Jimma University

Jimma Institute of Technology

Faculty of Mechanical Engineering

Parametric Optimization of Coffee Husk-Sawdust Chipboards Manufacturing

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

By

Guta Eresso

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DECLARATION

I, the undersigned, declare that this thesis entitled with" *parametric optimization of* coffee *husk-sawdust chipboard manufacturing"* is my original work, and has not been presented by any other person for an award of degree in this or any other University.

Name: Guta Eresso

Signature: ________________ Date: ________________

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ABSTRACT

The objective of this work was an experimental investigation and optimization of parameters of coffee husk-sawdust chipboard manufacturing. The performance measures considered were: - modulus of rupture, tensile modulus, swelling thickness and water absorption. The process parameters included in this study were pressing pressure, temperature, time, coffee husk to sawdust ratios and unsaturated polyester percentage. The results revealed that flexural strength of the chipboards with respect to the coffee husk to sawdust ratios increases as the weight fraction of wood sawdust increases, the maximum modulus of rupture obtained was 24.82 MPa at the 1:1 coffee to sawdust weight ratios. The tensile strength of the chipboard increases moderately as weight fraction of the sawdust increases. The results showed that maximum tensile modulus 62.34Mpa and 7.15Mpa tensile strength at the 1:1 coffee husk to sawdust weight ratios respectively. The capability of the chipboards to absorb water and dimensional instability increases significantly as coffee husk ratio increases. Higher swelling thickness was revealed for boards from the coffee husk. In multi-objective optimization of process parameters of chipboard manufacturing, experiments were conducted according to standard L18 design of experiment orthogonal array designed. The Taguchi with Grey relational method has been employed for optimization. Analysis was performed using Minitab 17 soft-ware and the results showed that the optimal combination for the parameters were: pressing pressure (4Mpa), temperature 160℃, time (8min.), 1:1 coffee husk to sawdust ratio and unsaturated polyester (60%). The ANOVA results showed that pressing temperature (33.11%), coffee husk to sawdust (18.68%) and unsaturated polyester loading percentage (17.92%) are the most influencing parameters that affects the multi-response of chipboard manufacturing followed by pressing time (13.22%) and pressing pressure (2.75%). A confirmation test result revealed the improvement in the grey grade for optimal process parameters by employing the Taguchi-Grey relational analysis method.

Key words: coffee husk, sawdust, UPR, chipboards, mechanical and physical properties, Taguchi-grey analysis, and optimization.

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GLOSSARY

Nomenclature

ANOVA	Analysis of Variance
ANSI	American National Standards Institute
ASTM	American Society for Testing and Material
BC	Binder Content
CAMC	Carbon Matrix Composite
CH	Coffee Husk
CMC	Ceramic Matrix Composite
CP	Coffee Pulp
DOE	Design of Experiment
FRC	Fiber Reinforcement Composite
GRC	Grey Relational Coefficient
GRG	Grey Relational Grade
Hr	Hour
IB	Internal Bonding
ICO	International Coffee Organization
MDF	Medium Density Fiber
MKEP	Methyl Ketone Peroxide
MMC	Metal Matrix Composite
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
Mpa	Mega Pascal
MRR	Material Removal Rate
MS	Mean of Square
MUPF	Melamine Urea Phenol Formaldehyde
NF	Natural Fiber
OA	Orthogonal Array
PF	Phenol Formaldehyde

PMC	Polymer Matrix Composites
PMDI	4, 4-Methyl Phenylmethane Di-Isocyanate
PS	Polystyrenes
PVC	Polyvinyl Chloride
RSM	Response Surface Methodology
RSM	Response Surface Methodology
RLDPE	Recycled Low Density Polyethylene
SD	Saw Dust
TM	Tensile Modulus
TS	Swelling Thickness
UF	Urea Formaldehyde
UPR	Unsaturated Polyester Resin
W	Wood
WA	Water Absorption

Symbols

m_c	Mass of Composite
m_f	Mass of Fiber
v_v	Volume of Void
ρ_v	Density of Composite
ρ_f	Density of Fiber
ρ_m	Density of Matrix
σ	Stress (MPa)
ε	Strain
P_b	Maximum Load (N)
β	Coefficients of Variables
γ	Optimal Level of the Design Parameters
γ_i	Mean Grey Relational Grade at the Optimal Level
γ_m	The Total Mean Grey Relational Grade
L	Span Length of Specimen (mm)
b	Width of the Specimen (mm)
h	Thickness of the Specimen (mm)
x_n	Variable or Predictors
y	The Response Value of the Predictors
WA (t)	Water Absorption (%) at Time t
W (0)	Initial Weight of Specimen (g)
W (t)	Weight of the Sample at a Given Immersion Time
T_0	Initial Thickness of Specimen
T_{24}	Thickness after 24 Hour

y_{ij}	Observed Response Value
σ^2	Mean Deviation
μ	Standard Deviation
$x^*_i(k)$	Signal to Noise Ratios
S/N	Standard Deviation
Min $y_i(k)$	The Smallest Value of $y_i(k)$ for the k^{th} Response
Max $y_i(k)$	The Largest Value of $y_i(k)$ for the k^{th} Response
$\Delta 0i$	The Difference of Absolute Value of $x_0(k)$ and $x_i(k)$
$x_i(k)$	The Given Sequence
$x_0(k)$	Referential Series
ζ	Distinguishing or Identification Coefficient
Δmin	Minimum Deviation
Δmax	Maximum Deviation
n	The Number of Process Responses
Υ_i	The Average Grey Grade for i^{th} Experimental
F	F-test
P	Significance Value
MS	Mean Sum
SS	Sum of Square
SSM	Sum of the Squares mean
SST	The Total Sum of the Square
PCT	The Percentage of Contribution

CHAPTER 1

1. Introduction

1. 1. Background

The development and demand for polymers and composites were growing rapidly from the 1970s. Attractive features of composite materials like lightweight, high specific strength, stronger, harder, stiffer, flexibility in design, and ease of getting the required properties attracted researchers' attention. Today, composite materials have taken 60% – 70% of the market share, due to their superior characteristics [1].

Composite materials are a new class of engineering materials made from two or more constituent materials that remain separate and distinct on the macroscopic level while forming a single component, which performs better than those of the individual constituents used independently [2, 3]. In the manufacturing of polymer matrix composites, the natural fiber used can be from animals and plants. They are available, renewable, biodegradable, and low-density compared with other synthetic materials [4, 5, 6]. These natural fibers from plants include agricultural residues such as rice husk, coffee husk, palm, corncob, oil palm, banana fiber, jute, sisal, other fruits, and vegetable residues are the composite materials used to produce the particleboard or chipboard.

In Ethiopia, coffee production and processing constitutes an important sector of the agro-industry, accounts for up to 65% of the total exports from the country [7]. The world's top five countries that produce coffee in 2019/20: Brazil, Vietnam, Colombia, Indonesia, and Ethiopia. Ethiopia produced 7.9 million of 60 Kg bags in 2019/20 coffee according to International Coffee Organization (ICO) [8]. In Ethiopia, Jimma zone is one of the areas in which coffee production took place [9].

During coffee processing, significant amounts of agricultural waste are generated ranging from 30% to 50% of the total weight of coffee produced, depending on the type of processing. The two coffee processing methods are the dry and wet methods. Coffee husks (CHs) and coffee pulp (CP) are the solid residues obtained after de-hulling the coffee cherries during dry or wet processing respectively. The major residues from the processing of coffee are disposed to an environment that causes environmental problems [10, 11].

In Ethiopia, enormous amounts of coffee husk and pulp are generated annually from the coffee processing industries. However, they have been poorly utilized, left to decompose, burnt on the field, or dumped into the environment [12]. Considering the amount of generated coffee husk and its environmental effects there will be an alternative need to use the waste i.e. animal feed, as a fuel, production of chipboard.

Particleboard or chipboard is a flat hot-pressed composite panel composed of randomly oriented particles or chips bonded by hot-pressing using thermosetting resins. Composite panel products are typically produced from wood products such as shavings, flakes, wafers, chips, sawdust, strands. It could be multi or single-layer. The panel (MDF), generally has a density of 650-700 Kg/m^3 [13]. Most European countries used the term particle rather than chip and therefore particleboard as a term for chipboard [14].

The interest in environment-friendly materials has led to the use of agricultural or non-wood by-products as raw materials for the production of particleboard. It is made up of particles of varying shape and size bonded together with an adhesive and consolidated under heat and pressure [15]. To manufacture particleboard different types of the binder are used to have proper physical and mechanical characteristics of the final product. The matrix or binder material used for reinforcing the fibers are classified as thermosets and thermoplastics. The choice of the adhesive depends on the usage of composite. A formaldehyde-based resin such as urea, phenol, and melamine is still used widely in the production of the panel. However, formaldehyde is a well-known harmful substance, which affects human health and pollutes the environment while formaldehyde is released. Therefore, a commonly used formaldehyde-free, unsaturated polyester resin was used in this work [16, 17, 18].

Natural fiber composites are manufactured in different techniques such as hand layup, pultrusion, injection molding, compression molding, and resin transfer molding [1, 19]. The most important manufacturing parameters influencing chipboard properties are:- curing conditions of resins and process parameters such as pressure, temperature, pressing time, cure time, binder type and content [20, 21].

In Figure 1.1 (a) [22], chipboard or particleboard manufacturing from CHs and wood.

Figure1.1: (a) Coffee husk particle board. (b) Coffee husk in Jimma zone.

It is important to have a proper understanding of the process parameters effects on the performance characteristics, both mechanical and physical properties of the chipboard. The physical properties of the board are: - density, percentage of thickness swelling, water absorption, moisture contents, and thermal insulation. The mechanical properties of the boards are:-modulus of rupture (MOR), modulus of elasticity (MOE), tensile strength, compressive strength, hardness, and impact [23].

The performance characteristics in different process variables have to be optimized to increase the quality of product and minimizing (trail-error) the cost of production. Therefore, multi-objective optimization is necessary to meet the quality and minimize cost in the manufacturing industry. The process parameters such as temperature, pressure, binder content, pressing time, cooling time, need to be optimized in order to produce finished boards with good quality [24].

Genichi Taguchi was active in the improvement of Japan’s industrial products and processes [25]. Taguchi approach is a form of DOE with special application principles and helps to study the effect of many factors (variables) on the desired quality characteristic most economically. By studying the effect of individual factors on the results, the best factor combination can be determined [26]. Taguchi designs experiments using specially constructed tables known as “orthogonal array” (OA). The use of these tables makes the design of experiments very easy and consistent and it requires a relatively lesser number of experimental trials to study the entire parameters. As a result, time, cost, and labor-saving can be achieved [27].

The Taguchi method is the optimization technique that is normally used for a single response. For multi-response optimization, Taguchi coupled with the grey relational analysis was used to optimize the chipboard manufacturing process variables such as pressing pressure, temperature, time, reinforcement weight faction, and resin content.

Grey relational analysis (GRA) describes the relationship between one main factor and all other factors in a given system. It is an efficient tool for multi-response analysis. The grey relational analysis based on the grey system theory can be employed to measure and explain the complicated interrelationship among the data when the trends of their development are either homogeneous or heterogeneous. The degree of the significance of a factor on the response of final product is an important task. This statistical significance of the factors can be evaluated through analysis of variance (ANOVA) [27, 28] .

Therefore, the objective of this work was to optimize the coffee husk-sawdust and unsaturated polyester resin based chipboard manufacturing by employing Taguchi-grey relation process parameters optimization methods. The best combination of the process parameters was obtained. ANOVA, statistical analysis was applied and the significance of parameters was determined with the corresponding contribution on the performance characteristics. Finally, the confirmation test was conducted to verify the optimal process parameters.

1.2. Statements of Problems

Coffee is one of the world's most popular fruit. Ethiopia is the top fifth country in the world. From the coffee production area in Ethiopia, Jimma is an area in which coffee is produced and processed in a coffee cherry. In dry coffee processing, the 30 % to 50% of the weight of the total coffee produced, coffee husk is generated. Most of the generated coffee husk is left on an open field, burnt on the field, and dumped into the river which results in environmental pollution. Therefore, the alternative way of handling wastes is a crucial activity. To solve the stated problems and to utilize a large amount of coffee husk with sawdust as a resource for the economy by producing chipboard is one of alternative way of handling coffee husk waste. Manufacturing of chipboard is not satisfactory; identifying and optimization of process parameters in manufacturing are important points to be considered. In manufacturing chipboard from coffee husk-sawdust, the process variables and performance characteristics need to be optimized as a result, a good quality product will be attained and reduced (trail - error)cost of manufacturing.

1.3. Objectives of the Study

1.3.1. General Objective

The main objective of this research is to find parametric optimization of coffee husk - sawdust chipboard manufacturing.

1.3.2. Specific Objectives

The specific objectives of the study are:-

- To manufacture chipboards considering pressing pressure, temperature, time and weight fraction.
- Determining physical and mechanical properties such as swelling thickness, water absorption, modulus of rupture and tensile strength.
- Determining the process parameters with higher influence.
- Finding the optimum value of process parameter.
- Performing Confirmation test.

1.4. Questions to be addressed in this Thesis

- What are the process parameters that influence the performance measure?
- What is the effect parameters physical and mechanical properties of coffee husk – sawdust chipboard?
- To what extent do the process parameters affect performance characteristics?
- What is the optimum value of process parameters?
- How much do the performance characteristics improved?

1.5. Motivation of the Study

Now a day, non-wood (agriculture) residues are being used in production of particleboards using resin under hot temperature and pressure. From agro-based residues, coffee husk is one of the available lignocellulose materials. Ethiopia is one of the greatest coffee producers, as result, coffee husk is abundantly available, which needs attention to change this huge amount of resource into economy and promoting development of particleboard technology. The process of changing waste into the chipboard process parameters needs best combination to attain good mechanical and physical properties of the manufactured chipboards. Confirmation test was conducted for verification.

1.6. Scope of the Study

The scope of this work is limited to determine physical and mechanical properties such as swelling thickness, water absorption, modulus of rupture and tensile strength of chipboard and finding optimum process parameters of coffee husk-sawdust chipboard manufacturing using Taguchi method coupled with grey relation analysis. Analysis of Variance was conducted to identify predominant factor and established their significance on performance characteristics. Finally, a confirmation test was conducted for verification.

1.7. Significance of the Study

Today, agricultural residues are used with wood as composite material for the production of chipboard or particleboard. Chipboard is produced from coffee husk-sawdust and resin at hot temperature by pressing. The study of mechanical and physical properties of coffee husk-sawdust chipboard is important issue concerning the application area of chipboards. Therefore, it is significant to use coffee husk which is locally available agricultural waste into the alternative way of usage such as replacing wood and plastic boards.

1.8 Organization of the Thesis

The thesis is divided into five chapters. Chapter 1, deals with the introduction and background of composite materials in board manufacturing. The motivation, scope, significance of study and problems are clearly identified. Additionally, the objective of the research is stated in this chapter. The outline of this work is also presented at the end of this chapter.

Chapter 2 reviews the literature specifically focused on studies composite materials, resin used in composite material fabrication, related research on coffee husk and agro-based composites, process parameters in optimization, optimization methods. From the literature review, the gap is clearly mentioned.

Chapter 3 describes experimental methods, materials and equipment used are specified. This includes, experiment work plan is designed. DOE and the formation of chipboard, specimen preparation, and test procedure for evaluation of physical and mechanical properties.

Chapter 4 research methodology for this work provided describes overall structure of this work to meet the already specified objectives. Multi-objective optimization of Taguchi-grey relational analysis of chipboard manufacturing process parameter and ANOVA analysis are discussed in detail and employed in analysis of the experimental data.

Chapter 5 obtain results from Taguchi-Grey relational analysis optimization techniques. S/N ratio values are computed and analyzed. The optimum levels of the process parameters are found out and a confirmation test is conducted for validity. The significance and percentage contribution of parameters were obtained using ANOVA analysis. Chapter 6 is the last chapter of this thesis and presents conclusions and recommendations. Additionally, future works in this area are provided.

CHAPTER 2

2. Literature Review

2.1. Introduction

The use of agro-fibers in other potential sectors such as building and furniture has gained interest in developing countries [22]. Researches have been carried out on a wide variety of agricultural waste from rice husk [29, 30], corncob [31], coffee husk [22, 32], maize cob [33] etc. Thus studies concentrated on finding the possibility of using locally available agricultural by-product into the alternative way of usage such as replacing wood and plastic products. The studies were focused on the characterization of mechanical and physical properties of the materials and parametric optimization of the manufacturing process. Considering these, a review of the related work was done to have a better understanding of the current study status. The literature review specifically focused on studies of composite materials, resin used in composite material fabrication, related research on the coffee husk and agro-based composites, process parameters in optimization, optimization methods.

2.2. General Research Review

2.3. Composite Materials

Composite material is a combination of two or more physically and/or chemically distinct, suitably arranged (distributed) phases with an interface separating them. It has characteristics that are not depicted by any of the components in isolation. This combination of materials results better properties than those of the individual components used alone [2, 3].

Figure 2.1, shows the composites are usually classified depending on the type of material used for the matrix. The four primary categories of composites are polymer matrix composites (PMCs), metal matrix composites (MMCs), ceramic matrix composites (CMCs), and carbon matrix composites (CAMCs) [34]. The two constituents of composite materials are matrix and reinforcement. The primary functions of the matrix are to transfer load or stresses between the reinforcing fibers or particles whereas, fibers are the load-carrying agent or improving its mechanical properties such as strength, stiffness in a composite [35]. Matrix materials are polymers, metals, ceramics, and carbon composites that consist of fibers in the matrix structure and can be classified according to fiber lengths such as continuous fiber reinforcement, discontinuous fiber reinforcement, flakes, and particulate reinforced composite [36]. Particulate is non-fibrous with no long dimension. Composite with particles as known reinforcement is called particulate composite which can be in a random or preferred orientation. Depending upon the type of availability, reinforcements are classified as either natural or synthetic. Natural fibers (NFs) are extensively available materials in nature from plants and animals.

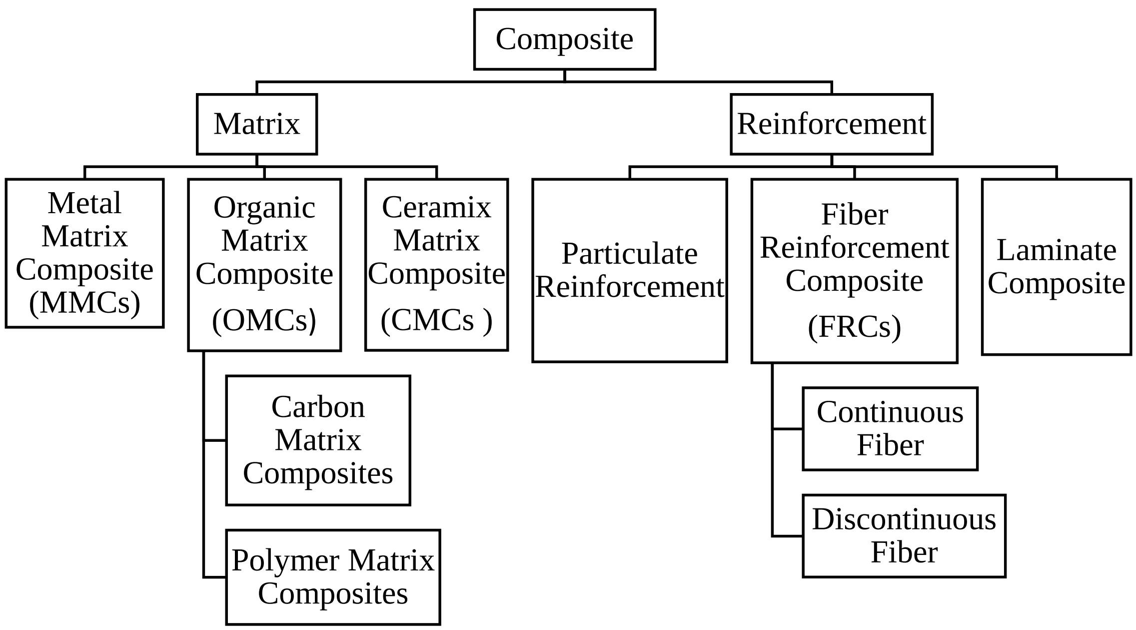


Figure 2.1: Classification composite materials [31].

They reveal better material properties like biodegradability, low cost per unit volume, high strength, and specific stiffness. This brings an advantage to use natural fibers for different application areas [37]. The main components in the single natural plant fibers are cellulose, hemicellulose, and lignin. Depending on the source of fiber, natural fiber is divided into three categories: mineral-based: asbestos, ceramics, animal-based: wool, silk, animal hair, and plant. Figure 2.2 shows the extensively available natural fibers from plants [38].

Based on processing techniques, matrix materials classified into thermosetting and thermoplastic matrices. Thermosetting matrices are synthetic matrices formed from a chemical reaction and when mixed with hardener or catalyst, they become irreversible, hard, and infusible resin. The most commonly used are unsaturated polyester, phenol-formaldehyde, vinyl ester, and epoxy while thermoplastic matrices mostly appeared solid and softened when heat is applied.

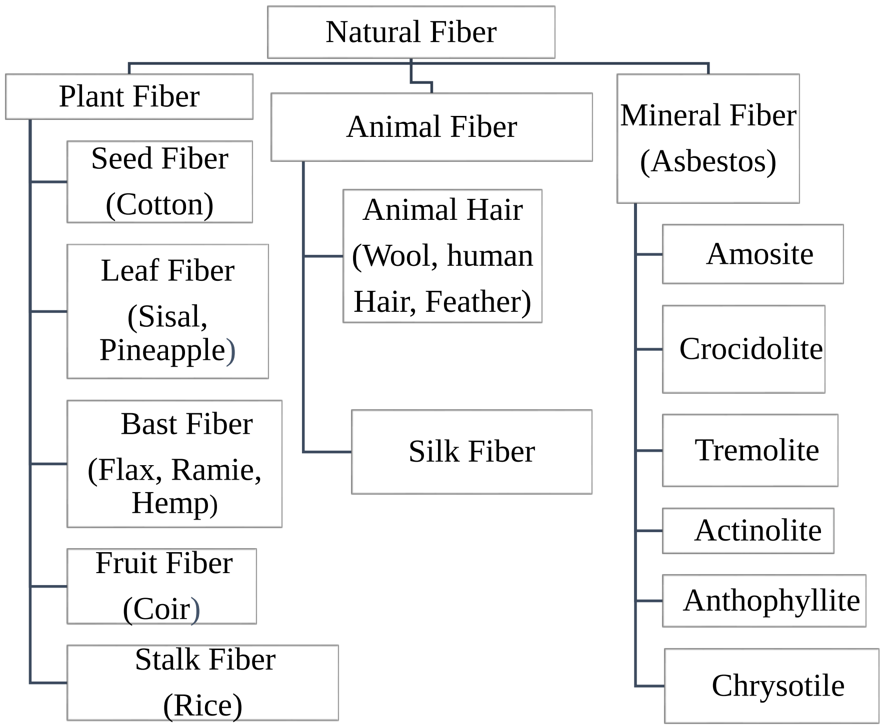


Figure 2.2: Classification of natural fibers [37].

They can be reversed by heating after being used and re-used again without much effect on their initial properties [39, 40]. The most widely used thermoplastics are polyvinylchloride (PVC), polystyrene (PS), polypropylene (PP), polyethylene, and natural rubber [41, 39, 40].

Unsaturated polyester used in this work is a thermoset resin commonly used as a matrix material in polymer composites withstand with an 80℃ working temperature. Hardening and curing agents are usually added. A catalyst MEKP is used to start curing reaction. The term unsaturated means that there are reactive sites in the molecule. The principal advantage of these resins is a balance of properties including mechanical, chemical, and electrical, dimensional stability, cost and ease of handling and processing [41, 42]. The UPR began curing at 114℃ during the hot pressing by giving enough time, a temperature of above 132℃ should be able to completely cure the UPR. Therefore, for this work 160℃ , 170℃ and 180℃ were selected as temperatures variables for the optimization of the coffee husk-sawdust chipboards manufacturing [43]. Thermosets polymer such as epoxy and unsaturated polyester resins are the most commonly used in a variety of applications due to their excellent properties [44, 45].

There are different types of composite panels, major types of composite panels are generally categorized either by the size of the material from which they are made or by a term that describes the board endues of the product. The various composite panels which can easily produce from various lignocellulosic resources are;-fiberboard, particleboard, mineral board, medium density fiberboard, and hardboard [23].

Table 2.1: Characteristics of unsaturated polyester [41].

S.No	Properties	Values
1	Density (g/cm^3)	1.1-1.4
2	Strength (Mpa)	30-100
3	Modulus, E (GPa)	2-4
4	Poisson’s ratio, v	0.2-0.33
5	Cure Shrinkage (%)	5-12
6	Use temp. (℃)	80

Each year, about 28.4 million meters cubic of particleboards are produced in Europe mainly for furniture and building applications [46]. Generally, particleboard is defined as a panel product manufactured from varying particles of wood or other lignocellulosic materials and a binder, consolidated together under pressure and temperature, the density levels for particleboard are the same as those for MDF [47].

The development of particleboard technology is now beginning to shift from composite materials of synthetic fibers to natural fiber-making materials. Composite is used to describe any wood or agriculture residues material bonded together with adhesives [22, 48]. The composite materials are usually prepared depending on different weight fractions or volume fractions of matrix or reinforcement material. A rule-of-mixtures is a tool that considers the composite properties as volume-weighted averages of the component properties. It is important to realize that the rule-of-mixtures work in only certain simple situations. Composite density is where the rule-of-mixtures is applied [41, 3]. Using the rule of mixture the various properties composite can be computed considering mass composite (m_c) and volume (v_c). The total mass of the composite is the sum total of the masses of fiber and matrix, as Equation (2.1).

$$m_c = m_f + m_m \tag{2.1}$$

The subscripts c, f, and m indicate composite, fiber, and matrix, respectively. Equation (2.2) is valid in the presence of any voids in the composite. The volume of the composite, however, must include the volume of voids, v_v. Thus

$$v_f = v_f + v_{m+}\ v_v \tag{2.2}$$

In this case the volume of voids, v_v. is assumed to be zero or not considered and the Equation (2.2), became

$$v_c \quad = v_f + v_m \tag{2.3}$$

$$\rho_c = m_c / v_c \tag{2.4}$$

Using Equation (2.4) the density is computed and in this work average mass of composite were 500g, the volume of the composite was 350mm x 290mm x 6 mm the average targeted density of 0.7g/cm^3, 6mm targeted thickness and the mass of the matrix were 200g, 250g, 300g and the mass of the reinforcements were 250g with different coffee husk and sawdust weight fraction.

A. Coffee Husk

Large amounts of coffee by-products are generated from the industrial processing of coffee cherries to obtain coffee beverage. Among the by-products generated the coffee husk is the major one. The dried pulp, parchment, and parts of the silver skin are removed with peeling machines. This waste is called husk [49].

In Figure 2.3, the structure of coffee husks shows that is comprised of the outer skin, pulp, and parchment, which are the main residues obtained in the dry processing of coffee berry. The coffee husks are rich in insoluble fiber, containing 24.5% cellulose, 29.7 %

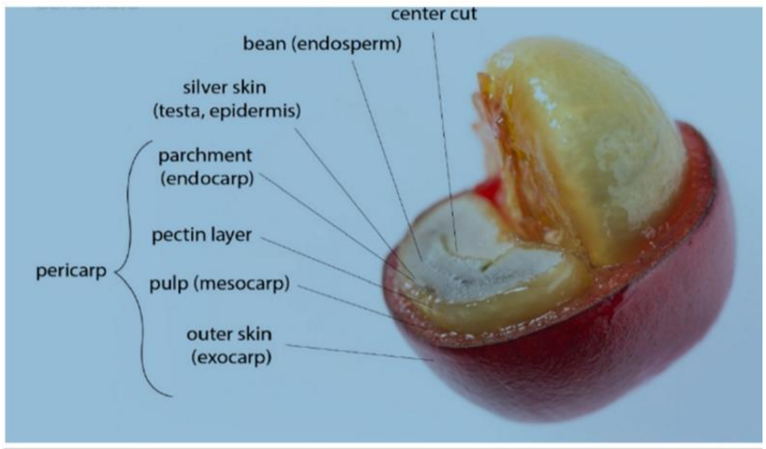


Figure 2.3: Coffee bean structure [48].

hemicelluloses and 23.7% lignin 31% [11]. The individual coffee husk and hull fibers are, typically classified as short fiber [22].

B. Sawdust

Saw dust is a waste of wood industries that produce lots of environmental pollution around wood industry. Wood dust is a known human carcinogen. Certain woods and their dust contain toxins that can produce severe allergic reactions. Effective utilization of waste sawdust can solve the environmental problem [42]. The majority of particleboards were made from wood. Wood is obtainable in a round, with large chips and residues. However, using round wood for the particleboard manufacturing is incurred an extra expenses for producing chips. Sawdust is one major wood residue and very cheap when compared with other wood residues like shaving; so using wood residues is recommended [14]. Sawdust is the main component of particleboard which is a by-product of wood working machining operations like sawing, splitting, milling, planning, drilling. These byproducts are mostly used as filler materials in the manufacturing of particleboards. Among the particleboards produced sawdust as filler and resin as binders are: coffee husk-sawdust [22], rice husk - sawdust reinforced polyester composite for ceiling board [50]. Particleboards produced from rice husk, wood as filler [51].

Figure 2.4: Cordia Africana wood sawdust.

2.4. Researches on Coffee Husk, Sawdust and Other Agro –Residues Based Composites

Now a day, the use of agricultural residues in manufacturing of sustainable particleboard is widely being explored [52]. The use of these materials benefits both the environment and socio-economic development [53]. Due to these many researchers came up with usage of wood-agro fibers to manufacture particle boards. Several studies have been taken on particleboard manufacturing from different agro-waste and wood or sawdust so far were: coffee husk and wood [22, 54], wood and maize cob [55] corncob [31] etc. Some of the literature related to the present work is reviewed below.

Bekalo and Reinhardt [22] have conducted an experimental investigation on the production of particleboard from fibers of coffee husk and hulls with 50% of wood adding different resin such as melamine urea phenol-formaldehyde (MUPF), urea-formaldehyde (UF), and poly-MDI (PMDI) in variable percentage, the researchers investigated the mechanical properties of particleboard from CH and wood. The result revealed that using 50% of wood with coffee husk in manufacturing in board particle is applicable.

Isabela Imakawa et al. [54] have done an investigation on the influence of the addition of coffee husk in physical properties of bamboo particleboard, coffee husk (0%, 10%, 20%, and 30%), and bamboo with castor oil-based polyurethane resin were used. The result revealed in physical properties: density, thickness swelling, and water absorption test for 24 hours showed no significant difference among the coffee husk percentages.

Mário V. S. et al. [55] have researched eucalyptus wood and coffee parchment fiber composite in the percentage of (0, 10, 20, 30, 40 and 50%) with 8% of UF. The researchers investigated the reduction in WA values with the addition of coffee parchment in particleboards. The MOE values showed decreasing trend according to linear regression model and a higher content of coffee parchment associated with eucalyptus wood reduce significantly the MOR values. Only IB revealed an increasing trend until the content of 30% coffee parchment.

Nadir A. et al. [56] they used the 70%wood and 30% rice husk particleboard and investigated the dimensional stability of particleboard significantly improved by increasing the resin content, increasing the contents of UF and PF resin increased the WA and UF resin bonded samples swelled two times more than PF resin bonded particleboard. The mechanical properties of PF resin bonded were better than the UF resin bonded. The result revealed that when the contents of UF and PF resins increased, internal bond strength increased. The bending strength and modulus of elasticity of the samples were not significantly increased by increasing contents of the UF and PF resins, except for the 12 wt% content.

E. M. Ciannamea et al. [57] researcher used phenol-formaldehyde (PF) as adhesive and single-layer particleboards were obtained by varying adhesive content (BC) between 8% to 14% and processing pressure (P) in the range of 0.28MPa to 1.38MPa, studied the effect of both variables on the board performance. The result revealed that particleboards with 11%and 14% of BC met the minimum requirements of MOR and MOE recommended by the ANSI specifications for commercial and industrial use. They conclude that the advantage of the use of rice husk in particleboard which can be applied in ceiling boards or partition-wall for building, only by controlling the processing conditions, thus decreasing production cost.

Mario v. et al. [55] they experimental studied production of particle from maize cob in the percentage of 0%, 25%, 50%, 75% and 100% with the particles of Pinus oocarpa wood 8% of UF and 1% of paraffin used. They found mean values of basic density for wood and maize cob were 0.473g/cm^3 and 0.170g/cm^3 respectively. The result showed that maize cob residue significantly improved in physical properties WA2h, TS2h, and TS24h; mechanical properties had decreased with maize cob percentage and percentages higher than 50% drastically decreased values of mechanical properties. The authors concluded incorporating maize cob does not affect physical properties of panels, but affected their mechanical properties.

Nisakorn N. et al. [32] studied by separating coffee husk into four different sizes by the milling process and mixed with 9%wt of isocyanate adhesive. All the coffee husk was formed to particle sheet by compression molding with the heater and tested the mechanical properties. The results showed that the coffee husk from the milling process at particle size about 2mm could be fabricated to particle sheet and passed TIS.876/2547. They concluded that the optimum ratio of isocyanate adhesive on the coffee particle sheet was accorded in the range 9 to 13 % and passed the TIS.876/2547. The researchers suggested that coffee husk can be formed to the particle sheet as a wood replacement.

Penlapus Y. et al. [31] have studied the corncob, as a composite with a starch binder to produce green particleboard. The author found that an increase of concentration of starch binder increased density and tensile strength of a composite, decrease thickness swelling and water absorption of composite decreased with higher binder content. The researcher showed that the mechanical performance of corncob and starch binder composite. The highest tensile strength of the particleboard composite was found to be 141N/mm^2 at 30 weight percent of starch binder content.

Chen Chiang. T et al. [19] have used sago residues mixed with PF and UF for particleboard fabrication. The targeted density was 600kg/m^3 and particles with weight fractions of 90%, 85% and 80% with UF and PF. The results revealed that boards' strength was enhanced when the resin loading increased, but this was only applicable to a certain percentage of resin loading and, after the optimum, the strength was dropped. This study showed that sago particles could utilized as a raw material in particleboard manufacturing.

Idris, U. D. et al. [58] investigated using watermelon peels as alternatives to wood-based particleboard composites by compressive molding using recycled low density polyethylene (RLDPE) as a binder. The result revealed that the density increased as the percentage of resin increases, thickness swelling and water absorption increased in decreasing the weight fraction of the RLDPE resin. The results showed that the MOE, MOR, and IB meet the minimum requirements of European standards, for general purposes like paneling, ceiling, partitioning. The researchers concluded that watermelon particles can be used as a substitute for wood-based particleboard for general purpose applications

Bektas et al. [59] have investigated three-layer particleboards produced from a mixture of sunflower stalks and poplar wood using UF adhesives and targeted density of $0.7 g/cm^3$ with resin ratios of 25, 50, and 75 percent particles from sunflower stalks or poplar. The results revealed that it is possible to produce particleboards from the chips of sunflower stalks alone. The result showed that an increase in concentration of sunflower stalk particles in the composite matrix reduces both the physical and mechanical properties of the particleboard. Furthermore, the properties of the panels have improved with the rising percentage of poplar particles in the panels. The researchers investigated the possibility of utilizing particles from sunflower stalks and poplar wood in the manufacture of three-layer particleboard.

Fla´via. M. et al. [60] have investigated the technological properties of particleboards manufactured from sugarcane and bamboo particles at different matrices. The result showed using greater proportion of sugarcane particles in manufacturing particleboards resulted in increased absorption, thickness swelling and higher compaction rate of the particleboards negatively influences their stability. The investigation showed that an increase in the compaction rate of particleboards increased the MOR value. The increase in the compaction rate of particleboards influenced the MOE and reduced that of TSW and WA. The compaction rate of the particleboards reduced their wettability and increased the impermeability of their surface.

Balducci et al. [61] have selected different vegetal-pith-rich parts of crop plants, such as sunflower, topinambur, miscanthus, and corn stalks and hemp shives, with different sizes of particles bonded with 6% pMDI and UF resins, to the production of lightweight particle boards. They produce one and three-layer particle boards, the aggregates were blended with resin and pressed to a target density of 400 or 600 kg/m^3. The authors found that density was the main drawing factor affecting the investigated properties. Lightweight boards failed to meet the requirements of the P2 application (EN 312). Under the same conditions, topinambur boards showed higher IB than the rest of materials, whilst corn stalks showed the lowest IB.

Bajwa et al. [62] evaluated the feasibility of cattails for manufacturing particle boards for commercial applications. Straw- and cattail-based particleboards bonded with 3% of polymethylene diphenyl diisocyanate (pMDI) were manufactured using a hot-plate press (190 ℃ and 1.54 Mpa for 420 s). The targeted density was 480kg/m^3, and proportion of cattail and wheat straw was varied between 100 %, 50%, and 25%. Cattails and straw were used in the form of chips between 2 and 6 cm in size. It was found that the incorporation of cattails resulted in an improvement of the overall properties. The best results were obtained for mixtures of 70 % cattails and 25% straw, which exhibited MOE of 446.3N/mm^2, flexural strength MOR of 17.95N/mm^2 and internal bond, and lower water absorption and thickness swelling. The authors suggest that the use of cattail and straw for the manufacture of particleboards is feasible.

2.5. Physical and Mechanical Properties of Chipboards

2.5.1. Swelling Thickness

Swelling thickness is physical properties of the board, where immersed in a water for 2hr or 24hr and swelling thickness ability is determined. The effect of thickness swelling in particleboard is because of the moisture and absorption properties [63].

D. Biswas et al. [64] used the B. balcooa and for B. Vulgaris bamboo planer waste culm species and hammer mill chips with UF. The result showed that the density of boards made from chips was lower compared to that of planer wastes for both the species and boards made from hammer milled chips showed a 15 % increment in MOR values for B. balcooa and 8% for B. Vulgaris. for B. balcooa, the MOE of particleboard made from the planer waste was 27% lower compared to that of particleboard made from the chips. The result showed that thickness swelling and water absorption values of particleboards made from both chip and planer waste increased with an increase in soaking time.

2.5.2. Water Absorption

Water absorption is the amount of water absorbed by the particleboards during the immersion of board in water at room temperature, for 2hr or 24hr. It affects the dimensional stability of board. When board surfaces contact with water in the application area, the thickness is changed which results in reduction of mechanical properties of the chipboards [63].

Isabela Imakawa et al. [54] have investigated the influence of addition of coffee husk in bamboo. The result revealed in physical properties, density thickness swelling, and water absorption test for 24 hours, showed no significant difference among the coffee husk percentages.

Scatolino et al. [33] studied the analysis of Pinus wood with the residue maize cob, an improvement of the water absorption after 2 and 24 h of water immersion was observed for particleboard made from25% of maize cob. However the proportion of 50% of maize cob did not cause for a decrease of these properties, the author found that an increase of thickness swelling after 2 and 24 h with the increase in maize cob proportion was observed.

2.5.3. Modulus of Rupture

Modulus of rupture is an important property for determining the application of the product of particleboard. MOR is the measure of strength before rupture the boards. It can be used to determine the particleboard's overall strength [63].

Mario v. et al. [55] have done research on eucalyptus wood and coffee parchment fiber composite in different percentages of with 8% of UF. The result showed that a higher content of coffee parchment associated with eucalyptus wood reduces significantly the MOR values.

Kumar et al. [65] evaluated the mechanical properties of polyester Typha fibers in the composition of wood powder and coconut shell ash. Four filler concentrations were fabricated, test results showed that tensile strength, elastic modulus, and micro-hardness of the composite increase with an increase in filler concentration.

Gokay N. et al. [66] have studied, the effects of particle moisture content, swelling ratio, and addition of wood dust on the mechanical properties and physical property of particleboard from Alder (Alnus glutinosa subsp. Barbata) wood (UF) for particleboard manufacturing. The result revealed that the addition of 10% wood dust to particles decreased the thickness swelling, modulus of elasticity, and bending strength while increasing the internal bond of particleboards.

2.5.4. Tensile Strength

Tensile strength is a significant property of the chipboard. A tensile strength test is a mechanical test performed on the board to determine maximum load that can be applied to a material before it ruptures or tears. The sample was placed on the machine and anchored at both ends. As the machine started, both tensioned ends were stretched till it failed. Failure occurred by splitting [63].

Jacob O. et al. [67] evaluated the effect of polyester content on the properties of coconut shell composites. The polyester composite was prepared by incorporating coconut shells at different contents into a polyester matrix. The effect of coconut shell content on the mechanical, water absorption, and morphological properties were studied. The results revealed that increases in coconut shell content have increased the tensile strength, young's modulus, and the water absorption but reduced the elongation at break.

Wycliffe O. et al. [30] investigated the effect of fiber concentration and fiber size on mechanical properties of rice husk fiber reinforced polyester composites, the experimental analysis revealed that both fiber size and fiber weight fraction have a significant effect on the tensile and impact characteristics of rice husk fiber reinforced polyester composites. Tensile moduli of fiber-reinforced composites appear to decrease with an increase in fiber weight fraction, except for medium size RHF composite. Concluded from these results, the UPR (unsaturated polyester) matrix has a greater stiffness than RHF.

2.6. Process Parameters and Optimization Techniques

The significant manufacturing parameters of chipboards are the size and proportion of materials, adhesive percentage or loading, pressing pressure, temperature, and pressing time [68, 15, 29]. Extensive works have been done on the particleboard manufacturing process parameters optimization process, among them, the related work was reviewed.

Dejun. L. et al. [69] have optimized the manufacturing and process optimization of porous rice strawboard. The significant manufacturing parameters included were the proportion of inorganic to organic gelling materials, adhesive added ratio, pressing pressure, temperature, and pressing frequency. The hot pressing board production technique was used. The performance characteristics considered in this research were MOR, IB, TS2h, and density. The analysis results revealed that the best combination of the parameters in the fabrication process was: a pressing pressure 30MPa, an inorganic to an organic gelled material ratio of 4:1, the proportion of adhesive in strawboard mass ratio of 40%, a pressing frequency control less than 10 times per minute, and a pressing temperature between 120 and 140℃. The results also showed that the pressing pressure, pressing temperature, and pressing frequency rate influenced the performance of the strawboard, from higher to lower order.

Wan Noor A. et al. [68] studied utilization of the oil palm trunk for the production of binder-less (self-bonding) particleboard. The authors considered the manufacturing variables such as steaming pressure, steaming time, hot pressing temperature, and hot pressing time was used to evaluate the mechanical dimensional stability properties of particleboard. The mechanical properties and physical properties studied were: MOR, IB, TS, and WA. Using the RSM they found the optimum process parameter combination condition for manufacturing.

Amenaghawon et al. [15] optimized mechanical properties of the corn and cassava particleboard using response surface methodology (RSM), the optimum value of modulus of rupture (MOR), and modulus of elasticity (MOE) investigated. They investigated the production of particleboards under different board densities, resin loading, and amount of agro residue using Box-Behnken design. Analysis of variance (ANOVA) revealed that MOR and MOE were influenced by the amount of resin and agro residue used. They concluded that board density did not have any significant effect on the MOR and MOE of the boards produced.

Mohammed, et al. [29] have done research on multi-objective optimization of injection molding of the rice husk with polypropylene considering control factor such as melting temperature, injection pressure, and injection speed and cooling time. L9 orthogonal arrays were selected to run the experiment. Using the Taguchi method coupled with Grey Relation analysis, GRG and GRC analysis revealed that injection pressure, followed by melting temperature, injection speed, and cooling time had the most substantial impacts on strength and hardness. The ANOVA analysis showed that injection pressure, has the highest percentage of contribution (59.59%), followed by temperature (15.87%), injection speed (14.68%), and cooling time (9.86%) and the validation is successful.

M. Mustafaiz et al. [70] reported electric discharge machining (EDM) process parameters included in the study chosen as significant were peak current (Ip), pulse time on (Ton), duty cycle (TAU), and voltage gap (V) and the response were MRR. From ANOVA analysis the author found Ton and peak current have a significant influence on the material removal rates during the machining process.

Maheswara. R et al. [71] conducted a study on the application of the Taguchi based grey relational grade method to optimize the multi-responses in cutting process parameters. They investigated the effect of EN19 steel cutting parameters such as cutting speed, feed, and depth of cut on material removal rate and surface roughness characteristics. The grey relational grade results revealed that the optimum cutting parameters are found at 250 m/min, 0.1mm/rev, and 0.8 mm. The ANOVA analysis showed that feed is the most influencing parameter on the multi-response and followed by speed and depth of cut. The author finally concluded that the Taguchi-based grey relational grade method is a highly effective method to solve multi-objective problems.

Hossein. H et al. [72] reported the Taguchi- grey relational optimization of different process parameters of the rotor spinning system such as rotor diameter, rotor speed, yarn linear density, navel type, and opening roller speed with three level. The performance characteristics selected were CVm%, tenacity, and number of hair per meter. The L27 orthogonal array was used for experimental design ANOVA analysis revealed that speed is the most significant factor for affecting the multiple performance characteristics and navel type has no significant effect on the multiple performances.

Basmacia. G et al. [73] have done an experimental investigation on surface roughness and cutting forces of PMD 23 cold work tool steel milled with multi-layer Al_2O_3+TiCN coated cutting tools. The milling process parameters selected were feed rate, spindle speed, and depth of cut with three levels. Taguchi L9 experimental designs were used. The authors used the Taguchi –Grey relational analysis, the optimum process parameter levels were obtained to be feed: 500 mm/min), spindle speed: 3500 rpm, and cutting depth: 1.0 mm. the result showed that the wiper inserts in obtaining excellent surface roughness.

Some of the commonly used manufacturing techniques are:-hand layup technique, compression molding technique, vacuum-assisted resin transfer molding technique, injection molding technique, and pultrusion technique [1]. Wood flour, flax, rice husk, and bagasse fibers are extensively used in light structural walls, insulation materials, floor and wall coverings, window frames, geotextiles, and roofing. The key drives for using natural fibers in the construction industry are low cost, low and easy maintenance, eco-friendly, easily available, and friendly government regulations [74]. Natural fiber-reinforced composites currently occupied many sectors due to their superior qualities such as low density, biodegradable and recyclable, acceptable specific strength, ease of availability, reduced tool wear during the molding process, better acoustic properties, low cost, and ease of processing.

Generally, the above-reviewed literature has done the characterization mechanical and physical, optimization particleboard manufacturing process parameters such as reinforcement percentage, particle size, matrix percentage, manufacturing conditions like pressing pressure, temperature, time, curing time, etc. Therefore, in the present work coffee husk and sawdust weight fraction, resin content or loading, pressing pressure, pressing time and pressing temperature was considered for the study of: - modulus of rupture, tensile strength, swelling thickness, and water absorption. Taguchi-grey relation analysis is used for the multi-objective from the available optimization techniques. In comparison with conventional methods which requires massive amount of samples, typical (e.g. linear exponential or logarithmic) distribution of samples and large amount of calculation work, GRA possesses the following advantages: simple and easy calculation, reasonable number of samples, typical distribution of samples is needless, no contradictory conclusions against the qualitative analysis, suitable and effective in dealing with discrete data [75]. Therefore, Taguchi –grey relational, multi-response process parameter optimization technique was selected to be employed in analysis of the experimental data.

2.7. Summary of Literatures

The composite materials have become an interesting study area. The natural fiber composites such as wood-based and non-wood (agro-based) are currently used for different interior and exterior applications. The researchers have done study on the mechanical and physical characterization of the material, effects of percentage of mixtures of composite and resin content, natural fiber type, size, and process parameters like pressing pressure, time, temperature, and curing time on both physical and mechanical performance of the particleboards. To manufacture the materials the researchers suggest that optimization of process parameters using different techniques is important to obtain optimal performance in the best combination of parameters and this brings the benefits of decreasing the trial experiments, reduce the cost of experiments, and quality product will be attained.

2.8. Research Gaps

Many researchers have done research on the agro-based residues such as coffee husk, rice husk, and bamboo, maize cob, combined with wood and different kind of resin, to produce the particle board as we have seen in a literature review. The effects of process parameters on the performance characteristics of the process have been done by many researchers on different residues (i.e. coffee husk) composites, however very few researchers have done the optimization of process parameters for chipboard manufacturing. Considering this as research gaps there is a need for parametric optimization of coffee husk-sawdust chipboard manufacturing process parameters using Taguchi method coupled with grey relation analysis for the multi-response process.

CHAPTER 3

3. Materials and Experimental Methods

3.1. Introduction

In the present work, composite board was made by using the coffee husk and sawdust with different weight fraction combinations. Unsaturated polyester resin (UPR) was used as the binder with different weight percentages and 2% of methyl ethyl ketone peroxide (MEKP) hardener also used as reagents for fast curing of the board. During preparation of chipboard; coffee husk, sawdust and binder contents were considered as process parameters that influence the performance characteristics (MOR, TM, WA, and TS). Additionally, the process parameters of machines such as pressing pressures, temperatures, and time were treated as process parameters to have the best combination of process parameters that give the optimal value. Mixed level L_{18} OA was used to design DOE of the experiment. The chipboards have been made in Addis Ababa, Ethiopia, at Addis Ababa Poly Technic (Ethio - China) College, in a woodworking workshop as per the DOE for each run, and specimens were prepared based on ASTM standards. The three-point flexural, tensile, water absorption, and swelling thickness tests were conducted at Ethiopian Defense Engineering University, in a mechanical engineering lab.

The experimental data were recorded for further statistical analysis using Taguchi-grey relational analysis. Taguchi-grey relational analysis has been done, and from the grey relational grade mean effect, the optimal parameter combination was determined. The ANOVA variance analysis was done to identify the most influential parameter on the response and contribution of each parameter was determined. The experimental work plan and methods were shown in Figure 3.1.

3.2. Materials Used

The coffee husks and sawdust were used as reinforcement and unsaturated polyester (UPR) as matrix and methyl ethyl ketone peroxide (MEKP) as curing agents. Sodium hydroxide (NaOH) for coffee husk treatment, mold releasing agent used to remove cured composite easily from the mold. UPR, MEKP, releasing agent, was purchased from a world fiberglass limited company located in Addis Ababa, Ethiopia. The coffee husk used in the present work was collected from Jimma zone coffee processing industry. Wood was used to make a mold box for mat preparation.

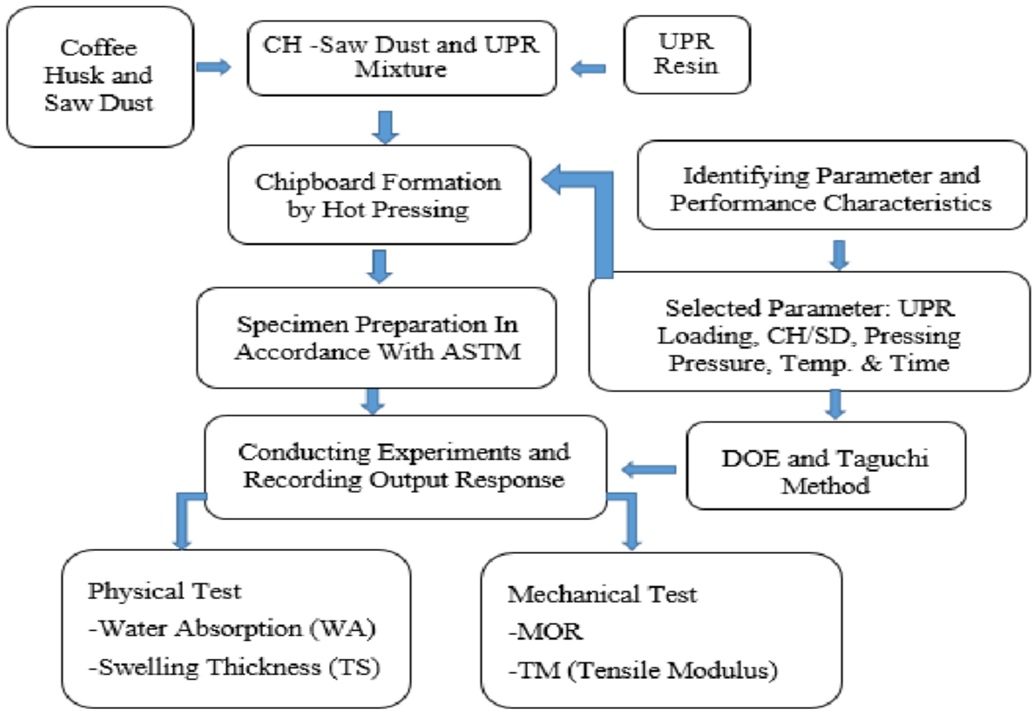


Figure 3.1: Experimental work structure.

3.3. Research Tools and Equipment

To meet the objective of the present work, the basic tools and equipment used were the MH3848x50T/60L hydraulic pressing machine, universal testing machine, vertical band saw, mold box, sieves, digital electronic balance, and digital venire caliper. Figure 3.2 (c) hydraulic press is the most efficient form of presses. It applies a hydraulic mechanism for applying large lifting or compression force. Once the mats of waste were formed into desired lengths, consolidated under press applies heat and pressure to activate the resin and bond fiber into a solid panel. Continuous presses are useful to produce particleboards. Press temperature and time vary according to the products that are being produced [76]. Other equipment used was polyester mixing containers, stirring rod, brush, mask, and glove were equipment used while facilitating the experimental work.

A. Coffee Husk and Sawdust Preparation

After coffee husk was collected the next important job is sizing and the treatment of the

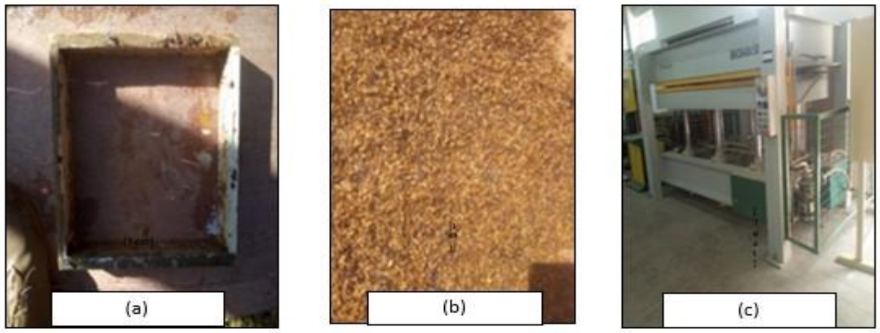


Figure 3.2: (a) wooden mold, (b) Coffee husk chips and (c) Hydraulic pressing machine.

Figure 3.3: (a) Digital venire caliper, (b) Triple beam balance, (c) digital weight measuring device.

fiber which influences the properties of the fiberboard. Coffee husk fibers were first washed with water to remove the impurities such as sand, dust, and particle. The fibers were then dried in the open sun for three days and ready for the next chemical treatment. From industrial caustic soda (NaOH), 5% w/v NaOH solution was prepared using water to treat the coffee husk fiber. Then coffee husk was immersed as shown in Figure 3.4 (a) in the 5% alkali solution (NaOH), the duration of immersion were stayed for 1 hour. Then the fiber is washed with water and dried in the open sun for four days took places. Treatments of the coffee husk (fiber) surface removed waxes and others, thus make the adhesion of fibers and polymer matrix easy. Chemical, biological and physical treatments may improve the morphological features, improve the mechanical properties of the board [22]. Figure 3.4 (b) once coffee husk was treated and dried, the size of coffee husk was reduced and allowed to pass through 5mm sieve to gain the uniform chip size which results in uniformity in the surface of the chipboard. In the same way, the sawdust from wood (Cordia Africana) was screened with 2mm of sieve to separate from the larger chips or sheaves and ready for the next work.

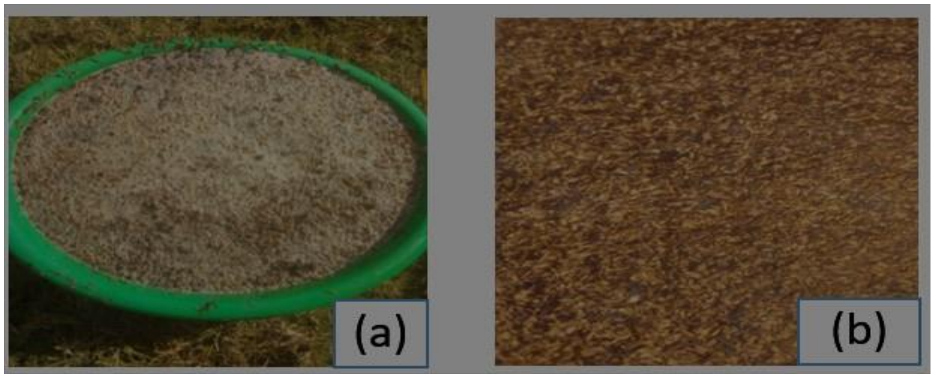


Figure 3.4: a) Coffee husk treatment with NaOH solution and (b) dried coffee.

3.4. Experimental Design

The experimental work plan is an important activity to conduct a successful experiment. In this work the controllable or process were pressing pressure in increasing from (4Mpa, 6Mpa), temperature (160℃ , 170℃ , 180℃), coffee husk fiber and sawdust weight fraction (fiber loading ratio) is 1:0, 1:1 and 3:1 as shown in Table 3.2**,** where the reinforcement used for a single board were 250g only and binder content (200g, 250g, 300g), average targeted density of 0.7g/cm^3 and 6mm targeted thickness. The hardener loading was 2% of the resin weight used for single chipboard. For example, the hardener loading for 200, 250, 300 grams of resin was 4g, 5g, and 6 g respectively. The average mass of the chipboard was 500, 550, 450 grams. It varied due to variation of the matrix loading in each experimental run. Physical and mechanical experiments conducted were swelling thickness, water absorption tensile, and flexural tests.

The OA was selected by considering number of parameters, and their corresponding levels. The number of process variables was five and one parameters with two level and others with three-level. The orthogonal array selector table was used to select the proper orthogonal array [77]. For present work L_{18} $(2^1 x 3^4)$ with mixed level OA was selected and Table 3.1, generated on a spreadsheet using Taguchi design on Mini tab, 17 software. Depending on the OA, the design of experiments was designed and leveled for each run shown in Table 3.4**.** Compression molding techniques were used in the manufacturing of the chipboard. Using the DOE, (Eighteen) 18s chipboard were made with different combinations of parameters such as pressing pressures, temperatures, time, binder content, coffee husk, and sawdust percentage. The chipboard was cured in 1-3 minutes but, to dry completely they were kept open sun-dried for three days, and ready for experiments. The next job was specimen preparation for both physical and mechanical tests for swelling thickness, water absorption, three-point bending, and tensile strength.

3.4.1. Process variables and levels

The reinforcement, matrix, pressing pressure, temperature and time were process variables considered in manufacturing chipboard of each run shown in Table 3.2**.**

B. Preparation of Chipboard

The properties of the final product of the chipboard depend on the type and size of fiber used. Therefore, preparation of the coffee husk is one of the crucial factors in chipboard manufacturing**.** Figure 3.7 shows the procedures to follow in chipboard preparation. The already sieved, treated and dried coffee husk, sawdust, and unsaturated polyester were weighted with a digital electronic balance to their corresponding loading in the DOE, the same was true for sawdust. The sawdust was from"wanza" wood (Cordia Africana) was collected from the woodwork industry and sieved with a 2mm sieve. The coffee husk fiber was mixed with the corresponding weight fraction of the experimental arrangement in Table 3.3 and UPR resin was poured into the material and stirred manually for 10 minutes to get homogeneity in the mixture. Then, the 2% of MEKP hardener was added to the mixture to initiate the reaction for the curing process. These reagents faster the curing time of the chipboard. The percentage of mixture or matrix was according to the design of the experiment. The wooden mold was cleaned and releasing agent was applied to the inner surface of the mold to prevent sticking of the composite material to the surface during the withdrawal of the board. The mixed material was poured into 350mm x 290mmx 6mm the wood made mold and cold-pressed at 1Mpa for 1 minute to form a mat. After the formation of mats; the mats were compressed using compression molding technique under hot pressing machine plates were kept at their leveling pressing temperature raised from 160, 170, 180 degree Celsius, pressure from 4 Mpa to 6Mpa and, pressing times from 8, 10, 12 minutes for each runs in accordance with design experiment with 6mm targeted thickness of the chipboard and released.

Table 3.1: Standard OA forL_{18} (2^1x3^4) Taguchi design.

Run	Pressure(MPa)	Temp(℃)	CH/ SD Ratio(g)	Time(min.)	UPR (%)
1	1	1	1	1	1
2	1	1	2	2	2
3	1	1	3	3	3
4	1	2	1	1	2
5	1	2	2	2	3
6	1	2	3	3	1
7	1	3	1	2	1
8	1	3	2	3	2
9	1	3	3	1	3
10	2	1	1	3	3
11	2	1	2	1	1
12	2	1	3	2	2
13	2	2	1	2	3
14	2	2	2	3	1
15	2	2	3	1	2
16	2	3	1	3	2
17	2	3	2	1	3
18	2	3	3	2	1

Table 3.2: Process parameters and levels.

Parameters/Levels		Level 1	Level 2	Level 3
A	Pressure(MPa)	4	6	-
B	Temperature (℃)	160	170	180
C	CH/SD Ratio(g)	1/-	3/1	1 / 1
D	Time(min.)	8	10	12
E	Resin content (%)	40	50	60

After the pressing processes, the chipboard is withdrawn from the mold using a hammer if there exists any sticking of the material to the mold and trimmed to 320mm x 270mm. Once it was released the next step was the preparation of the specimens according to the ASTM cut into sizes for each test by using a vertical band saw.

Table 3.3: The weight fraction of reinforcement treatment for experiment.

S.No	The Weight Fraction of Reinforcement(W_r)	
	Ratios (CH/SD)	Mass(g)
1	1:0	250/-
2	1:1	125/125
3	3:1	187.5/62.5

Table 3.4: Experimental runs arrangement and their leveling.

Run	Pressure(MPa)	Temp(°C)	CH/ SD Ratio(g)	Time(min.)	UPR (%)
1	4	160	1/-	8	40
2	4	160	3/1	10	50
3	4	160	1/1	12	60
4	4	170	1/-	8	50
5	4	170	3/1	10	60
6	4	170	1/1	12	40
7	4	180	1/-	10	40
8	4	180	3/1	12	50
9	4	180	1/1	8	60
10	6	160	1/-	12	60
11	6	160	3/1	8	40
12	6	160	1/1	10	50
13	6	170	1/-	10	60
14	6	170	3/1	12	40
15	6	170	1/1	8	50
16	6	180	1/-	12	50
17	6	180	3/1	8	60
18	6	180	1/1	10	40

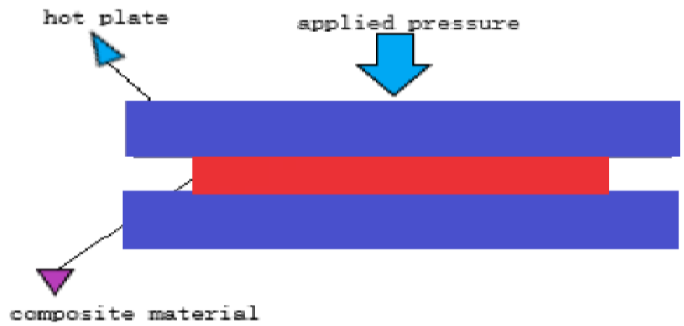


Figure 3.5: Compression molding working principle diagram.

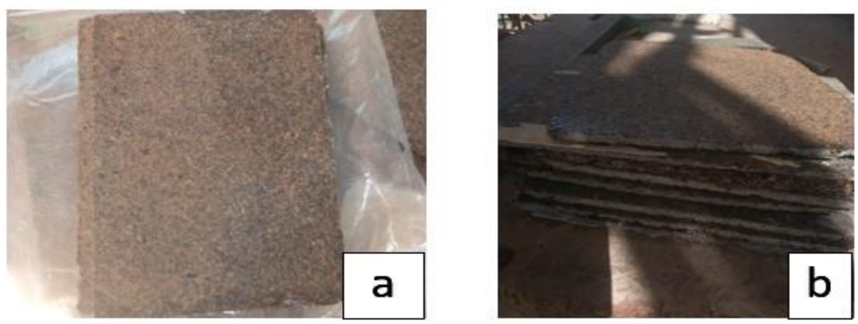


Figure 3.6: Chipboards made from coffee husk-saw dust

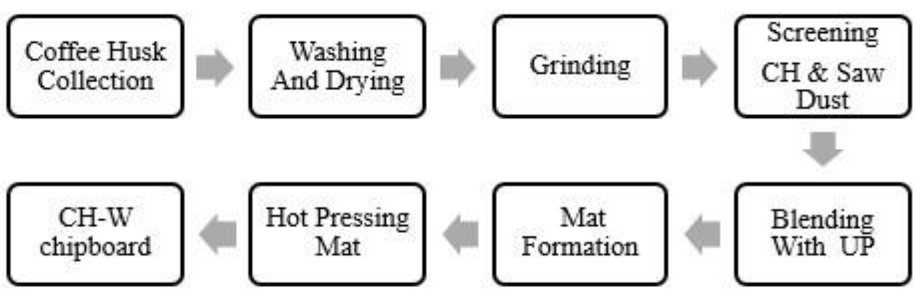


Figure 3.7: The schematic chipboard preparation procedure.

3.5. Experimental Set ups and Specimen Preparation

3.5.1. Specimen preparation

The specimen for the experimental work were prepared according to the ASTM D-1037-99"standard test methods for evaluating properties of wood-based fiber and particle panel materials". The specimens were prepared by cutting the chipboards to the sizes of samples for both physical and mechanical tests. The dimensions of specimen were in accordance with the ASTM for the three-point bending test, tensile test, swelling thickness, and water absorption test. To meet the objective of this work different experiments were conducted in accordance with the ASTM (American Society for Testing and Material) standards for mechanical properties (tensile and bending) and physical properties (WA and TS). The mechanical properties such as tensile modulus (TM) and modulus of rupture (MOR) were investigated, additionally, physical properties like swelling thickness and water absorption were investigated for each sample. The sample sizes of the specimens used as per ASTM D-1037-99 were shown in Table 3.5, where, t-is the thickness of the board and for this case, it was 6 mm.

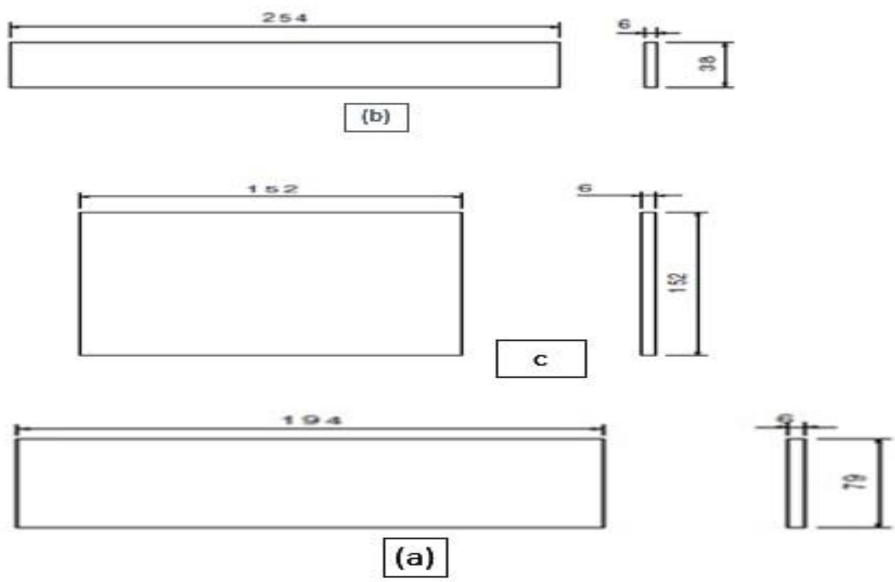


Figure 3.8: a) Bending test, b) Tensile test and c) WA and TA specimen dimensions.

Table 3.5: Standard sample size of the tests.

S.No	Physical and Mechanical properties	Sample size length	Dimension(mm)
1	Modulus of Rapture (MOR)	24xt mm+50mm	194 mmx76mm
2	Tensile modulus (TM)	255mm	254 mmx38mm
3	Swelling Thickness(TS)	152mm	152 mmx152mm
4	Water Absorption(WA)	152mm	152 mmx152mm

3.6. Mechanical Properties Test

3.6.1. Tensile Test

Tensile testing is almost universally employed to express the mechanical properties and to supply the most useful fundamental information regarding the behavior of materials. The testing machine most commonly used is called the universal testing machine. The name "Universal" is given in the sense that the machine may be adapted to carryout tension, compression, direct shearing, and bending tests. Tensile test was made on specimens both with the long dimension parallel to the long dimension of the board to determine whether or not the material has directional properties Tensile strength in the parallel-to-face orientation is the resistance of a board material to be pulled apart parallel to its surface. The maximum load at the time of fracture is divided by the cross-sectional area (width thickness) of the specimen to give maximum strength [23]. For a tensile test, grippers transmit the load from the testing machine to the specimen. Speed of testing applies the load continuously throughout the test at a uniform rate of motion of movable crosshead of the testing machine of (4 mm/min). The specimen dimension was in accordance with the ASTM and the tensile strength parallel to surface testing for the chipboard having the block type specimen was conducted. The tensile modulus (TM) and tensile strength (T) of the specimen can be computed using Equation 3.2. The tensile strength of the specimen was computed by the universal tensile machine according to Equation 3.1.

$$T = Pmax/A \qquad (3.1)$$

Where T is the tensile strength, P_{max} is the maximum tensile load applied, A is the original cross-sectional area.

$$TM = \frac{\sigma}{\varepsilon} \qquad (3.2)$$

Where σ is stress in Mpa and ε strain.

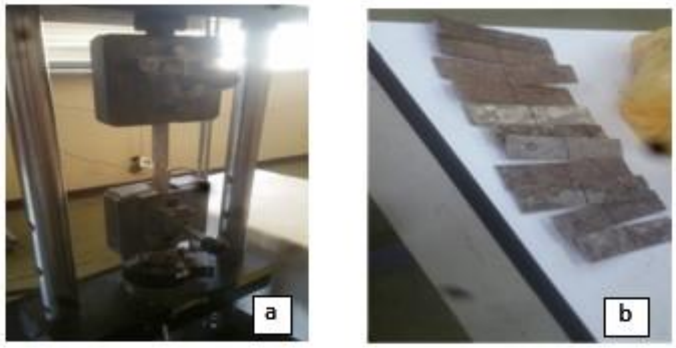


Figure 3.9: (a) Tensile test, (b) Tensile test specimen.

3.6.2. Flexural Test

Three-point bending tests were conducted using the universal testing machine for each specimen. The sizes of the specimen were from the ASTM standards. The span for each test shall be 24 times the nominal thickness of the specimen and the knife-edge supports were used in these experiments. The nose loading was selected to be 45 degrees and the movable crosshead loading speed of the machine was 3 mm/min applied uniformly.

Modulus of Rupture

Bending specimens of 76mm and wide 194mm long were cut from each full particleboard. A concentrated bending load was applied at the center with a span of 24 times the thickness of the specimen. The supports shall be such that no appreciable crushing of the specimen will occur at these points during the test. The supports used were knife edges provided with rollers and plates under the specimen at these points.

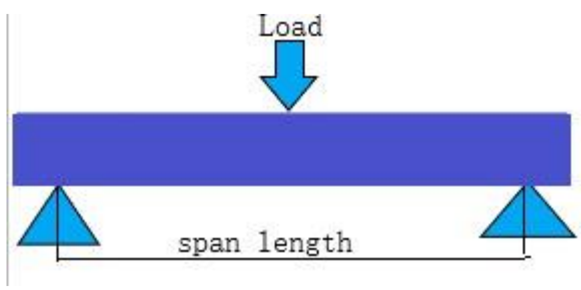


Figure 3.10: Three point bending test diagram.

Using Equation 3.3, the modulus of rupture (MOR) was calculated from load-deflection curves.

$$\mathrm{MOR} = \frac{3p_b * L}{2bh^2} \quad (3.3)$$

Where P_b is the maximum load (N), b is the width of the specimen, (mm), h is the thickness of the specimen, (mm), and L is span length, (mm).

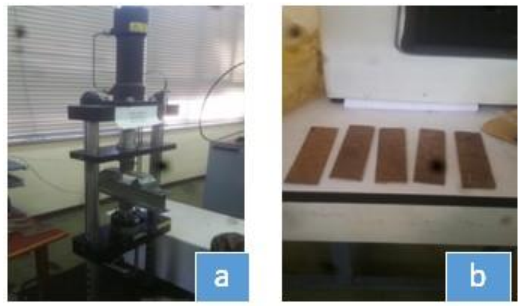


Figure 3.11: (a) Bending test, (b) Bending test specimens.

3.7. Physical Properties Test

3.7.1. Water Absorption

Water absorption is used to determine amount of water absorbed under specified conditions. The specimen's dimensions of 152mmx152mm were prepared for evaluation of water absorption. For the present work, a continuous 24hr submersion method was applied. For the water absorption, the test procedure is as followed, specimens are dried in an open /oven for a specified time and temperature and then placed in a desiccator to cool. Immediately upon cooling the specimens are weighed. The material is then emerged in water at agreed-upon conditions, often at 23 C for 24 hours or until equilibrium. Specimens are removed, patted dry with a lint-free cloth, and weighed. The amount of water absorbed can be drawn from the increase in weight of specimen during submersion, and express water absorption as the percentage of weight after conditioning. Water absorption is expressed as Equation 3.4, increase in weight percent the difference between the wet weight and dry weight divided by the dry weight multiplied by hundred. The values of the WA as percentages were calculated where WA (t) is the water absorption (%) at time t, $W_{(0)}$ is the initial weight, and $W_{(t)}$ is the weight of the sample at a given immersion time t.

$$WA(t) = \frac{W(t) - W_0}{W_0} * 100 \quad (3.4)$$

3.7.2. Swelling Thickness Test

The specimens with dimensions of 152 mm x 152 mm were prepared for evaluation of the thickness swelling. The thickness of each test sample was measured at the center of each side at four places by using a digital venire caliper. The average of the four readings was recorded. Each test sample was then immersed in water. After 24hrs each test sample was withdrawn from water and the wet surface wiped with a dry cloth. The thickness of each test sample is measured at the same points as before and the thickness increased is estimated using Equation 3.5, by multiplication of the initial and final thickness difference by a hundred then divided by the initial thickness of the sample.

$$\mathrm{T}S = \frac{T_{24} - T_0}{T_0} * 100 \qquad (3.5)$$

Where TS is the thickness swelling rate (%), t_0 and t_{24} are the thickness at the middle of the test specimen.

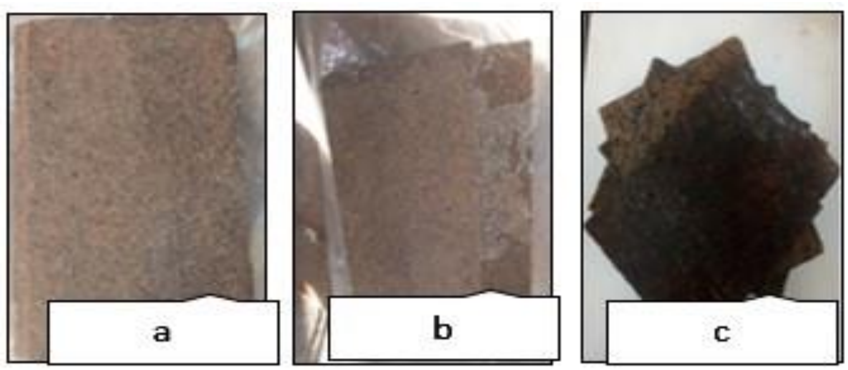


Figure 3.12: Sample specimens for WA, TS test (a, b) and (c) specimen after immersed

CHAPTER 4

4. Research Methodology

4.1. Introduction

The research methodology begins with reading related articles and journals of agricultural residues composites of particleboard production and parametric optimization of boards manufactured from both agro-residues and wood based composites, these bring to understand process parameters that affect the performance characteristics and recent status of the research. Then, gathering materials and information needed for sample preparation such as selecting parameters, factors level and selecting orthogonal array the specimens were prepared using ASTM standard and experimental setups to conduct experiments for each performance characteristic depending on the DOE. After the experiment is conducted and response data were recorded for further statistical analysis using the Taguchi method coupled with grey relational analysis and the best combination of the parameters was obtained and analysis of variance was done.

To meet the main objective of this work, different experiments were conducted in accordance with the ASTM standards for mechanical properties and physical properties. In this work, mechanical properties like tensile modulus (TM), modulus of rupture (MOR), swelling thickness (TS), and water absorption (WA) were investigated for each sample and optimal value was found. The methodology of this research is shown in Figure 4.1.

4.2. Taguchi Method

In the early 1980s, Genichi Taguchi begun to develop new methods applied to multidiscipline fields of study like engineering, biotechnology, marketing, and advertising experimentation [78]. Taguchi developed the techniques that are now known as Taguchi or fractional factorial Methods. Taguchi designed experiments using specially constructed tables known as "Orthogonal Arrays" (OA). The OA provides fractional factorial experiments, which satisfy a number of situations. The use of these tables makes the design of experiments very easy and consistent [27, 73].

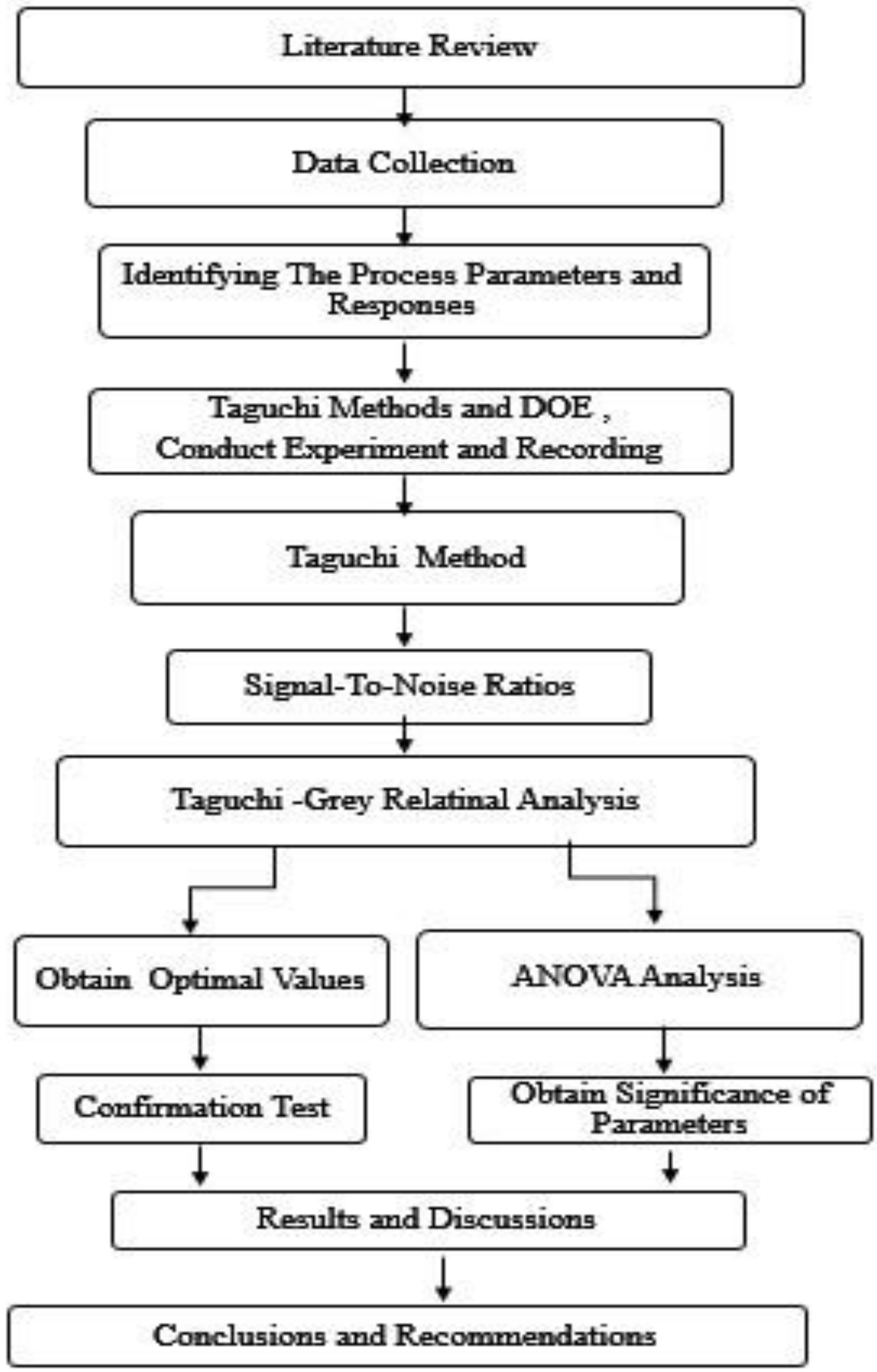


Figure 4. 1: The structure of research methodology.

The Taguchi method for experimental design is a powerful problem-solving technique for improving process performance product, process, design, and system with a significant reduction number of the experimental run, time, and cost. Taguchi technique increases the power of Analysis of experimental data by complex analysis of variance and an efficient way to determine the optimum factor level [79, 80].

The objective of Taguchi method is to select best combination of control parameters so that the product or process is most robust with respect to noise factor [81]. To determine the best design, it requires the use of a strategically designed experiment, which exposes the process to various levels of design parameters [77].

The design of experiments (DOE) is an organized approach to find out the effect of the input factors on the output of the process and help to optimize it, which was proposed by A.Fisher in the 1920s. This method is known as the factorial design of an experiment. This method used the full factorial DOE which is a set of possible combinations of factors. As a result, there exists an increase in the number of experiments in a full factorial design. Therefore, to reduce the number of experiments, DOE approach such as the Taguchi method used in the number of experimental runs selection [26, 27, 82].

The essential concept of the Taguchi quality method is a loss function for a particular production process, calculated by evaluating equivalent signal-to-noise ratios (SNRs), defined as the ratios between the magnitude of a process mean and its variation; this allows the best solutions to a problem to be defined as those leading to maximum SNRs and minimum values of the loss function [83].

In industrial applications, the various system elements are input, output, controllable factors, and uncontrollable factors. Uncontrollable factors are variables known to have an influence on the output but are either unidentified, difficult to control, or are not economically controlled which are called noise factors in Taguchi DOE [26]. The S/N ratio for each level of process parameters is computed based on S/N analysis. Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) is performed to see which process parameters are statistically significant. With the S/N and ANOVA analyses, the optimal combination of the process parameters can be predicted. Finally, a confirmation experiment is conducted to verify the optimal process parameters obtained from the parameter design. Example [84] have investigated the optimization of injection moulding parameters for manufacturing products from plastic blend.

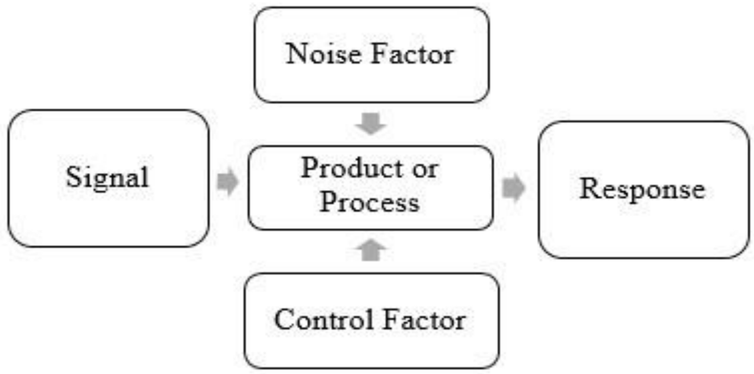


Figure 4.2: Block diagram of the system input and output factors.

4.3. Signal to Noise Ratio (S/N)

In Taguchi technique, the variation of the response is also examined using an appropriately chosen S/N ratio. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). These S/N ratios, derived from the quadratic loss function, are expressed on a decibel (dB) scale. The formula used to compute the S/N ratio depends on the objective function [85]. The three quality characteristics are larger is better, smaller is better, and nominal is best. No matter how the quality of the product is measured by a single criterion or by a combination of multiple criteria, the measure possess one of the following three quality characteristics that indicate the direction of desirability or objective of results and computed using the Equation 4.5, 4.6 and 4.3 [77, 78].

1. Larger the Better

Is applied when the quality objective of the value is intended to be maximization. For this case, the Modulus of rupture and Tensile Modulus needed to be larger.

$$\text{S / N ratio } (\eta_l) = -10 log_{10}[(\frac{1}{n})\sum_{i=1}^{n}(\frac{1}{{y_{ij}}^2}) \quad (4.1)$$

2. Smaller the Better

Is used when the required quality objective value is minimized, the smaller-the-better (SB) method applies; such as swelling thickness and water absorption.

$$\text{S /N Ratio } (\eta_s) = -10log_{10}[(\frac{1}{n})\sum_{i=1}^{n} {y_{ij}}^2] \qquad (4.2)$$

Where n= number of replications, y_{ij} = Observed response value and where, i =1 ,2...n;

j = 1, 2 ...k

3. Nominal the Better

This quality characteristics is applied when the nominal value is target value.

$$\text{S / N ratio } (\eta_s) = -10log_{10}(\frac{\mu^2}{\sigma^2}) \qquad (4.3)$$

$$\sigma^2 = \frac{\sum(y_{ij}-y)^2}{n-1} \qquad (4.4)$$

Where $\mu = y_1 + y_2 + y_3 + y_4 .... + y_n$

Taguchi Method Procedures

The process of performing a Taguchi experiment and analysis of the data steps are as follows.

Formulation of the problem— understanding of the nature of the problem.

- Identifying the output performance characteristics relevant to the problem.
- Identification of control factors, noise factors, and signal factors.
- Selection of factor levels and possible interactions.
- Design of an appropriate OA of the experiment.
- Running the experiment with appropriate data collection.
- Statistical analysis and interpretation of experimental results.
- Performing a confirmatory run of the experiment.

4.4. Grey Relational Analysis

The grey systems theory, established by Julong Deng in 1982 and it is a new methodology that focuses on the study of problems involving small samples and poor information [86]. The grey relational analysis based on the grey system theory can be used to solve the complicated interrelationships among the multiple performance characteristics effectively

[87]. Using grey relational analysis the complex multiple response optimization can be simplified into the optimization of a single response Grey relational grade.

The traditional, Taguchi method is a systematic application of design and analysis for experiments. It has proved to be an effective approach to produce high quality products at a relatively low-cost [88]. However, the original Taguchi method has been designed to optimize a single performance characteristic. To handle the multiple response performance characteristics optimization problems faced in manufacturing industries Taguchi coupled with grey relational analysis is adopted for this study.

The procedures for Taguchi-Grey Relational Analysis

In Taguchi-grey relational analysis, the performance characteristics of the chipboard manufacturing:-MOR, TM, TS, and WA were identified. The process parameters considered were:-pressing pressure, temperature, time, binder content (UPR), and composite percentage (CH-SD). The mixed L_{18} OA selected and leveled was. After the proper selection of OA, the sample was prepared and experimented according to the orthogonal array assignment, and data were recorded.

The next important step is the grey relational analysis. The grey relation analysis is used to convert the multiple response optimization problems into a single response optimization problem. In the present work, the objectives were to obtain lower WA, TS, and higher MOR, TM. The grey relation analysis converts this multi-objective problem into a single objective problem by using an overall grey relation grade. The optimal parametric combination is then evaluated by maximizing the overall grey relational grade. The overall grey relation grade is an average of grey relational coefficients of each selected response. The grey relational coefficient represents the correlation between the desired and actual experimental data. The grey relational coefficient is computed based on the experimental results of each selected response. In calculating the grey relational coefficient first the experimental data are normalized ranging from zero to one [0, 1], this process is known as a grey relational generation.

The experimental data for each quality characteristic is converted into an S/N ratio. These S/N ratios for each quality characteristic are normalized using the following grey relational generation Equation 4.5 and 4.6. The Taguchi-grey relation optimization of the process parameters was performed in the following steps [89]:

(a). Normalizing the experimental results of MOR, TM, WA, and TS for all runs.
(b). Performing the grey relational generating and calculating the GRC.
(c). Calculating grey relational grade by averaging grey relational coefficient.
(d). Performing statistical analysis of variance (ANOVA) for the input
(e). parameters with the grey relational grade and to find which parameter significantly affects the process.
(f). Selecting the optimal levels of process parameters.
(g). Conduct a confirmation experiment and verify the optimal process parameters setting.

A. Normalize the S/N Values

Data pre-processing is the first step in the procedure for using GRA. Data preprocessing involves transforming original sequence into a comparable sequence [90]. The responses quality characteristics are normalized ranging from zero to one. This process is known as a grey relational generation. There are three approaches used for the normalization process. If the target value of the original sequence is infinite, then it has a characteristic of the "larger-the better". The original sequence can be normalized using Equation (4.5). To avoid the effect of adopting different units and to reduce the variability.

$$x_i * (k) = \frac{y_i(k) - \min y(k)}{max\, y_i(k) - min y_i(k)} \tag{4.5}$$

When the lower-the-better characteristic of the original sequence is considered, then the original sequence should be normalized using Equation 4.6.

$$x_i * (k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - min y_i(k)} \tag{4.6}$$

Where, i=1, 2, 3......m, m = number of experimental runs in Taguchi orthogonal, in the present work L18 orthogonal array is selected then m = 18. k = 1, 2 ... n, n = number of quality characteristics or process responses, in the present work, n =4, $y_i(k)$, is the S/N ratio based on the experimental data. $miny_i(k)$, is the smallest value of $y_i(k)$ for the k^{th} response. $maxy_i(k)$, is the largest value of $y_i(k)$for the k^{th} response.$x_i^*(k)$, is normalized S/N ratios.

B. Computation of Grey Relational Coefficient and Grade

Once the sequence is normalized, the next step is to calculate the deviation sequence of the reference sequence using Equation 4.7 and then the grey relational coefficient is computed to express the relationship between the ideal and the actual experimental results. Deviation sequence is the difference between the desired performance characteristic (also called referential series) and the compared series (normalized data series). The grey relational coefficient can be found using Equation 4.8.

$$\Delta_{0i} = \|x_0(k) - x_i(k)\| \tag{4.7}$$

$$\boldsymbol{\xi_i(x)} = \frac{\Delta_{min} + \zeta\Delta_{max}}{\Delta_{0i}(k) + \zeta\Delta_{max}} \tag{4.8}$$

Where, $\zeta_i(x)$, signifies the GRC of individual response variables computed as a function of Δ_{min} and Δ_{max}, the minimum and maximum deviations of each response variable. Δ_{0i}=//x_0 $(k) - x_i$ (k)k// the difference of absolute value between $x_0(k)$ and $x_i(k)$. The distinguishing or identification coefficient represented by ζ is defined in the range $\zeta \varepsilon$ [0, 1], ζ, is generally set at 0.5 for this work to allocate equal weights to every parameter and it is calculated from the minimum, maximum deviation, and difference of desired and actual data. The grey relation coefficient values are used to find the grey relation grade. The grey grade for each experimental run can be obtained summation of the grey relation coefficient of each quality characteristic. The average grey grade for the ıth experimental run for all n responses is computed using Equation 4.9.

$$\Upsilon_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(x) \tag{4.9}$$

Where n is the number of process responses. The higher value of the grey relational grade represents the stronger relational degree between the reference sequence $x_0(k)$ and the given sequence, $x_i(k)$. The higher value of the grey relational grade means that the corresponding cutting parameter is closer to optimal [91].

4.5. Regression Model

Regression is a statistical modeling process that establishes a relation among dependent (response) and independent variables (input parameters or predictor). It is the most popular and widely applied technique. It is referred as multiple linear regressions and the equation is shown in Equation 4.10.

$$y = \beta_0 + \beta_1 * x_1 + \beta_2 * x_2 .... \beta_n * x_n \tag{4.10}$$

Where, β_0 is the constant value of the response (y) for the predictor (x) value 0. Additionally, it determines where the regression line intercepts the y-axis with the predictor variable(s) is zero. Depending on the relationship x can be a polynomial term. β_0 ,β_1 ,β_2 ....β_n , are the coefficients which determine the change in response for the one-unit change in the input parameter value [92, 81].

4.6. Statistical Analysis of Variance (ANOVA)

Variance Analysis (ANOVA) is one of the analysis methods used in investigating the effect of different parameters on the response. ANOVA provides the determination of the percentage contribution value of parameters affecting the output value [93]. The Taguchi experimental method could not judge the effect of individual parameters on the entire process; thus, ANOVA is used to compensate for this effect [82]. In the analysis of variance, the influence of the control factors was investigated in the experimental test. ANOVA table contains control factors, error, and total of all sources, degree of freedom (DF) of data, sum of square (SS) of data, means sum of square (MS) of data, Fischer's F distribution (F-value), p-value, and percentage contribution of the controlling factors [79].

F-test is the process of comparing the F-value with the standard table or calculated reference value. The purpose of this test is simply to distinguish the significant factors from insignificant ones. The change of the process parameter has a significant effect on the performance characteristic when the F value is large. The total and factor sums are the basic calculation needed for ANOVA. The quantities calculated as part of ANOVA table information are all derived from the original sums of squares for the factors as follows [79]. The mean sum (MS) of the square of the data can be calculated by dividing the SS by

Related DF. The mean sum of the square of the factors and error can be calculated as

$$SS_E = SS_T - SS_M \quad (4.11)$$

$$SS_M = n \ \sum(y_i - \tilde{y})^2 \quad (4.12)$$

$$SS_T = \sum(y_i - \tilde{y})^2 \quad (4.13)$$

MSM = SSM/k - 1, and MSM = SSM/n - k respectively. Where the total degree of freedom DFT = n-1,n is the number of data. The degree of freedom of factors (*DFM*) and error (*DFE*) are k-1 and n-k respectively.

F-value also called the F-test which is a ratio of two variances and compares the factors. Variances are measures of how much the date is scattered from the mean. It can be calculated by dividing the mean sum of the square of the factor (*MSM*) by the error mean square (MSM) as:

$$F = \frac{MS_M}{MS_E} \quad (4.14)$$

In the ANOVA table p-value helps to define the significance of the results in a statistical test to accept or reject the null hypothesis. Depending on the significance, the p-value expresses between 0 and 1. A smaller value provides a strong indication for rejecting the null hypothesis. Typically this value keeps 0.05 Percentage of contribution (*PCR*), is the ratio of the sum of the squares (*SSM*) of the variable to the total sum of the square (*SST*) of all the variables. It shows the influence of the particular variable (factor) in terms of percentage on the response of the product/process as:

$$PCR = \frac{SS_M}{SS_T} * 100 \quad (4.15)$$

4.7. Optimal Levels of Process Parameters

The grey relational analysis is performed using the obtained data from the Taguchi method. The highest overall grey relational represents the optimal parametric combination [24]. The higher grey relation grade implies better product quality. Therefore, on the basis of the grey relational grade, the factor effect can be estimated and optimal level for each controllable factor determined.

4.8. Confirmation Test

In this section, once parametric combinations are estimated using optimal levels of design parameters. The final step in the Taguchi-Grey relational analysis is to run experimental confirmation using optimal levels for the control parameters to confirm the process parameters combination [93]. The confirmation test has been performed to predict and verify the improvement of the selected performance characteristics of the chipboards using the optimal combination of the process parameters [94]. The estimated grey relational grade γ using the optimal level of the design parameters can be calculated using Equation 4.16.

$$\gamma = \gamma_m + \sum_{i=1}^{o} \gamma_i - \gamma_m \qquad (4.16)$$

Where γ_m the total is mean grey relational grade, γ_i is the mean grey relational grade at the optimal level, and o is the number of the main design parameters that affect the quality characteristics.

CHAPTER 5

5. Results and Discussions

The Experimental data of modulus of rupture, tensile modulus, water absorption, and swelling thickness for each test recorded for the run were given in Table 5.1.

Table 5.1: WA, TS, MOR and TM test results.

Process variables						Responses			
Exp.No	A	B	C	D	E	MOR	TM	WA	TS
1	1	1	1	1	1	8.42	263.97	103.19	39.19
2	1	1	2	2	2	18.08	394.74	57.55	12.61
3	1	1	3	3	3	20.2	623.38	66.58	25.36
4	1	2	1	1	2	8.98	279.51	98.6	30.16
5	1	2	2	2	3	17.79	366.97	63.56	21.86
6	1	2	3	3	1	20.98	538.91	38.29	22.14
7	1	3	1	2	1	12.24	246.86	74.02	26.17
8	1	3	2	3	2	18.69	342.86	26.57	12.71
9	1	3	3	1	3	20.84	455.88	28.45	20.75
10	2	1	1	3	3	17.06	333.33	99.76	26.04
11	2	1	2	1	1	20.63	367.71	51.28	19.31
12	2	1	3	2	2	22.97	334.86	39.31	11.42
13	2	2	1	2	3	16.5	225.94	83.22	24.55
14	2	2	2	3	1	20.7	375	55.56	14.75
15	2	2	3	1	2	22.27	583.78	37.12	15.03
16	2	3	1	3	2	12.93	219.07	66.76	20.52
17	2	3	2	1	3	21.01	480.91	27.3	17.18
18	2	3	3	2	1	24.82	380.45	20.39	10.52

5.1. Mechanical and Physical Results of the Chipboards

5.1.1. Flexural Strength

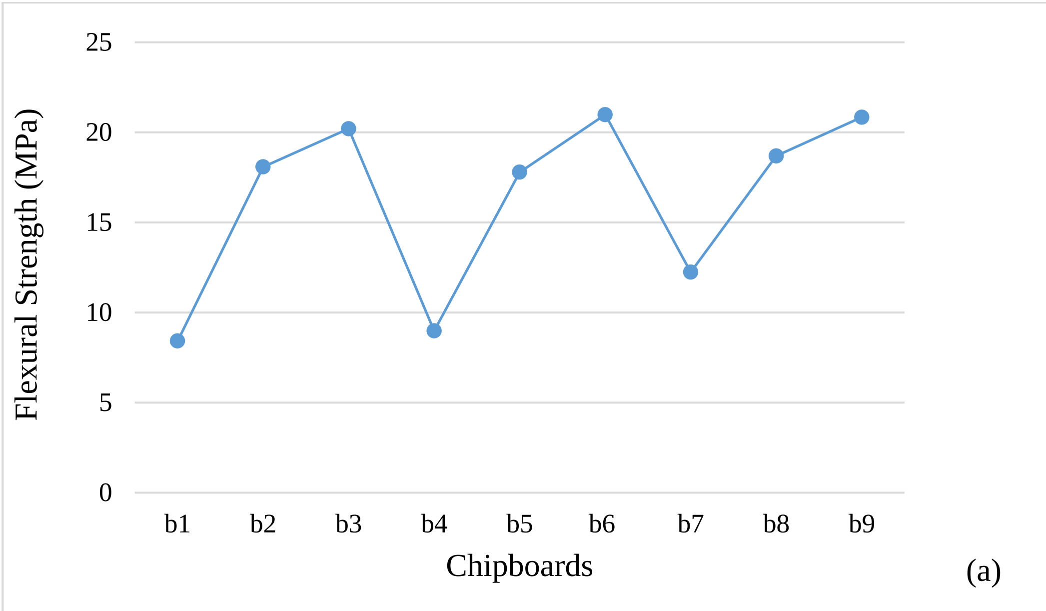


Figure 5.1: Flexural strength of chipboards.

The results revealed that flexural strength of chipboards for the coffee husk to sawdust ratios increases as the weight fraction of Cordia Africana wood sawdust increases as shown in Figure 5.1. Among the chipboard manufactured, the maximum modulus of rupture showed in Figure 5.1. is 24.82 MPa at the process parameters of CH/SD reinforcement weight ratios, 6MPa pressing pressure, 180 pressing temperature, 40% UPR matrix loading, and 10 minutes pressing time. The lower modulus of rupture is revealed to be 8.42 MPa at the process parameters of CH alone as reinforcement, 4MPa pressing pressure, 40% UPR matrix loading, and 8 minutes pressing time as shown in Figure 5.1.

5.1.2 Tensile Strength

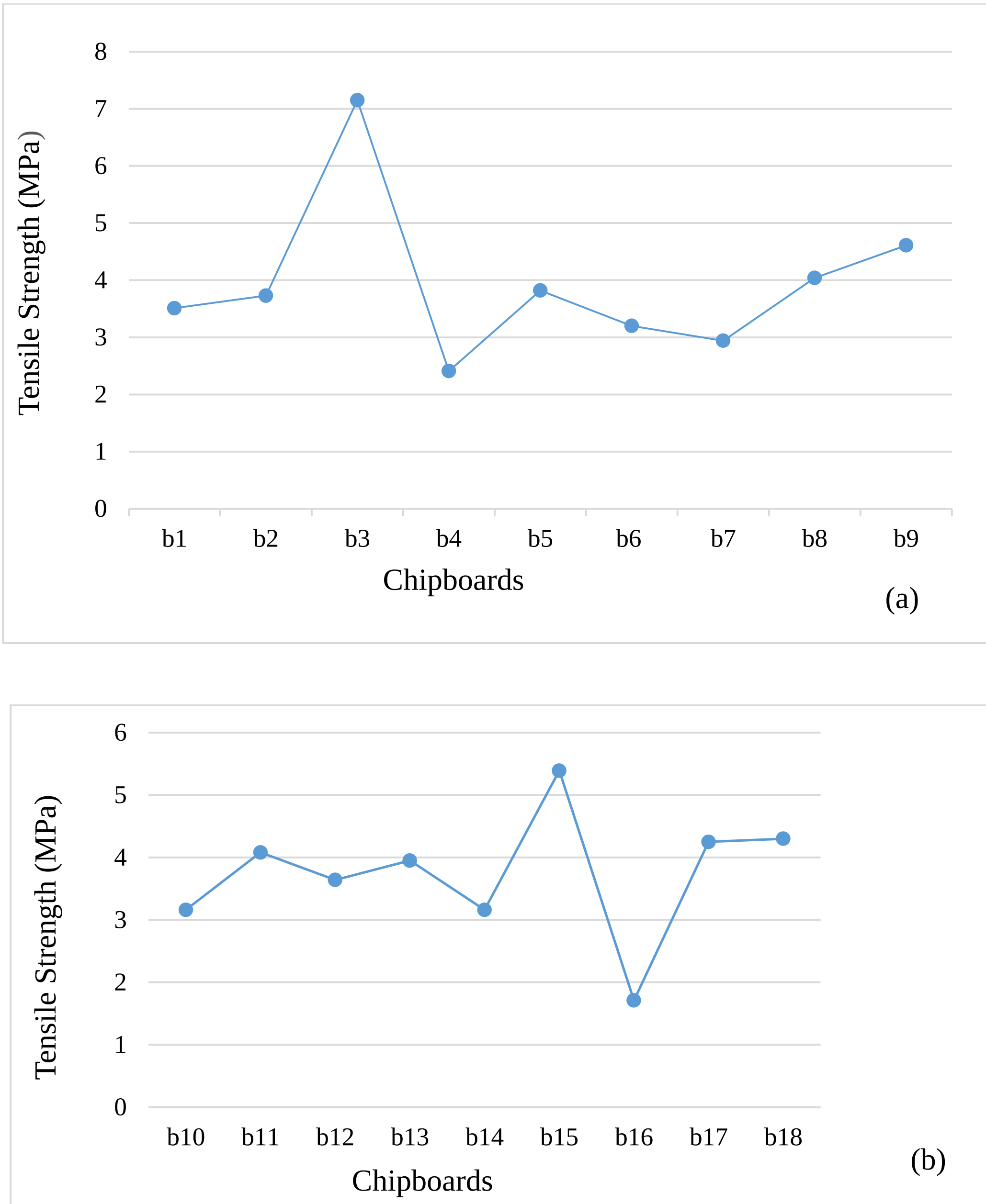


Figure 5.2: Tensile strength of chipboards.

The tensile strength of the chipboard increases moderately as the weight fraction of the sawdust increases. The maximum tensile strength of the board is 7.15MPa at the CH/SD reinforcement weight ratios, 4MPa pressing pressure, 160 pressing temperature, 60% UPR matrix loading and 12 minutes pressing time and 5.39MPa is obtained at the CH/SD reinforcement weight ratios, 6MPa pressing pressure, 170 pressing temperature, 50% UPR matrix loading and 8 minutes pressing time as shown in Figure 5.2 respectively. The minimum tensile strength is 1.71MPa at the CH reinforcement weight ratios, 6MPa pressing pressure, 180 pressing temperature, 50% UPR matrix loading, and 12 minutes pressing time.

5.1.3. Stress Strain Curves of the Chipboards

The stress versus strain curves of chipboards showed that the boards made from coffee husk (CH/-) only as reinforcement (i.e. b1, b4, b7, b10, b13, b16) have lower stress or strength with higher strain up to 3%. The CH/SD and 3CH/SD boards showed higher strength with lower strain compared to the CH chipboard.

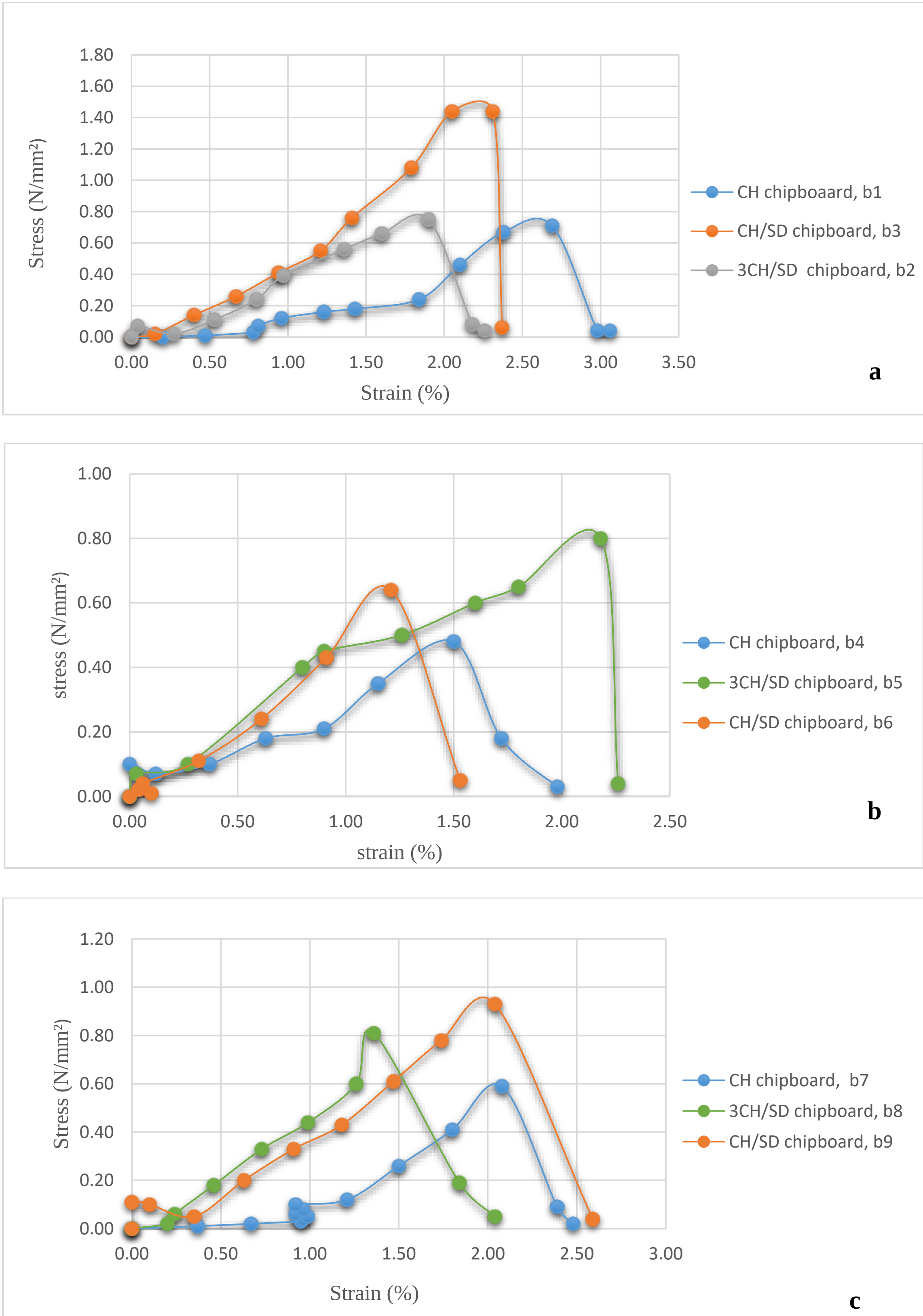
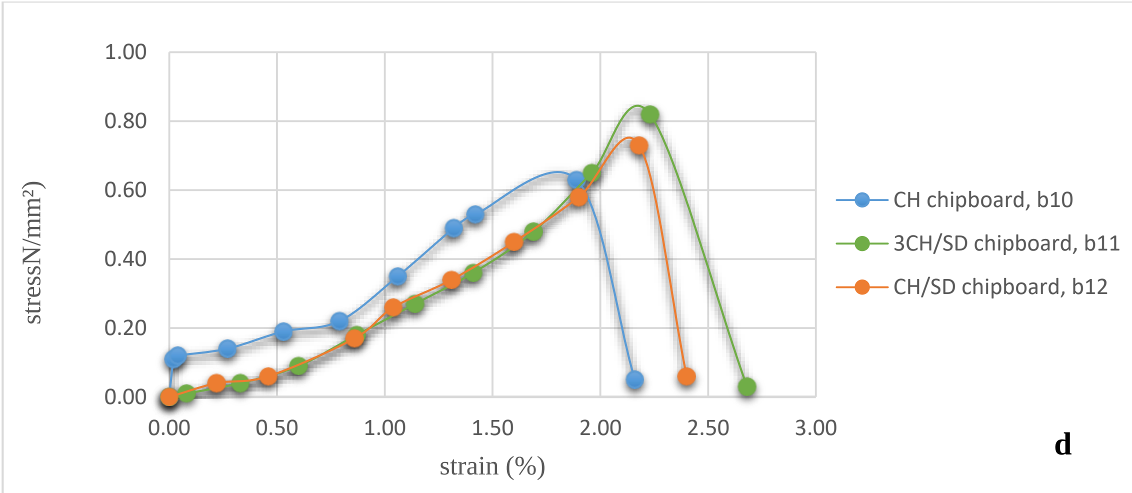
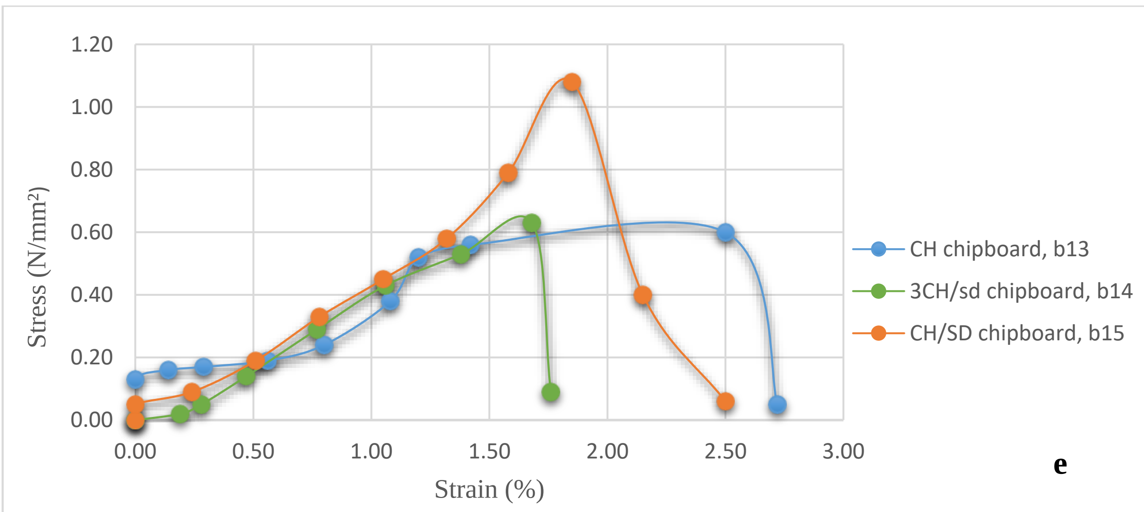


Figure 5.3: (a), (b), (c) Stress versus strain curves of chipboards.





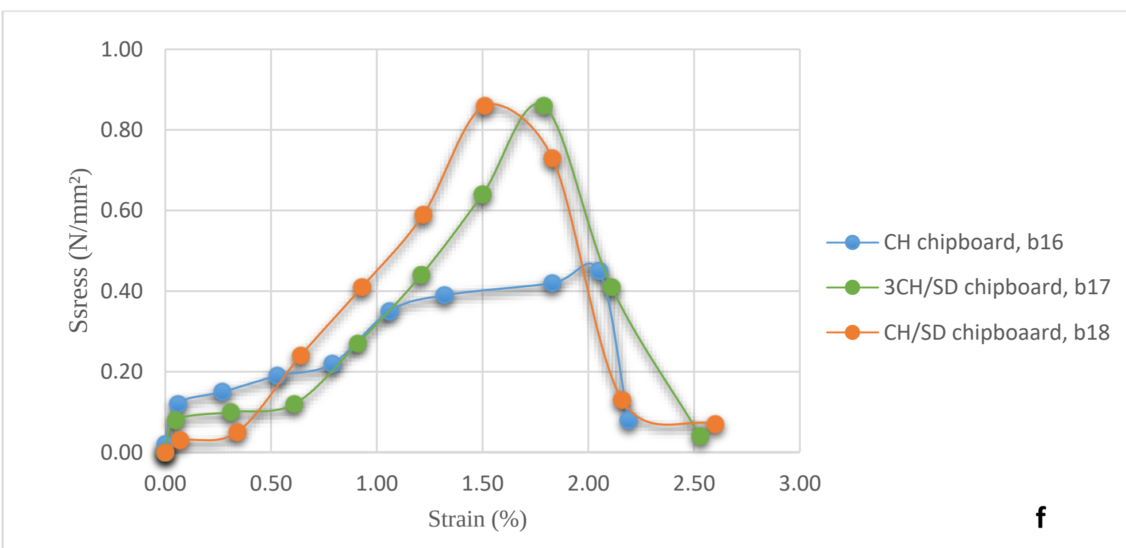


Figure 5.4: (d), (e), (f) Stress versus strain curves of chipboards.

5.1.4. Water Absorption

The capability of the chipboards to absorb moisture increases as coffee husk reinforcement ratio increases with respect to sawdust ratios. The weight of the board with CH is double its weight while the board is kept for 24hr in the water which showed that the coffee husk significantly affects water absorption of the chipboard. The higher water absorption obtained is 103.17% of the CH chipboard as shown in **(b**) of Figure 5.4. The lower water absorption is obtained for the CH/SD ratios as compared to CH and 3CH/SD chipboards.

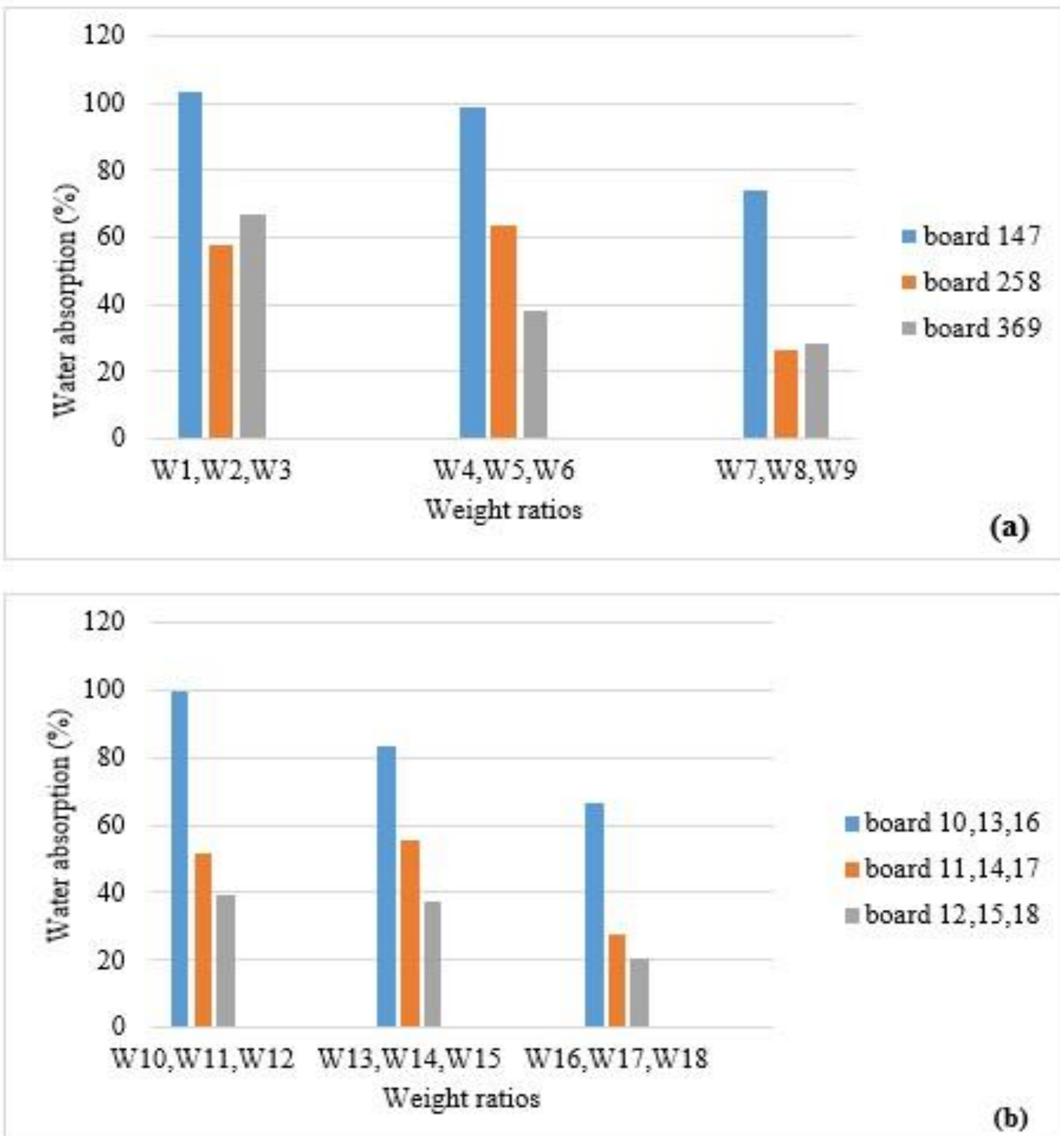


Figure 5.5: (a) and (b) Water Absorption of chipboards.

5.1.5. Swelling Thickness

The dimensional stability of the chipboards is significantly affected by coffee husk weight ratios. Among the chipboards made with different weight ratios of reinforcement; higher swelling thickness is revealed for boards from coffee husk alone as shown in Figure 5.5. The CH/SD ratios of chipboards showed better dimensional stability than the CH/- and 3CH/SD chipboards.

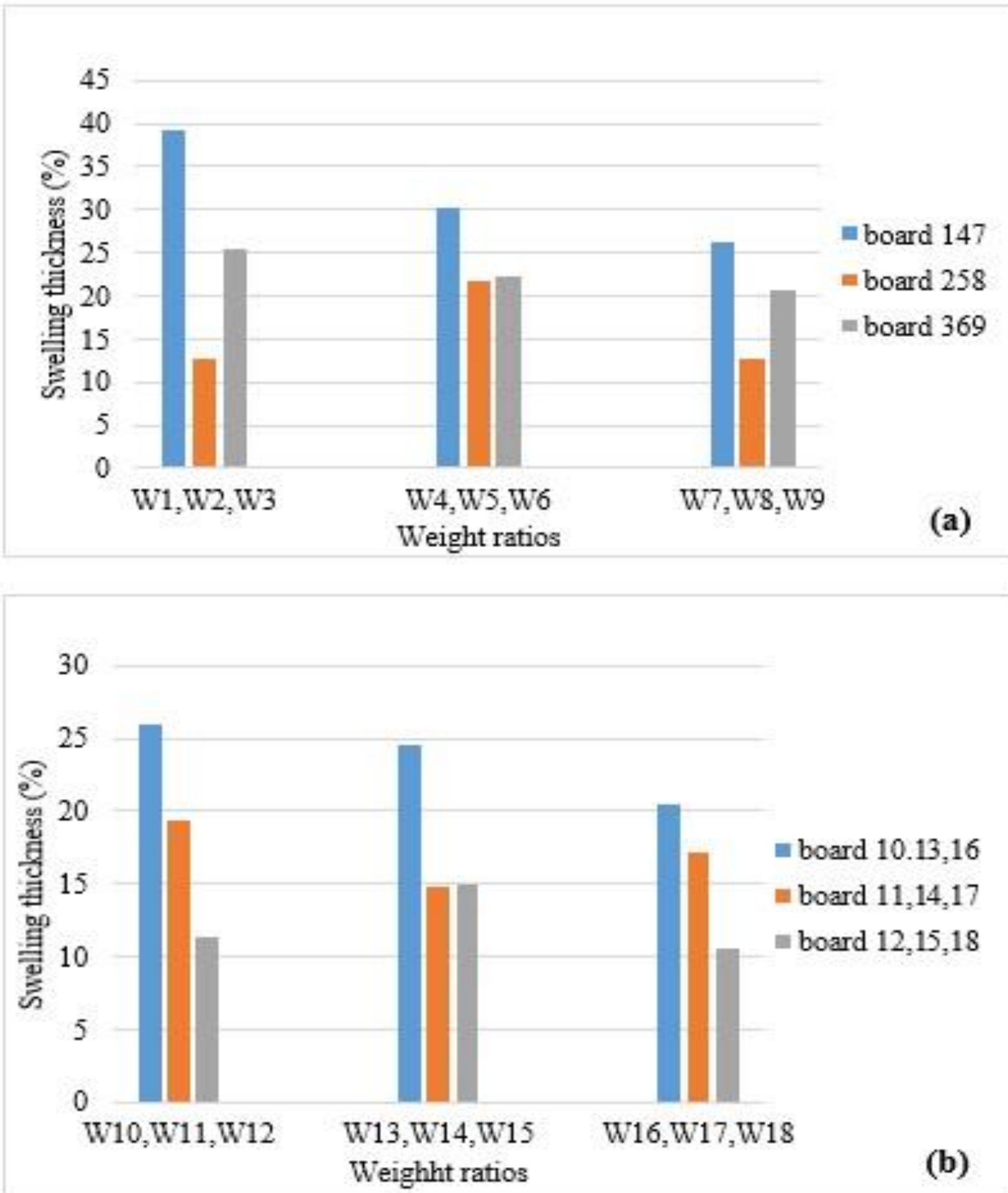


Figure 5.6: (a) and (b) Swelling thickness of chipboards.

5.2. Optimization of Process Parameters

5.2.1. Signal-To-Noise Ratio

From the Taguchi Method, the standard L18 OA Table 3.1, were used to manufacture coffee husk-sawdust chipboard and specimen was prepared for bending, tensile, water absorption, and swelling thickness in accordance with ASTM D-1037. In the chipboard manufacturing process parameters optimization process, experimental results (responses) were transformed into the signal-to-noise ratios to investigate or measure the quality characteristics deviating from the standard values [24] as shown in Table 5.2**.** The S/N ratios were computed using Equation 4.1 and 4.2 for the larger the better and lower the better quality characteristics respectively. The desirable quality characteristics are the larger the better for the modulus of rupture, tensile modulus, and the lower the better for the swelling thickness, water absorption.

5.3. Taguchi- Grey Relation Analysis

In grey relational analysis, the S/N ratios of the responses were transformed into the comparable sequences shown in Table 5.3 by normalizing (grey relational generation) the original sequence to the range between zero to one using Equation 4.5 and 4.6 for the smaller the better(WA, TS) and larger the better(MOR, TM) quality characteristics of the response respectively.

5.3.1. Normalization S/N ratio values

Pre-processing of the data must be performed before computing the grey relational coefficients. In this study, the grey relational generation or normalization of experimental results(S/N) ratios were performed in the range of 0 to 1 to avoid the effect of adopting different units and to reduce the variability. Using Equation 4.5 and 4.6 the grey relational generation results shown in the Table 5.5. The deviation sequence or the referential series shown in the Table 5.4, of performance characteristics were computed using Equation 4.7. The multi-criteria optimization problem has been transformed into a single equivalent objective function/ performance characteristics optimization problem using a combination of the Taguchi approach and grey relational analyses. The higher is the value of the grey relational grade, the corresponding factor combination is said to be close to the optimal, and therefore the higher GRG were obtained for optimal setting of process parameters [94]. The signal-to-noise (S/N) ratio is a measure of the magnitude of a data set relative to the standard deviation. If the S/N is large, the magnitude of the signal is large relative to the noise, as measured with the standard deviation [93]. Table 5.6, shows

Table 5.2: Results of performance measures and their S/N values.

Exp. No.	MOR	SNR	TM	SNR	WA	SNR	TS	SNR
1	8.42	18.506	263.97	48.431	103.19	-40.273	39.19	-31.864
2	18.08	25.144	394.74	51.293	57.55	-35.201	12.61	-22.014
3	20.20	26.107	623.38	55.895	66.58	-36.467	25.36	-28.083
4	8.98	19.066	279.51	48.928	98.60	-39.878	30.16	-29.589
5	17.79	25.004	366.97	51.926	63.56	-36.064	21.86	-26.793
6	20.98	26.436	538.91	54.630	38.29	-31.662	22.14	-26.904
7	12.24	21.756	246.86	47.849	74.02	-37.387	26.17	-28.356
8	18.69	25.432	342.86	50.702	26.57	-28.488	12.71	-22.083
9	20.84	26.378	455.88	53.177	28.45	-29.082	20.75	-26.34
10	17.06	24.640	333.33	50.457	99.76	-39.979	26.04	-28.313
11	20.63	26.290	367.71	51.310	51.28	-34.199	19.31	-25.716
12	22.97	27.223	334.86	50.497	39.31	-31.89	11.42	-21.153
13	16.50	24.350	225.94	47.080	83.22	-38.405	24.55	-27.801
14	20.70	26.319	375.00	51.481	55.56	-34.895	14.75	-23.376
15	22.27	26.954	583.78	55.325	37.12	-31.392	15.03	-23.539
16	12.93	22.232	219.07	46.812	66.76	-36.49	20.52	-26.244
17	21.01	26.449	480.91	53.641	27.30	-28.723	17.18	-24.70
18	24.82	27.896	380.45	51.606	20.39	-26.188	10.52	-20.44

the S/N ratio based on the larger-the-better criterion for the overall grey relational grade calculated using Equation 4.9.

Table 5.3: Normalization S/N ratio values.

		Normalized		
Exp. No.	MOR	TM	WA	TS
Ideal seq.	1.00	1.00	1.00	1.00
1	0	0.178284942	1	1
2	0.706908681	0.56306725	0.639900603	0.137780112
3	0.809473114	1	0.729783458	0.669030112
4	0.059563066	0.23298424	0.971955982	0.800857843
5	0.691950998	0.493312361	0.701171459	0.556109944
6	0.844519921	0.860764409	0.388640398	0.565826331
7	0.346055156	0.114203539	0.795101171	0.692927171
8	0.737603446	0.428328448	0.163294285	0.143820028
9	0.838326453	0.70076769	0.205466809	0.516456583
10	0.653192061	0.401372859	0.979126731	0.689163165
11	0.828957799	0.495238686	0.568761093	0.461834734
12	0.928346068	0.405751992	0.404827831	0.062412465
13	0.622317937	0.029526868	0.867376642	0.644345238
14	0.832091238	0.514011013	0.618175364	0.257002801
15	0.899717584	0.937240119	0.369471069	0.271271008
16	0.396784933	0	0.7314164	0.508053221
17	0.845841715	0.751879103	0.179978701	0.37289916
18	1	0.527808317	0	0

Table 5.4: Deviation sequence.

Exp.no	deviation sequence			
	MOR	TM	WA	TS
Ideal seq.	1.00	1.00	1.00	1.00
1	1	0.821715058	0	0
2	0.293091319	0.43693275	0.360099397	0.862219888
3	0.190526886	0	0.270216542	0.330969888
4	0.940436934	0.76701576	0.028044018	0.199142157
5	0.308049002	0.506687639	0.298828541	0.443890056
6	0.155480079	0.139235591	0.611359602	0.434173669
7	0.653944844	0.885796461	0.204898829	0.307072829
8	0.262396554	0.571671552	0.836705715	0.856179972
9	0.161673547	0.29923231	0.794533191	0.483543417
10	0.346807939	0.598627141	0.020873269	0.310836835
11	0.171042201	0.504761314	0.431238907	0.538165266
12	0.071653932	0.594248008	0.595172169	0.937587535
13	0.377682063	0.970473132	0.132623358	0.355654762
14	0.167908762	0.485988987	0.381824636	0.742997199
15	0.100282416	0.062759881	0.630528931	0.728728992
16	0.603215067	1	0.2685836	0.491946779
17	0.154158285	0.248120897	0.820021299	0.62710084
18	0	0.472191683	1	1

Table 5.5: Grey Relation coefficient and grade.

Exp.No.	Grey Relational coefficient					
	MOR	TM	WA	TS	(GRG)	Rank
Ideal	1.00	1.00	1.00	1.00	1.00	
seq.						
1	0.333333333	0.378296363	1	1	0.677907424	2
2	0.630444425	0.533656231	0.58132816	0.367047937	0.527773001	16
3	0.724084768	1	0.649168088	0.601706521	0.743739844	1
4	0.347116898	0.394628082	0.946890756	0.715162138	0.600949469	6
5	0.618774355	0.496678394	0.625916544	0.529722712	0.568119188	9
6	0.762799689	0.782184233	0.449899384	0.535232384	0.632528922	5
7	0.433296273	0.360803346	0.70932165	0.619522777	0.530736011	15
8	0.655826679	0.466560859	0.374053911	0.368682631	0.46628102	18
9	0.755659649	0.625600334	0.386239614	0.508365967	0.568966391	8
10	0.59045266	0.455113461	0.959926395	0.616646875	0.655534848	3
11	0.745109621	0.497630625	0.536919148	0.481618887	0.56531957	10
12	0.874655053	0.456934805	0.45654922	0.347804908	0.533985996	14
13	0.569682373	0.340026614	0.790359688	0.584347826	0.571104125	7
14	0.748605242	0.507105056	0.567006159	0.402253521	0.556242494	12
15	0.832941273	0.888478402	0.442270858	0.406924557	0.642653772	4
16	0.453220786	0.333333333	0.650547319	0.504059301	0.485290185	17
17	0.764341004	0.668341176	0.378781767	0.44361603	0.563769994	11
18	1	0.514301869	0.333333333	0.333333333	0.545242134	13

Table 5.6: Mean and S/N grey relation grade.

Exp.No	Grey Relational Grade		
	(GRG)	S/N Ratios of GRG	Mean of GRG
1	0.677907424	-3.37659	0.677907
2	0.527773001	-5.54536	0.528119
3	0.743739844	-2.57158	0.74374
4	0.600949469	-4.42324	0.600949
5	0.568119188	-4.91651	0.567773
6	0.632528922	-3.97839	0.632529
7	0.530736011	-5.50243	0.530736
8	0.46628102	-6.62705	0.466281
9	0.568966391	-4.89827	0.568966
10	0.655534848	-3.66808	0.655535
11	0.56531957	-4.95412	0.56532
12	0.533985996	-5.4494	0.533986
13	0.571104125	-4.86569	0.571104
14	0.556242494	-5.09472	0.556242
15	0.642653772	-3.84046	0.642654
16	0.485290185	-6.27997	0.48529
17	0.563769994	-4.97796	0.56377
18	0.545242134	-5.26821	0.545242

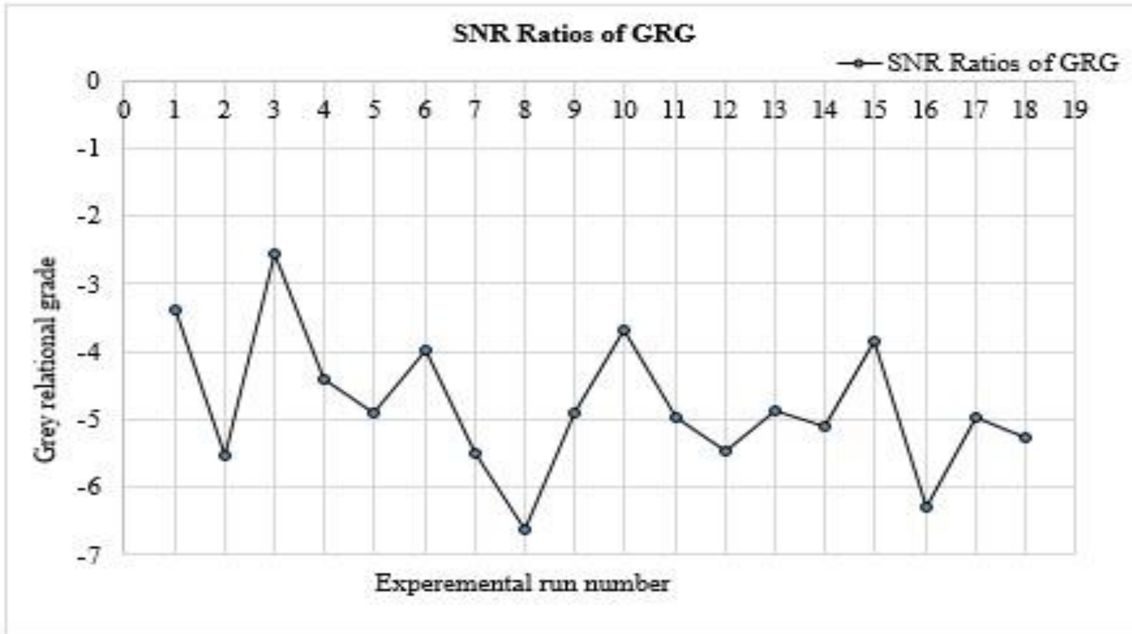


Figure 5.7: S/N graph of grey grade.

5.4. Optimal Levels of Process Parameters

The higher grey relation grade implies the better product quality; from the mean response table of the grey relational grade and main effect plot, the optimal process parameters combination and their levels Table 5.7 were obtained. Therefore, the optimal process parameters combination for this multi-objective chipboard manufacturing is $A_1B_1C_3D_1E_3$. Based on the mean effect plot the optimal combination of parameters levels to get the maximum grey grade is i.e. pressing pressure at 4MPa, pressing temperature 160 , reinforcement ratio (CH/SD) 1:1, pressing time 8min, unsaturated polyester 60%. In this study, the confirmation test was required because the optimum combination of parameters and their levels i.e. $A_1B_1C_3D_1E_3$ did not correspond to any experimental arrangement of the orthogonal array in the design of experiment. (∗) symbol shows the optimal values of the parameters.

Table 5.7: Mean grey relational grade

Mean of GRG					
Factors	Level 1	Level 2	Level 3	Max-Min	Rank
Pressure	0.5908*	0.5688	—	0.5688	1
Temperature	0.6174*	0.5953	0.5267	0.0907	2
CH/SD ratios	0.5869	0.5413	0.6112*	0.0699	3
Pressing Time	0.6033*	0.5462	0.5899	0.0571	5
UPR Content	0.5847	0.5429	0.6119*	0.0689	4

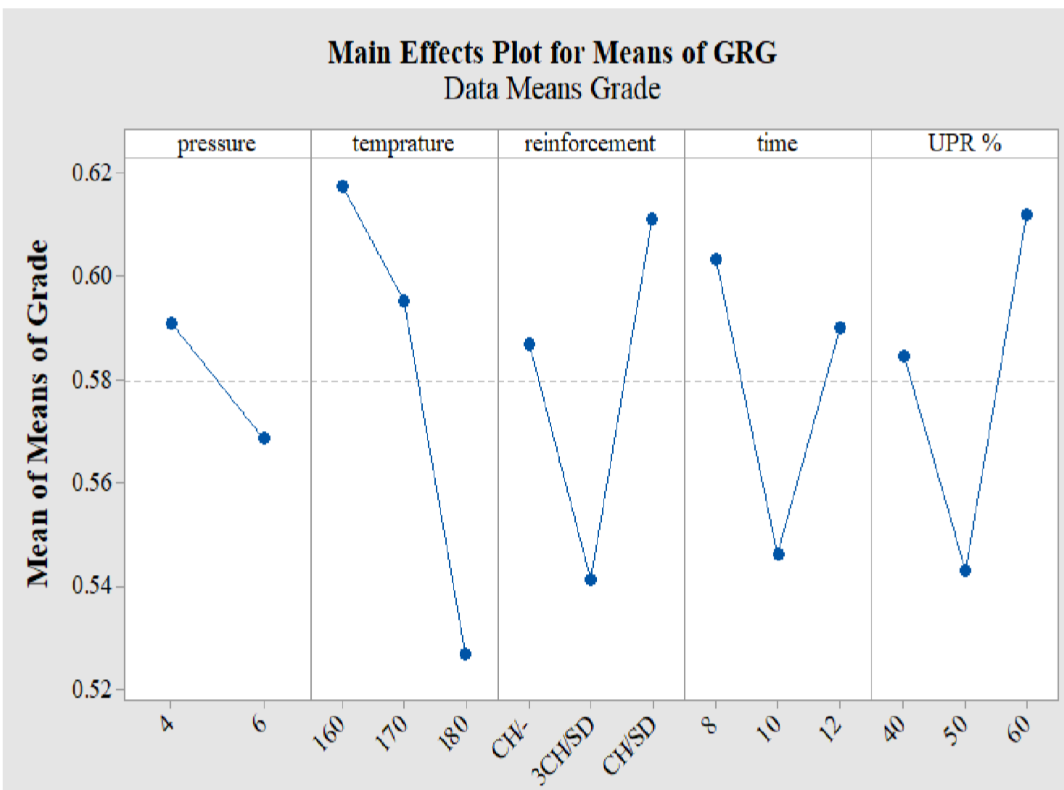


Figure 5.8: Main effect plot of mean grade.

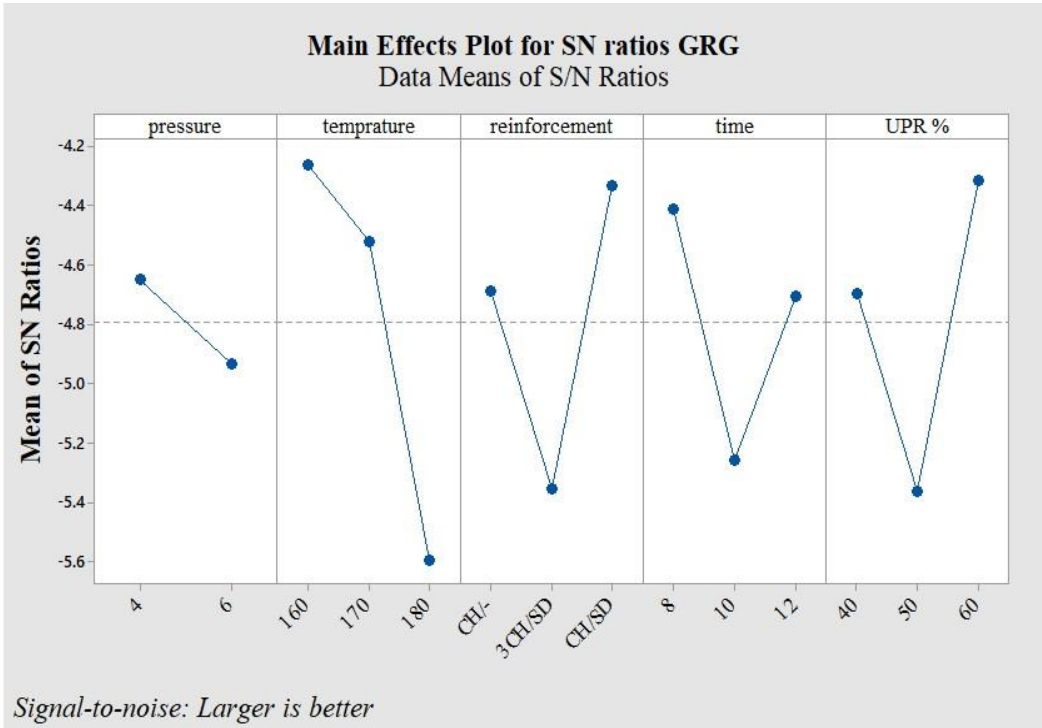


Figure 5.9: Main effect plot of SN of grade.

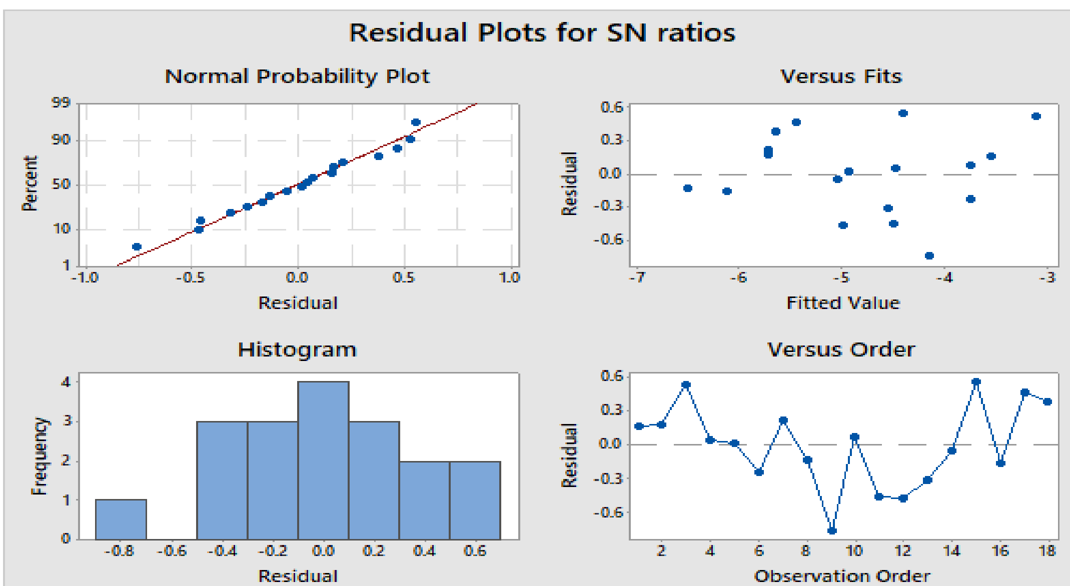


Figure 5.10: Normality plot, order, fits and residuals of grey relational grade.

5.5. Regression Analysis

In the present work, using grey relational analysis complex multiple response optimization can be simplified into optimization of a single response grey relational grade. Considering the grey grade as the overall evaluation of experimental data as the response and the process parameters or control factors were pressing temperature, pressing pressure, pressing time, unsaturated polyester content (UPR), and coffee to sawdust ratios. In the regression model the high R-square, the high determination coefficient indicates the goodness of fit for the model. It also represents, how much variation is present in the response. The regression model for the grey grade is obtained using Equation 4.10. The linear regression for the grey grade is shown below with the R-squared =0.85 and R adj=0.70 which shows the goodness and significance of the model for chipboard manufacturing. Regression Equation for a grey relational grade is given as,

$$GRADE=0.57979+0.01099(P_1-P_2)+(0.038Temp._1+0.0154Temp._2-0.053Temp._3)+(0.007C_1-0.039C_2+0.0314C_3)+(0.0235T_1-0.0336T_1+0.0102T_3)+(0.0049UPR_1-0.0369UPR_2)+0.0320UPR_3)$$

5.6 Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to investigate which chipboard manufacturing parameters significantly affect the performance characteristics. This is accomplished by separating the total variability of the grey relational grades, which is measured by the sum of the squared deviations from the total mean of the grey relational grade, into contributions from each of the chipboard manufacturing process parameters and the error. The F test was used to determine which chipboard manufacturing process parameters have a significant effect on the performance characteristics of the board. Most of the time, the change of the process parameter has a significant effect on the performance characteristics when the F value is large [94]. In the present study the significant process parameters in the chipboard manufacturing shown in Table 5.8**,** revealed that the pressing temperature, coffee husk to sawdust ratios, unsaturated polyester resin content, pressing time, and pressing pressure from lower to higher respectively. The ANOVA for the overall grey relational grade is shown in Table 5.8. (∗) shows the significant process parameters.

Depending on the analysis of variance, the most effective parameters of the chipboard manufacturing process by considering the performance characteristics such as modulus of rupture, tensile modulus, water absorption, and swelling thickness were determined. The percentage contribution indicates the relative power of a factor to reduce the variation. For a factor with a high percentage contribution, there is a great influence on the performance characteristics or responses. In the present work, the percentage of contribution of the chipboard manufacturing process parameters such as pressing pressure, pressing temperature, reinforcement weight fraction, resin weight fraction, or loading, and pressing time is shown in Table 5.8.

Table 5.8: ANOVA Results of chipboard manufacturing process parameters.

SOURCE	Df	SS	MS	F	P	PCR (%)
Pressure	1	0.002175	0.002175	1.49	0.256	2.75
Temperature	2	0.026816	0.013408	9.21	0.008*	33.11
Reinforcements	2	0.015131	0.007565	5.20	0.036*	18.68
Pressing time	2	0.010709	0.005354	3.68	0.074	13.22
Resin content	2	0.014518	0.007259	4.99	0.039*	17.92
Residual Error	8	0.011644	0.001455			13.58
Total	17	0.080992				

Among the identified process parameters the pressing temperature the reinforcement weight fraction and resin content were found to be the most influential process variable that affects the manufacturing process with their percentage of contribution were 33.11%, 18.68% and 17.92 respectively. The percentage of contributions of pressing pressure and pressing time were 2.75 % and 13.22% respectively.

5.7. Confirmation Test

After evaluating the optimal parameter settings, the next step is to predict and verify the enhancement of quality characteristics using optimal parametric combination $A_1B_1C_3D_1E_3$. Grey relational grade was estimated manually by using Equation 4.16 as shown below. The optimal level of the process parameters became 0.71. The confirmation test has been performed to predict and verify the improvements of the performance characteristics using the optimal values of the process parameters level. The predicted and the experimental results are shown in Table 5.9.

$$\gamma = \gamma_m + (\gamma_B - \gamma_m) + (\gamma_C - \gamma_m) + (\gamma_D - \gamma_m) + (\gamma_E - \gamma_m)$$

$$\gamma = 0.58+(0.6174 -0.58)+(0.6112-0.58)+(0.6033-0.58)+(0.6118-0.58)$$

$$\gamma = 0.58+0.0374+0.0321+0.0233+0.0.0312=0.71$$

Table 5.9: Results of confirmation test

	Factor settings optimal	process condition	
	initial	Prediction	Experiment
Factor levels	$A_1B_1C_1D_1E_1$	$A_1B_1C_3D_1E_3$	$A_1B_1C_3D_1E_3$
Modulus of rupture(MPa)	8.42		23.60
Tensile modulus(MPa)	26.397		54.00
Swelling thickness (%)	39.19		31.50
Water absorption (%)	103.39		67.18
S/N overall GRG	-3.376		-2.34
Overall GRG mean	0.678	0.71	0.76

where γ_m=0.58 and $\gamma_{(i)}$ is the mean grey relational grade at the optimal level, and four main design parameters affect the quality characteristics thus were pressing temperature, time, coffee husk to sawdust ratios, and UPR content.

The grey relational grade improvement from the initial parameter combination $A_1B_1C_1D_1E_1$, to the optimal parameter combination, $A_1B_1C_3D_1E_3$ was revealed that 0.082. Therefore considering this one can conclude that Taguchi coupled with grey relational multi-objective optimization is a useful method in chipboard or particleboard manufacturing.

CHAPTER 6

6. Conclusions and Recommendations

6.1. Conclusions

In the present study, applying the proposed design of experiments, the experiments were done for mechanical properties (modulus of rupture and tensile modulus) and the physical properties (water absorption and swelling thickness) of the coffee husk-sawdust chipboards manufacturing. The selected process parameter such as pressing pressure, pressing temperature, pressing time, matrix (UPR) content, and reinforcement ratio were optimized by employing the Taguchi method coupled with the grey relational analysis. Using the grey relational analysis the optimal or best values of process parameters combination of chipboard manufacturing were obtained, the confirmation tests were done for the validity of the optimal setting process parameters level. Statistical analysis, ANOVA was performed to accumulate the significant parameters and the percentage of contribution. Generally, from the above analysis, results, and discussions, the following conclusions can be drawn:

- The coffee husk –sawdust chipboards manufacturing is important from both social and economic point of view, and by monitoring or optimizing the process parameters in manufacturing. Therefore the optimized chipboard in this work passed the P1 standard, hence the board can be used for the interior application areas.
- The coffee husk –sawdust chipboards multi-response manufacturing was done successfully by using the grey relational analysis together with the Taguchi method.
- The optimal process parameters combination for this multi-objective chipboard Manufacturing were found to be $A_1B_1C_3D_1E_3$. The mean effect plot showed that optimal combination of parameter levels was, for Pressing pressure at level 1 (4MPa), pressing temperature at leve1 1 (160℃), reinforcement ratio (CH/SD) at level 3 (1/1), pressing time at level 1 (8min), unsaturated polyester at level 3 (60%) respectively.
- The ANOVA result revealed that the pressing temperature, the reinforcement weight fraction, and UPR content were found to be the most influential process

variable that affects the manufacturing process with their percentage of contribution were 33.11%, 18.68% and 17.92% respectively. The percentage of contributions of pressing pressure, pressing time was 2.75% and 13.22 % respectively.

- The confirmation test performed showed that the grey relational grade improvement from the initial parameter combination $A_1B_1C_1D_1E_1$, to the optimal parameter combination was revealed that 0.082 and the predicted GRG 0.71 is close to the experimental one 0.76.

6.2. Recommendations for Future Work

- Transforming of the coffee processing waste (CH) and sawdust into the board have an advantage for both environmental pollution and health. Therefore promoting this technology is an important issue to utilize these abundant resources.
- This study is limited to some of physical and mechanical properties optimizations by considering only the selected process parameters and responses, so in future work, the study will need to consider or include the following factors.
- The physical properties such as - density, moisture contents, and thermal insulation.
- The mechanical properties compressive strength, hardness, and impact.
- The different sizes of reinforcements and varying the percentage of hardener used in the composites.

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APPENDIXS

Appendix A

The DOE, orthogonal array selection and parameters leveling procedures

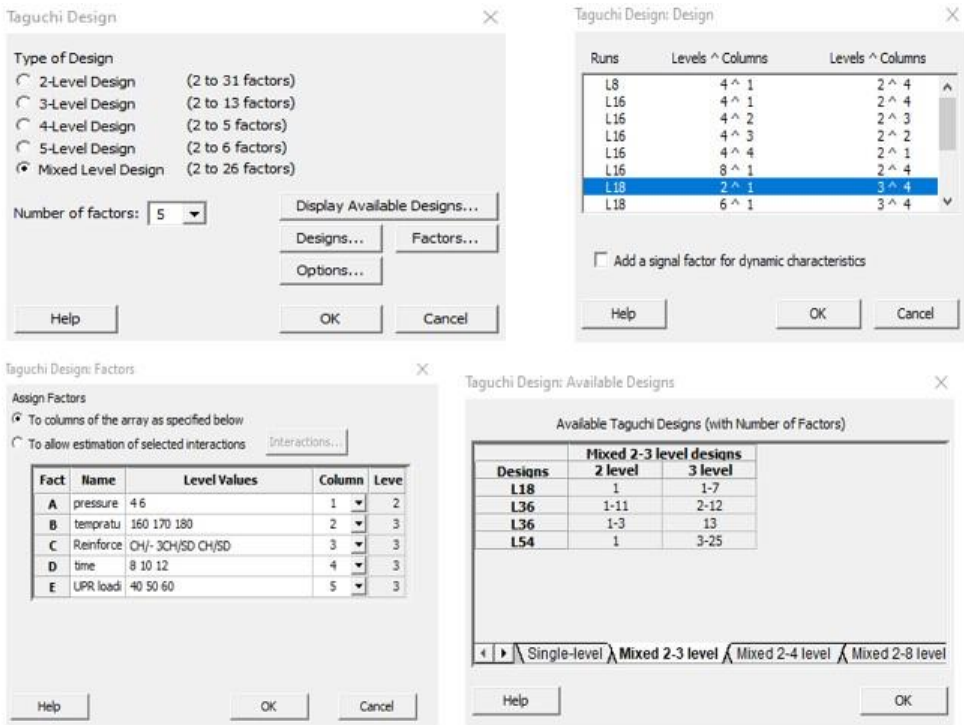
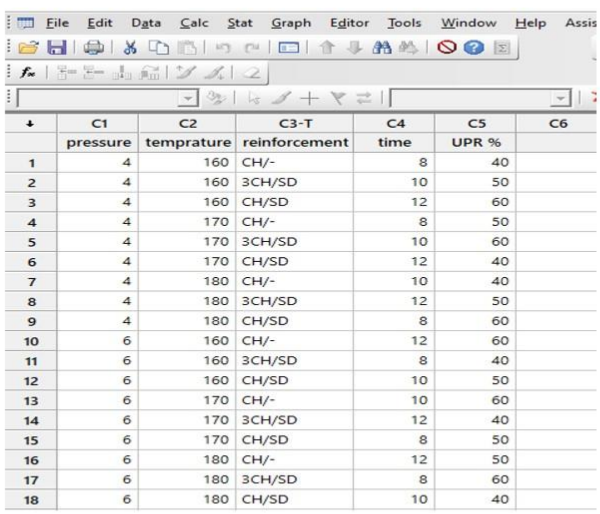


Figure A. 1: Orthogonal array selection and parameter.



↓	C1 pressure	C2 temprature	C3-T reinforcement	C4 time	C5 UPR %	C6
1	4	160	CH/-	8	40	
2	4	160	3CH/SD	10	50	
3	4	160	CH/SD	12	60	
4	4	170	CH/-	8	50	
5	4	170	3CH/SD	10	60	
6	4	170	CH/SD	12	40	
7	4	180	CH/-	10	40	
8	4	180	3CH/SD	12	50	
9	4	180	CH/SD	8	60	
10	6	160	CH/-	12	60	
11	6	160	3CH/SD	8	40	
12	6	160	CH/SD	10	50	
13	6	170	CH/-	10	60	
14	6	170	3CH/SD	12	40	
15	6	170	CH/SD	8	50	
16	6	180	CH/-	12	50	
17	6	180	3CH/SD	8	60	
18	6	180	CH/SD	10	40	

Figure 6.2: L18 Orthogonal array and the arrangements of parameters

The analysis of variance (ANOVA)

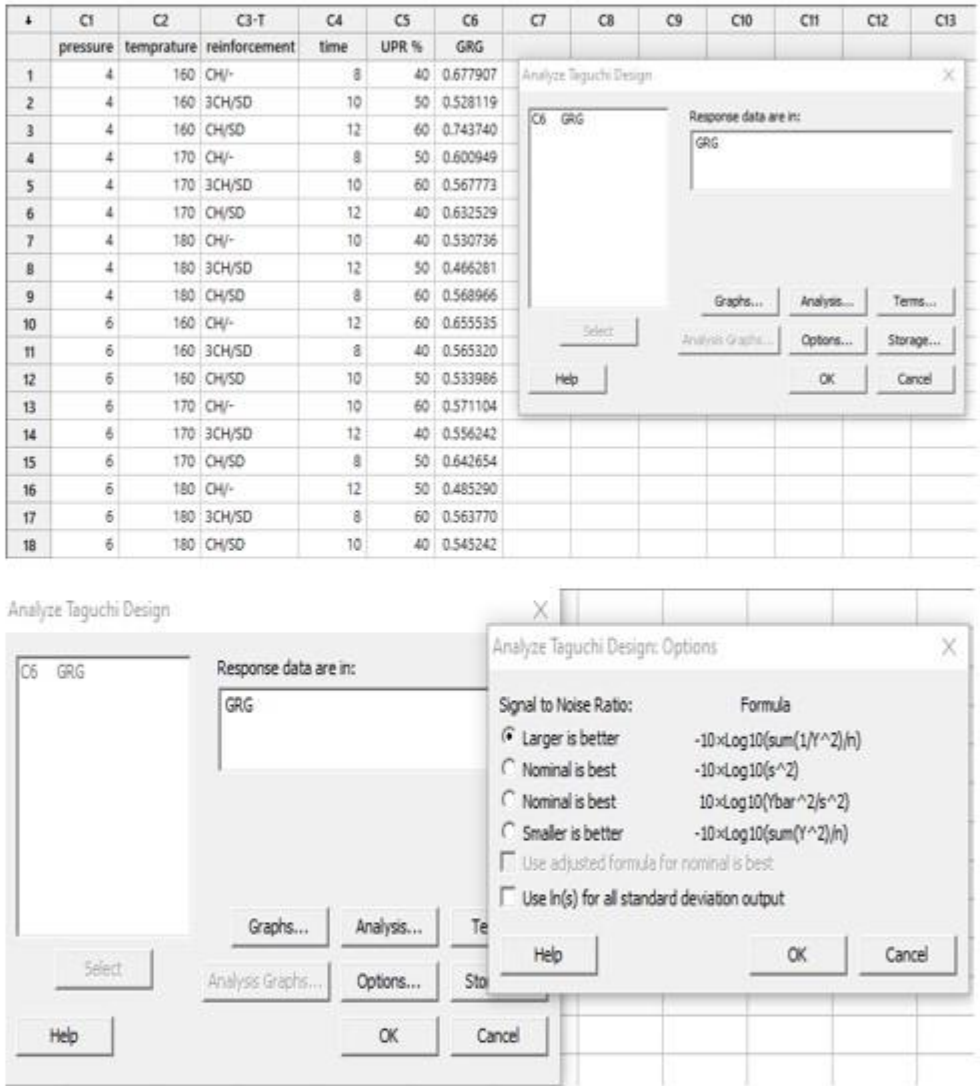


Figure A.2: Procedures for analysis of variance.

Appendix B

The experimental data

Table A.1: Tensile test results

Run	Tensile(Mpa)	Pmax (KN)	Stress(Mpa)	Strain (%)	Tensile modulus(Mpa)
1	3.51	0.80	0.71	2.69	26.397
2	3.73	0.85	0.75	1.90	39.474
3	7.15	1.63	1.44	2.31	62.338
4	2.41	0.55	0.48	1.72	27.951
5	3.82	0.80	0.80	2.18	36.697
6	3.20	0.72	0.64	1.21	53.891
7	2.94	0.67	0.59	1.39	24.686
8	4.04	0.92	0.63	1.83	34.286
9	4.61	1.05	0.93	2.64	45.588
10	3.16	0.72	0.63	1.89	33.333
11	4.08	0.94	0.82	2.23	36.771
12	3.64	0.83	0.73	2.18	33.486
13	3.95	0.55	0.87	3.85	22.594
14	3.16	0.72	0.63	1.68	37.500
15	5.39	1.23	1.08	1.85	58.378
6	1.71	0.48	0.45	2.05	21.907
17	4.25	0.98	0.86	1.79	48.091
18	4.30	0.98	0.73	1.83	38.045

Table A.2: Flexural test results

Run	Flexural Strength (Mpa)	Fmax(KN)
1	8.42	0.076
2	18.08	0.10
3	20.20	0.095
4	8.98	0.07
5	17.79	0.05
6	20.98	0.10
7	12.24	0.10
8	18.69	0.13
9	20.84	0.125
10	17.06	0.09
11	20.63	0.064
12	22.97	0.055
13	16.50	0.103
14	20.70	0.095
15	22.27	0.125
16	12.93	0.14
17	21.01	0.13
18	24.82	0.12

Table A.3: Water absorption test results

Exp. No	Wo (g)	Wf(g)	(Wf-Wo)(g)	WA(%)
1	153.15	311.15	158.00	103.169
2	161.00	253.66	92.66	57.55
3	168.43	280.57	112.14	66.58
4	151.2	297.26	146.06	96.60
5	159.4	260.71	101.31	63.56
6	162.91	225.29	62.38	38.29
7	153.45	267.03	113.58	74.02
8	165.2	209.09	43.89	26.57
9	170.09	218.48	48.39	28.45
10	144.82	288.86	144.04	99.46
11	148.15	224.12	75.97	51.28
12	166.3	231.67	65.37	39.31
13	151.4	277.40	126.00	83.22
14	160	248.90	88.90	55.56
15	172.2	236.12	63.92	37.12
16	152.55	254.39	101.84	66.76
17	164.00	208.77	44.77	27.30
18	168.00	202.26	34.26	20.39

Table A.4: Swelling thickness test results

Exp. No	Lo(mm)	Lf(mm)	(Lf-Lo)(mm)	TS (%)
1	5.88	8.18	2.300	39.19
2	5.91	6.655	0.745	12.61
3	5.85	7.334	1.484	25.36
4	5.66	7.367	1.707	30.16
5	5.75	7.007	1.257	21.86
6	5.80	7.084	1.284	22.14
7	5.77	7.28	1.510	26.17
8	5.85	6.594	0.744	12.71
9	5.66	6.834	1.174	20.75
10	5.61	7.071	1.461	26.04
11	5.57	6.93	1.36	19.31
12	5.82	6.896	1.076	11.42
13	5.75	7.161	1.411	24.55
14	5.80	6.655	0.855	14.75
15	5.84	6.717	0.877	15.03
16	5.76	6.942	1.182	20.52
17	5.86	6.861	1.001	17.18
18	5.82	6.432	0.612	10.52