

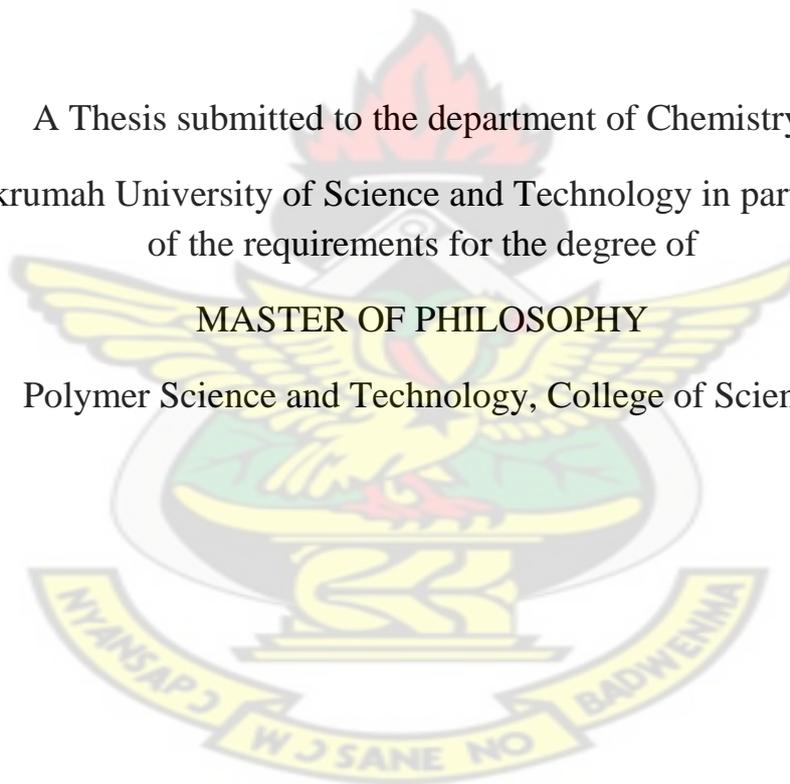
**PREPARATION AND CHARACTERIZATION OF WOOD PLASTIC
COMPOSITES USING RECYCLED (LDPE/HDPE) PLASTIC AND
SAWDUST**

By

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ABSTRACT

There has been a growing interest in Wood-Plastic Composite (WPC) products and their use in various applications over the past years. Increase in environmental awareness and the cheaper cost of raw materials are the main force driving the use of recycled plastics in making WPCs. Wood- plastic composites (WPCs) were fabricated using recycled HDPE/LDPE plastics and sawdust from Wawa and Mahogany (were fabricated). Part of the sawdust was treated with 5% NaOH solution before being used for the composite and the remaining was used without treatment. The FTIR of the treated as well as the untreated sawdust and the plastic were taken. The samples were made using extrusion and injection molding methods. The density and water absorption capacity of the products were determined. 50% loading, the treated mahogany-plastic composite absorbed (4.74%) the least amount of water compared to all the other formulations. The ultimate tensile strength and the modulus of elasticity (MOE) of the samples were also determined. At 10% loading, the treated mahogany-plastic composite had an ultimate tensile strength 35.54 MPa and modulus of elasticity of 3.25 MPa which are the highest among all. The results obtained showed that these properties are wood species dependent as the Mahogany-plastic composites gave the best properties compared to the Wawa and the mixture. This suggests a better adhesion between the hardwood filler and the HDPE/LDPE matrix compared to the softwood. The influence of the chemical treatment of sawdust on the physical and mechanical properties of sawdust-HDPE/LDPE composite was investigated at various loading levels from 10% up to 50%. Results indicate that the mechanical properties of the chemically treated sawdust-HDPE/LDPE composites were found to be higher than those of the untreated. This indicates that better dispersion of the filler with the HDPE/LDPE matrix has occurred upon chemical treatment of the filler. The water absorption test showed that composite prepared from the chemically treated sawdust

absorbed lower amount of water compared to the untreated sawdust composite. This suggests that hydrophilic nature of the cellulose in the sawdust has significantly decreased upon chemical treatment. The results clearly show that the properties of WPC depend on the wood species used and also the treatment given to the wood.

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DEDICATION

I dedicate this work to my sweet husband Mr. James Kermah and my beloved son Kwaku Nhyira Ninako Acheampong. I love you.

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All thanks and praise to the Almighty God for his immeasurable love for me. Thank you God, for you have brought me this far. Special thanks and gratitude to my supervisors Professor Victor Nana Berko Boateng and Doctor Godfred Darko for their patience, sincere guidance and endless support in making this work come to reality. God bless you. To my wonderful mother, Mrs. Mary Badu Yakass, I say God bless you for always been there for me. I would want to appreciate the contributions of all my siblings towards this work. To my niece, Theresa Dapaah, Thank you for helping me. To Luggard, I say God bless you brother for your help. My thanks also go to all the other lecturers in the department for their directions. To all my mates I say God bless you for your help and encouragements. To all the staff at the polymer laboratory at the Ghana Standards Authority, I say thank you for helping me with the tensile test. To everyone who contributed in making this work a success, God bless you.

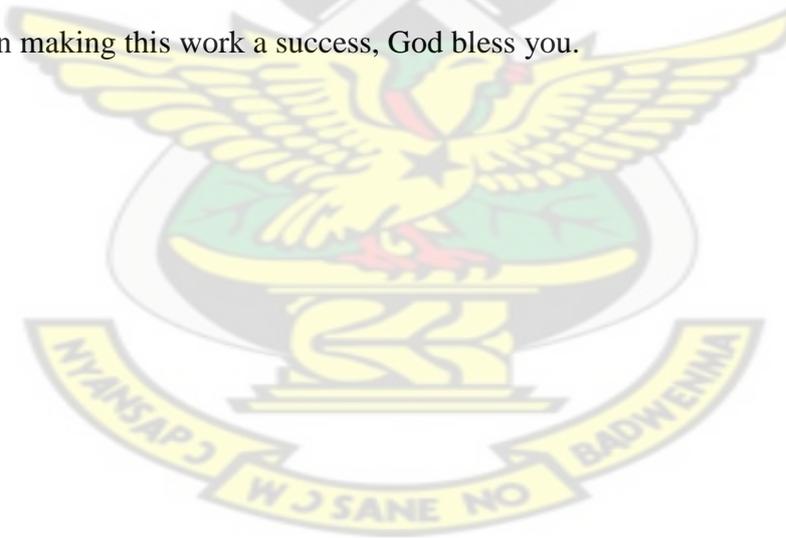


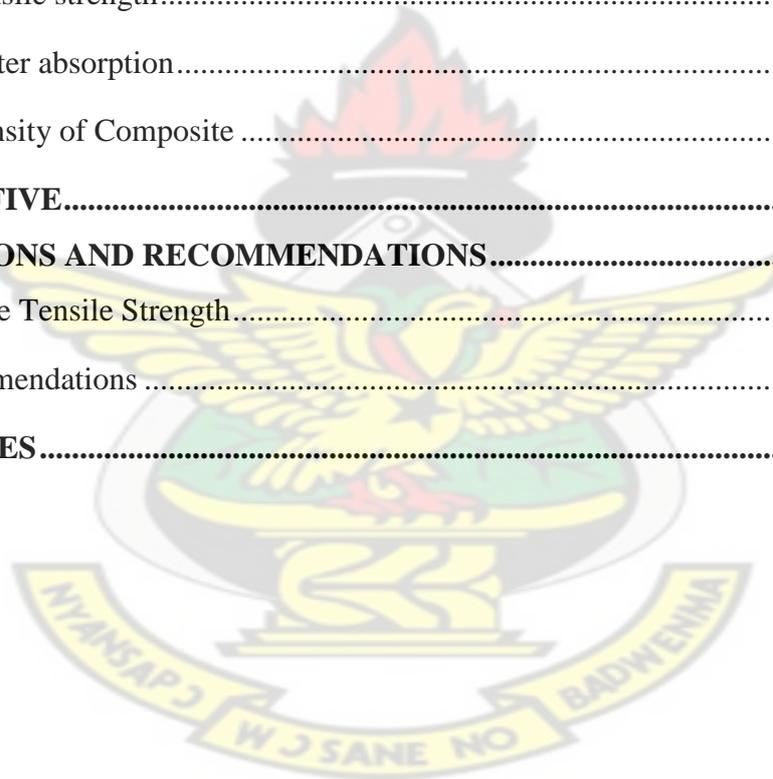
TABLE OF CONTENTS

DECLARATION	ii
ABSTRACT	iii
DEDICATION	v
ACKNOWLEDGEMENT	vi
TABLE OF CONTENTS	vii
LIST OF TABLES	xi
LIST OF FIGURES	xii
LIST OF EQUATIONS	xiv
CHAPTER ONE	1
1.1 INTRODUCTION.....	1
1.2 Background of the study.....	1
1.3 Problem Statement	3
1.4 Objectives	4
1.4.1 Main Objectives/goals	4
1.4.2 Specific objectives	4
1.5 Justification	4
1.6 Organization of Report.....	5
CHAPTER TWO	6
LITERATURE REVIEW	6
2.1 Introduction	6
2.2 Background	6
2.3 Development and History of Wood Plastic Composite (WPC)	7
2.4 Composition of Wood- Plastic Composite (WPC).....	11
2.4.1 Wood.....	11
2.4.1.1 Chemical Composition of Wood.....	11
2.4.1.2 Wood as filler	13
2.4.1.3 WAWA (Triplachiton Scleroxylon)	14
2.4.1.4 Mahogany.....	14

2.4.2	Plastics	15
2.4.2.1	Recycled Plastic as a Matrix for WPC.....	18
2.4.2.2	Properties of Recycled plastics	20
2.4.2.3	Melting point.....	21
2.4.3	Effect of Recycled Plastic on Tensile Properties of WPCs	21
2.4.4	Effect of Recycled Plastic on Hygroscopic Properties of WPCs.....	22
2.5	Characteristics of WPC	23
2.6	Applications of WPC.....	25
2.6.1	Building products.....	25
2.6.2	Infrastructures	26
2.6.3	Transportation.....	26
2.6.4	Structural Applications of WPCs.....	27
2.6.5	Engineering properties.....	27
2.6.6	Advantages of WPC.....	28
2.6.7	Challenges in WPC.....	28
2.7	Processing Techniques (Fabrication Of WPC)	30
2.8	Added Compounds	31
2.8.1	Chemical Treatment.....	32
2.8.1.1	Alkaline treatment.....	33
2.8.2	Influence of Coupling Treatment.....	34
2.8.3	Effects of Lubricants.....	37
2.9	Mechanical Properties of WPC	39
2.9.1	Factors that affect the mechanical properties of WPC	40
2.9.1.1	Effect of Wood Species on Mechanical Properties of WPC.....	41
2.9.1.2	Effect of wood filler loading on the properties of WPC	42
2.9.1.3	Effects of Particle Size on Properties of WPC.....	42
2.10	Thermal Behaviour.....	45

2.10.1 Thermal sensitivity	45
2.10.2 Thermal linear expansion.....	45
2.11 Water Absorption	46
CHAPTER THREE	50
METHODOLOGY.....	50
3.1 Materials	50
3.1.1 Post- consumer plastic sachet water	50
3.1.2 Sawdust.....	50
3.1.3 Chemicals and reagents	51
3.2 Equipments Used.....	52
3.2.1 Extruder	52
3.2.2 Injection Molder	53
3.2.3 Universal tensile machine.....	55
3.2.4 Sieve.....	55
3.2.5 Fourier Transform Infra-red Spectroscopy Analysis	56
3.3 Processing.....	56
3.3.1 Plastic.....	56
3.3.2 Wood Flour Preparation.....	56
3.3.2.1 Wood Flour Treatment (Modification with sodium hydroxide)	57
3.3.2.2 Sieving	57
3.3.2.3 FTIR	57
3.3.3 Specimen Preparation	57
3.3.3.1 Formulations for the composite preparation	57
3.3.3.2 Extrusion	58
3.3.3.3 Mold Used For Tensile Test.....	59
3.3.4 Mechanical testing	60
3.3.4.1 Stress	60

3.3.4.2 Strain	61
3.3.5 Density	61
3.3.6 Moisture absorption	61
CHAPTER FOUR.....	63
RESULTS AND DISCUSSION	63
4.1 Sieving.....	63
4.2 Chemical Properties- FTIR	64
4.3 Mechanical Properties	67
4.3.1 Stress – strain curves.....	67
4.3.2 Tensile strength.....	75
4.3.3 Water absorption.....	84
4.3.4 Density of Composite	88
CHAPTER FIVE.....	90
CONCLUSIONS AND RECOMMENDATIONS.....	90
5.1 Ultimate Tensile Strength.....	90
5.2 Recommendations	91
REFERENCES.....	93



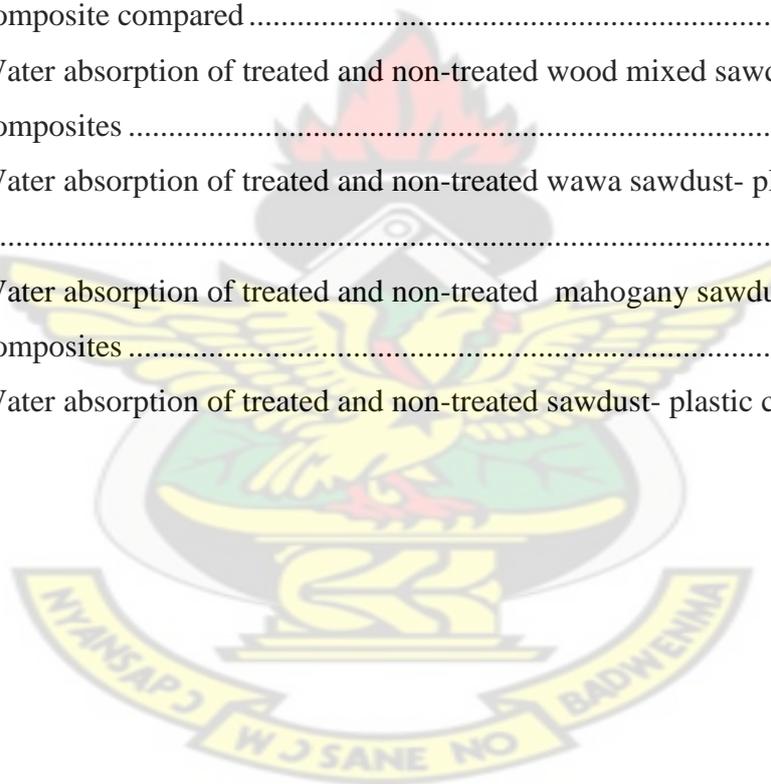
LIST OF TABLES

Table 2.1: Chemical composition of wood (Source (Gallagher 2006a)).....	12
Table 4.1 Tables for stress and strain for Untreated Wawa-plastic composite at 10% to 50% loading	68
Table 4.2 Tables for stress and strain for treated Wawa-plastic composite at 10% to 50% loading	69
Table 4.3 Tables for stress and strain for untreated Mahogany-plastic composite at 10% to 50% load levels.....	70
Table 4.4 Tables for stress and strain for treated Mahogany-plastic composite at 10% to 50% load levels.....	72
Table 4.5 Tables for stress and strain for untreated wood mixture-plastic composite at 10% to 50% loading.....	73
Table 4.6 Tables for stress and strain for treated wood mixture-plastic composite at 10% to 50% loading	74
Table 4.7 Tensile strength and modulus of Elasticity of treated and untreated mahogany plastic composite	77
Table 4.8 Tensile strength and modulus of Elasticity of treated and untreated Wawa plastic composite.....	79
Table 4.9 Tensile strength and modulus of Elasticity of treated and untreated Wawa- Mahogany mixture plastic composite.....	79
Table 4.10 Water absorption of treated and non-treated wood mixed sawdust- plastic composites	84
Table 4.11 Water absorption of treated and non-treated wood mixed sawdust- plastic composites	85
Table 4.12 Water absorption of treated and non-treated mahogany sawdust- plastic composites	86
Table 4.13 Densities of the various sawdust-HDPE/LDPE composite formed	89

LIST OF FIGURES

Figure 2.1 Chemical structure of cellulose	12
Figure 2.2: North American market share in 2003 of various thermoplastics in WPC	16
Figure 2.3: Percentage of individual plastic waste generated in Independence hall.....	19
Figure 2.4: Applications of natural fiber reinforced plastics in building products	25
Figure 2.5: Areas of applications of WPC in 2000 in Europe (Ashori 2008a)	26
Figure 3.1: Mahogany sawdust	51
Figure 3.2: Wawa sawdust	51
Figure 3.3: A table top extruder	52
Figure 3.4: Schematic diagram of a single screw extruder	53
Figure 3.5: A table top injection molder	54
Figure 3.6 Schematic diagram of a typical injection molding machine.....	54
Figure 3.7 Schematic diagram of Universal tensile machine.....	55
Figure 3.8: Tensile testing machine used for this work	55
Figure 3.9: A sieve	55
Figure 3.10 a picture of Bruker Alpha FT-IR Spectrometer.....	56
Figure 3.11: Strands of extrudate	58
Figure 3.12: Pellets of extrudate	59
Figure 3.13: The test specimen	59
Figure 3.14: Adaptor for the tensile bars	60
Figure 4.1 particle size distribution of the sawdust used	63
Figure 4.2 FTIR of treated and untreated mahogany sawdust	64
Figure 4.3 FTIR of treated and untreated Wawa sawdust.....	65
Figure 4.4 FTIR of the mixed wood sawdust.....	66
Figure 4.5 FTIR of the plastic water sachet	67
Figure 4.5 Stress – strain curves for the untreated Wawa and HDPE/LDPE composite	69
Figure 4.6: stress- strain curve for the treated Wawa and HDPE/LDPE composite.....	70
Figure 4.7: stress- strain curve for the untreated Mahogany and HDPE/LDPE composite	71
Figure 4.8: stress- strain curve for the treated Mahogany and HDPE/LDPE composite....	71
Figure 4.9: stress- strain curve for the untreated wawa-mahogany mixture and HDPE/LDPE composite	73
Figure 4.10: stress- strain curve for the treated wawa-mahogany mixture and HDPE/LDPE composite.....	74

Figure 4.11 Ultimate tensile strength of wawa, mahogany, and the mixture plastic composite compared	75
Figure 4.12: Ultimate tensile strength vs % Loading for Mahogany WF and HDPE/LDPE composite.....	77
Figure 4.13: Ultimate tensile strength vs. % loading for Wawa HDPE/LDPE composite.	79
Figure 4.14: Ultimate tensile strength of Mahogany and Wawa fiber mixture and LDPE/HDPE composite	80
Figure 4.15: Young’s modulus of treated and untreated Wawa – HDPE/LDPE composite compared	81
Figure 4.16: Young’s modulus of treated and untreated sawdust mixture	82
Figure 4.17: Young’s Modulus of treated and untreated Mahogany- HDPE/LDPE composite compared	82
Figure 4.18 Water absorption of treated and non-treated wood mixed sawdust- plastic composites	84
Figure 4.19 Water absorption of treated and non-treated wawa sawdust- plastic composites	85
Figure 4.20 Water absorption of treated and non-treated mahogany sawdust- plastic composites	86
Figure 4.21 Water absorption of treated and non-treated sawdust- plastic composites.....	86



LIST OF EQUATIONS

Equation 1 Tensile stress.....	60
Equation 2 Tensile strain.....	61
Equation 3 Density.....	61
Equation 4 Water absorption.....	62
Equation 5 Modulus of Elasticity.....	81

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CHAPTER ONE

1.1 INTRODUCTION

Composite is the combination of a matrix and a reinforcement, which when combined gives properties superior to those of the individual components (Ashori & Nourbakhsh 2009a). Wood plastic composite is therefore a combination of wood and plastic with the plastic as the matrix and the wood as the reinforcement.

Wood plastic composite, (WPC), can be made from virgin materials as well as recycled ones. This study looks at WPC made from recycled plastic and wood waste. In Ghana, plastic waste is enormous and its disposal has always been a challenge. In using recycled plastic for WPC, the advantages are that; raw materials are readily available, control the plastic waste menace and also save some virgin and natural products.

Substantial increase in human population and the consequential strain on natural resources such as forests and the associated harmful results as well as the plastic menace challenging the nation are some of the challenges that make the study of WPC important. The green mentality and the shift in attitude are favoring environmentally-friendly products such as WPC (Azadeh et al. 2011).

1.2 Background of the study

The use of plastics in the world and Ghana specifically is increasing daily due to the fact that plastic is cheap, light, flexible, easy to shape and recyclable (Wang et al. 2010). These properties and others make plastics find their way into the production of many products, from engineering, construction, domestic, electronics and many more products (Ziaei et al. 2011). Some plastic products are made to last longer after the end of life, while others are disposable. Disposable plastics are usually cheap and as such discarded after a first or

second use. Large volumes of waste plastic products are discarded daily in Ghana and are found in gutters, on the streets and market places if not collected. At the dump site and landfill sites, plastic waste cover a large space compared to the other waste product and their non-biodegradable nature worsen the situation. The three Rs (that is reduce, reuse or recycle) have usually been used to manage the plastic waste problem. In Ghana, only a small amount of the plastic waste generated daily is reused or recycled with the larger percentage going into landfill.

Several programmes and interventions such as the sensitization of the public on the use and littering of plastic waste, increment in taxes of sachet water producers (Alhassan et al. 2010) have aimed at solving the plastic waste menace but little emphasis has been placed on recycling though recycling has proven to be the best way to deal with the plastic waste. One way by which plastic can be recycled is the formation of composite with other substances such as natural fibers like wood (fiber, flour, and chips), sisal, jute, sugarcane, wheat and flax straw fiber.

WPCs can be used in several applications such as profiles, sheathing, Decking, Roof tiles, Window trim, automotive parts, stepping stones etc. Natural fibers such as wood are considered environmentally friendly and sustainable due to their renewability and biodegradability. Natural fillers have other added advantages over artificial fibers in the sense that they have low specific weight, high specific strength and stiffness, safer handling and working conditions; they are also non-abrasive to the processing equipment (Tong et al. 2014).

A composite made of wood and plastic is referred to as Wood Plastic Composite (WPC). A WPC combines the properties of plastic and wood that is the stiffness of wood and flexibility of plastics into unique properties better and different from that of plastic or

wood (Ashori & Nourbakhsh 2009a). Due to these properties, WPC can be used for materials with specific characteristics for specific purposes such as chairs and tables.

Some applications of WPC are profiles, sheathing, decking, roof tiles, window trims, automotive parts, stepping stones, and many others (Panthapulakkal et al 2006) in (Ashori 2008a). WPC's have many advantages such as; they do not rot, no need to paint, easy to shape, environmentally friendly, can be shaped to almost any design, can replace wood in many outdoor applications, can replace neat plastics in applications where the increase in stiffness is required, low cost of raw materials (Bengtsson & Oksman 2006). These properties have increased the demand for WPCs on the market therefore there is the need to improve up on the properties and performance of WPCs.

The WPC industries are growing very fast, the increasing environmental awareness and lower cost of materials seems to be the driving force. Several research works have been done into the improvement and performance of WPCs and others are still ongoing. The effects of material composition on the mechanical properties of WPC was studied by Kuo et al. (2009), effects of surface modification of wood flour on the properties of WPC has also been done by Dányádi et al. (2010a). Interfacial modification of WPC was done by Y. Cui et al. (2008).

This work looks at the effects of hard wood, soft wood and the mixture of hard and soft wood as fillers on the mechanical and physical properties of WPC. It will also look at the effect of NaOH treatment of the wood on the properties and then the different percentages of the filler and the matrix on the properties of the WPC

1.3 Problem Statement

Plastic waste is a huge challenge confronting this nation; due to the large volumes used and discarded every day and their non-degradable nature. Landfilling has usually been

used to dispose of plastic waste but has proved ineffective since it fills up the site quickly. Incineration of the plastic waste can also cause pollution. The need for effective and sustainable method to manage the menace is urgent. Recycling has proven to be the best way to solve the plastic waste problem. Other recycling methods have been used to manage the situation and this work offers an alternative mode of recycling plastic waste, which is the formation of WPC.

1.4 Objectives

1.4.1 Main Objectives/goals

- Determine the physic-chemical properties of the composite as a function of the compositional ratios
- Identify the compositional effect of wood species as well as sodium hydroxide treatment of the wood on the physical and mechanical properties of WPC fabricated from recycled HDPE/LDPE plastic and sawdust.

1.4.2 Specific objectives

- Fabricate WPCs from Wawa and Mahogany sawdust with recycled LDPE/HDPE plastic as the matrix by varying the percent composition of constituents.
- Prepare WPC from sawdust of Wawa and Mahogany pretreated with 5% NaOH solution and LDPE/HDPE plastic.
- Characterize and determine mechanical properties of the products formed.

1.5 Justification

Economically viable recycling and value addition to the plastic waste is of great urgency due to the increasing amount being generated each day. Composite formation is one of the many ways by which plastic waste can be recycled.

WPC products are gaining popularity around the world. Several works have been done on WPC with different plastics and wood waste at different percentages (Santos et al. 2013) . But little has been published on the wood specie used and its effects on the properties of products formed. Producing composite materials from recycled plastics water sachet and sawdust will help Ghana solve the problem of plastic waste. This is so because plastics water sachet take a larger percentage of the total plastic waste generated in Ghana daily. A research done by an undergraduate student at the Department of Chemistry KNUST reveals that out of the total plastic generated daily in one of the halls of residence, plastics water sachet take 32.56 % . A look around towns, on the streets, market places, gutters, and even dump sites in Ghana tells the story better. Some people resort to burning of the plastic which releases toxic substances such as dioxins, mercury and furan. When these toxins gets into the body leads to serious health implications, examples heart disease and can also aggravate respiratory ailments such as Asthma(Women in Europe for a Common Future 2012).

1.6 Organization of Report

This report has been grouped into six chapters. Chapter one is introduction which consists of the background, problem statement, the aim, specific objectives, justification of the study, scope of the study. Chapter two presents a review of available literature. Chapter three describes the research methodology. Chapter four present the results, the fifth chapter outlines the discussion while the sixth chapter presents the conclusions and the recommendations made.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The chapter starts with an overview of composites in general and the historic background of the development of WPC. The main components of WPCs, that are wood, plastics and coupling agents are discussed. An overview is given followed by aspects such as the advantages of WPC, their application and market share, processing techniques and current challenges. Some factors that affect the properties of WPCs are also discussed.

2.2 Background

Composite is a material formed with two or more components, combined as a macroscopic structural unit with one component as continuous matrix, and other as fillers or reinforcements. Normally, the matrix is the material that holds the reinforcements together and has lower strength than the reinforcements.

In the plastic based composites, the polymers, thermoplastics or thermoset, act as matrix and fibers of wood or other natural fibers as fillers. The reinforcing fibers are the main load-carrying component in the composites. The fibers provide high strength and stiffness as well as resistance to bending and breaking under the applied stress. Interface bonding between the fillers and the matrix is the key to transferring the stress from the matrix into the fillers across the interface. The interface adhesion between the polymer matrix and wood fillers can be improved using coupling agents.

The coupling agents will form a bond between the fibers and the matrix through the improved compatibility (wettability) and developing a mechanical or chemical bonding (Poletto et al. 2011). To achieve the required properties of the composites, properties of

both the fibers and the matrix are important although the extent of the influence of the fibers and the matrix may vary depending on the required properties of the composite.

The tensile strength of short fiber composite is more sensitive to polymer matrix properties, whereas elastic modulus is more strongly dependent on the fiber properties (Stark & Rowlands 2005). As WPC contained a low density plastic matrix reinforced with stiff wood fibers, polymer matrix is stretched more under the same stress compared to the fibers due to lower modulus than the fibers. Therefore, stiffness of the matrix has impact that is more significant on the overall stiffness of the composite and the stiffness of the composite is more sensitive to the properties of the matrix than the fillers.

2.3 Development and History of Wood Plastic Composite (WPC)

Composite materials are materials made from two or more constituent with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components (Ashori & Nourbakhsh 2009b).

The plastics used in WPC can be a thermoset which includes resins such as epoxies and phenolic or thermoplastic which includes polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), and polyethylene terephthalate (PET). In this thesis, WPC refers to wood-thermoplastic composite.

The use of thermoplastic materials such as PE and PP has a long tradition and even a longer tradition for the use of wood-based materials such as particleboard and fiberboard. WPC has emerged as the new material which is the combination of plastic component and wood based component (Segerholm 2012b).

The first generation of WPC's which were produced in the 1900s were a combination of recycled wood flour and a binder for relatively undemanding applications (Rowell & Youngquist 1991).

An earlier commercial composite material marketed under the trade name "Bakelite", was made of phenol – formaldehyde and wood flour (Mantia & Morreale 2011a). Its first commercial use was reportedly as a gearshift knob for Rolls Royce in 1916 (Clemons 2000b).

The birth of the WPC industry involved the interfacing of two industries that have different knowledge, expertise and perspectives (Mantia & Morreale 2011b). The plastics industry has knowledge of plastics processing and the forest products industry has more experience and resources in the building products market (Meran et al. 2008). It is not surprising that, some of the earliest companies to produce WPC's were window manufacturers who had experience with both wood & plastics (Kokta et al. 2010).

On one hand, the plastic industry sees in wood a relatively inexpensive filler that is readily available which can enhance mechanical properties such as stiffness and processing conditions such as increased profile extrusion rates. On the other hand, the forest industry see plastics as means to make innovative construction materials with characteristics that wood does not have; for instance resistance to environmental adversities such as moisture and insect attacks (Caufield et al. 2007b). It is also mentioned that almost all WPC can be machined, sanded, stained, and fastened in the same manner as wood without needing any further technologies (Semeralul 2009a).

The plastics industry has traditionally used inorganic fillers such as talc, calcium carbonate, mica, and glass fiber to improve the performance of plastics (Meran et al. 2008). Natural fibers such as wood, kenaf, flax and hemp were later introduced as fillers

because these are renewable resource, less expensive, lighter and less abrasive on processing equipment (Meran et al. 2008).

In 1991, the First International Conference on Wood fiber Plastic Composites in Madison, Wisconsin was convened with the intent of bringing together researchers and industrial representatives from both the plastics and forest products industries to share ideas and technology on wood fiber-plastics composites. Similar conferences in alternating years began in Toronto, Ontario, the following year. These conferences grew steadily in the 1990s (Youngquist et al. 1994a; Meran et al. 2008).

Through several researches, the new generations of WPCs have good physical and mechanical properties, high dimensional stability and can be used to fabricate complex shapes. These properties make WPCs high technology products and can be used in many applications.

The most common type of the new WPC's are produced by mixing wood flour or fiber and plastics to produce a material that can be processed like a conventional plastic, but has the best features of wood and plastics (Meran et al. 2008). The conversion and efficient use of wood fiber resources, producing more fiber on a shrinking land base, using environmentally friendly processes and technologies, and remaining competitive in the global market place was the main aim. Competition in high volume markets has focused attention on low priced materials that offer a more favorable strength to weight ratio (Clemons 2000a).

Compared to other polymeric materials, wood plastic composite (WPC) has the lowest material cost (Rowell & Youngquist 1991). Wood plastic composites are an attractive alternative because their manufacturing process is highly automated and adaptable to various species and forms of raw materials (Ashori & Nourbakhsh 2009b).

Sometimes wood is not considered as an engineering material because it does not have consistent, predictable, reproducible, continuous, and uniform properties. This might be true for solid wood but is not necessarily true for composites made from wood (Rowell & Youngquist 1991).

The importance and growing potential of wood plastic composites were evidenced in 1991 by the advent of the international conference on wood fiber-plastic composites, a forum on the science and technology for the processing and development of these materials (Anon 2009). The use of fillers by the plastic industry has grown steadily along with the growth in the production of major classes of plastic resins.

In 2000, Clemons reported that over the last 10 years, the WPC industry has grown rapidly due to the growing deck market. The majority of this growth has occurred in extruded profile forms, but it has also occurred in injection molded and compression molded products as well (Clemons 2000a). The growth in WPC applications has spurred an increase in the endeavors of individuals both in industry and academia (Gallagher 2006a).

The wood materials and engineering laboratory at Washington State University has directed an interdisciplinary and inter institutional research program for the development of HDPE (high density polyethylene)- and PVC-wood composite materials for use in waterfront structures. A major research and development effort is centered on waterfront applications for Navy facilities (Clemons 2000a).

WPC is being investigated to replace treated timber currently used to support piers and absorb the shock of docking ships. The material development component of the Navy project is focusing on evaluation and improvement of existing wood-plastic composite technologies as well as developing novel systems appropriate to the production of pier structural components (Sobczak et al. 2012).

2.4 Composition of Wood- Plastic Composite (WPC)

Wood-plastic composite combines the properties of wood and plastic. Basically WPC contains wood (flour, fiber, or chips), polymer matrix and some additives such as; pigments, antimicrobials, light stabilizers and coupling agents. These materials are used in varying content and are processed using the same techniques as neat thermoplastic polymer.

2.4.1 Wood

Wood is used for building materials, furniture, tools, and vehicles and as raw materials for paper, timber, and many others. Wood is a nature's composite material since it consists of cellulose structure in a matrix of lignin, hemicelluloses and extractives. There are several different wood species in the world and depending on the species and growth conditions, variations can occur in the properties and quantity of wood constituents and cell structure.

All the wood species are divided into two main classes; namely, softwoods and hardwoods. In botany, softwoods are referred to as gymnosperms and are mostly conifers such as pine and cedar. Hardwoods are angiosperms, mostly broadleaf, deciduous trees such as mahogany and maple. The cell structure of hardwood and softwood differ. Generally hardwoods have more complex structure and a larger number of different kinds of cells than softwoods.

2.4.1.1 Chemical Composition of Wood

The main constituents of wood are cellulose, hemicelluloses, lignin and extractives. The amount of each constituent in softwood and hardwood are presented in Table 2.1.

Table 2.1: Chemical composition of wood (Source (Gallagher 2006a))

COMPONENT	SOFTWOOD	HARDWOOD
Cellulose	42 ± 2 %	45 ± 2 %
Hemicellulose	27 ± 2 %	30 ± 5 %
Lignin	28 ± 2 %	20 ± 4 %
Extractives	3 ± 2 %	5 ± 3 %

Cellulose determines the character of fiber and as such the most important component in the wood. Cellulose has a chemical formula $(C_6H_{10}O_5)_n$ where n is the number of repeating sugar units or the degree of polymerization, DP. The repeating unit consists of two glucose molecules. The DP varies depending on the cellulose source and the treatment it has received (Hietala 2013a). The properties of cellulose depend on the DP of cellulose molecules.

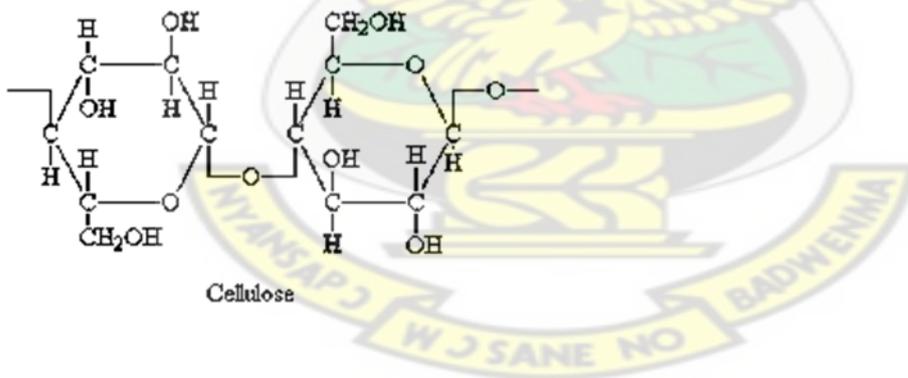


Figure 2.1 Chemical structure of cellulose

Hemicelluloses are branched heterogeneous polysaccharide comprising five different sugars: glucose, mannose, galactose, xylose, and arabinose. Hemicelluloses have lower molecular weight and lower DP than cellulose. It degrades and dissolves more easily than cellulose.

Lignin is amorphous polymer with a very complex structure. The primary function of lignin is to form the middle lamella and glue the fibers together. It does not greatly affect the mechanical properties of wood flour, yet it plays a central role in binding the cellulose fibrils that allow efficient stress transfer to the cellulose molecules.

Apart from cellulose, hemicellulose and lignin, different kinds of substances, e.g. resin acids, fatty acids, turpenoid compounds and alcohols, are also present in wood. These substances are called extractives, and they are responsible for wood properties such as color, odor, taste, decay resistance, density, hygroscopicity and flammability. They are called “extractives” because they can be removed from the wood by extraction with solvents.

2.4.1.2 Wood as filler

The advantages of wood as filler are: it is light in weight, very cheap, environmentally friendly, renewable, recyclable, and biodegradable. In spite of all these advantages, there are some drawbacks in using wood as filler. The poor interfacial adhesion between hydrophobic matrix (plastic) and the hydrophilic nature of the wood is a major problem.

The wood fillers and the plastics are not compactible enough to produce products with required properties for specific purposes particularly when resistance to breakage is required. The incompatibility is as a result of the polarity difference since the high -OH groups in the wood makes it hydrophilic and the plastic hydrophobic (Bodirlau et al. 2009b).

Researchers have identified some ways by which the adhesion between the polymer matrix and the wood filler can be improved. These are: addition of coupling agents (Kord et al. 2011), and modification or chemical treatment of the wood filler (Cui et al. 2008; Dányádi et al. 2010a).

The wood used as fillers can be a flour, fiber or chips. The size of the particles used in the composition and the amount used has also been identified to have effects on the properties of the WPC (Azad & Tajvidi 2009).

Sawdust as used in this work is a wood waste which is in the form of flour. Heaps of sawdust can be seen around sawmills and wood companies, though biodegradable; it contributes to the total waste generated. The two woods used in this work were Wawa (*Triplochiton Scleroxylon*) and Mahogany (*Swetenias mahogany*).

2.4.1.3 WAWA (*Triplochiton Scleroxylon*)

Wawa or Obeche has a creamy-white to pale yellow color with no demarcation between the sapwood and the heartwood. It is a light, fairly soft wood but firm and fine with even fine texture. It grows throughout West and Central Africa.

The working properties of Wawa are; it has very low stiffness and resistance to shock. It has moderately to poor steam bending properties. It is easy to work with hand and power tools. It takes glue well, and paints well with normal primers, nails easily, polishes well and stains well.

2.4.1.4 Mahogany

A straight-grained, reddish-brown timber with three tropical hardwood species of the genus *Swietenia*. The three species are; (1) Honduras or big-leaf mahogany - *Swietenia macrophylla*, (2) West Indian or Cuban Mahogany - *Swetenias mahogany*, and (3) *Swetenia humili* (Mahogany," Encyclopedia of Environmental Science 2000, ed. John F. Mongillo), p. 216.)

S. mahogany grows on the West Indian islands as far north as the Bahamas and Florida. *S. humilis* grows in dry regions of the Pacific coast of Central America. *S. macrophylla*

grows in Central America. All these species grows in Africa. (Samuel Bridgewater. A Natural History of Belize: Inside the Maya Forest (2012, Natural History Museum), 164-65.)

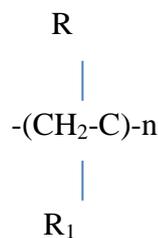
Mahogany is a commercially important lumber because of its beauty, durability and colour. It is used mainly for paneling, furniture, boats, musical instruments and many other items. It has an excellent workability, durable and can also resist rot.

2.4.2 Plastics

Plastics can be divided into two categories, either thermoplastics or thermosets. Thermosets, as the name implies, become set and rigid once the resin is heated or catalyzed and cured (Segerholm 2012a). Thermoplastics, on the other hand, can be reprocessed by heating to induce viscous flow and when cooled it sets into the desired shape (Segerholm 2012a).

Thermoplastics morphology can be subdivided into amorphous (highly disordered) or crystalline (highly ordered), although polymers are rarely one or the other but a combination of the two. The molecular organization of these amorphous and crystalline parts plays a crucial role in the properties of the polymer (Segerholm 2012a).

Polyolefin are of particular interest in the area of wood plastic composites. Polyolefin have a basic formula that represents its chemical composition consisting of carbon and hydrogen:



Thermoplastics are those that get soften when heated and can be reheated and reshaped. Thermoset on the other hand become hard when heated and cannot be reheated or remolded. Because thermoplastics can be reheated, it can be easily recycled without any difficulty. Examples of thermoplastics are polypropylene (PP), polyethylene PE (high density, HDPE or low density LDPE), polyethylene terephthalate (PET), polyvinyl Chloride (PVC), and polystyrene (PS).

Other matrices that have gained increased interest in recent years are so-called bioderived plastics, e.g. cellulose esters and polylactates, which are made partly or fully from renewable resources.

Plastics account for 15 - 20% by weight of Municipal Solid Waste (MSW) in Ghana (Alhassan et al. 2010). Of the plastics mostly used, polyethylene (PE) is the largest (about 50% by weight ie, both high and low density) followed by polypropylene (PP), which accounts for about 15 %, polyethylene terephthalate, about 14 %, PS is about 11% and the uncoded and the others accounts for the rest. Figure 2.2 shows the percentage of plastics used in North America as at 2003 and the percentage keeps on increasing.

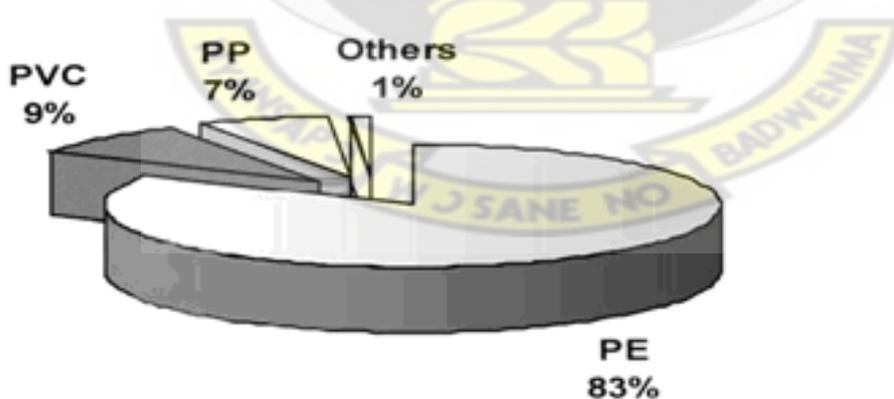


Figure 2.2: North American market share in 2003 of various thermoplastics in WPC (Semeralul 2009b)

Plastic products used for packaging are often discarded after a single use, resulting in a large supply of waste plastic materials. Most plastics in use today are thermoplastics, which mean that the material can be melted and reshaped.

Most thermoplastics are highly suitable for mechanical recycling. Numerous studies have shown that the important properties of the most common plastics are fairly well preserved throughout several cycles of processing and ageing (Najafi 2013; Wechsler et al. 2008a; Ashori & Nourbakhsh 2009b).

In WPC, either virgin or recycled plastic can be used. Of these, polyethylene, a semi-crystalline polymer, is the most commonly used in both recycled and virgin forms. Polyethylene comes in several forms, the most common of which are low density (LDPE) and high density (HDPE) forms. LDPE has a high percentage of amorphous regions, making it flexible and rubbery, and thus used in grocery bags and coatings. HDPE has a more crystalline structure, making it stiffer and stronger than LDPE, and is suitable for more demanding applications.

Common uses include films, injection molded products, and milk jugs. The chemical structure of PE is a repeating units of $-(CH_2-CH_2)-$. PE is also classified according to its melt viscosity or melt flow index (MFI), which are reflections of its molecular weight.

Different molecular weights are used in different processing techniques. For example, injection molding requires low melt viscosities, while extrusion requires higher melt viscosities. PE is used in almost all thermoplastic processing and has an enormous amount of applications (Youngquist et al. 1994b).

In this work, post-consumer water sachet is used. Water sachet plastic is made from the combination of HDPE and LDPE. Currently, polyethylene is the most attractive

thermoplastic in making wood plastic composite. This is due to its substantial percentage volume in the main stream waste and its high resistance to atmospheric and biological agents (Chaharmahali et al. 2010).

2.4.2.1 Recycled Plastic as a Matrix for WPC

Recycled and waste thermoplastics present a promising raw material source for WPC because they are some of the major components of global municipal solid waste (MSW) and especially because of the large volume and low cost of these materials. According to Ashori 2008, waste plastics account for 11.2% of the annual 84.2 thousand tons of the municipal waste stream generated in Tehran during 2006. EPA, 2011 also reported that 12.4% of 250 million tons of MSW in the USA in 2010 were plastics.

From a studies conducted at the KNUST campus, high density polyethylene (HDPE), low density polyethylene (LDPE/LLDPE), polypropylene (PP), Polyethylene terephthalate (PET), polystyrene (PS) and polyvinyl chloride (PVC) are the primary constituents of plastics in MSW. Figure 2.3 shows the summary of the work done at KNUST. The blend of the mixed waste plastics can be changed depending on the regional habits and seasons of a year and on the mode of waste collection (Najafi 2013), also Achankeng (2003) shows that only about 12.4% of plastic waste generated are recycled.

Table 4.2: Summary of derivations obtained from data

	WASTE/kg	PET/kg	HDPE/kg	PVC/kg	LDPE/kg	PS/kg	PP/kg	OTHERS/kg	UNCODED/kg	SACHET WATER/kg
Total mass	4093.794	91.38	40.59	0.856	79.84	68.92	92.23	30.66	8.12	199.21
Average mass	341.1495	7.61	3.38	-	6.65	5.74	7.69	2.55	0.68	16.60
Plastic%	14.94	14.94	6.63	0.14	13.05	11.11	15.07	5.17	1.33	32.56

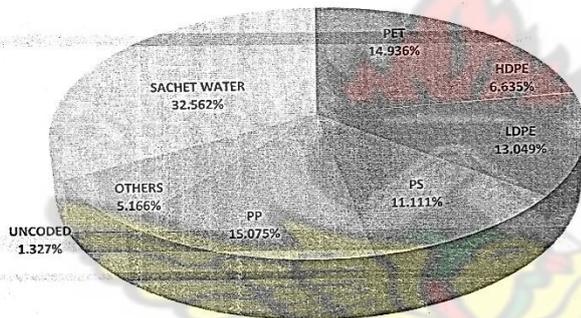


Figure 4.5: Percentage of individual plastic waste generated in Independence hall

Figure 2.3: Percentage of individual plastic waste generated in Independence hall

(Source: unpublished undergraduate work at KNUST by Osie Bonsu Eric (2013).

Reutilizing the post-consumed polymeric materials reduces the environmental impact and the consumption of virgin plastics (Najafi 2013). Most single polymer plastics made from petroleum are relatively easy to recycle. Therefore, with an efficient collection, separation and recycling system, discarded plastics can be recycled into new products with only the addition of energy (Jayaraman & Bhattacharyya 2004).

Products manufactured from waste plastics for use are increasing, including floor carpets, flower vases, waste paper baskets, park benches, picnic tables (Caufield et al. 2007a). Also, recycled plastics can be used in wood plastic composites (WPCs), which use will provide an additional market for recycled plastics.

Generally in WPC manufacturing, virgin thermoplastic polymers are widely used. The most prevalent polymers are PE, PP, PVC and PS. The waste and recycled plastics have been used for manufacturing WPCs already in 1990s and the use has significantly increased in the developed and developing countries in recent years.

By knowing the properties of recycled plastics, the processes for manufacturing WPCs can be well controlled and then the relationship between the properties of recycled plastics and their mechanical aspects can be better understood as well as those of the resulted WPC products (Najafi 2013).

2.4.2.2 Properties of Recycled plastics

If the recycled plastics are considered as new materials in WPCs production, it is necessary to understand well the elemental and fundamental structure of these materials. At the end of the first life cycle of plastic products, or after being re-used several times, plastics can be recycled to yield new polymeric materials or products. Since recycled plastics may be obtained from various sources, having been exposed to different storage and reprocessing conditions, they may therefore exhibit different performance depending on their degradation level (Najafi 2013). Then the post-consumer plastics waste may contain many grades, colors and contaminants, leading to varying outcomes when these plastics are combined with wood flour or fillers.

Plastics degradation is a problem that frequently occurs when a polymer is submitted to a process or service. According to the mode of initiation, the following types of degradation

can be distinguished: thermal, chemical, mechanical, and biological (Najafi et al. 2013). The properties of waste plastics are important in WPCs manufacturing, because the properties of WPCs are a function of the plastic properties. One of the properties of plastics that can affect the properties of WPCs is melting point.

2.4.2.3 Melting point

To enable a thermoplastic flow, it needs to be heated above its melting point. Any recycled plastics which can melt and be processed below the degradation temperature of wood or other lignocellulosic fillers (200°C) are usually suitable for manufacturing WPCs (Anon 2008). Najafi et al (2006) reported that no significant differences were observed in the melting points of virgin and recycled plastics, but in some cases the plastic waste that contains any impurities and additives may have a melting point above 200 °C (Najafi et al. 2006)

Melting points are critical when the recycled plastics are a mixed waste of different polymers with a different melting temperature. In such a case, the melting point is not a point but a distribution of temperature. The plastics with a lower melting temperature flow faster than those with a higher melting point; thus the final product will be heterogeneous.

2.4.3 Effect of Recycled Plastic on Tensile Properties of WPCs

Tensile and flexural properties of wood/recycled plastic composites have been studied by some authors. Youngquist et al (1994) compared the mechanical properties of the WPCs made from two types of recycled PP and two types of recycled fibers (waste newspaper and old magazines). They observed that the mechanical and physical properties of the WPC made from recycled materials were similar to the one made from virgin materials (Youngquist et al. 1994c).

Najafi et al (2006b) found that the flexural and tensile properties of specimens containing recycled plastics (HDPE and PP) are statistically comparable to those composites made of virgin plastics. The composite containing recycled PE and recycled PP blend exhibited statistically a higher flexural modulus compared to those made of mixed virgin plastics (virgin PE/virgin PP) (Najafi et al. 2006).

Ashori & Nourbakhsh (2009) investigated the tensile and flexural properties of the composites made from recycled plastics and old newspaper fibers. The results indicate that the composites with recycled HDPE provide moderately superior properties as compared to recycled PP samples (Ashori & Nourbakhsh 2009a). Adhikary et al. (2008a) have shown that the mechanical properties (flexural and tensile properties) of the composites made from post-consumer recycled HDPE are similar to or, in some cases, better than the composites made of the virgin HDPE (Kamal B Adhikary et al. 2008a)

2.4.4 Effect of Recycled Plastic on Hygroscopic Properties of WPCs

The most important characteristics of WPCs exposed to environmental conditions are water absorption and the consequent thickness swelling. Therefore, the hygroscopic characteristics have to be taken into account in the design of WPCs for their final application as limiting parameters. Some research works have been done on water absorption of WPCs made of virgin plastics as well as recycled plastics (Wietzke et al. 2010; Hosseinhashemi et al. 2011; Najafi et al. 2007).

Najafi et al. (2006) found that the maximum water absorption and diffusion coefficients of WPCs of recycled plastics (PP or HDPE) are higher than those made of virgin plastics. WPCs made of the mixture of recycled PP and recycled HDPE exhibited the highest water absorption and diffusion coefficients. Water absorption of the composites was proved to follow the kinetics of a Fickian diffusion process (Najafi et al. 2006).

Short-term water absorption of wood plastic composites (WPCs) produced from sawdust and virgin and recycled plastic (HDPE and PP) was studied by Najafi et al. (2007). The results showed that water absorption of WPCs made of recycled plastics is higher than those made of virgin plastics and those made of a mixture of recycled PP and recycled HDPE exhibit the highest water absorption.

Cui et al. (2011) showed that the composites made from the recycled plastics show comparable water absorption and thickness swelling to the composites made of the virgin plastics. However, with the incorporation of the coupling agent in the composite formulation the water uptake and thickness swelling can be reduced significantly (Cui et al 2011).

Adhikary et al. (2008) also showed that the wood plastic composites containing 50% by weight of recycled HDPE have lower water absorption and thickness swelling compared to those made of 50% virgin HDPE. The composites containing a mixture of recycled HDPE and PP exhibit the highest swelling parameter rate (Adhikary et al. 2008).

2.5 Characteristics of WPC

Composite materials are materials made from two or more constituent with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual (Aadullah 2009) .

The engineering importance of a composite material is that two or more distinctly different materials combine to form a composite material that possesses properties that are superior, or important in some other manner, to the properties of the individual components (Najafi 2013). The use of lignocellulose filler – thermoplastic polymer bio-composite for different application has been rapidly increasing since the 1990s (Wechsler & Hiziroglu 2007). The main use of WPCs currently is in the building and construction to

replace impregnated wood in outdoor application such as decking, railings and window and door frames (Hietala 2013b). The initial growth of WPCs as a building material was in the decking market, other profile products for example siding, fencing, and piling also exists to a lesser extent (Clemons 2000a).

In WPC the polymer matrix forms a continuous phase which surrounds the wood component. Wood has low thermal stability and as such only polymers with processing temperatures below 200°C are used in WPCs. Mostly low-cost commodity thermoplastics which flow easily when melted are used. Examples are polyethylene (PE), polypropylene (PP), and polyvinyl Chloride (PVC) (Najafi et al. 2007).

The properties of WPC vary considerably. The individual properties of the wood and the plastic determine the properties of a WPC. Stiffness is influenced by the form, size, dispersion and content of the wood (Hietala 2013b). The interfacial adhesion between the wood and matrix determines the strength, moisture uptake and long-term properties of the WPC (Ghasemi & Farsi 2010a).

Wood component enhances the stiffness of the polymer matrix, but also increases brittleness. WPCs are less stiff compared to solid wood but the fungal resistance and dimensional stability of WPC are better than that of solid wood. This is because, WPC absorbs water slowly due to the polymer matrix (Hietala 2013b). However, mechanical properties such as creep resistance, stiffness and strength are lower than the solid wood (Adhikary et al. 2008b).

In WPC the true performance is determined by the type of components, the amount of each component, and the technology used to manufacture the product. The type of plastics, wood, and additives, and the amount of each component as well as processing parameters will greatly impact the final product (Youngquist, 1999).

2.6 Applications of WPC

Ashori (2008) mentions the obvious fact that industries are always on the lookout for innovative materials and improved processes to produce better products to increase their profit margin and keep their technological edge. Therefore, it is not surprising to see WPC being used in large applications from aerospace to electronics (Ashori 2008)

2.6.1 Building products

The building products are the largest market for WPCs which include decking, fencing, garden furniture, exterior windows and doors etc. As compared to solid wood, WPCs have advantages of lower maintenance, higher durability, and more resistance to warping and splintering. Since WPCs usually have lower mechanical properties than solid wood, it is not suitable for application where strength and stiffness are critical. In 2000, a survey conducted in the Europe show that about 31% of WPC is used in the automotive as shown in figure 2.6. Figure 2.4 shows some building products made from WPC.



Figure 2.4: Applications of natural fiber reinforced plastics in building products (Farsi 2000).

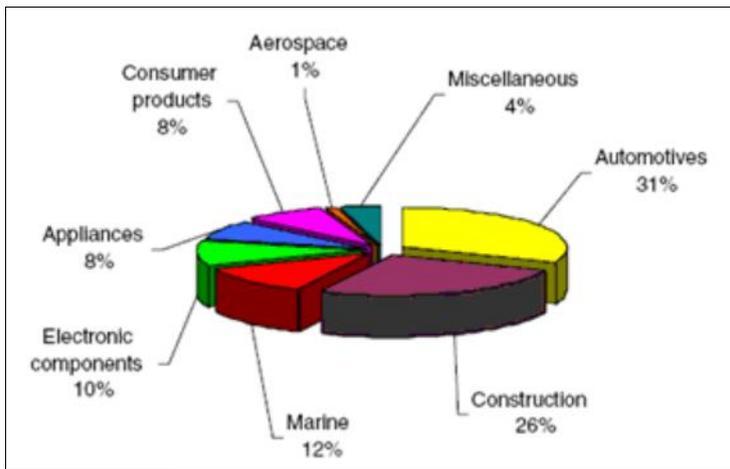


Figure 2.5: Areas of applications of WPC in 2000 in Europe (Ashori 2008a)

2.6.2 Infrastructures

Marine use and railroad cross-ties are major applications of WPCs in infrastructure sector. As WPCs do not contain toxic preservatives that may leak into seawater and cause environmental problems, the WPCs can replace the preservative-treated lumber for marine use. This has great potential because high quality wood is becoming less and less available because of restriction on the logging of native species and tropical hardwood. Also the WPC use for railroad cross-ties appears to be suitable due to the stable and durable properties under tough conditions.

2.6.3 Transportation

Automotive and highway applications of the WPCs are also found in the transport sector where the WPCs are used as substrates for interior of door panels, roof headliners, seat backs, spare tone covers, and trunk-liners in automobiles (Youngquist et al. 1994b). Highway applications include the highway signs, noise barrier, guardrail posts, and fence posts.

2.6.4 Structural Applications of WPCs

All materials or products must be evaluated to ensure that they will perform adequately in their end-use application. For wood fiber-thermoplastic composites, important characteristics requiring evaluation include ultraviolet light durability, engineering properties, creep, and thermal effects (English & Falk 1996). Testing, design, and evaluation standards are needed to measure and maintain the required performance.

Durability of WPCs can be enhanced by ultraviolet light stabilization of the polymer and a complete encapsulation of the wood component. Depending on the surface condition of the composite element, paints and other finishes may enhance durability as well. Properly manufactured, and properly specified, wood fiber-plastic composites should have excellent durability in exposed conditions (Caufield et al. 2007a).

2.6.5 Engineering properties

Performance requirements for structures and structural components are expressed in terms of designated design loads and displacements; therefore, characterization of structural performance must encompass these two aspects of product, component, or system behavior. In designing any product, the first concern is the capacity to resist expected loads safely (English & Falk 1996).

The second concern is to ensure that the product performs within acceptable limits of serviceability (usually short- and/or long-term deflection) when subjected to loads not exceeding the design load. For example, to be used in building construction, wood-plastic composite products must be able to resist a design load with a low probability of causing member failure and a stiffness sufficiently high to meet acceptable limits.

The design load can be established through short-term engineering strength and stiffness testing as well as long-term creep and duration of load evaluation. One difficulty in

determining design loads for wood-plastic composites is the tendency for the test specimens to deform excessively before failure.

2.6.6 Advantages of WPC

Some of the advantages of using WPC in the auto industry are: reduction in material weight and energy consumption, enhancement of acoustic performance and processing time, lowering production cost, improving safety and shatterproof performance under extreme temperature changes, and improving biodegradability of the auto interior parts (Thompson et al. 2010). WPC are used as trim parts in dashboards, parcel shelves, seat cushions, backrests, door panels and cabin linings.

Jiang & Kamdem (2004) further explain the cost advantage of WPC by stating that wood fiber is one of the lower-cost fillers for plastics. The average market prices of wood fiber is less than one-tenth that of glass fibers and is comparable to other low-cost inorganic fillers, such as talc and calcium carbonate.

2.6.7 Challenges in WPC

Rowell & Youngquist (1991a) admitted that there are challenges that need to be addressed before WPC can reach its full potential. A major source for these challenges is the fact that WPC involves two different types of industries. The plastic industry is accustomed to high flowing, high temperature processing conditions, something that the wood/agricultural industry is not really familiar with. Also, shrinkage and swelling in the plastic industry is normally due to temperature; while the biomass in the WPC shrinks and swells due to moisture (Semeralul 2009b).

(Jiang & Kamdem 2004) further discuss the challenging issues with WPC in their review on the research and technical development of WPC made of PVC and WF. The natural phase incompatibility between the non-polar, hydrophobic thermoplastic and the polar,

hydrophilic wood causes a weak interface between the matrix and the filler. Furthermore, the dispersion of the fillers in the viscous matrix is hindered by strong wood-wood interactions resulting from the physical entanglement of the fibers, the polar nature of wood and the hydrogen bonding.

The wood fibers usually contain 8 to 12% moisture, which under normal plastic processing temperatures will evaporate and swell the polymer melt, and result in inconsistent flow, irregular foaming and defects and voids inside the product (Bledzki & Faruk 2006).

Furthermore, wood also has both low thermal stability and bulk density along with wide particle size range, causing problems with feeding and conveying while processing (Semeralul 2009b).

Another major challenge in processing WPC is thermal degradation. This is due to the fact that the rate of thermal decomposition of lignocelluloses increase exponentially with an increase in temperature (Semeralul 2009b). Typical processing temperatures of WPC are in the range of 180–200°C which is enough for decomposition of wood to occur (Georgopoulos et al. 2005). Such decomposition of the lignocellulose creates volatiles which generate voids in WPC, thereby diminishing their mechanical properties. Georgopoulos et al (2005, further added that thermal degradation of the fibres in WPC leads to poor organoleptic properties (such as poor colours and odours) and generates gaseous products when processing takes place at temperatures above 200 °C. Such changes and emissions create low density, high porosity, and consequently reduced mechanical properties.

2.7 Processing Techniques (Fabrication Of WPC)

Processing of wood-plastic composite typically consists of three steps: 1) wood raw material processing, 2) compounding and 3) molding of the products by injection molding, profile extrusion or compression molding. The purpose of the wood processing step is to increase the value and quality of the wood raw material by separating it into different sizes and species and drying it before the compounding step. There are also wood fiber companies which provide pre-processed wood fibers for many applications.

In the compounding step the actual composite is manufactured by blending the reinforcement with the matrix polymer. Some of the compounding processes are easy, like using pre-compounded materials in a single screw extruder while others are complicated like compounding in one step in a twin-screw extruder (Youngquist et al. 1994b).

The manufacturing techniques of WPC are mainly based on existing methods for processing plastics and other composite materials. These techniques include press molding, compression molding, extrusion, and injection molding. The majority of current WPCs, that have thermoplastic matrices mainly use compounding and extrusion in their manufacturing methods. During compounding, the thermoplastic polymer is heated until it melts either by an external heat source or as a result of mechanical shearing in the extruder.

The wood flour, along with other additives, are then added and thoroughly mixed to obtain a homogeneous mixture. Once the ingredients have been thoroughly mixed, the compound can be extruded directly into the final form or pelletized and collected for further extrusion or injection molding processes (Semeralul 2009b).

Typically, a twin-screw extruder is used in the compounding. The compounded material can be immediately pressed or shaped into an end product or formed into pellets for

further processing. Examples of the twin-screw extruders are; parallel co-rotating, conical counter-rotating and parallel counter-rotating. The products can be manufactured using sheet or profile extrusion, injection molding, calendaring, thermoforming or compression molding.

Most WPCs are made by profile extrusion, in which the molten composite is forced through a die of specific shape to produce a continuous profile (Hietala 2013b). These kinds of products are mainly used in building materials, such as decking boards. When more complex shapes are wanted, other methods such as injection or compression molding can be used.

A variety of extruder types and processing methods are used in the production of WPC. For example, some processors use single-screw extruders to produce the end product from compounded pellets, whereas some compound and shape the final products in one step using twin-screw extruders. This kind of processing is also called direct extrusion (Hietala 2013b). In direct extrusion either profiles or sheet materials for compression molding can be manufactured.

2.8 Added Compounds

Wood and thermoplastic are not the only components in WPCs. These composites also contain additional materials that are added in small amounts to affect processing and performance. Although formulations are highly proprietary, additives such as coupling agents, light stabilizers, pigments, lubricants, fungicides, and foaming agents are all used to some extent.

2.8.1 Chemical Treatment

The most important aspect with respect to optimal mechanical performance and the durability to be specific, of wood reinforced composites is the optimization of the interfacial bond between wood and polymer matrix (Bodirlau et al. 2009a). The quality of the wood-matrix interface is significant for the application of natural fibers as reinforcement for plastics. Since the fibers and matrices are chemically different, strong adhesion at their interfaces is needed for an effective transfer of stress and bond distribution throughout an interface (Caufield et al. 2007a). A good compatibility between cellulose fibers and nonpolar matrices is achieved from polymeric chains that will favor entanglements and interdiffusion with the matrix (Bakraji & Salman 2003).

Due to polarity mismatching of natural fibers and plastic, their interfacial boundaries are often weak and lead to undesirable mechanical properties (Ghasemi & Farsi 2010b). Many studies have been carried out to improve the adhesion between two phases including incorporation of coupling agent into the compound and modification of the fibers (Kord 2011a; Kord 2012; Kord et al. 2011). Different coupling agents have been used to modify the polymeric matrix and improve the interfacial strength and subsequently the mechanical properties of the products (Bodirlau et al. 2009a).

Another approach for enhancement of interfacial adhesion in WPC is fiber treatment before mixing with polymer. Some of these treatments have physical nature and some have chemical nature (Dányádi et al. 2010). Natural fibers have a good potential for chemical treatment due to presence of hydroxyl groups in lignin and cellulose. Reaction of hydroxyl groups can change the surface energy and the polarity of the natural fibers (Ghasemi & Farsi 2010b).

Wood modification can change important properties of the wood such as biological durability, hardness, dimensional stability and UV stability by converting hydrophilic OH-groups into a more hydrophobic groups (Bodirlau et al. 2009a).

One type of natural fillers is sawdust which is obtained from wood and in large amount from wood industry as a waste. The use of sawdust is not very popular for WPC, but this material is light, cheap, stiff and it can be added to commodity matrix in certain loading levels hence offering one of the best solutions for the utilization of waste wood and cheap product (Abdul et al. 2011a). The sawdust used in WPC in place of the longer individual wood fibers is most often added in particulate forms.

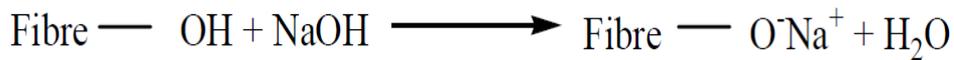
Alkalization (or mercerization) is a common method for physical treatment of natural fiber surfaces. In this method, lignocellulosic fibers are immersed in aqueous NaOH solution for a period of time. NaOH solution dissolves lignin, wax and oils from the fiber surface and leaves a clean and porous cellulosic surface. This treatment leads to higher specific mechanical properties since cellulose has much higher mechanical properties compared to lignin and also increases specific surface area leading to better interaction with the matrix (Kazemi 2013).

2.8.1.1 Alkaline treatment

The important modification done by alkaline treatment is the disruption of hydrogen bonding in the network structure, thereby increasing surface roughness. Addition of aqueous sodium hydroxide (NaOH) to natural fiber promotes the ionization of the hydroxyl group to the alkoxide (Agrawal et al., 2000) in(Farsi 2000).

Alkaline treatment increases surface roughness resulting in better mechanical interlocking and the amount of cellulose exposed on the fiber surface. This increases the number of possible reaction sites and allows better fiber wetting.

The following reaction, takes place as a result of alkali treatment.



(Nozari et al. 2013) studied the mechanical properties and water uptake of WF/LDPE composite after fiber surface mercerization and found out that treating the WF by 2% NaOH, the tensile strength increased by 10.8%.

2.8.2 Influence of Coupling Treatment

The preservation and conservation of the environment in order to ensure sustainable development is much emphasized nowadays. In order to ensure preservation and conservation of the environment, the various waste generated have to be getting rid of. The surest way to get rid of a waste is to recycle it into a useful product (Braunegg et al. 2004).

Plastic waste can be recycled by forming a composite with lignocellulosic residues. The lignocellulosic material can be sawdust, wood flour, plant fibers, agricultural and agroindustrial lignocellulosic waste (Ashori & Nourbakhsh 2009b).

The preparation of wood-plastic composite requires a good compatibility at the interface from polymeric matrix with the wood (Catto et al. 2014a). The hydrophilic nature of the wood and the hydrophobic nature of the plastic results in the poor adhesion between the two phases (Rowell & Youngquist 1991).

To increase the interfacial adhesion between the wood and the plastic matrix, some coupling agents have to be used to modify the wood and thereby improve the mechanical properties of the polymeric composite (Rowell & Youngquist 1991). An efficient

approach to improve the interphase compatibility of the composite is the use of coupling agent (Lei et al. 2007).

A coupling agent is a chemical that function at the interface to create a chemical bridge between the wood filler and the plastic matrix (Stark & Rowlands 2005). The coupling agent chemically bonds with the OH groups in the sawdust and limits water absorption by the composites. As such, it is important to use coupling agents to improve the quality of adhesion between the plastic matrix and the wood filler. To reduce gaps in the interfacial region, and to block the hydrophilic groups, coupling agents must be used (Kord et al. 2011). Water resistance by WPCs can be enhanced by the use of coupling agent by improving the polymer or fiber bonding (Kord 2011b).

Interfacial strength between plastic matrix and natural filler reinforcement have direct effects on the properties of WPCs (Kord 2011b). Coupling agents can increase the impact strength, flexural strength, hardness, natural durability and fungal resistance of WPCs (Kord 2012). Poor adhesion between the matrix and the filler results in poor ability to transfer stress from the matrix to the filler thereby reducing the composite properties (Ghasemi & Farsi 2010b).

To obtain a composite product based in non-polar thermoplastics with competitive final product, it is necessary to achieve a good compatibility between the filler and the matrix by the modification of the filler surface or by adding coupling agents (Bodirlau et al. 2009a). Coupling agents play a large role in helping to improve the compatibility between polar components (i.e., wood fibers) and non-polar polymeric material.

Over 40 different coupling agents have been assessed in various applications to improve the compatibility between dissimilar materials (Catto et al. 2014b). The two approaches usually used are to modify the wood fiber to make it more hydrophobic or to make the

plastics it more hydrophilic. The most popular treatments have been to react the wood with isocyanates, anhydrides, or silanes or alternatively blend an anhydride modified copolymer with the matrix to aid coupling with wood at the interface.

Adhikary et al (2008) studied the effects of the fiber loading and addition of coupling agent on the mechanical properties of waste sawdust and post-consumer recycled HDPE. It was observed that the tensile strength of the composite along with the stiffness increased due to the addition of a coupling agent (maleated polypropylene). This increase is attributed to the improved interfacial bonding between the HDPE matrix and the reinforcing wood flour due to the formation of ester bonds (Adhikary et al. 2010).

Lu et al. (2005a) studied issues concerning the use of coupling agent in an HDPE-wood composite. They concluded that for the modified composites, the improvement on the interfacial bonding strength, flexural modulus, and other mechanical properties was mainly related to the coupling agent type, function groups, molecular weight, concentration, and chain structure. The maximum value of interfacial adhesion was achieved at the 3 wt % concentration level for most maleated composites. MAPE coupling agents were more effective in improving interfacial adhesion in wood fiber-HDPE composites with compared to the other coupling agents used. Maleic anhydride grafted PE, PP or HDPE are the most common coupling used in WPC.

Out of seven coupling agents investigated by Sernalul (2009), the maleated polyethylene showed the best improvement in the interfacial bonding strength between HDPE and woods the most. The reason he gave was that the maleic anhydride groups of MAPE were easily hydrolyzed into double carboxylic groups. These double carboxylic groups were in turn more reactive for esterification under an initiator than the monocarboxylic groups of other coupling agents (Sernalul 2009b).

Coupling agents usually account for about 1-3% of the total weight of a formulation of WPC. Generally, the effectiveness of the coupling agent will increase as concentration increases up to a certain surface saturation concentration (Cui et al. 2008). At this coupling agent saturated concentration, the mechanical properties will decrease due to inhibition to promote adhesion (George et al. 2001a).

Therefore, there is an optimal amount of coupling agent to be added to achieve superior properties. The properties that can be increased include flexural strength, and tensile strength, and impact strength (George et al. 2001b). Coupling agents have also been shown to influence crystallization morphology and nucleation behavior in semi-crystalline polymer matrices within WPCs. Consequently, due to this change, coupling agents have an impact on the mechanical properties of WPC (Ghasemi & Farsi 2010b).

2.8.3 Effects of Lubricants

Lubricants are additives added to WPC formulations to improve flow characteristics i.e., faster production rate and improved surface features and extruder output during processing (Adhikary et al. 2010). Lubricants function to minimize the friction force between moving surfaces and also improve the melt homogenization and viscosity. Lubricants are classified as either internal or external. Internal lubricants act in reducing the molecular friction between polymer chains, thus reducing the melt viscosity (Hietala 2013b).

Internal lubricants typically reduce bulk viscosity by being partially compatible with the plastic, thus helping to open the polymer chain with the lubricants' soluble component, while providing intermolecular lubrication with the less soluble portion of the lubricant molecule. Because of its low molecular weight, a maleated polyethylene (MAPE) coupling agent also tends to decrease the overall WP melt viscosity at lower shear rates, thereby

acting as an internal lubricant(Rude, 2007). Types of internal lubricants are; Fatty Alcohols, Esters, EVA Waxes (Adhikary et al. 2010).

External lubricants typically provide lubrication between the polymer and the metal surface of the processing equipment. An external lubricant migrates to the surface during processing, helping to reduce the friction between the polymer melt and the metallic surface of the processing equipment (Carraher, 2003). Types; polyethylene homopolymers, paraffin, esters, metallic soaps, amides, fatty acids and oxidized polyethylene (Fulmer 1999a).

However, most lubricants have characteristics of both internal and external lubricants. WPC producers utilize lubricants to aid processing by increasing output rate and product aesthetics (Adhikary et al. 2010). Common lubricants used in WPC production are stearate derivatives such as zinc stearate and ethylene bisteramide (EBS) (Fulmer 1999b). Since lubricants are surface-active agents, they can interact with coupling agents, and therefore, lubricants negate the effect of adding coupling agents. High fiber content leads to difficulty in extrusion processing due to the high melt viscosity of wood–plastic blends, which ultimately affects the surface quality and mechanical properties of extruded WPC products (Lu et al. 2005b).

Alternatively, the melt viscosity of wood plastic blends during extrusion can be reduced by increasing processing temperatures or by using processing additives, such as compatibilizer and lubricants, in the composite formulations. Thermal degradation temperature which is around 200°C limits the use of higher processing temperatures to overcome the high melt viscosity of WP blends. Processing WPC around the thermal degradation temperature of WF, results in a decrease in mechanical properties.

Both coupling agent and lubricant promote WPC processing. This is so because coupling agents improve compatibility between the WF and the polymer, whereas lubricants increased wettability and produced wall slipping with polymer compounds (Adhikary et al. 2010).

(Poletto et al. 2011) found that the addition of internal lubricant drops the tensile and flexural strengths by 20%, while the apparent viscosity was reduced by 24%. (Zhang et al. 2009) reported that HDPE/WF composites containing lubricant processed by dispersive and distributive mixtures in a twin-screw extruder showed uniform WF distribution in the HDPE matrix with a decrease in complex viscosity.

Adikary and Park (2012) concluded that tensile strength decreased but flexural strength increased when the lubricant content was increased up to 7%. Both properties decreased 10% lubricant content. They also added that low lubricant content caused fiber and matrix breakage, high lubricant content caused debonding and fiber pull-out. These clearly shows that optimum amount of lubricant is to be used if the best properties of WPC is to be obtained.

2.9 Mechanical Properties of WPC

Improvements in mechanical strength can enable WPC to gain more ground in structural applications, which can dramatically alter the nature of materials used in such applications. The mechanical properties of composites are dependent on the interface and interphase interactions between the wood flour and polymer matrix (Danesh et al. 2012).

Improving the mechanical properties is a common objective in many WPC studies. A major stumbling block in WPC realizing their potential is their weak mechanical strength (Semeralul 2009b). The mechanical properties include; tensile strength, flexural strength, impact strength.

2.9.1 Factors that affect the mechanical properties of WPC

Different factors influence the mechanical properties of WPCs as observed in a number of research works (Poletto et al. 2011; Wechsler et al. 2008b; Stark et al. 2005). Many researchers such as (Gyoung et al. 2010; Adhikary et al. 2010; Catto et al. 2014b; Ghasemi & Farsi 2010b; Kord 2012; Kord et al. 2011; Lu et al. 2005b) have conducted extensive research on the effects of coupling agents on the mechanical properties of WPCs. They all concluded that coupling agents greatly affects the mechanical properties.

For instance, it was observed by Adhikary et al (2009) that the tensile strength of the composite and its stiffness increase due to the addition of a coupling agent. Flexural strength studies reveal a similar trend, as of tensile strength, although less variation is observed in the flexural strength with different formulations than in the case of tensile strength (Adhikary et al. 2010).

Westin et al. (2008); Tajvidi & Azad (2009a); Petchwattana & Covavisaruch (2011a); Poletto et al. 2011; Kuo et al. (2009) studied the effects of type of filler (inorganic or organic), filler content, and particle size of the filler. The conclusions from all the researches indicate that there are effects (positive or negative) of these parameters on the mechanical properties of WPCs.

The type of plastics used as the matrix (either virgin or recycled), or the specific plastic used have also been extensively looked at. Their results show that there are correlations between plastic type and the mechanical properties of WPCs.

This work will look at the effect of wood species on the mechanical properties of WPCs.

2.9.1.1 Effect of Wood Species on Mechanical Properties of WPC

Wood species have an important influence on the properties of wood-thermoplastic composites (Stark et al. 2005), predominantly because wood structure controls the flow direction of the thermoplastic movement in cell lumens (Escobar 2008).

WPCs can be made from many wood species, and mainly are formed by introducing wood flour softwoods and hardwoods in a continuous extrusion process. Nowadays, there is tremendous interest in understanding how wood particles and the surrounding plastic matrix behave at both the macroscopic and microscopic levels. This mechanical interlocking is an important mechanism for adhesion that could relate to the performance of composites.

Due to the complex flow process controlling the penetration of a thermoplastic into the wood structure, it is difficult to state that whether one wood species is superior to the other as a filler material, especially when some additives enhance adhesion and stress transfer between phases. Wood is a complex structure consisting of discontinuous fibers embedded in an organic matrix acting as glue. The tortuous structure of wood, generated by the interconnectivity of anatomical structure called pits, creates differing degrees of fluid mobility and final interpenetration in some dynamic processes. Because the conversion of solid wood into wood flour results in a more complex filler structure with a non-uniform surface morphology than conventional fillers, it is difficult to quantify and model the mechanical contribution of a particular filler or the stiffness and strength of a natural fiber composite. Also, collapse of the hollow wood cells may impede penetration of the thermoplastic and affects the performance of a WPC.

2.9.1.2 Effect of wood filler loading on the properties of WPC

In general, the physical and mechanical properties of WPCs depend on their constituent materials, interface interactions, and processing conditions. The homogeneity of WPCs (i.e., WF distribution and wetting) is important for the development of the mechanical properties. The distribution of WF in the polymer matrix depends upon the polymer's viscosity and on increased wetting by the lubricant and coupling agent (Adhikary et al. 2010).

Adhikary and colleagues observed that both tensile and flexural properties (i.e., strength and modulus) of WPCs increased with increased WF contents up to 50 wt%; however, both properties decreased when WF content was further increased to 60 wt%. The optimal tensile and flexural properties were obtained with 50 wt% WF at 7 and 3 wt% lubricant and MAPE contents (Adhikary et al. 2010).

A continuous thermoplastic matrix is required for wood fiber-plastic composites to be processed in conventional plastics processing equipment. In most cases, the upper fiber loading limit is about 70 wt% (English & Falk 1996). In fact, most producers limit fiber addition to about 50 wt% to keep melt viscosity at workable levels. But, wood fiber-plastic composites can be made with more than 70 % wood using other processes, such as compression molding.

2.9.1.3 Effects of Particle Size on Properties of WPC

An extensive body of research has been conducted on the effect that wood fiber size has on WPC properties (Sykacek et al. 2009a; Stark et al. 2005; Tajvidi & Azad 2009b)(Gallagher 2006b). The results from these studies show that aspect ratio (length/width) has the largest effect on WPC mechanical performance (Bouafif et al. 2009a).

One of the critical parameters influencing the strength properties of WPCs is the size of the fibers. Short and tiny fibers (average particle size 0.24–0.35 mm) should be preferred. They provide a higher specific surface area and the fibers are distributed more homogeneously compared to composites with long fibers and so the compatibility of fiber and matrix is improved. With this, swelling decreases and breaks during processing are reduced (Ashori 2008b).

Wood fiber, which is currently incorporated into commercial WPC formulations, range in size from 10 to 80 meshes (1700 to 180 μm) (Bouafif et al. 2009b). A search of literature suggests that the smallest wood fiber size investigated is no smaller than 235 mesh or 74 μm (Gunawan et al. 2012). As particle size of reinforcing agents decreases from micro to nanosize in composite materials there is a drastic improvement in properties such as mechanical (Stark et al. 2005). The enhanced nano-composites performance is due to optimized interfacial interaction between the matrix and filler particles. Improved adhesion is due to the large surface area of the nano-sized particles, which facilitate stress transfer to the reinforcing phase (Petchwattana & Covavisaruch 2011b).

(Gallagher 2006b) observed that the majority of research conducted on wood fiber size has focused on the effects of mechanical properties, and little is understood on the effect of wood fiber size on processability, such as rheological characteristics.

In a study on the effects of particle conducted by (Stark & Rowlands 2005), they concluded that it is the particle shape, and not the size that has the greatest influence on strength and stiffness of WPC. If the particle is more slender, there is a better redistribution and transfer of stresses between the filler and the matrix.

Therefore, the process for wood particle preparation should be designed to give particles with high length to width ratio (Gallagher 2006b). However, the size distribution may also

be of great importance. For indoor products, the challenge is mainly to achieve sufficient mechanical properties of the material for the intended product, since better mechanical properties give more freedom for the design of a product (Gallagher 2006b).

A comparison between rigid and flexible fibers in polymer melts demonstrated that viscosity was greater for rigid fiber filled systems over flexible fiber filled systems. In terms of filler concentration, the inter-particle interactions increase slightly as concentration increases at lower filler loadings; however, at higher filler content the inter-particle interactions increase strongly (Rimdusit et al. 2011).

Gallagher observed that a decrease in wood fiber size significantly increased the melt flow rate (MFR) or lower the melt viscosity of the WPC system. As wood loading increased so does the effect of fiber size on the MFR and viscosity (Gallagher 2006b). Stark (2005) found out that MFR decreases with an increase in filler concentration but increased as particle size increase for the range of wood flour examined. The increase was attributed to the unfilled regions in the systems. This trend was acknowledged as a function of the difference in the geometries of the wood fiber (Stark & Rowlands 2005).

Commercial WPC is generally produced from wood flour, with a low length-to-diameter (L/D) ratio. For example, commercial pine flour particles have L/D ratios ranging from 3.3 to 4.5 (Stark et al. 2005). Although such small particle sizes integrate well into extrusion processes, low L/D ratios cause stress concentrations leading to decreased strength compared to neat polymer (Migneault et al. 2009a).

Both strength and stiffness increases can be realized with increasing fiber length if adhesion between wood fibers and the plastic matrix is good; fibers are uniformly dispersed in the matrix; and fibers are adequately oriented (English & Falk 1996). However, when using wood fibers without effective dispersion or coupling agents, the

benefits of mechanical properties are negated (Migneault et al. 2009b). Stark & Rowlands (2005) compared the effect of softwood flour particles and hardwood fibers on strength properties of WPC made with polypropylene in a mold-injection process. They concluded that it is not the particle length that affects strength properties, but rather the L/D value (Stark et al. 2005). Strength and rigidity of composites increased with increasing L/D ratio.

2.10 Thermal Behaviour

2.10.1 Thermal sensitivity

Wood fiber will release volatiles or even burn at the temperatures required for processing many thermoplastics. As a rule of thumb, if melt temperatures are kept below 200°C and processing times are kept to a reasonable limit, devolatilization should not occur (English & Falk 1996). This limits the use of wood fiber fillers to lower melting polymers, such as polypropylene, low and high-density polyethylene (LDPE, HDPE), polystyrene, and polyvinyl chloride.

2.10.2 Thermal linear expansion

Thermoplastics are much more sensitive to linear expansion from temperature variations than from humidity variations (English & Falk 1996). Adding wood to thermoplastics significantly decreases thermal linear expansion; however, wood fiber-plastic composites are considerably more thermally sensitive than solid wood. Increasing the fiber content substantially decreases the coefficient of thermal linear expansion, but the lowest value is still approximately 250 times that reported for solid wood (English & Falk 1996). Minimizing the thermal expansion of wood fiber-plastic composites is important, so these composites can be used compatibly with other materials exhibiting lower thermal expansion rates, such as solid wood. The stiffness or modulus of elasticity, of a wood

fiber- plastic composite decreases significantly with increasing temperature (English & Falk 1996).

2.11 Water Absorption

Wood can absorb or desorb water depending on the environmental conditions such as humidity and temperature, because it is hydrophilic. Wood also changes dimension when its moisture content fluctuates below the fiber saturation point (FSP) (Kord 2011c). Wood composite such as fiberboards are processed from woody materials in the shape of flour, fibers, flakes and shavings bonded with synthetic adhesives consolidated under high temperature and pressure (Kord 2011c).

The application of WPC such as decking, window frames, bathroom parts and other outdoor applications exposes them to aqueous media. This has made it very important to evaluate the water uptake behavior of WPCs (Najafi et al. 2007). As a limiting parameter, water absorption has to be taken into consideration when WPC is to be designed into products.

Water can be absorbed by WPC due to the hygroscopic nature of natural fillers and also through the gaps and flaws at the interface between filler and plastic (Mosadeghzad et al. 2009).

Particle size strongly affects water absorption. The larger the particle size, the higher the water absorption. The effect of particle size on the water absorption of the composites is more considerable at lower fiber contents (Azad & Tajvidi 2009).

Water absorption in natural fiber plastic composite is due to the cumulating effects of some parallel mechanisms such as; water absorption due to the individual fibers or particles due top to hygroscopic nature of the cellulosic fibers. The microgaps in the

interface between the fiber and the plastic can also hold water. Voids due to water vapor generation during hot melt process can also contribute to water absorption (Azad & Tajvidi 2009).

Wood fiber is a natural structure made of cellulose fibers which contains numerous hydroxyl groups that are strongly hydrophilic. The rate at which water is absorbed by a composite depends on many variables including fiber type, matrix, temperature, the difference in water distribution within the composite, reaction between water and the matrix, among others (Bledzki & Faruk 2004).

Larger particles present lower wettability and higher probability of particle-particle interconnection due to incomplete encapsulation of the particles by the plastic (Najafi 2013). The reason for higher effect of fiber content at smaller particle sizes is the fact that the particles possess higher surface areas at lower size. The lower the fiber content and the smaller the particle size, the lower the water diffusion coefficients (Najafi 2013).

Poor resistance of the fibers to moisture absorption can be undesirable effects on the mechanical properties and dimensional stability of WPCs (Leu et al. 2012). The high water uptake can weaken the interfacial bond between natural fibers and hydrophobic polymer matrices. This weakened interface causes the reduction of mechanical properties of the composite.

When WPCs are exposed to moisture, the hydrophilic fibers will swell; cracks may form in the plastic matrix, which can also contribute to the penetration of water into the composite (Cui et al 2011). Exposing WPCs to moisture can result in a decrease in the flexural modulus and strength because of the degradation of the wood-plastic interfacial quality (Cui et al. 2008).

The weak interfacial bonding between natural fibers and polymer matrix can be improved by a number of fiber surface modifications. Some of the surface agents include silane, Sodium hydroxide, Isocyanate, permanganate, maleic anhydride and peroxides.

Studies on WPCs and moisture transport have revealed that there is very low initial moisture content (MC) and the absorption rate is very slow. However, there is an unequal distribution of moisture in the composites and the outermost part can reach very high moisture levels, high enough to support fungal degradation (Wang et al. 2011).

It is also important to stress that even if moisture uptake is slow in WPCs, even when immersed in water, the uptake may continue over a long period of time. The rate and extent of moisture increase when the wood content exceeds approximately 50% of the total weight of the composite (Cui et al. 2011).

In addition, a moist environment will swell the wood particles close to the surface, and the particles will shrink upon drying. This will cause stresses within the material and create microcracks, which will expose more particles deeper in the material. This swelling and shrinkage will also cause cracks at the interfaces between the wood particles and the matrix (Segerholm 2012a).

Adhikary (2008) have shown that thickness swelling and moisture levels of WPCs can be reduced by using acetylated *Acacia magnum* as a wood component. Moisture intrusion in WPCs directly affects the dimensions of the material due to the swelling forces of the wood component. Indirectly, if the material is able to absorb moisture, it will be more susceptible to decay by fungi and other micro-organisms (Segerholm 2012a). The surfaces of WPCs are usually smooth, and a thin surface layer generally consists of a high proportion of the polymer matrix.

In the initial stage of moisture exposure, this polymer-rich surface phase retards the rate of moisture absorption. Therefore, the WPCs will appear to be very moisture resistant. However, when the composite is subjected to UV radiation and or water, this surface layer may be degraded, resulting in a decreased moisture resistance and a critical intrusion of water into the bulk of the material may occur more easily (Segerholm 2012a).

KNUST



CHAPTER THREE

METHODOLOGY

This chapter looks at the materials and equipment used in this work and also the methodology adopted in doing this work.

3.1 Materials

3.1.1 Post- consumer plastic sachet water .

In Ghana, water is packaged in a plastic sachet in 500ml. This sachet is made from a mixture of 65% HDPE (High Density Polyethylene) and 35% LDPE (Low Density Polyethylene). Blue ink is usually used for the labeling giving the shredded plastic waste a blue color instead of the white color of the virgin form since it is not erased.

3.1.2 Sawdust

Sawdust of two different wood species, a hard wood and a soft wood was collected from a local sawmill at Agona in the Ashanti Region of Ghana. The hardwood was Mahogany (*Swetenias mahogany*). A straight-grained, reddish-brown timber. Mahogany is a commercially important lumber because of its beauty, durability and colour. It is used mainly for paneling, furniture, boats, musical instruments and many other items. It has an excellent workability, durable and can also resist rot. At 12% moisture content, it has a density of 0.45, Modulus of Rapture (MOR) 79,300 KPa, modulus of elasticity (MOE)10,300 MPa (Green et al. 1999)



Figure 3.1: Mahogany sawdust



Figure 3.2: Wawa sawdust

The softwood was Wawa (*Triplochiton Scleroxylon*). Wawa or Obeche obtained from Ghana has a creamy-white to pale yellow colour with no demarcation between the sapwood and the heartwood. It is a light, fairly soft wood but firm and fine with even fine texture. It grows throughout West and Central Africa.

The working properties of Wawa are; it has very low stiffness and resistance to shock. It has moderately to poor steam bending properties. It is easy to work with hand and power tools. It takes glue well, and paints well with normal primers, nails easily, polishes well and stains well. At 12% moisture content its specific gravity is 0.3, MOR of 35,200 KPa and MOE of 51,000 MPa. Modulus of Elasticity (MOE) 10,300 MPa. (Green et al. 1999).

Figures 3.1 and 3.2 show the pictures of wawa and mahogany sawdust.

3.1.3 Chemicals and reagents

Sodium Hydroxide pellets with the specifications of; Relative Molecular mass = 40, percentage purity = 98%, Maximum Limits of impurities; Sodium carbonate (Na_2CO_3)

2%, Chlorides (Cl) 0.01%, Sulphate (SO₄) 0.05%, Potassium (K) 0.1%. This was purchased from PAKUS ventures in Kumasi-Ghana.

3.2 Equipments Used

3.2.1 Extruder

A table top extruder at the Engineering department of the KNUST was used. Designed and manufactured by J. B Engineering (Chippenham) Ltd Unit 20. Bumpers Enterprise Center, Chippenham, Wiltshire SN14 60A, England.



Figure 3.3: A table top extruder

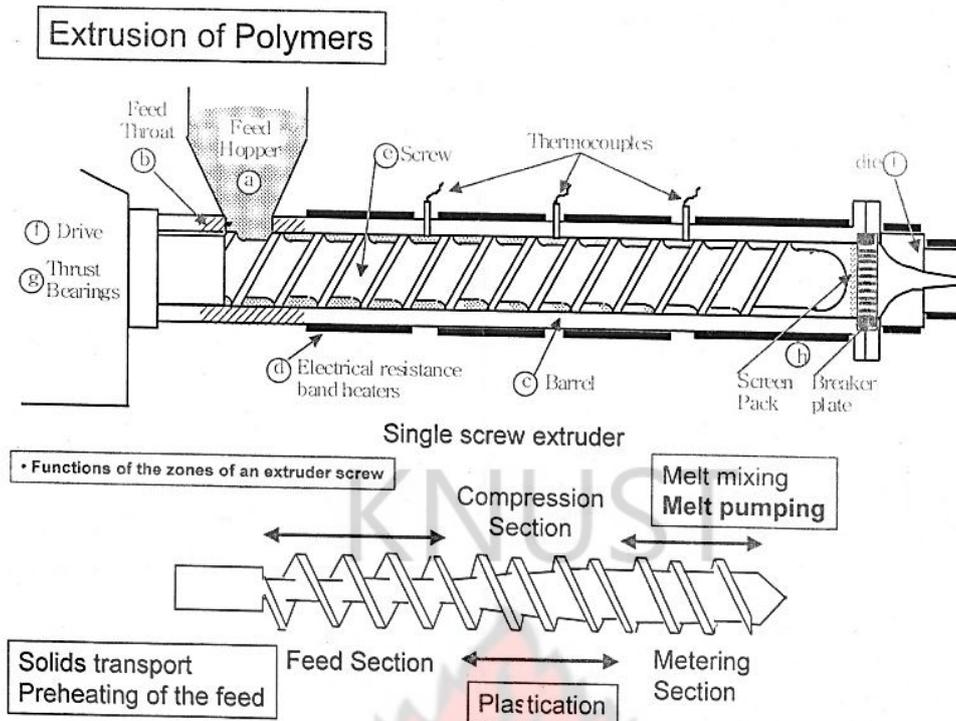


Figure 3.4: Schematic diagram of a single screw extruder

The key features of the extruder are: the hopper, the screw, the thermocouples and the die.

3.2.2 Injection Molder

A table top Injection molder at the Engineering department of the KNUST was used. Designed and manufactured by J. B Engineering (Chippenham) Ltd Unit 20. Bumpers Enterprise Center, Chippenham, Wiltshire SN14 60A, England.



Figure 3.5: A table top injection molder

The key features are: Feed hopper, screw, barrel, hydraulic motor, nozzle, and the mold.

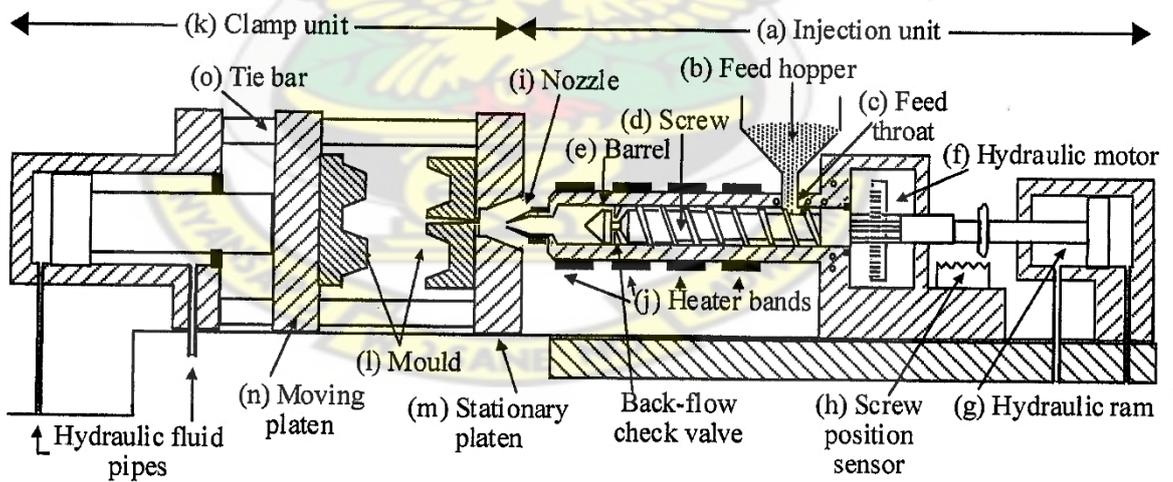


Figure 3.6 Schematic diagram of a typical injection molding machine

3.2.3 Universal tensile machine

A hounsfield Universal tensile tester which works based on Hooks law (stress versus strain) was used. Hounsfield tensile Engineering Ltd UK. Mode number H50ks with a load cell of 50N capacity.

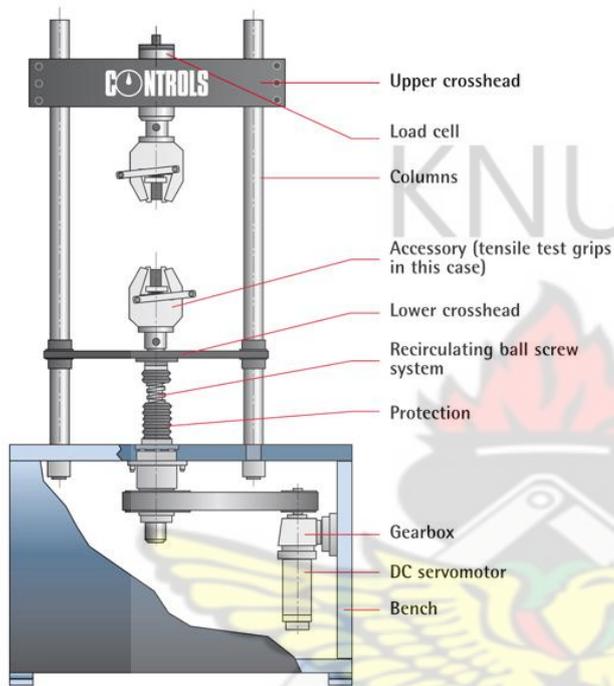


Fig 3.7 Schematic diagram of Universal tensile machine

Figure 3.8: Tensile testing machine used for this work

3.2.4 Sieve

A Sieve with a pore size of 425 μ m was used.



Figure 3.9: A sieve

3.2.5 Fourier Transform Infra-red Spectroscopy Analysis

A Bruker Alpha FTIR spectrometer by Bruker Optics was used.



Figure 3.10 a picture of Bruker Alpha FT-IR Spectrometer

3.3 Processing

3.3.1 Plastic

The recycled water sachet plastics were obtained from a local plastic recycling plant in already shredded form. The plastics were derived from post-consumer plastic waste. The shredded plastics were thoroughly washed with water and dried in the sun for 48 hours. The dried shredded plastics were bagged until when it was used.

3.3.2 Wood Flour Preparation

The sawdust was obtained from a local sawmill at Agona in the Ashanti Region. The sawdust of the soft and hard woods were collected separately as they were being milled in other to avoid mixing. The weight of the wet sawdust was found and after that it was dried in the sun for 72 hours.

3.3.2.1 Wood Flour Treatment (Modification with sodium hydroxide)

300g of the wood flour for each wood species was weighed and put into a bowl. 5% Sodium hydroxide solution was prepared and enough water that can cover the sawdust was added. The sawdust was soaked in the solution for 5 hours. It was then washed with distilled water several times until it tested neutral to red litmus paper. This was done to ensure that all traces of the NaOH have been removed. The residue was then dried in the sun for 72 hours. The untreated sawdust was also dried in the sun for the same period of time.

3.3.2.2 Sieving

The dried sawdust was sieved with a sieve with pore size of 425 μ m. A sieve with pore size of 100 μ m, 350 μ m and 425 μ m were selected and used but the 425 μ m size gave the best results (needed amount and the right particle size)

3.3.2.3 FTIR

The samples were placed in the sample compartment of the Bruker Alpha FTIR spectrometer and the spectrum were used for the analysis. The infrared spectra of the raw and the treated sawdust were recorded on an Alpha Bruker FTIR. The transmittance range of the scan was 4000 cm^{-1} to 400 cm^{-1} . The obtained spectra are discussed in the next chapter.

3.3.3 Specimen Preparation

3.3.3.1 Formulations for the composite preparation

10, 20, 30, 40, and 50 % wt for the sawdust were measured and mixed with 90, 80, 70, 60, and 50 % for the plastic respectively. This was done for the mahogany as well as the Wawa. These mixtures were packed and labeled as such. For each formulation, mixtures of the two different woods were also made.

3.3.3.2 Extrusion

The various formulations were extruded using a single screw extruder with L/D value of 24/3. The barrel temperatures of the extruder were fixed at 120 °C for zone one, 110 °C for zone two, and 100 °C for zone three. The die temperature was set at 115 °C. The extruder was preheated to a temperature of 120°C. Similar method was used by Sykacek et al. (2009b) The shredded plastic was first poured into the hopper followed by the sawdust. The extruded strands that exited the die had a blue coloration due to the ink which was used to label the sachet water. The strands were collected and air dried as it exited the die.

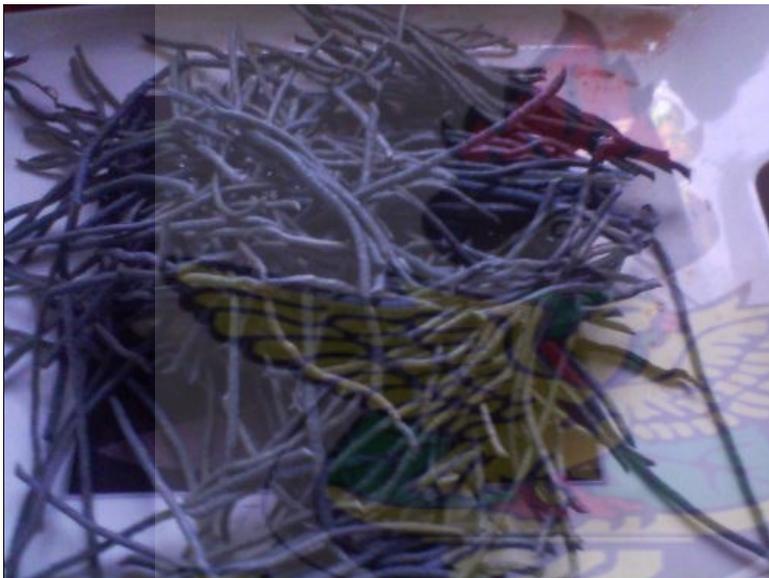


Figure 3.11: Strands of extrudate

The blue ink which was used to label the plastic sachet gave the extrudate a blue-black colour. The strands were subsequently cut into pellets using scissors for further use.



Figure 3.12: Pellets of extrudate

3.3.3.3 Mold Used For Tensile Test

The WPC pellets were fed into an injection molder with the mold already fixed in it. The temperature was set at 120 °c. The test specimens were molded into dumbbell shape with a uniform thickness. It has a total length (L) of 60mm, length without the heads (L1) 40mm, a diameter of 4.98mm

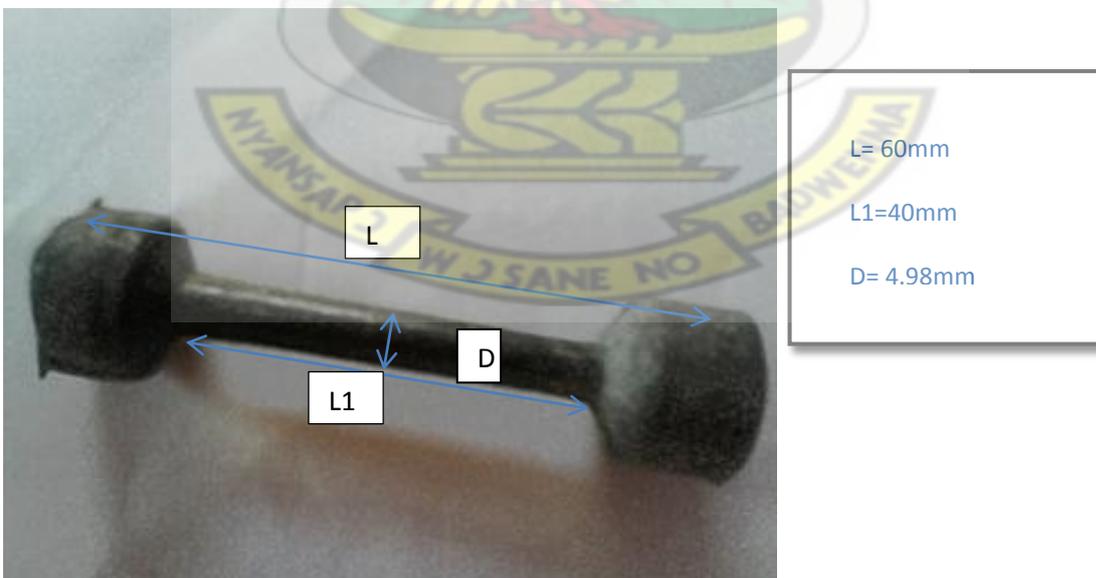


Figure 3.13: The test specimen

3.3.4 Mechanical testing

Tensile test was conducted using Universal Tensile Machine according to ASTM D 638 with a cross head speed of 20 mm/min. The specimen was first fit into an adaptor and this was also fixed into the grips of the tensile testing machine.



Figure 3.14: Adaptor for the tensile bars

The machine pulls the sample until failure occurs. The force that was applied on the sample until failure occurred was recorded as well as elongation. For each sample five replicates were measured and the average value was recorded and used to calculate the stress and the strain values. The stress and the strain were calculated from the force and the elongation obtained. The tensile strength was calculated from the stress- strain curves. The average values obtained from tensile analysis were determined from at least five tests on each sample.

3.3.4.1 Stress

The stress is the force per unit area (MPa). Tensile stress is one of the most important and widely measured properties of materials used in structural applications. The tensile stress

was calculated as:
$$\sigma = \frac{F}{A} \quad (\text{Eq. 1})$$

Where σ is the stress, F = Force, A = area.

The force was measured by the machine and the area was the original cross sectional area of the specimen.

3.3.4.2 Strain

This is expressed as the increase in length of specimen after stress is applied to it divided by the original length.

$$\varepsilon = \frac{L1-L0}{L0} \quad (\text{Eq. 2})$$

Where ε = strain, $L1$ = change in length and L_0 is the original length of the specimen.

3.3.5 Density

The density of the wood-plastic composites was measured using the water displacement method. The specimen used for the density was the same as the one used for the tensile test. The mass of each specimen was obtained using a digital balance and the volume was measured using the displacement of water. A beaker was filled with water to the brim and the specimen was dropped gently into it. The amount of water that overflowed after the specimen was dropped was measured as the volume of the specimen. Density = mass/volume was the formula used.

$$\frac{m}{V} = \rho \quad (\text{Eq. 3})$$

The results are presented in table. Bouafif et al. (2009b) also used this method.

3.3.6 Moisture absorption

The moisture absorption of the composite specimen was studied according to the ASTM D 5229 standard by dipping the specimen into water and determining the water uptake as a function of time until the moisture equilibrium content was reached.

The samples were dried in the sun for 24 hours. A digital INSTRON balance was used for the measurement. The initial weight of each sample was measured and recorded. The samples were immersed in distilled water at room temperature for fifteen (15) days. The samples were removed from the water and a clean cloth was used to wipe the water on and the weight measured after every two hours for the first day. This was repeated after very three hours on the second and third day. The process was repeated after every 24 hours from day four to day nine. It was repeated for every 48 hours for the last six days. The increase in weight of the samples were calculated using the formula

$$\text{Water absorption} = \frac{\text{final weight} - \text{original weight}}{\text{original weight}} \times 100 \quad (\text{Eq. 4})$$



CHAPTER FOUR

RESULTS AND DISCUSSION

The results are discussed in several sections in accordance with the goals of the study. First the effect of the type of wood as filler on the mechanical properties of the composites is presented. Then the effect of alkaline treatment of the filler on the mechanical properties of the composite is discussed. Finally changes in water absorption are related to the type and amount of filler and whether treated or untreated.

4.1 Sieving

A sieve with pore size of 100 μm was selected first and it gave about 10% filtrate, the 350 μm sieve gave about 50% filtrate but the 425 μm gave about 85% of the particles. This sieved brought out enough particles which were smooth enough to form the composite. The particles with a size of 425 μm and below passed through the sieve giving the filtrate a smooth feel. From literature, particle sizes affect the adhesion between the matrix and the filler (Azad & Tajvidi 2009).

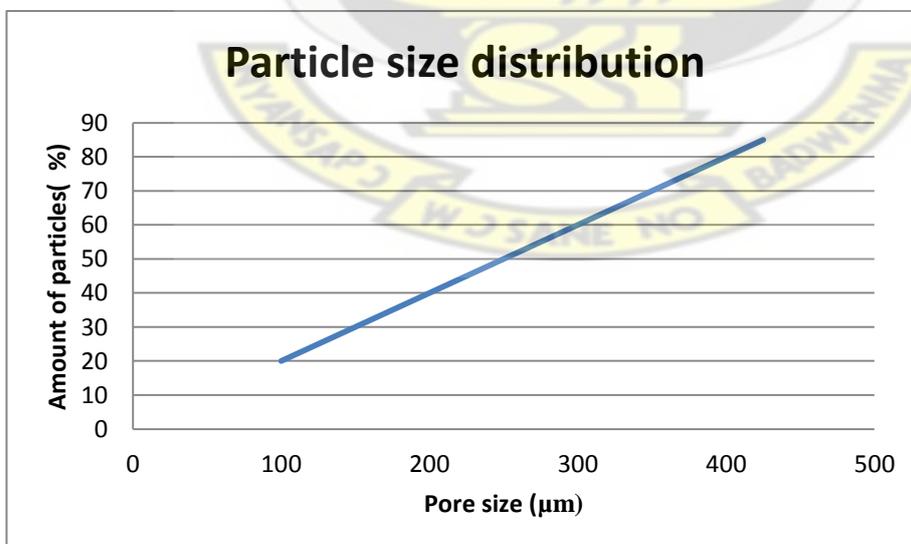


Figure 4.1 particle size distribution of the sawdust used

4.2 Chemical Properties- FTIR

The FTIR of the sawdust and the plastic used were taken and the figures are shown in fig 4.2.

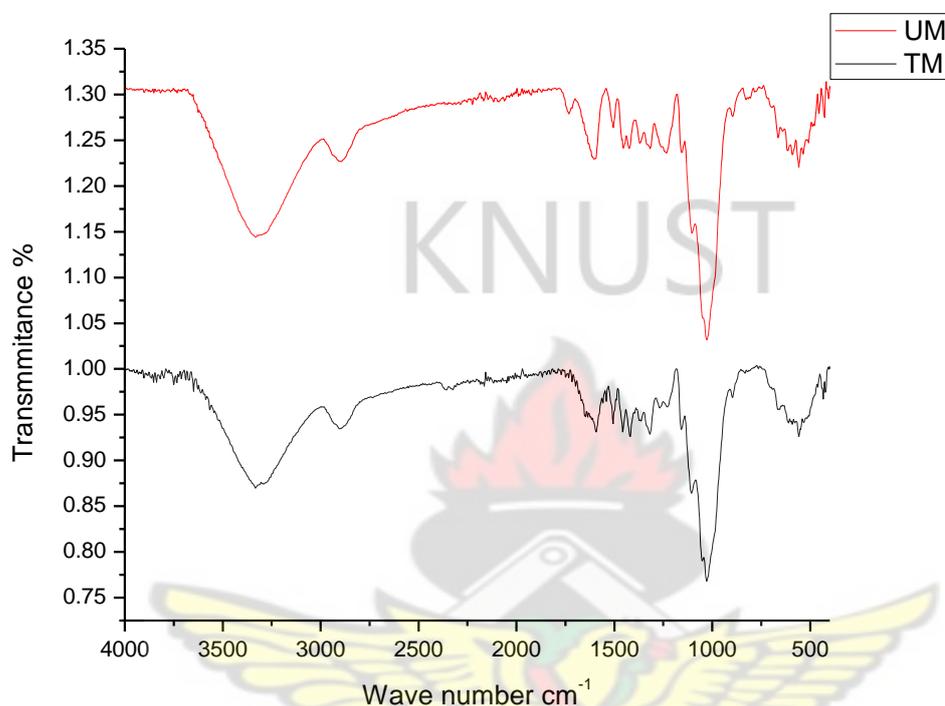


Figure 4.2 FTIR of treated and untreated mahogany sawdust

The FTIR spectrum of the untreated mahogany sawdust is shown in fig 4.1 which clearly shows the absorption bands in the region of 3380 cm⁻¹, 2968 cm⁻¹ and 1663 cm⁻¹ due to O-H stretch, C-H stretch, and C=C stretch, respectively. These absorption bands are due to hydroxyl group in cellulose, carbonyl group in hemicellulose, and carbonyl aldehyde in lignin. The absorption band at treated sawdust show at O-H slightly shifted towards 3380 cm⁻¹ and at C-H stretch absorbance shifted towards 2951 cm⁻¹ respectively. It can be seen that, the carbonyl peak C=C at 1663 cm⁻¹ was slightly shifted towards 1682 cm⁻¹ in the spectra of treated sawdust because the carbonyl bonds in the hemicellulose was broken due to the chemical treatment. The C-N stretch at 1059cm⁻¹ representing an alkene also

shifted to 1061 and 626 cm^{-1} C-H bend which is an alkyne group shifted to 641 cm^{-1} (FTIR 2015).

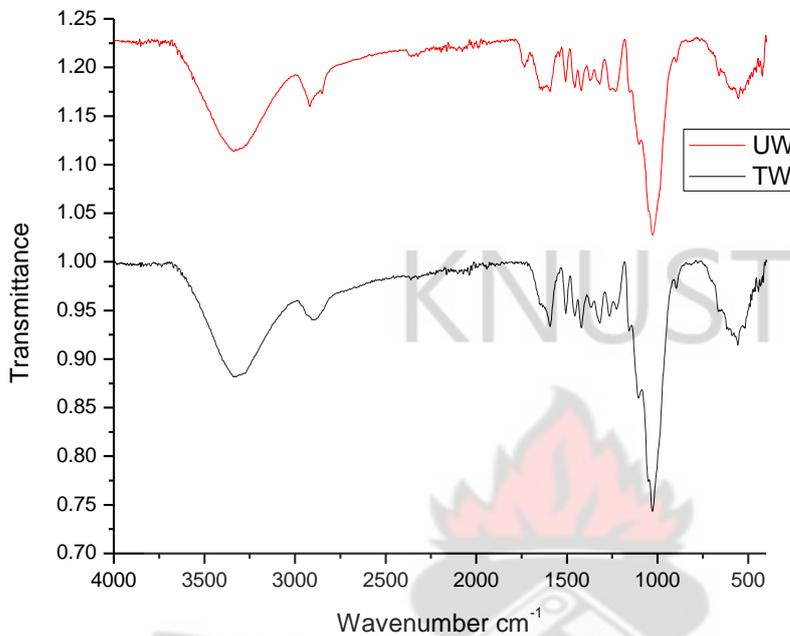


Figure 4.3 FTIR of treated and untreated Wawa sawdust

The FTIR of treated and untreated Wawa sawdust

The FTIR spectrum of the untreated mahogany sawdust is shown in fig 4.2 which clearly shows the absorption bands in the region of 3396 cm^{-1} , 2968 cm^{-1} and 1698 cm^{-1} due to O-H stretch, C-H stretch, and C=C stretch, respectively. These absorption bands are due to hydroxyl group in cellulose, carbonyl group in hemicellulose, and carbonyl aldehyde in lignin. The absorption band at treated sawdust show at O-H slightly shifted towards 3396 cm^{-1} and at C-H stretch absorbance shifted towards 2951 cm^{-1} respectively. It can be seen that, the carbonyl peak C=C at 1698 cm^{-1} was slightly shifted towards 1669 cm^{-1} in the spectra of treated sawdust because the carbonyl bonds in the hemicellulose was broken due to the chemical treatment. The C-N stretch at 1059 cm^{-1} representing an alkene also remained at 1059 cm^{-1} and 612 cm^{-1} C-H bend which is an alkyne group shifted to 626 cm^{-1}

The FTIR spectrum of the mixed sawdust is shown in figure 4.3. The spectrum shows absorption band in 3413cm^{-1} region which is O-H stretch, corresponding to alcohols. 2841cm^{-1} : C-H stretch for alkanes, 2990cm^{-1} : =C-H stretch for alkanes, 1042cm^{-1} : C-N stretch for alkene, 849cm^{-1} : C-Cl stretch for alkyl halides.

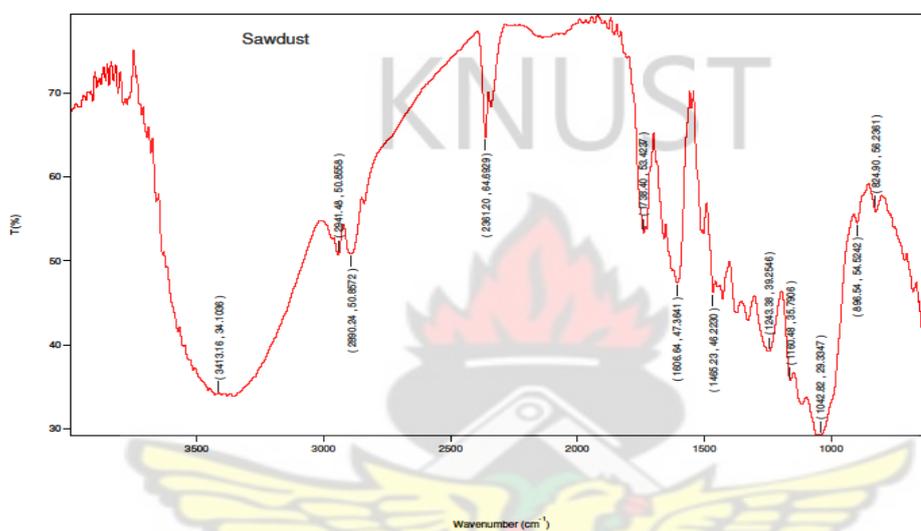


Figure 4.4 FTIR of the mixed wood sawdust

The FTIR spectroscopic analysis of the plastic water sachet is shown in figure 4.4. The spectrum clearly shows the absorption band in the 2825cm^{-1} region which a C-H stretch is corresponding to aldehydes. 2900cm^{-1} , C-H Stretch corresponding to alkane, 1450cm^{-1} bend corresponding to alkane, and 725cm^{-1} rock corresponding to alkane.

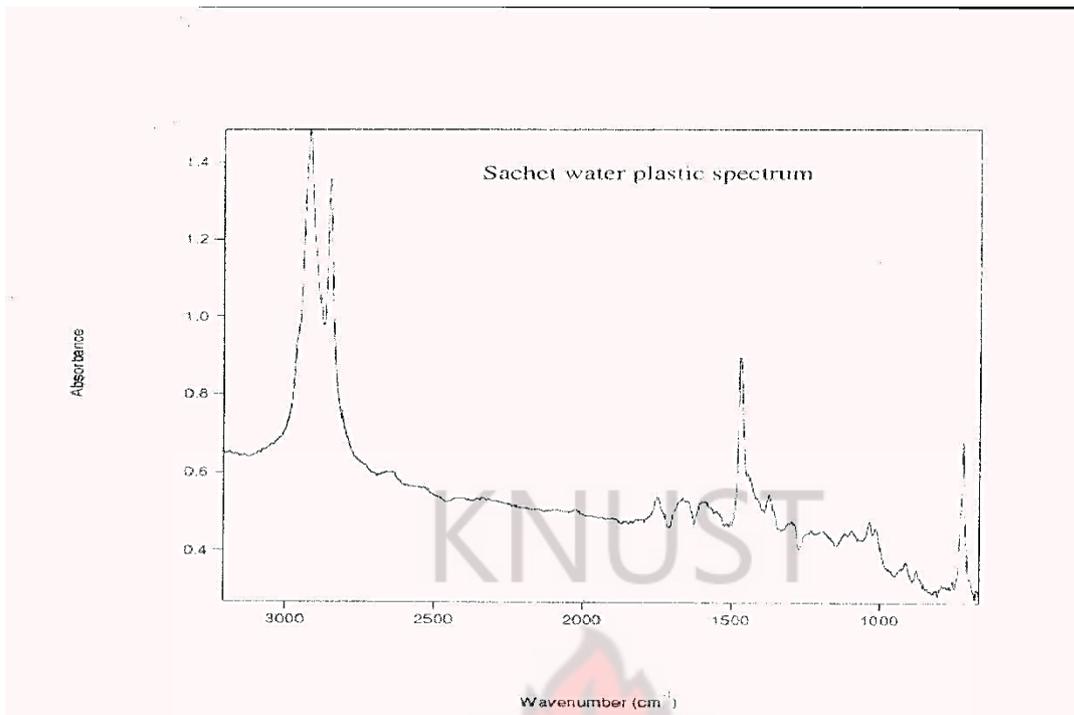


Figure 4.5 FTIR of the plastic water sachet

4.3 Mechanical Properties

4.3.1 Stress – strain curves

The Stress- Strain curve of a material can be used to determine several properties. Stress is the measure of force applied over an area. Strain is the normalized displacement. The maximum stress a material can withstand is the ultimate tensile strength, the linear behavior of a material over a given range and the slope of that function is called Modulus of Elasticity (MOE) or Young's modulus.

The stress and strain values for the various formulations were computed from the force or load applied on the sample and the extent of elongation. The values recorded were used for curves. The stress – strain curves of the various formulations are shown in fig 4.1-4.6. The stress-strain curves are drawn from the tables 4.1-The sample codes are UW which is for untreated Wawa, TW for treated Wawa, UM for untreated mahogany, TM for treated

Mahogany, UMW for untreated wood mixture and TMW for treated wood mixture. 1 is for 10%, 2 for 20%, 3 for 30%, 4 for 40%, and 5 for 50% fiber loadings

Table 4.1 is the stress and strain values obtained for the Wawa-plastic composite with % loadings of 10 % to 50%. These figures were used to draw stress-strain curves.

Table 4.1 Tables for stress and strain for Untreated Wawa-plastic composite at 10% to 50% loading

Stress (MPa)	Strain (%)								
UW1	UW1	UW2	UW2	UW3	UW3	UW4	UW4	UW5	UW5
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.52	3.70	7.15	3.81	7.78	4.93	7.91	2.25	9.53	2.59
11.57	7.00	16.87	9.05	15.09	8.17	13.45	5.43	13.48	3.94
19.80	9.90	23.88	10.92	19.10	11.47	16.68	7.15	18.50	5.43
25.53	13.17	26.35	12.25	22.45	13.04	20.32	10.86	22.07	7.21
28.09	16.23	30.03	14.32	23.79	13.91	22.43	11.45	25.33	7.84
32.41	18.45	27.67	16.41	28.98	15.37	28.31	12.53	26.43	9.62
27.62	20.14	24.84	18.48	26.65	16.97	26.96	15.78	24.33	11.41

Figures 4.1 to 4.6 show the stress- strain behavior of the WPC fabricated. The stress-strain behavior is qualitatively similar for each composite. Each stress-stain curve shows a moderate yield point for each blend followed by a drop in the stress with small changes in strain.

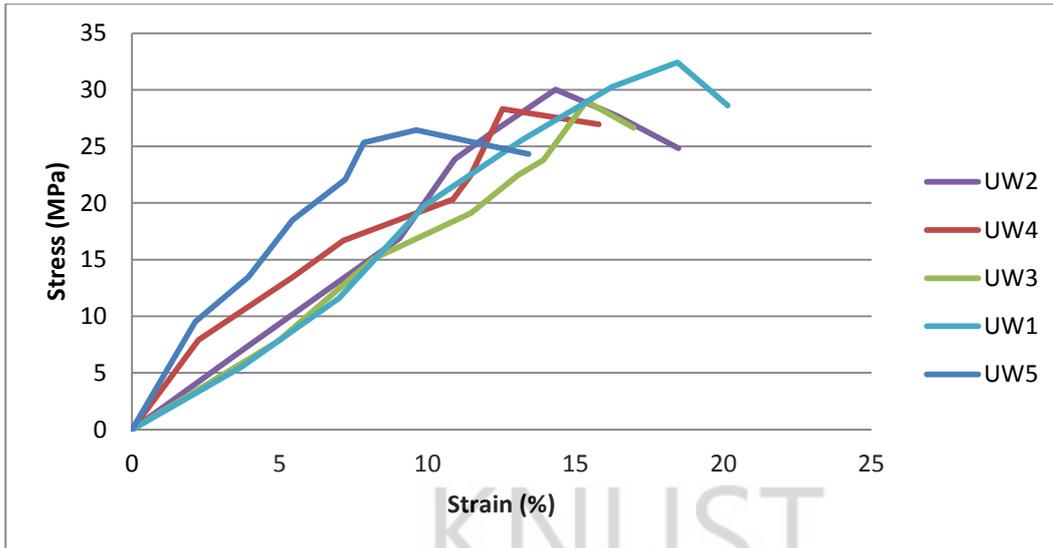


Figure 4.5 Stress – strain curves for the untreated Wawa and HDPE/LDPE composite

It can be seen from the chart that UW1(10%loading) extended more than all the others. Strain decreases as the percent loading increases. The 10% loading had the highest stress value of 32.41. the strain- strain curves are used to determine the tensile strength and the modulus of elasticity.

Table 4.2 Tables for stress and strain for treated Wawa-plastic composite at 10% to 50% loading

Stress (MPa)	Strain (%)								
TW1	TW1	TW2	TW2	TW3	TW3	TW4	TW4	TW5	TW5
0	0	0	0	0	0	0	0	0	0
5.69	6.70	6.19	3.81	8.78	4.53	7.81	5.25	9.53	3.59
11.57	8.20	15.87	9.45	17.09	8.77	11.15	7.43	10.41	3.94
20.56	10.67	23.88	11.92	19.10	10.37	15.68	10.65	17.52	6.43
25.53	14.17	26.35	13.32	23.45	13.14	18.11	11.06	20.77	7.28
27.09	16.81	33.09	14.32	23.79	15.91	21.43	11.95	25.33	7.98
34.11	19.45	28.67	17.41	30.98	16.37	28.94	13.51	28.73	10.62
29.62	22.14	23.84	20.22	27.65	19.12	24.98	15.68	24.83	13.41

Table 4.2 is the results obtained from the tensile test of the treated Wawa-plastic composite at 10% to 50% loading. The table was used to draw the stress-strain curve in fig 4.2.

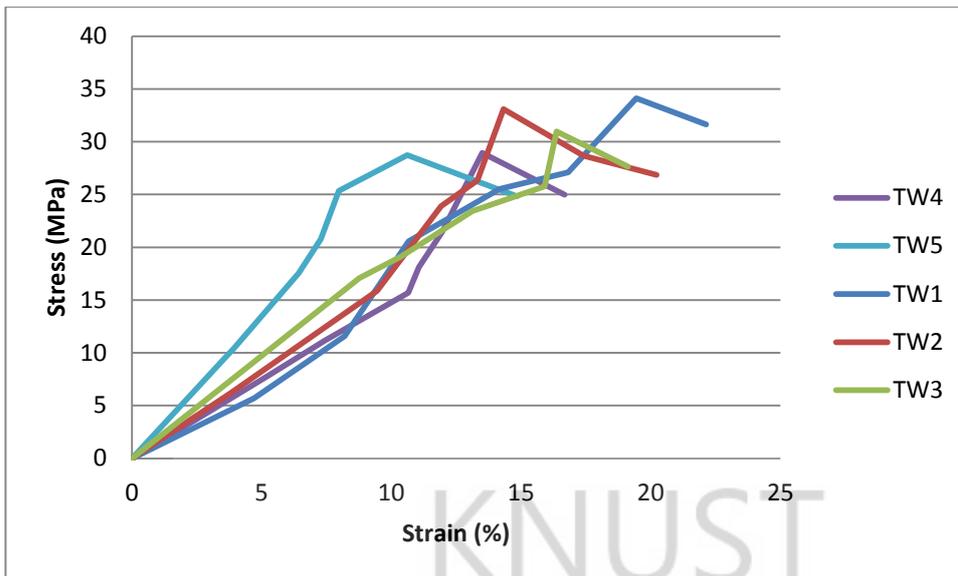


Figure 4.6: stress- strain curve for the treated Wawa and HDPE/LDPE composite

It can be seen from the chart that TW1 (10%loading) extended more than all the others. Strain decreases as the percent loading increases. The 10% loading had the highest stress value of 34.11. This figure is higher than that of the untreated at the same percent loading. The strain- strain curves are used to determine the tensile strength and the modulus of elasticity.

Table 4.3 Tables for stress and strain for untreated Mahogany-plastic composite at 10% to 50% load levels

Stress (MPa)	Strain (%)								
M1	M1	M2	M2	M3	M3	M4	M4	M5	M5
0	0	0	0	0	0	0	0	0	0
2.73	4.02	3.95	3.41	3.54	3.14	2.55	2.13	5.66	2.03
14.14	7.29	12.42	7.46	8.16	6.91	10.17	4.36	11.58	4.12
18.71	9.75	20.89	10.71	20.71	9.98	18.12	7.87	16.56	5.68
24.68	10.51	31.52	12.43	25.43	11.45	25.68	10.44	26.57	9.25
34.45	13.78	33.92	13.72	32.11	14.15	31.87	11.43	30.22	10.05
31.15	18.13	31.45	15.72	30.58	17.49	30.31	16.63	29.85	13.95
30.54	25.32	30.68	22.82	28.28	20.99	27.53	17.56	29.11	14.72

Table 4.3 is the results obtained from the tensile test of the untreated mahogany-plastic composite at 10% to 50% loading. The table was used to draw the stress-strain curve fig 4.3.

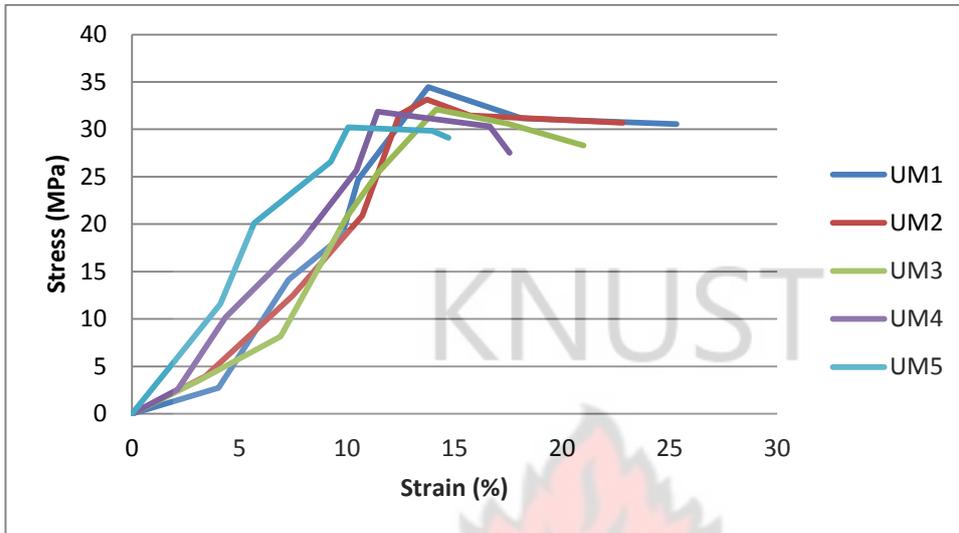


Figure 4.7: stress- strain curve for the untreated Mahogany and HDPE/LDPE composite

It can be seen from the chart that UM1 (10% loading) extended more than all the others. Strain decreases as the percent loading increases. The 10% loading had the highest stress value of 34.45MPa which is higher compared to that of Wawa at the same percent loading. The strain- strain curves are used to determine the tensile strength and the modulus of elasticity.

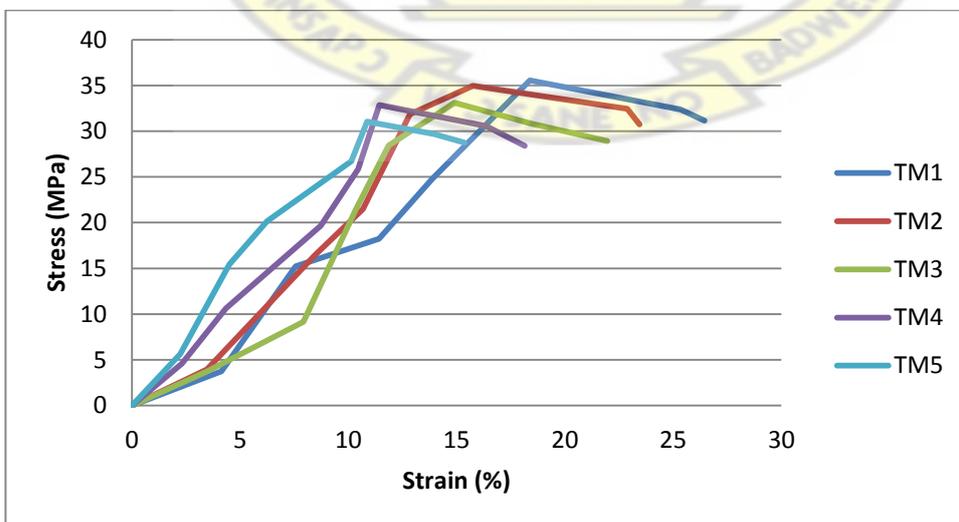


Figure 4.8: stress- strain curve for the treated Mahogany and HDPE/LDPE composite

Table 4.4 Tables for stress and strain for treated Mahogany-plastic composite at 10% to 50% load levels

Stress (MPa)	Strain (%)								
TM1	TM1	TM2	TM2	TM3	TM3	TM4	TM4	TM5	TM5
0	0	0	0	0	0	0	0	0	0
3.75	4.13	3.95	3.46	3.72	3.45	2.59	2.11	5.64	2.23
15.24	7.56	16.42	8.45	9.16	7.92	10.64	4.34	15.43	4.51
18.24	11.42	21.49	10.67	21.45	10.34	16.68	6.72	20.16	6.24
24.76	13.87	31.86	12.84	28.43	11.86	25.86	10.45	26.73	10.13
35.54	18.38	34.96	15.76	33.12	14.91	32.87	11.43	31.05	10.86
32.36	25.34	32.45	22.89	30.84	18.42	30.57	16.36	29.68	13.95
31.16	26.45	30.73	23.45	28.93	21.96	28.41	18.15	28.73	15.36

Table 4.4 is the results obtained from the tensile test of the untreated mahogany-plastic composite at 10% to 50% loading. The table was used to draw the stress-strain curve in figure 4.4. It can be seen from the chart that TM1 (10% loading) extended more than all the others. Strain decreases as the percent loading increases. The 10% loading had the highest stress value of 35.54MPa which is higher compared to that of untreated mahogany at the same percent loading. The strain- strain curves are used to determine the tensile strength and the modulus of elasticity.

Table 4.5 Tables for stress and strain for untreated wood mixture-plastic composite at 10% to 50% loading

Stress (MPa) MW1	Strain (%) MW1	Stress (MPa) MW2	Strain (%) MW2	Stress (MPa) MW3	Strain (%) MW3	Stress (MPa) MW4	Strain (%) MW4	Stress (MPa) MW5	Strain (%) MW5
0	0	0	0	0	0	0	0	0	0
5.83	4.83	5.05	3.25	5.61	2.84	5.71	2.84	7.14	3.19
7.27	5.62	8.88	4.04	8.91	4.99	9.26	3.56	9.26	4.04
13.52	8.94	17.58	6.58	17.70	7.61	10.21	5.79	12.52	5.25
23.51	11.54	26.98	9.86	23.48	10.87	16.26	7.21	15.73	10.03
33.02	12.04	33.33	12.96	26.56	13.98	20.05	8.11	20.26	11.34
33.77	13.52	25.14	16.93	24.87	14.15	20.66	13.33	20.87	12.11
32.09	18.47	22.68	17.43	23.57	15.44	23.45	13.98	21.54	12.85

Table 4.4 is the results obtained from the tensile test of the untreated mahogany-plastic composite at 10% to 50% loading. The table was used to draw the stress-strain curve in figure 4.4.

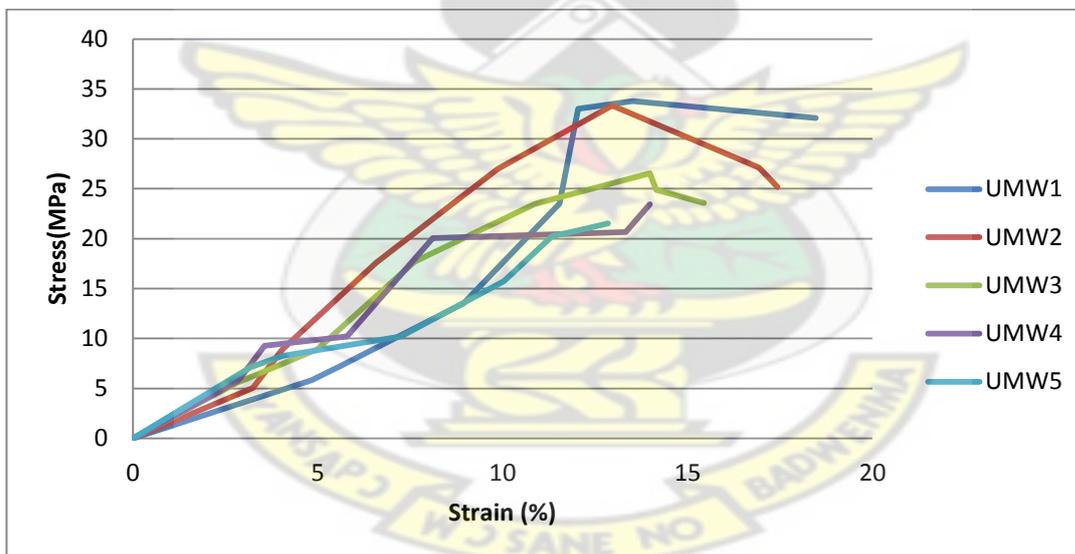


Figure 4.9: stress- strain curve for the untreated wawa-mahogany mixture and HDPE/LDPE composite

It can be seen from the chart that TM1 (10% loading) extended more than all the others. Strain decreases as the percent loading increases. The 10% loading had the highest stress value of 35.54MPa which is higher compared to that of untreated mahogany at the same

percent loading. The strain- strain curves are used to determine the tensile strength and the modulus of elasticity.

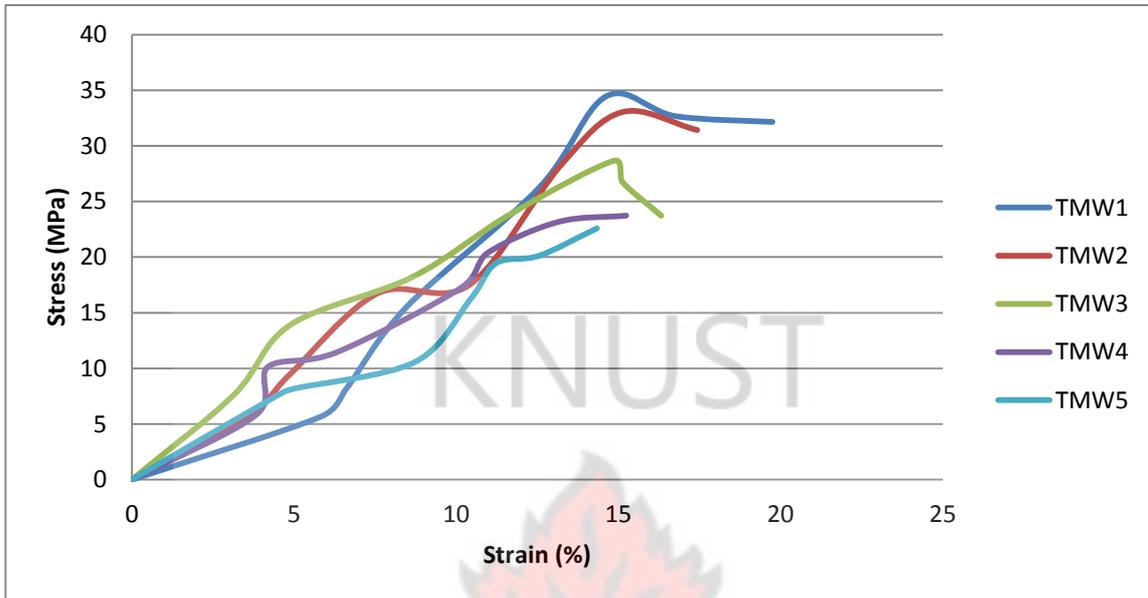


Figure 4.10: stress- strain curve for the treated wawa-mahogany mixture and HDPE/LDPE composite.

Table 4.6 Tables for stress and strain for treated wood mixture-plastic composite at 10% to 50% loading

Stress (MPa)	Strain (%)								
TMW 1	TMW 1	TMW 2	TMW 2	TMW 3	TMW 3	TMW 4	TWM 4	TMW 5	TWM 5
0	0	0	0	0	0	0	0	0	0
5.67	5.83	5.48	3.52	5.61	3.14	5.87	3.85	7.24	4.29
8.21	6.62	9.43	4.86	9.92	4.89	10.12	4.19	8.14	4.95
15.52	8.47	16.72	7.56	18.21	8.65	11.45	6.32	10.56	6.72
26.25	12.56	17.51	10.41	23.86	11.67	17.26	10.16	16.26	10.45
34.46	14.63	28.24	13.22	28.65	14.85	20.36	10.96	19.45	11.23
32.67	16.75	33.04	15.13	24.73	15.13	23.15	13.13	20.13	12.56
32.15	19.75	31.42	17.43	23.72	16.32	23.73	15.24	22.59	14.34

From the curves, it is obvious that as the percentage of wood filler increases, the strain (elongation) decreases. Adding fillers to a neat polymer melt changes its rheology, influencing both the way the melt processes and the properties of the ultimate product.

Key factors are filler size and shape, filler concentration, and the extent of any interactions among the particles. The consequences of adding fillers are an increase in melt viscosity and a decrease in die swell. Filled polymers have a higher viscosity at low shear rates, and yielding may occur with increased filler concentration. This trend was also observed by Abdul et al. (2011b).

4.3.2 Tensile strength

The ultimate tensile strength values were obtained from the highest stress values from the stress vs. strain curves in figs 4.8, 4.9 and 4.10. The values are recorded in tables 4.7, 4.8, and 4.9.

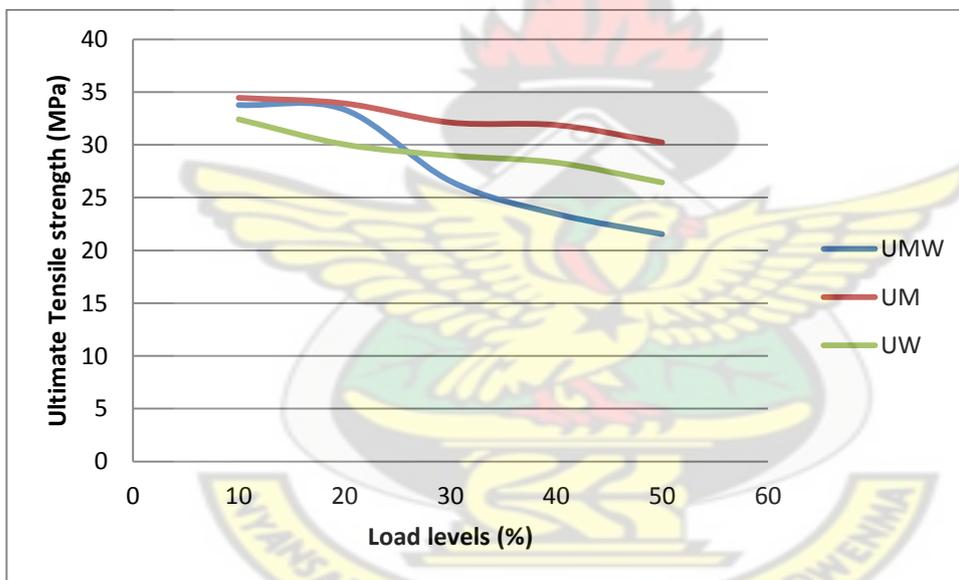


Fig 4.11 Ultimate tensile strength of wawa, mahogany, and the mixture plastic composite compared

Figure 4.11 shows the ultimate tensile strength of the composite formulated from the wawa, mahogany and their mixture and the plastic water sachet. All the graphs show a general pattern, that is the ultimate tensile decreased as the % loading of the sawdust increases.

It can be seen from the figure that the ultimate tensile strength decreases as the sawdust content decreases. For the mahogany composite, the tensile strength decreased from 34.45

MPa to 30.22 MPa when the loading was increased from 10% to 50%. The same trend was observed in all the other formulations. Comparing the three different formulations that is the Softwood (Wawa), hardwood (Mahogany) and the mixture of the two, it can be seen that at all % loading of sawdust, the hardwood recorded the highest tensile strength values followed by the softwood. The mixture of the two woods recorded the least values. This might be due to poor mixing of the two different woods. Hardwood and softwood each possess different properties such as amount of extractives, specific gravity and pores. Mixing the two woods cannot produce better surface for adhesion with the matrix thereby reducing the tensile strength of the composite. Between the hardwood and softwood, it was observed that the hardwood had the highest tensile strength in all the percent loading. This observation might be attributed to the fact that hardwood (mahogany) has high interfacial area which has the potential for better mechanical interlocking with the matrix. The high specific gravity of Mahogany (0.45) compared with that of Obeche or Wawa (0.3) (Green et al. 1999) influences good dispersion of particles into the plastic matrix.

The wawa (Obeche) on the other hand has more OH groups which prevents proper adhesion. Poor adhesion between the particles of the wood and the plastic matrix reduces the tensile strength of the composite. The low specific gravity of Wawa (0.3) might also be a factor for the low tensile strength. Wawa has a lower density compared to Mahogany and this might result in high void content in the wawa than the mahogany. High voids content reduced the tensile strength of the composite since voids do not transmit stresses and can cause stress concentration. This was also observed by Gacitua (2009), when he compared the tensile strength of two different woods. He concluded that the wood with the smaller average voids size area had the highest tensile strength. Void content is a significant factor affecting the performance of WPCs and the probability of failure under stress (Gacitua & Wolcott 2009).

Comparing the tensile strength of the treated sawdust and the untreated sawdust formulations, it can be seen that the tensile strength of all the treated fiber formulations were higher than that of the untreated filler formulations. For example at 30% fiber loading, from figure 4.12, the tensile strength of the untreated Mahogany sawdust was 32.11MPa while that of the treated one was 34.13MPa.

Table 4.7 Tensile strength and modulus of Elasticity of treated and untreated mahogany plastic composite

% Loading	Ultimate tensile Strength (MPa)	Modulus of Elasticity (MPa)	Ultimate tensile strength (MPa)	Modulus of Elasticity (MPa)
	UM	UM	TM	TM
10	34.45	1.35	35.54	2.04
20	33.92	2.00	34.96	2.15
30	32.11	2.29	33.12	2.34
40	31.87	2.83	32.87	3.17
50	30.22	3.00	31.05	3.25

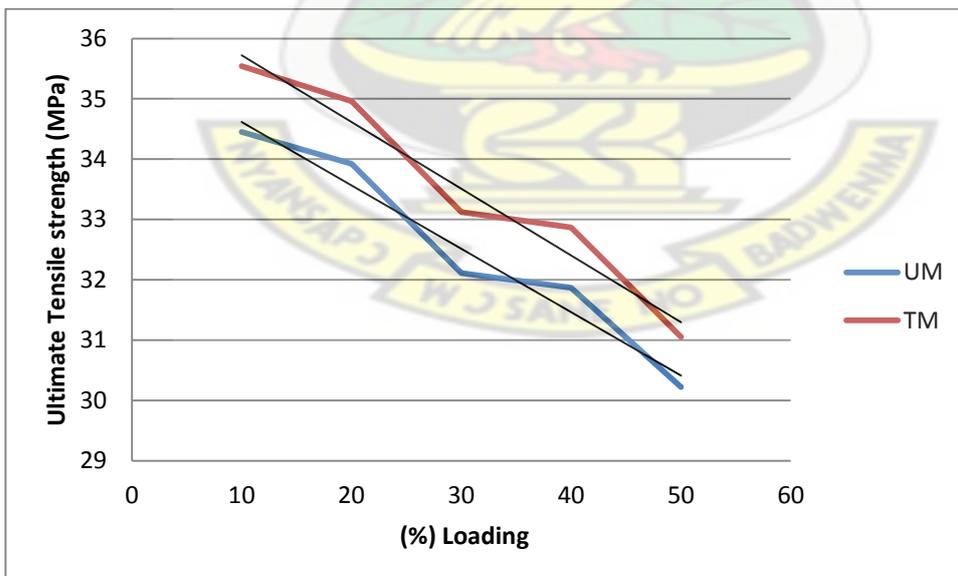


Figure 4.12: Ultimate tensile strength vs % Loading for Mahogany WF and HDPE/LDPE composite.

This difference might be attributed to the fact that treating the sawdust with NaOH dissolves lignin, and oils from the surface of the sawdust leaving a clean and porous cellulosic surface. This treatment led to higher specific mechanical properties since cellulose has much higher mechanical properties compared to lignin and also increases specific surface area leading to better interaction with the matrix. Kazemi et al (2013) reported a similar results (Kazemi et al. 2013). The results also confirms the work done by Nozari et al.(2013) when he studied the mechanical properties and water uptake of WF/LDPE composite after treating the fiber bwith 2% NaOH. He reported that the tensile strength increased by 10.8%. Farsi (2000) also gave a similar report in his work ‘Thermoplastic Matrix Reinforced with Natural Fibers : A Study on Interfacial Behavior’ .Similar results were obtained from the treated and the untreated wawa-plastic composite, though the differences in the tensile strength were minimal compared to that observed in the Mahogany.

Compared to the tensile strength of the untreated sawdust-plastic composites, the treated sawdust-plastic composites are found to show much higher strength. This may be attributed to the effect of chemical treatment on the interfacial bonding between the matrix and the fiber. This indicates the aptitude of the chemical treatment of the sawdust in improving the interfacial adhesion between the sawdust and the plastic used leading to increased stress transfer efficiency from the matrix to the fiber with a consequent improvement in the mechanical properties of the composites.

Table 4.8 is the result from the wawa-plastic composite and the graph is shown in figure 4.12.

Table 4.8 Tensile strength and modulus of Elasticity of treated and untreated Wawa plastic composite

% Loading	Tensile Strength(MPa)	Modulus of Elasticity(MPa)	Tensile Strength(MPa)	Modulus of Elasticity(MPa)
	UW	UW	TW	TW
10	32.41	1.8	34.11	1.5
20	30.03	2.0	33.09	1.86
30	28.98	2.4	30.98	2.14
40	28.31	2.7	28.94	2.34
50	26.43	3.0	28.73	2.50

Table 4.9 Tensile strength and modulus of Elasticity of treated and untreated Wawa-Mahogany mixture plastic composite

% Loading	Ultimate tensile strength (MPa)	Modulus of Elasticity (MPa)	Ultimate tensile strength (MPa)	Modulus of Elasticity (MPa)
	UMW	UMW	TMW	TMW
10	33.77	2.13	34.46	2.21
20	33.33	2.33	33.04	2.43
30	26.56	2.40	28.65	2.45
40	23.45	2.50	23.73	2.60
50	21.54	2.67	22.59	2.73

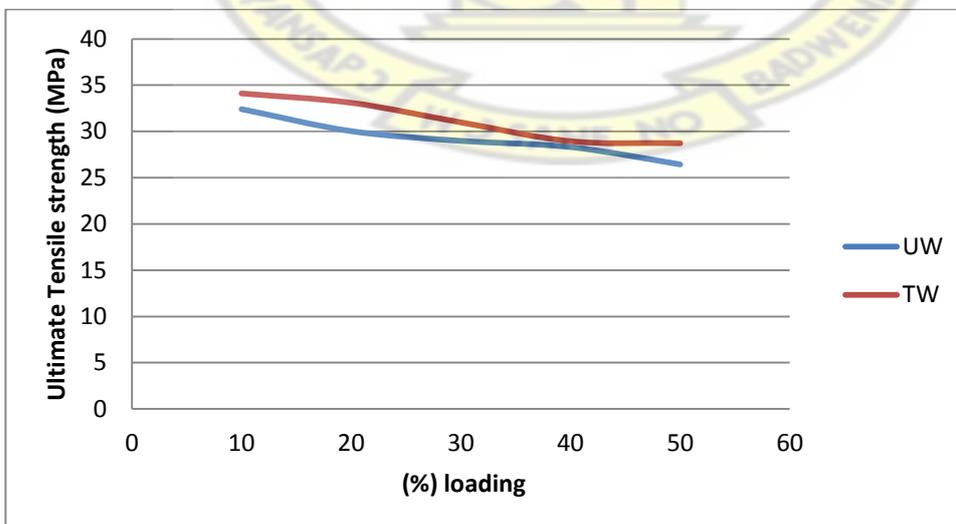


Figure 4.13: Ultimate tensile strength vs. % loading for Wawa HDPE/LDPE composite.

Figure 4.12 shows the ultimate tensile strength of the treated and the untreated wawa sawdust-plastic composite. The values were obtained from the highest stress at the various % loadings.

In figure 4.14, the ultimate tensile strength of the mixed wood-plastic composite is shown. There is only small difference between the treated and the untreated sawdust plastic composite.

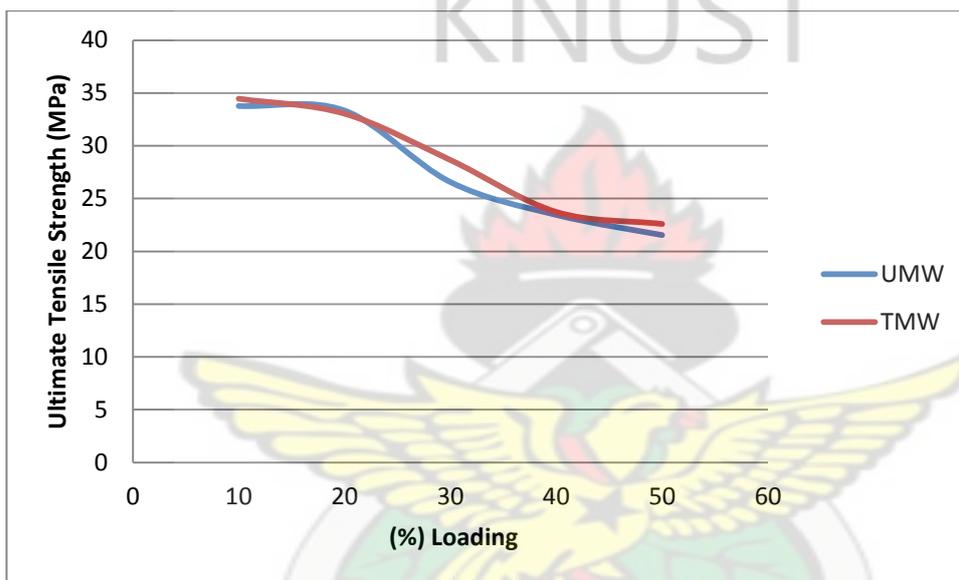


Figure 4.14: Ultimate tensile strength of Mahogany and Wawa fiber mixture and LDPE/HDPE composite

The importance of natural fiber reinforced composites of polymeric materials comes from the substantial improvement of strength and modulus that offers a possibility of composites in practical applications. As the % loading of sawdust increased, the weak interfacial area between the filler and the matrix increased, which consequently decreased the tensile strength Ashori & Nourbakhsh (2009a) also observed this. An increase in the filler content increases the micro spaces between the filler and the matrix, which weaken the filler–matrix interfacial adhesion. As a result, the values of tensile strength show a decreasing trend with increasing filler content in the composite. The presence of hydroxyl

groups in the cellulose of sawdust is responsible for its inherent hydrophilic nature (Abdul et al. 2011a)

Modulus of Elasticity (Young's modulus)

Young's modulus is the measure of the stiffness of a material. How much strain a material will undergo when a stress is applied. It is the change in stress over the change in strain.

$$\frac{\Delta\sigma}{\Delta\varepsilon} = \text{modulus of Elasticity} \quad (\text{Eq. 5})$$

The Young's moduli of the composites were calculated from the stress vs. Strain curves and there was a general trend for the values. The results are shown in tables 4.7, 4.8, and 4.9. The values were used to draw figures 4.15, 4.16, and 4.17.

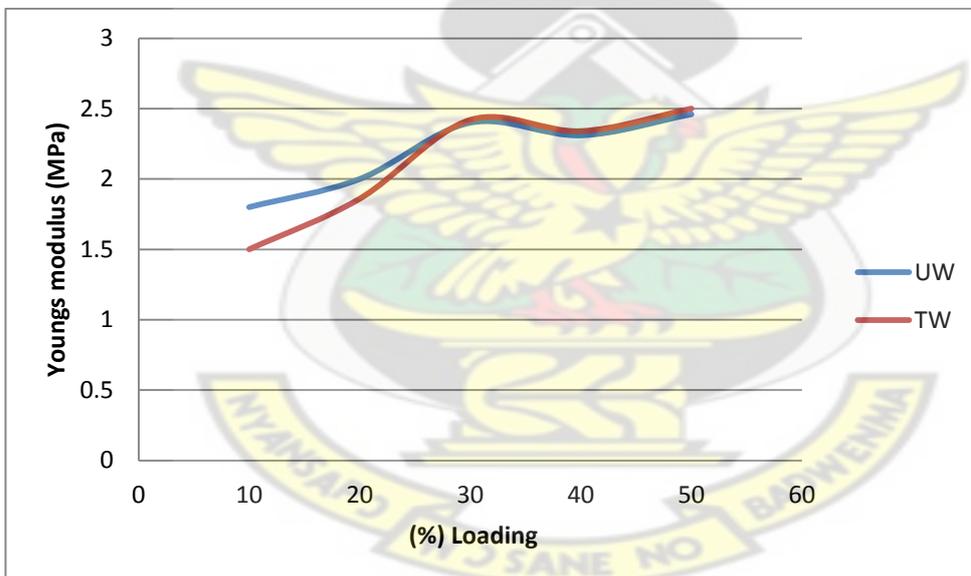


Figure 4.15: Young's modulus of treated and untreated Wawa – HDPE/LDPE composite compared

Of all the composite formulations, the Young's modulus increases with increasing loading of sawdust. As seen in the Wawa composite, the Young's modulus increased from 1.5MPa to 2.5MPa when the % loading of sawdust increased from 10% to 50%. Comparing the treated and the untreated WF formulations, it was observed that the treated sawdust-

HDPE/LDPE composites have higher Young's modulus than that of the untreated sawdust composites. For example, at 30% loading, the Young's modulus of the treated mahogany sawdust-HDPE/LDPE was 2.34MPa and that of the untreated formulation was 2.29MPa. All the other formulations gave high values for the treated compared to the untreated. This is in agreement with the work done by (Abdul et al. 2011b)

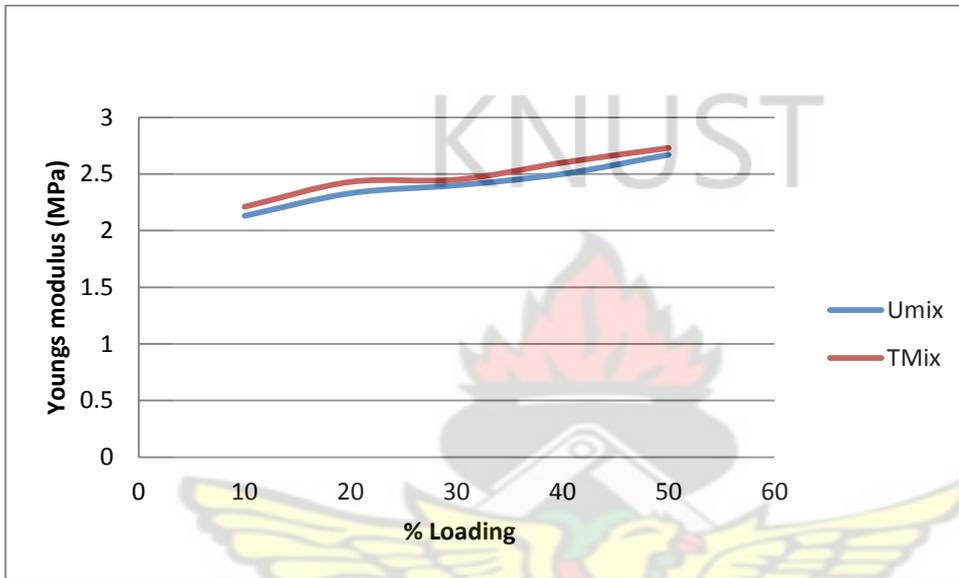


Figure 4.16: Young's modulus of treated and untreated sawdust mixture

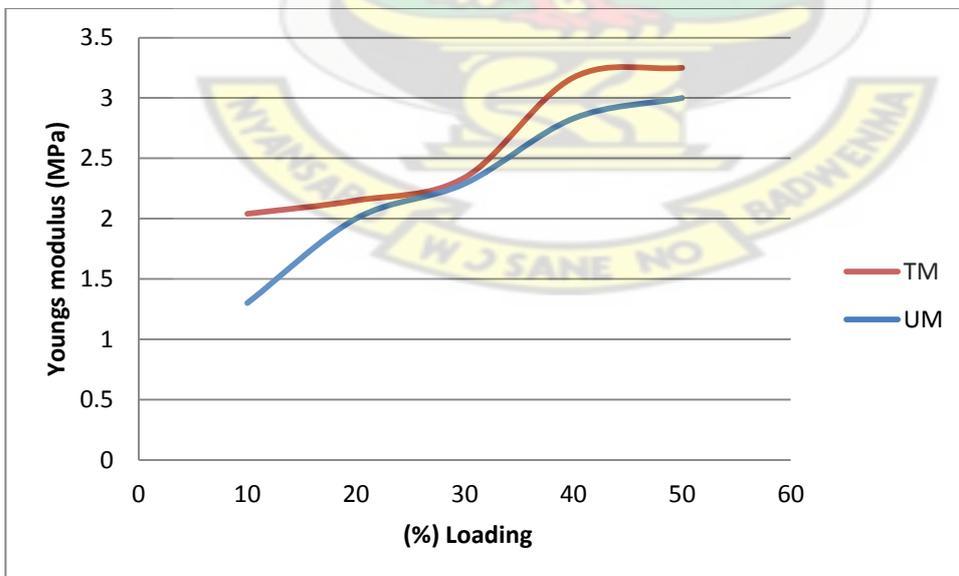


Figure 4.17: Young's Modulus of treated and untreated Mahogany- HDPE/LDPE composite compared

Comparing figures 4.16 and 4.17, it can be seen the untreated wood mixture-HDPE/LDPE shows slight increase in the MOE as the percent loading from 2.13 MPa to 2.67 MPa as the sawdust content increases from 10% to 50%. Unlike the untreated mahogany-HDPE/LDPE composite in which the MOE increased from 1.35 MPa to 3.0 MPa. This might be due to the presence of high content of voids in the wood mixture compared to that of mahogany.

The addition of the filler is expected to increase the modulus of composites that results from the inclusion of rigid filler particles into the thermoplastics. It is evident from the Figures that increase in both untreated and treated sawdust content in the matrix results in an increase in the modulus of the composites. This trend supports the research done by Afrifah (2010)(Afrifah et al. 2010).

The treated sawdust composites are found to show higher modulus compared to the composites of untreated sawdust. Usually crystallites possess higher modulus compared to amorphous substances. During chemical treated with NaOH, the sawdust surface probably attains somewhat crystalline nature, which might be dominated over its bulk nature thus give higher modulus of the treated sawdust/HDPE/LDPE composites. When Abdul et al (2011) studied Treated Tropical Wood Sawdust-Polypropylene Polymer Composite: Mechanical and Morphological Study, he came out with similar results. Incorporation of fiber into the polymer matrix reduced the matrix mobility, resulting in stiffness of the composite. As a result, Young's modulus increased with increasing the filler content of the composites. During alkali treatment, the physical structure of the fiber changed which removed surface impurities and waxy materials. This caused the improvement of the interfacial bonding between fiber and matrix

4.3.3 Water absorption

The water absorption test was done by the immersion test for 15 days. After that the increase in the weight of the specimens was calculated using the following equation:

$$\text{water absorption} = \frac{\text{final weight} - \text{original weight}}{\text{original weight}} \times 100 \quad (\text{Eq. 6})$$

Table 4.10 Water absorption of treated and non-treated wood mixed sawdust- plastic composites

Mixture filler loading	Water absorption (%)	
	Treated	Non-treated
0	0.32	0.32
10	2.11	2.90
20	2.93	3.25
30	3.23	4.18
40	3.78	5.43
50	5.46	6.77

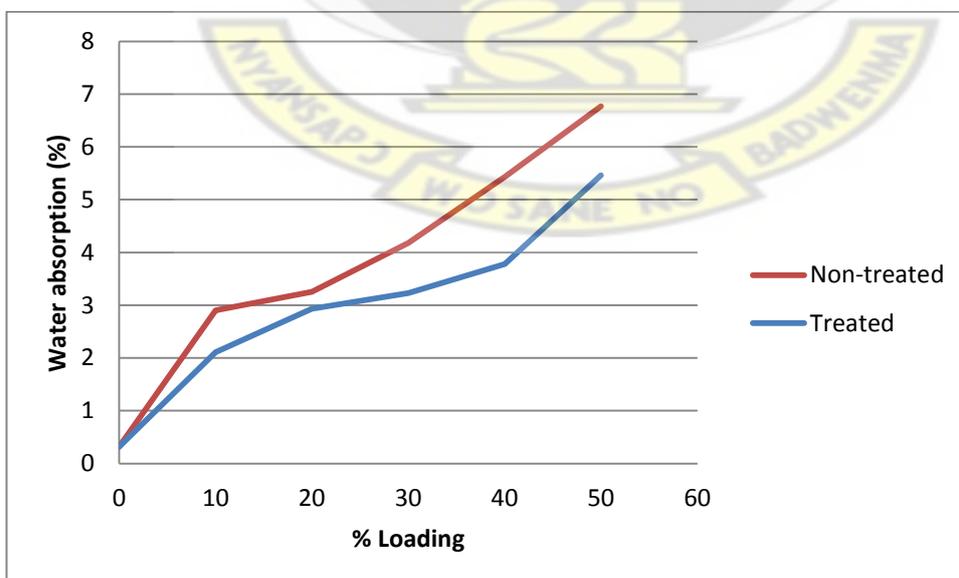


Figure 4.18 Water absorption of treated and non-treated wood mixed sawdust- plastic composites

Table 4.11 Water absorption of treated and non-treated wood mixed sawdust- plastic composites

Wawa filler loading	Water absorption (%)	
	Treated	Non-treated
0	0.32	0.32
10	2.08	2.38
20	2.53	4.23
30	4.86	6.27
40	6.11	7.20
50	6.92	8.63

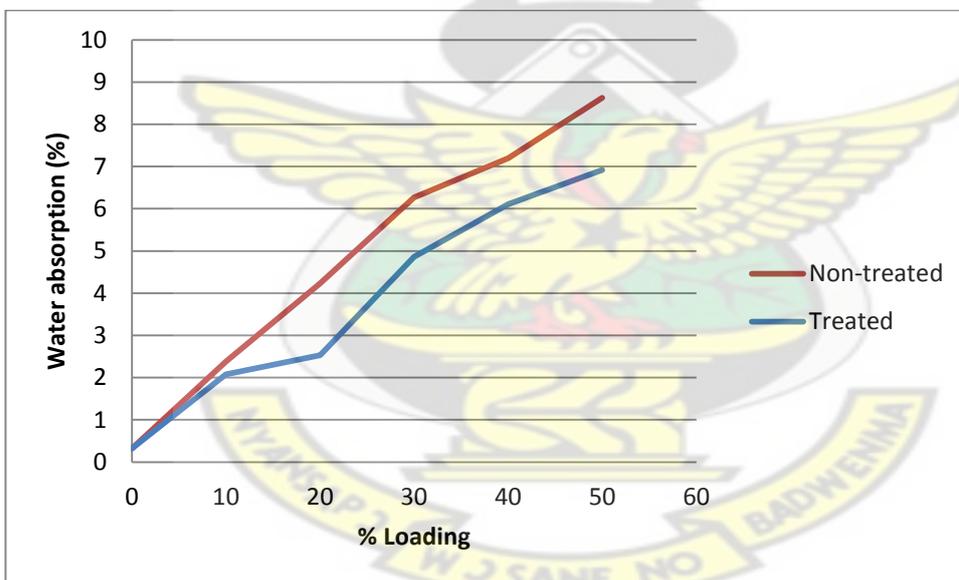


Figure 4.19 Water absorption of treated and non-treated wawa sawdust- plastic composites

Table 4.12 Water absorption of treated and non-treated mahogany sawdust- plastic composites

Mahogany filler loading	Water absorption (%)	
	Treated	Non-treated
0	0.32	0.32
10	1.74	2.14
20	2.43	2.78
30	2.88	3.45
40	3.13	4.63
50	4.74	5.03

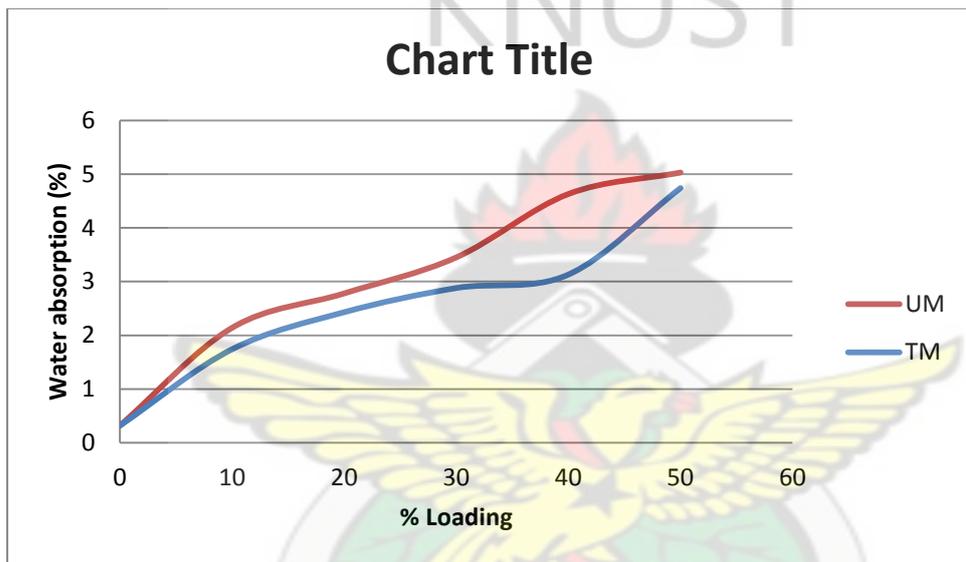


Figure 4.20 Water absorption of treated and non-treated mahogany sawdust- plastic composites

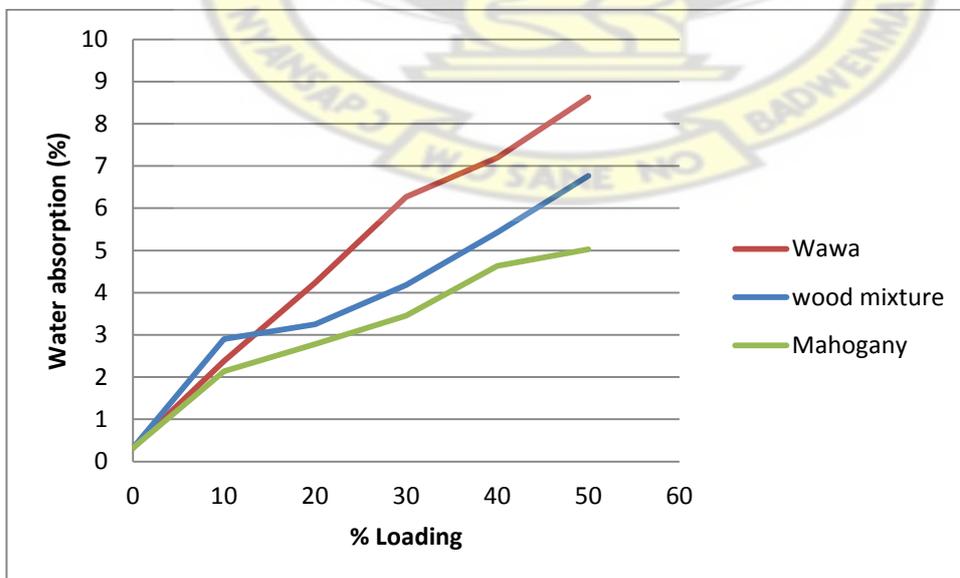


Figure 4.21 Water absorption of treated and non-treated sawdust- plastic composites

Water absorption behaviors of the composites at room temperature against filler loading are shown in Figs. It is evident in the figures that water absorption (%) increases with an increase in filler loading. After the 15 days the results obtained were as follows. The composite made from 20% non-treated wawa filler absorbed 4.23% water whereas the same amount of treated sawdust absorbed 2.53. 30% non-treated sawdust mixture absorbed 4.18% whereas 30% treated sawdust mixture absorbed 2.83% water. 2.43% was recorded by the 20% treated mahogany sawdust, and the non-treated recorded 2.78%. In all the three comparison made, the treated sawdust formulations absorbed the least water. This observation suggests that the hydrophilic nature of sawdust has substantially decreased upon its chemical treatment with Sodium Hydroxide solution. The figure below shows the water absorption of treated and untreated sawdust plastic composite.

For the non-treated sawdust formulations, the general trend observed was that as filler loading increases, water absorption increases as well. This supports the research done by (Abdul et al. 2011c) (Adhikary et al. 2008a) (NAJAFI et al. 2007a). This can clearly be seen in figure...

From the three formulations that is, wawa (softwood), mahogany (hardwood) and the mixture, it was observed that the hardwood (mahogany) absorbed the least water.

The rate of water absorption in wood depends on several factors such as; water absorption is most rapid in the longitudinal directions, the rate at which air can escape from wood affects water absorption as water displaces air in the lamina, density as well as diffusivity of woods. Density and diffusivity are caused by the porous structure of wood and the reactivity of the chemical components. These factors might be the reason why the soft wood absorbed much water than the hard wood as well as the mixture.

Wood can absorb large amounts of moisture; its water content can reach levels as high as 10 wt. %. Moreover, even wood embedded into the polymer absorbs a considerable amount of water, which may change the dimensions of large products and cause problems in certain applications (Dányádi et al. 2010). Wood also may deteriorate with time if its water content is continuously at a high level. Accordingly the decrease of the water absorption capacity of wood used in composites would have beneficiary effect on the lifetime of the product and on its application properties (Dányádi et al. 2010).

Increase in filler loading increases the number of free hydroxyl groups in the composites which forms hydrogen bond with the water molecules ,which consequently increases the water absorption (Abdul et al. 2011b).

(Kord 2011d) and (Bledzki & Faruk 2006) reported that natural fiber-polymer composites without compatibilizers show remarkable water absorption due to the presence of voids. (English & Falk 1996) also reported that water absorption is due to individual fibers, microgaps in the interface between fibers and plastic, voids due to water vapor generation during hot melt process. These might be the reason why the water absorption increase as the filler loading increased.

No swelling effect was observed after the immersion in all the samples, which may be due to encapsulation of the wood fiber into the matrix. This indicates that water absorption takes place mainly in the micro-voids of the composite specimen. Chemically treated sawdust reinforced composites showed low water absorption tendency compared to those prepared with untreated sawdust.

4.3.4 Density of Composite

It is observed from table 4.18 density of the composites from the treated and the untreated sawdust increased as the sawdust wt% loading increased. The treated sawdust composite

had higher densities compared to the untreated ones of the same wood type and at same fiber loading. For example wawa sawdust-HDPE/LDPE composite at load levels 30%, the density for the treated was 0.945g/cm³ and that of the untreated one was 0.897g/cm³.

This shows that there was present of voids inside the raw composites. After the chemical treatment, better interaction between the matrix and the fiber existed hence had resulted in void minimization in the composites.

Comparing the densities of the two wood species it can be observe that, the softwood composites had low densities than that of the hardwood. This might be due to the fact that the softwood without the plastic is lighter than the hardwood and this gave the composite made of the softwood lighter than the one made of the hardwood.

Table 4.13 Densities of the various sawdust-HDPE/LDPE composite formed

Sample code Wawa	Density (g/cm ³)	Sample code Mahogany	Density (g/cm ³)	Sample code Mixture	Density (g/cm ³)
UW1	0.879	UM1	0.883	UMW1	0.878
UW2	0.885	UM2	0.889	UMW2	0.887
UW3	0.897	UM3	0.931	UMW3	0.891
UW4	0.941	UM4	0.952	UMW4	0.897
UW5	0.973	UM5	0.984	UMW5	0.987
TW1	0.898	TM1	0.891	TMW1	0.891
TW2	0.932	TM2	0.898	TMW2	0.914
TW3	0.945	TM3	0.959	TMW3	0.956
TW4	0.974	TM4	0.981	TMW4	0.998
TW5	1.054	TM5	1.134	TMW5	1.123

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

In this work, the effect of wood species on the mechanical properties of WPC was determined. The effect of chemical treatment of the wood on the mechanical properties of WPC was also determined. The WPCs were manufactured from Wawa (softwood) and Mahogany (hardwood) as the filler and HDPE/LDPE (water sachet plastic) as the matrix. The woods were used individually and the mixture of the two was also used.

The conclusions made from the study were as follows;

5.1 Ultimate Tensile Strength

The ultimate tensile strength of all the WPC fabricated decreased as the amount of WF added to the plastic increased. For example, the ultimate tensile strength for the untreated Wawa-LDPE/HDPE composite decreased from 32.41MPa to 26.43MPa as the filler loading increased from 10% to 50%. Among the three different fillers used, that is Wawa, Mahogany and the mixture of the two, the mahogany composites gave the highest ultimate tensile strength and the mixture gave the least at all load levels. In all the formulations at all load levels, the treated WF-HDPE/LDPE composites gave the highest ultimate tensile strength.

Modulus of Elasticity (MOE) or Young's Modulus

The MOE of all the composites fabricated increased as the WF content increased. Among all the formulations, the treated mahogany- Plastic composite gave the highest MOE of 3.25 MPa at 50 % filler content.

Density

The general trend was that density increases as sawdust content increased. The treated mahogany-plastic composite had the highest density of 1.134g/cm³ at 50% sawdust content.

Water Absorption

The amount of water absorbed depends on the sawdust content of the composite. In all the WPC made, the amount of water absorbed at the end of the 15 days increased as the sawdust content increased. The treated sawdust-plastic composites absorbed the least water in all the formulations. Comparing all the formulations, the WPC with Mahogany as filler absorbed the least amount of water and the Wawa absorbed the most. At 50% sawdust content, the untreated Wawa-plastic composite absorbed the highest amount of water of 8.63% sawdust content with the treated Mahogany-plastic composite absorbing the least amount of water of 4.74%.

Generally, wood species played a major role in the performance of WPC, so a careful selection of wood might be a useful tool for improving overall performance of WPC.

5.2 Recommendations

Based on the research and the conclusions, the following recommendations can be made;

1. Other wood species must be researched into to find the wood that gives the best properties of the WPCs.
2. A series of concentrations of the NaOH must be used to treat the woods in other to find out the concentration that gives the optimum results.

3. Other tests such as impact test, flexural test be done on the WPC made from Water sachet plastic (recycled HDPE/LDPE) and sawdust to determine the impact strength and the flexural strength of the products formed.
4. The Department should be resourced or retooled with the needed equipment such as injection molder, tensile tester to enhance more research into WPCs and other related areas.
5. The government should facilitate in the setting up of WPCs companies in the countries to convert the plastic waste into useful products in other to curb the plastic menace in the country. Example WPC to make desk for schools



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