JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF MECHANICAL ENGINEERING

MSC: MANUFACTURING SYSTEM ENGINEERING

Manufacturing, Modeling and Functionality Testing of Coffee Husk Chipboard

By;

Adane Birhanu

Roll no: 0983/09

Final Thesis submitted to School of graduate studies of Jimma University in Partial Fulfillment for **Masters of Science in Mechanical Engineering specialty in Manufacturing System Engineering**

December 29, 2018

Manufacturing, Modeling and Functionality Testing of Coffee Husk Chipboard

Post Graduate School of Mechanical Engineering

Jimma Institute of Technology

Jimma University

By;

Adane Birhanu

Under the supervision of:

1. Mr. Mesay Alemu (main advisor)
2. Dr. Anil Kumar (co-advisor)

A Thesis Submitted to School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for Degree of Masters Science in Manufacturing Systems Engineering

December 29, 2018

DECLARATION

I, undersigned and declare that this thesis is my original work, has not been presented for a degree in this or any other university and that all sources of materials used for the thesis have been fully acknowledged.

Name Signature Date

Adane Birhanu ____________________ _______________

Approval of the advisors

Advisor: Mr. Mesay Alemu Signature _____________ Date ________________

Co advisor: Dr. Anil Kumar Signature_______________ Date ______________

This is to certify that the thesis prepared by Adane Birhanu, entitled: **Manufacturing, Modeling and Functionality Testing of Coffee Husk Chipboard** and submitted in partial fulfillment of the requirements for the degree of Master of Science in Manufacturing Systems Engineering compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Abstract

Coffee husk is the outer membrane of coffee bean that obtain during processing of coffee cherries. It is considered as a short fibers and can be used in place of wood particle for chipboard manufacturing because it contain the same basic composition with wood but differ in percentages. This residue most of the time considered as fertilizer released to the farmers land. But researchers identify that it have less fertilizer value and less usable as food for cattle. The study area of the thesis is functionality test of coffee husks for manufacturing chipboards. These chipboards are made from only coffee husks and coffee husk - wood particle glued by ureaformaldyde resins. These are done by calculating volume fraction of the particle and resin in the mixture. After manufacturing, important physical tests (the density, moisture content, water absorption and thickness swelling) and some mechanical tests of the chipboards are analyzed. Mathematical modeling of MOE and life span of the coffee husk boards. Also Solid work software simulation to analyze bending and compression strength properties of the chipboard. From experimental result the boards are medium density that are commercial standards. The more moisture content value of coffee husk chipboards can be traced back to the hygroscopic behavior of the coffee husk. The hardness test measured using Rockwell hardness shows the board made from coffee husks - wood particle is harder than pure coffee husk chipboard. The bending and compression strength obtained from simulation is almost similar to the result obtained by different researchers. The life span of the chipboard is service time of the board and depend on three major factors such as load, temperature and moisture content and decrease with the increment of these factors and prone to degradation of the chipboard. At the end the result of the work conclude that coffee husk can be alternative raw material for chipboard manufacturing industries.

Key words: Coffee husk chipboard, Mathematical modeling, UF resins, Bending strength, Hardness test, Degradation.

Acknowledgement

First of all, I want to thank The Almighty GOD for giving me the time and chances to finally complete this research work.

Next I would like to express my sincere gratitude to my advisor Mr. Mesay Alemu for his invaluable guidance, continuous encouragement and constant support in making this research possible. He has always support me in times when I faced difficulties during completing this research and constantly giving the best advice to help me.

I also want to thank my co-advisor Dr. Anil Kumer who have given his best in making me understand how this research has to be done and have guided me throughout the research.

My sincere thanks go to all staff of the school Mechanical Engineering, JIT, who helped me in many ways whenever I needed. Thanks for always putting up the best effort in helping me to finish this research.

The best thanks goes to my family. I am very thankful to have them as family because they never gave up on me and constantly support me morally and financially

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NOMENCLATURE

V_c	Volume of wood composite
M	Mass of the chipboard
V_{ch}	Volume of coffee husk
V_u	Volume of ureaformaldyde
ρ_c	Density of composite
v_{ch}	Volume fraction of coffee husk
v_u	Volume fraction of ureaformaldyde
w_c	Weight fraction of wood composite
w_u	Weight fraction of ureaformaldyde
ρ_u	Density of ureaformaldyde
ρ_{ch}	Density of coffee husk
η_L	Longitudinal coefficient
η_T	Tangential coefficient
E_L	Longitudinal modulus of elasticity
E_{ch}	Modulus of elasticity of coffee husk
E_U	Modulus of elasticity ureaformaldyde
E_T	Tangential modulus of elasticity
l_{ch}	Length of coffee husk fiber
d_{ch}	Diameter of coffee husk fiber
$E_{chipboard}$	Modulus of elasticity of coffee husk chipboard
$G_{chipboard}$	Shear modulus of coffee husk chipboard
p_{ch}	Load carried by coffee husk fiber

$p_{chipboard}$	Load on chipboard
σ	Engineering stress
E	Young's modulus
ϵ	Engineering strain
D_b	Bending elastic properties of chipboard
D_s	Shear elastic properties of chipboard
σ_L	Longitudinal stress
σ_T	Tangential stress
$\sigma_{chipboard}$	Chipboard stress
τ	Life time
τ_o	Constant life time
U_o	Binding energy
γ	Is the coefficient of transformation of the mechanical
T_m	Maximum temperature
T	Absolute temperature
α	Coefficient taking into account impact of moisture content
W	Actual moisture during operation, %;
W_e	Effective moisture, %
W_m	Maximum moisture, %
K	Boltzmann's constant
m_2	Mass after oven drier
m_1	Mass before oven drier
w_2	Weight after water immersion
w_1	Weight before water immersion

LIST OF ABBREVIATIONS

OSB	Oriented strand board
MDF	Medium-density fiberboard
LVL	Laminated veneer lumber
PSL	parallel strand lumber
PF	Phenol formaldehyde
UF	Urea formaldehyde
IB	Internal bond strength
MC	Moisture contents
TS	Thickness swelling
WA	Water absorption
MUF	Melamin urea formaldyde
MDI	Methylene diphenyl diisocyanate
W	Wood particle
CH	Coffee husk fibers
Mpa	Mega Pascal
Gpa	Giga Pascal
MOE	Modulus of elasticity

CHAPTER ONE

1. INTRODUCTION

This chapter discusses about the background of the thesis, objective, problem statement, scope of the thesis and its significance.

1.1 Background

Ethiopia is one of the countries which use agriculture as a backbone of their economy. And, the majority of the export products come from agriculture. As we know our country has enormous amounts of coffee husks which is the outer membrane of coffee seeds that is obtained during the processing of coffee cherries. In current practice this resource poorly utilized or dumped in the environment.

Government has given attention to the industrial sector and, hence, a number of governmental and private investors owned industries are being planted at different locations. From these industries, chipboard manufacturing industries dramatically increased. Due to continuous increasing of new construction and other purpose, increment of demand for chipboard ultimately.

All chipboard industries in our country still are relying on the wood for chipboard manufacturing purpose through cutting from the plantation areas.

In recent years, there is a growing tendency towards recycling of the waste and using it for producing the composite wooden products like particle board. On the other side depletion of forest resources has increased demand for these kinds of products. Use of renewable materials for manufacturing particleboards could contribute the solution of raw material shortage for the particleboard industry [1].

Wood composite is used to describe any wood material bonded together with adhesives. The current product mix ranges from fiberboard to laminated beams and components. Wood based composite materials are classified into the following categories. Panel products (plywood, oriented strand board, particleboard, fiberboard, medium-density fiberboard, (hard board). Structural timber products (glued-laminated timber (glulam), laminated veneer lumber, laminated strand lumber, parallel strand lumber). And wood and non-wood composites (wood fiber–thermoplastics, inorganic-bonded composites).Wood-based composites are made from a wide range of materials from fibers obtained from underutilized small diameter or plantation trees to structural lumber. Regardless of the raw material used in their manufacture, wood-based composites provide uniform and predictable in-service performance, largely as a consequence of standards used to monitor and control their manufacture. The mechanical properties of wood composites depend upon a variety of factors, including wood species, forest management regimes, the type of adhesive used to bind the wood elements together, geometry of the wood elements (fibers, flakes, strands, particles, veneer, lumber), and density of the final product [1-2].

Wood based board materials sometimes referred as wood based panels include a range of derivative wood products which are manufactured by binding together wood strands, particles, fibers or veneers with adhesives or other binders to form composite materials. Chipboards are among the wood based boards manufactured from dry process by mixing wood particles or flakes together with a resin and forming the mix into a sheet [3].

Wood residues in the form of sawdust, chips, slabs, shavings, and plywood trims from sawmills, Joinery manufacturers and plywood mills are commonly used for particleboard production, the shavings being the most expensive and sawdust the cheapest. Residues from low density wood species which are less dense and easier to process are preferred for particleboard manufacture as the material needs to be compacted above its natural density to ensure good contact between the particles. This is because the level of compaction determines the physical and mechanical strength properties of the particleboard [4].

Shortage of wood raw materials could be minimized by utilizing vast quantities of lignocellulose wastes available in the country. By varying the process parameters and binding agents, a wide variety of composite agro-based products could be made from such raw material and can substitute solid wood for various purposes.

Using only wood for chipboard industry has tremendous problems like deforestation, scarce of raw materials, increasing cost of raw materials (wood) and directly or indirectly reduces the quality of end products.

Figure 1. 1 Cutting wood for chipboard

The rapidly changing economic and environmental needs of society are putting ever-increasing pressures on the forest too. In practical terms this means, increasing the conversion and efficient use of wood resources is develop the stress on this land. With diminishing gradually wood resources, utility in the industry on other hand increasing the costs for the wood based panel products.

To overcome these environmental problems and other related issues, utilization of coffee husk resources as current alternative raw materials for chipboard manufacturing that significantly increase products and productivities of our country.

Therefore, the main task of the research is to manufacture coffee husk chipboard on exist machineries of chipboard industry, then testing end product chipboard, and concluding utility of coffee husk for chipboard industries as the alternative raw material is possible.

1.2 Problem statement

Many researchers done different works on the chipboard, that made from lignocellulose materials; wood and agricultural residues. Most manufactured chipboards are made from wood particle and some agricultural products. Cutting forest for this purpose leads to global warming which it damages the life of the living things.

The coffee husk that is considered as waste material obtained from the dry coffee processing, most of the time left on the land and it is reason for pollution. Since this residue has less value in the fertilizer even using it with manure of cattle is less usable. So to address this less usage of the resources and decrease deforestation, it is essential to use coffee husk for chipboard production. The thesis focused on applicability of this coffee residue in case of chipboard manufacturing and studying physical and mechanical tests properties of the produced chipboard in order to decide its applicability.

1.3 Objectives of the thesis

1.3.1 General objectives

The main objective of the thesis is to check functionality of coffee husk in chipboard manufacturing and modeling the properties of produced coffee husk chipboards.

1.3.2 Specific objectives of the thesis

- Manufacturing of two types of chipboards from full coffee husk and coffee husk-wood particle on the locally existing chipboard manufacturing machineries.
- Analyzing some physical and mechanical tests of the manufactured chipboards.
- Mathematical modeling of properties and life span of produced chipboard
- Application of Solid work software to model bending and compression strength of the chipboard.

1.4 Scope of the thesis

- Manufacturing of chipboards by full or partial replacement of wood particle by coffee husk on the locally existing chipboard manufacturing industry.
- Checking the functionality of coffee husk chipboards.
- Analyzing physical (density, moisture content, water absorption and thickness swelling) and some mechanical tests (hardness and compression test) of the boards.
- Mathematical modeling of properties and life span of the produced boards.
- Solid work software simulation to obtain bending and compression strength of the boards.

1.5 Significance of the study

- First, obtaining new chipboard by using coffee husk to as alternative raw material in chipboard manufacturing industries and identifying its functionality.
- Second to know the physical and mechanical properties of the manufactured chipboard.
- Thirdly decrease deforestation due to full or partial alternative use of the coffee husk as raw material in chipboard manufacturing.

1.6 Limitation of thesis

- Unavailability of ureaformaldyde powder in local market is the first limitation of the research.
- Some chipboard manufacturing industries reject the proposal of producing chipboard on their manufacturing machineries.
- During fabrication some amount of ash released from the processing machine which is common problem of all particles and may cause health problems.
- Less availability of the chipboard testing machines nearby are the main problem encountered for the thesis accomplishment.

1.7 Thesis Organization

This thesis focuses on the **Manufacturing, Modeling and Functionality Testing of Coffee Husk Chipboard** and discuss the results.

The thesis steady manuscript comprises of six chapters.

Chapter 1: Introduces the background of the wood composites and the chipboard (particle board) from coffee husks and other residues. Also discusses about objectives, problem statement, scope, significant and limitations of thesis.

Chapter 2: Reviewed all relevant research papers regarding wood composites and the chipboard (particle board) from coffee husks and other residues, coffee husks, types of adhesive used, previous works of the other researchers and work.

Chapter 3: Study the methodology used for manufacturing the coffee husk and coffee husk-wood chipboard and place where manufacturing of the products done.

Chapter 4: Deal with the physical test (density, moisture contents, water absorption and thickness swelling) and some mechanical test of the chipboard. Also the mathematical and software modeling of chipboard.

Chapter 5: Focused on discussing the result of the works done.

Chapter 6: Is dedicated to the conclusion, recommendations and future work of this thesis

CHAPTER TWO

2. LITERATURE REVIEW

This chapter study about different works done on the coffee husk, wood particle composite, types of particle board, types of resins and previous works collected from journals, books, articles, papers, .websites etc.

2.1 Coffee husk

Coffee is a major commodity export-earner for Ethiopia, accounting for more than 50% of the country's annual commodity exports. Most of the coffee production areas and processing plants in Ethiopia are found in the southern and eastern parts of the country, notably in the Southern Nations, Nationalities and People's Region (SNNPR) and in Oromia.

Coffee is deemed a commodity ranking second only to petroleum in terms of currency (usually US dollars) traded worldwide. As such, this commodity is quite relevant to the economy of producing countries, including Brazil, Vietnam, Colombia, Ethiopia, Indonesia, Mexico and India [5]. Brazil is the largest coffee producer and exporter in the world, and is the second largest consumer. The production of coffee in Brazil in the last five years ranged from 2.0 to 2.7 million tons. Such production represents an average of over 2.5 million tons of solid residues being generated every year. These solid residues (coffee husks and pulp, defective coffee beans and spent coffee grounds) pose several problems in terms of adequate disposal, given the high amounts generated, environmental concerns and also specific problems associated with each type of residue. In this regard, several studies have been undertaken and are still being developed in terms of alternative uses for such solid residues [5-7].

Coffee husks are the major solid residues from the handling and processing of coffee. A dehulling machine is used to separate the sundried coffee husks, the parchment and the beans from each other. The main by-product from the dry method is the coffee husk which is composed of the dried skin, pulp and parchment. Of each ton harvest coffee fruit, 0.18 ton of coffee husk are produced. There are two major methods in the processing of coffee cherries (primary coffee processing): dry and wet processing.

1. Dry processing is the simplest technique for processing coffee cherries. After harvesting, the coffee cherries are dried to about 10–11% moisture content. Thereafter, the coffee

beans are separated by removing the material covering the beans (outer skin, pulp, parchment and silver skin) in a de-hulling machine. Generated solid residues are denominated coffee husks (outer skin + pulp + parchment) and silver skin. Drying can be accomplished by either "natural" or "artificial" methods. Natural or sun-drying is the method commonly employed in large farms.

2. Wet processing, on the other hand, does not require drying of the cherries themselves. In this type of processing, first the outer skin and pulp are mechanically removed, thus generating the solid residue, denominated coffee pulp [6,8].

Coffee hulls are characterized chemically by a high concentration of crude fiber and in this respect they are similar to various other by-products used as fillers in animal feeds. The cellular contents of coffee hulls amount to about 12%, while the cellular wall components, that are the neutral and acid detergent fibers, are found in amounts of 88 and 67%, respectively. Cellulose can be utilized by ruminants as a source of energy; however, the utilization of coffee hulls is limited by lignin, silica, and other compounds. Lignin content runs as high as 18% and insoluble ash about 5%. To increase the metabolic utilization of coffee hulls it is necessary to hydrolyze cellulose and similar compounds. Because of its structure and chemical composition, coffee hulls do not offer many other possibilities for use, although it is considered a good fuel [9].

In the case of coffee husks, it has been pointed out that, its low digestible protein content, in addition to the fact that the starch equivalent is comparable to low quality, has prevented its use as animal feed. Even though coffee husks and pulp are rich in organic nature and nutrients, they also contain compounds such as caffeine, tannins, and polyphenols. Due to the presence of the latter compounds, these organic solid residues present toxic nature, which not only adds to the problem of environmental pollution, but also restricts its use as animal feed. Caffeine is an active compound, being one of the nature's most powerful stimulants. It is the major substance to which the stimulation effect of coffee is attributed. It is also present in coffee husks at approximately 1.3% concentration on dry weight basis. Tannins are generally thought to be an anti-nutritional factor and to prevent coffee husks from being used at percentages over 10% in animal feed [5,10].

2.1.1 Chemical composition, morphology of coffee husk

The coffee husk was chemically analyzed as a lignocellulose material which is a collective name for different species of wood and plants. For utilization of coffee husk in materials like board and composite, cellulose is the main component responsible for structure and stiffness its lignin [9].

Table 2. 1 Chemical composition of coffee husk wastes [8-9]

Components	**Coffee husks**
Carbohydrates	58-85 (%)
Proteins	8-11 (%)
Fibers length	0.3 mm
Fibers diameter	0.02 mm
Fats	0.5-3 (%)
Caffeine	1.3 (%)
Lignin	20 (%)
Cellulose	19-26 (%)
Pectin	12.4-13 (%)
Tannins	4.5-5.4 (%)

Coffee husk has pure lignocellulose and no fertilizer value at all. In the same way coffee husk has some amount of caffeine and tannins that makes toxic in nature, results are disposal problem [5-6].

Figure 2. 1 Coffee husk

2.2 Wood composite Material

Wood-based composite is a composite material mainly composed of wood elements. Theses wood elements are usually bonded together by a thermosetting adhesive (wood truss products could also be regarded as wood- based composites, but connected by metal connectors). The commonly used adhesives include urea-based adhesives (such as urea formaldehyde), phenolic-based adhesive (including phenol resorcinol adhesives), isocyanine-based adhesives, and adhesives from renewable resources (like soybean, lignin etc.) [1-2,4].

The wood elements in wood composites can be in many different forms such as: Dimension lumber for laminated glued timber (Glulam). And wood trusses, veneers for plywood, laminated veneer lumber (LVL), and parallel strand lumber (PSL), Fibers for medium density fiberboard (MDF) high density fiberboard (hardboard), and other fiber-based products, Particles for particleboard, Flakes or strands for flake board, oriented strand board (OSB),oriented strand lumber (OSL), and laminated strand lumber (LSL). Plywood is a panel product built up wholly or primarily of sheets of veneer called plies. It is constructed with an odd number of layers with the grain direction of adjacent layers oriented perpendicular to one another. A layer can consist of a single ply or of two or more plies laminated with their grain direction parallel. Oriented strand board (OSB) is an engineered structural use panel manufactured from thin wood strands bonded together with water resistant resin, typically Phenol formaldehyde (PF) or polymeric 4,4-methyl phenyl methane di-isocyanate (PMDI) [1-2,4,11-12].

The term fiberboard includes hardboard, medium-density fiberboard (MDF), and cellulosic fiberboard. Several things differentiate fiberboard from particleboard, most notably the physical configuration of the wood element. Because wood is fibrous by nature, fiberboard exploits the inherent strength of wood to a greater extent than does particleboard [2,12].

A composite materials are generally engineered materials made from two or more constituents with different physical or chemical properties, which remain separate and distinct within the finished structure. The composite should also have properties which surpass the properties of the individual constituents that make up the composites [4,12].

The production of particleboards and engineered composite panels made from coffee husk was the idea to develop new composite material from agricultural resources and to give chance for more usage of agricultural products. Shortage of wood raw materials could be minimized by utilizing vast quantities of lignocellulose wastes available in the country. By varying the process parameters and binding agents, a wide variety of composite agro-based products could be made from such raw material and can substitute solid wood for various purposes [9].

2.3 Particle board

Particleboard is a wood based panel composite manufactured by compressing small wood particles while simultaneously bonding them with an adhesive. It is used in furniture, desk and counter tops, cabinets, floor, wall, ceiling panels, and office dividers. It is produced by mechanically reducing the wood raw material into small particles, applying adhesive to the particles, and consolidating a loose mat of the particles with heat and pressure into a panel product. The particleboard industry initially used cut flakes as a raw material. However, economic concerns prompted development of the ability to use sawdust, planer shavings, and to a lesser extent, mill residues and other waste materials. To manufacture particleboard with good strength, smooth surfaces, and equal swelling, manufacturers ideally use a homogeneous raw material. Particleboard has become one of the most popular wood-based composite materials for decorating materials because of its low density, good thermal insulation, sound absorption, and wonderful machining properties. The primary lignocellulose material used in the particleboard industry is wood. The panel product that is typically made from small wood particles of mill residue such as sawdust, shavings, or flakes, or from other lignocelluloses particles like rice hulls, is designated particleboard. Especially, medium-density particleboard, is widely used for construction, furniture, and interior decoration including wall and ceiling paneling [11-12]**.**

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 [13].

Raw materials for particle board productions are as follows:

1. Wood particles
    - Virgin wood, mainly softwood, but other species can be used
    - Round wood
    - Co-products (sawdust, slabs, etc.)
    - Short rotation coppice (poplar)
    - Recovered/recycled wood (urban forest)
    - Pallet wood, packaging etc.
    - Management can be problematic due to difficulties in identifying contaminants (polymeric - paints and varnishes; preservatives).
2. Non-wood:
    - Agricultural by-products
    - Wheat straw, bagasse, hemp, rice straw
    - Basically any fibrous lignocellulose material [15]

Particleboard panel products typically are made from small lignocellulose particles and flakes that are bonded together with a synthetic adhesive under heat and pressure. The density levels for particleboard are the same as those for medium density fibers.

- Low density particle board $< 640 \frac{kg}{m3}$
- Medium density particle board $640 - 800 \frac{kg}{m3}$
- High density particle board $> 800 \frac{kg}{m3}$ [2]

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 oriented strand board, medium density fiberboard and hardboard is the material or particles used in its production. The major types of particles used to manufacture particleboard include wood shavings, flakes, sawdust and agricultural residues. Other wood composite panel such as fiberboard has its major constituent as fiber and fiber bundles. The strength of the product is determined by the adhesive used and not the fiber used, although the size and the shape have influence on the strength. Particleboard can also be said to be a three layers or single layer board. The three layer board has fine particles on both faces and layer wood flakes particles in the middle [11-12].

Particleboard is a non-structural wood composite made from lignocellulose particles bonded with an adhesive under heat and pressure typically 165-200 °C and (2-4) MPa respectively depending on the adhesive, raw material, board density and thickness. It is a randomly oriented composite which takes advantage of the wood particle characteristics for the final board strength properties [4].

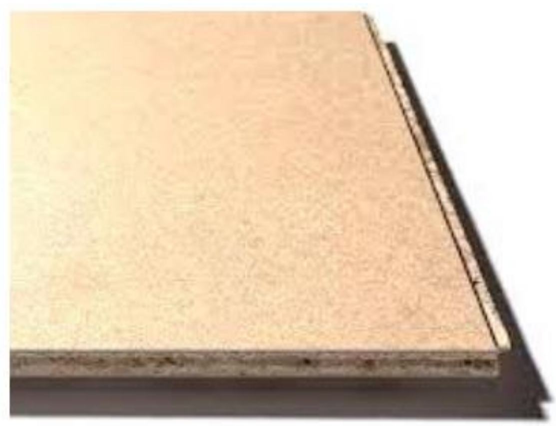


Figure 2. 2 Single layer particleboard Figure 2. 3 Three layers particleboard [11].

It generally consists of approximately 90 weight % wood and less than 10 weight % adhesive. Unlike conventional fiber-reinforced composites such as glass fiber polypropylene, particleboard makes use of a lower weight percentage of resin which is applied in droplet form on the particle surface. The boards are typically 3-layered formed with a face to core ratio of 40:60 with the face comprising of fine particles and the core consisting of the coarse particles; this sandwich design provides a smooth board surface for lamination.

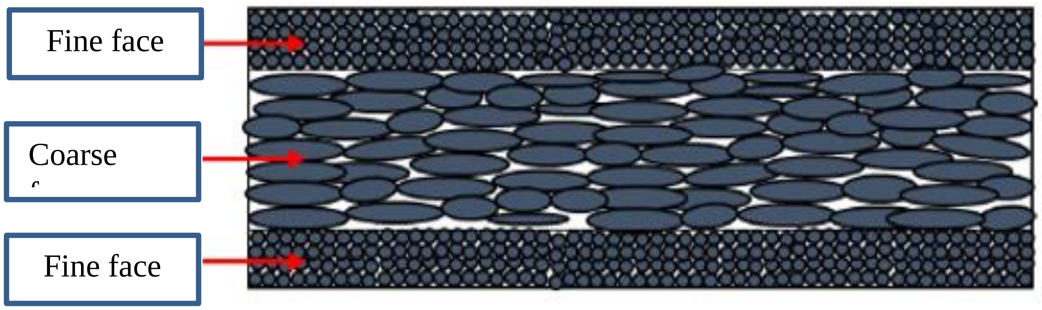


Figure 2. 4 Multi layered face of chipboard [4]

Any lignocellulose material can be used as raw material for particleboard manufacturing. Besides wood, they can use residues from agribusiness such as: cereal straw, bagasse of sugar cane, cornstalks and corn cobs, cotton stalks, kenaf, rice husks, sunflower stalks and hulls, among others [14].

Requirements for grades of particleboard and particleboard flooring products, as specified by the American National Standard for Particleboard. Today, approximately 85% of interior-type particleboards are used as core stock for a wide variety of furniture and cabinet applications. Composite panels made from agricultural materials are in the same product category as wood-based composite panels and include low-density insulating board, medium-density fiberboard, hardboard, and particleboard. Composite panel binders may be synthetic thermosetting resins or modified naturally occurring resins like tannin or lignin, starches, thermoplastics, and inorganics [2].

2.4 Types of resins

The resins are generally applied as liquids in the form of an atomized spray and can also be applied in solid (powder) form that forms a liquid on heating, before reverting to an insoluble, infusible, solid form (e.g. PF). There are different types of resins available in the world which can be categorized into two major groups.

a. Primarily thermosetting resins
   - Main type (90%) is Urea formaldehyde (UF) - brittle and subject to hydrolysis
   - MUF (melamine urea formaldehyde) - better moisture resistance than standard UF
   - Phenol formaldehyde (PF) - more resilient and less subject to hydrolysis

- MDI (methylene diphenyl diisocyanate) and PMD - highly reactive and bonds well
- Other adhesives
- Inorganic (cement bonded)

b. Thermoplastics

- Renewable resource-based adhesives
- Tannin-based adhesives
- Lignin-based adhesives
- Glues based on vegetable oils
- Soy flour-based adhesives
- Furan polymer-based adhesives

The urea-formaldehyde (UF) and phenol formaldehyde (PF) are the main adhesives used by the wood panel industry and 90% of the particleboards of the world are produced using urea-formaldehyde resin, although this adhesive demonstrates low resistance to humidity. The phenol-formaldehyde adhesive, however, is recommended for the production of panels for external use or environments of high relative humidity [15-16]**.**

The adhesive is the most expensive component of the panels; therefore, the right definition of its type and content is extremely important to optimize the cost/effectiveness ratio.

The advantage of UF adhesives are their

- Initial water solubility renders them eminently suitable for bulk and relatively inexpensive production
- Hardness
- No flammability
- Good thermal properties
- Absence of color in cured polymers
- Easy adaptability to a variety of curing conditions [12,16] .

UF resins however have some disadvantages such as their low resistance to moisture hence its use for interior products, and continuous formaldehyde emissions while in use because of the hydrolysis of the weakly bonded formaldehyde.

These disadvantages of UF resin can be reduced by fortifying it with melamine which has a low solubility in water but is more expensive compared with urea.

PF resins formed by a reaction of phenol with formaldehyde on the other hand have more durable bonds which are resistant to moisture, thus low formaldehyde release after board production and as such their use for exterior products.

The disadvantages of PF resins include its dark color glue line and slow curing nature (compared to UF) requiring longer press times at higher temperatures [4,16].

Urea formaldehyde adhesive is used in the production of an adhesive for bonding particleboard (61% of the urea-formaldehyde used by the industry), medium density fiberboard (27%), hardwood plywood (5%) and a laminating adhesive for bonding (7%), for example, furniture case goods, overlays to panels, and interior flush doors.

Using different conditions of reactions and preparations a practically endless variety of condensed UF chemical structures is possible. UF resins are thermosetting resins and consist of linear or branched oligomers and polymers always mixed with some amounts of monomers.

The presence of some unreacted urea is often helpful to achieve specific effects and a better storage stability of the resin. The presence of free formaldehyde has, however, both positive and negative effects. On the one hand, it is necessary to induce the subsequent hardening reaction while, on the other hand, it causes a certain level of formaldehyde emission during the hot press, resin hardening cycle.

Even in the hardened state, low levels of residual formaldehyde can lead to the displeasing odor of formaldehyde emission from the boards while in service. This fact has changed significantly the composition and formulation of UF resins during the past 20 years.

The reaction between urea and formaldehyde is complex. The combination of these two chemical compound results in both linear and branched polymers, as well as tridimensional networks, in the cured resin. This is due to functionality of four in urea (due to the presence of four replaceable hydrogen atoms) in reality urea is only trifunctional as tetramethyolurea has never been isolated, except in the formation of substituted irons and a functionality of two in formaldehyde.

The most important factors determining the properties of the reaction products are:

- The relative molar proportion of urea and formaldehyde
- The reaction temperature
- The various pH values at which condensation takes place.

These factors influence the rate of increase of the molecular weight of the resin. Therefore the characteristics of the reaction products differ considerably when lower and higher condensation stages are compared, especially solubility, water retention, and rate of curing to the adhesive. These all depend to a large extent on molecular weights [12,15-16].

Table 2. 2 Chemical analysis of urea formaldehyde [16]

Characteristic	**Percentage (%)**
Solid Content	65%
Viscosity (30℃)	2.3p
PH	7.5
Gel time (100℃)	65s

Table 2. 3 Mechanical properties of ureaformaldyde

Mechanical Properties of urea formaldyde	
1. Elastic (Young's, Tensile) Modulus	9.0 GPa
2. Elongation at Break	1.0 %
3.Tensile Strength: Ultimate (UTS)	30 MPa
4.Yield strength	100 Mpa
Thermal Properties	
1.Specific Heat Capacity	1200 J/kg
2.Thermal Conductivity	0.4 W/m-K
3.Thermal Expansion	55 µm/m-K
Other Material Properties	
1.Density	1.5 g/cm3
2.Dielectric Strength (Breakdown Potential)	35 kV/mm

3.Electrical Resistivity Order of Magnitude	9.0 10x Ω-m

[17]

2.5 Bonding exist between agricultural residue and the resins or adhesives

For wood bonding, studying adhesion theories requires an understanding of wood material characteristics, surface science, polymer characteristics, and the interactions between polymers and surfaces. At present no practical unifying theory describing all adhesive bonds exists, although a unified adhesion theory has been proposed. Recent applications of adhesion theories to describing the nature of wood adhesive bonding have focused effort on the durability of wood adhesive bonds.

Table 2. 4 Comparison of six adhesion interactions mechanism relative to length scale [18]

Category of Adhesion Mechanism	Type of Interaction	Length Scale
Mechanical	Interlocking or entanglement	0.01–1000 µm
Diffusion	Interlocking or entanglement	10 nm–2 µm
Electrostatic	Charge	0.1–1.0 µm
Covalent bonding	Charge	0.1–0.2 nm
Acid-base interaction	Charge	0.1–0.4 nm
Lifshitz-van der Waals	Charge	0.5–1.0 nm

2.5.1. Mechanical interlocking theory

Mechanical interlocking is one of the basic adhesion mechanisms that can be divided into two groups, specifically: locking by friction and locking by dovetailing. Mechanical interlocking strongly depends on the geometry of the bonding sites and the mechanical properties of the materials involved [15].

In addition to geometry factors, surface roughness has a big effect on adhesion. Rougher surfaces provide better adhesion than smooth surfaces. Rough surface with a 60° peak angle has twice as much surface area as a flat surface. On the other hand, absorption has an important role in mechanical interlocking, because absorption affects the penetration of a liquid into pores or irregularities on the adherent surface. Therefore, higher absorption produces better adhesion in mechanical interlocking systems [25]. The length scale, which changes according to type of interaction, is another factor that affects adhesion.

2.6 Previous work

Strength properties of boards are the measure of its resistance to external forces or loads which tend to deform its mass. The resistance of boards to such forces depends on their magnitude and the manner of loading (bending, tension, compression and shear). Mechanical properties in all wood based boards are the most important ones since when choosing a board for application; it must have certain characteristics of shape, rigidity and strength [3].

The quantity of the resin when increased within certain limits improves the strength properties but the composition of an adhesive is also important. Different types of particleboard and fiberboard on the other hand are being used not only in furniture industry but also in construction mostly for partitioning and ceiling boards [4].

The bonding properties and performance of multi-layered kenaf board which have three layer; kenaf bast, kenaf core and rubber wood were apparently less sensitive when exposed to alkaline environment. Kenaf core inner surface exhibited higher wettability than the outer surfaces [11].

The effects of adhesive used can be divided into two when used with UF resin, it improved the MOE and MOR of the board but not the IB, TS and WA and when used with MUF resin, it improved only the IB. The best performance was given by boards made from 100% kenaf core irrespective of the type of resin used. Observed that, increasing the content of adhesive, the mechanical properties and the dimensional stability of the panels increased as well [2].

The composites made from vegetable organic additions of bagasse ,fibrous residue remaining after sugarcane, with and without ashes from the same waste materials, in plaster and cement matrices allow reusing waste materials that are sustainable and provide eco-efficient execution of architectural projects solutions [2,6].

2.7 Gap of the works

- Many researchers have done different works on chipboard related works but no one done research on local coffee husk to produce chipboards.
- Some researchers identify that chipboards are produced using partial or full replacement of wood particle by coffee husk but they didn't state that he or she has been used the already available wood chipboard manufacturing machineries.
- And also in the available research work it is difficult to found the modeling of some software and mathematical equations for chipboards.

CHAPTER THREE

3. THESIS METHODOLOGIES, MATERIALS AND CHIPBOARD MANUFACTURING

Under this chapter the methodologies and manufacturing of coffee husk chipboard and coffee husk - wood particle chipboard are studied.

3.1 Methodologies

The methodologies of the study describes the procedure under taken to calculate the volume fraction of coffee husk and resins content.

3.1.1 Calculating volume fraction of the coffee husk and the resins content of the chipboard

The density of any wood composite material can be defined as the ratio of weight of the composite material to the volume of the composite material and is expressed as

$$\rho_{c=\frac{w_c}{V_c}} \qquad 3.\ 1$$

$$v_c = v_{ch} + v_u \qquad 3.\ 2$$

Because we have no the density of the coffee husk chipboard, we can obtain from experimental test and obtain the value to be $686.56 kg/m3$. During production of the board the weight fraction of the coffee husk used is about 80%. From the literature used the density of the ureaformaldyde is about $1500\ kg/m3$. Having these value we can calculate the density of coffee husk, volume fraction of the coffee husk and the ureaformaldye resins using the formula of Halpin-Tsai rule of mixture of the short fiber. The density of the composite material in terms of weight fractions can be written as:

$$\rho_c = \frac{1}{\left(\frac{w_{ch}}{\rho_{ch}} + \frac{w_u}{\rho_u}\right)} \qquad 3.\ 3$$

Now the density of the coffee husk can be calculated using the above equation

$$686.56 = \frac{1}{\left(\frac{0.8}{\rho_{ch}} + \frac{0.2}{1500}\right)}$$

$\rho_{ch} = 604.59\ kg/m3$, is the density of coffee husk

Volume fraction of the coffee husk and urea formaldyde resin can be:

$$v_{ch} = \frac{\frac{w_{ch}}{\rho_{ch}}}{\left(\frac{w_{ch}}{\rho_{ch}} + \frac{w_u}{\rho_u}\right)} \qquad 3.4$$

$$v_{ch} = \frac{\frac{0.8}{604.59}}{\left(\frac{0.8}{604.59} + \frac{0.2}{1500}\right)}$$

$$v_{ch} = 0.9$$

Since volume fraction of the two raw material must equal to one the volume fraction of ureaformaldyde is:

$$v_{ch} + v_u = 1 \qquad 3.5$$

$$v_u = 1 - v_{ch}$$

$$v_u = 0.10$$

Therefore, volume fraction of coffee husk and ureaformaldyde are 0.9 and 0.1 respectively. But when using different volume fraction of coffee husk and wood particle this 0.9 is divide according to percentages. So when we use 75wt% of coffee husk the volume fraction is 0.675 and 25wt% of wood particle 0.225, 50wt% of coffee husk and 50wt% of wood particle the volume fraction is 0.45 for each.

3.2 Materials and manufacturing process of the chipboards

Manufacturing process start from raw material preparation up to the final product of the chipboard.

3.2.1 Raw materials for the product

Coffee husks which lignocellulose material were collected from Addis Ababa, specific place SEFERA. Then the coffee husk were taken (on date 3-10-2018) to Xiawei Tang chipboard manufacturing plc. , which is located in Sebeta town and belongs to Chinese investors.

The ureaformaldyde adhesives are not available in the local markets and obtained from the company which they imported it from Indonesia in powder form. The resins are generally applied as liquids and appropriate adhesion mechanism is important.

3.2.2 General steps during manufacturing process

The steps for the manufacturing the coffee husk chipboard can expressed using a simple flow diagram as follows:

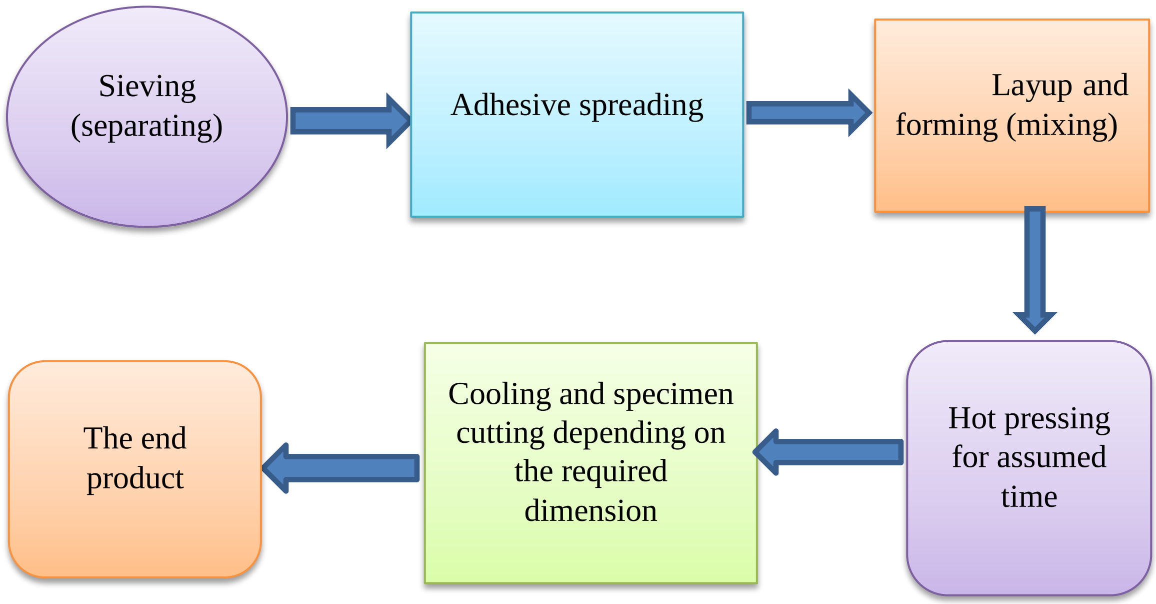


Figure 3. 1 Follow diagram for manufacturing process

3.2.2.1 Sieving (separating)

Like that of wood particle the steps of conversion to particles (chipping) aim to manufacture a homogeneous product, therefore to produce chips of suitable size & shape to form furnish is not needed. The need for material like knife systems, hammer mill systems, attrition systems are not necessary and by this it save our time and extra costs. Particle drying is also not much important in case the raw material is sun dried, save consuming much energy.

3.2.2.2 Adhesive spreading

An adhesive or glue needs to be applied to the surface of the coffee husk to bind it together. Even though different adhesive can be used, but the available resins in the company is urea formaldyde which imported from Indonesia and not available in local market. The resins are generally applied as liquids. Smaller droplets preferred, giving better resin distribution and in my case about 13% volume fraction of urea formaldyde is used to blend the husks which actually depend on the moisture content of the coffee husks.

Figure 3. 2 Ureaformaldyde and coffee husk prepared

3.2.2.3 Layup and forming (mixing)

Control particle size distribution or classification is important so as to optimize the position and size of the particles relative to their position in the board and small particles on the surface, bigger particles in the core here hand layup is used.

Laying up and forming prior to pre-pressing and hot pressing is important process in the formation of the structure of the board and therefore strongly affects the board properties.

- Improved bending properties
- Good surface finish
- Optimize density

Figure 3. 3 Hand layup (mixing)

For a bond to form between particles and adhesives, the adhesive needs to wet and flow over a surface, and in some cases penetrate into the substrate. It is important to understand that the terms mean different things even though they sound familiar. Wetting is the ability of an adhesive drop to form a low contact angle with the surface.

In contrast, flow involves the adhesive spreading over that surface under reasonable time. Flow is important because covering more of the surface allows for a stronger bond. Thus, a very viscous adhesive may wet a surface, but it might not flow to cover the surface in a reasonable time frame.

Penetration is the ability of the adhesive to move into the voids on the substrate surface or into the substrate itself. The filling of the cavity has long been one measure of penetration, but penetration can also involve the movement of the adhesive into the cell wall.

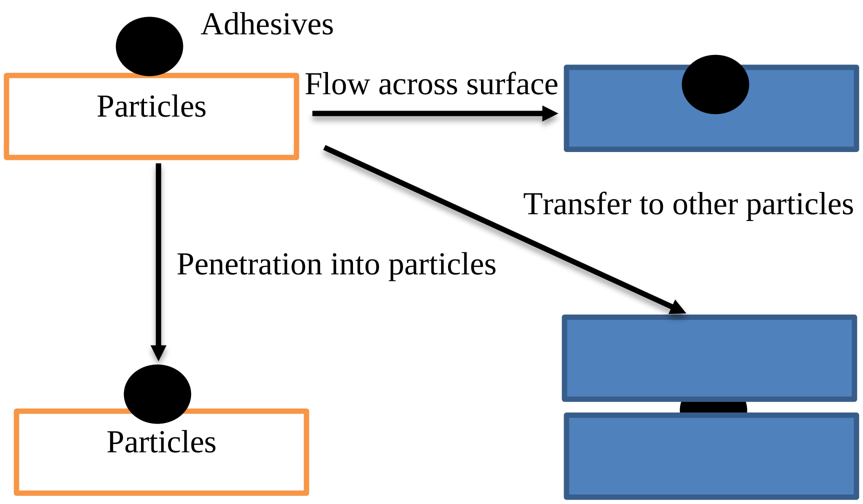


Figure 3. 4 Particle wetting process

The contact angle is the angle at the edge of a droplet and the plane of that surface upon which it is placed. Therefore, a material with a high contact angle has poor surface wetting ability. The addition of surfactants or less polar solvents reduces the adhesive's surface energy as indicated by a decreased contact angle. Another very important property that is closely associated with wetting is flow over the surface.

Flow is dependent upon not only the contact angle, but also the viscosity of the adhesive. With a lower viscosity, the adhesive flows better and wets more of the surface. While flow is movement across the surface, penetration is the movement into the substrate. Adhesives will not penetrate into the bulk of many substrates like metals and many plastics, but penetration is important in the sense of movement of the adhesive into the micro crevices on the surface [31].

3.2.2.4 Pre-pressing and hot pressing

Pre-pressing is used to reduce the bulk thickness, increase bulk density and give some mechanical strength to the mattress. Main mechanism are making the mattress strong, the development of the board internal structure and curing the adhesive in binding the particles together. Pressing may be batch-wise in a single or multi opening press, or in a continuous press [19].

Here the press is multi-layer and it have about six layer which press at the same time. The press machine have maximum temperature of 200℃, and for the production the temperature is set at 150℃. The pressure at this time have set at $3Mpa$ and the pressing duration are 3 minutes.

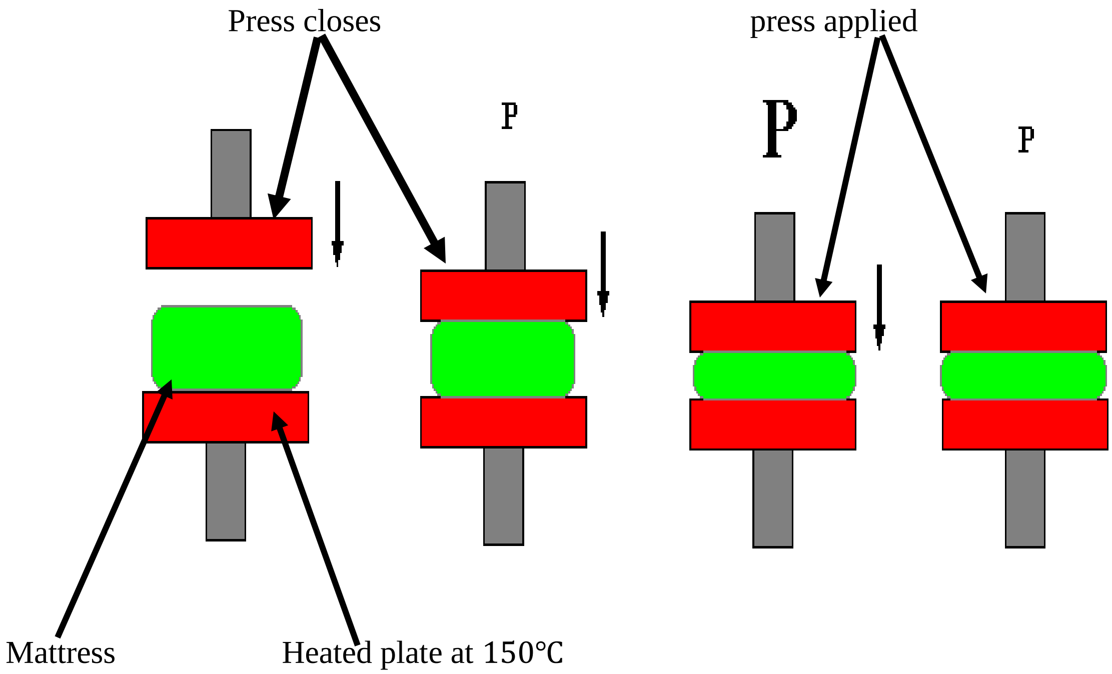


Figure 3. 5 Pressing process

The multi layered press machine have its own adjustment button for temperature, pressure and press time. Hydraulic press is the most efficient form of presses. It applies hydraulic mechanism for applying large lifting or compressive force. The press applies heat and pressure to activate the resin and bond the fiber in to a solid panel. Presses are generally heated using steam generated by an onsite boiler that burns wood residue.

The pressing operation is extremely important step in board. Press temperature and time will depend on the type of raw material is used and type of product being produced. During Pressing operation both press temperature and time are very important parameters because they can affect all the properties of the. Both press temperature and time should be carefully monitored and controlled. Press pressure is of minor importance when compared with Press time and temperature. Therefore, Press temperature and Press time are needed to be closely monitored and controlled to maintain adequate temperature levels [28].

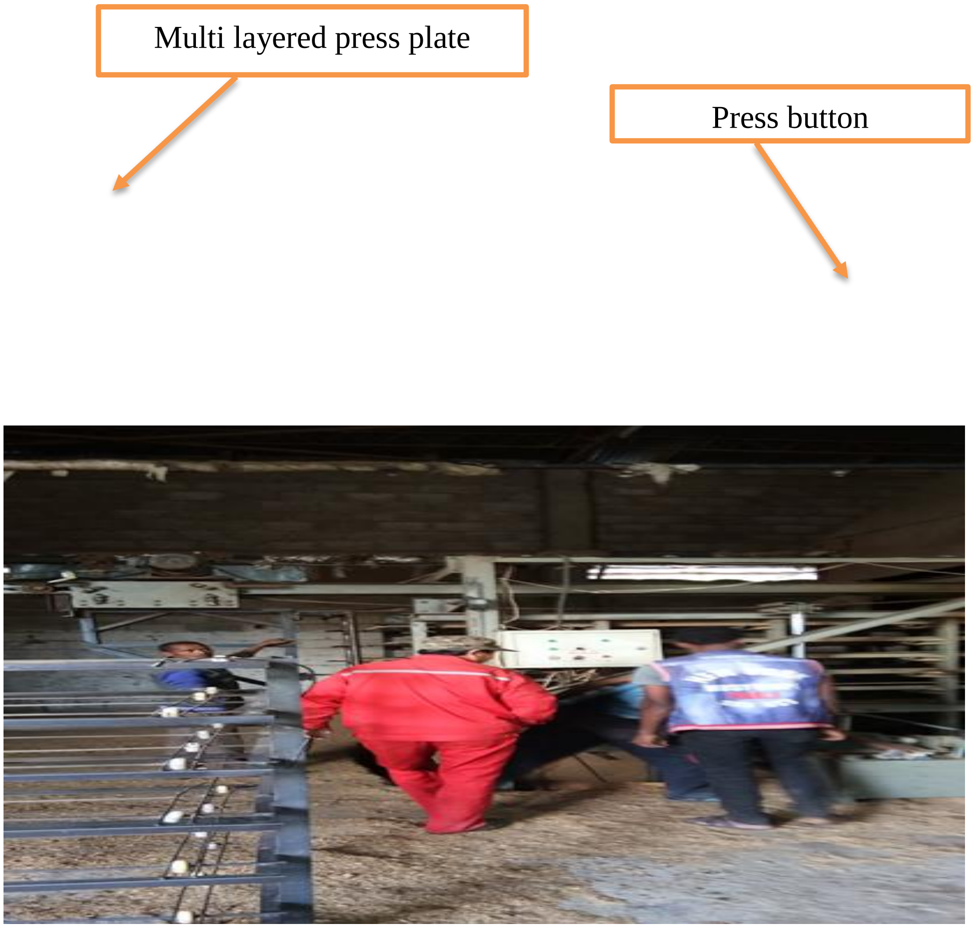

Multi layered press plate
Press button

Figure 3. 6 Pressing plate and time keeping

3.2.2.5 The chipboard products

The resulting chipboard are three depending on the weight fraction of each raw material used for production of coffee husk and coffee husk-wood chipboards with thickness of 6.7 mm each. At exit from press, adhesive cured sufficiently to retain board integrity.

Boards need to be cooled before finishing as if done too soon, board properties may be affected and tools will become blocked and on exit boards trimmed before cooling.

The last product of the chipboard may be affected by the followings:

- Raw material characteristics
- Strength, chemical composition, density
- Interaction between particles
- Particle to particle bonding

- Structural organization of constituents
- Size and shape of the particles
- Orientation of particles
- Packing
- Relative proportions of the constituents

Figure 3. 7 Coffee husk and coffee husk-wood particle chipboards

The manufactured chipboards are the above and according to our need and the size of pressing plate the dimension can be varied. The board samples were cut into different dimensions in order to use for physical and mechanical tests.

CHAPTER FOUR

4. EXPERIMENTAL INVESTIGATION, MATHEMATHICAL AND SOFTWARE MODELING OF THE CHIPBOARDS

Here the chapter study about experimental conducted, the modeling performed using solid work software and mathematical analysis. The product of the manufacturing are coffee husk and coffee husk-wood particle chipboard. Data on the effects of moisture content, water absorption, thickness swelling, compressive strength, bending strength and hardness are very much essential for the analysis of physical and mechanical properties of the board.

4.1 Experimental investigation

Under this, the experimental performed are physical test and some mechanical test of the three chipboards. The statistics relating to physical and mechanical properties of the board are major concern to guarantee the right application where the product or material is being utilized and to give important data for the use in new applications. The data on these properties will mainly depend on the type of material and resin used for the process. The chipboards are coffee husk chipboard, coffee husk-wood particle chipboard and wood particle chipboard.

4.1.1 Physical Testing methods

The physical test of the chipboard is the change observed on the physical of the chipboard which is thickness change or weight change. From the different physical change available, here density, moisture content, water absorption and thickness swellings of the chipboards are tested. Prior to property evaluation of the mechanical properties, the board samples were cut.

4.1.1.1 Density test

The samples were cut into $5 \times 5\ cm$ for each type of chipboard and then samples size (length, width and thickness) were measured and weighted with the weight balance having accuracy of 0.1g to determine the density. The density is calculated as follows using the following equation [3,20].

$$D = \frac{M}{V} \times 10^3 \qquad 4.1$$

Table 4. 1 Measurement result

Types of chipboard	Original weight (w1) (g)	Oven drier weight in (g)	Weight after 2h water immersion in (g)	Weight after 24h water immersion in (g)	Thickness after 2h water immersion (mm)	Thickness after 24h water immersion (mm)	Thickness before water immersion (mm)
1. CH chipboard	11.5	10.3	18	20	8.9	9.6	6.7
2. CH-W chipboard	12.9	11.8	19	22	8.5	9.3	6.7
3. W chipboard	13	12.2	17	20	8	8.8	6.7

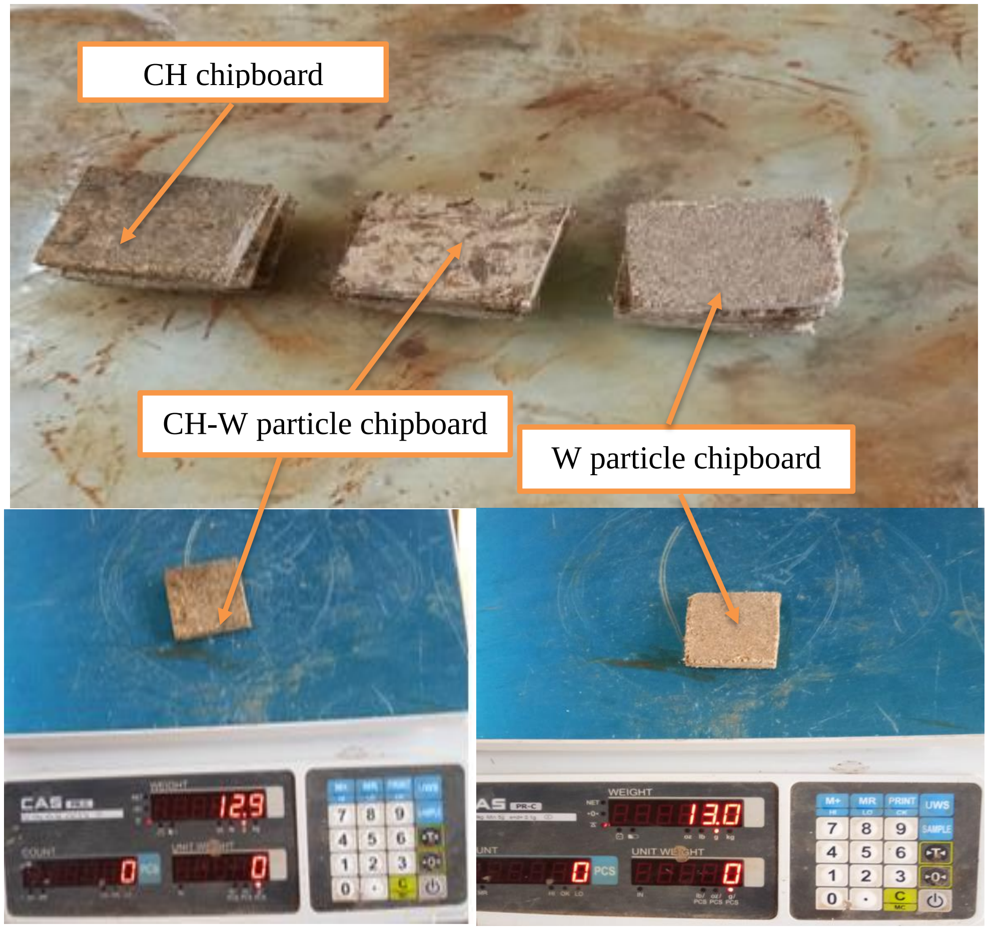


Figure 4. 1 Measuring weight balance of chipboard

4.1.1.2. Moisture content

The samples were cut into $5 \times 5\ cm$ for each type of chipboard and the weight were recorded (m_1) using weight balance then the samples were dried at $103 \pm 2°\mathrm{C}$ in oven drier to obtain constant weight for 24 hours. Taking out of drier again the weight of the sample is recorded(m_2). To determine their moisture content the following equation is used [20,21].

$$MC = \frac{m_1 - m_2}{m_2} \times 100 \qquad 4.2$$

Figure 4. 2 Oven drier machine

4.1.1.3. Water absorption:

The samples were cut into $5 \times 5\ cm$ for each type of chipboard and then samples were weighed to record the sample weight before water immersion(w_1). Next, the samples were immersed into water at $2.5\ cm$ from the water surface and at a depth of 1 cm from the bottom of the basin.

Then, the samples were immersed in water for 2 hour and 24 hour. After that, the samples were weighed again and recorded as a weight of sample after water immersion(w_2) at respective hour. The WA value was calculated using the following equation [12],[19].

$$WA = \frac{w_2 - w_1}{w_1} \times 100 \qquad 4.3$$

4.1.1.4. Thickness swelling:

The samples were cut into $5 \times 5\ cm$ for each type of chipboard, then the thickness of samples were measured using verneir caliper of accuracy $0.02mm$ to record the thickness of sample before water immersion(t_1). Next, the samples were immersed into water at $2.5\ cm$ from water surface and $1\ cm$ from the bottom of the basin. Then, the samples were tested by water immersion for an hour and $24\ hour$. After that, the samples were measured again and recorded as a thickness of sample after water immersion (t_2). The TS test was done to determine dimensional variations and calculated using the following equation [14],[19].

$$TS = \frac{t_2 - t_1}{t_1} \times 100 \qquad 4.4$$

Table 4. 2 Physical test value of the boards

Type of chipboard	Density (kg/m3)	Moisture Content in %	**W**ater absorption in % (2h)	Water absorption in % for 24h	Thickness swelling in % for 2h	Thickness swelling in % for 24h
Coffee husk chipboard	686.56	11.65	56.52	73.91	32.8	43.28
Coffee husk-Wood chipboard	770	9.32	47.3	70.54	26.86	38.81
Wood chipboard	776	8	30.76	53.8	19.4	31.34

4. 2 Mechanical test

Mechanical test is the test performed to analyze the mechanical change of the specimen under the applied load. There are different mechanical test to be undertaken but here we will measure two types of tests (hardness test and compression test of the chipboard).

4.2.1 Compression test

The compression test is just the opposite of tensile test and load is applied downward to the specimen to test the strength of material. The length of the specimen decrease from its original length [32-33]. In the following, compression experimental tests are done for the three chipboards. The compression testing machine used here is the universal testing machine.

Figure 4. 3 Compression test for CH-W chipboard

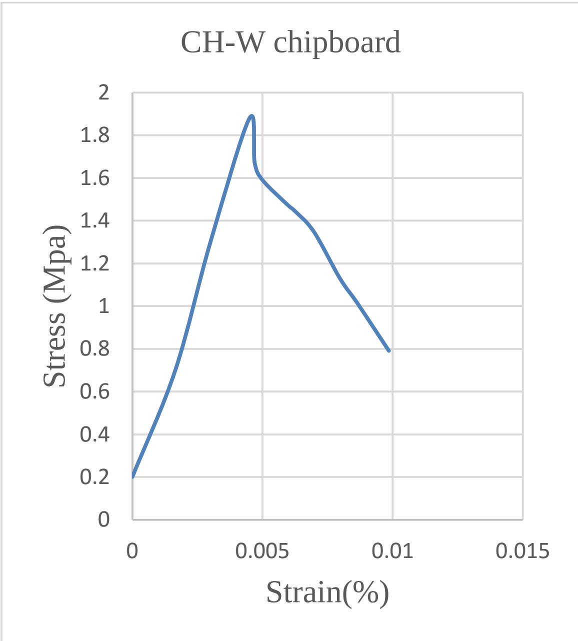


Figure 4.4 Compression test result for CH-W chipboard

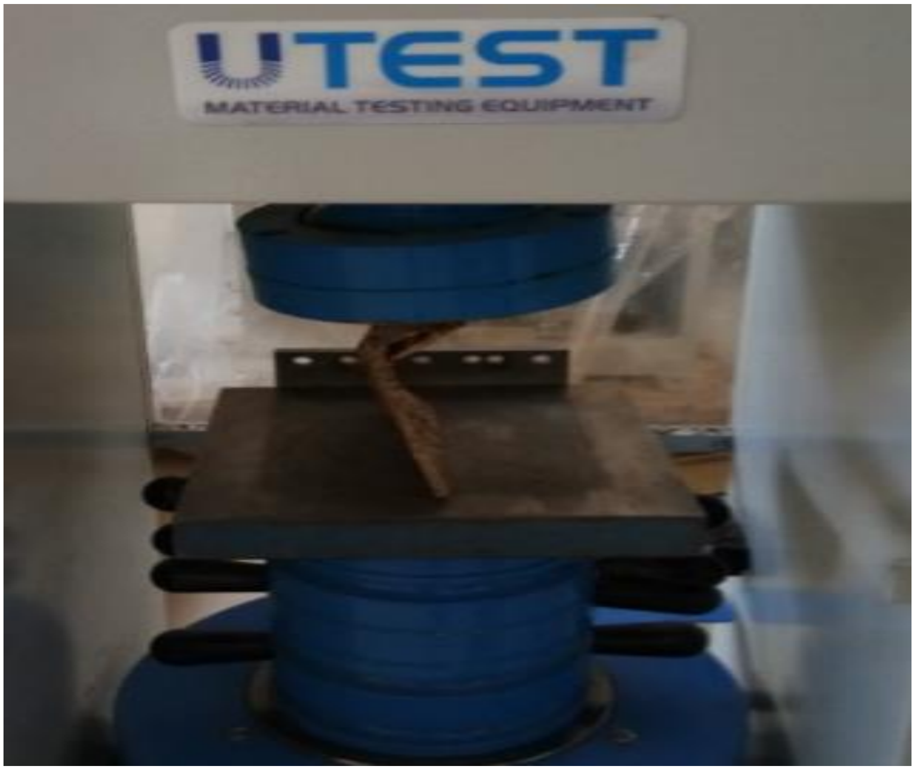


Figure 4. 4 Compression test for CH chipboard

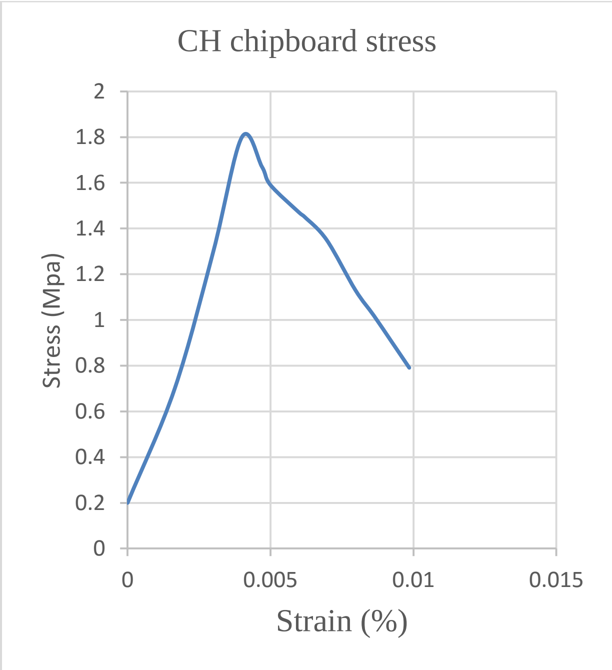


Figure 4. 5 Compression test result for CH chipboard

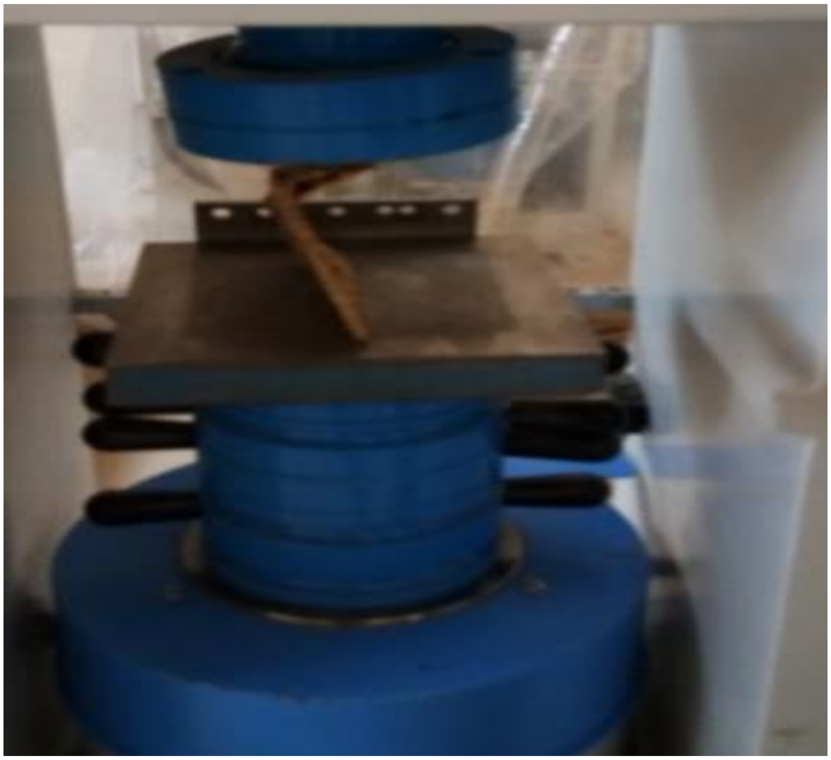


Figure 4. 6 Compression test of wood chipboard

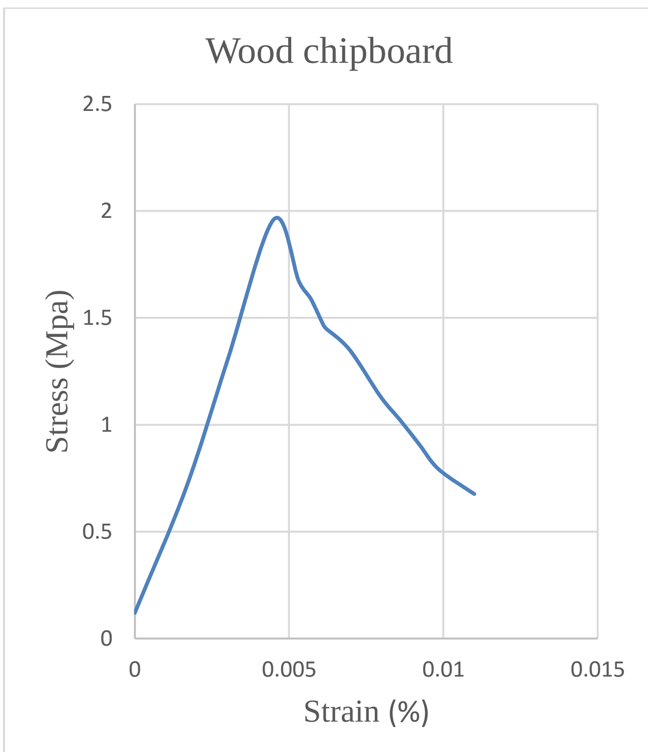


Figure 4. 7 Compression test result for wood chipboard

4.2.2 Hardness test of the chipboards

The hardness is resistance to surface indentation under standard test conditions. There are about three different hardness testing methods like Brinell, Vickers & Rockwell. From these the available one is Rockwell hardness test. It measures depth of the indenter penetration into the specimen surface. Hardness values are commonly given in the A, B, C, R, L, M, E and K scales. The higher the value in each of the scales, the harder the material.

The indenter may either be a steel (carbide) ball of some specified diameter or a spherical diamond-tipped cone of 118° angle and 0.2mm tip radius also called indenter. The type of indenter and the test load determine the hardness scale (A, B, C, etc.). A minor load of 3kg or 10kg is first applied, causing an initial penetration and holding the indenter in place. Then, the dial is set to zero and the major load is applied. Upon removal of the major load, the depth reading is taken while the minor load is still on. The hardness number may then be read directly from the scale. The most common used are the "C", and "B" scales and express hardness as an arbitrary dimensionless number.

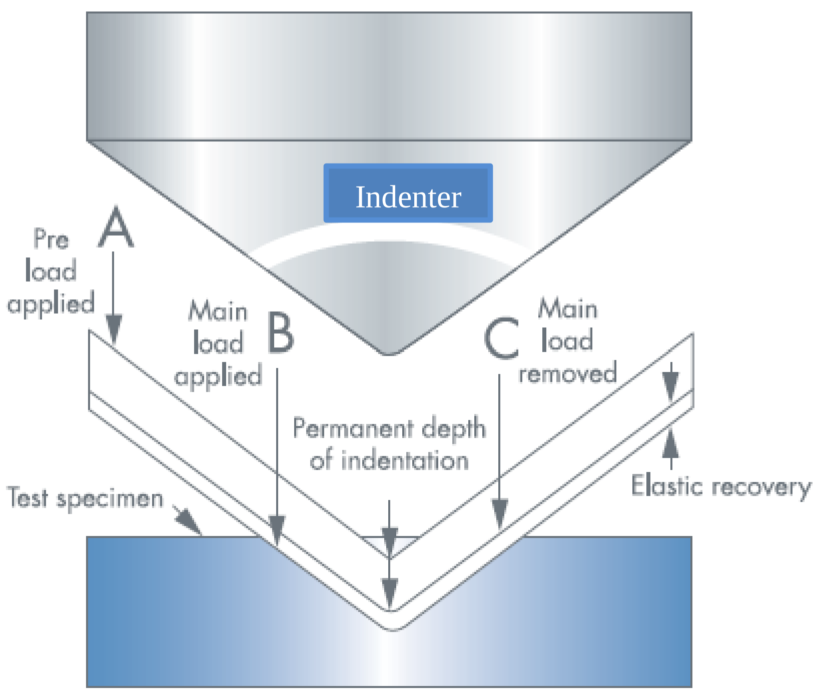


Figure 4.9 Hardness setup

Its hardness values are noted by HR'X' is the letter for the scale used. Hardness relation to strength is that both are measures of the pressure it takes to get plastic deformation to occur in materials. The determination of the Rockwell hardness of a material involves the application of a minor load followed by a major load, and then noting the depth of penetration, converted to a hardness value directly from a dial or display, in which a harder material gives a higher number.

The major advantage of Rockwell hardness is its ability to display hardness values directly, thus obviating tedious calculations involved in other hardness measurement techniques. Also, the relatively simple and inexpensive set-up enables installation under various conditions [33]. The hardness of the chipboard is its resistance to surface indentation under standard test conditions and the values are obtained in the following.

Figure 4. 8 Wood chipboard hardness test

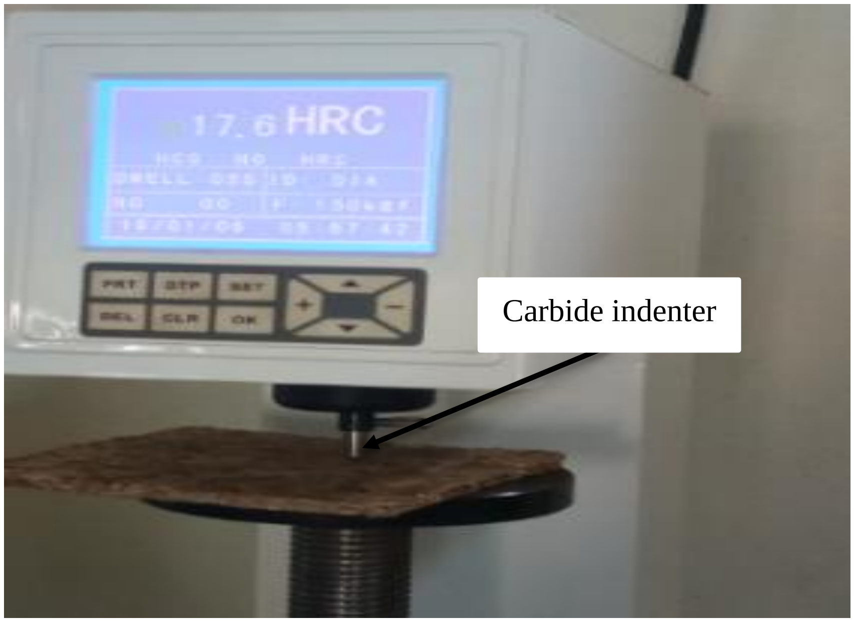


Figure 4. 9 CH chipboard hardness test

Figure 4. 10 CH –W chipboard hardness test

The hardness test value of the three chipboard is given in the following table.

Table 4. 3 Hardness results

Types of chipboard	Rockwell hardness result (HRC)
1. Coffee husk chipboard	17.6
2. CH-W chipboard	19.5
3. Wood chipboard	24

4.3 Mathematical and software modeling of the coffee husk chipboard

The mathematical modeling of the chipboard can be done by Halpin Tsai equation to find modulus of elastic properties.

The elastic properties of the board can be defined by the properties a chipboard can have at elastic region just before it gain plasticity on the strain stress diagram. These properties are modulus of elasticity, shear modulus and Poisson ratio. Simulation the bending strength and the compression of the specimen due to applied load.

4.3.1 Modulus of Elasticity of the chipboard

Elasticity of chipboard implies that deformations produced by low stress below the proportional limit are completely recoverable after loads are removed. When loaded to stress levels above the proportional limit, plastic deformation or failure occurs.

Using Halpin Tsai equation and taking the coffee husk as randomly oriented short fiber with the length and diameter of the coffee husk is $0.3mm$ and $0.02mm$ respectively, we can calculate the MOE, Poisson ratio and shear modulus of the chipboard. Starting from the assumption the fibers are aligned and load applied either longitudinal or tangential direction [22].

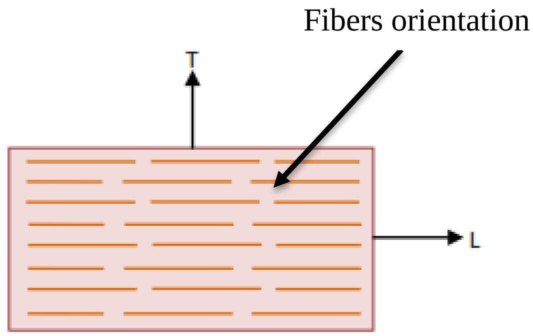


Figure 4. 11 Aligned short fibers

The longitudinal and tangential elastic modulus of the aligned short fiber become:

Since the elastic modulus of the coffee husk is not available on the literature, we assume related density nearest to 604.59 kg/m^3. Wood can be selected which have density of 607 kg/m^3 and also its elastic modulus is about $10.684 Gpa$. Therefore we can approximate the coffee husk modulus of elasticity to be $10.684 Gpa$. Using the following equation we can calculate MOE, G and Poisson ratio of coffee husk chipboards.

$$\eta_L = \frac{(E_{CH}/E_U)-1}{\frac{E_{CH}}{E_U}+2\left(\frac{l_{ch}}{d_{ch}}\right)} \qquad 4.5$$

$$= \frac{(10.7/9)-1}{\frac{10.7}{9}+2\left(\frac{0.3}{0.02}\right)}$$

$$\eta_L = 0.006$$

$$\eta_T = \frac{(E_{CH}/E_U)-1}{\frac{E_{CH}}{E_U}+2} \qquad 4.6$$

$$= \frac{10.7/9)-1}{\frac{10.7}{9}+2}$$

$$\eta_T = 0.059$$

$$E_L = \frac{1+2\left(\frac{l_{ch}}{d_{ch}}\right)\eta_L v_{ch}}{1-\eta_L v_{CH}} E_u \qquad 4.7$$

$$= \frac{1+2\left(\frac{0.3}{0.02}\right)0.006 \times 0.87}{1-(0.006 \times 0.87)} \times 9$$

$$E_L = 10.964 \ Gpa$$

$$E_T = \frac{1+2\eta_T v_f}{1-\eta_T v_{CH}} E_u \qquad 4.8$$

$$= \frac{1 + (2 \times 0.059 \times 0.87)}{1 - (0.059 \times 0.87)} \times 9$$

$$E_T = 10.46\ Gpa$$

Since the fiber of coffee husk is randomly oriented short fiber in chipboard, modulus of elasticity of the manufactured chipboard can be calculated using equation:

$$E_{chipboard} = E_{random} = \tfrac{3}{8}E_L + \tfrac{5}{8}E_T \qquad \text{Equation 4. 9}$$

$$E_{chipboard} = (\tfrac{3}{8} \times 10.964) + (\tfrac{5}{8} \times 10.46)$$

$$E_{chipboard} = 10.649\ Gpa$$

4.3.1.1 Shear Modulus of chipboard

Shear modulus, also called modulus of rigidity, indicates the resistance to deflection of a chipboard caused by shear stresses. Shear stress is different from tension or compression stress in that it tends to make one side of a board slip past the other side of a member adjacent to it.

$$G_{chipboard} = G_{random} = \tfrac{1}{8}E_L + \tfrac{1}{4}E_T \qquad \text{Equation 4. 10}$$

$$G_{random} = (\tfrac{1}{8} \times 10.964) + (\tfrac{1}{4} \times 10.46)$$

$$G_{random} = 3.923 Gpa$$

4.3.1.2 Poisson ratio of the chipboard

Poisson ratio which is the ratio of transverse contraction strain to the longitudinal extension strain in the direction of the stretching force. And from the randomly oriented short fiber equation:

$$V_{chipboard} = V_{random} = \frac{E_{random}}{2G_{random}} - 1 \qquad \text{Equation 4. 11}$$

$$= \frac{10.649}{2 \times 3.923} - 1$$

$$V_{chipboard} = 0.36$$

To know how fraction of loads carried by the coffee husk and ureaformaldyde using the following equation of rule of mixture we can find as follows:

$$\frac{p_{ch}}{p_{chipboard}} = \frac{E_{ch}/E_u}{E_{ch}/E_u + V_u/V_{ch}} \qquad \text{Equation 4. 12}$$

$$= \frac{10.7/9}{\frac{10.7}{9} + 0.13/0.87}$$

$$\frac{p_{ch}}{p_{chipboard}} = 0.89$$

Therefore from these we can conclude that the coffee husk can carries 89% of the load applied while the left load carried by urea-formaldyde resins. Tensile load applied to a discontinuous fiber is transferred to the fibers of coffee husk by a shearing mechanism between fibers and adhesives. Since, the adhesives has low modulus, the longitudinal strain in the adhesives is higher than that in the adjacent fibers. If a perfect bond is assumed between the two constituents, the difference in longitudinal strains creates a shear stress distribution across the fiber adhesive interface by ignoring the stress transfer at the fiber end cross sections and the interaction between the neighboring fibers.

4.3.2 Finite element method modeling of the coffee husk chipboard

Based on the Novel approach, from real structure to the structural idealization of the chipboard composite system can be developed. Starting from Hooks law for a plane-stress problem [23].

$$\sigma = E\epsilon \qquad 4.\ 13$$

$$\{\sigma\} = [E]\{\epsilon\}$$

$$\sigma = \begin{bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{bmatrix} \quad \text{And} \quad \epsilon = \begin{bmatrix} \epsilon_x \\ \epsilon_y \\ 2\epsilon_{xy} \end{bmatrix}$$

Which it takes for plane-stress problem $\sigma = D\epsilon$ which can be written for bending elastic property as $\{\sigma_b\} = [D_b]\{\epsilon_b\}$, and the main work here is to determine the D = f (properties of components: coffee husk and ureaformaldyde).

The bending elastic properties of chipboard,

$$D_b = \begin{bmatrix} \frac{E}{1-v^2} & \frac{Ev}{1-v^2} & 0 \\ \frac{Ev}{1-v^2} & \frac{E}{1-v^2} & 0 \\ 0 & 0 & G \end{bmatrix}, \text{for linear isotropic material}$$

$$D_b = \begin{bmatrix} 11.74 & 3.87 & 0 \\ 3.87 & 11.74 & 0 \\ 0 & 0 & 3.92 \end{bmatrix} \times 10^9$$

And the shearing elastic property, $\{\sigma_s\} = [D_s]\{\epsilon_s\}$

$$D_s = \begin{bmatrix} \frac{E}{2(1+V)} & 0 \\ 0 & \frac{E}{2(1+2)} \end{bmatrix}$$

$$D_s = \begin{bmatrix} 3.93 & 0 \\ 0 & 3.93 \end{bmatrix} \times 10^9$$

4.3.3 Strength Properties of the coffee husk chipboard

The strength of chipboard are the measure of its resistance to external loads which tend to deform its mass. The resistance of boards to such forces depends on their magnitude and the manner of loading.

4.3.3.1 Yield strength

The yield strength of chipboard which is the stress beyond which a material becomes plastic, can be calculated in the manner of shear modulus when yield strength of coffee husk and ureaformaldyde are known.

$$\eta_L = \frac{(\sigma_{CH}/\sigma_U) - 1}{\frac{\sigma_{CH}}{\sigma_U} + 2\left(\frac{l_{ch}}{d_{ch}}\right)}$$

$$= \frac{(50/100) - 1}{\frac{50}{100} + 2\left(\frac{0.3}{0.02}\right)}$$

$$\eta_L = -0.016$$

$$\eta_T = \frac{(\sigma_{CH}/\sigma_U) - 1}{\frac{\sigma_{CH}}{\sigma_U} + 2}$$

$$= \frac{(50/100) - 1}{\frac{50}{100} + 2}$$

$$\eta_T = -0.2$$

$$\sigma_L = \frac{1 + 2\left(\frac{l_{ch}}{d_{ch}}\right)\eta_L v_{ch}}{1 - \eta_L v_{CH}} \sigma_u$$

$$= \frac{1 + 2\left(\frac{0.3}{0.02}\right) \times (0.9 \times -0.016)}{1 - (-0.016 \times 0.9)} \times 100$$

$$\sigma_L = 57.44\ Mpa$$

$$\sigma_T = \frac{1 + 2\eta_T v_{ch}}{1 - \eta_T v_{CH}} \sigma_u$$

$$= \frac{1 + 2(-0.02 \times 0.9}{1 - (-0.2 \times 0.9)} \times 100$$

$$\sigma_T = 55.54\ Mpa$$

$$\sigma_{chipboard} = \sigma_{random} = \tfrac{3}{8}\sigma_L + \tfrac{5}{8}\sigma_T \qquad 4.14$$

$$= \tfrac{3}{8} \times 57.44 + \tfrac{5}{8} \times 55.54$$

$$\sigma_{chipboard} = 56.25\ Mpa$$

4.3.3.2 Bending strength of the chipboard

Bending strength of chipboard refers to the maximum stress that can be developed due to applied loads prior to failure. The other name of bending strength is modulus of rupture of the materials. Strength properties are affected by many factors, such as board density, quantity of adhesive, particle dimensions and orientation, and moisture content [3].

Maximum bending strength indicates the maximum load-carrying capacity of a chipboard in bending and is proportional to maximum moment borne by the specimen.

Using solid work, we draw the chipboard of $150 \times 25 \times 6.7\ mm^3$ solid material with input of material properties.

Table 4. 4 Mechanical properties of chipboard

Name	**Particle board**
Model type	Linear Elastic Isotropic
Yield strength	5.625e+10 N/m^2
Elastic modulus	1.0964e+10 N/m^2
Poisson's ratio	0.36
Mass density	686.56 kg/m^3
Shear modulus	3.923e+09 N/m^2

And then meshing it with standard mesh size of 1.7277 mm, Jacobian points of 4 points and at tolerance of 0.0863849mm. It also have total nodes of 33624 and total elements of 21857 at maximum aspect ratio of 3.592.

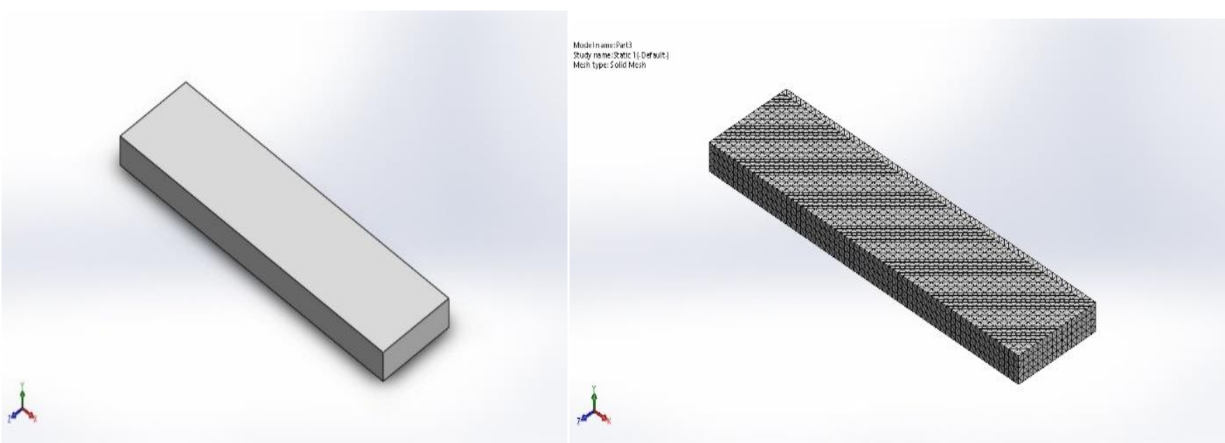


Figure 4. 12 Solid and meshed chipboard

At static state normal force was applied to the face and the following amount force distributed along each direction. Almost all force applied along the thickness of the chipboard which along y-direction.

Table 4. 5 Amount of force applied

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.00105047	99.9996	9.08375e-05	99.9996

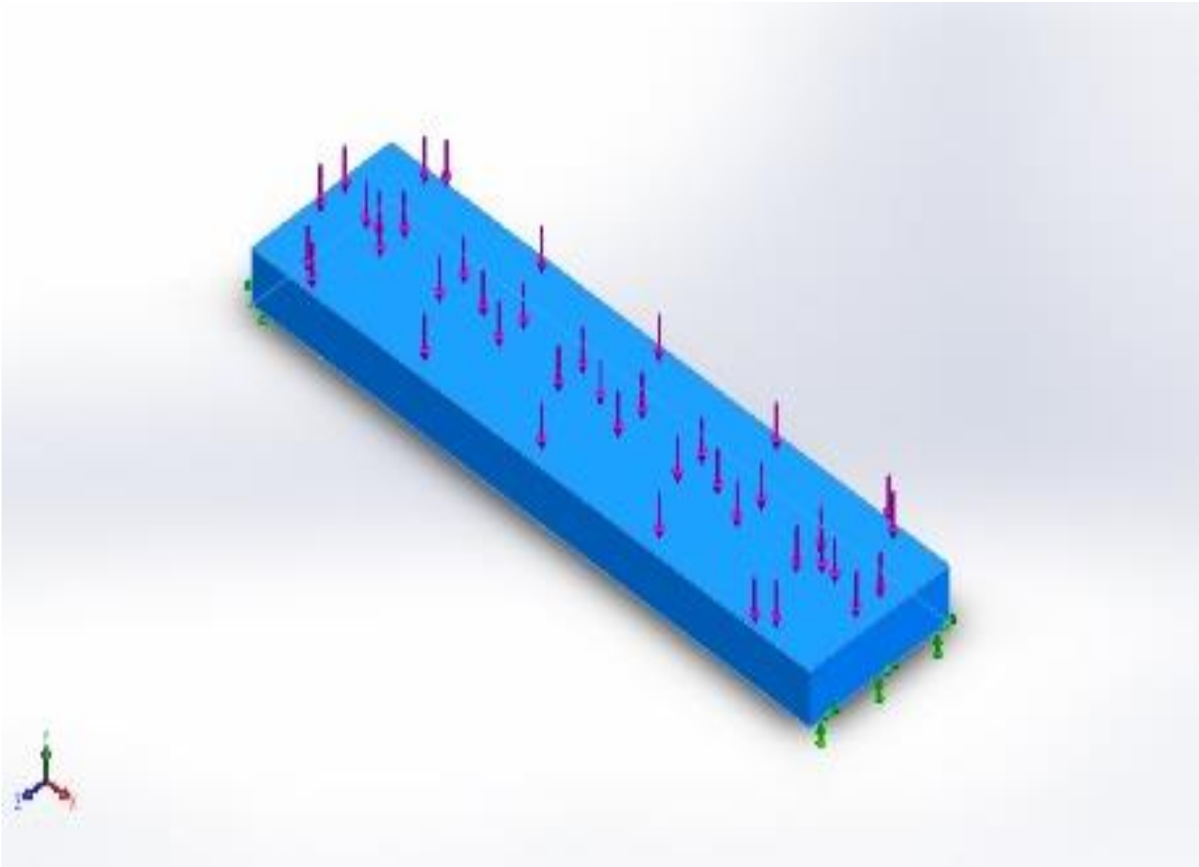


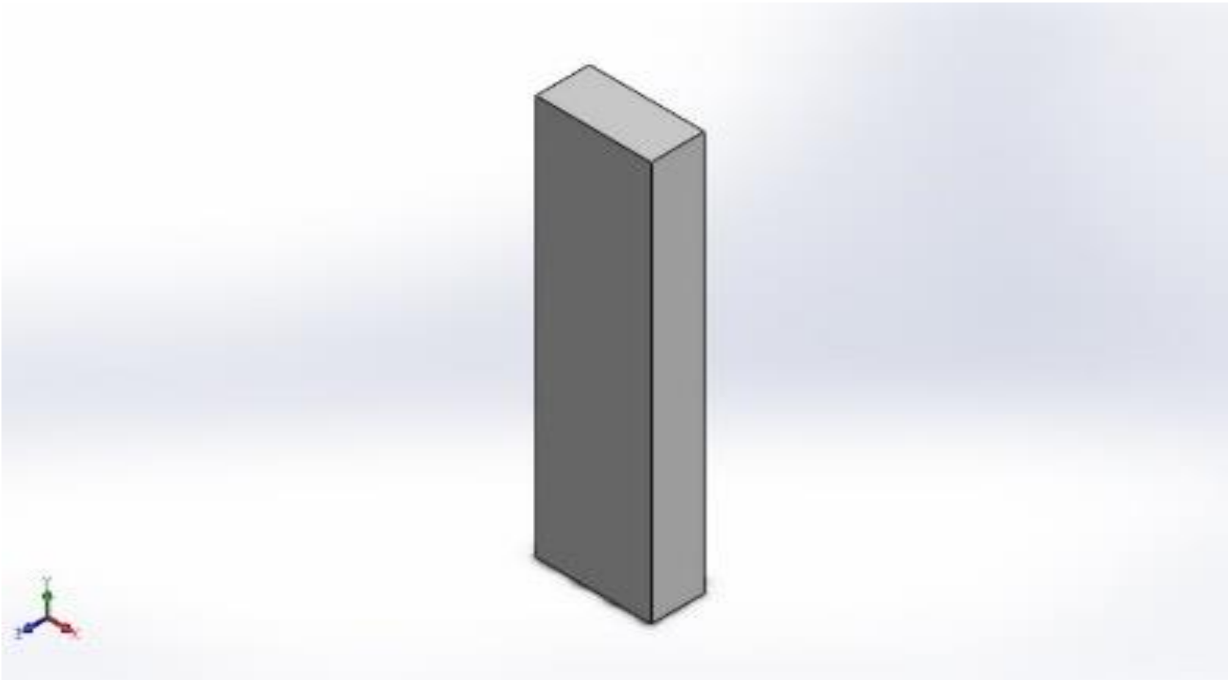
Figure 4. 13 Normal force applied

Table 4. 6 Maximum and minimum stress

Name	**Type**	**Min**	**Max**
Stress	VON: von Mises Stress	1.130e-02 MPa Node: 12819	6.917e+00 MPa Node: 31242
Displacement	URES: Displacement	0.000e+00 mm Node: 1	3.162e-02 mm Node: 30020
Strain	ESTRN: Equivalent Strain	8.232e-07 Element: 1046	3.606e-04 Element: 5790

4.4.4 Compressive strength simulation

Strength property of the material and is just the opposite of the tensile test. The material is tested using solid work software.



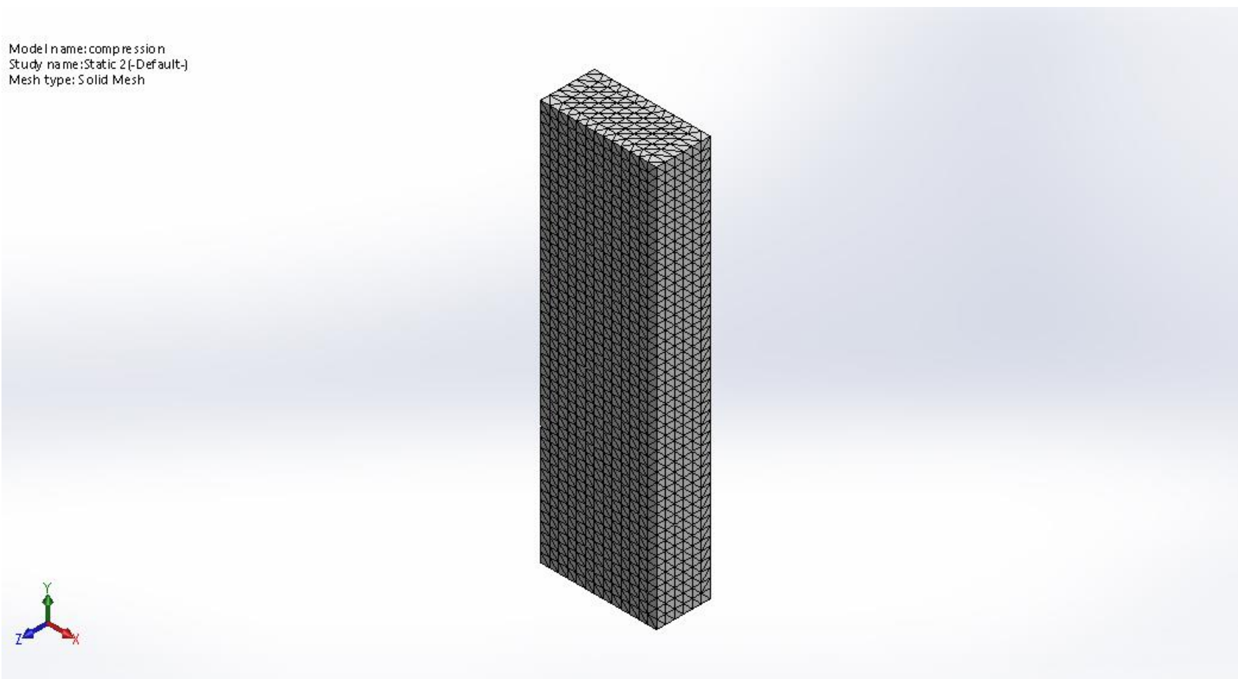


Figure 4. 14 Solid board drawn and discretization on solid work

Force is applied down ward to the specimens along y-axis and the result of the mesh is stress, strain and deflection due to compression.

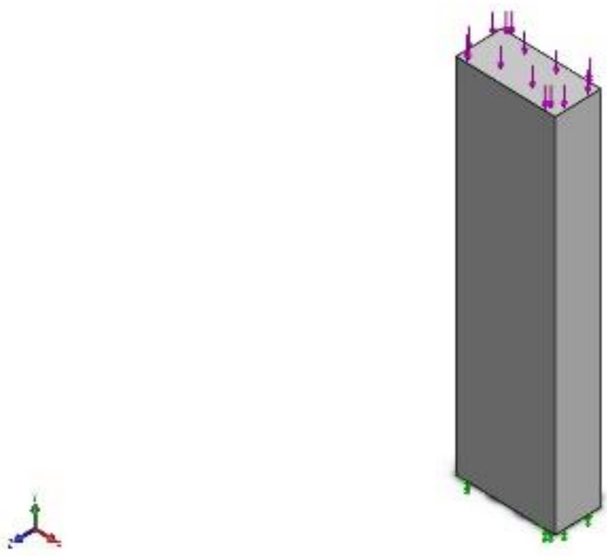


Figure 4. 15 Compressive force applied

The result of simulation are compressive stress, strain and deflection and also compressive stress strain diagram can be obtained.

4.4.5 Mathematical modeling of Durability or life time of the produced chipboards

Strength of materials is often evaluated based on modeling their degradation or propagation of imperfections (cracks, dislocations, etc.)

Estimating how long chipboard maintain the required performance under actual environmental conditions has been a goal of evaluating the durability of materials. To achieve this, the gradation mechanism must be clarified in relation to various conditions. Different researchers have reported the effects of temperature on the mechanical properties of wood and non-wood products.

Depending on these findings we can also estimate the life time of the coffee husk chipboard that may be affected by the temperature changes, due to load applied and moisture effects. To estimate how long the chipboard can exist we are going to develop some mathematical equation.

The chipboard has its own binding energy U_o that comes from the two constituent material of the board. The following equation relate the binding energy of the board, external temperature and life time [27].

$$\tau = \tau_o e^{\left(\frac{U_o}{KT}\right)} \qquad 4.15$$

The measurement of the heat contained in a material is merely a statistical measure of the motions of the individual particles that make up the material [24].

The reactants must first acquire a minimum amount of energy, called activation energy, U_o get transformed into chemical products. When the effective energy U_o becomes zero, the damage propagation becomes sudden, catastrophic and temperature independent. So the same way in the coffee husk chipboard the degradation start to occur first reducing activation energy.

Previous studies have shown a significant dependence of the chipboard strength and rigidity on the temperature and moisture content of the material. In this case, phenomenological relationships were obtained in the form of formulas that relate these quantities, on the basis of which it is possible to predict the change in strength characteristics with a change in the conditions of their operation. The fundamental form of the kinetic theory of strength equation is [29].

$$\tau = \tau_o e^{\left[\frac{U_o - \gamma\sigma}{RT}\right]} \qquad 4.16$$

The kinetic theory is based on the idea of the breakdown of the chemical bond at a thermal, which is activated by the mechanical stress σ. In this case U_o is understood as the activation energy of the process it must be equal to the energy of the chemical bond being broken, to the period of oscillations of chemically bound atoms. If σ is the stress on the molecule, $\gamma\sigma$ is mechanically induced decrease in the energy of the ruptured coupling, and γ is the coefficient of transformation of the mechanical stressing into energy, $E_f = (U_o - \gamma\sigma)$ for the given bond. Into the above, fourth parameter for polymeric materials was physically induced [25,30].

$$\tau = \tau_o e^{\left[\frac{U_o - \gamma\sigma}{RT}\left(\frac{T_m - T}{Tm}\right)\right]} \qquad 4.17$$

The composite materials based on wood revealed that the influence of moisture content was taken into account by introducing additional corrections, determined as a result of prolonged experiments.

Based on the numerous studies carried out, a model of durability taking into account the moisture content of the wood based materials [25].

$$\tau = \tau_o e^{\left[\frac{U_O - \gamma\sigma}{RT}\left(\frac{T_m - T}{Tm}\right) e^{\alpha W_e}{}^{-1}\right]} \quad 4.\ 18$$

This formula, in addition to external factors such as stress and temperature, it contains an effective moisture

$$W_e = \frac{W_m - W}{W_m} \quad 4.\ 19$$

Generally, in the above equation all factors have their own effect on the life span of the coffee husk chipboard. As moisture, load and temperature increase, the durability of the chipboard decrease and resulted in degradation of the board.

CHAPTER FIVE

5. RESULT AND DISCUSSIONS

Chapter five focus on the outcome of thesis and give brief description of the result obtained from the work done.

5.1 Experimental Results

The experimental test done is physical test such as density, moisture contents, water absorption, and thickness swelling of the chipboards.

5.1.1 Density test of the chipboards

The density of the coffee husk, coffee husk-wood and wood chipboards are shown in Figure 5.1 where the density values increased from coffee husk to wood chipboards. This is because the wood density is higher than coffee husk and also the coffee husk mixed with wood particle also have higher density than that of pure coffee husk.

The most important factors controlling the density of a boards are the raw material density, the adhesive density and the compaction of the mat in the heating press [21]. It is noted that difference in raw material and impregnation ratio is making some effect on the board density. The boards are medium density boards $(640 - 800\frac{kg}{m3})$ that are commercial standards [20]. Board density is having lot of impact on properties like bending strength, MOE, hardness, TS and WA

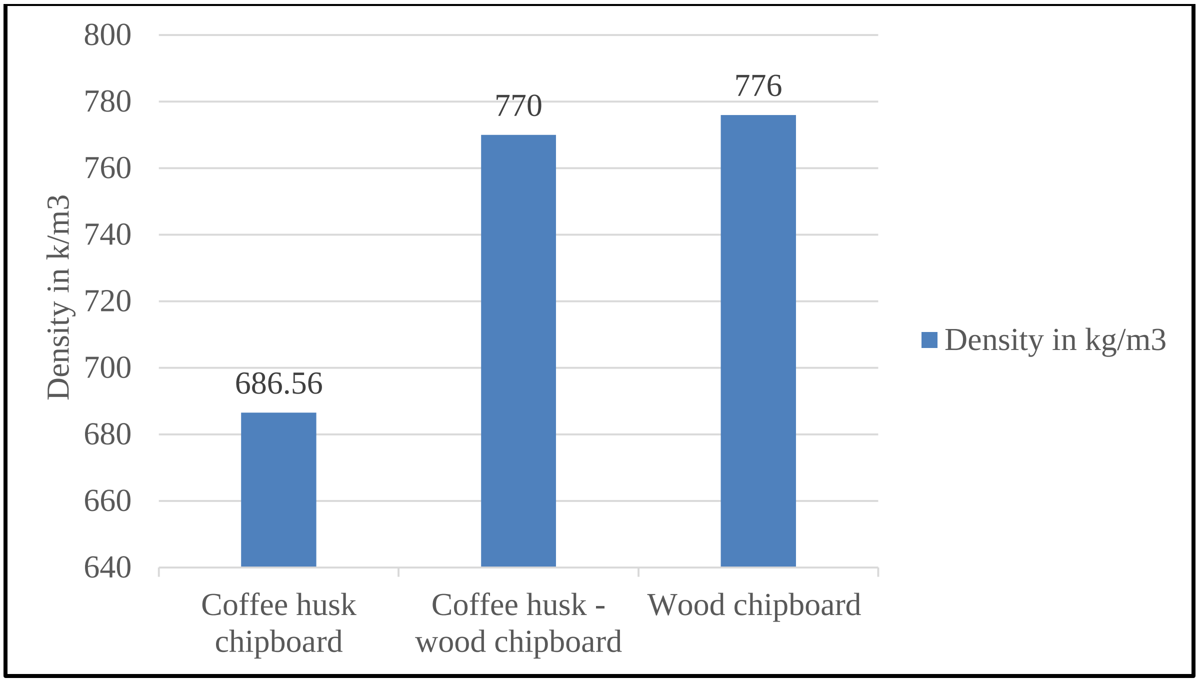


Figure 5. 1 Density

5.1.2 Moisture content of the chipboards

The difference in moisture content of the chipboards are given in the following figures. The higher moisture content means more react with water. The more moisture content value of coffee husk chipboards can be traced back to the hygroscopic behavior of the coffee husk and more water is absorbed.

As we observed, the value for moisture is high for three boards. This is because chipboards are glued with urea-formaldehyde (UF) resins that are less water resistant, and therefore easily prone to degradation. Chipboards produced from UF glues are therefore less suitable in moisture sensitive areas which agree with different researchers works [3].

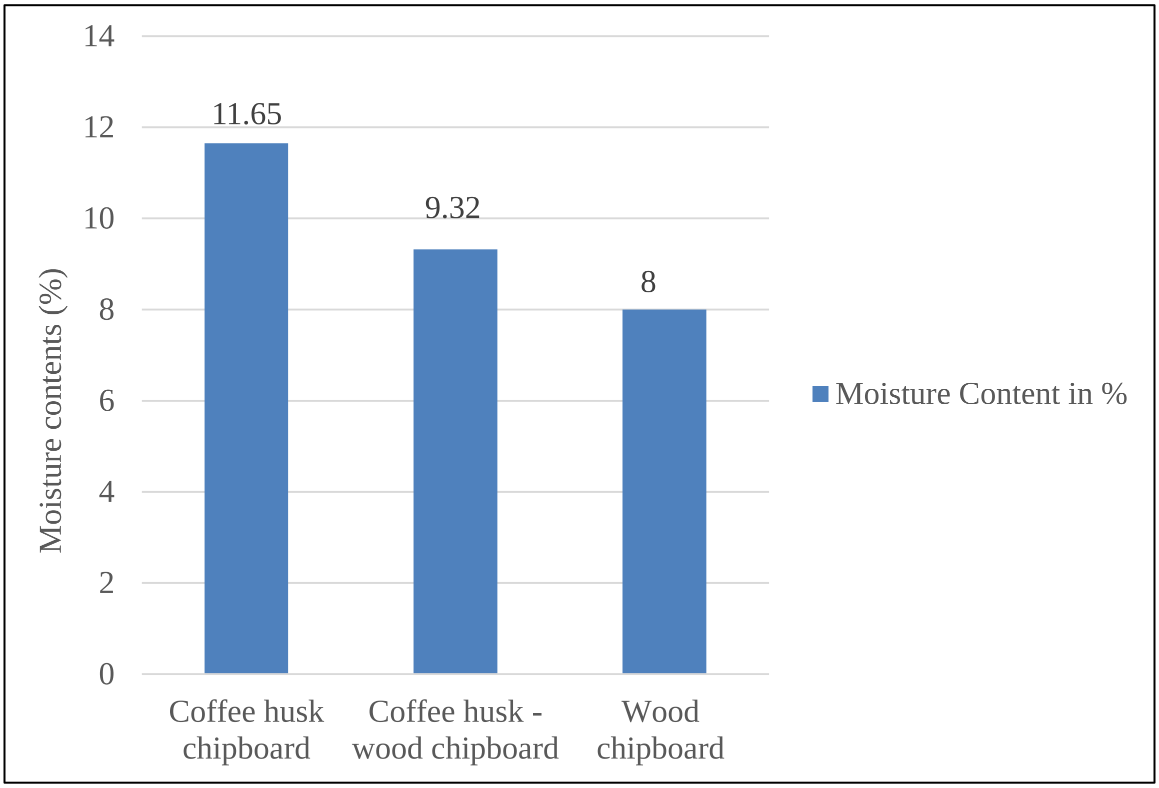


Figure 5. 2 Moisture content

5.1.3 Water absorption of the chipboards

The WA of the three chipboards are shown in the figure 5.3 and 5.4 for the 2h and 24 respectively. Compare to the other two chipboards, coffee husk chipboard has more WA value, this may be because of more porosity and less density of the coffee husks that agrees with previous studies and this can be improved by increasing press time and temperature, content of adhesives [26].

And also increasing weight fraction of wood particle during manufacturing of coffee husk-wood particle chipboard decrease WA. The WA values in this study were relatively high owing to the porous character of the lower UF content board, which absorb more water than the compressed higher UF content board. WA properties were higher for 24 h of water immersion than water immersion for 2 h. When soaking time increased the WA value increased which agrees with previous studies [26].

The WA results of the 24 h water immersion test were highly correlated with the board density. Water entry into the higher density boards occurred at a slower rate due to the decreased porosity and the increased wood density material. The longer times for these relative humidity allowed the moisture to equalize much more uniformly through the board than was possible for the 24 h water immersion.

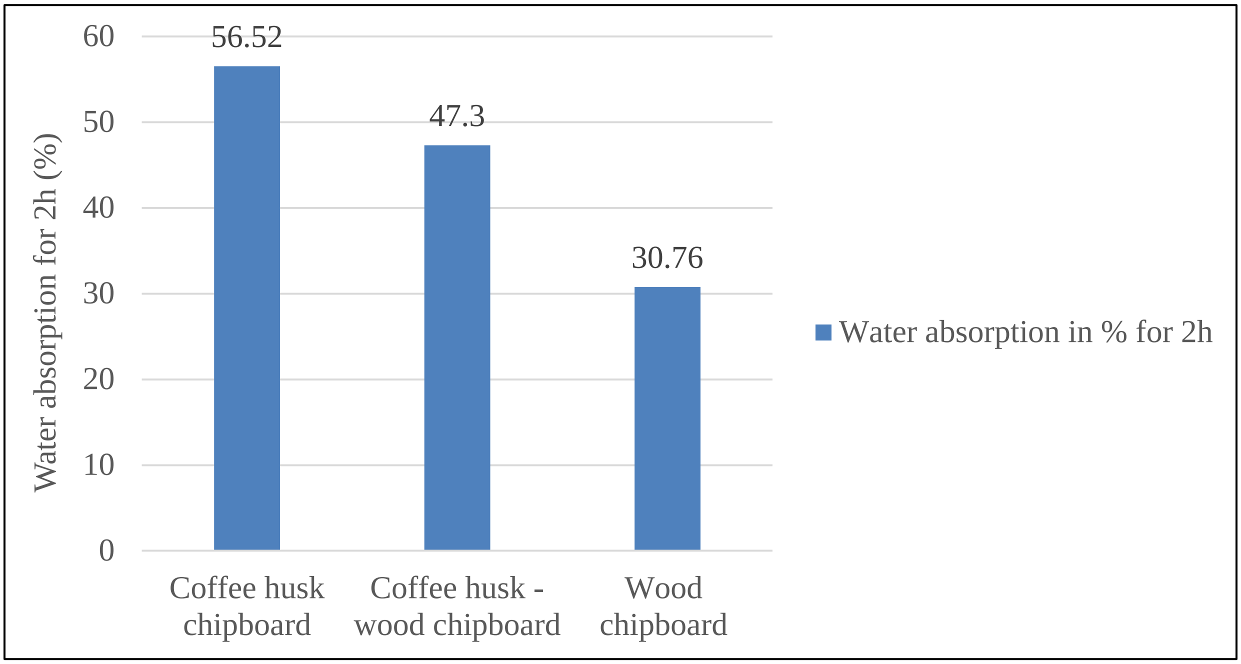


Figure 5. 3 Water absorption for 2h

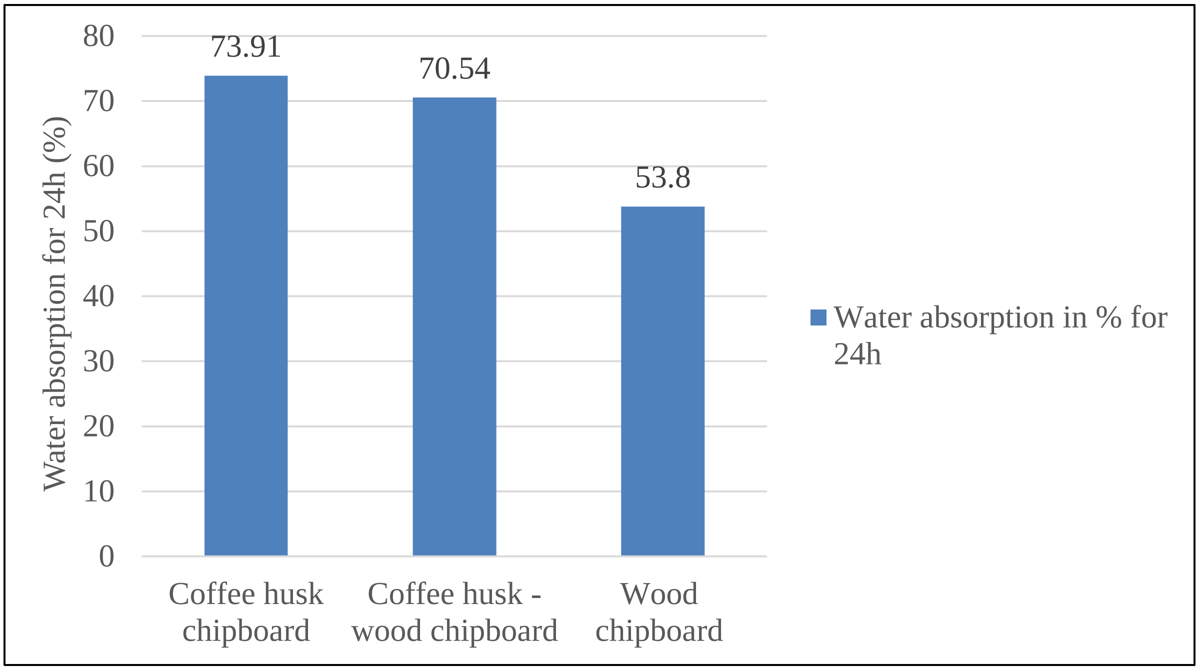


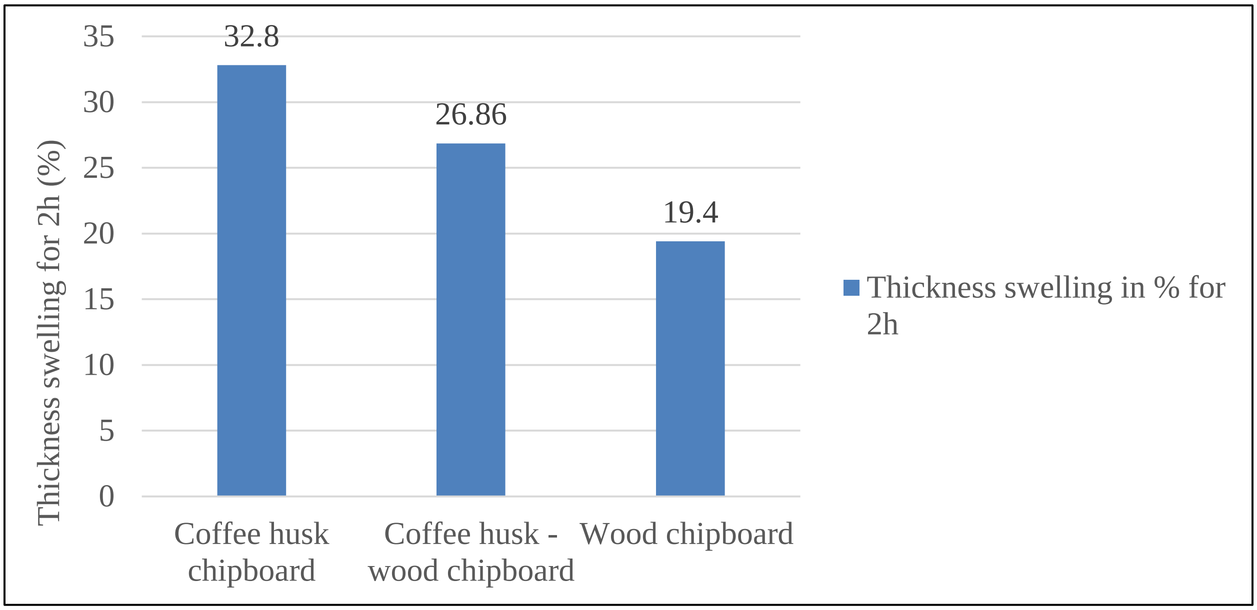
Figure 5. 4 Water absorption for 24h

5.1.4 Thickness swelling of the chipboard

The TS values was described in the figure 5.5 and 5.6 for 2h and 24 respectively. Which imply that it is high values in both 24h and 2h water immersion because of low density. When we compare to previous works these values are high which it needs improvement through increment of adhesive content and its compaction time [26].

The reduced porosity of the high-density boards, as compared to those of lower density, prevented rapid liquid water penetration. This leads to a higher degree of cross-linking resulting in retarded water penetration. The diffusion path of water into the individual component chipboard was much longer and the subsequent rate of TS was reduced for the high-density material.

Therefore, it is not remarkable that TS is normally reported to increase with increasing board



density.

Figure 5. 5 Thickness swelling for 2h

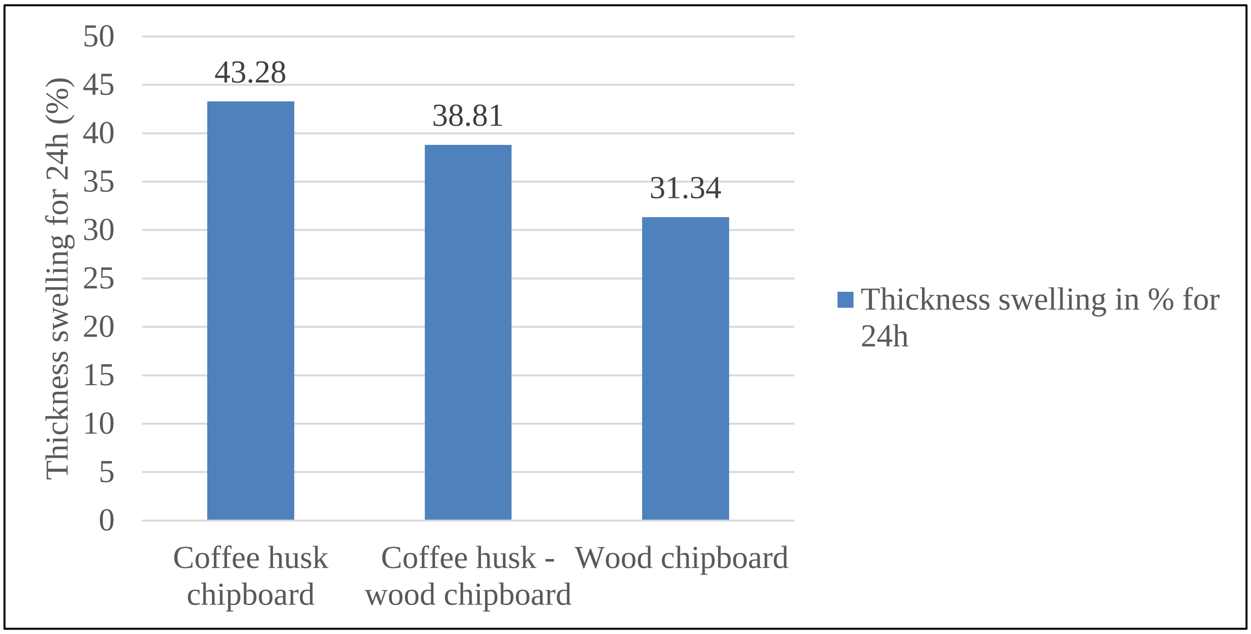


Figure 5. 6 Thickness swelling for 24 h

5.2 Rockwell hardness value of the chipboard

The value of this test is given in the figure 5.7. From the result we can see that mixing the coffee husk with wood particle increase hardness depending on amount of wood particle added. The highest hardness value for W chipboard relative to the other two board indicates wood particle is harder than the coffee husks and during production of board adding wood particle to coffee husk resulted in better production.

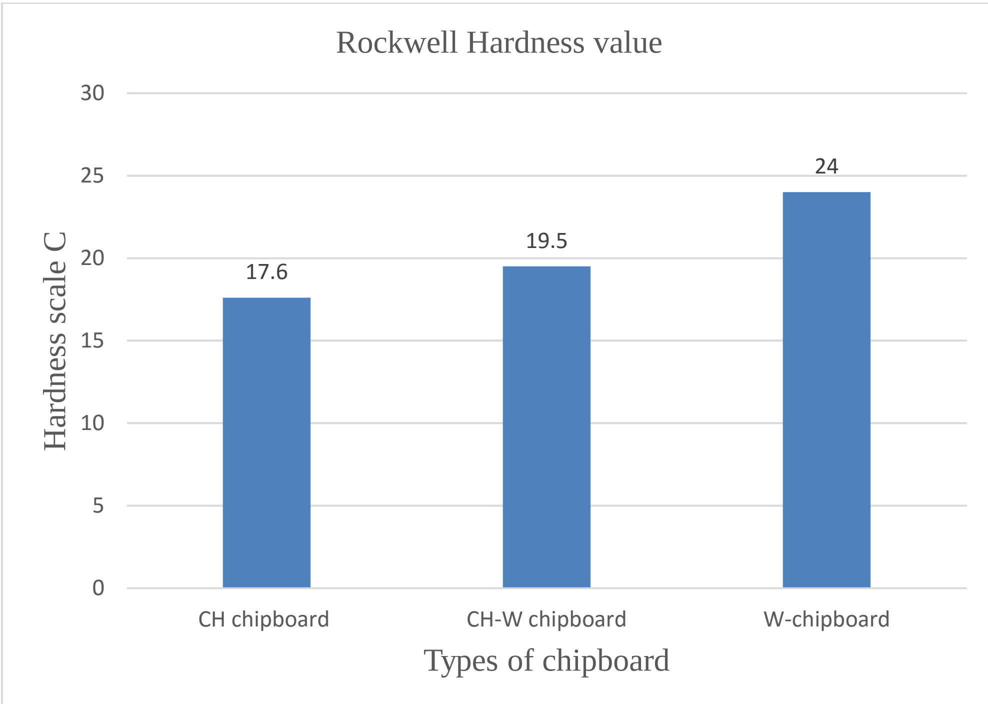


Figure 5. 7 Hardness value

5.3 Modulus of elasticity of coffee husk chipboard

The slope of the linear curve is the modulus of elasticity of the boards. Bending MOE, a measure of the resistance to bending deflection, which is relative to the stiffness [1].

The MOE is important property and obtained from the two directional elasticity, longitudinal MOE value and that of tangential MOE. Using equation of randomly oriented short fiber the MOE of the coffee husk chipboard is obtained and which is the resistance to bending deflection of the chipboard. The calculated value almost near to experimental result done by other researcher [26]. This strongly influenced by the particle compaction amount, particle geometry, percentage of adhesives and density.

5.4 Finite element method

Here we use this finite element to express the properties of the chipboard is affected by its component materials and their respective properties. And using the plane-stress to obtain the properties of the chipboard. The bending and shearing elastic properties in terms of the properties of the components can described by the stiffness properties, D. From this we conclude that the bending elasticity is along the two direction means horizontal and vertical directions. The shear modulus is only in one direction along the thickness of the chipboard.

5.5 Bending strength

From the solid work software result three properties can be obtained. The maximum and minimum bending stress, the maximum and minimum deflection of the chipboard lastly the maximum and minimum strains. From figure 5.6 the maximum and minimum bending strength are 6.917 Mpa and 0.0113 Mpa respectively.

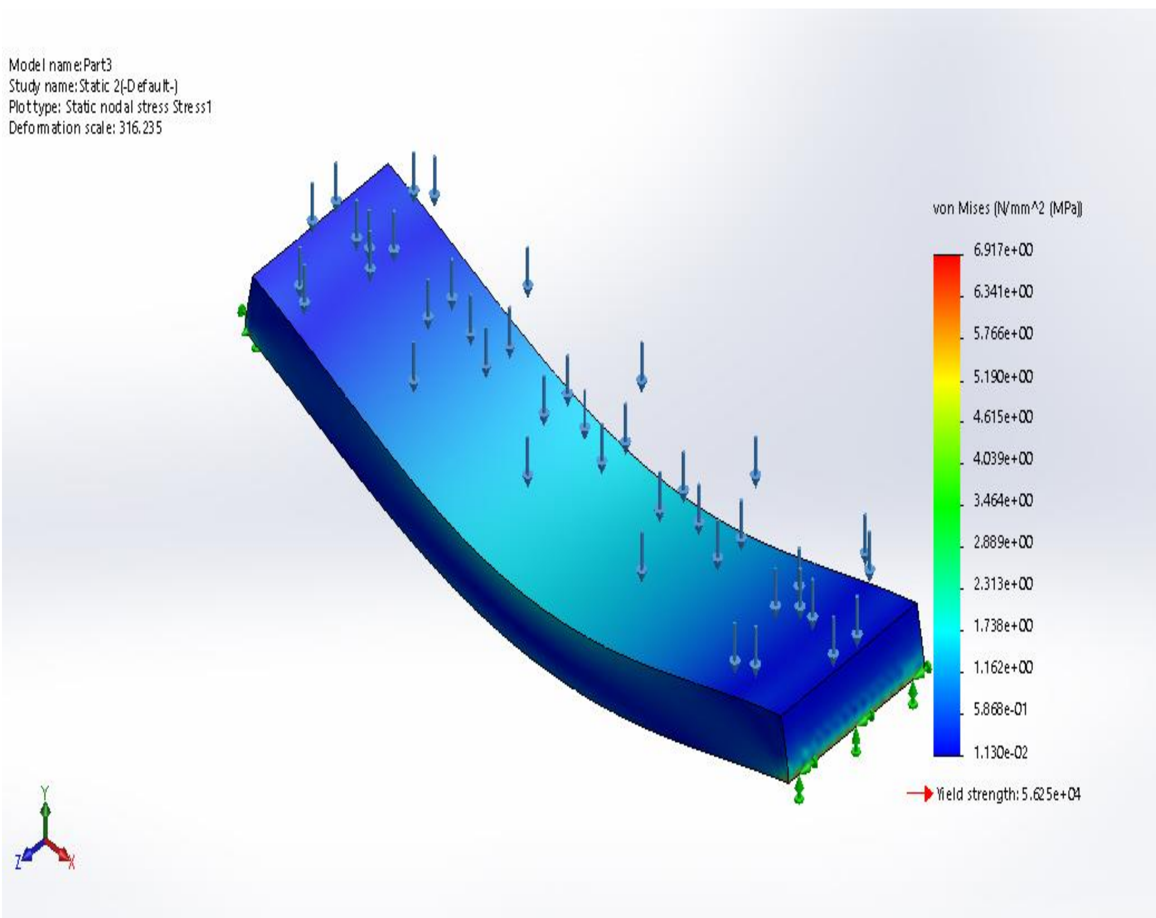


Figure 5. 8 Bending stress

The deflection of the chipboard can be seen from the following figure. Here the two deflection are maximum and minimum deflection.

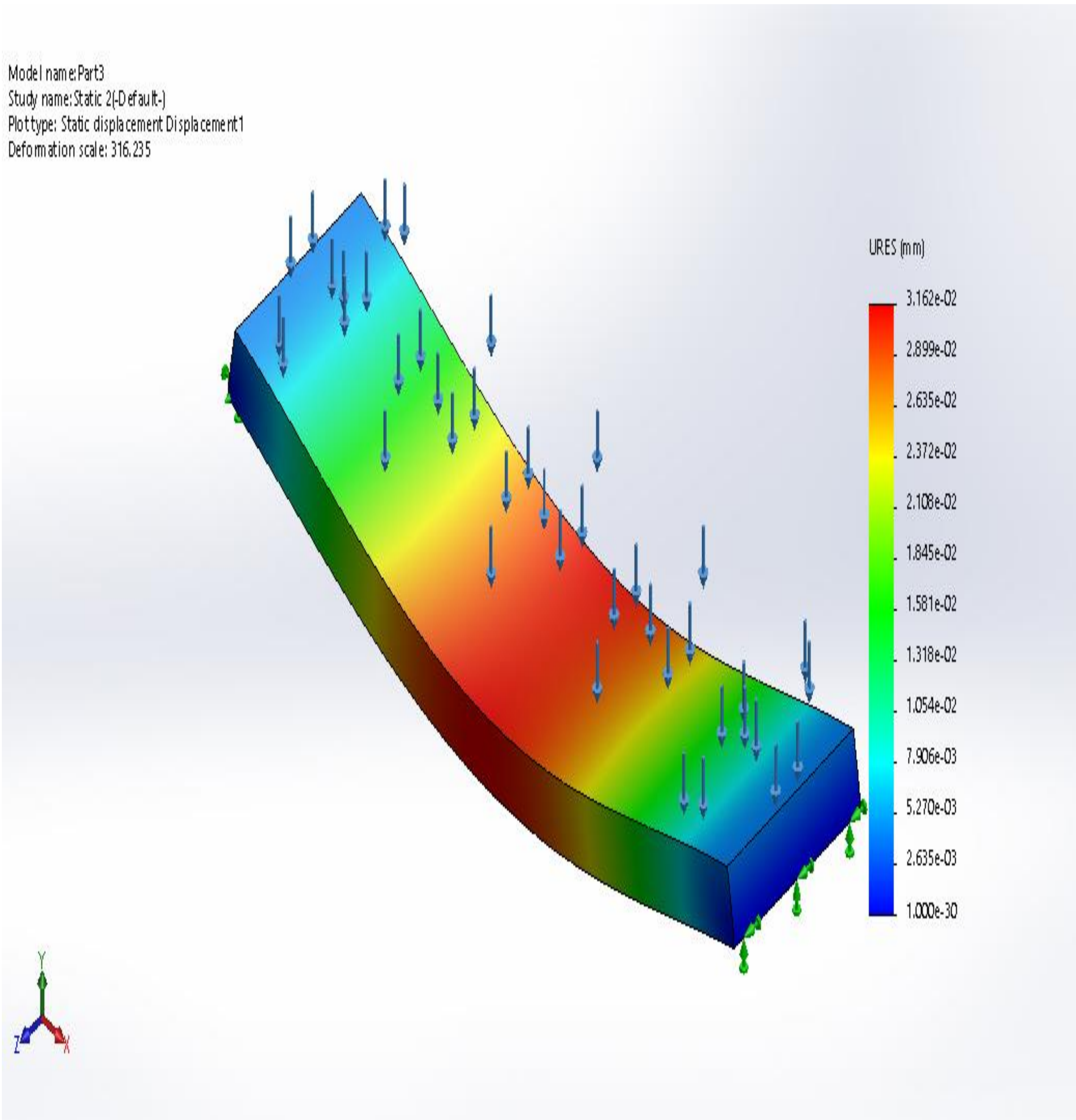


Figure 5. 9 Deflection the chipboard

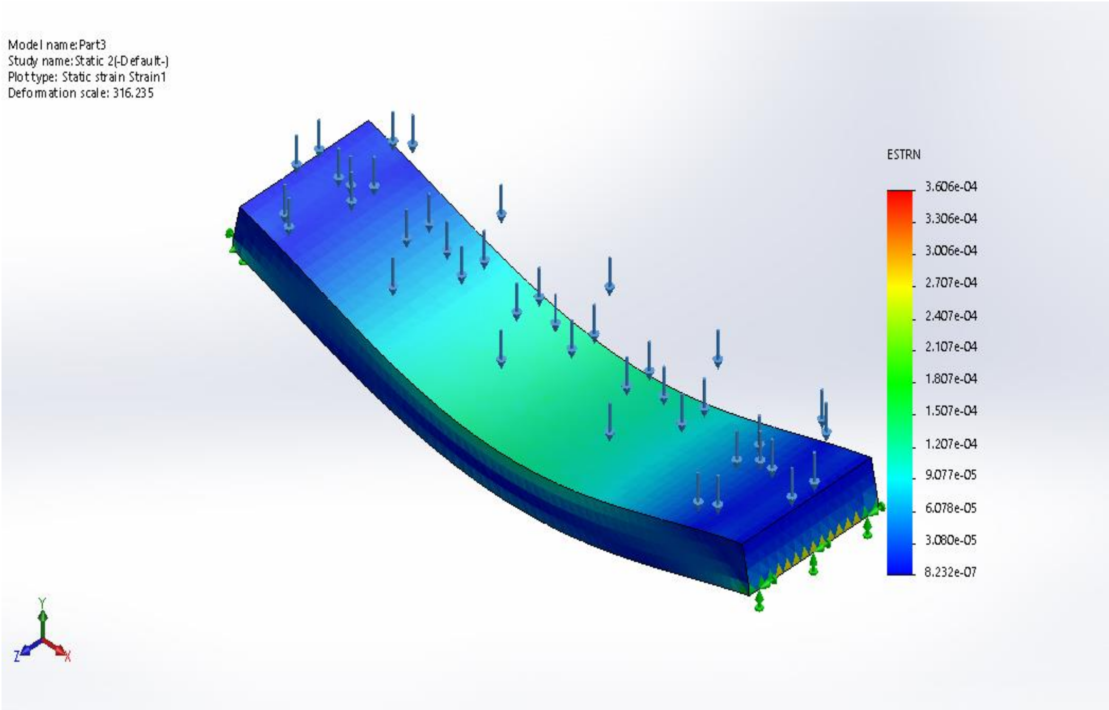


Figure 5. 10 Bending Strain

From the software simulation we can obtain stress strain property of the board which is shown in the figure 5.11 and at the maximum stress value of 6.97 Mpa the board will fail and the stress value decrease after failure. The bending strength depends on the density of the board, particle configuration, adhesive type and level and pressing condition which agree with different works [26].

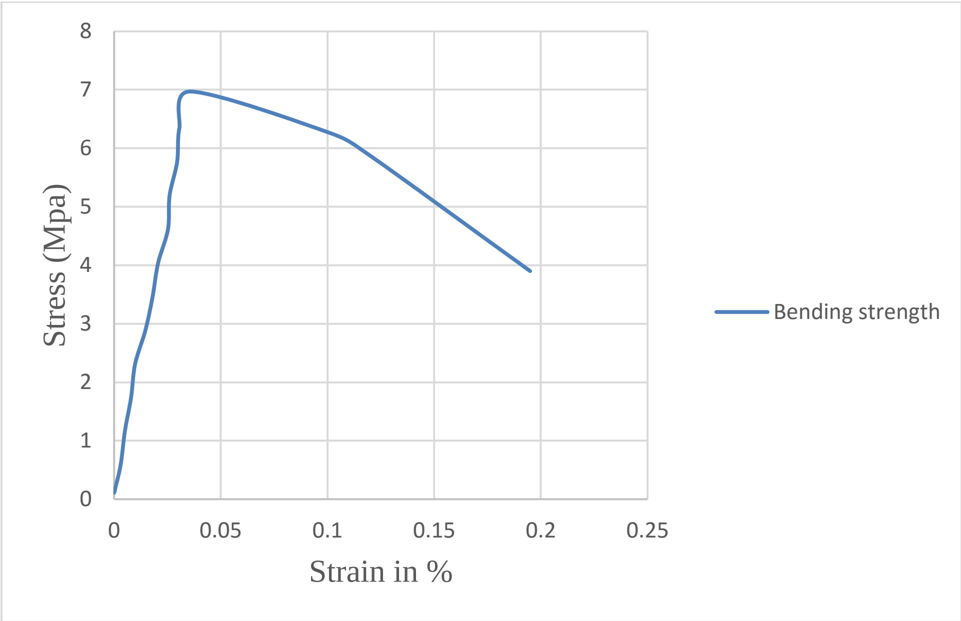


Figure 5. 11 Bending stress-strain

Once a material reaches its ultimate stress strength of the stress-strain curve, its cross-sectional area would reduce dramatically, a term known as necking.

5.6 Compression strength simulation

Compression modeling have the resulted in obtaining stress, strain and deflection of the specimens during compressive load is applied. The length of the board decrease due to the external load and resulted in maximum stress of 1.827 Mpa.

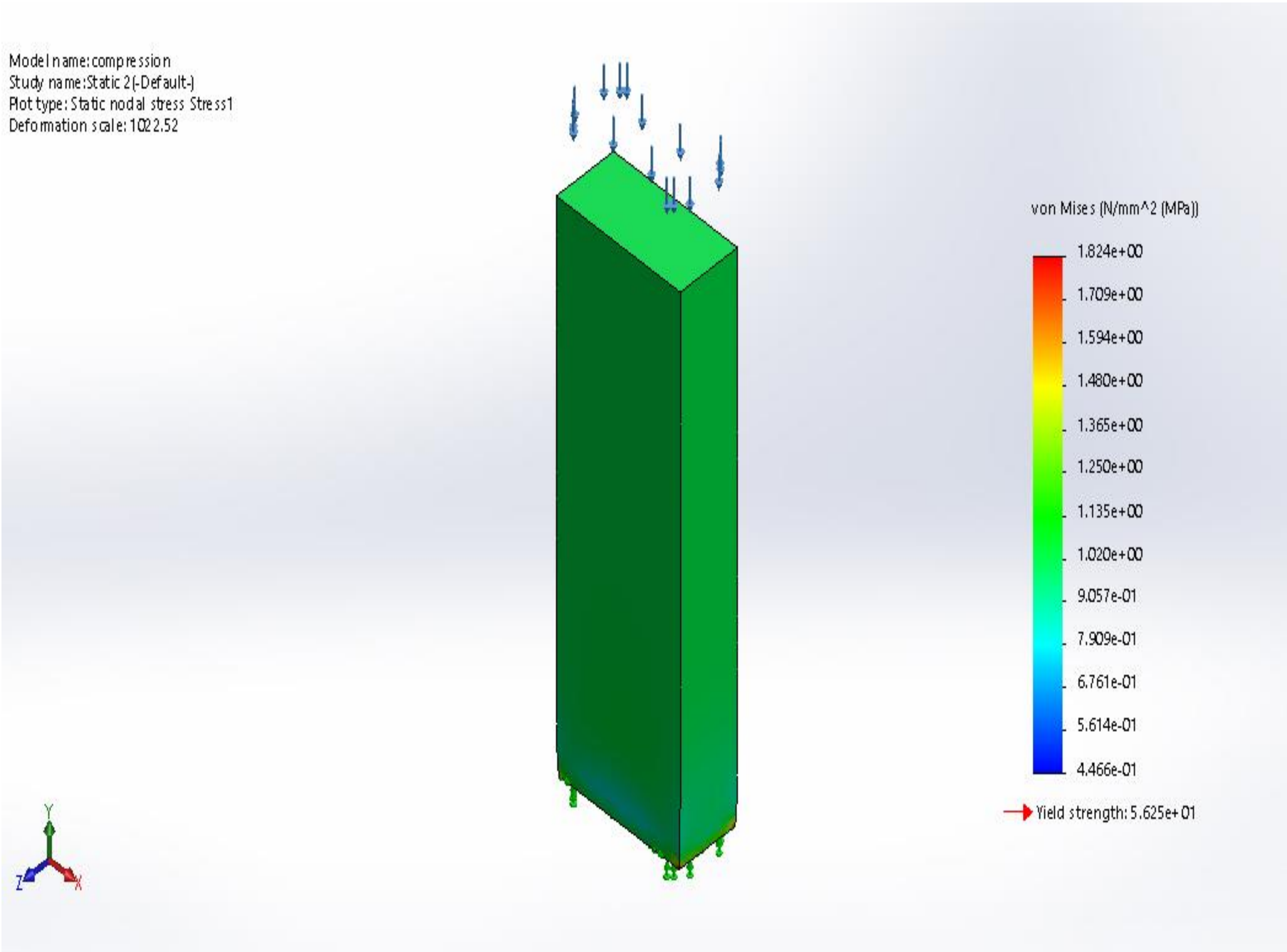


Figure 5. 12 Compression stress

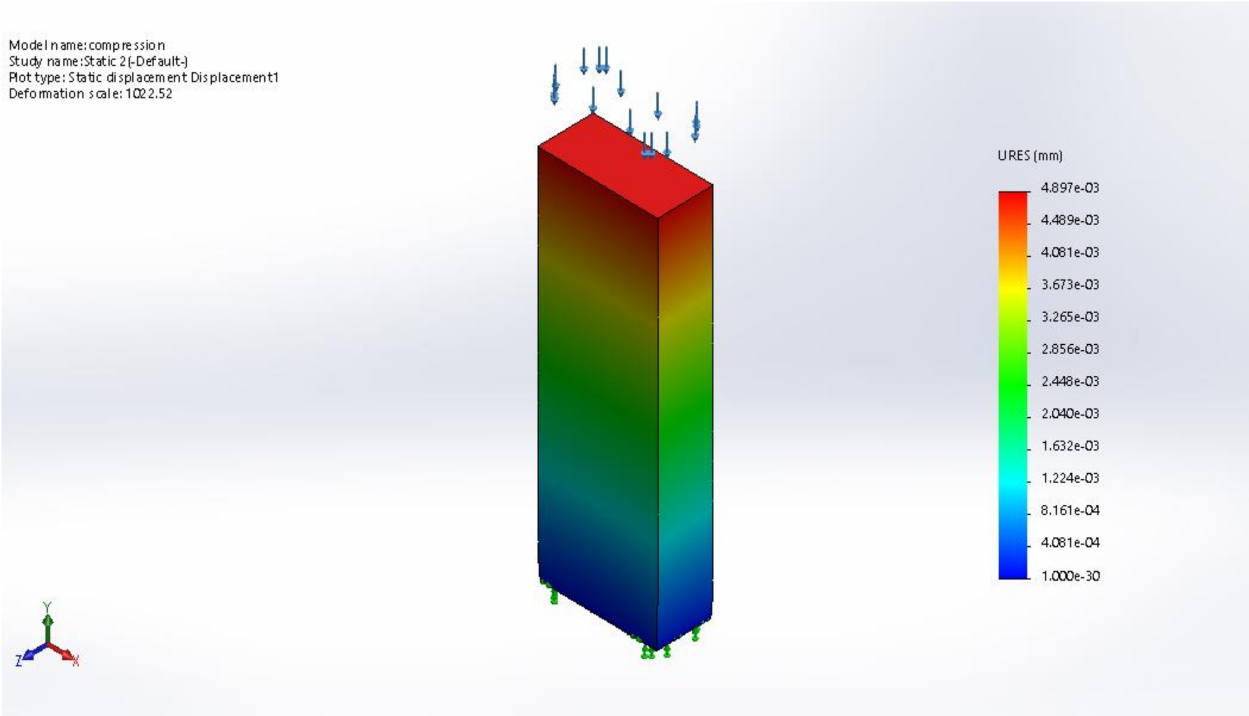


Figure 5. 13 Compression deflection

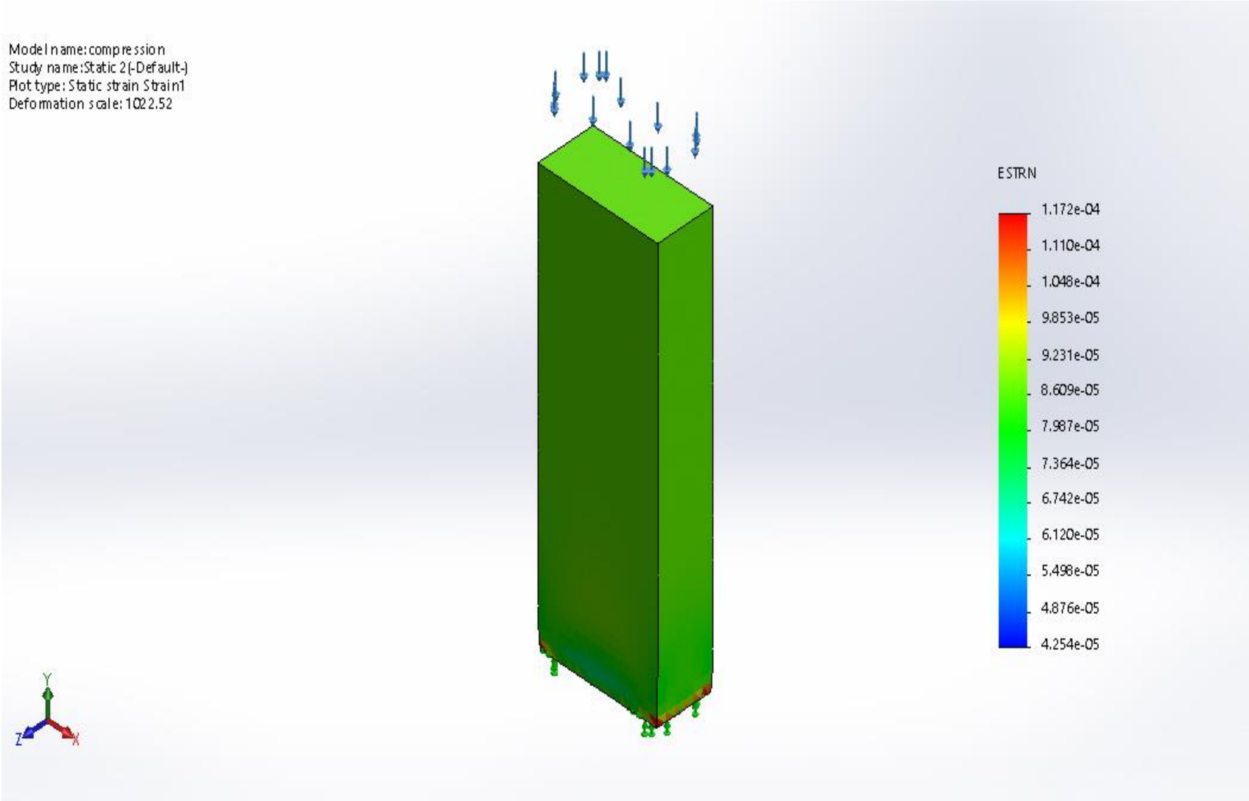


Figure 5. 14 Compression strain

5.7 Compression strength of experimental and software result

The experimental and software result of compression stress strain graph is shown in the figure 5.13.From the two values we can see that the chipboard fails almost at the same value. The elastic region of the chipboard is the normal property of the chipboard which occur before it fail. The board compressed at the value of 1.8Mpa and 1.84 Mpa during experimental and software simulation respectively.

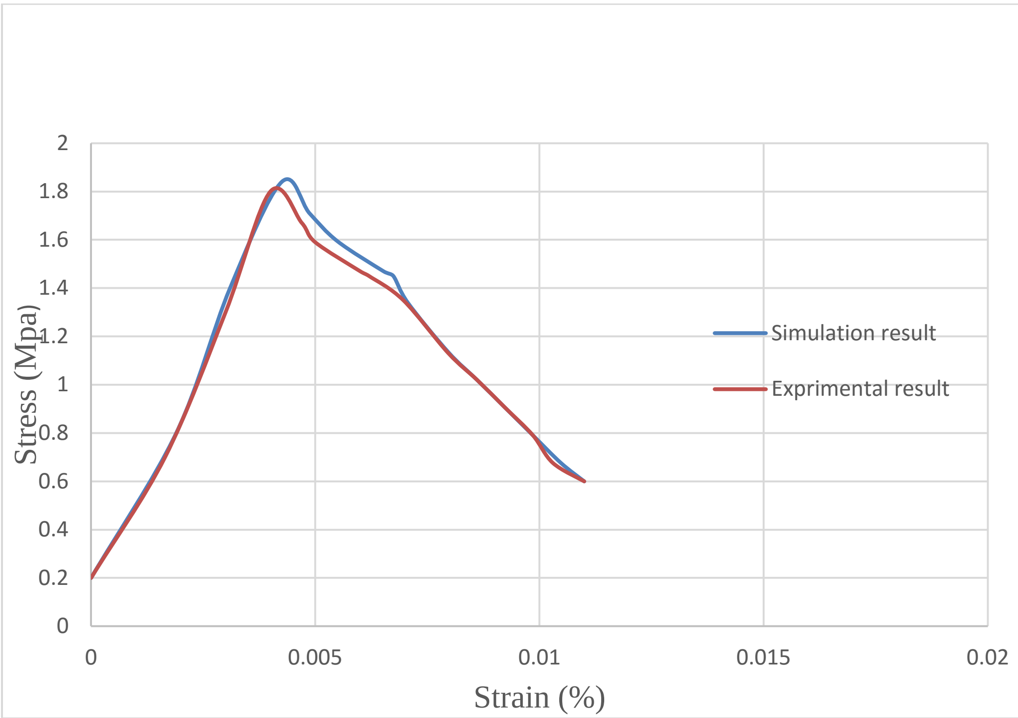


Figure 5. 15 Compression stress strain from software and experiment

5.8 Mathematical modeling of Durability or life time of the produced chipboards

The durability of the chipboard is its life time of service. When this time start to decrease it shows that the degradation of the board is occurred. Service time can be estimated depending on the amount of external load applied moisture and temperatures. The binding energy of the material is the energy by which the raw materials bonded together and this decrease with increasing these factors. From the following equation we can say that the degradation increase as the durability of the board decrease.

$$\tau = \tau_o e^{\left[\frac{U_o - \gamma\sigma}{RT}\left(\frac{Tm - T}{Tm}\right) e^{\alpha W_e}{}^{-1}\right]} \qquad 5.1$$

Here three major constituent factor affecting the life span τ are applied stress, temperature and moisture. As the value of these factors increase durability decrease which cause degradation of the chipboard. This mean the binding energy U_o of the board decrease gradually resulting in more degradation as load applied increase. And when binding energy becomes zero the board lose its strength and finally fail.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATION

This is the last chapter of the thesis and generally discusses about the conclusion, recommendation and the future work of the research.

6.1 Conclusion

The main purpose of the present study was to find the application of locally available coffee husk raw materials in chipboard industry as partial or full replacement of wood chipboards.

- The boards are medium density boards ($640 - 800\frac{kg}{m3}$) that are commercial standard.
- Board density has a lot of impact on properties like bending strength, MOE, hardness, TS and WA.
- The more moisture content value of coffee husk chipboards can be traced back to the hygroscopic behavior of the coffee husk.
- The chipboards glued with urea-formaldehyde (UF) resins which are less water resistant, are more prone to moisture.
- The highest hardness value for W chipboard relative to the other two board indicates wood particle is harder than the coffee husks and during production of board adding wood particle to coffee husk resulted in better production.
- Using equation of randomly oriented short fiber the MOE of the coffee husk chipboard is obtained and which is the resistance to bending deflection of the chipboard.
- The bending strength depends on the density of the board, particle configuration, adhesive type and level, and pressing condition which agree with different works.
- The durability of the chipboard is service life time of the board and load, temperature and moisture content are the three major factors that affect its service time and cause the degradation of the chipboard. As the value of these factors increase durability decrease which cause degradation of the chipboard
- The finding suggest that the use of coffee husk in full or partial replacement of wood particle in chipboard production is practicable and effective with minor improvement.

6.2 Recommendation and future work

- Press time and resin ratio has significant effect on physical and mechanical properties of the chipboards so optimization analysis is necessary to improve the quality of the chipboards.
- To meet the SI standard of chipboard it is recommendable to increase the composition of the adhesives accordingly.
- Using other resins such as PMDI rather than UF resins to increase strength and decrease TS and WA are alternative works.
- Mixing coffee husk with wood particle during manufacturing chipboard is more appropriate for the work.
- Due to shortage of experimental apparatus, both modulus of rupture and internal bond strength tests which are very important for chipboard are not done it is good if other researchers try to do.
- Since the production of chipboard is possible using coffee husks in partial or full replacement of wood particles, it is important to recommend chipboard industry to use this coffee bean wastage in manufacturing of chipboards and decrease deforestation.
- Lastly, it is important if some investors produce the adhesives in Ethiopia in order to decrease the expensive cost for importing.

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