stress between the two phases when loaded by a coupling agent. Typical coupling agents used in the process include anhydrides or organic acids. Fibrous composite materials typically have two or more distinct phases, which include high strength/stiffness reinforcing fibers and the encapsulating matrix material. Fibers can be either discontinuous (chopped) or continuous. Polymer matrices typically fall into two categories: thermoplastic and thermosetting polymers.

2.4.1 Mechanical properties of cellulose fiber-plastic composites

Chtourou et al, (2009) have evaluated the mechanical properties of wood fiber–waste plastic composites. They have investigated the use of saw dust–waste thermoplastic composites for guard-rail posts on highways. Miller et al, (1998) have assessed the tensile strength of wood fiber–waste plastic composites with particular emphasis on coupling agents. Their results have shown that plastic wastes reinforced with cellulose fiber and appropriate coupling agents can be used to make composite materials with good mechanical strength. Lu et al, (2000) recently reviewed work done by some researchers who examined the mechanical properties of the composites and the effects of various coupling agents on the interfacial bonding between the fibers and the polymer; they have stated that the presence of a suitable coupling agent is crucial for the achievement of significant gains in the mechanical properties of these composites. Recently, bio-based wood polymer composites (WPC) have been receiving considerable attention due to their low processing cost, problem-free biodegradation, and improved physical, mechanical, and biological performance. Wood is mainly composed of three polymers, namely cellulose, hemicellulose, and lignin, with a minor proportion of extractives that is subject to biodegradation.

Monteiro et al, (2008) worked on reinforced coir fiber with polyester to form a composite and determined the structural characteristics and mechanical properties of the coir fiber/polyester composites. Individually loose coir fibers were used in two distinct forms: tangled or pressed in mats with a thickness of 1.0 cm. The fibers were used untreated, except that they were dried at 50°C for 24 h. Two kinds of coir fibers, tangled mass and pressed mats were used in this work. A commercially available unsaturated orthoftalic polyester resin with 1 wt % of methyl-ethyl-ketone as catalyst was used as matrix for the composites. After being thoroughly mixed, the resin was poured into the cavity of a steel mould, which was previously filled with a suitable amount of coir fiber. Composites with amounts of coir fibers ranging from 10 to 80 wt% were manufactured at two pressure levels, namely: 2.6 and 5.2 MPa. The cure was done under pressure at room temperature. As the fibers in any of the two configurations (tangled or mat) did not have a preferred orientation, the composites fabricated in the present work are considered as randomly oriented. Rectangular specimens 122 mm long, 25 mm wide and 10 mm thick were bend tested using the three-point bending procedure. The span-to-depth ratio was maintained constant at 9, and the minimum number of specimens used for each of the test conditions and coir fiber arrangements was 6. Before their incorporation in the composites, the coir fibers were analysed by scanning electron microscopy (SEM). The analysis was performed on gold-sputtered samples in a microscope, coupled with EDS, operating at a beam voltage of 15 kV.

Their results show that random oriented coir fiber–polyester composites have flexural strengths that enable their use as nonstructural building elements. The low modulus of

elasticity is attributed to their lack of an efficient reinforcement by the coir fibers, in comparison with that of the bare polyester resin.

2.4.2 Sawdust-polyethylene composite

Jae-Pil et al, (2012) experimented on sawdust–reinforced polyethylene (PE) (1:1) composites with ethylene–vinyl alcohol copolymer (EVAL) as adhesion promoter to improve mechanical strength. Linear low density polyethylene (LLDPE, Tm 122°C; melt index 5 g/10 min; density 0.9 g/cm³) was used as matrix material. The saw dust used as wood filler was of the following particle size range and weight: 20–30 mesh

10 wt %, 30–60 mesh 80 wt % and 60–100 mesh 10 wt %. This wood was dried at 105^oC for 12 hr. Ethylene–vinyl alcohol (EVAL) and vinyl-acetate (VA) was of the following content: 2, 8, 15 and 30 mol % were prepared from hydrolysis of ethylenevinyl acetate (EVAcs). Saw dust (50 wt % of composite with the exception of EVAL) was placed in a blender. EVAL (1–10 wt % of wood) was added and mixed at 60 rpm for 5 min at 160^oC. LLDPE was charged into the blender and mixed continuously for 10 min at the same temperature. The kneaded samples were moulded into films by hot-pressing with Carver Hot-Press. The samples were placed between a pair of Teflon films with a thin spacer. The temperature of the hot press was set at 160^oC. After heating for 5 min, the samples were sustained to 3.5 MPa pressing and allowed to stand at this pressure for 5 min. The samples were cooled to room temperature after subsequent cold pressing at the same pressure for 1 min.

The tensile properties of the composites were measured according to ASTM S 638 using an Instron tensile testing machine, model 4201 at room temperature and 50% relative humidity. The standard General Tensile Test Program method was used to evaluate the mechanical properties. The cross head speed was 10 mm/min and the reported properties were measured at yield point. The results were obtained from average of ten repeated measurements.

The EVAL copolymers containing various VA were found to be adhesion promoters for wood plastic composite. The EVAL coated saw dust–LLDPE composites had the improved mechanical strength as compared to the composites of uncoated saw dust. The results indicated that EVAL played an important role in improving the mechanical properties of LLDPE composites containing saw dust. The WPC prepared from EVAL coated saw dust and LLDPE had a good mechanical strength improved by hydrogen bonding between hydroxyl groups of saw dust and hydroxyl groups of EVAL. The fracture surface of EVAL-coated saw dust–LLDPE composites showed good adhesion.

2.4.3 Coir reinforced polyethylene composite

Arrakhiz et al, (2012) worked on HDPE with coir fibers of 20 cm length as reinforcement. Before use, the fibers were ground into small 2–3 mm length pieces, treated with sodium hydroxide (NaOH), acetic acid (CH₃COOH), dodecane bromide, and 3-(trimethoxysilyl) propylamine (C₉H₂₃NO₃Si). The crushed coir fibers were first washed with water and then kept for 48 h in a 1.6 mol/L sodium hydroxide aqueous solution. After removal of the fibers from the NaOH solution, they were treated with acetic acid (100 mL) to neutralize the remaining hydroxide after which they were air-dried for 24 h. 3 ml dodecane bromide was added to 5g of coir fibers and 20 ml of NaOH in isopropanol. The solution was vigorously stirred at room temperature for 12 h. The coir fibers were recovered by filtration, washed thoroughly with isopropanol and ethyl ether and then dried for 12 h at 50 °C.

A solution of 0.5 wt. % silane coupling agent 3-(trimethoxysilyl) propylamine was prepared in acetone. The pH of the solution was adjusted to 3.5 with acetic acid, after which the solution was stirred continuously for an additional 5 min. Fibers were immersed in the resulting solution for 45 min, after which they were dried at 65°C for 12 h to initiate the chemical reaction between the fibers and silane coupling agent. The fibers were then thoroughly washed with water to remove chemical residues until a pH value of 7 was measured. The last step involved drying the fibers at 80 °C for 48 h. Composites of high density polyethylene (HDPE) with 20 wt % of chemically treated coir fibers were blended using a heated rolls mill. Compounding of each 30 g composite batch was performed at 200°C with the roll mill operating at 60 RPM for 3 min. Under these conditions, a homogeneous dispersion and distribution of the fibers was achieved in the HDPE matrix. The neat HDPE matrix was first filled in the heated mixing cavity while the mills were under constant rotational speed. After 30 s, the fibers were carefully added onto the melted HDPE and mixed for 3 min. At that point, the measured torque was found to be constant. The rolls were then stopped and the composite removed from the heated rolls before being cut into small pieces for hot press moulding. Hot press moulding was performed using a semi-automatic press with both platens heated to 190°C. The sample being moulded was held for 30 s at that temperature under compression before being cooled to room temperature. The mould used was shaped according to (ISO 527-1 1993) for mechanical testing.

Results have shown that composites obtained with treated fibers possess better mechanical properties than those of composites made with untreated fibers. The calculated Young's modulus in the composites was higher for the alkaline treated fibers than the raw fibers. Moreover, torsional test shows that the NaOH treatment gives more flexibility to the fibers with the silane treatment making the fibers more rigid. A study of the plastic energy absorbed by all the composites has shown a clear limitation of the added fibers. But the use of coupling agents such as silane increased noticeably the stored energy when compared to composites made from raw coir or

alkali-treated fibers.

CHAPTER THREE

3.0 Experiments

3.1 Materials

Samples of empty water sachet plastics made from low density polyethylene (LDPE) that litter the streets of Accra since Accra was the site of execution of the project were sampled. Saw dust from *Ceiba pentandra* (soft wood) whose common name is ceiba, was obtained from Muus sawmill at Taifa in the Greater Accra region. Unrefined coconut oil which acts as coupling agent was purchased from Madina market in Accra.

3.1.1 Determination of plastic and oil melting temperatures

10 g of plastic was added to varied proportion of coconut oil 0, 10, 20, 40, 50 g stirred till it melted. The temperature was then recorded at each plastic and oil content melted.

3.1.2 Sieve analysis of saw dust

The procedure used was taken from ASTM C 136. The sawdust was dried at 105° C for 12 h in a convection oven (Gallenkamp Plus Oven). The dried saw dust was sieved using Fragtech Standard Sieves of apertures 63 µm, 90 µm, 355 µm, 500 µm and 630 µm. At the base was a receiver. 50 g of sawdust was placed on the top sieve and shaken continuously for 10 minutes using an autoshaker (Wagtech International Ltd model). The material on each sieve was weighed and then divided by the total weight to give a percentage retained on each sieve. The following equation was used,

 $\% Retained = \frac{W Sieve}{W Total} \times 100\%$ Where W_{Sieve} is the weight of sawdust on the sieve and W_{Total} is the total weight of the sawdust. The total percentage of aggregate that was retained on each sieve was added to the amount in the previous sieves cumulatively.

The values were then plotted on a graph with cumulative percent passing on the Y axis and logarithmic sieve size on the x axis.

3.1.3 Preparation of plastics.

The sampled LDPE plastics were washed thoroughly with water and dried at 60°C for 12 h in a convection oven before shredding.

3.1.4 Preparation of the composite material

The coupling agent (coconut oil) was added at varied proportion of 0,5,10,15,20 wt % on shredded PE plastic at the proportion of 30 to 55 wt % mixed and heated in a beaker till melted to the molten state at 120°C. The required quantity of saw dust was added to the melted plastic and stirred continuously until uniformly mixed at 140°C for 10 min. The total weight of each sample was 30 g. Temperature was measured using K-type thermocouples.

The molten mixture was poured into a rectangular metal mould of dimension 132 mm x 37 mm x 7 mm and pressed to a maximum pressure of 10 MPa whilst still hot using a 10 tonnes laboratory press (Apex Construction Ltd, London and Dartford).

3.1.5 Determination of sawdust particle density

Particle density of saw dust sample was determined by the methods employed by (Araki et al, 2004). An empty 10 ml density flask was initially weighed and subsequently filled to the 10 ml volume mark with sawdust. Its combined weight was then recorded. The

weight of the empty density flask was subtracted from the combined weight. The density was then calculated using the formula:

Particle density
$$\left(\frac{g}{cm3}\right) = \frac{(W_b - W_a)}{V_0}$$

 W_b = Weight of sawdust and flask (g).

W_a =Weight of empty flask (g).

Where:

 $V_o = Volume of the flask (cm³).$

3.1.6 Determination of moisture content

The crucible was first pre-ignited by heating it to 650°C for 1h and then placing it in a desiccator to cool to room temperature of 25°C. It was then weighed to the nearest 0.1 g. 1.0 g (W) of sawdust was accurately weighed unto a tarred ignited crucible and placed in an electric oven (Gallenkamp Plus Oven) at 105°C till constant weight (D) was achieved. The moisture content was then calculated using the following equation:

Percentage of Moisture Content = $\frac{W - D}{W} \times 100$

W = initial sample weight

D = dry sample weight

3.1.7 Determination of volatile matter

The volatile matter was determined by ASTM procedure D2867. A pre-ignited crucible was weighed (A) and then covered with a lid and reweighed (B) to the nearest 0.1 g. 1g

of sawdust was then placed in a pre-ignited covered crucible and weighed (C). The covered crucible was then placed in a furnace and heated to 950°C for 7 minutes. The crucible was then removed and placed in a desiccator to cool to room temperature (25°C). The crucible with the cover was weighed to the nearest 0.1

g. The volatile matter was determined by the equation below.

Percent volatile matter(%) = $\left(\frac{C-D}{C-B}\right) \times 100$

Where:

B = mass of the crucible and cover (g).

C = mass of crucible, cover, and sample (g)

D = mass of crucible, cover, and devolatized sample (g)

3.1.8 Determination of ash content.

The ash content was also determined using ASTM method D2866 (1999) by first igniting the crucible at 650°C for 1h. The crucible was then placed in a desiccator to cool to room temperature (25°C).1 g of sawdust was weighed and placed into an ignited crucible and placed in the furnace at 650°C for 3h till constant weight was achieved. The crucible was removed and placed in the desiccator and allowed to cool to room temperature (25°C).

The ash content was calculated by using the following formula. $Total \ ash \ \% = \left(\frac{D-B}{C-B}\right) \times 100$

Where:

- B = weight of crucible (g)
- C = Weight of crucible and original sample (g)
- D = Weight of crucible and ashed sample (g)

3.1.9 Selection of oil quantity

A typical formulation of a sample weighed 30 g. The oil content was varied as follows: 0, 5, 10, 15, and 20 wt % using 63 μ m-90 μ m particle size as recommended in literature by Sark et al, (1997). The remainder of the proportion was equally split between sawdust to plastic ratio. The material preparation is referred according to the process detailed in section 3.1. The density, porosity and flexural strength were determined to ascertain the optimum oil ratio.

Table 3.1 Sample formulations for varying coconut oil content.

% Oil	0	5	10	15	20
Oil wt(g)	0	1.5	3.0	4.5	6.0
Plastic wt (g)	15	14.25	13.5	12.75	12.0
Sawdust wt (g)	15	14.25	13.5	12.759	12.0

3.1.10 Selection of sieve size

An oil content of 10 wt % was maintained, and particle size varied according to sieve size 63 μ m, 90 μ m, 355 μ m, 500 μ m and 630 μ m. The sawdust to plastic ratio was maintained at a 50:50 ratio for the various particle sizes. The total weight of this formulation was 30 g. The samples prepared were tested for flexural strength, porosity and density. Table 3.2 shows the composition for the particle size selection. **Table 3.2**

Sample formulation for sieve size selection

Sieve size (µm)	63	90	355	500	630

Plastic wt(g)	13.5	13.5	13.5	13.5	13.5
Sawdust wt(g)	13.5	13.5	13.5	13.5	13.5

3.2 Selection of Plastic loading to sawdust ratio

Upon determining the optimum oil ratio, 10 % oil composition was used. Plastic loading was varied at 30,35, 40, 45, 50, and 55 wt %. The particle size of the sawdust used was 90-355 μ m. Table 3.3 shows the composition used for these experiments.

Table 3. 3 Sample formulations for variable plastic loading.

Plastic Loading (g)	30	35	40	45	50	55
Plastic wt (g)	9	10.5	12	13.5	15	16.5
Sawdust wt (g)	18	16.5	15	13.5	12	10.5

3.2.1 Flexural strength determination

(ASTM) D790-03 Procedure A, three bend point set up was used to determine the flexural strength analysis. An average of five repeats reported in ASTM methods. The dimensions of each test specimen were kept at approximately $127 \times 127 \times 5$ mm. The length of support span was 80 mm, and the loading nose had a radius of 6.75 mm. The Flexural yield was estimated by the following equation.

$$\sigma = \frac{3FL}{2bd^2}$$

Where, σ is the flexural yield, P is load at the fracture point, L is the length of the support span, b is the sample width and d is the sample thickness.



Figure 3.1: Representation of three-point bend test from (ASTM) D 79-03

3.2.2 Density

The density of the composite material at 25°C was also determined by the displacement method, ASTM D792-00 test method A, by weighing the sample in air and attaching a sinker to it and weighing it again in deionized water. The density of the material was then calculated from the equation.

Specific Gravity =
$$\frac{a}{a + w - b}$$

Where a, is the apparent mass of material, without wire or sinker, in air, b, is apparent mass of material and sinker completely immersed and of the wire partially immersed in liquid, and w, is apparent mass of totally immersed sinker and of partially immersed wire.

3.2.3 Porosity

The water absorption of the fractured samples from flexural strength testing was determined according to the ASTM D570-98. The sample was sawn to smoothen the

fractured surface of the specimen. It was then conditioned by drying in an oven for 24 h at 50 °C before cooling in a desiccator with silica as desiccant. The sample was immediately weighed upon removal from the desiccator. The conditioned specimen was completely immersed in a container of deionised water maintained at laboratory temperature of 25°C for 24 h. After the 24 h immersion period the sample was removed from the water and all surface water wiped off with a dry cloth and immediately weighed on balance scale. The porosity was determined using equations 7, and 8.

$$W_{s} \square W_{d}$$
Pore Vol. $(V_{p}) \square$ ------ (7)

Where W_s is the sample core weight, W_d is the dry core weight and ρ_f is the density of the saturated sample.

 $\Box V_p \Box porosity (\%) \Box \Box \Box \Box 100$

Where V_b is obtained by measuring the dimension of the sample using a Hilka digital calliper and multiplying the answers.

3.2.4 Microscopic studies

The morphology of the surface that explains the activity of the plastic melt before the addition of coconut oil and sawdust from Ceiba Pentandra particles sizes were studied using a Bresser LCD Micro digital electronic microscope. A thin film of LDPE sample was placed on the microscopic slides and examined at 40X

magnification. The micrograph was then compared with a thin film of melted plastics at 110°C. With a surface active ingredient (coconut oil) at different percentages (0, 10, 20, 30, 40, 50 %) serving as a coupling agent, was examined under the same magnification. Changes to the surface morphology were noted.

3.2.5 Scanning Electron Microscopy (SEM)

The fractured surfaces of the flexural test specimens were characterized using Electron Microscopy (EOL JSM-6390LV) at magnifications of 100X. SEM images were taken and analysed.



CHAPTER FOUR

4.1 Plastic and coconut oil (coupling agent) interaction

The result as shown on Figure 4.1 indicates that melting temperature of LDPE decreased from 110°C to 85°C as the percentage of coconut oil in the matrix increased from 0 % to 50 %. The coconut oil also prevented lump forming when the plastics were heated to 110°C by isolating smaller polyethylene particles through the formation of a sol-gel emulsion. The heating process breaks the intermolecular bond of the LDPE film and small individual polyethylene fragments as shown in Figure 4.2.



Figure 4.1: Melting temperature changes of plastic with varying coconut oil content

The contrasting white and dark patches as shown in Figure 4.2, reveals the surface topography of the coupling agent and plastic interaction. The darker areas of the image represent those areas of the sample that coconut oil breaks the intermolecular bond of the LDPE film. The focal light therefore passes through the sample without reflection

on the objective lens to produce the white patches. From Figure 4.2, dark areas increased as oil content increased from 0% to 50%. This indicates that small fragments are prevented from migrating to nearby particles to form a sintered lump.



Figure4.2: Micrograph of melted plastic with and without coconut oil at 40x magnification for (a)0 (b)10% oil (c) 20%oil (d) 30% oil € 40% oil (f) 50%oil.

4.2 Sieve analysis of sawdust

The size of the fiber in wood plastic composites has been demonstrated in literature to affect the physical water absorption and mechanical properties of composite materials (Bouafif et al, 2009). The sieve analysis in Figure 4.3 showed that 60 % of the particles are retained by the mesh of size 630 microns which implies the particles had a diameter greater than 630 microns. 39.5 % of the wood-dust particles fell within the size range of between 63 μ m and 630 μ m and still a fewer particles (0.5

%) are within the size domain of a powdered form (< 63 μ m).



Figure 4.3: Size distribution of wood dust from a typical sawmill

ENSAD CORSANE

A microscopic study of the particle morphology of the different particles of the sawdust shown Figure 2.3 suggested a fibrous morphology rather than rounded particles for all the different sizes. On the average a relatively high length to diameter ratio which has positive implications on the mechanical property of composite material fell within the domain of the wood dust 90-355 µm size which has the tendency to enhance surface activity and blends with the plastic-coupling agent gel matrix.

BADW



Figure 4.4: Micrograph of the saw dust particles at 40x magnification for (a) < 63μ m (b) 63μ m-90 (c) 90μ m-355 (d) 355μ m-500 (e) 500μ m-630 (f) >630\mum.

4.3 Physical properties of the composites: porosity and density

4.3.1 The effect of coconut oil concentration on porosity of composite samples

The porosity of the composite decreased through a minimum value of 18.5 % at 10 wt % coconut oil and then increased to a maximum of 24.4 % at 20 wt % coconut oil as shown in Figure 4.5. This observation is attributed to the fact that a compact or dense composite body is formed at 0 wt % to 10 wt %. Coconut oil. The relatively high adhesion comes to a head when the amount of coupling agent, coconut oil is 10 %. However, as the percentage of coconut oil increased beyond 10 wt %, the plastics are loosely held to the particles as well as to itself resulting in the creation of further and larger pores.



Figure 4.5: Effect of varying coconut oil concentration on porosity of composite at plastic to wood ratio of 50/50 by weight.

4.3.2 Porosity of composite prepared with wood dust of different particle sizes

The porosity of the composite was found to be dependent on the fiber particle size as shown in Figure 4.6. The larger the particle size, the higher the porosity which was in good agreement with previous report (Steckel et al, 2007). Larger particles led to greater hydrophilic-exposed surfaces; and poor adhesion between wood particles and the polymer matrix generating voids around the wood particles.





Figure 4.6: Variation of the porosity of the composite with particle size of sawdust at 10 wt% oil concentration of coupling agent and a plastic to sawdust ratio of 50/50 by weight.

4.3.3 Effect of plastic loading on porosity.

The porosity of the composite increased from 12.6 % to 35.5 % as the plastic loading decreased from 55 wt % to 30 wt % after a 24 h immersion period as shown in Figure 4.7. Higher water resistance of composites with the increasing plastic content can be attributed to the hydrophobic character of plastics. The wood used is a soft wood. Soft wood has lower density by virtue of the greater amount of pores in the wood due to this reason porosity increased as sawdust content increases. Similar result for this increasing pattern were also reported by (Chen et al, 2006) for the composites made from HDPE and recycled wood particles.

WJSANE



Figure 4.7: Variation in porosity of composite with 10 wt% coconut oil and plastic to sawdust ratio of 50/50 by weight.

4.3.4 Density of composites at different coconut oil composition

Lightweight materials with very strong mechanical properties are most desirable in the design of new materials for architectural purposes (Sales et al, 2010 and Wu et al, 2007). Density of a material is therefore useful in calculating strength -to-weight and weight-to-cost ratios (ASTM 792-00). Increasing the percentage of coconut oil in the composite, the density rose through a maximum at 10 wt % coconut oil before decreasing. This trend is in agreement with the decline in porosity with the minimum porosity occurring at the 10 wt % content of oil. This shows that, properties in the oil becomes compatible with the plastic and sawdust at 10 wt % oil.

WJSANE

NC



Figure 4.8: Variation in density of the composite with coconut oil composition at a plastic to sawdust ratio of 50/50 by weight

4.3.5 Density of composite prepared with wood dust of different particle sizes

Figure 4.9 shows a decrease in density from 0.97 to 0.75 as sawdust particle size increased. It is well documented in literature that raw material particle size influences the density of composites. Small particles give a higher density (Travnicek, 2011). Also, bigger particles can create bigger pores in the composites leading to reduced density contrary to smaller which ensure effective packing, thus increasing composite density.





Figure 4.9: Variation of density of the WPC with particle size of wood dust in the composite at 10 wt% oil concentration of coupling agent and a plastic to wood ratio of 50/50 by weight.

4.3.6 Effect of plastic loading on density of composite

Increasing the plastic loading in the composite increased the density as shown in Figure 4.10. Density of LPDE is 0.910-0.940 g/cm³ which is much higher than Ceiba sawdust density of 0.409 g/cm³ and hence increasing the ratio of plastic in the composite had a cumulative effect on the density of the composite.





Figure 4.10: Effect of varying plastic loading on density of composite at 10wt % coconut oil

4.4 Mechanical property of the composites

4.4.1 Flexural strength

According to Klyosov, (2007) the International Code Council (ICC) can pass a material for construction if it has a flexural strength of 0.012 MPa. The flexural strength of the composite with 50/50 plastic to wood ratio using different ratios of coconut oil as coupling agent is presented in Figure 4.11. The results showed an increase in the flexural strength from 3.3 MPa to 6.1 MPa as coconut oil ratio increased from 0 to10wt %. It then decreased from 6.1 MPa to 2.2 MPa as coconut increased to 20 wt %. This could be attributed to polar and non-polar functional groups in the molecular structure of coconut oil which act as the coupling agent. This enhanced interaction with both the hydrophobic plastic and the hydrophilic wood from 0-10 wt % allowing for the distribution of stress on both the plastic and the wood particles in the composite. Beyond 10 wt % of coconut oil the flexural strength drops as a result of the increased porosity of the material from the dilute dispersion

of the plastic entity in the composite.



Figure 4.11: Flexural strength variations with varying concentrations of coupling agent (coconut oil) with 50/50 LDPE plastics to saw dust ratio.

The flexural strength of the composite prepared from 50:50wt % plastic: saw dust ratio with 10 wt % coconut oil and also using varying wood particle sizes (63,

90,355,500 and 630 μ m) is shown in Figure 4.12. The maximum flexural strength (6.1 MPa) was obtained by composite material formulated with wood particles retained on 90 micron sieve.

This was because particles retained in the 90-355 microns had particle length to diameter ratio (see Figure 4.4b). The small particle diameter offers more surface area of contact with the plastic-coupling agent matrix than bigger ones. Also, bigger particles can create bigger flaws in the composites contrary to smaller flaws created by smaller particles, thus reducing composite strength (Leidner et al, 1974). Fracture surface area increases with increasing particle size. As a result, less energy is required to break a specimen containing larger particles (Stark et al, 1997). The deviation of 63µm is related to the fact that powdery morphology of the particles





Figure 4.12: Behaviour of flexural strength of composite material with saw dust particle size with 10 wt% oil and plastic to sawdust ratio of 50/50 by weight.

Results as depicted in Figure 4.13 indicated that an increase in plastic loading of the composite material resulted in an increase in the flexural strength of the material. Plastic loading increased with decreased sawdust content. It appeared that the binding capacity of the plastic gradually decreased with increasing sawdust content. The mechanical behaviour of WPCs was influenced by the uniformity of

lignocellulosic materials dispersed in the polymeric matrix (Chen et al, 2006, Raj et al, 1989).



Figure 4.13: Effect of LDPE plastics loading on flexural strength of the composite at 10 wt. % of coconut oil.

4.5 Microstructures characterization

4.5.1 SEM of composite fractured surface

A number of composite flexural fractured surfaces were examined. The interfacial bonding between the matrix and fiber are shown in Figure 4.14 to 4.16. The microstructure of the samples in Figure 4.14 show the SEM images of fracture surfaces by variation of particle size of saw dust in the composite with 10 wt % oil as coupling agent and a plastic to sawdust ratio of 50/50 by weight 63-90, 90-355, 355500, 500-630 and <630 at 100× magnification.

Figure 4.14 (a) (c) (d) and (e) exhibited a considerable amount of fiber pullout and voids as particle size of sawdust increases indicating that interfacial bonding was lowered. The fracture surface of the composite with higher saw dust content appears to be dominated by voids.

The sample containing 90-355µm particle size in Fig.4.14 (b) fractured was without signs of fibers being pulled out, indicating good interface bond meaning that the interfacial bonding between the filler and the matrix polymer was strong.



Figure 4.14: SEM images(×100) of fractured surface of variation of particle size of saw dust in the composite with 10 wt% oil concentration of coupling agent and a plastic to sawdust ratio of 50/50 by weight (a) 63-90 μm (b) 90-355 μm (c) 355-500 μm (d) 500-630 μm (f) >630 μm.

Figure 4 15(a) to 4 15(e) shows the SEM images of fractured surfaces of the composites made of varying coconut oil concentration on composite at plastic to sawdust ratio of 50/50 by weight for (a) 0 % (b) 5 % (c) 10 % (d) 15 % (e) 20 % oil. The images revealed relatively no fiber pullout and less voids at oil content of 10 % at Figure 4.15 (c). This confirms the result in Figure 4.5.



Figure 4. 15: SEM image fractured surface of varying coconut oil concentration on composite at plastic to sawdust ratio of 50/50 by weight for(a) 0 % (b) 5 % (c) 10 % (d) 15 % (e) 20 % oil

SEM image from Figure 4.16(a) to 4.16(f) were made of varying plastic and saw dust in the composite at 10 wt % oil. Plastic loading was varied at 30, 35, 40, 45, 50 and 55. Fractured samples shows systematic close matrix-fiber surface without any sign of pullout from Figure 4.16 (a) to (f) and more compact surface at Figure 4.16(d) to (f),This is because composite filled with more plastic have less void



Figure 4.16 Fractured surface of composite with varying plastic loading of (a) 30% (b) 35% (c) 40% (d) 45% (e) 50% (f) 55%.

CHAPTER FIVE

5.0 Conclusions

The composite panels for partitioning room samples were formulated from sawdust, low density polyethylene (LDPE) and coconut oil as coupling agent using the Melt and Stir method. Composites were prepared with different plastic sawdust ratios, varying coconut oil content and particle sizes. Each composite sample was then tested for porosity, density and flexural strength. Microstructure of the fractured samples was examined using scanning electron microscope. Melted plastic with coconut oil surfaces were also looked at with optical microscope.

Composites made with 10 wt % coconut oil, plastic to sawdust ratio of 50/50 by weight and 90-355 μ m exhibited lower water absorption at value 17.82 %. Porosity increased from 14.8 to 26.9 % with increasing sawdust particle size of 63, 90, 355, 500, 630 μ m.

Increasing the percentage of coconut oil from 0 to 20 wt % in the composite, the density rose through a maximum at 10 wt % coconut oil. Density of particle size composite showed a decrease in density from 0.75 to 0.97 g/cm³ as sawdust particle size increased. Increasing the plastic loading in the composite increased the density.

Flexural strength evaluation suggested that increasing plastic loading improves the strength of composites. Increasing sawdust size from 63 to 355 μ m decreases flexural strength from 6.2 to 5.1 Mpa. Increasing sawdust particles content improves stiffness of composites, but decreases flexural strength.

The flexural strength showed that 90-355 micron sieve size with the polymer 13.5 wt % and sawdust 13.5 wt % was the best in terms of flexural strength. All the composite samples exceed the minimum ICC standard of 0.012 MPa (250 Ib/sq ft) for flexural strength.

SEM images of fractured surfaces of the composites made of varying coconut oil concentration revealed relatively no fiber pullout and less voids at composite with 10 wt % oil. Fractured surfaces of varying particle size of saw dust in the composite with 10 wt % oil concentration exhibited a considerable amount of fiber pullout and voids as particle size of sawdust increases indicating that interfacial bonding was lowered.

There are small discontinuities and a reasonably uniform distribution of saw dust particles in the LDPE matrix with samples containing 90-355 µm particles indicating good interfacial bonding between the filler and the matrix polymer. The composite with 10 wt % oil concentrations and varying ratios of plastic loading showed increase in compatibility and lesser voids as percentage of plastic loading increases.

5.1 Recommendation for future work

The experimental results provided in this study will help the development of a composite material from plastic waste, sawdust and coconut oil, but there is still more work needed to quantify the product.

Determination of the physicochemical parameters and the macro structure of composite material alone is not enough to promote its use. However, other oils like palm oil, palm kernel oil, and almond oil as coupling agents should be further investigated to improve the composite.

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