UNIVERSITY OF EDUCATION, WINNEBA

COLLEGE OF TECHNOLOGY EDUCATION, KUMASI

PHYSICAL, MECHANICAL AND DURABILITY PROPERTIES OF PARTICLEBOARD PRODUCED FROM *CEIBA PENTANDRA* SAWDUST AND CORN COB PARTICLES USING CASSAVA STARCH OR UREA FORMALDEHYDE ADHESIVE AS SEPARATE BINDER

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(Bsc. WOOD TECHNOLOGY EDUCATION)

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A dissertation in the Department of CONSTRUCTION AND WOOD TECHNOLOGY EDUCATION, Faculty of TECHNICAL EDUCATION, submitted to the School of Graduate Studies, University of Education, Winneba in partial fulfilment of the requirements for the award of the Master of Philosophy (Wood Science and Technology) degree

JULY, 2016

DECLARATION

STUDENT'S DECLARATION

I, **Oppong Sefah,** declare that this Dissertation with the exception of quotation and references contained in published works which have all been identified and dully acknowledge, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

SIGNATURE …………………………

DATE …………………………………

SUPERVISOR'S DECLARATION

We hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of Dissertation as laid down by the University of Education, Winneba.

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DEDICATION

This piece of work is dedicated to my dear wife Mrs Angela Oppong for her unrelenting support and prayers towards a successful completion of this work and my beautiful daughter Adiepena Boafowaa Oppong.

TABLE OF CONTENTS

CONTENT **PAGE**

Declaration ii

Acknowledgement.. iii

Dedication iv

Table of contents ....**Error! Bookmark not defined.**x

List of tables..**Error! Bookmark not defined.**xi

List of figures..**Error! Bookmark not defined.**xiii

Abstract..xv

CHAPTER ONE 1

INTRODUCTION.. 1

1.1 Background of the Study 1

1.2 Statement of the Problem 3

1.3 Purpose of the Study 4

1.4 Objective of the Study 5

1.5 Research Question 5

1.6 Scope of the Study.. 6

1.7 Significance of the Study.. 6

1.8 Limitation 7

1.9 Delimitation of the Study 8

1.10 Organisation of the Study 8

CHAPTER TWO 10

LITERATURE REVIEW 10

2.1 Forest Resource in Ghana 10

2.2 Quantity of Wood Residue in Ghana 11

2.2.1 Logging Residues 12

2.2.2 Wood Processing Residues 12

2.3 Agricultural Residue in Ghana 14

2.4 Physical and Chemical Properties of Corn Cob 15

2.5 Particleboard 16

2.6 History and Development of Particleboard 18

2.7 Particleboard Production Line 19

2.7.1 Particle Preparation 21

2.7.2 Particle Drying and Screening 21

2.7.3 Blending and Mat Forming 22

2.7.4 Pressing 23

2.7.5 Board Finishing 24

2.8 Pressing Parameters of Particleboard 24

2.8.1 Mat Moisture Content 25

2.8.2 Adhesive Type 27

2.8.3 Press Closing Rate 29

2.8.4 Press Time, Temperature, and Pressure 30

2.9 Factors Affecting the Properties of Particleboard 31

2.9.1 Mixture of Species 32

2.9.2 Wood Density 33

2.9.3 Particles Sizes 34

2.9.4 Type of Resin 35

2.9.5 Pressure and Temperature 36

2.10 Physical Properties of Particleboard 37

2.11 Bending Strength Properties of Particleboard 38

2.11.1 Modulus of Rupture 38

2.11.2 Modulus of Elasticity 40

2.12 Dimensional Characteristics of Particleboard 41

2.13 Dimensional Changes in Veneer, Fibre and Particle Panel Product 42

2.14 Common Uses of Particleboard 44

2.15 Particleboard Standards and Certification 44

2.16 Safety of Particleboard 45

2.17 Use of Formaldehyde Adhesives in Particleboard Manufacturing 45

2.18 Risk of Formaldehyde Emission to Indoor Air 46

2.19 Environmental Impact of Particleboard 47

2.20 Origin and Distribution of Cassava 49

CHAPTER THREE 52

MATERIALS AND METHODS 52

3.1 Research Design 52

3.2 Materials 52

3.2.1 Collection and Preparation of Sawdust 53

3.2.2 Collection and Preparation of Corn Cob 54

3.2.3 Preparation of Cassava Starch 55

3.2.4 Mould Box Preparation 56

3.3 Methods 57

3.3.1 Preparation of Mix Ratios of Materials 57

3.3.2 Determination of Moisture Content of Materials 58

3.3.3 Mat Forming and Pressing 59

3.3.4 Particleboard Finishing 60

3.4 Testing the Physical and Mechanical Properties of the Particleboard 62

3.4.1Determination of Density of Corn Cob and *Ceiba pentandra* Particleboard ... 63

3.4.2 Determination of Moisture Content of Corn Cob and *Ceiba pentandra* Particleboard 64

3.4.3 Determination of Thickness Swelling of Corn Cob and *Ceiba pentandra* Particleboard 65

3.4.4 Determination of Water Absorption of Corn Cob and *Ceiba pentandra* Particleboard 67

3.4.5 Determination of Decay rate of Corn Cob and *Ceiba pentandra* Particleboard 68

3.4.6Determination of Moisture Uptake of Corn Cob and *Ceiba pentandra* Particleboard 70

3.4.7 Mechanical Properties 71

3.4.7.1 Modulus of Elasticity (MOE) 72

3.4.8.2 Modulus of Rapture 73

3.5 Analysis of Test Results 73

CHAPTER FOUR........ 75

RESULTS OF THE STUDY 75

4.1 Physical Properties of Particleboard Produced from *Ceiba pentandra* and Corn cob using Urea formaldehyde and Cassava starch as Binders 75

4.1.1 Density of the Particleboard........ 75

4.1.2 Moisture Content of the Particleboard........ 78

4.1.3 Thickness Swelling of the Particleboard 80

4.1.4 Water Absorption Rate of the Particleboard 82

4.2 Mechanical Properties of Particleboard Produced from *Ceiba pentandra* and Corn cob using Urea formaldehyde and Cassava starch as Binders........ 84

4.2.1 Modulus of Elasticity of the Particleboard 84

4.2.2 Modulus of Rapture of the Particleboard 86

4.3 Durability Properties of Particleboard Produced from *Ceiba pentandra* and Corn cob using Urea formaldehyde and Cassava starch as Binders........ 89

4.3.1 Decay rate of the Particleboard 89

4.3.2 Moisture Uptake of the Particleboard 90

CHAPTER FIVE 93

DISCUSSION 93

5.1 Physical Properties of Particleboard Produced from *Ceiba pentandra* and Corn cob using Urea formaldehyde and Cassava starch as Binders 93

5.1.1 Density of the Particleboard 93

5.1.2 Moisture Content of the Particleboard 94

5.1.3 Thickness Swelling of the Particleboard 95

5.1.4 Water Absorption of the Particleboard 97

5.2 Mechanical Properties of Particleboard Produced from *Ceiba pentandra* and Corn cob using Urea formaldehyde and Cassava starch as Binders 99

5.2.1 Modulus of Elasticity of the Particleboard 99

5.2.2 Modulus of Rapture of the Particleboard 101

5.3 Durability Test of Particleboard Produced from *Ceiba pentandra* and Corn cob using Urea formaldehyde and Cassava starch as Binders 103

5.3.1 Decay rate of the Particleboard 103

5.3.2 Moisture Uptake of the Particleboard 104

CHAPTER SIX 106

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS....... 106

6.1 Summary of the Findings 106

6.2 Conclusion 108

6.3 Recommendations 108

REFERENCE..110

APPENDICES………………………………………………………………………130

LIST OF TABLES

CONTENT **PAGE**

Table 2.1 Average Annual Logs and Sawdust Production (1000m^3) 13

Table 2.2 Productions of Different Agricultural Crops in Ghana for 2010 and Estimated Potential Residues 14

Table 2.3 Chemical Analysis of Corn Cob 16

Table 2.4 Chemical Analysis of Urea Formaldehyde 46

Table 2.5 Cassava Production Estimates in Ghana (2007-2011) 50

Table 2.6 The Proximate Composition of Cassava Starch 51

Table 3.1 Quantity of Materials for Manufacturing of Particleboard 59

Table 3.2 Production Parameters of the Particleboard 60

Table 3.3 Description of Particleboard Specimens 63

Table 3.4 Decay Rating System according to EN 252 (1990) 69

Table 4.1 ANOVA Effects of Mixing percentage, Binder and their Interaction on Density of the Particleboard. 76

Table 4.2 ANOVA effects of Mixing percentage, Binder and their Interaction on Moisture Content of the Particleboard. 79

Table 4.3 Thickness Swelling of the Particleborad Produced..80

Table 4.4 ANOVA effects of Mixing percentage, Binder and their Interaction on Thickness Swelling rate of the Particleboard produced. 81

Table 4.5 Water Absorption rate of the Particleboard Produced 82

Table 4.6 ANOVA effects of Mixing percentage, Binder and their Interaction on Water Absorption of the Particleboard produced. 83

Table 4.7 ANOVA effects of Mixing percentage, Binder and their Interaction on Modulus of Elasticity of the Particleboard produced. 86

Table 4.8 ANOVA effects of Mixing percentage, Binder and their Interaction on Modulus of Rapture of the Particleboard produced.. 88

Table 4.9 Decay rate of Particleboard Produced... 89

Table 4.10 ANOVA effects of mixing percentage, Binder and their Interaction on Decay rate of the Particleboard produced. 90

Table 4.11 Moisture Uptake of Particleboard Produced 91

Table 4.12 ANOVA effects of Mixing percentage, Binder and their Interaction on Moisture Uptake of the Particleboard produced. 92

LIST OF FIGURES

CONTENT PAGE

Figure 2.1 Single Layer Particleboard ... 17

Figure 2.2 Three Layers Particleboard ... 17

Figure 3.1 *Ceiba pentandra* Saw Dust Particles ... 54

Figure 3.2 Corn Cob Particles ... 55

Figure 3.3 Cassava Starch Powder Preparations ... 56

Figure 3.4 Aluminium Mould Box for Pressing the Particleboard Samples ... 57

Figure 3.5 Finished Particleboards ... 61

Figure 3.6 Density and Moisture Content Test Samples ... 64

Figure 3.7 Thickness Swelling and Water Absorption Test Samples ... 67

Figure 3.8 Graveyard ... 69

Figure 3.9 Graveyard Test Samples ... 70

Figure 3.10 Mechanical Test Samples ... 71

Figure 3.11 Instron Testing Machine ... 72

Figure 4.1 Density of the Particleboard ... 76

Figure 4.2 Moisture Content of the Particleboard ... 78

Figure 4.3 Modulus of Elasticity of Particleboard 85

Figure 4.4 Modulus of Rapture of Particleboard 87

ABSTRACT

In Ghana, large quantities of wood and agricultural waste are left unutilized with its attendant negative environmental issues. Producing particle board from such waste would contribute to minimizing deforestation and positively impact the environment. This study therefore compared the properties of particleboard produced from *Ceiba pentandra* (CP) sawdust and corn cob (CC) particles using cassava starch or urea formaldehyde as separate binder. The study used a completely randomised experimental design. Three layer medium density particleboard was produced with CP and CC mix proportions of 90:10, 70:30 and 50:50 percent (by weight) respectively. 4500g of particles, 600g of binder and 225g of water were mixed and blended together manually. The mixtures were pressed at 160^{o}C and 32kg/cm^2 for 30minutes. Particleboard produced was tested using ASTM D. 1037-72 (1975) and EN 252 (1990) standards. Results showed that the density of the particleboard produced range from 0.6290g/cm^3 – 0.8223g/cm^3 at 11.4% - 17% moisture content. The mean thickness swelling range from 6.66% - 10.00% whiles water absorption range from 40.13% - 53.74%. However, the highest modulus of elasticity (MOE) of 2182.3N/mm^2 and modulus of rapture (MOR) of 12.58N/mm^2 were obtained from particleboard made from 90% CP and 10% CC with cassava starch binder. The results further indicated that mix ratio, binder as well as their interaction significantly influenced density, thickness swelling, water absorption, moisture content and MOR. Particleboard made from 90% CP and 10% CC with cassava starch binder gave the best properties and thus recommended for the production of medium density particleboard.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Globally, depletion of tropical forests remains a major concern to policy makers and environmentalist on account of the critical role tropical forests play in protecting the global ecosystem (Chigbo, Andreas, Frederic, Lehmann & Nduka, 2013). Tropical forests hold on average about fifty percent (50%} more carbon per hectare (Hougton, 2005). According to UN report (2007), Ghana is rated among the highest deforestation countries in Africa. In 1900, the area of tropical forest was estimated at 8 million hectares but by 1946, the combined area of reserved and unreserved forest was estimated to have halved to 4 million hectares (Forestry Commission, 2010). In 2016, Ghana‟s forest reserve is estimated to have been reduced from 8 million hectares (1900) to 1.8 million hectares in 2016 (Ghanaian Times, 2016). The average annual rate of deforestation between the periods was about two percent (2%), which is higher than the average annual rate for both central and west Africa which stands at 0.6 percent (FAO, 2012).

Over harvesting has led to the downwards revision of the National Annual Allowable Cut (NAAC) in forest reserves from 1.2 million m^3 in 1990 to 500,000 m^3 in 2005 (ITTO, 2008). The off reserve component of the total NAAL (2 million m^3) was set as high as 1.5 million mainly due to extensive illegal logging and the assumption that with time those areas are likely to be converted to other land uses (Marfo, 2009). Currently, it is estimated that the nation‟s (Ghana) forest depletes by 65,000 hectares every year. In view of this, one can emphatically conclude that Ghana will lose its forest resources within the next three decades (2046), if measures were not put in place to halt the trend. One of the strategies that can be applied to sustain the Ghanaian forest is to increase productivity: productivity is the ratio of input and output should balance. This can be done by utilizing waste from wood processing.

According to Olesen and Plackett (1999), the global annual production of waste (sawdust & agricultural residues) is estimated about 4 billion m^3 of which roughly 60% comes from agricultural residues and 40% from saw dust. Ghana alone annually generates about 3 million m^3 wastes (Puopiel, 2010). These huge waste generated can be converted into useful product such as particleboard, and pulp and paper. Particleboard could be produced from combination of different materials which are combined together to form useful product with excellent properties and performance (Ates, Ni & Tozluoglu, 2008).

Ghana as a developing nation with emerging industrial economy, the waste generation such as wood and agricultural waste is increasing due to the industrial growth (Duku, Gu & Hagan*,* 2011). These agricultural and wood waste generated have created challenges of management system which end up in open air burning in the country and that it calls for pragmatic solutions. It is imperative to introduce and develop the technology to help utilize the numerous accumulations of these wastes in Ghana. This is what has necessitated the investigation into the use of *Ceiba pentandra* sawdust and corn cob particles as agricultural residue for particleboard production using cassava starch as binder.

1.2 Statement of the Problem

Ghana has enormous wood and agricultural residues such as sawdust and corn cob which remain unutilised (FAOSTAT, 2010). Attempts to dispose these residues by burning tend to pose serious environmental hazards. Converting these residues to utilisable structural materials such as particleboard provides a pragmatic way of dealing with the problem and could minimise the hazards posed to the environment through the burning of these residues (Agbin & Omaliko, 1993). Due to air and environmental pollution these wastes accumulation in large quantity can pose and its severed consequences it could result, it call for pragmatic approach to find a way to utilize the waste in more productive ways in the country to help minimize environmental pollution. In addition, over harvesting of timber species to meet the constructional demand has resulted in a severe deforestation in the country. Ghana‟s forest reserve is estimated to have been reduced from 8 million 1.8 million hectares (Ghanaian Times, 2016). Among some of the pragmatic measures to protect tropical forests from rapid depletion is to turn wood waste and agricultural residues into utilisable composite materials to complement solid wood. Ghana generates about 3 million metric tons of wastes annually (Puopiel, 2010). Studies have shown successful utilization of lignocellusic materials such as pinewood and maize cob (Mario, Silva, Rafael, & Lourival, 2013), rice husk and sawdust (Adedeji, 2011), eucalyptus wood and coffee husk (Mendes, 2010), and eucalyptus wood and rice husk (Melo, 2009) for particleboard production. It is against this background that investigation should be carried out to ascertain whether combination of corn cob and *Ceiba pentandra* would enhance the quality of particleboard. This would help to reduce the over dependence on timber and thereby improving the deforestation situation in the country.

Moreover, resin formaldehydes are volatile organic compound which produces formalin. Emission of formalin from resin formaldehydes has been a major problem to the fibreboard industry and the world at large due to health threats posed to humanity (Kollmann, Kuenzi & Stamm, 1975). Studies have shown that, other researchers have succeeded in manufacturing particleboard with different binding agent apart from conventional formaldehyde. For example, Adedeji (2011) carried out investigation into the production of particleboard using rice husk and sawdust with cement as binder and concluded that the panels produced have potentials to be used for non-structural purposes such as ceiling and partition. Idris, Aigbodion, Atuanya and Abdullahi (2011) also investigated the suitability of using water melon peels as alternative to wood based particleboard using recycled low density polythene as a binder and concluded that water melon particles can be used as a substitute for wood based particleboard for general purpose. This means that apart from the resin formaldehydes, different binding agent can be used as substitute to reduce over dependency of urea formaldehyde resins to limit the level of indoor emissions as it has been tested in the develop countries. This called for an investigation into the production of particleboard made from corn cob and *Ceiba pentandra* using cassava starch as a binding agent and accessing its strength effect against particleboard made of urea formaldehyde.

1.3 Purpose of the Study

The purpose of this study was twofold: first, to determine the possibility of producing utilisable particleboard from different mix ratios of corn cob and *Ceiba pentandra* sawdust and second, to compare the effectiveness of cassava starch as a binder in particleboard production with urea formaldehyde resin as commonly used binder.

1.4 Objectives of the Study

The study achieved the following objectives:

1. To determine the variation in physical properties of particleboard produced from different mix ratios of *Ceiba pentandra* sawdust and corn cob particles using urea formaldehyde adhesive or cassava starch as binder.
2. To determine the variation in mechanical properties of particleboard produced from different mix ratios of *Ceiba pentandra* sawdust and corn cob particles using urea formaldehyde adhesive or cassava starch as binder.
3. To determine the variation in durability properties of particleboard produced from different mix ratios of *Ceiba pentandra* sawdust and corn cob particles using urea formaldehyde adhesive or cassava starch as binder.

1.5 Research Questions

In order to achieve the stated objectives of this study, the following research questions have been developed to guide the study:

1. What are the physical properties of particleboard produced from different mix ratios of *Ceiba pentandra* sawdust and corn cob particles using urea formaldehyde adhesive or cassava starch as binder?

2. What are the mechanical properties of particleboard produced from different mix ratios of *Ceiba pentandra* sawdust and corn cob particles using urea formaldehyde adhesive or cassava starch as binder?
3. What are the durability properties of particleboard produced from different mix ratios of *Ceiba pentandra* sawdust and corn cob particles using urea formaldehyde adhesive or cassava starch as binder?

1.6 Scope of the Study

The study focused on the production of particleboard from *Ceiba pentandra* sawdust and corn cob particles using urea formaldehyde adhesive or cassava starch as binder respectively, as well as assessing the physical, mechanical and durability properties of particleboard produced such as the density, moisture content, thickness swelling, water absorption, modulus of elasticity and modulus of rapture, decay and termites resistance, moisture uptake/load level after exposing the particleboard produced to eight weeks weather conditions.

1.7 Significance of the Study

The study rational is to determine if corn cob and *Ceiba pentandra* particleboard have the potentials as wood based particleboard, therefore the outcome of this work will go a long way to:

1. Benefit the industry constructional material aside conventional wood product for particleboard production.

2. Release the pressure on the demand for wood particles for particleboard production to save the natural forest.
3. Help in generating cost effective building material that can be used for interior designs such as ceiling, flooring, cabinet and counter tops.
4. Generate supplementary income to the farmers, to improve socioeconomic status of the rural livelihood.
5. Help towards alleviating problems with environmental pollution in the country especially the rural areas.
6. Help create job opportunities among both the youth and the farmers to reduce the unemployment rate in the country.

1.8 Limitation

Estimating the effect of internal bond and tensile stress on the mechanical properties of particleboard produced from *Ceiba pentandra* and corn cob with cassava starch as binder would have enhanced the value of the study, however the unavailability of equipment hindered such estimation.

The researcher had wanted to examine the combination of urea formaldehyde and cassava starch (50:50) as binder to determine the effect of its bonds on the particleboard produced from *Ceiba pentandra* and corn cob, but lack of funds did not permit.

1.9 Delimitation of the study

This research was directed on the potential utilization of *Ceiba pentandra* and corn cob for the production of particleboard using cassava starch as binder. It is expected that the outcome of this research work will add to existing literature or knowledge on effective use of *Ceiba pentandra* sawdust and corn cob residues. These materials were used for the study because they are abundant materials that are burnt open air by the local sawmills and farmers to pollute the environment.

1.10 Organisation of the Study

This research work was divided into six (6) chapters:

- The first chapter (chapter one) presents the introduction of the study, statement of the study, purpose of the study, specific objectives of the study, scope of the study, research questions, significance of the study, limitation of the study, delimitation of the study and the general outlined of the study.
- The second chapter (chapter two) reviewed literature on the forest resources in Ghana, quantity of wood residue and agricultural residue in Ghana, physical and chemical properties of corn cob, history and development of particleboard, particleboard production line, factors affecting the properties of particleboard, physical properties of particleboard, dimensional characteristics of particleboard, common uses of particleboard, particleboard standards and certification, safety of particleboard, uses of formaldehyde adhesives in particleboard manufacturing,

risk of formaldehyde emission to indoor air, environmental impact of particleboard and global cassava production and Ghana as well.

- The third chapter (chapter three) explains the materials and the methodology that were used throughout the experimental studies. The collection and preparation of the samples are explained. The general procedures to produce the particleboards are outlined as well as the methods used to analyse the data are also explained.
- The fourth chapter (chapter four) presents the results or findings that were obtained from the experimental studies.
- Chapter five present the discussions of the experimental results of the main experiments that were conducted.
- Chapter six which is the last chapter presents the summary of the findings, concludes the overall research work and suggests recommendation for future research.

The next chapter presents comprehensive review of relevant literature on the research work. It outlines information on the Ghana forest resources and the sustainable economic development of particleboard, the current trends and setbacks. It also presents wood and agricultural residues and urea formaldehyde for particleboard production and its characteristics as well as the cassava cultivation in Ghana.

CHAPTER TWO

LITERATURE REVIEW

This chapter consists of review of relevant literature on the research work. It comprises of information on the Ghana forest resources and the sustainable economic development of particleboard, the current trends and setbacks. It also reviews wood and agricultural residues and binders for production of particleboard and their quality characteristics.

2.1 Forest Resource in Ghana

Ghana is well endowed with natural resources including fertile soils, forest and minerals deposits of gold, diamond, manganese and bauxite. The climate is generally tropical and warm, with aridity increasing from south to north. One of the most commonly used natural resources is its forest, which has been undergoing rapid depletion and degradation. Ghana has one of the highest deforestation rates in Africa: at approximately two percent annually (UN Report, 2007). Ghana has a total area of approximately 238,540 km^2 of which land constitute about 230,202 km^2 with nine ecological zones (Hall & Swaine, 1981), although for forest policy formulation purposes, these are broadly categorized into three vegetation zones: the high forest zone, transitional zone and savanna zone. The high forest zone covered about 8.2 million hectares of which forest and commercial volume of timber resources are located (Forestry Commission, 2010).

In 1900, the area of high forest was estimated 8 million hectares but by 1946, the combined area of reserved and unreserved forest was estimated to have halved 4 million hectares. Deforestation during 1990 – 2000 was estimated about 135,000 hectares per year and during the period of 2000 – 2005, it was estimated to be 115,000 per year ((Forestry Commission, 2010). The average annual rate of deforestation between the period was about two percent (2%), which is higher than the average annual rate for both central and western Africa which stands at 0.6 percent (FAO, 2012).

Over harvesting has led to the downwards revision of the National Annual Allowance Cut (NAAC) in forest reserves from 1.2 million m^3 in 1990 to 500,000 m^3 in 2005 (ITTO, 2008). The off reserve component of the total NAAL (2 million m^3) was set as high as 1.5 million mainly due to extensive illegal logging and the assumption that with time those areas are likely to be converted to other land uses (Marfo, 2010). Currently, it is estimated that the nation"s (Ghana) forest depletes by 65,000 hectares every year. In view of this, one can emphatically concluded that Ghana will lose its forest resources within the next three decades, if measures were not taken place. One of the strategies that can apply to sustain the forest of Ghanaian economy is to increase productivity: productivity is the ratio of input and output should balance. This can be done by utilizing every product obtained as results of processing wood at both plymill and sawmill to produce fibreboard to ensure efficiency in production.

2.2 Quantity of Wood Residue in Ghana

Margin (2001) stated that wood residue or waste is generated at all stages of the life of a piece timber from harvesting, sawmilling, ply milling through trading (ie; furniture & Joinery manufacture), to end of life disposal (ie; demolition, disposal of old items). In general, residues generated from forest product industry could be divided into two categories: logging residues and wood processing waste (Duku, Gu & Hagan, 2011).

2.2.1 Logging Residues

Logging residues are the leaves, branches, bark, stumps, off cuts, saw dust and other wood and tree waste generated during and after logging at logging site (Gustavsson, Eriksson, & Sathre, 2011). According to Amoah and Becker (2009), commercial logging efficiency in Ghana showed an average logging recovery of 75 percent, using this percentage of recovery and figures in Table 2.1. It could be estimated that logging residues generated in International Tropical Timbers Organization (ITTO) members countries, Africa and Ghana in 2008 were 77,016,000 m^3, 6,045,400 m^3 and 430,530 m^3 respectively.

Adams (1995) argue that 60/40 ratio is often found in every cubic metre of log, 40 percent consist of 12 percent stem wood (above the first branches), 13.4 percent branch wood, 9.4 percent natural defects, 1.8 percent stem wood (below first branch), 1.3 percent felling damage, 1.6 percent stump wood and 0.5 percent other loses. Most of the wood residues are left in the forest to rot, in particular areas where demand for wood fuel is low. Practically, not all of the logging residues can be used for particleboard production due to technical constraints, ecosystem functions and leaving appropriate levels of logging residues protect soil quality and eliminates the need for the use of fertilizers (Domson & Vlosky, 2007).

2.2.2 Wood Processing Residues

Wood processing waste such as discard logs, bark, sawdust, off cuts, trimming, split wood, sander dust, planner shaving, peeler waste and drying waste (veneers) are generated through sawmill and plymill processing activities. Sekyere and Okyere (2007) reported that sawmills in Ghana have recovery rates ranging from 20 – 40 percent of log input, averaging 33.3 percent According to the wood Explorer Glossary, generally the percentage of the log that winds up as lumber is between 54 – 55 percent sawdust is 4 – 19 percent and chips 27 – 41 percent. In Ghana, sawdust is abundant in large quantity at all sawmills in four regions: Ashanti, Brong Ahafo, Eastern and Western region. However, only few mills in Ghana are able to use part of the generated saw dust as fuel to power their steams. Solid and sawdust accounted for 79 and 21 percent respectively of the residues generated in Ghana (Atakora, Hagan, & Brew-Hammond, unpublished). Estimates from reports of ITTO (2008), annual review and assessment of world timber situation as shown in Table 2.1 suggest that on the average sawdust generated annually between 2004 – 2008 in the whole ITTO member countries, Africa and Ghana was about 25,415,280 m^3, 1,994,980 m^3 and 142,076 m^3 respectively.

Table 2.1 Average Annual Logs and Sawdust Production (1000m^3)

Region	Year					Average annual quantity of logs produced	Estimated quantity of sawdust generated per annum
	2004	2005	2006	2007	2008		
All ITTO Member Countries	226,248	236,232	232,899	234,770	225,091	231,048	25,415
Africa	18,005	17,633	18,805	18,175	18,063	18,136	1,995
Ghana	1,370	1,220	1,324	1,324	1,220	1,292	142

Source: ITTO Annual Review and Assessment of World Timber Situation, 2008

2.3 Agricultural Residue in Ghana

Ghana is an agricultural country; over 60 percent of her estimated workforce is employed by the agricultural sector (Amesimeku, 2012). This culminates into the cultivation of various crops such as millet, rice, maize, cocoa, cassava and sugarcane. This leads to the generation of large volumes of agricultural crop residues such as rice shucks, corn cobs, millet stalks, bagasse and cocoa bean shells as presented in Table 2.2. These residues normally obtained from field and processing sites are often left to decay or burnt inefficiently in their loose form causing air pollution (Maninder, Kathuria, & Grover, 2012).

Table 2.2 Productions of Different Agricultural Crops in Ghana for 2010 and Estimated Potential Residues

Crop	Residue	Residue to product ratio (tonnes/tonnes of crop)	Total crop production („000 tonnes)	Residue production („000 tonnes)
Maize	Cob	1.00	1,872	1,872
Millet	Stalk	3.00	219	657
Rice	Straw	1.50	429	643.5
Sugar cane	Bagasse	0.30	145	43.5
Coconut	Shell	0.60	298	178.8
Oil palm fruits	EFB	0.25	2,004	501
Cocoa	Pods, Husk	1.00	632	632
Coffee	Husk	2.10	1.2	2.52
Total			**5,600.20**	**4,530.32**

Source: FAOSTAT (2010)

As shown in Table 2.2, by the end of the year 2010, about 1,872,000 tonnes of corn residues was generated in Ghana. This constitutes about 41percent of the total agricultural crop residues. Corn cob, a residue of corn crop is a lignocellulosic material which contains high amount of organic constituents. Therefore it is considered as a potential source of particleboard, an alternative source of conventional wood for constructional purpose (Mario, *et al.*, 2013).

Crop residues need to be recycled, and directing such waste material to production of particleboard panels, is a possible alternative, given that as a rule particleboard panels can be produced from any lignocellulosic material capable of providing high mechanical strength and pre-established special weight (Rowell, Han, & Rowell, 2000).

2.4 Physical and Chemical Properties of Corn Cob

The bulk density of crushed cobs was 227 kg/m^3 and it is more than double the density of uncrushed corn cobs unprocessed (Martinov, Veselinov, Bojic, & Djatkov, 2011). Zhang, Ghaly, & Li, (2012) in their study titled "physical properties of corn residues" indicated that the average bulk density of corn cobs was 282.38 kg/m^3. A group of researchers, Clark and Lathrop (1953) and Foley (1978) found that corn cobs contain 32.3 – 45.6 percent cellulose, 39 – 48 percent hemicellulose - mostly composed of pentose and 6.7 – 13.9 percent lignin. Mullen, *et al.* (2010) also established that cellulose, hemicellulose and lignin form 30%, 57% and 13% respectively of corn cobs. Mario *et al.,* (2013) also reported that corn cob has low lignin content as indicated in Table 4.3, which means that increasing corn cob percentage (mix ratio) could negatively influence the mechanical properties, because lignin content is largely responsible for forming solid bond during pressing.

Table 2.3 Chemical Analysis of Corn Cob

Components	Percentage (%)
Extractives	7.0
Lignin	14.7
Ash	1.6
Hemicellulose	76.7

Source: Mario *et al.* (2013)

2.5 Particleboard

Haygreen and Bowyer (1996) defined particleboard as a panel product produced by compressing small particles of wood whiles simultaneously bonding them with adhesive. Maloney (1977) also defined particleboard as a panel product manufactured from lignocellulose materials, primary in the form of discrete particles, combined with synthetic resin or other suitable binder and bonded together under heat and pressure. Particleboard is a panel product manufactured by spraying wood particles with adhesive, forming them into a mat, compressing the mat to desired thickness between heated platens to cure the adhesive (Hoadley, 2000). Particleboard is a composite panel product consisting of cellulosic particles (wood species and agricultural residues) of various sizes that are bonded together with a synthetic resin or other binder under heat and pressure. Particle geometry, resin level, board density and manufacturing processes may be modified to produce products suitable for specific end use. The primary difference between particleboard and other reconstituted wood products such as waferboard, oriented strand board, medium density fibreboard and hardboard is the material or particles used in its production. The major types of particles used to manufacture

At the time of manufacture, additives can be incorporated to impart specific performance enhancements including greater dimensional stability, increased fire retardency and moisture resistance. Most particleboard is formed into panels, however moulded particleboard product such as furniture parts, door skins or moulded pallets are also produced (Maloney, 1977). Particleboard is cheaper, denser and more uniform than conventional wood and plywood and is substituted for other product when appearance and strength are less important than cost. It can be made more attractive by painting, spraying and also the use of veneer that are glued onto the surfaces. It is consistent, durable and produced to precise thickness in a variety of panel sizes. Particleboard can be used for flooring, ceiling, furniture and cabinet in both residential and commercial setting including kitchen and hospital.

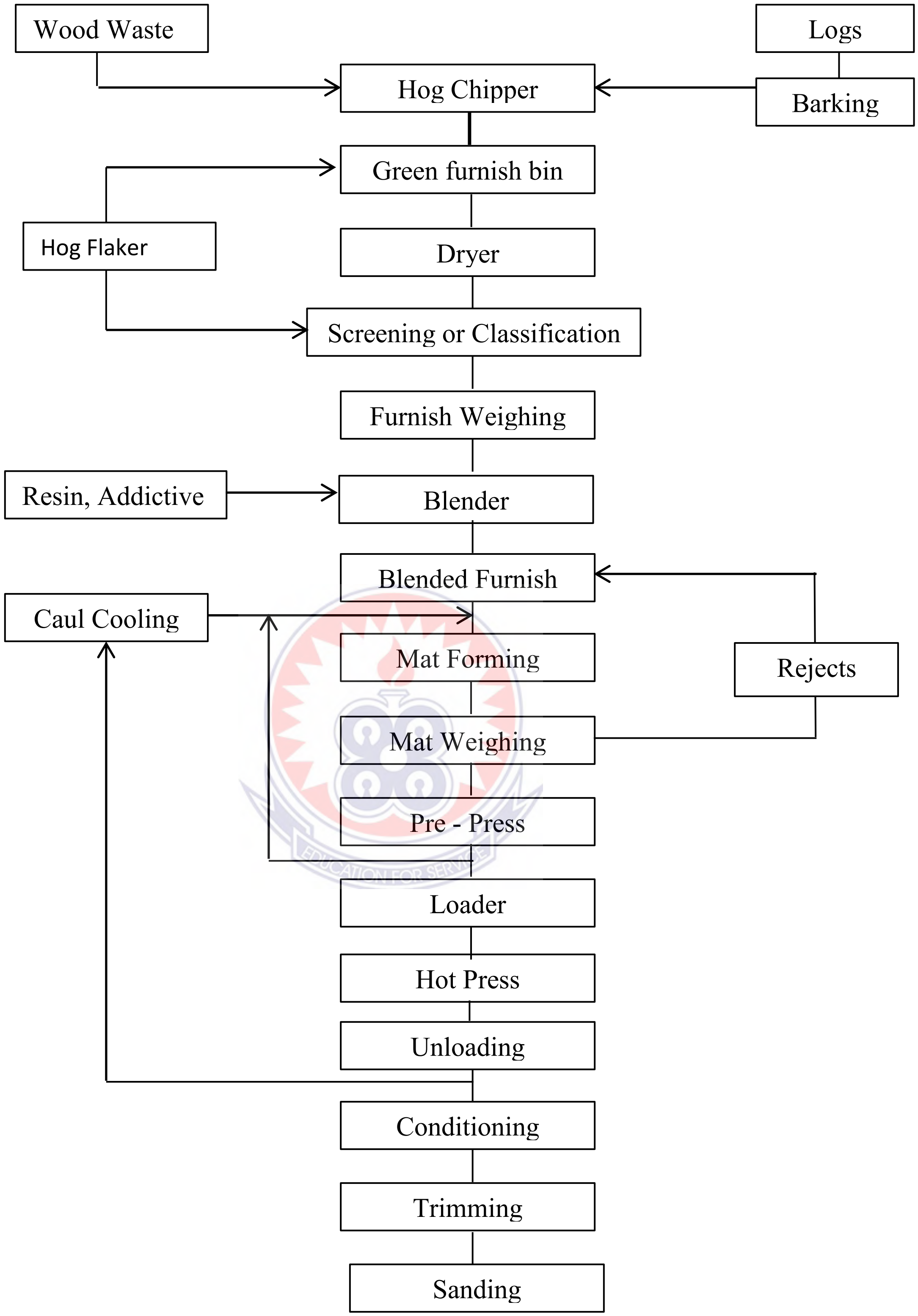
2.6 History and Development of Particleboard

Modern plywood, an alternative to natural wood was invented in the 19th century, but by the end of the 1940's a shortage of lumber made it difficult to manufacture plywood affordably. Particleboard was advised to be a replacement of plywood. Its artist was Max Himmelheber of Germany. The first commercial piece was produced during World War II at a factory in Bremen – Germany. It used waste materials such as planner shavings, offcuts or sawdust, hammer milled into chips and bound together with a phenolic resin. Hammer – milling involves smashing wood particles into smaller and smaller pieces until they finally passes through a desired screen. Most other early particleboard manufacturers used similar processes, though often with slightly different resin. It was found that better strength, appearance and resin economy could be achieved by using more uniform, manufactured chips. Manufacturers began processing solid birch, beech, alder, pine, and pruce into consistent chips and flakes. These finer layers were then placed on the outsides of the board, with the central section composed of coarser cheaper chips. These types of boards are known as three layers particleboard. More recently, graded – density particleboard has also involved. It contains particles that gradually become smaller as they get closer to the surfaces (Anon, 2010).

Haygreen and Bowyer (1996) agreed that the development of the particleboard industry was stimulated in Europe by lumber shortages and United States by large quantities of unused softwoods mill residues. In the late 1940's, a number of particleboard plants were built in Europe and United States but product was crude and the industry struggled to capture new markets. By 1960, the industry had been established and growing rapidly as the world production increased from 0.02 million m^3 per year to 3 million m^3 per year in 1960 to 20 million m^3 per year in 1990 (Anon, 2010). As the world need for sawn wood increased from 55 million tonnes from 1913 to 62 million tonnes in 1950 and then to 102 million tonnes 1980, particleboard has no record at all in 1913 and 1950 until 1980 then there was a record of 24.1 million tonnes (Westoby, 1989).

2.7 Particleboard Production line

According to Food and Agricultural Organization (FAO, 1958) corporate document repository and Wood Product Industry (2002), particleboard production involves a certain number of operations as described in Figure 3. The major operations include particle preparation, particle drying and screening, blending and mat forming, pressing and board finishing.



Source: http://www.fao.org/docrep/t0269e/t0269e05.gif

Fig. 2.2 Particleboard Manufacturing Setup

2.7.1 Particle Preparation

Particleboard furnish is derived from a multiple of sources and as the competition for solid wood and solid wood residues increases, manufacturers are having to resort to the use of low grade residues, such as hogged mill waste, sawdust, planer shavings, etc., as well as wood species not previously considered. In view of the wide assortment of furnish delivered to the mill-yard, segregation as to size, and if possible, species, must be carried out prior to the reduction process. Bark is removed from logs, if not already done in the forests, so as to avoid blunting chipper knives, and the provision of stone-traps and magnetic separators safeguard other reduction equipment from damage which would otherwise be caused if contraries were introduced with the fibre furnish. The particle size and geometry, as required for the core and surface layers of the particleboard, are produced by a diverse range of reduction equipment which is matched to the variety and size of wood and wood residues used. Chippers, knife-ring-flakers, hammer mills, disc refiners, etc., each operating on a different principle, using either knives, hammer bars, grooved disc plates, etc., are but some in common use in the industry.

2.7.2 Particle Drying and Screening

The greater part of the furnish delivered to the mill needs to be dried so that the overall moisture level of the particles is in the order of three to eight percent for the purpose of bonding with liquid resins. Particle drying is a continuous process with the particles moving along the length of rotating horizontal dryers whilst being suspended and exposed to hot gases or heat emitted from tube bundles which convey hot water, steam or thermic oil. Heat is produced by the combustion of oil, gas or process residues. Flash drying is now being considered an acceptable alternative to rotary dryers and requires somewhat lower drying temperatures. Directly after drying, the particles are screened for size in vibrating or gyrating screens, or by way of air classification. Screening normally takes place after the dryers as moist particles tend to stick together, plugging screen plates and lowering the overall efficiency of the screening process. Particles are separated according to size, for the purpose of grading the furnish for the board face and core layers. It is essential that the oversized particles be recycled for further reduction and that the fines are screened out, so as to avoid consuming a disproportionate amount of resin binder, and to provide a valued source of fuel.

2.7.3 Blending and Mat Forming

Adhesives in the form of urea, phenol and melamine formaldehyde are generally used to bind together the particle mix, with the former being the most favoured resin in use. Between three and ten percent by weight of resin, together with other additives used to impart such properties as fire resistance, etc., are blended under controlled conditions in batches or as a continuous operation. Blending may either take place in large vats at slow speed, or in small blenders with rapid mixing and shorter blending times. In the more modern particleboard plants mat forming is a wholly mechanical process, whereas the older formers require manual equalizing. In spite of the wide variety of formers currently available, the underlying principles of mat formation are generally similar, in that a uniform flow of particles are fed to the former from a surge bin, which in turn meters an evenly distributed layer of particles into a frame on a moving belt or caul.

The formers may be fitted with single or multiple forming heads, which are either stationary or moving, and are so designed that the finest particles are delivered to form the surface layers of the mat and the coarser materials to form the core. In all cases it is paramount that an evenly distributed mat of the desired weight be formed. Mats that do not conform to standard are rejected and recycled. Transportation of the mats to the pre-press and hot press is undertaken by either forming the mat on metal plates, called cauls, which are then either manually or mechanically wheeled to the presses, or in the case of caules systems, by using flexible metal webs, plastic belts and trays that transport the mats through to the hot-press.

2.7.4 Pressing

Pre-pressing of the mats prior to the introduction in the multi-platen hot presses, is now becoming a common feature in the pressing operation, due to the consolidation and reduction in mat width. This allows for ease of handling and the use of narrower openings in the hot-press, thereby considerably reducing pressing time. Whereas the pre-presses may be of the hot or cold type, the main press is always heated, by passing hot water, steam or oil through the platens to attain temperatures in the order of 140-200°C, depending on the resins in use and the type of press. Single or multiple opening hot presses may be used with the loading and unloading undertaken manually or mechanically by cable, chain lifts or hydraulics, depending on the age and sophistication of the plant. Although in the larger modern installations both pressing time and pressures are automatically regulated, hand control is still preferred in many plants as it permits adjustments to be made for the different mat qualities.

2.7.5 Board Finishing

On leaving the hot press the boards are either separated from the cauls by hand, or mechanically by means of chains or turning devices. The cauls are stacked, allowed to cool and then returned to the forming station on push carts or mechanically transported on a fixed return line. The boards in turn, are cooled and conditioned so as to avoid degradation of the urea resins. Trimming saws are used to cut the boards to size, with the edge trimmings being either recycled or used for fuel. In order to meet set standards as to thickness and surface quality, a combination of knife planers and belt or drum sanders may be used. Once the boards have been surface finished they are cut to size along their length and widths with a combination of saws, according to the dictates of the market Particleboard is normally produced as 1220 x 2440 mm panels with thicknesses ranging from 3-35 mm, 19 mm being the most common. Generally boards are manufactured in the medium-density range of 400 - 800 kg per cubic metre, although high-density board of 800-1120 kg per cubic metre is used as core stock.

2.8 Pressing Parameters of Particleboard

The pressing operation is obviously an extremely critical step in particleboard production. It is during this step that many of the physical properties are determined, especially those properties influenced by the density. Mat moisture content, adhesive type, press closing speed, and press time and temperature are the most significant pressing conditions or parameters affecting the properties of particleboard.

2.8.1 Mat Moisture Content

The mat moisture content is an extremely critical factor not only for the total press time, but also in development of the vertical density gradient. The surface moisture evaporates and migrates to the mat center when the hot plates contact the mat. This speeds the transfer of heat to the core which allows the adhesive to react more quickly than if the heat moved by conduction through the wood and air spaces. However, excessive moisture migration to the core imposes the requirement of excessively long press cycles to allow removal of moisture through the edges to prevent delamination of the board upon pressure release. Excessive moisture also interferes with the chemical reaction of condensation polymerization, by which urea-formaldehyde and phenol-formaldehyde adhesives harden. Moisture at the mat surface also reduces the compressive strength of the wood and results in surface densification from compressive failure as the press is closed. Excessive surface densification results in low-density cores for a given average board density. The bending strength and tensile strength parallel to the board surface will increase as this densification occurs but the internal bond, interlinear shear, and screw withdrawal will be lower as a result of the low density core.

Heebink, Lehmann and Heft (1972) reported 10 to 12 percent to be the optimum moisture content for mats with uniform distributions. Lower moisture contents required higher pressures to consolidate the mat and were characterized by poor interparticle bonding. Higher moisture contents necessitated longer press cycles to allow sufficient moisture to escape. Heebink, Hann and Haskell (1974) found that higher MOR and MOE values for three-layer flakeboards than for those of an earlier study (unpublished) were partially due to a non-uniform moisture distribution. As opposed to a uniform distribution of 12 percent moisture content, a face and core moisture content of 15 and 5 percent, respectively, contributed to improved board strength. Strickler (1959) showed that the time required for heating the mat core decreased with increasing surface moisture content. At higher surface moisture contents (above 15 percent) the MOR and MOE decreased when the core was at 9 percent moisture content. The internal bond also decreased but the thickness swelling improved as the surface moisture content increased. At higher surface moisture contents (above 15 percent) the MOR and MOE decreased when the core was at 9 percent moisture content, The internal bond also decreased but the thickness swelling improved as the surface moisture content increased. Kehr and Schoelzel (1967) also found a sharp decrease in the resistance of the mat to compression as increased quantities of water were sprayed on the mat surface. This, again, was the result of the reduced compressive strength of wood at higher moisture levels. Lehmann (1960) found MOR values increased with increasing mat moisture to 13.4 percent moisture content, and then decreased at moisture contents of 16.5 and 20.0 percent. Internal bond increased as the moisture content decreased. Lehmann (1960) also showed an increased dimensional stability and reduced water absorption as the mat moisture content increased. Rice (1964) used mat moisture contents of 9, 12, and 15 percent to study the effect of mat moisture on board properties. The MOR and MOE values were increased 18 and 13 percent respectively, by increasing the mat moisture content from 9 to 15 percent. Likewise, the dimensional stability of the panel improved substantially. The increased mat moisture content also reduced the closing time to stops with a constant pressure but the problem of thickness shrinkage in the press was greater with high moisture content mats. Gatchell, Heebink and Hefty (1966) reported an optimum in static bending strength and internal bond at a moisture content of 12 percent. The mat moisture content and moisture content distribution can be varied only within a rather limited range; hence the effect of this variable on particleboard properties is limited. With uniform mat moisture content, the optimum range appears to be 11 to 14 percent.

2.8.2 Adhesive Type

Formaldehyde provides an important source of single carbon molecules in the production of polymer adhesives used in the manufacture of many products, including pressed wood products such as particleboard (Ettore *et al.,* 1988). Urea formaldehyde adhesives are used in much of the particleboard worldwide. Urea formaldehyde adhesives are easy to work with, provide strong, durable bonds and are economical. Formaldehyde acts as the cross linker or polymerizer in urea formaldehyde adhesives. Wood based panels are now widely used in construction and furniture and are probably the most important source of formaldehyde in indoor air. The increased emphasis on structural-grade particleboard should provide impetus for the further development and utilization other durable adhesives in particleboard. All investigators are unanimous in their findings that as the adhesive content increases all strength properties of the resultant particleboard increase. Consequently, this review will briefly cover adhesive variables such as reactivity, synthesis conditions, and type, as they have been reported to affect particleboard properties. Deppe and Ernest (1965) produced particleboards with diisocyanate binders and obtained modulus of rupture (MOR) values at 2.5 percent diisocyanate comparable to those obtained at 3 percent phenol-formaldehyde.

Schorning, Roffael and Stegmann (1972) attempted to develop new particleboard adhesives, both under alkaline and acidic curing conditions. Anderson, Neff, Cox, Tatem, and Hightower (1974) have studied the bark extracts of various species for potential particleboard adhesives. Bark extract as a possible adhesive source is an extremely active research area and a review of this field will not be attempted here. It does appear that bark extract offers a very good potential but further research is necessary to fully exploit this material. Schuler (1974) made particleboard from chipping residues with seven levels of urea formaldehyde adhesive ranging from 2 to 12 percent (resin solids on wood). No improvements were evident in MOR and MOE when the adhesive level was increased above 5 percent. For both properties, the 12 percent adhesive content was below the 10 percent level at all particleboard densities. The percent thickness swell, after both 2 and 24 hours water soak attained a minimum at 10 percent and were both higher at 12 percent adhesive content.

There appear to be no consistent data available which indicate a particular adhesive level is optimum. Much of this inconsistency is due to the lack of uniformity in stating the adhesive content levels. Adhesive contents based on the oven dry wood weight are extremely dependent upon particle configuration; however, the experimental difficulties inherent in determining the particle surface area per unit wood weight limits the usefulness of calculating spreads per unit of particle surface area. Consequently, each particle configuration will have an optimum adhesive content dependent upon the desired panel products and the economics of production. Multi-layer particleboard with different adhesive levels in the core and surface layers is one widely-used technique to obtain satisfactory board properties with the most economic use of adhesive.

2.8.3 Press Closing Rate

Generally, the closing rate of most hot presses is established by adjustment of the initial pressure; higher initial pressures result in the platens closing to stops, or desired thickness, more quickly than closing speeds attained at lower initial pressures (Kehr & Schoelzel 1967). The closing rate of the press and the moisture content of the mat are both important factors in the formation of the vertical density gradient. Quickly closing the press will subject the mat surfaces to the platen heat and allow compressive failure at the mat surface before the interior has warmed sufficiently to allow distribution of the compressive failure through a greater portion of the mat thickness. Consequently, faster press closings would be expected to increase the vertical density gradient and improve the bending strength but at the expense of the internal bond and screw holding strength.

Liiri (1969) monitored the pressure on a series of mats pressed with increasing closing times and found the maximum pressure required for mat consolidation decreased with increased closing times. The longer the mat was exposed to elevated temperature, the higher was the degree of wood plasticization and the lower the pressure required to compact it to the desired thickness. Rice and Har (1963) reported decreasing internal bond values for flakeboard as the closing time of the press increased. Rapid press closure increased MOR, as expected and substantially increased thickness swelling for uncatalyzed adhesives, but only slightly increased the thickness swelling for the catalyzed resin. The internal bond of flakeboards with both catalyzed and uncatalyzed adhesives dropped approximately 50 percent when the time to press closing was increased from 1.5 to 3.4 minutes. The effect of press closure speed on the properties of particleboard appears to be fairly well established. The press closure rate influences the properties related to the vertical density gradient since this is highly dependent on closing speeds. Press closing rates can be adjusted to optimize the desired properties, but adjustments have to be within fairly narrow boundaries as dictated by the resin reactivity and mechanical limitations of the press.

2.8.4 Press Time, Temperature, and Pressure

The function of the hot press in particleboard production is to consolidate the chip mat to the desired thickness and density followed by polymerization of the adhesive between adjacent chips into a cross linked solid polymer to hold the mat in this consolidated state when removed from the press. To facilitate the chemical reaction and allow reasonable press times, all production presses in the particleboard industry employ some method of heating the mat. Most commonly, this is done by heated platens which contact the mat surfaces. Heat then flows from the platens through the mat surfaces into the interior. Because the entire board is not uniformly heated throughout the thickness, the curing of the adhesive does not occur uniformly; the adhesive at the mat surface is the first to cure and that at the central region the last. Because the mat center is always at the lowest temperature, the pressing time and temperature should be such to ensure that the core reaches a sufficiently high temperature to allow the resin to cure. This can be accomplished by increasing the press time at a constant temperature or by increasing the press temperature at a constant pressing time. Particleboard produced in presses equipped with a high frequency generator are heated more uniformly because heat is generated within the mat and does not migrate from the hot plates. The adhesive cures much more uniformly through the thickness and the mat center is not any cooler than the remainder of the mat.

The effect of platen temperature on compression time for three-layer particleboards has been studied by Kehr and Schoelzel (1967) at three moisture contents. Increasing the platen temperature from 120°C to 180°C rapidly reduced the compression time required for a mat moisture content of 11 percent. However, very little change in compression time with temperature was evident at 18 percent moisture content, although the compression time was lower than for that of the 11 percent mat. This indicates that wood at 18 percent moisture content is sufficiently plasticized for compression and that additional plasticization imparted by the heat is not required. Lehmann (1960) used three press temperatures (227, 307, and 344°F) to study the effect on dimensional and strength properties of yellow poplar flakeboard. The extremely long press times employed (20 - 45 minutes) probably allowed complete cure of the adhesive in all cases and may account for the lack of significance of press temperature on most properties. Thickness of the board out of the press was significantly decreased as the press temperature increased, probably due to increased drying and subsequently higher shrinkage. Pressing time and temperature are extremely important parameters in particleboard manufacturing and have to be carefully controlled to ensure that the core temperature attains the level required to cure the adhesive without subjecting the board surface to a high, degradative temperature.

2.9 Factors Affecting the Properties of Particleboard

There are many factors affecting the properties of particleboard, the most important are mixture species of the wood fibre structure, density, type and size of particles and method of drying particles (Eom, Kim, Baek & Kim, 2005). It might seem that a strong high density wood should produce strong particleboard, in fact the lower the wood density the higher the board strength at a given particleboard. According to Suchsland (1959) lower density wood species are preferable because it reduce variability of density within the mat formation. Suchslard demonstrated that because of the variation in density across the face of a board, it is necessary to compress wood particles beyond the average density of species to obtain adequate contact between the particles. Other factors include particle screening and separation particle distribution, type and amount of binding agents, methods of mat formation, structure of particleboard, moisture of particles prior to pressing, final moisture content of board and board conditioning (Moslemi, 1974). Moslemi conclusion, he outlined mixture species of the wood fibre structure, density, particle size and types of adhesive as the major factor.

2.9.1 Mixture of Species

Use of mixed wood species, particularly in those operations in which the raw material is residue from other manufacturing processes, is a common practice. Mixtures of softwoods and hardwoods and in some cases a small percentage of bark (up to 15 percent) may be used (FAO, 1958). The characteristics of wood particleboard from mixed species are comparable with those of particleboard from a single species (Kumar, 1965), and are dependent primarily on the average density of the mixture used (Haygreen & French, 1971). In an approximate calculation of the production costs, addition of heavy hardwoods to softwood chips was economically advantageous. The use of mixtures of many species which include agricultural residues for making particleboard could minimise the use of solid wood and help slow down rapid degradation of tropical forests.

2.9.2 Wood Density

No single property is known that alone will indicate conclusively the suitability of wood species as a raw material for particleboard manufacture. However, wood density is considered the most important species variable that affects particleboard properties (FAO, 1958). It is defined as mass or weight per unit volume, which usually measured in pounds per cubic foot (1b/ft3) or kilogram per cubic meter. Wood density influences binder consumption, the bulk of particles to be consolidated; therefore, it influences the strength and the surface smoothness of the board (Lynam, 1959). As a general conclusion, at a given board density, an increase in raw material density causes a decrease of particleboard strength properties (Foster, 1967) and an increase in linear expansion and thickness swelling (Liiri, 1969). Leamlaksakul (2010) agreed on this factor when making single layer experimental particleboard panels from bamboo waste (Dendrocalamusasper backer). Leamlaksakul conclude that density has an impact on internal bond and other strength properties.

Therefore density is a measure of the compactness of the individual particles in a board, and is dependent mainly on the density of the wood and the pressure applied during pressing. An increase in board density is accomplished essentially by increasing the weight of the wood in the mat or the compression of the mat or by both. This results in an increase in resin efficiency by additional and improved glue bonds (Gatchell *et al.*, 1966). Most researchers have found a positive relationship between particleboard properties and board density. An increase in board density increases values for modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB). Increases in swelling should be expected with increase in board density (Roffael & Rauch, 1972). However, increases in mechanical strength with increases in density can be sufficient to offset increased swelling tendency (Lamore, 1959), and high density can increase efficiency of resin usage, therefore reducing thickness swelling. The two most important factors controlling the average final density of a particleboard are the raw material density and the compaction of the mat in the hot press. Any change in one of these factors requires an adjustment of the other if the average board density is to remain constant. Likewise, either of these factors can be changed to increase or decrease the average particleboard density. However, higher density panels produced by increasing the compaction level will not have properties equal to the same-density panel produced with higher density wood furnish. The pressing operation consolidates the particle mat to the desired thickness and polymerizes the binder system between individual particles. The first function eliminates many of the voids in the mat and compresses the wood structures; the latter function ensures retention of the consolidated mat upon release of the pressure. The amount and condition of the material in the mat, together with the pressing techniques, determine the average resultant board density.

2.9.3 Particles Sizes

Particle sizes have a significant effect on the mechanical properties on the particleboard; result reported in a giant reed particleboard experiment by Garcia-Ortuno, *et al.* (2011) proved that different particle sizes have profound effect on the strength properties of the particleboards. The report revealed that particleboards produced with particle sizes 1mm to 2mm had the most durable mechanical properties. The particles of this size were covered better by the adhesive and had tighter bonds (Pan, Zhang, Zhang & Jenkins, 2007). The particleboards with different sizes showed significant differences in water adsorption and thickness swelling. The particleboard made from 2mm to 4mm particles sizes had the lowest water adsorption and thickness swelling, which was consistent with the mechanical property results. It is therefore important to take into consideration the particle sizes during mill operations for particleboard production. The particle sizes of the raw material should be 1mm to 4mm so as to obtain maximum results for the strength properties.

2.9.4 Type of Resin

In a study by Pan *et al.*, (2007) where saline eucalyptus was used to manufacture medium density particleboard, the aim of the research was to develop value-added application for the saline wood using different resin type. The result of the research indicated that generally, particleboards made with 4 percent polymeric methane diphenyldi isocyanate had better quality than the particleboards made with 7 percent urea formaldehyde (UF), especially when determining the water resistance. However, when UF content was increased in the tested range from 7 to 16 percent, the quality of particleboards was improved. Then it was assumed that oil present in the eucalyptus may have acted as wax that is normally added for typical particleboard manufacture for improving water resistance properties. Another possibility was that the oil can easily react with polymeric methane diphenyldi isocyanate to improve the bonding quality between polymeric methane diphenyldi isocyanate and eucalyptus. Therefore when water resistance is important, polymeric methane diphenyldi isocyanate appears to be the preferred adhesive for particleboard fabrication even though it is expensive than urea formaldehyde.

2.9.5 Pressure and Temperature

Particleboard usage is largely depends on the ability to resist water adsorption, welling, internal bond and other mechanical properties. Manufacturing process of particleboard involved processes which include pressure and temperature to press the particles. According to Heebink *et al.* (1972), decreasing the pressing time at the same time temperature caused the increase in moisture content. Malanit, Barbu and Fruhwald, (2009) reported that, the high temperature caused of increasing resin bonding for resulting better strength. Thus increased press pressure and temperature, increases modulus of elasticity and modulus of rapture values respectively. At low temperature and short pressing time will cause pre-curing of adhesives. Nemli (2002) reported that the increase of pressing temperature time, pressure and resin content is significantly able to improve the internal bond. Heineman, Fruhwald and Humphrey (2002) described the differences‟ in internal bond properties using 10 percent urea formaldehyde resin in five (5) temperature levels, there are two conceptual approaches to explain these phenomenon. First, temperature will affect urea formaldehyde bonding in the particles. Temperature will facilitates the liquids in the particles, followed by acceleration diffusion of resin molecules in wood lumen. At low temperature, resin diffusion in wood will become lower that it will cause the decrease in mechanical interlocking. Second, pressing temperature and pressure affected the chemical changes such as lignin melting, modification of hydrogen bonding that will increase the bonding strength values. However, pressing at low temperature reduce the mobility of polymer hydroxyl group. According to researchers, it is obvious that temperature, pressure and pressing time in particleboard manufacturing affect the quality of the product.

2.10 Physical Properties of Particleboard

Various particleboard physical properties are not readily classified as either strength or hygroscopic characteristics, but are important for most particleboard applications. Many of these properties water absorption and thickness swelling have a significant influence on the resultant strength and hygroscopic characteristics of the particleboard panel. However, these, as well as formaldehyde release and surface characteristics, are also dependent upon processing parameters such as pressing conditions, resin content, and particle geometry. Particleboard is a hygroscopic and dimensionally unstable material when exposed to water vapour or liquid water (Kelly, 1977). Because the material possesses hygroscopic properties similar to solid wood, it adsorbs moisture from high humidity atmosphere and increase in volume but subsequent drying does not results in the return of the original volume of the particleboard. Consequently, the determination of water absorption and thickness swelling of particleboard is necessary since excessive dimensional changes in the material after installation can be disastrous: proper installation and effort to eliminate large moisture fluctuation are mandatory for satisfactory utilization of particleboard (Kelly, 1977).

2.11 Bending Strength Properties of Particleboard

The bending strength of particleboard is measured on the ASTM Standard Method D 1037-72 (1975) for static bending. The four strength properties obtainable from this test (ASTM, 1975) are the modulus of rupture, modulus of elasticity, stress at proportional limit and work at maximum load. The modulus of rupture is the most widely determined property from static bending tests of particleboard. The modulus of elasticity, or stiffness, is much less often determined and stress at proportional limit and work to maximum load are rarely encountered in the literature.

2.11.1 Modulus of Rupture

The modulus of rupture (MOR) is an important property determining the applicability of particleboard for structural components. Many processing parameters and their effects on the MOR have been studied; the most widely reported parameters and their effects are particleboard density and particle configuration and orientation. The density of the board divided by the density of the wood equal the compaction ratio (Hse, 1975). Hse illustrated a high correlation between compaction ratio and MOR for particleboards at three different densities produced from nine hardwood species from low to high specific gravity. Stewart and Lehmann (1973) found the MOR to increase linearly with increasing panel density for four hardwood species ranging in specific gravity from 0.37 to 0.67. However, the modulus of rupture decreased as the species density increased--i.e., as the compaction ratio decreased--for all board densities. Obviously, compaction ratio is directly proportional to the particleboard density for furnish with constant specific gravity. All studies in which board density versus MOR has been determined report an increase in modulus of rupture with increasing board density: that is, as the compaction ratio increases the modulus of rupture increases. Consequently, compaction ratio may be an excellent method of quantitatively determining the relationship between board density and modulus of rupture.

Particle configuration and orientation: Many reports appear in the literature on studies concerned with the effect of particle geometry and alignment on the resultant particleboard strength properties. Post (1958) found a continuous increase in MOR for oak particleboard with increasing flake length over the studied range of 0.5 to 4 inches, but the rate of increase decreased with lengths greater than 2 inches. However, as the flake thickness increased above 0.010 inch, MOR decreased for all flake lengths. The flake length/thickness ratio was found by Post (1958) to be closely related to MOR at all flake lengths and thicknesses. MOR continued to increase but only slowly even at the highest ratio (300) used in the study. In a related study, Post (1961) stated that the length/thickness ratio is a better indicator of the effect of particle configuration on MOR than either dimension individually. Brumbaugh (1960) studied the effect of flake size on Douglas-fir particleboard of three densities. Modulus of rupture values increased with increasing flake length within the studied range of 0.5 to 4 inches. Lehmann (1974) found increasing flake thicknesses always reduced MOR, when other factors were constant for phenol-formaldehyde bonded flakeboard for structural applications. Gatchell *et al.* (1966) found an increase in MOR as flake thickness decreased with phenolic-bonded flakes. The available literature seems to indicate that particle thickness has more influence on MOR values than particle length. Particles of high length/thickness ratios, in which structural damage is minimal, normally produce particleboards with superior MOR values. Large particles at the board surface normally do not felt as well or produce as smooth a surface as smaller particles. Consequently, a balance has to be established between modulus of rupture and other board properties; one widely used compromise is a three-layer construction in which small particles, for smoothness, are used for particleboard surfaces and larger particles, with less adhesive, are used in the core.

2.11.2 Modulus of Elasticity

The modulus of elasticity (MOE) is an important property because it is a measure of the stiffness, or resistance to bending, when a material is stressed. The effective MOE of particleboard is measured by mid-span loading as described in ASTM (1975). The non-uniformity of platen-pressed particleboard in the thickness direction prevents the determination of a true MOE. In general, modulus of elasticity and modulus of rupture are affected similarly by various processing parameters. Increasing board density increases both properties; increasing surface density and surface particle alignment increases both properties; and higher adhesive contents normally increase MOR and MOE. Vital, Lehmann, and Boone (1974) have calculated regression equations for MOE versus MOR values for the data of their respective studies. Particleboards of constant average density possess higher MOE values as the wood density decreases, the compaction ratio increases. Hse (1975) plotted MOE versus compaction ratio for phenol formaldehyde bonded particleboards from flakes of eight different hardwoods with widely different wood densities. The rapid increase in MOE with increasing compaction ratio was highly significant. Moreover the modulus of elasticity is strongly dependent upon flake length; longer flakes produce particleboards with substantially higher effective MOE (Lehmann 1974).

2.12 Dimensional Characteristics of Particleboard

Dimensional change of particleboard, both in thickness and in the plane of the panel (known as linear change) can be important in much supplication. Generally, particleboard is not quite as stable in the linear direction as plywood. Medium density particleboard is allowed a linear swelling up to 0.35 percent in going from 50 to 90 percent relative humidity. However, for particleboard made from flakes, linear expansion is limited to 0.20 percent. Although these changes sound small, they are large enough to cause problems if panels are improperly installed with no provision for swelling. When particleboard is used as underlaying, it is recommended that it glued to the sub floor to reduce it linear change (ANSI, 1993). The swelling in thickness of particleboard exceeds the normal swelling of wood and can be quite significant, ranging from about 10 to 25 percent when going from dry to wet conditions. Thus urea-bonded particleboard should generally not be used where it may be subjected to wetting. Thickness swelling is only partially reversible so if particleboard is repeatedly wetted and re-dried. Its thickness will continually will continually grow. The permanent non recoverable component of the swelling is called spring back. This repose of thickness to moisture occurs in all types of particleboard including the phenolic bonded boards used for structural applications. There, exterior particleboard should be applied in minimize the pick-up of water. Despite these dimensional characteristics, some types of particleboard can be successfully used for exterior applications (Haygreen & Bowyer, 1996).

2.13 Dimensional Changes in Veneer, Fibre and Particle Panel Product

The dimensional stability characteristics of most lumber products correspond closely to these unrestrained values for wood. Products such as solid wood furniture, millwork, laminated beams, and construction lumber all behave in a similar way in regard to radial, tangential, and longitudinal shrinking. Wood products produced from veneer, particles and fibre, in contrast, have unique dimensional behaviour‟s under moisture change. These differences from solid wood result basically from three causes; first, the degree of restraint to swelling provided by one element in the product to other elements in the product; second, the degree of compression or crushing the wood elements (veneer, particle, or individual fibres) undergo during the manufacture of the product; and third, the effect adhesives and other additives have on the ability of the elements to respond dimensionally to moisture change. In some cases these additives bulk the cell walls to some degree, thus lowering the equilibrium moisture content (EMC) of the wood itself. Plywood is produced by gluing together veneer, generally 1mm or less in thickness in such a way that in alternate layer (veneers) the longitudinal direction to the adjacent layer. If the veneers are not glued together, they can shrink or swell as normal wood. However, when glued into plywood, the face veneers restrain swelling of the core veneer in its transvers direction, while the core restrains the swelling of the faces in their transvers direction. As a result, plywood is a very dimensionally stable product in the plane of the panel. It exhibits much less dimensional change in their in either direction than normal radial or tangential characteristics of the species. It will shrink or swell slightly more, however, than the normal longitudinal change for the species. The second factor affecting the swelling characteristics of wood–based panel products is the amount of compression the product undergoes during manufacture. The thickness swelling or shrinking of plywood with moisture change is about the same as the normal solid wood since little compression occurs. However, in some cases, thickness swelling in plywood may be slightly more than normal wood if excessively high pressures occurred during the pressing process. Wood that is compressed will tend to partially recover its original dimension when rewet (Haygreen & Bowyer, 1996). In the manufacture of particleboard, small shaving, flakes or wafers of wood are sprayed with droplets of a synthetic resin adhesive. These particles are compressed from 1.2 to 2.0 times their original density, and simultaneously resin is cured. If such a product is subjected to steaming or other moisture content increases, the wood will swell in the normal way and in addition the crushed particles will tend to return to their original thickness. For this reason compressed wood–based panel products often exhibit greater thickness swelling than normal wood. The third factor is the amount of additives in the product. Synthetic resin adhesives and waxes are the most–common additives. The wax is intended to provide resistance to liquid water pick-up. Wax does not bulk the cell wall or change the ultimate EMC but rather helps the products shed liquid water, making it water–repellent. Generally, the greater the amount of adhesives used to manufacture a panel product the less the thickness swelling response to moisture pick-up. Not only are the wood element in a product held more tightly when more resin is used but some resin may penetrate into the cell walls and provide a degree of hulking, or replacement of water molecules. Most fiber and particle products are manufactured under commercial or industry standards, which place limits on the swelling properties. Specific property limitations in the standards vary depending upon use of the product. For example, in the commercial standards for particleboard, limits are set on linear swelling (in the plane of the panel), ranging from 0.25 to 0.55 percent. There is no specification as to thickness swelling. In the product standard for hardboard (a high-density wood fiber product), there are limits for thickness swell ranging from 8 to 30 percent but no specification as to linear swelling. Users of wood-based product should obtain data on dimensional characteristics of the specific product they are to use from the manufacturer. Products of the same type but from different manufactures can vary considerably in this regard. Dimensional changes can almost always be accommodated by proper design, which considers whether the product is to use for furniture, case goods, residential construction, or millwork (Haygreen & Bowyer, 1996).

2.14 Common Uses of Particleboard

According to Davis and Dhingra (2001), today‟s particleboard gives industrial users the consistent quality and design flexibility needed for fast, efficient production lines and quality consumer products. Particleboard panels are manufactured in a variety of dimensions and physical properties providing maximum design flexibility for specifies and end users. Some of the common uses of particleboard are countertops, door core, floor underlaying, manufacture of home decking, office and residential furniture, shelving, store fixtures, stair treads and kitchen cabinets.

2.15 Particleboard Standards and Certification

The American National Standard for Particleboard (ANSI, 1993 & 2009) is the North American industry voluntary standard, which classifies particleboard by physical, mechanical and dimensional characteristics as well as formaldehyde levels. The Standard was developed through the sponsorship of the Composite Panel Association (CPA) in conjunction with producers, users and general interest groups. The standard has a tiered system of emission levels allowing either a maximum of 0.18 ppm or 0.09 ppm for industrial grades or 0.20 parts per million (ppm) for manufactured home decking. To meet the needs of the market many particleboard manufacturers have voluntarily developed ultra-low-emitting and no added urea-formaldehyde (NAUF) products, so there are a wide variety of products available today with reduced formaldehyde levels, as well as a growing number of non-formaldehyde alternatives (ANSI, 1993). ANSI (2009) also indicated that the moisture content of particleboard should not exceed 10 percent.

2.16 Safety of Particleboard

Safety concerns are of two parts, one being fine dust released when particleboard is machined (e.g., sawing or routing), and occupational exposure limits exist in many countries recognizing the hazard of wood dusts. The other concern is with the release of formaldehyde which is classified by the World Health Organization (WHO) as a known human carcinogen (Anon., 2006). Particleboard is a reconstituted wood product containing wood, resin and wax. Machine tools should be fitted with dust extractors and the wearing of a dust mask and eye protection is recommended when sawing.

2.17 Use of Formaldehyde Adhesives in Particleboard Manufacturing

According to the U.S. Consumer Product Safety Commission, formaldehyde is one of the most widespread chemicals in the world. It is a simple compound made of carbon, hydrogen and oxygen, and is a colourless, strong-smelling gas. It is one of the large families of chemical compounds called volatile organic compounds. The use of the word 'volatile' means that the compounds vaporize, that is, become a gas, at normal room temperature. Formaldehyde is naturally produced in plants and animals. Urea formaldehyde adhesives are used in most particleboard products worldwide. It enables the adhesive to bond the wood particles and fibres together. These adhesives are easy to work with, strong, durable and cost-effective. Changes in resin technology and improved manufacturing controls have dramatically reduced formaldehyde emissions in particleboard, as much as 80-90% since the early 1980's. Product standards (ANSI, 2009) contain formaldehyde emissions limits at levels lower than those common in the past. Apart from urea formaldehyde level of emission rate, Hazwani, Jamaludin, Nur-Atigah and Zyan (2014) also reported other chemical component found in the UF adhesive. These chemical analyses are illustrated in table 2.4.

Table 2.4 Chemical Analysis of Urea Formaldehyde

Characteristic	Percentage (%)
Solid Content	65%
Specific Gravity (30°c)	1.266g/cm3
Viscosity (30°c)	2.3p
PH	7.5
Gel time (100°c)	65s

Source: Hazwani *et al.* (2014)

2.18 Risk of Formaldehyde Emission to Indoor Air

The formaldehyde content of the resin and the emissions to indoor air has been a major problem for the fibreboard industry and is still a problem regarding products made from fibreboard (Kollmann, Kuenzi & Stamm*,* 1975). Formaldehyde is normally present at levels less than 0.03 parts per million of air (ppm) in both outdoor and indoor air. Rural areas have lower concentrations than urban areas. Indoor levels can increase with the presence of products that may add formaldehyde to the air. Typical exposures to humans are much lower and the risk of causing cancer is believed to be small. Formaldehyde is just one of several gases present indoors that may cause illnesses. Many of these gases, as well as colds and flu, cause similar symptoms.

2.19 Environmental Impact of Particleboard

Tamakloe (2000) reported that over 90 percent of Ghana‟s high forest has been logged since the late 1940^s. The rate of deforestation is 5 percent in off-reserves and 2 percent in on-reserves. The off-reserves have been seriously degraded and fragmented to less than 5 percent of the forested area 83,489km^2. The current deforestation rate is about 22,000 hectares (ha) per annum. Ghana, therefore, may face future export deficits and there is the likelihood that the country‟s forestry sector will die out. Wagner, Cobbinah and Bonsu (2008) also added that only 20 percent of Ghana‟s forest reserve remains. Grainger (1993) agreed that deforestation and logging have environmental effects which include the treat to biological diversity. The tropical rain forest is one of the world‟s 12 major types of ecosystem. It contains between two and five million species of plant species. Deforestation and logging also have effect on the soil. Rainfall in humid tropics is not only high and continuous throughout the year but also very erosive, arriving in brief, heavy showers. Fortunately, rain is slowed down by the dense vegetation cover of litter and herbaceous vegetation protects soil from the impact of raindrops and, together with the dense network of shallow tree roots, from being washed away by surface water. Other effects of deforestation and logging are changes in climate which eventually lead to changes in water flows.

FAO (1950) also put the usefulness of the forest in the field of protective influence on the climate, soil and water resources, productive uses such as supply of wood and other forest products and accessory benefits such as recreation, amazing improvement in the conditions of health and comfort of the people and in the local economy in general resulting from the afforestation.

Also, enormous quantities of sawdust are produced annually by sawmills. The sawdust produced in cutting a thousand 30cm board of 2.5cm hardwood lumber with a saw cutting a 0.625cm kerf is at least 63 m^3 of solid wood (Tamakloe, 2000). Economical disposal of sawdust and shavings is a problem of growing concern to the wood industries as in most cases there is no market for the sawdust produced (Ofori, Appiah, Agbozo, Brentuo & Ofosu-Asiedu, 1993). In addition, Hardkin (1969) reported that planing and machining of lumber and other manufacture from wood leads to further residues. A planer mill produces about 272kg of dry residue per thousand 30cm board. Thus, the total amount of air-dry wood fines originating in U.S industries alone exceeds 15 million tons a year enough to make a (triangular cross section) pile 1524cm high, 3048cm wide, and over 241km long. However, technology is evolving for using waste or low grade wood blended with plastics to make an array of high-performance reinforcement composite products. This technology provides a strategy for producing advanced materials that take advantage of the enhance properties of both wood and agricultural residue (Youngquist, Myers, Muehl, Krzysik & Clemons, 1993).2.20 Cassava Production in Ghana

2.20 Origin and distribution of Cassava

Cassava (Manihot esculenta crantz) was introduced in Ghana from Brazil, its country of origin, to the tropical areas of Africa. In the Gold Coast (now Ghana), the Portuguese grew the crop around their trading ports, forts and castles. It was a principal food eaten by both Portuguese and slaves. By the second half of the 18th century, cassava had become the most widely grown and used crop of the people of the coastal plains. The Akan name for cassava „Bankye" could most probably be a construction of „Aban Kye" – Gift from the Castle (Korang-Amoako, Codjoe & Adams, 1987). Cassava is now grown in all regions of Ghana but particularly abundant in Central, Eastern, Brong Ahafo, Ashanti and Volta regions as indicated in Table 2.5. According to the statistics of MOFA, cassava roots production has increased by almost 40 percent from 2007 to 2011. In large part this is due to an increase in average yield per hectare of 26 percent over that period from 12.76 to 16.17 tonnes per hectare. The amount of land under cultivation has increased 11 percent in that time.

Table 2.5 Cassava Production Estimates in Ghana (2007-2011)

Region	Cassava Production Estimate In Metric Tonnes (MT)				
	2007	2008	2009	2010	2011
Western	690,396	707,894	711,950	687,350	556,700
Central	1,861,160	1,992,384	2,036,500	1,914,979	1,976,946
Eastern	2,619,247	2,929,343	3,062,770	3,618,825	3,858,149
Greater Accra	56,576	64,279	67,530	68,170	71,863
Volta	1,048,075	1,357,227	1,558,480	1,529,022	1,660,007
Ashanti	1,160,603	1,205,218	1,255,190	1,842,666	1,900,444
Brong Ahafo	2,426,982	2,489,550	2,606,970	2,728,351	2,883,353
Northern	354,890	605,201	931,240	1,114,723	1,333,406
Upper West	-	-	-	-	-
Upper East	-	-	-	-	-
Total	10,217,929	11,351,095	12,230,630	13,504,086	14,240,867

Source: MOFA/SRID 2012

These figures represent harvested quantities of cassava, it is estimated that an additional 30 percent remain in the ground unharvested (Onumah, Dziedzoave, Abaka-Yankson, Martin & Quartey, 2008) due to insufficient demand, lack of buyers, or more likely weak marketing connections. The main planting season for cassava is during the rainy season from May to September. Cassava is harvested approximately 12 months after planting, harvesting take place any time from March to August where largest percentage of harvested cassava root comes to market. Currently according to Food and Agriculture Organizational Statistic (2012), cassava is now the most cultivated crop among the top ten commodities produced in Ghana.

Ajala, Otutu and Bamgbose (2012) also outlined the chemical components (Table 2.6) found in the cassava starch when accessing the effect of delayed processing on some physic-chemical properties of cassava starch.

Table 2.6 The Proximate Composition of Cassava Starch

Composition	Percentage (%)
Starch	91.66
Moisture	8.07
Ash	0.25
Fat	0.01
Protein	0.01
PH	6.5
Gel Time (100oC)	50s

Source: Ajala *et al.* (2012)

The next chapter of the study describes the materials and methods that were used in gathering data to achieve the objectives of this research work.

CHAPTER THREE

MATERIALS AND METHODS

This chapter of the study describes the materials and methods that were used in obtaining data to achieve the objectives of this research work. It includes the research design, selection and collection of research materials, materials preparation, experimental procedures and data analysis.

3.1 Research Design

The research method used for this study was experimental design. The reason being that this work involved the study of causual relationship resulting from manipulation of research factor: species mix ratio (*Ceiba pentandra* & corn cob) and binder (urea formaldehyde & cassava starch) to determine their effects on the physical, mechanical and durability properties of the particleboard. Two-way factorial design with three treatments in complete randomized design was employed for the study. According to Trochim (2006), randomized experiment is most appropriate research design when the interest of the researcher is in establishing the cause-effect relationship.

3.2 Materials

The materials used in the study were *Ceiba pentandra* and corn cob (Obaatanpa variety) - particles. The selection of the species was based on the fact that *Ceiba pentandra* is the most processed timber species in Evans Timber and Processing Limited and also corn as crop is first among the top ten crop production in Ghana (FAOSTAT, 2010). Therefore, it can be concluded that, the resources base is not threatened. Other materials used in the studies include cassava starch (Manihot esculenta), urea formaldehyde (molar ratio of 1:1.1) and aluminium thin sheet (3mm).

3.2.1 Collection and Preparation of Sawdust

Sawdust from *Ceiba pentandra* was collected from Evans Timber Limited (ETL) at Abofour a suburb of Offinso Municipal in Ashanti Region of Ghana. ETL was selected because ninety percent of the wood processed by the company is from *Ceiba pentandra*. Also the company accepted to make their facility available for the study. Logs from which sawdust was collected were physically pre-inspected to ensure that sawdust obtained were without visual defect like rot.

Sawdust were obtained from ten (10) logs of ceiba with end to end average diameter of 68 x 62 inches from natural forest through chain saw cut/kerf during cross cutting of logs into bolt for peeling. The dusts were air dried at an average humidity and temperature of 75% and 28 – 30^{o}C respectively as obtained from metrological services department. Particles were air dried on a polythene sheet for eight days. The number of days required for the materials to completely dry depends on the environmental conditions (temperature and relative humidity) as well as initial moisture content of the sawdust. After air dried, the sawdust were milled to <1mm – 3mm in accordance of AMST procedures. The milling was done at Alabar, Azuma Milling Center in Kumasi Metropolis. The sawdust was transferred to a 1mm sieve. Particles retained on the sieve were used as core and particles that were able to pass through the sieve were used as face covering. The two set of particles were batched (Figure 3.1).

3.3.2 Determination of Moisture Content of Materials

The moisture content of the graded particles were determined before mat formation was done. This was done in accordance ASTM procedures. A sample of 2g of particles of corn cob and *Ceiba pentandra* were weighed into a grass disc and placed in a laboratory oven at the General Chemical Laboratory of the Department of Wood Science and Technology, Faculty of Renewable Natural Resources (FRNR) - KNUST at a temperature of 103 ± 2°C and dried until the difference in mass between two successive weighing separated by an internal of two hours was less than 0.01g. The oven-dry moisture content of the specimen was computed as follows;

$$Moisture\ Content\ (\%) = \frac{M_1 - M_0}{M_o} \times 100$$

Where:

M1 = Mass of the test sample drying (g)

M0 = Oven-dry mass of the test sample (g)

3.3.3 Mat Forming and Pressing

The quantities of the materials used to manufacture each sample of particleboard are listed in Table 3.1.

Table 3.1 Quantity of Materials for the Manufacturing of Particleboard

Materials	Amount (Grams)
Particles (Corn cob and Sawdust)	4500
Binder (Cassava starch & Urea formaldehyde)	600 (13.34%)
Water	225 (5%)

The liquid adhesive (cassava starch powder and water) and the particles were mixed and blended together manually at Koskply Company Limited Yard, Tanoso – Techiman Brong Ahafo Region of Ghana. The particleboards were produced in three layers. Each surface layer consists of 15% fine particles and the remaining 70% consisting coarse particles were concentrated in the core. The adhesive were applied separately on the core and surface particles.

The mix was distributed uniformly in 450mm x 300mm x 75mm mould box. The mats was formed by placing the portion of particles corresponding to one of the faces in the mould, followed by the core portion and topped with second half of the fine particles to form the top layer. The replications were replicated for eighteen times (both mix ratios and binders). The mattresses were hot pressed at 160^{o}c with 585Psi (32 kg/cm^{2}) powered by a thermal – oil heat generating plant for 30 minutes (Table 3.2). The operating temperature of the hot pressed was powered by boiler plant which generate its heat source from firewood. The press cycle were timed and controlled by a fully automatic control system that assured consistent quality. The pressed particleboards were left in the pressed machine to cool overnight.

Table 3.2 Production Parameters of particleboard

Parameters	Value
Pressing Temperature (°C)	160 °C
Pressing Time (mins.)	30 mins.
Press Pressure (kg/cm^2)	32 kg/cm^2
Press Closing Rate (mm/min)	4.5 mm/min
Thickness (mm)	20 mm
Target Density (kg/m^3)	800 kg/m^3

3.3.4 Particleboard Finishing

After cooling overnight, the edges of the boards were then squared by sawing with a circular saw machine to obtain boards as shown in (Figure 3.5). The boards were piled up and allowed to cool at room temperature of 28°C – 30°C for 21days. The boards were then transferred to Forestry Research Institute of Ghana (FORIG) workshop yard. After two days the test samples (specimen) were cut in accordance with ANSI (2009), ASTM (1975) and EN 252 (1990) for testing particleboard strength properties. Specimens were allowed to dry for 7 days to complete the adhesive curing process after which test specimen were taken.

3.4 Testing the Physical, Mechanical and Durability Properties of the Particleboard

The physical properties of particleboard produced from Corn Cob and *Ceiba pentandra* sawdust with cassava starch or urea formaldehyde adhesives were tested. The physical properties tested included density (D), moisture content (MC), water absorption (WA) and thickness swelling (TS). Mechanical properties such as modulus of elasticity (MOE), modulus of rapture (MOR) and durability properties such as decay and termite resistance (DTR), moisture uptake (MU) were tested in accordance with America Standard of Testing Materials (ASTM D – 1037-77, 1975), ANSI (2009) and EN 252 (1990). For the purpose of the tests, thirty test were cut from each mix ratio (90:10, 70:30 & 50:50 - *Ceiba pentandra* and corn cob respectively) of particleboard of each binder (urea formaldehyde and cassava starch) for physical, mechanical and durability test as shown in Figure 3.5. The samples were sawn to 30mm x 20mm x 20mm for density and moisture content test, 150mm x 50mm x 20mm for WA and TS test and 300mm x 20mm x 20mm for bending test (MOE & MOR) and durability test (DRR & MU) in accordance with standards of each test.

Table 3.3 Description of Particleboard specimens

Specimen	Materials Mix ratio		Binder
	Ceiba pentandra (%)	Corn Cob (%)	
A	90	10	Urea Formaldehyde
B	70	30	Urea Formaldehyde
C	50	50	Urea Formaldehyde
D	90	10	Cassava Starch
E	70	30	Cassava Starch
F	50	50	Cassava Starch

3.4.1 Determination of Density of *Ceiba pentandra* and Corn Cob Particleboard

Density of the pressed board was determined in accordance with ASTM D – 1037-96a. Oven dry masses of the specimens were determined by weighing with electronic balance after placing the specimen in an oven to attain constant weight. Oven – dry method which employs the use of oven dry masses of the specimen divide by its volume was used to determine the density of each test sample.

Density of each specimen was then computed as:

$$Density = \frac{oven\ dry\ mass}{Volume\ of\ the\ Specimen}$$

The density of each test sample was replicated thirty times from each treatment

MC = Moisture Content

M_1 = Mass of the Specimen before drying

M_0 = Mass of the Specimen after drying

The moisture content of the test sample was replicated thirty times from each treatment

3.4.3 Determination of Thickness Swelling of Corn Cob and *Ceiba pentandra* Particleboard

Thickness swelling test of the particleboard was done in accordance with ASTM standards (D. 1037 – 99, 1975) and American National Standards for Particleboard (ANSI, A208. 1, 1999). The rectangular test samples with dimension 150mm x 50mm x 20mm were soaked in water at room temperature (25 – 28 ^{o}C) for 24 hours to determine a long term water resistance properties of the corn cob and *Ceiba pentandra* particleboard (Figure 3.7). The initial thickness of the specimens was recorded with the use of veneer calliper before soaking. After twenty four hours soaking, the thicknesses of the samples were measured immediately to calculate the thickness swelling rate of the samples.

The TS was determined from the Leamlaksakul (2010) formula:

$$TS_{24} = \frac{(t_{24} - t_o)}{t_o} \times 100$$

Where:

TS_{24} = thickness swelling rate (%)

t_0 = initial thickness of test samples before soaking in water

$$WA_{24} = \frac{W_{24} - W_0}{W_o} \times 100$$

Where:

WA_{24} = the Water Absorption rate (%)

W_0 = initial weight of the test samples before immersion

W_{24} = final weight of the test samples after 24 hours immersion

The water absorption rate of the test sample was replicated six times from each treatment.

3.4.5 Determination of Decay and termite resistance rate of Corn Cob and *Ceiba pentandra* Particleboard

The graveyard test was carried out at Center for Scientific and Industrial Research – Forestry Research Institute of Ghana (CSIR – FORIG) field test site. Soil type of the test field was sandy containing organic materials and soil living organisms such as *Isopterans* (termites) and fungus. Graveyard test was performed according to European Standards (EN 252, 1990). Field test was for determining the durability of the particleboard in ground contact. The test samples considered in this study were cut from all the treatments under the two sections (UF & CS binder) measured 300mm x 20mm x 20mm. Test samples were buried two thirds to their full length (Figure 3.8). Rows were created in with distance of approximately 300mm. The test samples were planted in period between the month of June to August (Major raining season period in Ghana). The specimens were free of cracks, decay and other obvious defects. The initial weight was recorded and planted the test samples for eight weeks.

3.4.8.2 Modulus of Rapture

The MOR of the test samples at given moisture content was computed at an adjustment of strength at 12% MC by the formula (Haygreen & Bowyer, 1996):

$$MOR = \frac{3pl}{2bd^2}$$

Where:

P = maximum load (N)

L = span of the specimen (mm)

b = width of the specimen (mm)

d = depth of the specimen (mm)

Modulus of rapture test was replicated thirty times from the treatment.

3.5 Analysis of Test Results

This study was conducted to ascertain the physical, mechanical and durability properties of particleboard produced from *Ceiba pentandra* and corn cob particles using three mix ratios (90:10, 70:30 & 50:50) bounded with either urea formaldehyde or cassava starch. Statistical package for the social science (SPSS) software was used for data analysis. Descriptive statistics was used to summarize the density, moisture content, thickness swelling, water absorption, modulus of elasticity, modulus of rapture, decay rate and moisture uptake of the particleboards. Two – way Analysis of Variance (ANOVA),Spearman correlation matrix and post hosc were used to investigate the effects of experimental factor (mix ratio & binder) on the quality of particleboard produced.

Differences between and within treatment means were determined at a significant level of = 0.05.

The next chapter presents the test results and findings of the experiment conducted to determine the optimum condition of particleboard produced from *Ceiba pentandra* (CP) and corn cob (CC) using urea formaldehyde (UF) and cassava starch (CS) as binder.

CHAPTER FOUR

RESULTS OF THE STUDY

Utilizing mixtures of wood species (sawdust) and agricultural residues could be a way of eliminating environmental pollution and income generation to a nation and farmers respectively. This chapter presents the results of a study to determine the optimum condition for the production of particleboard using *Ceiba pentandra* (CP) and corn cob (CC) with urea formaldehyde (UF) or cassava starch (CS) as binder. The result comprise of the physical properties (density, moisture content, thickness swelling, & water absorption), mechanical properties (modulus of elasticity & modulus of rapture) and durability properties (decay rate and moisture uptake/load) of the particleboards produced.

4.1 Physical Properties of Particleboard Produced from *Ceiba pentandra* and Corn cob using Urea formaldehyde and Cassava starch as Binders

4.1.1 Density of the Particleboard

Figure 4.1 indicates the density of the particleboard produced from *Ceiba pentandra* and corn cob using urea formaldehyde adhesive or cassava starch as binder. From the results, the highest density of $0.8223 g/cm^3$ was obtained from Particleboard produced from 50% *Ceiba pentandra* and 50% corn cob using cassava starch as binder. The least density of particleboard ($0.6290 g/cm^3$) was obtained from combining 90% *Ceiba pentandra* and 10% corn cob particles using urea formaldehyde adhesive.

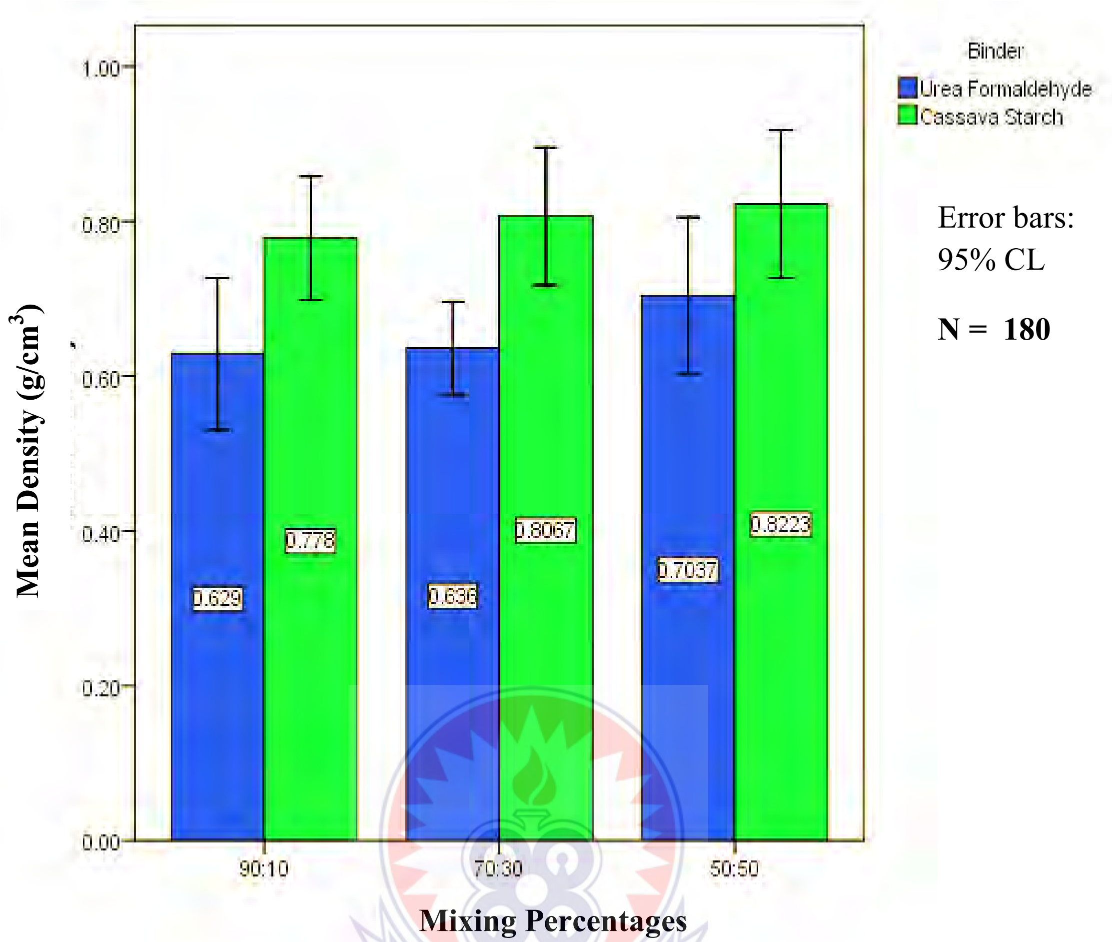


Figure 4.1 Density of the Particleboard Produced

The densities of particleboard produced range from 0.6290g/cm^3 to 0.8223g/cm^3. Generally, the densities of particleboards produced using cassava starch as binder were higher than their corresponding values for urea formaldehyde adhesive. Besides, for all the two binders, the value of the density of particleboard produced increased with increasing proportion of corn cobs in the mixture. This was indicated by a positive significant correlation between proportion of corn cobs mixture and the density values obtained [Pearson‟s r = 0.272, P-value = <0.05, N = 180, 1-tailed a = 0.05]

Table 4.1 indicates the results of two – way ANOVA to determine the effect of mixing percentage, the binder and their interaction on the density of particleboard produced from *Ceiba pentandra* and corn cobs. The results show that at 5% level of significance, mixing percentage, and binder as well as their interaction had significant effect on the density of the particleboard produced ($P < 0.05$).

Table 4.1 ANOVA Effects of Mixing percentage, Binder and their Interaction on Density of the Particleboard.

Source	Sum of Squares	DF	Mean Square	F	P-value
Mixing percentage	0.112	2	0.056	28.649	0.001*
Binder	0.961	1	0.961	491.975	0.001*
Mixing percentage and Binder	0.020	2	0.010	5.241	0.006*
Total	97.165	180			

* Statistically significant at 0.05 level of significance

Legends:

DF = Degree of Freedom

The multiple coefficient of determination R^2 and root mean square error (RMSE) of the ANOVA model were 0.763 and 0.002 respectively. Thus the R^2 value of 0.763 means that about 76.3% of the variance in density of the particleboard produced could be explained by the experimental factors considered. Post hoc (Tukey HSD) multiple comparison was further conducted to ascertain the mix ratio that produced the significant differences in density of the particleboard produced. The results (appendix 1) shows that the significant differences occurred between mix ratio 50:50 and 90:10, 50:50 and 70:30 at 5% significance level (P-value <0.05).

4.1.2 Moisture Content of the Particleboard

Figure 4.2 indicates the moisture content of the particleboard produced from combining *Ceiba pentandra* and corn cob particles using urea formaldehyde or cassava starch as binder. The highest moisture content of 17.3% was obtained from 50% *Ceiba pentandra* and 50% corn cobs using urea formaldehyde adhesives. The least moisture content of particleboard produced (11.4%) was obtained from 90% *Ceiba pentandra* and 10% corn cobs using cassava starch as binder. The moisture content of particleboard obtained range from 11.4% to 17.3%. Generally, the moisture contents of particleboard produced using cassava starch as binder were lower than their corresponding values for urea formaldehyde adhesives. The lower the moisture content value of the particleboard, better it is for structural design.

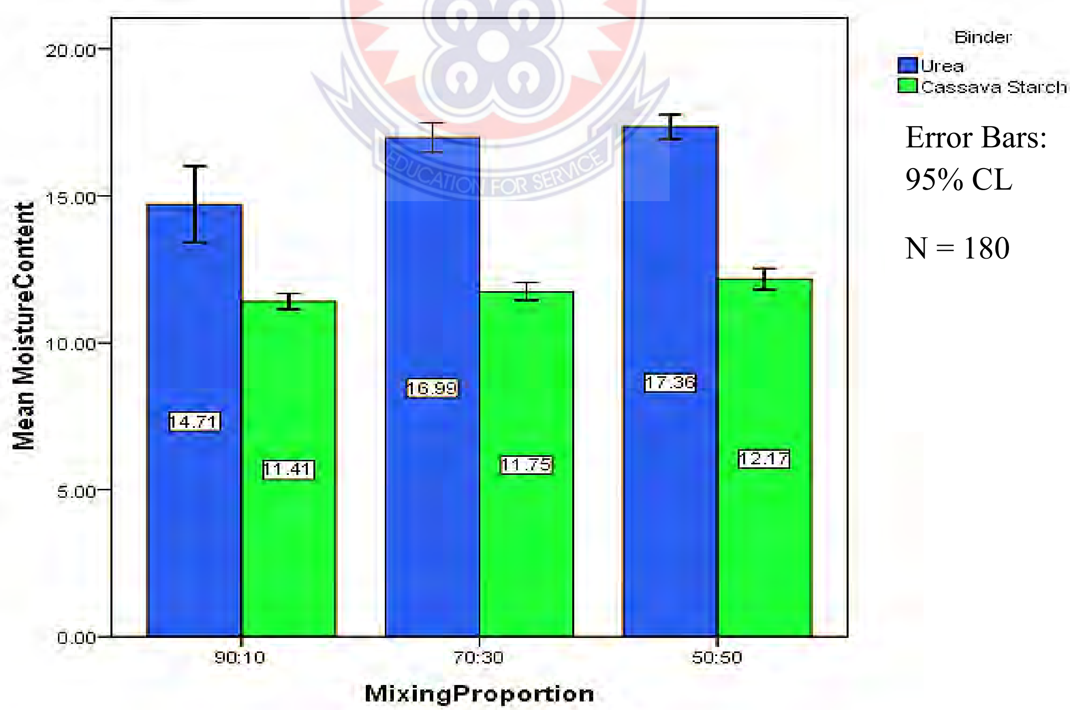


Figure 4.2 Moisture Content of the Particleboard

The values of the moisture content of particleboard produced using both binders decreased with decreasing proportion of corn cobs in the mixture. This was indicated by a positive significant correlation between proportion of corn cobs in the mixture and moisture content values obtained [Pearson"s r = 0.235, P-value = <0.05, N = 180, 1-tailed a = 0.05]

The result in Table 4.2 indicates the results of two-way analysis of variance (ANOVA) to determine the effect of mixing percentage, binder and their interaction on the moisture content of the particleboard produced. The findings indicate that at 5% level of significance, mixing percentage, binder and their interactions had significant effects on the moisture content of particleboard produced (P-value <0.05).

Table 4.2 ANOVA of effects of Mixing percentage, Binder and their Interaction on Moisture Content of the Particleboard.

Source	Sum of Squares	DF	Mean Square	F	P-value
Mixing percentage	95.534	2	47.767	16.713	0.001*
Binder	942.061	1	942.061	329.613	0.001*
Mixing percentage and Binder	36.662	2	18.331	6.414	0.002*
Total	37173.454	180			

* Statistically significant at 0.05 level of significance
Legends:
DF = Degree of Freedom

The multiple coefficient of the determination value, R^2 and the RMSE for the ANOVA model were 0.684 and 2.858 respectively. Thus it could be deduced that mixing percentage and binder and their interaction explains about 68.4% of the variability in the moisture content of the particleboard produced. Post hoc (Turkey HSD) multiple comparison was further conducted to identify the mix ratio that produced the significant differences in moisture content of the particleboard produced. The results (appendix 2) indicates that significant differences occurred between mix ratio 90:10 and 70:30 as well as 50:50 at 5% significance level (P-value <0.05).

4.1.3 Thickness Swelling of the Particleboard

Table 4.3 indicates the test results conducted to find out 24 hours thickness swelling rate of particleboard produced from combining *Ceiba pentandra* and corn cob particles using urea formaldehyde adhesives or cassava starch as binder. The thickness swelling rate of particleboard produced range from 5.83% to 10.00%. The highest thickness swelling rate of 10% was obtained from particleboard produced from combining 50% *Ceiba pentandra* and 50% corn cobs using urea formaldehyde adhesives. The least thickness swelling rate of particleboard produced (5.83%) was obtained from combining 90% *Ceiba pentandra* and 10% corn cobs particles using cassava starch as binder. The lower the thickness swelling rate of particleboard, suitable it is for humid conditions.

Table 4.3 Thickness Swelling rate of the Particleboard Produced

Mixing percentage	N	Urea Formaldehyde		Cassava Starch	
		Mean (%)	Standard Deviation	Mean (%)	Standard Deviation
90:10	6	6.6667	2.58199	5.8333	2.04124
70:30	6	8.3333	2.58199	7.5000	2.73861
50:50	6	10.0000	3.16228	8.3333	2.58199

Generally, the thickness swelling rate of particleboard produced using cassava starch as binder were lower than their corresponding values for urea formaldehydes adhesives. Besides, for all the two binders, the value of thickness swelling rate of particleboard increased with increasing corn cob proportion in the mixture. This was indicated by a positive correlation between proportion of corn cobs in the mixture and thickness swelling values obtained [Pearson‟s r = 0.473, P-value = <0.05, N = 36, 1-tailed a = 0.05]. Similar findings has been reported by Balizad, Hussein, and Abdullah (2016), they found that increasing agro residues unto wood particles increases thickness swelling rate.

Two - way analysis of variance (ANOVA) of effect of mixing percentage, binder and their interaction on thickness swelling rate of particleboard produced is indicated in Table 4.4. The results shown that mixing percentage of CP and CC had positive significant effect on the thickness swelling of the particleboard produced. On the other hand, interaction between mixing percentage and binder had no significant effect on the thickness swelling of the particleboard produce (P-value <0.05).

Table 4.4 ANOVA of effects of Mixing percentage, Binder and their Interaction on Thickness Swelling rate of the Particleboard produced.

Source	Sum of Squares	DF	Mean Square	F	P-value
Mixing percentage	51.389	2	25.694	3.700	0.037*
Binder	11.111	1	11.111	1.800	0.216+
Mixing percentage and Binder	1.389	2	0.694	0.100	0.905+
Total	2450.000	36			

* Statistically significant at 0.05 level of significance, + Not Statistically Significant at 0.05 level of significance.

Legends:
DF = Degree of Freedom

The multiple coefficient of determination R^2 and RMSE values for the ANOVA model were 0.235 and 6.944 respectively. The multiple coefficient of determination value of 0.235 means that mixing percentage of the species and binder could explain only 23.5% of the variable in thickness swelling of the particleboard produced. Post hoc (Turkey HSD) multiple comparison was further conducted to ascertain the mix ratio that produce the significant differences in thickness swelling of the particleboard produced. The results (appendix 3) shows that the significant differences occurred only between mix ratio 50:50 and 90:10 at 5% significance level (P-value <0.05).

4.1.4 Water Absorption Rate of the Particleboard

Table 4.5 indicates the results of 24 hour water absorption rate of particleboard produced from *Ceiba pentandra* and corn cob particles with urea formaldehyde or cassava starch as binder. The highest water absorption rate after 24hours water immersion of particleboard produced (53.74%) was obtained from combining 50% *Ceiba pentandra* and 50% corn cobs particles using urea formaldehyde adhesives. The least water absorption rate of 40.13% was obtained from particleboard produced using from 90% *Ceiba pentandra* and 10% corn cobs particles using cassava starch as binder. The lower water absorption rate of particleboard, more applicable it is for humid condition.

Table 4.5 Water Absorption rate of the Particleboard Produced

Mixing percentage	N	Urea Formaldehyde		Cassava Starch	
		Mean (%)	Standard Deviation	Mean (%)	Standard Deviation
90:10	12	42.7650	3.65417	40.1367	5.89711
70:30	12	50.7133	3.15185	43.5100	6.51230
50:50	12	53.7400	3.48420	50.9050	10.30944

The water absorption rates of particleboard produced using cassava starch as binder were lower than their corresponding values for urea formaldehyde adhesives. Generally, the result indicates that, water absorption rate of particleboard produced increased with increasing corn cob mixing percentages regardless of binder type. This was indicated by a positive significant correlation between corn cob proportion in the mixture and water absorption values obtained [Pearson‟s r = 0.595, P-value = <0.05, N = 36; 1-tailed, a = 0.05].

Table 4.6 indicates the test result of two – way ANOVA to determine the effect of mixing percentage, binder, and their interaction on the water absorption for 24 hours water immersion. The results indicate that the mixing percentage and binder at 5% level of significance had significant effect on the water absorption of particleboard produced (P-value <0.05). However, the interaction between mixing percentage and binder had no significant effect at 5% level of significance (P-value <0.05)

Table 4.6 ANOVA effects of Mixing percentage, Binder and their Interaction on Water Absorption of the Particleboard produced.

Source	Sum of Squares	DF	Mean Square	F	P-value
Mixing percentage	709.564	2	354.782	9.725	0.001*
Binder	160.444	1	160.444	4.398	0.045*
Mixing percentage and Binder	40.056	2	20.028	.549	0.583+
Total	81398.883	36			

* Statistically significant at 0.05 level of significance, + Not Statistically Significant at 0.05 level of significance.

Legends:
DF = Degree of Freedom

The multiple coefficient of determination R^2 and root mean square error (RMSE) values of the ANOVA model were 0.454 and 36.483 respectively. Thus, it could therefore be concluded that mixing percentage and binder could explain about 45.4% of the variability in water absorption rate of the particleboard produced. Post hoc (Turkey HSD) multiple comparison was further conducted to identify the mix ratio that produce the significant differences in water absorption of the particleboard produced. The results (appendix 4) indicates that the significant differences occurred only between mix ratio 50:50 and 90:10 at 5% significance level (P-value <0.05).

4.2 Mechanical Properties of Particleboard Produced from *Ceiba pentandra* and Corn cob using Urea formaldehyde or Cassava starch as Binders

4.2.1 Modulus of Elasticity of the Particleboard

In this part of the study, the modulus of elasticity of the particleboard produced from combination of *Ceiba pentandra* and corn cob using urea formaldehyde or cassava starch as binder is indicated in Figure 4.3. The modulus of elasticity of particleboard produced range from 1648.6N/mm^2 to 2182.3N/mm^2. The highest modulus of elasticity of particleboard produced (2182.3N/mm^2) was obtained from 90% *Ceiba pentandra* and 10% corn cob with cassava starch as binder. The least modulus of elasticity of 1648.6N/mm^2 was obtained from particleboard produced from combining 50% *Ceiba pentandra* and 50% corn cob particles using urea formaldehyde adhesives. The higher the modulus of elasticity mean value, better the particleboard produced for structural work. The result generally indicates that, the modulus of elasticity of particleboard produced using cassava starch as binder were higher than their corresponding values for urea formaldehyde adhesives. Besides, for all the two binders, the value of the modulus of elasticity of particleboard produced increased with increasing proportion of *Ceiba pentandra* in the mixture. This was indicated by a positive significant correlation between proportion of *Ceiba pentandra* in the mixture and modulus of elasticity values obtained [Pearson‟s r = 0.86, p-value = 0.001, N = 180; 1-tailed, a = 0.05]

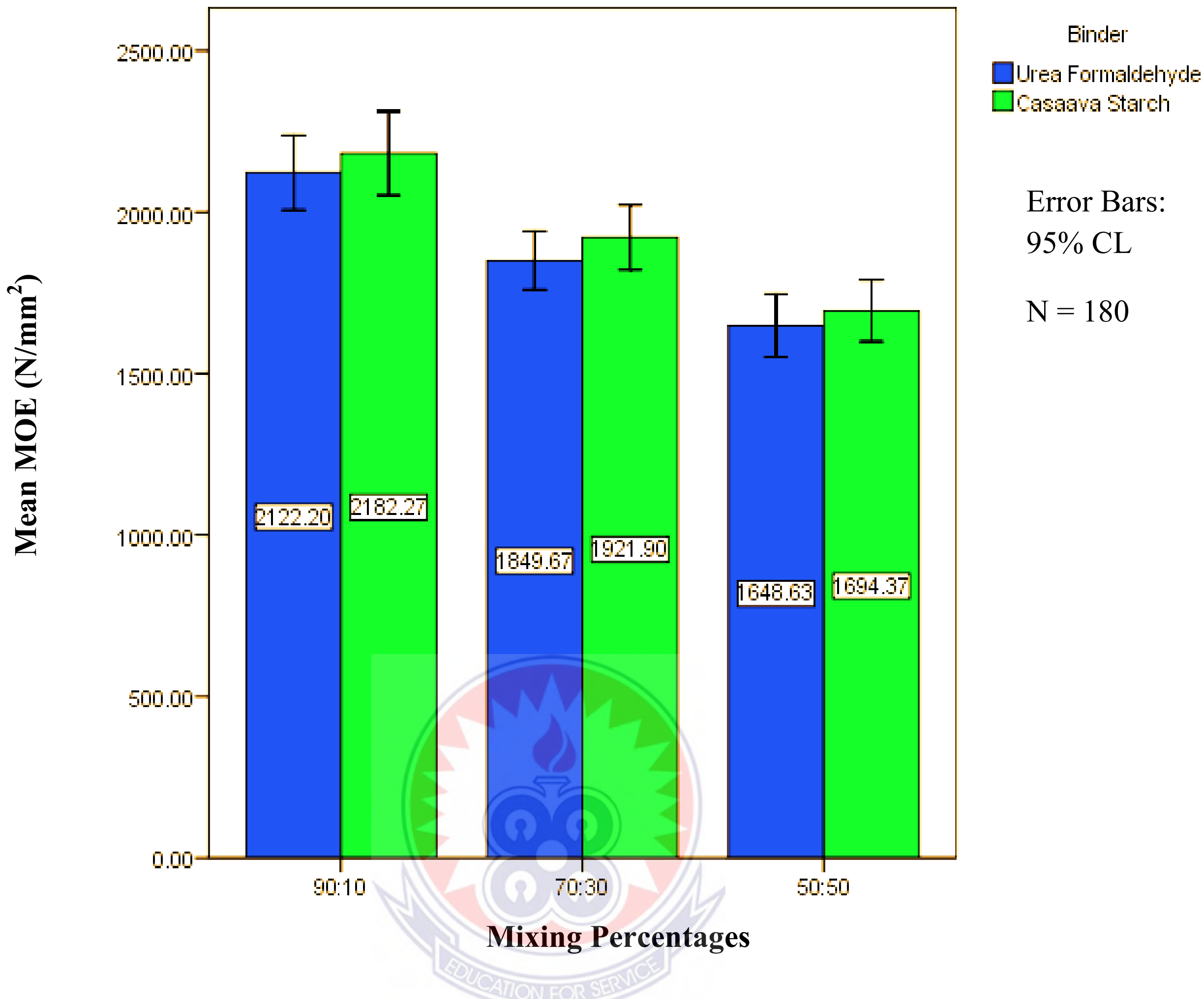


Figure 4.3 Modulus of Elasticity of Particleboard

Table 4.7 indicates the results of two – way ANOVA to determine the effect of mixing percentage, binder and their interaction on the modulus of elasticity of particleboard produced from *Ceiba pentandra* and corn cobs. The results indicates that at 5% level of significance, mixing percentage had significant effect on modulus of elasticity value of the particleboard produced (P-value <0.05). However, Binder and its interaction with mixing percentage at 5% level of significance had no significant effect of modulus of elasticity value of the particleboard.

Table 4.7 ANOVA effects of Mixing percentage, Binder and their Interaction on Modulus of Elasticity of the Particleboard produced.

Source	Sum of Squares	DF	Mean Square	F	P-value
Mixing percentage	6960349.744	2	3480174.872	43.264	0.001*
Binder	158479.339	1	158479.339	1.970	0.162⁺
Mixing percentage and Binder	5278.611	2	2639.306	.033	0.968⁺
Total	6.731E8	180			

* Statistically significant at 0.05 level of significance, ⁺ Not Statistically Significant at 0.05 level of significance.

Legends:
DF = Degree of Freedom

The multiple coefficient of determination R^2 and root mean square error value of the ANOVA model were 0.337 and 80441.126 respectively. Thus the R^2 value of 0.337 means that about 33.7% of the variance in modulus of elasticity of particleboard produced could be explained by the experimental factors considered. Post hoc (Tukey HSD) multiple comparison was further conducted to ascertain the mix ratio that produce the significant differences in modulus of elasticity of the particleboard produced. The results (appendix 5) indicates that the significant differences occurred between mix ratio 90:10 and 70:30 as well as 50:50 and also 70:30 and 50:50 at 5% significance level (P-value <0.05).

4.2.2 Modulus of Rapture of Particleboard

Figure 4.4 indicates the test results conducted to find out the modulus of rapture of the particleboard produced from combining *Ceiba pentandra* and corn cob particles using urea formaldehyde or cassava starch as binder. The modulus of elasticity of particleboard obtained range from 10.3130N/mm^2 to 12.5847N/mm^2. Particleboard produced from combining 90% *Ceiba pentandra* and 10% corn cob using cassava starch as binder had the highest modulus of rapture value (12.5847N/mm^2). The least modulus of rapture value of 10.3130N/mm^2 was obtained from particleboard produced from 50% *Ceiba pentandra* and 50% corn cobs particles using urea formaldehyde adhesive.

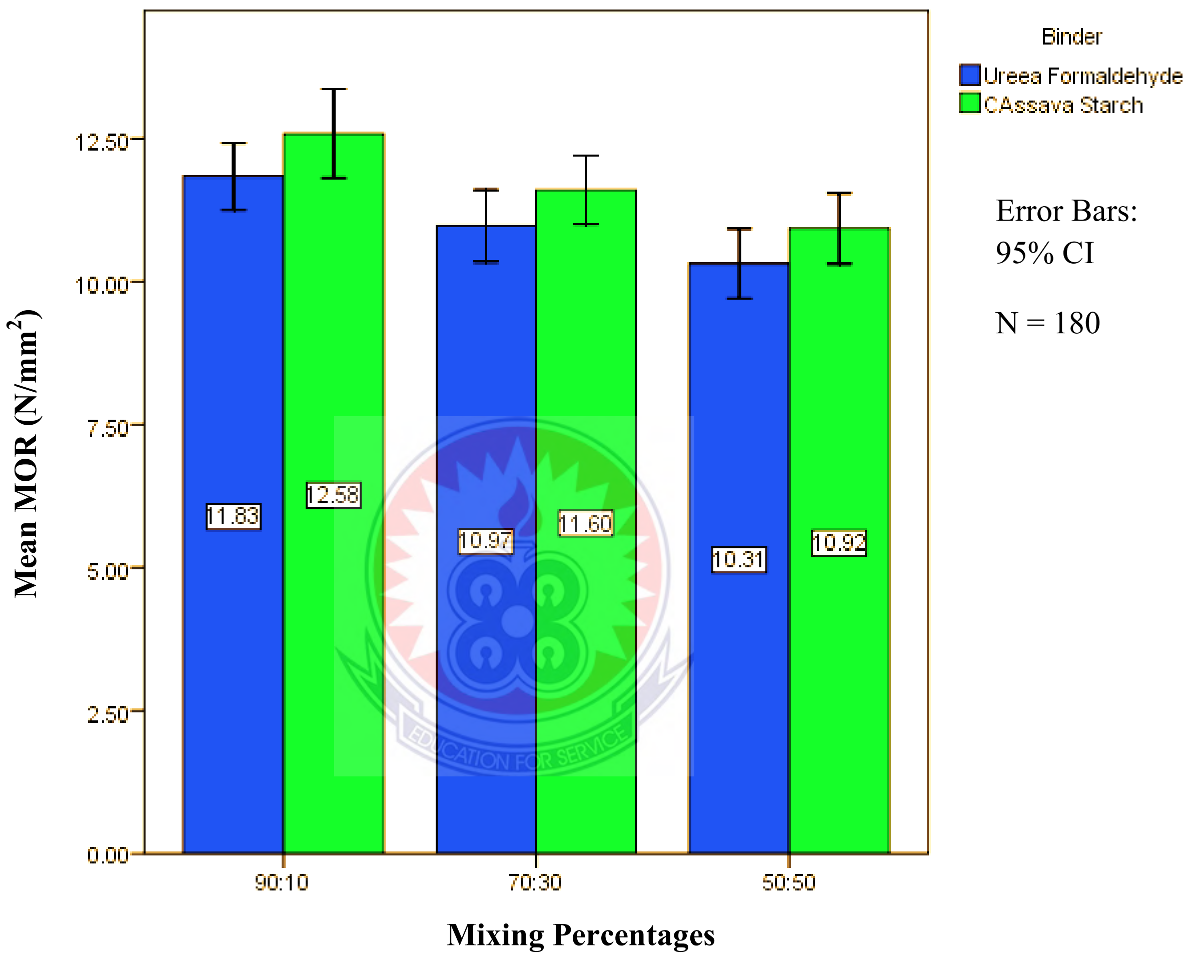


Figure 4.4 Modulus of Rapture of Particleboard

The modulus of elasticity values of particleboard produced using cassava starch as binder were higher than their corresponding values for urea formaldehyde adhesives. However, for all the two binders the value of the modulus of elasticity of particleboard produced increased with increasing proportion of *Ceiba pentandra* in the mixture. This was indicated by a significant correlation between proportion of *Ceiba pentandra* in the mixture and modulus of elasticity values obtained [Pearson"s r = 0.181, p-value = <0.05, N = 180; 1-tailed, a = 0.05]

Table 4.8 shows the results of a two – way analysis of variance to determine the effect of mixing percentage, binder and their interaction on the modulus of rapture of particleboard produced. The result indicates that, mixing percentage and binder have significant effect on the MOR values of the particleboard produced (P – value <0.05).

Table 4.8 ANOVA of effects of Mixing percentage, Binder and their Interaction on Modulus of Rapture of the Particleboard produced.

Source	Sum of Squares	DF	Mean Square	F	P-value
Mixing percentage	76.609	2	38.304	13.108	0.001*
Binder	19.801	1	19.801	6.776	0.010*
Mixing percentage and Binder	0.172	2	0.086	0.029	0.971^{+}
Total	23882.624	180			

* Statistically significant at 0.05 level of significance, $^{+}$Not Statistically Significant at 0.05 level of significance.

Legends:
DF = Degree of Freedom

The multiple coefficients of determination R^2 and root mean square error values of ANOVA model were 0.160 and 2.961 respectively. Thus, it could therefore be concluded that mixing percentage and binder explained about 16% of the variability in modulus of rapture values of particleboard produced. Post hoc (Turkey HSD) multiple comparison was further conducted to ascertain the mix ratio that produce the significant differences in modulus of rapture of the particleboard produced. The results (appendix 6) shows that the significant differences occurred only between mix ratio 90:10 and 70:30 as well as 50:50 at 5% significance level (P-value <0.05).

4.3 Durability Properties of Particleboard Produced from *Ceiba pentandra* and Corn cob using Urea formaldehyde or Cassava starch as Binders

4.3.1 Decay Rate of Particleboard

Result of eight weeks (8weeks) durability test conducted to determine the durability of the particleboard in ground contact is indicated in Table 4.9. The highest decay rate of 71.8750% was obtained from particleboard produced from combining 50% *Ceiba pentandra* and 50% corn cobs particle using urea formaldehyde adhesives. The least decay rate of particleboard produced (56.2500%) was obtained from combining 50% *Ceiba pentandra* and 50% corn cobs particles using cassava starch as binder. The lower the value of decay rate of particleboard, better the board for external usage.

Table 4.9 Decay rate of Particleboard Produced

Mixing percentage	Urea Formaldehyde		Cassava Starch	
	Mean (%)	Standard Deviation	Mean (%)	Standard Deviation
90:10	62.5000	23.14550	56.2500	25.87746
70:30	65.6250	26.51650	59.3750	26.51650
50:50	71.8750	20.86307	68.7500	25.87746

The decay rate obtained from particleboard produced ranges from 56.2500% to 71.8750%. Generally, the decay rates of particleboard produced using urea formaldehyde adhesives were higher than their corresponding values for cassava starch as binder. However, for all the two binders the value of decay rate of particleboard increased with increasing corn cobs proportion in the mixture regardless the binder type. This was indicated by a positive significant correlation between proportion of *Ceiba pentandra* in the mixture and decay rate values obtained [Pearson‟s r = 0.187, P-value = <0.05, N = 48, 1-tailed a = 0.05].

Table 4.10 shows the two – way analysis of variance (ANOVA) to determine the effect of mixing percentage, binder and their interactions on decay rate of the particleboard produced. The results indicate that at 5% level of significance, mixing percentages, binder as well as their interactions have no significant effect on the decay rate of particleboard produced (P-value <0.05).

Table 4.10 ANOVA effects of mixing percentage, Binder and their Interaction on Decay rate of the Particleboard produced.

Source	Sum of Squares	DF	Mean Square	F	P-value
Mixing percentage	1.625	2	0.812	0.820	0.447^{+}
Binder	0.521	1	0.521	0.526	0.473^{+}
Mixing percentage and Binder	0.042	2	0.021	0.021	0.979^{+}
Total	359.000	48			

* Statistically significant at 0.05 level of significance, $^{+}$Not Statistically Significant at 0.05 level of significance.

Legends:
DF = Degree of Freedom

The multiple coefficient of determination value R^2 and the root mean square error for the ANOVA Model were 0.510 and 0.991 respectively. Thus the R^2 value of 0.510 means that about 51% of the variance in decay rate of particleboard produced could be explained by the experimental factors considered.

4.3.2 Moisture Uptake of the Particleboard

Eight weeks (8 weeks) grave yard test conducted to determine the durability of the particleboard in respect to moisture uptake/load when exposed to weather conditions is indicated in Table 4.11. From the test results, the highest moisture uptake of Particleboard produced (91.49%) was obtained from 70% *Ceiba pentandra* and 30% corn cob particles using urea formaldehyde adhesives. The least moisture uptake of 83.82%

was obtained from particleboard produced from combining 90% *Ceiba pentandra* and 10% corn cobs particles using cassava starch as binder.

Table 4.11 Moisture Uptake of the Particleboard Produced

Mixing percentage	N	Urea Formaldehyde		Cassava Starch	
		Mean (%)	Standard Deviation	Mean (%)	Standard Deviation
90:10	8	88.2788	22.76316	83.8212	19.50950
70:30	8	91.4950	23.40769	87.3250	27.54617
50:50	8	91.3250	91.3250	87.8887	26.01654

The moisture uptake of particleboard produced range from 83.82% to 91.49%. Generally, the results suggest that, moisture uptake of particleboard produced using cassava starch as binder were lower than their corresponding values for urea formaldehyde adhesives. Besides, for both binders the value of moisture uptake of particleboard produced increased with increasing corn cobs proportion in the mixture. This was indicated by a positive significant correlation between proportion of corn cobs in the mixture and the moisture uptake values obtained [Pearson‟s r = 0.0667, P-value = <0.05, N = 8, 1-tailed a = 0.05]

Table 4.12 shows the results of two – way analysis of variance (ANOVA) of the effect of mixing percentage, binder and their interaction on moisture uptake of the particleboard produced. The result indicates that at 5% level of significance, mixing percentage and binder as well their interactions had no significant effect on moisture uptake of the particleboard produced (P-value <0.05).

Table 4.12 ANOVA effects of Mixing percentage, Binder and their Interaction on Moisture Uptake of the Particleboard produced.

Source	Sum of Squares	DF	Mean Square	F	P-value
Mixing percentage	127.892	2	63.946	0.116	0.891^{+}
Binder	194.045	1	194.045	0.352	0.556^{+}
Mixing percentage and Binder	2.219	2	1.109	0.002	0.998^{+}
Total	398173.127	48			

* Statistically significant at 0.05 level of significance, $^{+}$Not Statistically Significant at 0.05 level of significance.

Legends:
DF = Degree of Freedom

The multiple coefficient of determination R^2 and root mean square error for the ANOVA Model were 0.140 and 550.633 respectively. Thus the R^2 value of 0.140 means that mixing percentage and binder could explain only 14% of the variance in moisture of the particleboard produced.

CHAPTER FIVE

DISCUSSION

5.1 Physical Properties of Particleboard Produced from *Ceiba pentandra* and Corn cob using Urea formaldehyde and Cassava starch as Binders

5.1.1 Density of the Particleboard

The density of the particleboard produced range from 0.6290g/cm^3 to 0.8223g/cm^3. According to ANSI (2009), medium density particleboard range from 0.590g/cm^3 to 0.815g/cm^3, particleboard density below 0.590g/m^3 and above 0.815g/cm^3 is classified as low and high density particleboards respectively. Therefore all the particleboard produced conform the medium density particleboard certification except particleboard produced from 50% *Ceiba pentandra* and 50% corn cobs particles using cassava starch as binder (0.8223g/cm^3). However, the densities of particleboard produced using cassava starch were higher than their corresponding values for urea formaldehyde adhesives. This means that the type of binder used influenced particleboard density. Ashori, Matini and Tarmian (2013) shared similar view; they explained that, the variation of the granular composition of the wood particles and of dosage in binder influences the density of the particleboard. This could be attributed to the carbohydrate functional group in the cassava starch which formed during sun drying. According to Zhu (2015), the presence of the carbohydrate functional groups correlated with expansion performance during heating.

The densities of particleboard produced for all the two binders increased with increasing corn cobs particles proportion in the mixture. Mario *et al*. (2013) had similar findings, when evaluating the basic density of maize cob and pinewood particleboard production.

They recorded increased density from 0.630g/cm^3 [100:0 pinewood and maize cob] to 0.68g/cm^3 [25:75 pinewood and maize cob respectively]. Maloney (1993) also reported similar results from 0.593g/cm^3 to 0.800g/cm^3 when evaluating properties of modern particleboard and dry process fibreboard manufacturing. Wong *et al.* (1998) were also of the view that, densities of the particleboard increased when the density of the saw dust is slightly reduced.

The particleboard were produced with a constant pressure (32kg/cm^2), increased the pressure could have increased the densities of the all particleboards produced to conform requirement of high density particleboard certifications. Because increasing pressure of the press to consolidate more voids in the mat to compact the wood structures could have increased the density of the particleboards (Kelly, 1977).

5.1.2 Moisture Content of Particleboard

Particleboard moisture content is an important index which influences its dimensional changes both in thickness and the plane of the board. Moisture content of particleboards produced ranged from 11.4% to 17.3%. According to ANSI (2009), the moisture content of medium density particleboard should not exceed 10%, therefore all the particleboard produced from both binders conformed the low density particleboard certifications. This can be attributed to the press temperature of the particleboard. According to Loh, *et al.* (2010), particleboard can be produced with high temperature to achieve low moisture content to conform ANSI standard. This phenomenon was explained when they produced particleboard from rubber wood using high temperature of 200^{o}C to achieve moisture content of 4% to 6%. However, the moisture content values of particleboard produced using cassava starch as binder were lower than their corresponding values for urea formaldehyde adhesives. This could be associated with the gel time of the cassava starch. With 100°C temperature, cassava starch hardens faster than urea formaldehyde adhesive as revealed in literature (Table 2.4). This means that at low press temperature (160°C), cassava starch particles dries and harden faster to conceal the pores of particleboard.

The moisture content of particleboard produced using both binders increased with increasing corn cob particles percentages in the mixture. This could be attributed to the chemical component (extractives) found in the species (corn cob). Moisture content is related to the extractives content, the higher the content of extractives the lower the moisture content (Gorisek, 2009). Mantanis, Young and Rowell (1994) also reported that, the removal of chemical substances such as extractives from the species caused an increased in the moisture content of the particleboard produced. From the results, to produce particleboard to conform the ANSI standard of medium density particleboard certification; it is advised that particleboards should be pressed with combination of 90% *Ceiba pentandra* and 10% corn cob at a higher temperature and pressure.

5.1.3 Thickness Swelling of the Particleboard

Thickness swelling is the act of expansion or inflation of wood particles when it is immense in water for period of time. The swelling rate determines the ability of the particles to resist expansion, the lower the swelling rate the higher the dimensional stability of the board. The thickness swelling rate of particleboard obtained for 24 hours immersion ranged from 5.83% to 10.00%. Based on the European Standards (EN 312, 2005) for medium density particleboard, the maximum thickness swelling requirement for 24 hours water immersion is 15%. Therefore all the particleboard produced using both binders (urea formaldehyde and cassava starch) complies with medium density particleboard certification. This means that particleboards produced can be used as non-load bearing application in humid conditions. The lower thickness swelling values obtained could be attributed to compatibility during mat formation (Rahman *et al.,* 2013). The fact could also be explained by the lignin content of both species used for the particleboard production as revealed in the literature. Khedari, Nankongnab and Hirunlab (2004) share similar view. They explained that particleboard made from high lignin content substances are lower in thickness swelling values because, lignin improved bond formation between particles during mat formation.

Generally, the thickness swelling rate values of particleboard produced using cassava starch as binder were lower than their corresponding values for urea formaldehyde adhesives. Besides, for all the two binders the values of thickness swelling rate increased with increasing corn cobs particles proportion in the mixture. This may be attributed to the pith found in the corn cob which formed part of the particleboard. Pith consists of parenchyma cells, which are softer than the other cells, naturally spongy and have high capacity of expansion (Rawle *et al.,* 2012; Abdullah, *et al.,* 2012).

Mendes (2010) reported higher thickness swelling values for 24 hours water immersion from 32% to 37%, when evaluating particleboards with different mixing percentages of coffee husk added to eucalyptus wood. Melo (2009) when evaluating different mixing percentage of rice husk added to eucalyptus wood, found another increased thickness swelling values from 45% to 49%. However, Sekaluva, Tumutegyereize and Kigyundu (2013) found lower value of thickness swelling rate of 26% for 24 hours. Wang and

Winistorfer (2003) also of the view that, the thickness swelling rates increased when increasing the water exposure period and that could result in large difference in thickness swelling values between surface and the core layer. Amesimeku (2012) also made other observation that saw dust particle geometry exhibited greater increase in thickness swelling after immersion irrespective of the pre-treatments as a result of water uptake by the air spaces and voids in the fine particles composite.

5.1.4 Water Absorption of the Particleboard

Water absorption is used to determine the amount of water wood particles absorbed under specified conditions. It is important index used to determine the performance of material in humid environment. The water absorption rate values obtained after 24 hours water immersion range from 40.13% to 53%. Generally, the water absorption rate values of particleboard produced using cassava starch as binder were lower than their corresponding values for urea formaldehyde adhesives. However, values obtained for binders were lower than what Guler and Buyuksari (2011) recorded when evaluating particleboard panels produced from peanut husk with density of 0.700g/cm^3, using 10% urea formaldehyde adhesive. They found increased thickness swelling rate from 56% to 68%. Mendes (2010) also recorded highest thickness swelling rate of 96% when incorporating coffee husk with eucalyptus particles.

The value of water absorption rate of the particleboard produced using both binders increased with increasing proportion of corn cobs in the mixture. During the 24hours immersion, water already had enough time to permeate through the entire particleboard structure, and with corn cob being low density residue, absorbed more water than *Ceiba* *pentandra* particles. Mario *et al.* (2013) reported similar increasing tendency for water absorption after 24 hours particleboard immersion when considering the physical properties of particleboard made from maize cob and pinewood. They recorded thickness swelling rate of 73% [particleboard produced from 75% pinewood and 25% maize cob] and 82% Thickness swelling rate [board made from 25% pinewood and 75% maize cob].

Najafi, Tajvidi and Hamidina (2007) also of the view that, beside the mixing percentages of wood particles and the agricultural residue, there were other factors such as temperature which could influence the water absorption rate. Another factor that could influence higher water absorption rate is the particle geometry; it created a larger superficial area. Larger superficial area allows higher water absorption as it creates a bigger contact area and lower availability of adhesive per particle (Iwakiri *et al.*, 2005). Rahman *et al.* (2013) also argues that higher water absorption rate could be attributed to the hydrophilic nature of the wood particles. Wood is a hydrophilic porous composite which consist of cellulose, lignin and hemicellulose polymers that are rich functional groups such as hydroxyls, which readily interact with water molecules by hydrogen bonding (Clemons, 2002). Khedari *et al.* (2004) also shared similar conclusion on the fact that, since lignin is a natural wood binder, water absorption values of particleboards made from high lignin content materials are lower because of the improved bond formation between particles during and forming process. From the results, it could be advised that particleboards could be produced from combining 90% *Ceiba pentandra* sawdust and 10% corn cob particles using cassava starch as binder.

5.2 Mechanical Properties of Particleboard Produced from *Ceiba pentandra* and Corn cob using Urea formaldehyde and Cassava starch as Binders

5.2.1 Modulus of Elasticity of the Particleboard

The modulus of elasticity measures material resistance to being deformed elastically, it describe the tendency of an object to deform along an axis when opposing forces is applied. It also measures the stiffness of the material, which is the important index in selecting material for structural purposes. It gives indication that a stiffer material will have a higher elastic modulus (McNatt, 1973). The modulus of elasticity of particleboard obtained range from 2182.3N/mm^2 to 1648N/mm^2. According to ANSI (2009), which indicates 1380N/mm^2 as the minimum requirement for medium density particleboard, all the particleboard produced using both binders complied with medium density particleboard certification. This means that the particleboard produced can used for general purpose such as table coverings, kitchen cabinet, ceiling, partitions, etc. Similar results have been reported by scholars when producing panels made with underutilized raw material (sawdust) as well as agricultural residues (Papadopuolo *et al.* 2004: Tabarsa *et al.,* 2011: Azizi *et al.,* 2011: & Khanjanzadeh *et al*., 2012).

Modulus of elasticity values of particleboard produced using cassava starch as binder were higher than their corresponding values for urea formaldehyde adhesives. A fact that observed, which may led to the high modulus of elasticity values is the gel time and expansion of the binders. Cassava starch binder has the fastest gel time as revealed in the literature (Table 2.4) and expands its volume during heating to provide thicker bond over urea formaldehyde adhesives.

Modulus of elasticity values of particleboard produced from combining 90% *Ceiba pentandra* and 10% corn cobs particles using both binders were higher than other mixing percentages (70:30 & 50:50). This means that increased *Ceiba pentandra* mixing percentages significantly increased the modulus of elasticity values. The decreased tendency of incorporating agricultural residues to wood species was also noted by Mendes *et al.* (2010), when accessing the values of modulus of elasticity as a function of increasing percentages of coffee husk in the particleboard panels produced. They found a decrease from 800MPa to 300MPa for modulus of elasticity. Melo *et al.* (2009) also reported similar values when evaluated the properties of particleboard panels made from eucalyptus and rice husks. They recorded 1225MPa and 196MPa for eucalyptus panels and rice husks respectively.

Another fact that may have led to decreasing particleboard mechanical strength as increasing proportion of corn cobs in the mixture is the chemical properties such as the ash and lignin content found in the species. According to Iwakiri (2005), an ash content above 0.5% affect adhesive bond performance. However, the ash value found in the corn cob was 1.6% (Mario *et al.,* 2013), which may affected the bonding strength. The lignin content promotes high compaction and connection between particles (Maloney, 1993). As indicated in the literature, the *Ceiba pentandra* species contained higher lignin (32%) than corn cob (14.7%).

The results as indicated in Figure 4.1 and 4.5 shows that particleboard with less density poses high modulus of elasticity values. Hse (1975) reported similar values when evaluated properties of flakeboards from hardwood. Hse found that hardwood with less densities recorded higher modulus of elasticity values than hardwood with higher density. This means that as density decreased, the compaction ratio also increased.

5.2.2 Modulus of Rapture of the Particleboard

The modulus of rapture (MOR) is an important property of determining the applicability of the material (particleboard) for structural purposes. The modulus of rapture of particleboard produced range from 12.58N/mm^2 to 10.31N/mm^2. According to National Standard for medium density particleboard certification (7.6N/mm^2 to 15N/mm^2), all the particleboard produced conformed to medium density particleboard certification. This implies that particleboard produced can be used for general purpose such as coffee table, wardrobe, office desk, ceiling, cladding, etc. However, the modulus of rapture values of particleboard produced using cassava starch as binder were higher than their corresponding values for urea formaldehyde adhesives.

The values of MOR and density were negatively correlated; this means that there was a negative correlation between density and strength of the particleboard produced. The fact could be associated with the ash content in the corn cob which is higher than *Ceiba pentandra* (Table 2.3). According Iwakiri (2005), ash content above 0.5% affect adhesive bond performance. Another fact could be associates with lower lignin content found in the corn cobs which promotes less compaction and connection between the particles (Maloney, 1993). Corn cob has 5.6% lignin content as against 18 to 35% lignin content found in solid woods (Pettersen, 1984). Lignin is thought to contribute considerably to the strength and durability properties of particleboard made of lignocellulosic materials (Granada, *et al.,* 2002)

Modulus of rapture values of particleboard produced from combining 90% *Ceiba pentandra* and 10% corn cobs particles were higher than the other mixing percentages [70:30 & 50:50]. This implies that increasing corn cob mixing percentages decreased modulus of rapture values. Mendes *et al.* (2010) reported the same decreasing tendency as they found a decreased from 6MPa to 2MPa MOR values when incorporated coffee husk into pinewood. Mario *et al.* (2013) also found similar results when mixed maize cob with pinewood, they recorded decreased MOR values of 9MPa (75% pinewood & 25% maize cob) and 3MPa for particleboard made from 75% maize cob and 25% pinewood.

A fact which could led to decreasing tendency of modulus of rapture values when incorporating high percentages of agricultural residues such as corn cob to wood species could be associated with the chemical components (ash and lignin content) found in the agro residues as compared to wood species. Iwakiri (2005) explained that lower ash content gives effective and stronger adhesive bond to resist stress. Maloney (1993) also reported that higher lignin content promote high compaction and connection rate between particles. Guler and Buyuksari (2011) shared similar opinion when evaluated the properties of particleboard panels produced with peanut husk using different concentrations of urea formaldehyde in the faces (10%) and in the core (8%). They recorded decreased modulus of rapture values from 11MPa to 9.3MPa. Sekaluvu *et al*. (2013) recorded lower modulus of elasticity value of 1.5MPa as they produced particleboard panels made with only maize cobs.

5.3 Durability Test of Particleboard Produced from *Ceiba pentandra* and Corn cob using Urea formaldehyde or Cassava starch as Binders

5.3.1 Decay rate of the Particleboard

Durability is defined as the ability of a material to withstand environmental stress over an extended period of time (Green, Winandy, & Kretschmann, 1999). The natural durability of timber may be defined as inherent resistance of timber to attack by wood decaying fungi and wood destroying insect and also the degree of resistance to deterioration by the whole range of chemical, biological, mechanical and physical wood destroying agents (Ani *et al.,* 2005). Decay of a material is caused by the actions of bacterial, fungi, and other wood organisms. Decay rate of particleboard produced obtained after eight weeks exposure to weathering conditions range from 56.2500% to 71.8750%. Particleboard produced using cassava starch as binder obtained lower decay rate values than their corresponding value for urea formaldehyde adhesives. It implies that type of adhesive used to produce particleboard can improve it resistance to degradation over time (River, Ebewele & Meyers, 1994: Mototani & Yuki 1996). However, according to EN 255 (1990) standard of rating scale, all the particleboard produced were not severely attacked by termites and other decay organisms during eight weeks durability test conducted to examine the impact of degradation.

Besides, for all the two binders the value of decay rate of the particleboard produced increased with increasing proportion of corn cob particles in the mixture. The lower the decay rate value, better the particleboard external usage. However, particleboard and other composite panels degrade quicker than solid wood products due to larger surface area of the wood particles (Feist & Hou, 1984). Sunlight and rainfall delignify the particleboard and eventually decay the substance after eight weeks exposure to weathering conditions. Adams (1992) reported that, after three days substantial delignification took place and weeks of sunlight exposure causes severe degradation. Ebewele, River, Scolt and Koustsky (1997) reported that adhesive thickness and grain orientations affect particleboard degradation. They found that increases in cure time increased the material degradation.

5.3.2 Moisture Uptake of the Particleboard

Moisture uptake test was conducted on naturally weathered to examine the potential of moisture behaviour of the particleboard when exposed to the environment. Moisture uptake of the particleboard obtained range from 83.82 to 91.93%. Generally, the moisture uptake values of the particleboard produced using cassava starch as binder were lower than their corresponding values for urea formaldehyde adhesives. This could be attributed to the gel time and expansion of cassava starch upon heating. Cassava starch on heating expands to give thicker bond than urea formaldehyde which make the particleboard more permeable to absorb moisture easily when exposed to humid environment.

Moisture uptake values for both binders of all the particleboard produced increased with increasing corn cob proportion in the mixture. This indicates that moisture uptake of the particleboard decreased with decreasing corn cob mixing percentages. Moisture uptake is related to chemical substance such as lignin and extractive content found in the species. Species with higher lignin and extractives content perform better on moisture uptake when exposed to humid conditions (Mantanis *et al.,* 1994).

However, there is no single factor that has a more detrimental effect on wood composite than water. Without moisture, adhesively bonded joints would last almost indefinitely (Adams, 1992). Moisture sources affecting particleboard performance can be internal or external such as rainwater, ground water, water vapour, plumbing leaks and showers. It is crucial to use adhesive that have resistance to moisture uptake to prolong service longevity. In view of the test results, it can be concluded that particleboard produced using cassava starch increased the bond service time.

CHAPTER SIX

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

This chapter summaries the key findings of the study, draws conclusions and suggests recommendations. It also gives the indication on the areas of the study that could be replicated or further research.

6.1 Summary of the Findings

- The study revealed that, the addition of corn cob particles had a significant improvement on the densities of the particleboard produced. The results revealed that, the particleboards produced conformed with the ANSI (2009) standards for medium density particleboard.

- The study showed that, type of binder used for particleboard production had significant effect on moisture content of the particleboard produced. The results further revealed that cassava starch binder increased and improved density, modulus of elasticity, modulus of rapture values than urea formaldehyde adhesive.

- It was found that, the particleboard produced with combination of 90% *Ceiba pentandra* and 10% corn cob with cassava starch binder recorded the lowest moisture content value (11.4%), thickness swelling (5.83%), water absorption (40.13%), decay rate (2.25) and moisture uptake (83.82%).

- Results from the study also indicate that, 24 hours thickness swelling values obtained from the particleboard produced conformed with EN 312 (2005) requirements of medium density particleboard. The European committee for standardization outlined 15% maximum thickness swelling for 24 hours.

- It was also observed that, increasing *Ceiba pentandra* mixing percentages in the particleboard produced increased mechanical strength properties values (MOE & MOR). Again it was also found out from results and literature that increased corn cob mixing percentages above 50% will perform poorly in mechanical strength properties.

- It was found that mechanical strength properties of the particleboards produced comply with the ANSI (2009) standard requirements for medium density particleboards. ANSI indicates modulus of elasticity value ranged between $1380N/mm^2 – 2750N/mm^2$ and $11.0N/mm^2 – 16.5N/mm^2$ ranged value for modulus of rapture.

- The results further indicates that mix ratio and binder as well as their interactions at 5% level of significance, had significant effects on the modulus of elasticity, water absorption (24hrs), thickness swelling (24hrs), moisture content and density of the particleboard produced.

- Finally, the results indicate that particleboard produced especially with cassava starch was not severely attacked by termites during the eight weeks durability test conducted to examine the impact of degradation.

6.2 Conclusion

From the experimental investigations conducted, the following conclusions were drawn:

1. The corn cob particles incorporated into *Ceiba pentandra* significantly influenced the physical properties of the particleboard produced.

2. It was feasible to produce medium density particleboard from combination 90% *Ceiba pentandra* and 10% corn cob particles to minimize environmental pollutions and to sustain the natural forest.

3. Cassava starch as binder is feasible to be used as binding agent to replace urea formaldehyde adhesives usage in particleboard production to minimize the level of indoor air emissions.

4. Particleboards produced with 90% *Ceiba pentandra* and 10% corn cob with cassava starch could be used for structural purposes due to high modulus of elasticity and modulus of elasticity values obtained from the results. It can be concluded that particleboard can be produced with cassava starch to increase particleboard service time.

6.3 Recommendations

Based on the findings of the study conducted, the following recommendations are made:

1. Since the introduction of cassava starch as binder have significant improvement on the bending strength, durability and physical properties, particleboard produced

could be recommended to be used for general structural purposes both internal and external usage.

2. Due to high water absorption and thickness swelling rate of the particleboard produced, it can suitably be used as flush door for humid conditions such as bath rooms.

3. Particleboard made from *Ceiba pentandra* and corn cob particles can suitably be used for making cabinets, desk, wardrobe, and other furniture to reduce high demand for solid wood to conserve the natural forest.

4. Again particleboard produced from *Ceiba pentandra* and corn cob using cassava starch as binder can suitably be used for constructional purposes such as ceiling, cladding, partitions and flooring due to high mechanical and physical properties obtained from the test results.

5. Since *Ceiba pentandra* and corn cob particles are feasible to produced particleboard, it can suitably be recommended to the industry as raw material for particleboard production to help minimized environmental pollution to achieve the United Nations Millennium Development Goal (MDG) of achieving zero waste in the country.

6. For future replication, it will be essential to consider variation of temperature, pressure, binder percentages and other physical and mechanical properties that are not covered in this study.

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APPENDICES

Appendix 1 Post hoc (Tukey HSD) Multiple Comparison of the Means of Density of Particleboard Produced from *Ceiba pentandra* and Corn cob Particles

Grouping (I)	Grouping (J)	N	Mean (I-J)	P-value
90:10	70:30	30	-0.0178	0.072^{+}
	50:50	30	-0.0595	0.001*
70:30	90:10	30	0.0178	0.072^{+}
	50:50	30	-0.0417	0.001*
50:50	90:10	30	0.0595	0.001*
	70:30	30	0.0417	0.001*

* Statistically significant at 0.05 level of significance, $^{+}$Not Statistically Significant at 0.05 level of significance.

Appendix 2 Post hoc (Tukey HSD) Multiple Comparison of the Means of Moisture Content of Particleboard Produced from *Ceiba pentandra* and Corn cob Particles

Grouping (I)	Grouping (J)	N	Mean (I-J)	P-value
90:10	70:30	30	-1.3113	0.001*
	50:50	30	-1.7038	0.001*
70:30	90:10	30	1.3113	0.001*
	50:50	30	-0.3925	0.413^{+}
50:50	90:10	30	1.7038	0.001*
	70:30	30	0.3925	0.0413^{+}

* Statistically significant at 0.05 level of significance, $^{+}$Not Statistically Significant at 0.05 level of significance.

Appendix 3 Post hoc (Tukey HSD) Multiple Comparison of the Means of Thickness Swelling of Particleboard Produced from *Ceiba pentandra* and Corn cob Particles

Grouping (I)	Grouping (J)	N	Mean (I-J)	P-value
90:10	70:30	6	-1.6667	0.283^{+}
	50:50	6	-2.9167	0.029*
70:30	90:10	6	1.6667	0.283^{+}
	50:50	6	-1.2500	0.485^{+}
50:50	90:10	6	2.9167	0.029*
	70:30	6	1.2500	0.485^{+}

* Statistically significant at 0.05 level of significance, $^{+}$Not Statistically Significant at 0.05 level of significance.

Appendix 4 Post hoc (Tukey HSD) Multiple Comparison of the Means of Water Absorption of Particleboard Produced from *Ceiba pentandra* and Corn cob Particles

Grouping (I)	Grouping (J)	N	Mean (I-J)	P-value
90:10	70:30	6	-5.6608	0.072+
	50:50	6	-10.8717	0.001*
70:30	90:10	6	5.6608	0.072+
	50:50	6	-5.2108	0.104+
50:50	90:10	6	10.8717	0.001*
	70:30	6	5.2108	0.104+

* Statistically significant at 0.05 level of significance, + Not Statistically Significant at 0.05 level of significance.

Appendix 5 Post hoc (Tukey HSD) Multiple Comparison of the Means of Modulus of Elasticity of Particleboard Produced from *Ceiba pentandra* and Corn cob Particles

Grouping (I)	Grouping (J)	N	Mean (I-J)	P-value
90:10	70:30	30	266.4500	0.001*
	50:50	30	480.7333	0.001*
70:30	90:10	30	-266.4500	0.001*
	50:50	30	214.2833	0.001*
50:50	90:10	30	-480.7333	0.001*
	70:30	30	-214.2833	0.001*

* Statistically significant at 0.05 level of significance, + Not Statistically Significant at 0.05 level of significance.

Appendix 6 Post hoc (Tukey HSD) Multiple Comparison of the Means of Modulus of Rapture of Particleboard Produced from *Ceiba pentandra* and Corn cob Particles

Grouping (I)	Grouping (J)	N	Mean (I-J)	P-value
90:10	70:30	30	0.9220	0.010*
	50:50	30	1.5913	0.001*
70:30	90:10	30	-0.9220	0.001*
	50:50	30	0.6693	0.084+
50:50	90:10	30	-1.5913	0.001*
	70:30	30	-0.6693	0.084+

* Statistically significant at 0.05 level of significance, + Not Statistically Significant at 0.05 level of significance.