

**PRODUCTION AND CHARACTERIZATION OF PARTICLEBOARD FROM
LEATHER SHAVINGS AND WASTE PAPERS**

BY

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DECLARATION

DECLARATION BY THE CANDIDATE:

I declare that this thesis is my original work and has not been presented for a degree in any other University or educational institution. No part of this thesis may be reproduced in any form without prior written permission of the author and/or Moi University

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DEDICATION

This project is dedicated to my family members who have been a blessing throughout this project and in my studies.

God bless you all.

ABSTRACT

Large quantities of leather solid wastes are generated by leather industries and these wastes are either thrown away or dumped in open lands causing environmental issues. Wet blue leather solid wastes are biologically resistant as a result of complexation between chromium (III) salts and the carboxyl groups of collagens. Chrome shavings waste is one of the highly generated solid wastes and there is no proper utilization of these huge amount of waste. Preparation of leather boards from chrome shavings waste is economical and helps in reducing environmental pollution. Incorporating waste papers into the preparation of particleboards enhances the mechanical and physical properties. The aim of this study was to design and produce a particle board from leather shavings and waste papers through the compression method, to determine the effects of resin content, blend ratio and fat treatment of particles on the properties of the board as well as to characterize the physical and mechanical properties of the fabricated board. The leather and paper waste were blended in ratios of 1:1, 1:3 and 3:1 and moulded into particleboard using a cold hydraulic press. A two variable parameter design was used to determine the effects they have on properties of fabricated board. The particulars of leather shavings included 4.4 pH, 10.3% moisture content, 80.6% volatile matter and 2.7% chromium. The resulting fabricated board was characterized by density in the range 1089 to 1379 kg/m³. The moisture content of the board varied between 1.3% and 5.5% while water absorption was between 1.8% to 6.3%. The internal bond strength was at the range of 2.82 to 16.56 MPa, Modulus of Rupture (MOR) from 10.06 to 21.05 MPa and modulus of elasticity was ranging between 3.054-6.094 GPa. Finally, the maximum and minimum impact strength was 67 KJ/m² and 32.33 KJ/m², respectively. From the results of this study it was concluded that leather shavings and waste papers can be used as alternative raw materials for particleboard production and that physical and mechanical properties were depended on the resin content and the blend ratio. Particle treatment had positive effects on the properties of the particleboard. Future work should study the effects of more parameters on particleboard and do optimization studies on production of particleboard. In addition, further study is required on microscopy to determine bonding between particles and hence how bonding affects board properties.

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LIST OF ACRONYMS AND ABBREVIATION

ABBREVIATION	DEFINITION
SCB	Sugarcane Bagasse
MEKP	Methyl Ethyl Peroxide
BPO	Benzoyl Peroxide
UP	Unsaturated Polyester
IB	Internal Bond
MOR	Modulus of Rupture
MOE	Modulus of Elasticity
ASTM	American Society for Testing and Materials
JIS	Japanese Industrial Standards

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Particleboard is an engineered panel composite manufactured from particle materials with the addition of a resin. It finds its application in furniture, counters and desktops, insulators, cabinets, wall and ceiling panels, flooring, bulletin boards, office dividers, building, and packing materials. Due to the fact that particleboard is a homogenous material suitable for both industrial production and construction, the demand for particleboard has recently increased throughout the world (San, Ayrimis, & Gumuskaya, 2014). Particleboards were developed as alternative building materials replacing plywood in panelling, table tops, cabinets, door skin, and furniture component applications. Both softwood and hardwood have been traditional sources of raw materials for particleboard. Agricultural residues such as rice husk, rice straw, wheat straw, sugarcane bagasse, coffee husk, peanut hull, grasses, and corn cobs, have also been studied extensively for particleboard manufacture and they have showed potential as raw materials for the boards (Batiancela & Acda, 2015).

For many years, industries have been using traditional wood fibres such as sawmill residues, wood chips and logs in the manufacture of wood panel products. On the other hand, increasing demand for these products as well as depletion of forest resources have led to a shortage of raw materials. This problem is likely to persist unless suitable alternatives are found. Efforts have been made by several countries to overcome the wood shortage by utilizing recycling systems and reuse techniques for waste materials (Nourbakhsh, 2010).

Leather solid waste (LSW) can play a major role in providing the balance between supply and demand. Solid wastes from the leather industry are inevitable since leather processing is primarily associated with conversion of a multi-component skin to a single protein, collagen. Due to the nature of chemicals employed and the intrinsic nature of leather processing, there is also generation of a certain quantum of solid wastes (Ponsubbiah, Suryanarayana, & Gupta, 2018). Jiang, Liu and Han (2016) explained that leather-making is an important and traditional global industrial sector, providing various finished leather qualities and leather products. The leather industry has achieved a rapid growth causing an increase in investment due to the increase in global demand for leather goods. Globally, the leather industry is one of the most polluting industries which is considered to be responsible for an unfavourable impact on the environment (Mushahary, 2017). More waste generation is experienced as a result of increase in meat consumption and more production of leather goods and shoes. The three types of hides and skins most often used in leather manufacture are from cattle, sheep and pigs. These raw materials are converted into final products in various industries like the shoe industry, bag industry, clothing industry, furnishing and decoration industry. Huge amounts of raw materials are extracted and preserved by applying chemical processes before they are turned into final finished products of desirable quality (Konya, Zitte, & Ugwulor, 2013).

According to Jiang et al. (2016) approximately 1000 kg of wet salted hides would yield only 200 kg of finished leather generating more than 600 kg of solid wastes and by-products. In addition, the conversion of raw skin/ hides into the finished leather needs the use of about 100 chemicals to remove unwanted components, thus generating various solid wastes and waste water. The other type of waste which is abundant is paper. The amount of papers

thrown in domestic places is high causing a threat to the environment (Aksogan, Resatoglu, & Binici, 2017). In a year, more than 600 million tonnes of paper is produced but only 50-65% is recycled (Yang, Yu, You, Li, & Jiang, 2018). Thus, pollution to the environment will inevitably occur. The method of treatments for these pollutants is attracting much attention calling for urgent strategies.

In particleboard production, adhesives play a vital role in bonding the particles together. One type of binder that can be used as an adhesive is unsaturated polyester, which is available in Kenya and at an affordable price. This resin is also easy to handle and is dimensionally stable (Bagherpour, 2012). Formaldehyde based adhesives are mostly used in the manufacture of particleboard but according to Vnučec, Kutnar, & Goršek (2016), they have been classified as known carcinogenic materials despite their excellent strength, durability and cost effectiveness. Therefore, it would be very useful for development of particleboard from leather/paper using unsaturated polyester as an adhesive.

Hence the main objective of the present work is to convert wet blue leather and paper solid waste material into a potential particle board material and to propose a new route for solid waste management.

1.2 Statement of the problem

In Kenya, solid waste is mainly collected and disposed of in open dumpsites. It is also important to note that the role of waste management has been relegated to Councils which are the local authorities for urban areas. With increasing urban populations, there is more waste generated thus putting a strain on the existing capacity managed by local authorities. The impacts of solid waste to the environment, especially hazardous and non-biodegradables

ones cannot be overstated. As leather industries mostly use chrome sulphate for the leather manufacturing process, the solid wastes generated from the industry contain chromium (Cr) which when released to the environment create unfavourable outcomes by altering the normal physiochemical properties of soil and water. Leather wastes can last up to 50 years when disposed in the environment thus creating disposal challenges on landfills. Chromium is extremely poisonous and carcinogenic to animals, human, vegetation as well as the overall environment. It can cause mutation, cancer and also hinders enzymes and synthesis of nucleic acid. Also, the treatments of these wastes are expensive, complex or not applicable worldwide due to proficient work force environment. Waste paper is another type of waste which when disposed in landfills creates methane as it decomposes. Methane is a dangerous greenhouse gas, since it has 21 times more global warming potential than carbon dioxide. To safeguard the environment, efforts are being made for recycling different wastes and utilizing them in value added applications. This paper aims at providing an alternative solution to waste disposal and utilization of this waste in value addition applications.

1.3 Justification of the study

Since leather industries mostly use chrome for the leather manufacturing process, the solid wastes generated from the industry contain chromium making them flexible and durable. Currently there are around 14 tanneries in Kenya with a daily production of 40 million tons of wet blue leather. This explains why there is the highest number of chrome splits, shavings and trimmings (Mwonder, Ombui, & Onyuka, 2020). The amount of waste paper produced in Nairobi alone is about 18% of solid wastes (NEMA 2014). Due to this, it is evident that these wastes are abundantly available. When these wastes are not properly disposed, they cause environmental pollution. Making board from these wastes will provide an alternative

solution to waste disposal as well as value addition to wet blue leather waste and waste papers. It will also allow conservation of natural resources such as wood materials. To add to these benefits, the use of these wastes will reduce environmental pollution since it contributes to the protection of mother land. Production of particleboards from these wastes also contributes to the Kenyan government Agenda four of affordable housing.

1.4 Significance of the study

Many challenges in the leather industry are related to pollution and expenses incurred in transportation and dumping. The use of leather shavings and waste paper as an alternative to raw materials for particleboard production will reduce the amount of waste in landfills thus reducing environmental pollution. It will provide alternative ways to manage solid wastes and minimize the amount of solid wastes dumped to the environment. Utilization of these wastes on particleboard production will increase the production of particleboards in Kenya and create employment to people thus boosting the economy of the country. From the society point of view, this process provides for a clean environment around the tanneries. The baseline data from this study can also be used by other researchers for further study.

1.5 Objectives of the study

1.5.1 Main objective

To produce and characterize a particleboard from wet blue leather shavings and paper waste.

1.5.2 Specific objectives

- i. To characterize physio-chemical properties of leather shavings
- ii. To fabricate a particleboard from treated and untreated shredded solid waste at different resin content and blend ratio

- iii. To characterize physical and mechanical properties of the fabricated particleboard.

1.6 Scope of the study

This project was carried out using wet blue leather solid waste (leather shavings from wet blue and post tanning processes) and waste papers (newspaper and office paper) from Kenya Industrial Research and Development Institute, Nairobi. Unsaturated polyester (commercial code GP 1778) was used as resin and was purchased from Henkel Company, Nairobi. The particleboard that was produced was fabricated using the compression method. The design parameters that were varied during the manufacturing process were resin content and blend ratio. The fabricated boards were characterized in terms of physical properties such as density, moisture content and water absorption and mechanical properties such as impact strength, compression strength, tensile strength and bending strength. The results obtained were analysed using Minitab software (version 17).

1.7 Research methodology

1.7.1 Laboratory analysis

Analysis of the physio-chemical properties of leather shavings and paper solid wastes was carried out to enable the determination of the physical and chemical composition of the solid wastes in terms of moisture content, volatile organic compound, pH and chromium content. Through the laboratory analysis, specific objective number one on characterization of leather solid waste was achieved.

1.7.2 Previous related works

Extensive literature review on published journals, papers and books was done to relay on current and previous research works related to this research study. Through literature review

the best method of fabricating hand-made particleboard was identified as well as the best testing methods for the fabricated board. The study also allowed visualization of possible potential uses of leather/paper solid wastes in Kenya, and the recycling of these solid wastes. Through this methodology objective number two on fabrication of leather/paper solid waste particle board as well as objective number three on characterization of solid waste board was achieved.

1.7.3 Experimental work

After characterizing leather solid wastes and waste paper and determining the best method for fabricating particle board, different boards were fabricated. Experimental conditions were varied during the fabrication process by using different proportions of waste paper and leather shavings to obtain a paper-shavings board. This methodology helped achieve objective number two on fabrication of particleboard from solid waste.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

According to Lima, Farinassi, Marin and Pereira (2016) solid wood was the first raw material used for furniture production but its use has become increasingly rare as a result of reduction in availability of timber. As stated by Alam et al.(2015) there has been significant increase in demand of particleboard due to manufacturing of furniture, house construction, interior decoration, home construction, flooring, kitchen worktops, work surface in offices, table tops and other industrial products. This huge demand of particleboard has led to a decrease in native woody species causing the search for new materials that may competently meet the demand. This pressure on forests supports research on new materials and utilization of readily available raw materials. Utilization of residue has been currently increasing thus the characteristics of particleboard produced with these residues have been investigated by researchers (Melo, Stangerlin, & Pedrosa, 2014).

On the other hand, the leather industry has been an old age industry serving the society with a wide range of consumer leather goods but with an enormous amount of solid wastes being generated. The feeble capacity of town managers together with low level of public awareness and lack of knowledge on environmental effects has led to unrestrained solid wastes disposal. Thus, the problem of waste disposal as well as the demand of alternative sources of raw materials in board making is ever increasing. Alternate non-woody plant fibres may play a major role in minimizing the demand of manufacturing the composite panels and reducing environmental pollution (Sumathi & Senthil, 2016).

2.2 Types of solid wastes and their potential on recycling

2.2.1 Sugarcane bagasse

This is one of the largest agricultural fibrous residues produced after juice extraction of sugarcane. Globally, it is estimated that about 700 M tonnes of bagasse is produced annually. Its composition depends on the maturity, harvesting method, the variety and efficiency of the sugar processing (Loh, Sujan, Rahman, & Das, 2013; Weber & Drelich, 2016). Bagasse is a natural fibre that can be easily obtained and used in manufacture of particleboard polymer blending substances and furniture. The main constituents of this bagasse are cellulose, hemicellulose, ash, lignin and wax. Because of this composition, sugarcane bagasse makes an ideal component as reinforcement in composite materials (Rino & Dahlan, 2017). The bulk of bagasse consists of a rind which is the hard-fibrous substance and a pith which is a soft material. Longer and finer fibres are found in the rind bound together by lignin and hemicellulose in a random manner while smaller fibres with majority sucrose are found in the pith (Motaung & Mochane, 2017).

According to Holanda and Ramos (2016) bagasse has been utilized as a raw material in power generation and in manufacture of paper pulp. Through burning of bagasse, a tonne of sugar can produce 70 kW/h of energy. Sugarcane bagasse have also been used to prepare fibre reinforced polymer composites for commercial use and improvements in mechanical properties of the composite as reported by (Motaung & Mochane, 2017; Weber & Drelich, 2016). In addition, this residue ash has been incorporated into clay bricks for clay brick bodies, through replacement of natural clay by up to 20% wt. for civil construction (Faria, Gurgel, & Holanda, 2012).

As suggested by Loh, Sujan, Rahman, & Das (2013) sugarcane bagasse; can be mixed with starch and glycerol to produce composite materials; mixed with starch, agar and gelatine to produce tableware packaging material; mixed with Arabic gum and water to produce ceramic and refractory products and can also be used to replace cement in concrete manufacture. The diagram of sugarcane bagasse is shown in Figure 2.1.



Figure 2.1: Sugarcane bagasse (SCB) wastes (Loh, Sujan, Rahman, & Das, 2013; Rino & Dahlan, 2017)

2.2.2 Wastes rubber tire

Waste-Tire rubber also known as End of Life Tires is one of the most substantial environmental danger constituting important parts of solid waste. Disposal of this waste is a key environmental issue due to the vast amount of used rubber resulting from increased automobile production. A very serious threat is posed to ecology since millions of tires are discarded, thrown away or buried every year over the world. Through estimation, 100 million

tires end their life every year and more than half of these wastes are discarded to landfills. Tire burning which was considered as the easiest and cheapest way of disposal is causing fire hazards thus calling for other methods of disposal (Khitab, Awan, Anwar, & Mughal, 2017; Skariah & Gupta, 2016).

The disposal of tires in landfills has negative impacts since they take very long time to decompose and take up a lot of space in the landfill. Due to these reasons efforts have been made to discover prospective uses of these wastes in the construction sector. According to Herrera-sosa et al.(2015), waste steel fibres from recycled tires have been used to improve mechanical properties of the concrete by using it as mechanical reinforcement. On the other hand, recovered rubber has been used to replace natural aggregates in order to improve elasticity features and lower brittleness. This recovered rubber can also lead to reduction in water absorption of concrete thus providing protection against corrosion.

Moreover, the use of recycled tires as a foundation pad for rotating machinery and for damping vibrations in the railway station or where impact resistance, energy absorption, or blast is required, was reported. Rubber waste in crumb form has also been used as light weight aggregate in materials containing cement and was reported to improve thermal and acoustic characteristics (Herrera-sosa et al., 2015).

According to Revelo, Correa, Aguilar, & Colorado (2019) ground powder rubber particles were used as reinforcement together with polyurethane resin in composite production. From these results the composite exhibited flexible properties allowing application in places where loads were common such as floor tiles used in gyms. Literature also showed that waste tire

particles obtained by the grinding process were used as reinforcements of hydraulic concrete and there were improvements on mechanical properties (Herrera-sosa et al., 2015).

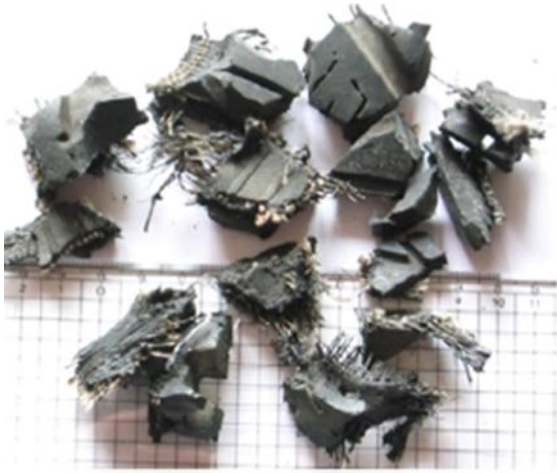


Figure 2.2: Crushed Rubber (waste tire chips) (Skariah & Gupta, 2016)

2.2.3 Rice wastes

The main types of solid wastes in the rice industry include straw, husk, ash, bran and broken rice. Rice straw is a fibrous lignocellulosic material which is separated from the grain during harvest (Pode,2016). Moraes et al.(2014) argues that 1.35 tonnes of rice straw remain in the field for every tonne of grain harvested. It has high content of silica compared to other rice residues. As a way of cheap disposal and fungi spread prevention, rice straw is usually burnt in open air. However, this method of disposal generates large amounts of greenhouse gases thus polluting the environment and causing traffic accidents as a result of poor visibility.

Rice straw has been used as resource for energy generation and as source of biomass for power generation which is a clean and sustainable energy. Studies have also been done on production of biomass briquettes and ethanol manufacture from rice straw. Application of

rice straw as animal feed treated with chemicals such as urea was also reported (Moraes et al., 2014).

Rice husk is another rice waste and is mainly the protective layer of the grain. It comprises of four layers which can be spongy, fibrous, and structural or cellular. It has a high volume but low density. The main elements of rice husk are cellulose (50%), lignin (30%) and inorganic residues (20%). Its negative characteristics include low nutritional properties, abrasion, large volume and resistance to degradation (Moraes et al., 2014).

Literature shows that rice husk has been used as biomass for power generation since its calorific value is high and as a source of material for bioethanol production (Moraes et al., 2014). Production of levulinic acid which is used in tobacco and pharmaceutical industries has also been stated (Moraes et al., 2014). In addition to this, rice husk has also been used as a bulking agent in composting and as poultry litter because of its greater weight gain for the animals, availability and greater productivity index (Moraes et al., 2014).

According to Poda (2016), rice husk ash is a lightweight, bulky and highly porous material produced by burning husk. It consists of trace elements such as sodium, potassium, calcium, magnesium, iron, zinc and copper. Rice husk ash has been used in production of silicon carbide and pure silica. It also indicates that it has been used as polymer filler in natural rubber compounds so as to promote better mechanical, physical and thermal properties. This rice husk ash was used as adsorbents, support for metal catalyst, in synthesis of zeolites and in civil construction as cement.

Utilization of rice husk together with phenol-formaldehyde resin in particleboard production for external application was reported (Ciannamea, Marin, Ruseckaite, & Stefani, 2017).

Rice husk has also been combined with gum Arabic in production of particleboard samples and from these results, the mechanical properties of the boards were suitable for building and structural applications such as partitioning and as ceiling boards (Ndububa & Nwobodo, 2015; Suleiman, 2016). Suleiman (2016) pointed out that rice husk can be used in the manufacture of particleboard using starch as a biodegradable adhesive. This utilization of renewable resources can reduce strain on forest resources such as wood. Moreover, according to Madu, Nwankwojike, & Ani (2018) rice husk and saw dust reinforced polyester composite for ceiling board application has been produced as source of building materials in Nigeria through the waste to wealth initiative. The diagrams showing rice wastes are in Figure 2.3.



(a)



(b)

Figure 2.3: Rice wastes (a) rice straw (b) rice husk (Moraes et al., 2014)

2.2.4 Waste papers

Waste papers are all kinds of paper which have accomplished their functions in many application areas and then disposed of (Aksogan et al., 2017). They are a mixture of plant material rich in cellulose. Industry and businesses are the biggest sources of recovered papers of which around 10 % comes from offices (Yang et al., 2018). These wastes include newspaper, office paper, magazines and packaging cardboard. Yearly, more than 600 million

tonnes of waste paper is generated but only about 50-65% is recycled. This is because recycled paper fibres turn into low quality paper products and they contain other wastes. Recycling of one ton of waste paper can save 17 trees and 7000 gallons of water thus benefiting the environment (Yang et al., 2018).

In literature, waste paper has been used together with urea formaldehyde to make single layer particleboard and the results showed that the board satisfied the minimum requirements for load-bearing for use in dry and humid conditions (Eshraghi & Khademieslam, 2012). Madahi (2018) reported the production of high-pressure laminate from waste paper. According to Wang, Templer, & Murphy (2012) and Wang, Sharifzadeh, Templer, & Murphy (2012) waste paper has been utilized as raw material in bio-thermal production by applying the corn-based process. In addition to this, literature depicts that waste paper has been utilized in production of thermal and ultrasonic insulation material for building applications (Aksogan, Resatoglu, & Binici, 2017).

2.2.4.1 Waste paper in Kenya

The management of solid waste in all 47 counties in the country remains a major challenge. The County Governments have inherited improper waste management from most local authorities who practiced this state of affairs. This has led to the current poor waste management situation across the country (NEMA, 2015). For a while now, less than 40% of the Nairobi city receives waste collection services. The remaining 60% is either dumped in open spaces and burnt, or scavenged. It is therefore required to establish urgent considerations for a proper solid waste disposal and management plan (Khamala & Alex, 2013).

In Nairobi city, paper waste is produced at a rate of 546 tons/day (17.5% of total wastes) and out of these, 44 tons/day (8% of paper) is recycled. This leaves the remaining 9.5% for direct disposal (Kasozi & Harro von Blottnitz, 2010). The estimate rates of paper recycled in Nairobi County are between 75-100 tonnes per day and are largely dependent on the recycling enterprises being able to source decent quality (e.g. not contaminated or wet) waste paper products. Market leaders in the paper recycling industry in Nairobi and across Kenya include: Chandaria Industries, Madhupaper and Kamongo Waste Paper (Palfreman & Theron, 2015). Table 2.1 shows the percentage of paper produced in selected towns in Kenya.

Table 2.1: Amount of paper waste produced in selected towns (Khamala & Alex, 2013; NEMA, 2015).

Town	Paper waste
Nairobi	11.30%
Kisumu	12.3%
Nakuru	17.3%

2.2.5 Wood wastes

Wood is a renewable and natural material used to produce a wide range of wood-based products. Several types of solid wastes are generated by different wood supply sectors. Solid-waste generation in sawmills is around 40%-60% while that of paper and wood pulp industry is around 30% (Souza et al., 2018). As stated by Cetiner & Shea (2018) wood waste is mainly a by-product of construction and demolition, packaging, municipal activities, joinery and furniture manufacture.

As reported by Moreno & Font (2015) and Röder & Thornley (2017) waste from furniture has been considered as a source of energy through the thermal degradation process. The biochar produced from wood sawdust has been used as an additive in cement mortar and it showed better properties (Gupta, Kua, & Koh, 2018). Literature also shows that wood waste has been utilized as reinforcement in particleboard manufacture (Souza et al., 2018; Hossain et al., 2018; Chanhoun, Padonou, Codjo, & Doko, 2018; David, Moreno, & Saron, 2017). According to Cetiner & Shea (2018) wood waste has also been used as a thermal insulation material within frame wall construction and as a raw material in production of activated carbon for mercury removal from waste water (Sajjadi et al., 2018). Figure 2.4 represents some of the wood wastes.

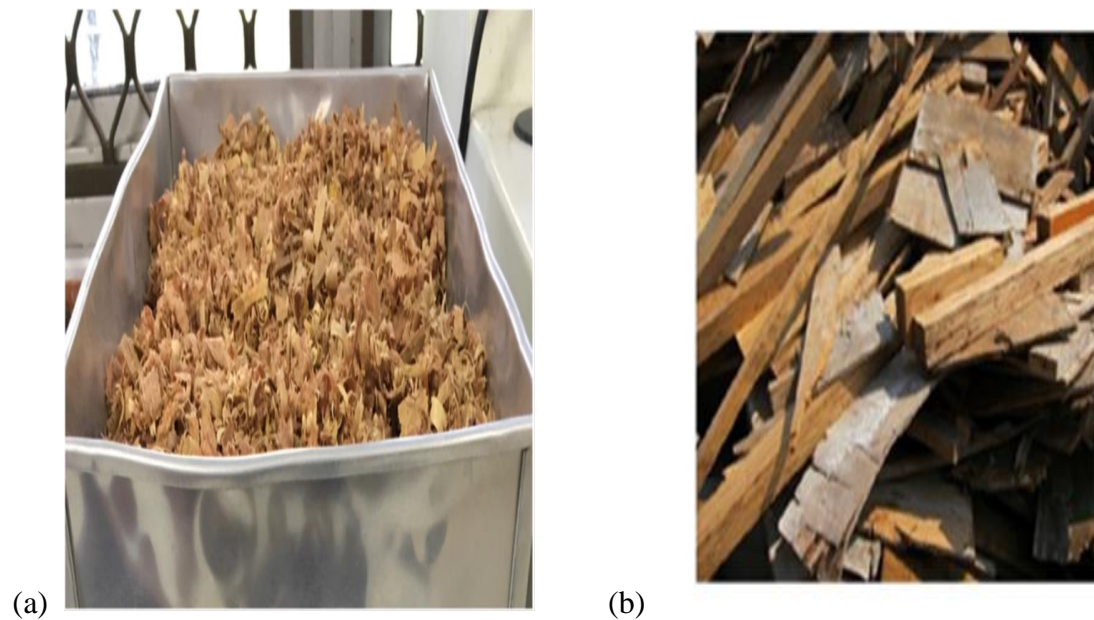


Figure 2.4 :(a) Mixed wood saw dust (b) waste wood formwork (Gupta, Kua, & Koh, 2018; Wang et al., 2018)

2.2.6 Bamboo waste

Bamboo is an adaptable and renewable resource widely used in many construction applications. It is characterized by low weight and high strength. The mechanical strength, fibre characteristics and chemical constituents of bamboo vary from age to age and from species to species. It consists of cellulose (50-70%), pentosan (25-30%) and lignin (20-28%) (Saikia, Dutta, Kalita, Bora, & Goswami, 2015). As argued by Alam et al.(2015) bamboo culm is made up of straight woody portion, hollow and cylindrical which is formed by nodes and internodes. Bamboo like branches, leaves, nodes, lower part of the culm and rhizomes are bamboo wastes generated during the production process of bamboo products. These bamboo wastes are mostly utilized as fuel.

From literature, bamboo leaf ash has been utilized in blended cement to analyse its behaviour in relation to pozzolanic activity and the results showed that the waste had high reactivity. Bamboo leaves have also been used to prepare absorbents for toxic substances such as dye and heavy metals and in ceramic formulation for electrical insulation (Frías et al., 2012; Muangthai, Yooram, & Dungkhong, 2016; Marimuthu & Mohanra, 2017).

Posada, Jaramillo, Marleny, & Garcı(2016) and Wahab & Fauzi (2017) pointed out that bamboo waste has been used as a raw material in bio composite manufacture because of its mechanical and physical properties that give high durability and strength. Bamboo wastes and branches were utilized as fillers in single layer particleboard production and bamboo waste furniture was used to produce activated carbons for arsenic removal in aqueous solutions (Alam et al., 2015; Giraldo, 2013). In addition to this, bamboo waste has been upgraded as solid and liquid bio fuel through the torrefaction and co-pyrolysis processes

respectively (Yuan et al., 2017;Chen et al., 2018). The diagram of bamboo waste is shown in Figure 2.5.



Figure 2.5: Bamboo wastes (H C Chakrabarti, 2018)

2.2.7 Leather solid waste

Leather solid waste is anything that is neither gas nor liquid produced by leather activities and can produce harmful effects to the environment. Solid wastes generated in the leather industry are mainly derived from the treatment of chromium-tanned leathers by mechanical processes such as shaving, buffing, splitting and trimming (Ocak, 2012). These solid wastes contain wet blue splits, shaving dusts, hair, fleshing and trimming from post tanned processes. Chrome shavings are small pieces of leather shaved off from uniform wet blues by a bladed cylinder. The wet blue is the wet chrome tanned leather without dressing. Buffing dusts are generated after treating the surface of leather by abrasion. Leather solid waste is therefore composed of a large amount of structural fibrous proteins called collagen and 3-6% chromium. Due to their irregular shape and extremely small size; wet blue splits are sometimes used for making very small fancy items but are mostly thrown and dumped as

solid wastes (Kennedy, Ratnaji, Konikkara, & Vijaya, 2018; Lakrafla et al., 2013). A huge investment is required for treating these solid wastes once they are dumped. However, approaching this problem with inter-disciplinary thought would lead to production of valuable products for societal application using a small investment. The characteristics of wet blue splits include resistance to biological factors; high content of dissolved, suspended organic and inorganic solids mainly consisting of chromium and proteins. This results in high demand for oxygen and threats to the environment. The complexation between chromium and the carbonyl groups of collagen brings stability of these wet blue splits. Although Cr (III) is viewed as a non-toxic substance, possible oxidation of Cr (III) to Cr (VI), threatens the environment since Cr (VI) is a toxic compound (Kennedy, Ratnaji, Konikkara, & Vijaya, 2018).

In literature, there are few studies on the treatment of chromium containing wet blue leather wastes through extraction of chromium from wastes for re-use in the tanning process and isolation of protein fractions (Rahaman et al., 2016). As an alternative to this exercise, the thermal treatment of leather waste for energy generation and other useful products through combustion, pyrolysis and incineration was also reported (Priebe et al., 2016; Agustini, Costa, & Gutterres, 2018; Sethuraman, Srinivas, & Sekaran, 2013). Transformation of this leather waste into light weight constructional materials and hierarchical porous carbons was stated by Mushahary (2017) and Konikkara, Kennedy, & Vijaya (2016). Leather solid wastes were also used by Ponsubbiah, Suryanarayana, & Gupta (2018); Teklay et al. (2018); Czlonka et al. (2018) and Moses, Sumathi, & Bright (2017) as raw materials for making composites for various applications. The conventional recycling methods cannot be considered a solution to the waste management process for leather wastes with Cr content in

an ecological way. Conversion and utilization of leather solid wastes by cleaner methods can reduce the problems of environmental pollution and compliment the challenges of the wood sector. Not only does this kind of process demand the use of low-quality waste but also generates value added products, connecting the way between the leather and board sectors.

2.2.8 Leather particle treatment

According to Jankauskaitė, Jiyembetova, & Gulbinienė,(2016), leather absorbs water because of attractive interaction between the leather and water. Collagen fibres of leather contain many functional groups such as $-OH$, $-COOH$, $-NH_2$ and $-CONH-$ which are hydrophilic and have good water affinity. Therefore, several leather surface modifications are applied to leather to improve the water resistance property. There are various methods of improving this property as explained in subsequent paragraphs.

1. Sealing the leather with an impermeable layer

In this method, the surface of leather is attached to a foil or thin laminate of waterproof synthetic material by use of an adhesive. The film will thus prevent the spreading of water over the surface and the leather will not be wetted under static conditions. The disadvantage of this process is that it reduces the water vapour permeability when produced using modern technologies.

2. Closed waterproofing

Closed waterproofing is a process where the spaces between the leather fibres are closed using a water repellent substance. This process can be achieved by using hydrophilic waterproofing substances or by incorporating water insoluble substances on leather such as

molten waxes and solid fats. A long-established system of imparting special feel to leather is grease impregnation but this process blocks any water or air permeability and makes leather extremely heavy. A method was then introduced where certain surfactants (such as hydroxycarboxylic acid derivatives) are applied on leather and where they absorb a certain quantity of water forming highly viscous water-in emulsion, filling the gaps in the fibre network. Since these micelles are hydrophobic on their outer side, the gaps are filled with a waterproofing material. However, this method partially seals pores thus it normally weakens the water vapour permeability and water vapour absorption of the leather.

3. Open waterproofing

The last method of modifying the leather surface is by creating a hydrophobic net around the fibres without filling spaces. This is the best approach of providing water repellent leather. The process involves using a low surface energy water repellent agent to form a hydrophobic layer through binding of the agent to the fibre and fibrils. In this method high interaction between the fibres and the water repellent agent is required since water vapour can penetrate into the fibre network and fail to spread over the hydrophilic fibre wetting internal surface.

2.2.9 Leather processing and waste generation

Leather processing is subdivided into three sub-processes namely, preparatory stage (beam house), tanning stage and post tanning stage. An additional process called finishing is usually set up in leather processing.

1) Beam house process

In the preparatory stage or beam house stage, the skin of the animal is prepared for tanning. This process involves preservation, soaking, liming, unhairing, fleshing, splitting, reliming, delimiting, bating, degreasing, bleaching, pickling, and depickling. Soaking is a process of rehydrating the skin/hide to remove the salt used for the preservation, soluble protein, dirt, blood and dung. Liming and unhairing are processes aiding in removal of hairs and keratinous matter thus improving flexibility and fullness of leather. Excessive organic materials present are then removed by mechanical process called fleshing for easy penetration of chemicals in subsequent processes. Splitting is carried out using splitting machine after fleshing to produce hide of a set thickness. The lime and other alkalis used in the liming process are removed using water or chemical treatment by a process called delimiting. The removal of hair roots and pigments are achieved by the bating process. The degreasing process is carried out to remove excess fats. Finally, the bathed pelts are treated with sulphuric acid, formic acid and salt to obtain the desired pH for the optimal penetration of the tanning agent through the pickling process (Maina, Ollengo, & Nthiga, 2019; Sivaram & Barik, 2019; Bethelhem haile tesema, 2018).

2) Tanning process

This is the second stage of leather processing where raw skin is converted into stable material which does not deteriorate. Two methods of tanning are mainly adopted namely, chrome tanning and vegetable tanning. Chrome tanning involves the use of sulphate chemical while vegetable tanning utilizes natural tannin materials from different parts of plants. Chrome tanning is more commonly used than vegetable tanning since it less time consuming with high thermal and water stability (Nogueira et al., 2011; Sivaram & Barik, 2019).

3) Post tanning process and finishing

The next process after tanning is post tanning (wet finishing) where practices such as neutralization, washing, retanning, dyeing and fat liquoring are done. Neutralization is a procedure which is done to remove acidity in leather thus aiding in uniform penetration of dyes. The properties and performance of leather are modified through the retanning process where the finished leather is made full, elastic, and levelled out with no loose grain. After retanning is done, the leather is fat-liquored to prevent fibres sticking when the leather is dried after completion of the wet processes. The colouring stage is done through dyeing. Finally, the drying process is performed in heated frame tunnels or a vacuum to remove excess water and bind chemicals to the leather. The product obtained after the post tanning process is crust leather which is resistant to decomposition. Drying is followed by buffing, conditioning and staking (Sivaram & Barik, 2019; Maina et al., 2019).

Finishing is the last processing stage where appearance of leather is enhanced. The main aim of this stage is to provide performance characteristics of leather in terms of handle, adhesion, colour, flex, rub fastness and other properties as required by the end user. This process also helps in hiding the defects, providing fashion and contributing to leather beauty.

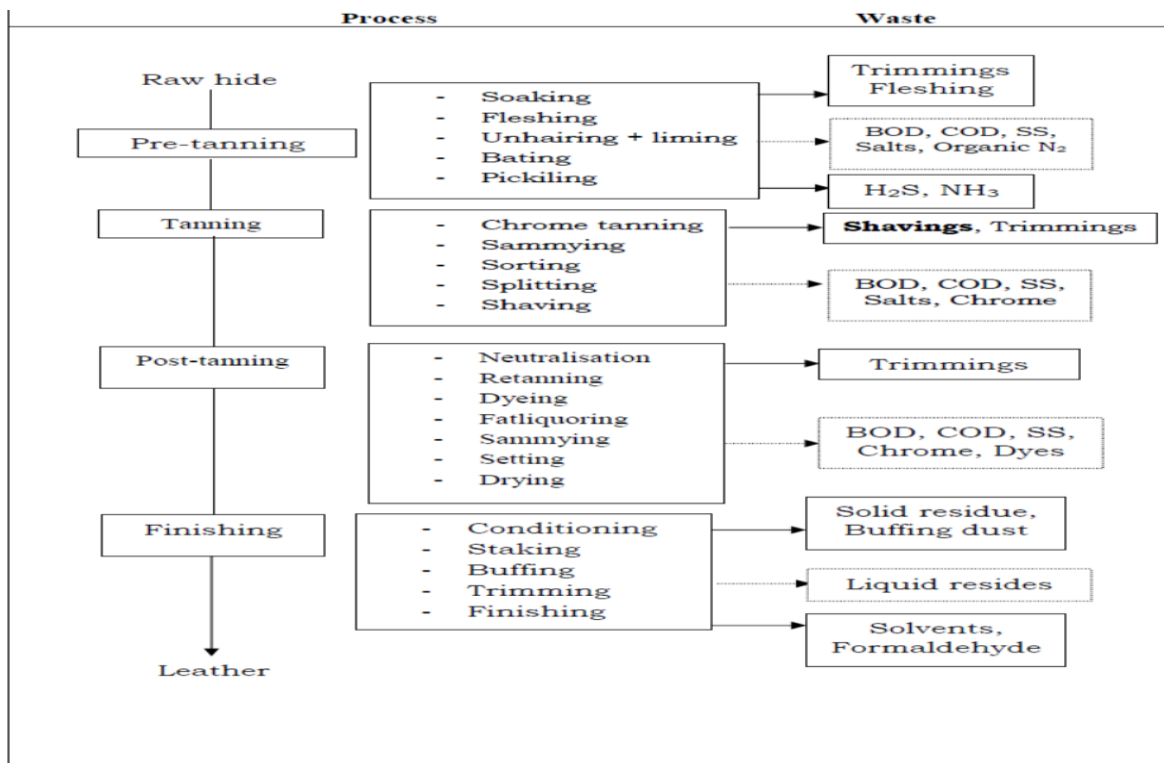


Figure 2.6: Leather processing flow diagram and types of solid wastes generated (Amal, 2014)

Type of waste generated during leather processing

During the tanning process three different categories of waste types are generated namely; solid, liquid and gaseous. Out of 100% raw hide only 20-25% is converted into finished leather and about 75-80% into solid waste (Mushahary, 2017; Bethelhem, 2018).

Liquid wastes include huge amounts of water and pollutants discharged during the tanning process. This waste water contains chromium and other chemicals since parts of the chemicals are not absorbed in the production process and will discharge to the environment together with the water used in leather processing (Sivaram & Barik, 2019).

Gaseous waste in terms of BOD comes from beam house operation due to degradation of hides and hair, in addition to this there are chemicals and dust released to the air due to dry finishing (Bethelhem haile teseema, 2018).

2.2.10 Leather industry in Kenya

Presently, there are 14 tanneries in Kenya operating at an average installed capacity of 70% with a daily production of 40 million tons of wet blue leather. The tanneries mainly produce wet blue leather for export (Mwonderu, Ombui, & Onyuka, 2020; Oruko et al., 2014).

Types and quantities of leather solid wastes generated in selected tanneries

Table 2.2 illustrate the proportion of various types of leather solid wastes produced in selected tanneries during the month of study. It can be seen that chrome splits and trimmings constituted 36.2% of the total waste generated, followed by chrome shavings at 32.1%. The amount and composition of leather waste generated depends on several factors such as tanning techniques (number, type and sequence of unit operations). Chrome shavings were among the highest type of tanned waste generated in selected tanneries and posed the most difficulty in disposal of chrome on the environment (Mwonderu et al., 2020).

Table 2.2: Types and quantities of leather solid wastes generated in the month of study for the 6 pre-selected Kenyan tanneries (Mwonder et al., 2020).

Type of waste (kg)	Nakuru	East Africa	Alpharama	Aziz	Reddamac	Bata	Total	Proportion (%)
Chrome shavings	150,000	100,000	148,000	60,000	40,000	180,000	678,000	32.1
Chrome splits & trimmings	175,000	120,000	205,000	15,000	20,000	230,000	765,000	36.2
Vegetable shavings	0	10,000	92,000	6,000	10,000	75,000	193,000	9.1
Vegetable splits & trimmings	0	12,000	165,000	3,000	5,000	130,000	315,000	14.9
Crust trimmings	0	4,500	38,000	2,000	5,000	25,000	74,500	3.5
Buffing dust	0	6,500	18,560	10,000	4,000	10,500	49,560	2.4
Finished trimmings	0	6,500	8,500	5,000	5,000	12,500	37,500	1.8
Total	325,000	259,500	675,060	101,000	89,000	663,000	2,112,580	100

Tanned solid waste management practices in Kenya

The methods used in leather solid wastes disposal by most tanneries in Kenya are shown in Table 2.3. These methods include, landfilling, open dumping, incineration, and use as a source of fuel. In all of the six tanneries, no recycling and reuse was done. Since there are no established methods of leather solid wastes utilization in Kenya, safe and economical disposal/utilization of chrome tanned solid waste is a challenge (Mwonder et al., 2020).

Table 2.3: Current modes of leather solid wastes disposal and utilization in selected Kenyan tanneries (Mwonder et al., 2020).

Tannery	Current leather waste disposal/ utilization mode
Nakuru Tanners (Nakuru town) East Africa Tannery (Nairobi)	Landfilling mode of disposal. No documented method of recycling or re-using of leather waste Dried fleshings and trimmings are disposed of by: Open dumping Incineration and Being used as a source of fuel. No recycling of leather waste is done
Alpharama Ltd. (Athi River)	Landfilling is the only mode of disposal of leather waste in this tannery. Neither recycling nor re-using of leather waste is done
Aziz Tannery Ltd. (Nairobi)	Leather waste disposal is done by open dumping and incineration. There is no documented mode of either recycling or re-using of leather waste in this tannery.
Reddamac Leather Centre (Zingo Investments, Nairobi)	Leather waste disposal is done by the following two modes: Open dumping and Landfilling. Neither recycling nor re-using of leather waste is done.
Bata Shoe Company (Limuru)	Landfilling is the only mode of disposal Neither recycling nor re-using of leather waste is done.

2.3 Resin systems of the matrix

In composites, resin is another important constituent which binds the reinforcement together. Two classes of resins are available namely thermoplastic and thermosetting resins. A thermoplastic resin remains solid at room temperature but melts when heated. These types of resins do not solidify permanently (do not chemically crosslink) thus they are undesirable for structural applications. On the other hand, thermosetting resin undergoes irreversible crosslinking and solidifies permanently. This characteristic makes thermosetting resins very desirable in many applications. Unsaturated polyesters, epoxies and vinyl esters are the most commonly used resins in composites manufacture while polyurethanes and phenolics are the least used (Bagherpour, 2012).

2.3.1 Unsaturated polyester

Polyester can be classified as saturated resin (polyethylene terephthalate) or unsaturated resin depending on the condensation polymerization process. Isophthalic polyesters (saturated) are made from isophthalic acid or terephthalic acid but orthophthalic polyesters are made by phthalic anhydride. The unsaturated polyester amounts to about 75% of all polyester resins due to its excellent environmental resistance and good mechanical properties (Park, 2011). It is produced from condensation reaction of dicarboxylic acids and dihydric alcohols. During the curing process, a reactive monomer in the range of 30-50% is added into polyester which then copolymerizes with it contributing to the final properties of the cured resin (Park, 2011). Most polyester resins consist of a solution of polyester in a monomer which is usually styrene. This styrene enables easier handling of the resin by reducing its viscosity and also enhances curing of a liquid resin to solid resin through crosslinking without evolution of any by-product. These resins are also called contact or low-pressure resins since they can be moulded without pressure but they have limited storage life as they will gel on their own over a long period of time (Park, 2011). Because of this reason, small quantities of inhibitors are added to slow this gelling at the time of resin manufacture.

Before using polyester resins, a catalyst is usually added to initiate the polymerization reaction. This catalyst simply activates the process but does not take part in the chemical reaction. Methyl ethyl ketone peroxide (MEKP) or benzoyl peroxide (BPO) is the most often used catalyst in the amounts varying from 1-2 % (Park, 2011). In the presence of polyester resin, this catalyst will decompose forming free radicals which react with unsaturated groups initiating polymerization. The amount of catalyst and processing temperature are some factors that can control the rate of polymerization. When the temperatures are high or when

the catalyst is more the reaction will be faster and vice versa. The curing temperature, monomers, type and amount of reactant and catalyst affects the properties of polyester resin. When molecular weight of polyester is high, there will be more points of unsaturation in molecules and the strength of cured resin will be high (Park, 2011).

Figure 2.6 a, represents the molecular chains of polyester where the 'B' indicates the reactive sites (monomer) in the molecules. In order to form complex three-dimensional networks (see Figure 2.6 b), a styrene 'S' is added in the presence of a catalyst to cross link the polymer chains of each reactive site. At this stage, the polyester resin is then said to be cured, chemically resistant and the chemical reaction is irreversible (Park, 2011).

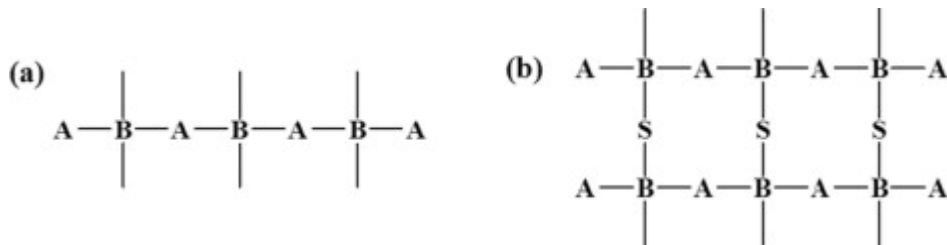


Figure 2.6: Schematic representation of polyester resin: (a) uncured and (b) cured.

Since polyester resins have the capacity to be modified during construction of polymer chains, they are considered as versatile resins. They have great usefulness in all sections of the composites industry. The advantages of these resins include; balance of properties, dimensional stability, affordable cost, high corrosion resistance and fire retardants and ease in handling, processing and fabricating (Bagherpour, 2012). Because of these properties, polyester resin is the best balance between the performance and structural capabilities (Bagherpour, 2012). Table 2.4 shows typical properties of cured unsaturated polyester (UP) as stated by Jones (2017) and Park (2011).

Table 2.4: Typical properties of cured unsaturated polyester

Property	Unsaturated polyester
Density (kg/m ³)	1200
Tensile strength (MPa)	70
Tensile modulus (G Pa)	3.5
Flexural strength (MPa)	205-690
Compressive strength (MPa)	140
Hardness (Rockwell MPa)	110
Hardness (Barcol MPa)	40
Elongation at break (%)	2.5-4.5
Volume contraction during cure (%)	8

2.4 Solid waste characterization

2.4.1 Physio-chemical characteristics

2.4.1.1 pH value

Determination of the pH of the sample solid wastes involves shaking five grams of sample of solid wastes in 100 ml of distilled water for 16 – 24 hours followed by direct measurement of the pH. The level of pH in the waste varies depending on the characteristics of feed material and decomposition rate (Abajihad, 2012).

2.4.1.2 Moisture Content

Determination of moisture content entails weighing of samples into a pre weighed dish and drying them in an oven at 105°C to a constant weight. The percent moisture content (MC) is then calculated as a percentage loss in weight before and after drying. The moisture content is obtained by utilizing wet and dry weight (Kalanatarifard & Yang, 2012).

2.4.1.3 Volatile Matter Content

Determination of volatile matter content of solid waste as described by Kalanatarifard & Yang (2012) involves ignition of the sample at 950°C. The samples of wastes used in

moisture content determination are weighed and placed in a muffle furnace for 7 minutes at 950°C. After combustion, the samples are weighed again to determine the ash dry weight, with volatile solid content being the difference between the dried solids and the ash. The volatile matter is computed by dividing the difference between dry sample and ash weight with sample weight.

2.4.1.4 Determination of Chromium, Sodium and Calcium Content

Determination of chromium, sodium and calcium content of solid waste can be conducted using Atomic Absorption Spectrophotometer. The sample is first treated with an acid digestion process then after reaching room temperature, 100 ml of pure water is added. Cr is measured at 357.9 nm with 0.7 slit intervals by using air plus acetylene (C₂H₂) mixture, Na is measured at 589.6 nm with 1.4 slit intervals by using air plus propane (C₃H₈) mixture and Ca is measured at 422.7 nm with 1.4 slit intervals by using air plus C₂H₂ mixture (Ahmed, 2017; Abajihad, 2012). The physical and chemical properties of leather solid wastes are shown in Table 2.5.

Table 2.5: Physiochemical characterization of leather solid wastes (Sethuraman et al., 2013)

Parameter	Value
Moisture %	10
Volatile Matter %	60.30
Ash %	7.58
pH of soluble matter	4.67
Chromium (wt. %)	2.8
Density (g/cm ³)	0.260

2.5 Handmade board making

2.5.1 Particleboard production process (Muruganandam, Ranjitha, & Harshavardhan, 2016; A Harshavardhan, 2017)

- a) *Sample collection*: The first step in board production is collection of raw materials from the source. This material can be residues or any material that is set to be used in the process.
- b) *Segregation, drying, shredding and grinding*: Separation of the collected material depending on the size required is the next step. When sorting is done, they are dried in order to reduce moisture content. The sun drying method is the best option to use since it has low capital/ operating costs and requires little expertise. After the moisture content reduction, dried waste is shredded, grinded into powder and passed through the standard sieves. The shredding process enables easy handling of wastes for board making.
- c) *Resin impregnation*: The particles obtained after sieving are mixed with the resin and blended together manually until a homogenous mixture is obtained.
- d) *Hydraulic pressing*: Pressing is the final step of the manufacturing process where the particles are poured into the rectangular mold covered with another metal on the top and conveyed to the hydraulic press by applying heavy weight. The press will apply heat and pressure to activate the resin and bond the particle into the solid panel. To facilitate the curing process the resin is mixed with a catalyst/hardener which speeds up the process by accelerating the hardening process.

2.6 Properties of particleboard

2.6.1 Physical properties

2.6.1.1 Density

Density is a basic property of particleboard and is expressed as weight per unit volume. The difference in raw material type and impregnation ratio affects the density of the boards. All particleboards should be of medium density ranging from 592.68 kg/m³-800.92 kg/m³ that is commercial standard. The board density has a lot of impact on properties such as Modulus of Rupture (MOR), Modulus of Elasticity (MOE), Internal Bond (IB), Thickness Swelling (TS) and Water Absorption (WA). The density of particleboard is obtained by dividing the weight of the board by its volume (Muruganandam, Ranjitha, & Harshavardhan, 2016).

2.6.1.2 Moisture Content

Equilibrium moisture content for different particleboard ranges from 8% to 9% and depends on the relative humidity. Particleboards should therefore be conditioned up to equilibrium with the humidity level similar to that of their usage. Measurement of moisture content can be achieved by weighing or by using an electric moisture meter. Change in moisture content causes changes in linear dimensions and thickness (Muruganandam et al., 2016).

2.6.1.3 Water Absorption

Water absorption is an important property of particleboards in that it has severe effects on properties such as bending strength and bending stiffness. It is a very important test for material to be used in exterior applications. The water absorption property is affected by the type of resin, length of exposure, temperature and additives used. It involves immersion of a test piece into distilled water at room temperature (20-30⁰ C) for 24 hours duration until

constant weight is obtained. There is a chance of strength reduction on boards because of the water. This property is obtained by dividing the difference between final and initial weight by initial weight (Muruganandam, Ranjitha, & Harshavardhan, 2016).

2.6.1.4 Thickness Swelling

The thickness property of particleboard is affected by moisture and absorption properties. It is very low after drying. Thickness swelling of boards should not be more than 2-3%. Thickness swelling is determined by immersing the specimen in distilled water at room temperature. The difference in the thickness divided by initial thickness will give the thickness swelling fraction (Muruganandam, Ranjitha, & Harshavardhan, 2016).

2.6.2 Mechanical properties

2.6.2.1 Internal Bond (IB) Strength

Internal bond strength is one of the significant properties commonly examined for any type of Particleboards. Tensile strength is the maximum load that a material withstands before it ruptures or tears. It is a destructive test process providing information about tensile strength, yield strength and ductility of a material as well as elongation. A tensile strength of a composite material is usually high in the direction parallel to the direction of fibres. The test involves placing of the sample on the machine anchored at both ends and pumping the machine manually till the sample fails. Failure occurs by splitting (Muruganandam, Ranjitha, & Harshavardhan, 2016).

2.6.2.2 Bending Stiffness (MOE)

It is also known as modulus of elasticity and is a measure of stiffness or resistance to bending when the load is applied. The modulus of elasticity of a material can be defined as the slope

of its stress-strain curve in elastic deformation region of the graph. Material with high tensile modulus is a stiffer material. It is an important property which shows the effect based on the moisture content, particle size and type of raw material used (Muruganandam, Ranjitha, & Harshavardhan, 2016).

2.6.2.3 Bending Strength (MOR)

Modulus of rupture (flexural strength) is an important property of particle board which depends on board density. It is defined as maximum stress which a material can withstand before yielding in flexure test and is useful when determining the structural component of a product for various application. This property can be conducted on both rigid and semi rigid materials, resin and laminate fibre composite. The outcomes of bending tests can be used in selecting the material for parts requiring support without flexion. It involves applying concentrated load at the centre of a lying specimen by loading a nose thus producing three-point bending at a specific rate. The semi qualitative idea about the fibre/matrix interfacial strength of a composite is provided by this test. Editable and raw data on flexural stress and strain both at yield and break point are provided by flexural testing (Muruganandam, Ranjitha, & Harshavardhan, 2016).

2.6.2.4 Compressive strength

This property is defined as the maximum stress that a material can withstand without fracture when loaded in transverse direction. Compression testing methods provide ways of introducing compression load while preventing material from bulking. Polymers, composites and elastomers can undergo compression testing. Generally, three methods of introducing compression load into a test specimen are available. The first one is end loading where all the load is loaded onto the flat end of the test specimen. The second method is shear loading

which involves introduction of the load into wide faces of the test specimen. The final method is combined loading where both end and shear loading are combined. Compression testing involves compressing of a sample piece between the platens of a compression testing machine. Compressive strength is calculated by dividing the maximum load by the original cross-section area of a specimen in the compression test (A Harshavardhan, 2017;Saba, Jawaid, & Sultan, 2019).

2.6.2.5 Impact strength

The impact test determines the behaviour of a specimen from known material (such as ceramics, composites and polymers) under suddenly applied load. It is mainly used in determination of brittleness, toughness and impact strength of engineering materials. The impact property of a material provides good information on liability and safety. There are two types of impact tests namely Izod and Charpy impact tests. In the Charpy test the specimen is held horizontally between the two vertical bars but the Izod test involves erecting the specimen like a fence.

i. Charpy impact

This is the oldest commonly used test for evaluating the relative toughness of a material in a fast and economical way. The energy absorbed by a standard notched specimen is measured while the specimen breaks under impact load. It is an economical quality control method of determining the notch sensitivity and impact toughness of materials such as polymers, composites metals and ceramics. The Charpy test involves securing the specimen at each end and striking it with a hammer on a pendulum arm. The toughness of a material is affected by

low temperatures, high strain rates and stress concentrators such as notches, cracks, and voids.

ii. Izod impact

This test is used at low temperatures and the specimen is normally machined to a square or round shape with notch or notches. In the Izod impact test the specimen is held in a vertical position and a pendulum with determined weight at the end of its arm is let to swing down striking the specimen. The impact properties of fibre reinforced polymer composites are determined by interfacial adhesion between the fibre and matrix as well as properties of individual fibres (Saba et al., 2019). Typical property values for standard particleboards are summarized in Table 2.6.

Table 2.6: Typical property values for standard particleboard (EWPA, 2008)

Property	Units	thickness		
		<=12 mm	13 – 22 mm	>23 mm
Density	Kg/m ³	660-700	660-680	600-660
Bending strength (MOR)	MPa	18	15	14
Bending stiffness (MOE)	MPa	2800	2600	2400
Internal bond (IB)	MPa	0.6	0.45	0.4
Surface soundness	MPa	1.25	1.30	1.30
Screw holding-face	N	-	600	700
Screw holding-edge	N	-	700	750
Thickness swell	%	15	12	8
Formaldehyde E1	Mg/l	1.0-1.5	1.0-1.5	1.0-1.5

2.7 Research gaps

Knowledge gaps have been evident in this study regarding solid waste management since most of the study done provides a hypothetical review without solid scientific evidence. The

national and regional scenes have been reluctant in studying solid waste management and most of the study is derived from the international front. Knowledge gaps have been evident and there is a need for the local scholars to do more research in the regional and local level in order to zero in those gaps.

Wet blue leather shavings and waste paper have not been used to produce particleboard using unsaturated polyester as resin. Conservation of natural resources (wood material) and increment of particleboard production through utilization of these wastes is an identified research gap depicted in this study.

CHAPTER THREE

3.0 MATERIALS AND METHODOLOGY

3.1 Materials

3.1.1. Collection and characterization of leather waste

Leather shavings solid waste was collected from Kenya Industrial Research and Development Institute. This waste is generated during leather processing as a by-product. The leather shavings were dried to a moisture content of around 10% which aided in adhesion of the shavings to resin. The air-dried leather shavings were shredded using laboratory mill machine model 4 (Figure 3.1) and sieved using a 2 mm mesh. The particles which went through the sieve were used for the development of the particleboard. The waste papers (newspapers, office papers) were also collected from the same institution and prepared in the same manner as the leather wastes. The raw wastes were characterized in order to determine their properties according to standard methods and equipment presented in Table 3.1

Table 3.1: Standard methods used to determine properties of the raw wastes

Test	Method	Equipment
pH value	(Abajihad ,2012)	pH meter
Moisture content	ASTM D3173	Oven & weighing balance
Volatile matter	ASTM D3175	Muffle furnace
Chromium content	(Ahmed ,2017; Abajihad ,2012)	Atomic Absorption Spectrophotometer



Figure 3.1: The laboratory mill machine

3.1.2 Particleboard preparation from shredded solid wastes

3.1.2.1 Unsaturated polyester resin and catalyst

Unsaturated polyester (GP 1778) was used as a resin and methyl ethyl ketone peroxide (MEKP) as a catalyst. These products were sourced from Henkel Chemicals Ltd, Industrial Area, and Nairobi. The amount of catalyst used was 2% of the resin content.

3.1.2.2 Mould Release Agent

Aluminium foil was used as the mould release agent. Incorporation of this agent provided a protective layer on the mould and prevented the composite from sticking onto the mould.

3.1.3 Characterization of physical and mechanical properties of the particleboards

The particleboards were characterized in order to determine their physical and mechanical properties according to standard methods and equipment presented in Table 3.2.

Table 3.2: Standard methods used to determine the physical and mechanical properties of the particleboards

Test	Standard method	Equipment
Density	JIS A 5908 (2003)	Electronic weighing machine
Moisture content	JIS A 5908 (2003)	Oven Electronic weighing machine
Water absorption	JIS A 5908 (2003)	Beaker Electronic weighing machine
Internal bond	JIS A 5908 (2003)	Universal testing machine (Model No. UT-10)
Compressive strength	ASTM D1037	Universal testing machine (Model No. UT-10)
Modulus of Rupture & Modulus of Elasticity	JIS A 5908 (2003)	Universal testing machine (Model No. UT-10)
Impact strength	ASTM D256	Impact testing machine Model number HLE

3.2 Methods

3.2.1 Characterization of the solid wastes

3.2.1.1 pH value

This property was conducted using a pH meter as per the Abajihad, (2012) procedure. Five samples were tested and the average was utilized in calculation.

- A sample of 2 g oven-dried specimen was weighed in a 250 ml beaker.
- A volume of 100 ml of distilled water was added
- The beaker was then shaken and direct measurement of the pH using a pH meter was recorded after 24 h.

3.2.1.2 Moisture Content

The moisture content of the waste sample was determined using an electronic weighing machine and oven as per ASTM D3173 standard for measuring moisture content.

- Firstly, five samples were weighed in a pre-weighed dish prior to drying
- After that, the samples were placed in an oven at a temperature of 105°C to a constant weight. The percentage of mean moisture content was then obtained by utilizing equation 3.1:

$$\text{moisture content}(\%) = \left(\frac{\text{wet weight} - \text{dry weight}}{\text{wet weight}} \right) \times 100 \quad (3.1)$$

3.2.1.3 Volatile Matter Content

Determination of volatile matter content of solid waste was conducted as per ASTM D3175 standard using a muffle furnace. Five samples were used in this test.

- The sample was oven dried, weighed and placed in a muffle furnace for 7 minutes at 950°C
- After combustion, the sample was weighed again to determine the ash dry weight.

The volatile solid content was computed using equation 3.2:

$$\text{volatile matter content}(\%) = \left(\frac{\text{dry sample weight} - \text{ash weight}}{\text{dry sample weight}} \right) \times 100 \quad (3.2)$$

3.2.1.4 Determination of Chromium Content

Determination of chromium content of leather waste was conducted using an Atomic Absorption Spectrophotometer (Shimadzu 6300 machine, see Figure 3.2) as per ISO 17072-2:2012 standard. Five random samples of leather shavings were used in this type of test.

- 1 gram of the ground sample was weighed and 8ml of concentrated nitric acid and 2ml concentrated hydrogen peroxide were added in the digestion tube including blank and digested in a milestone start microwave digester with maximum temperature of 250°C and pressure of 1200 psi for thirty minutes.
- The digested samples were poured into 50ml Erlenmeyer flask and made up to the mark with 2% nitric acid solution and filtered through 0.45µm pore diameter membrane filter to avoid possible contamination.
- The samples were analyzed in the same operational manner used in the calibration routine and the calibration solution was prepared from ultra-high purity grade ICP-OES chromium standard (99.99% pure).
- Five calibration solutions were prepared, that is, (1 ppm, 2 ppm, 3 ppm, 5 ppm and 10 ppm) by plotting a calibration curve with 205.56 nm and 267.716 nm wavelength with the plotted curve type of linear with the rinse blank also being used between all sample solutions with specific wavelength of 205.56 nm and 267.716 nm
- The main gas supply used was a mixture of air and acetylene.
- Finally, element specific emission spectra were produced by radio-frequency inductively coupled plasma.



Figure 3.2: Atomic Absorption Spectrophotometer used in the study

3.2.2 Fabrication of particleboard from leather shavings and waste paper

3.2.2.1 Preparation of the mould for making sample particleboard

A mould measuring 310×310×25 mm was fabricated using mild steel sheet; a material which could withstand the pressing load. A lid measuring 300×300×10 mm was also fabricated to provide smooth finish at the top of the mould (Figure 3.3).

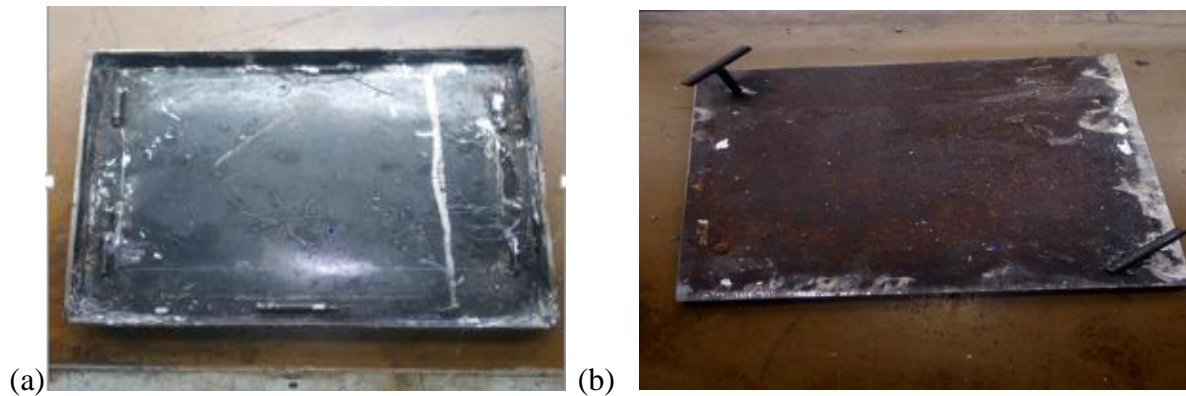


Figure 3.3: (a) Mould for forming particleboard sample (b) mould lid

3.2.2.2 *Experimental Design*

Experiments containing two dependent variables namely matrix weight fraction and blend ratio were conducted using the design shown in Table 3.3. The particleboards were all produced with a constant pressure of 0.55 N/mm^2 (50KN) using a cold hydraulic press and a constant curing time of at least 4 hours. This was in line with Cruz et al., (2011) who allowed polyester bonded composites to cure under pressure for 4 hours at room temperature before removing. Pressing pressure of 0.55 N/mm^2 was adopted as in a study by Saotome & Korai, (2013). The blend ratio was first kept constant while the resin content was varied and then the resin content was kept constant but blend ratio was varied. Production of particleboards at varied blend ratios was done at constant matrix weight fraction of 70%. This percentage was selected since it was in line with what Cruz et al.,(2011) used in the production of a composite using polyester resin as a binder. The same procedure was repeated using treated samples. In particleboard manufacturing, unsaturated polyester content with natural fibres is usually set to be around 50% - 90% (K. J. Wong, Yousif, & Low, 2010; Haghdan & Smith, 2017). However, when using leather/paper waste blended with standard amount of polyester, the content did not consolidate because the leather/paper waste consisted of tiny particles.

Therefore, in order to produce leather/paper waste board, a slightly higher polyester content was required than those of other fibres such as jute, flax, wood and hemp. A study carried out by Rachtanapun, Sattayarak, & Ketsamak, (2012) encountered the same scenario and a higher amount of resin content was used in particleboard production. In this study, polyester content of 60-90% weight fraction was utilized.

The blend ratio used in terms of weight of leather to waste paper was 100:0, 75:25, 50:50, 25:75, 0:100. These ratios were considered in order to examine the effects they had on the properties of particleboards. A total of 8 different untreated particleboards were fabricated in three replicates and repeated for treated samples.

Table 3.3: The experiment development table

Experiment No.	Matrix weight fraction (wt. %)	Particle blending(leather: paper)	Particle weight fraction (g)
1	60	100/0	172
2	70	100/0	172
3	80	100/0	172
4	90	100/0	172
5	70	0/100	172
6	70	25/75	172
7	70	50/50	172
8	70	75/25	172

3.2.2.3 Particle treatment

There are many polar functional groups in collagen fibres such as –OH and -COOH that make these fibres hydrophilic and difficult to bond well with hydrophobic polyester resin. Surface modification of these fibres was therefore done to investigate its effects on the properties of the particleboard.

In this study fat liquoring was used for surface modification of the particle. The particles (leather and paper) were weighed, loaded into the drum, water (100% weight of particles)

added and then ran for one hour. This step enabled wetting back of the particles. After one hour the water was drained from the drum. A fat emulsion of 2 % weight of the particles was prepared using warm water, added into the drum and ran for another hour. After this, 2% of formic acid was added to the sample and ran for another 30 minutes. Finally, the treated sample was drained and dried ready for use.

3.2.2.4 Particleboard fabrication

A single-layer particleboard sample measuring 300 mm x 300 mm x 6 mm was fabricated using the compression method. Boards with different resin content and blend ratios were produced in order to investigate their effects on the properties of the board. The following procedure was followed in fabrication process;

- The mould was cleaned and dried.
- The particles were mixed with resin manually and stirred until a homogenous mixture was obtained
- A protective pretreatment of the mould surface by the mould release agent was applied. This mould release agent prevented the particleboard from sticking onto the mould.
- After this, a homogenous mixture of the resin and particles was poured into the mould.
- The top of the mould was then covered with the lid and conveyed to the hydraulic press (Figure 3.4) with a pressing load of 50 KN. This load generated a pressure of 0.55 N/mm^2 consolidating the mixture into a composite.
- When the board was cured, it was removed from the mould after at least 4 hours.
- The same procedure was repeated as required.

The pressing process of particleboard is illustrated in Figure 3.4.



Figure 3.4: Compression of particle board on hydraulic press machine

3.2.3 Characterization of the particleboard

3.2.3.1 *Physical properties*

i. Density

The density of the board was conducted using a weighing machine (see Figure 3.5) according to JIS A 5908 (2003) standard for measuring density.

- 5 Specimens measuring 5 cm x 5 cm were cut randomly from the fabricated boards
- The samples were measured (length, width and thickness) and weighed
- The actual density was then calculated using equation 3.3 as follows:

$$density(g/cm^3) = \frac{W_a}{V_a} \quad (3.3)$$

Where W_a =air dry weight

V_a =air dry volume



Figure 3.5: Electronic weighing machine

ii. Moisture Content

The moisture content of the particle board was carried out following JIS A 5908 (2003) standard utilizing an electronic weighing machine and an oven. Five specimens were used and the average was used in moisture calculation. The procedure included;

- Cutting random specimens measuring 5 cm x 5 cm from the fabricated board.
- Determining the weight of the samples prior to drying.
- Putting the samples into the oven at a temperature of $103^{\circ}\text{C} + 2^{\circ}\text{C}$ until constant weight was achieved
- Calculation of the moisture content of the board utilizing equation 3.4;

$$\text{moisture content (\%)} = \left(\frac{W_a - W_o}{W_o} \right) \times 100 \quad (3.4)$$

Where W_a =air dry weight

W_o =oven dry weight

iii. Water Absorption Test and thickness swelling

This test was conducted as per JIS A 5908 (2003) standard using electronic weighing machine and a beaker. The steps were as follows;

- 5 Samples measuring 5 x 5 cm were cut randomly from the fabricated board
- Measurement of thickness and weight were done before immersion in water
- Second reading of the measurements were taken after 24 hours immersion to record the increase in weight and thickness of the samples
- The thickness swelling and water absorption were calculated utilizing these formulas (see equation 3.5 and 3.6 respectively);

$$\text{water absorption}(\%) = \left(\frac{W_f - W_i}{W_i} \right) \times 100 \quad (3.5)$$

Where W_f =final weight

W_i =initial weight

$$\text{thickness swelling}(\%) = \left(\frac{T_f - T_i}{T_i} \right) \times 100 \quad (3.6)$$

Where T_f =final thickness

T_i =initial thickness

3.2.3.2 Mechanical properties

i. Internal Bond Strength

The internal bond strength of the board was determined according to JIS A 5908 (2003) using a universal testing machine Model UT-10 with capacity of 100 KN (see Figure 3.6). 5 specimens were used in internal bond strength test.

- Specimens measuring 5 cm x 5 cm were cut from each particleboard
- The sample was placed on the machine, anchored at both ends and the machine was pumped with crosshead speeds of 2 mm/min until the sample failed by splitting.
- The rupture load was then recorded and internal bond strength was calculated using equation 3.7;

$$\text{Internal bond (IB)} = \left(\frac{P_l}{bl} \right) \quad (3.7)$$

Where P_l =rupture load

b =breath of the specimen

l =length of the specimen

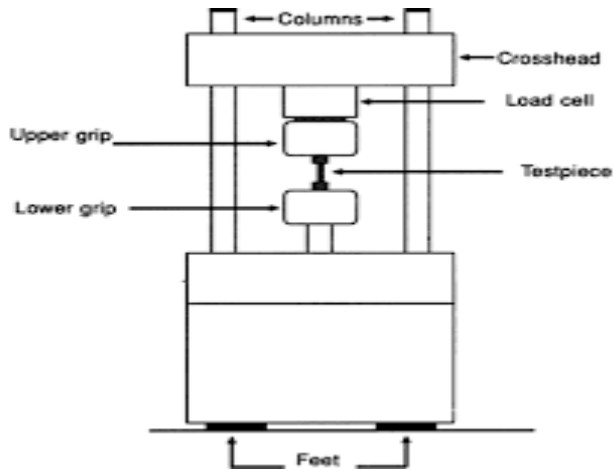


Figure 3.6: Schematic diagram for internal bond test on universal testing machine

ii. Bending Stiffness (MOE) and Bending Strength (MOR)

These tests were conducted according to JIS A 5908 (2003) using universal testing machine (Model No. UT-10, Capacity 100KN). Schematic diagram of a three-point bending test is shown in Figure 3.7. The following procedure as stated by the standard was followed:

- 5 bending specimens measuring 5 cm wide 20 cm long were cut from fabricated particleboard.
- A concentrated bending load was applied at the center with a span of 15 times the thickness of the specimen with crosshead speeds of 10 mm/min.
- The bending modulus of rupture (MOR) and modulus of elasticity (MOE) were calculated from load deflection curves according to equations 3.8 and 3.9 respectively.

$$\text{Modulus of rupture (MOR)} = \frac{3P_b L}{2bh^2} \quad (3.8)$$

$$\text{Modulus of elasticity (MOE)} = \frac{P_{bp} L^3}{4bh^3 \gamma_p} \quad (3.9)$$

Where, P_b is the maximum load (N),

P_{bp} is the load at the proportional limit (N),

Y_p is the displacement corresponding to P_{bp} (mm),

b is the width of the specimen (mm),

h is the thickness of the specimen (mm), and L is the span (mm).

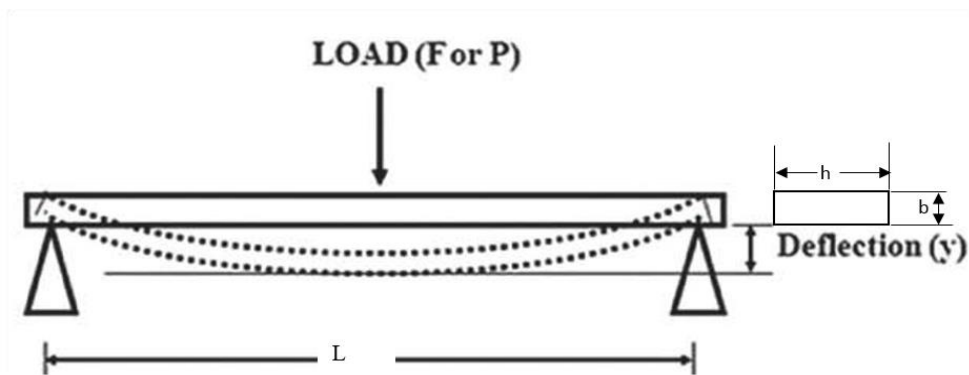


Figure 3.7: Schematic diagram for bending test on universal testing machine

iii. Compression strength

Compression test for fabricated boards was carried out on a universal material testing machine in accordance with specification of ASTM D-1037 standard for measuring compression strength. Schematic diagram of compression test is shown in Figure 3.8

- 5 specimens measuring 5 cm x 5 cm were cut from each particleboard
- The sample was placed on the machine with a load of 5 KN and a crosshead speed of 2 mm/min until the sample crushed.

- The maximum compression load was recorded and compressive strength calculated using Equation 3.10 as follows:

$$\text{Compressive strength } (T_c) = \frac{W_c}{bt} \quad (3.10)$$

Where T_c =compressive strength

W_c =maximum compression load (N)

b =breadth of the sample (mm)

t =thickness of the sample (mm)

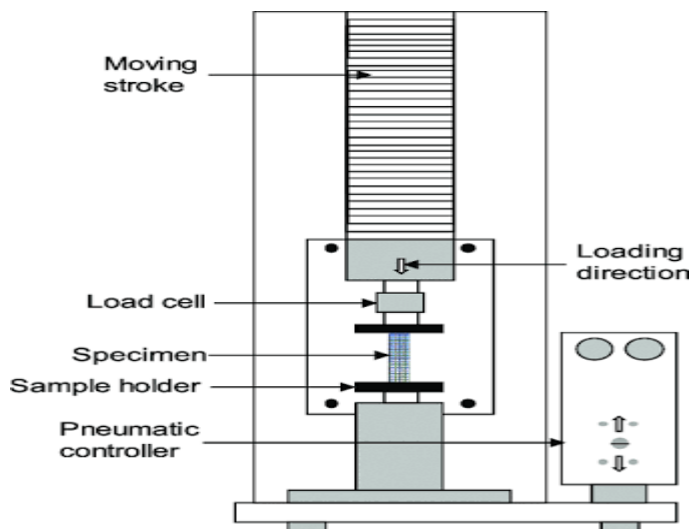


Figure 3.8: Schematic diagram of particleboard sample under compression test on universal testing machine

iv. Impact test

This property was conducted according to ASTM D256 standard for measuring impact strength using Charpy Impact tester Model number HLE. Figure 3.9 depicts schematic diagram for impact test under the impact tester machine. Five samples were tested and the average of the impact values was utilized.

- The sample measuring 5 cm by 5 cm was prepared from fabricated particleboard and loaded into the pendulum Charpy type machine.
- An arm held at a specific height (constant potential energy) was released to strike the sample on its downwards swing
- Energy absorbed was recorded and impact strength computed using equation 3.11.

$$\text{impact strength} = \frac{E}{hb} \quad (3.11)$$

Where, E=energy absorbed in J

h=thickness in mm

b=width in mm

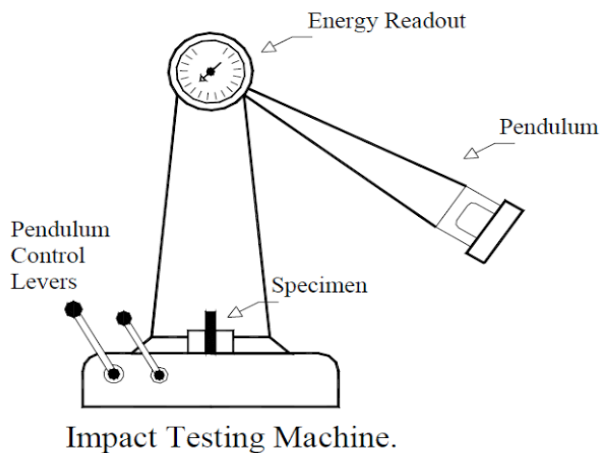


Figure 3.9: Schematic diagram of a particleboard sample under impact test machine

3.24 Statistical analysis

Statistical analysis was performed using Minitab software (version 17) at 95% confidence level. The significance of different blend ratios and matrix weight fraction were determined by variance analysis (Regression) and least significant difference (LSD) test ($\alpha \leq 0.05$). On the other hand, the significance between treated and untreated particleboards was determined by paired T-test and least significant difference (LSD) test ($\alpha \leq 0.05$).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1. Characterization of leather shavings waste

Table 4.1 provides data on the properties of leather shavings which was used in board fabrication. The pH value of leather shavings waste was found within the range at which chromium sulphate chemical is fixed to leather (3-4). The moisture content of leather shavings was 10.3 % and this value could have impacts on board properties (Nemli, Sari, Bardak, & Ayrilmis, 2012). The volatile matter of leather shavings was 80.6 and this value was important since organic matter can reduce Cr (vi) which is toxic to Cr (iii) which is nontoxic thus reducing environmental pollution (Kim, Dixon, Kim, & Dixon, 2011). The chromium content was 2.7 and this value could imply that dumping of leather shavings could indeed pollute the environment. The physio-chemical characteristics of chrome shaving waste was almost similar with data in literature (Sethuraman et al., 2013).

Table 4.1: Characterization of leather shavings

composition	Leather shavings	(Sethuraman et.,2013)
pH	4.4	4.67
Moisture content%	10.3	10
Volatile %	80.6	60.30
Chromium (wt. %)	2.7	2.8

4.2 Fabricated particleboard

Figure 4.1 displays the picture of particleboards produced from leather shavings and waste paper at different matrix mass fraction and blend ratio.



Figure 4.1: Samples of fabricated particleboard

4.3 The physical and mechanical properties of fabricated particleboard

Table 4.2 displays the summary of particleboards made from untreated leather shavings using resin content from 60% to 90%. This assessment was done to investigate the effects of matrix mass fraction on the physical and mechanical properties of fabricated boards.

Table 4.2: Variation of properties of untreated particleboard with change in resin content

Specimen ID	Leather: paper (wt. %)	Matrix mass fraction (%)	No. samples	Mean water absorption (%)	Mean density (Kg/m ³)	Mean moisture content (%)	Mean MOR(MPa)	mean MOE (GPa)	Mean Compression strength (MPa)	Mean internal bond strength (MPa)	Mean impact strength (KJ/m ²)
1	100:0	60%	5	6.3	1089	5.5	14.31	5.030	18.57	6.46	48.33
2	100:0	70%	5	5.2	1145	4.2	13.38	4.150	13.74	5.83	56.67
3	100:0	80%	5	4.8	1176	3.6	10.48	3.646	10.88	4.16	64
4	100:0	90%	5	3.3	1216	3.0	10.06	3.054	13.11	2.82	46.3

Table 4.3 shows the physical and mechanical properties of particleboard manufactured using consistent resin weight fraction of 70 % at varying untreated leather: paper blend ratio.

Table 4.3: Variation of properties of untreated particleboard with change in blend ratio

Specimen ID	Leather: paper (wt %)	Matrix mass fraction (%)	No. samples	Mean moisture content (%)	Mean density (Kg/m ³)	Mean water absorption (%)	Mean MOR(MPa)	mean MOE (GPa)	Mean Compression strength (MPa) N/mm ²	Mean internal bond strength (MPa)	Mean impact strength (KJ/m ²)
5	0:100	70%	5	1.8	1320	2.3	20.11	5.650	29.32	13.61	33.67
6	25:75	70%	5	2.3	1300	2.9	16.23	5.474	30.61	11.71	38.67
7	50:50	70%	5	3.2	1258	3.5	11.44	5.265	20.68	7.86	32.33
8	75:25	70%	5	3.5	1247	4.2	15.60	5.106	10.74	6.76	46.67

The properties (physical and mechanical) of particleboard made from treated leather shavings and using matrix weight fraction from 60 %-90 % is exhibited in Table 4.4. The leather particles were treated with fat liquor for comparison with untreated ones.

Table 4.4: Variation of properties of treated particleboard with change in resin content

Specimen ID	Leather: paper (wt%)	Matrix mass fraction (%)	No. samples	Mean moisture content (%)	Mean density (Kg/m ³)	Mean water absorption (%)	Mean MOR (MPa)	mean MOE (GPa)	Mean Compression strength (MPa)	Mean internal bond strength (MPa)	Mean impact strength (KJ/m ²)
9	100:0	60%	5	4.6	1209	5.2	14.50	5.325	20.88	10.03	50.67
10	100:0	70%	5	3.5	1300	4.6	13.58	4.514	18.08	9.56	57.33
11	100:0	80%	5	3.0	1317	4.0	11.87	4.234	12.70	8.97	67.00
12	100:0	90%	5	2.4	1379	2.6	11.58	3.940	16.72	7.52	47.67

Table 4.5 shows the physical and mechanical properties of particleboard produced using constant matrix weight fraction of 70% at varying treated leather: paper blend ratio. This summary shows the effects of mixing treated particles of leather and paper waste on the properties of the particleboard.

Table 4.5: Variation of properties of treated particleboard with change in blend ratio

Specimen ID	Leather: paper (wt%)	Matrix mass fraction (%)	No. samples	Mean moisture content (%)	Mean density (Kg/m ³)	Mean water absorption (%)	Mean MOR (MPa)	mean MOE (GPa)	Mean Compression strength (MPa)	Mean internal bond strength (MPa)	Mean impact strength (KJ/m ²)
13	0:100	70%	5	1.3	1374	1.8	21.05	6.094	30.61	16.56	46.67
14	25:75	70%	5	1.8	1346	2.1	18.08	5.912	33.70	12.57	40.33
15	50:50	70%	5	2.5	1332	2.7	14.93	5.825	22.15	10.78	34.00
16	75:25	70%	5	3.5	1310	3.6	14.44	5.616	15.57	12.18	49.33

4.3.1 The effects of resin content on the density of particleboard

From Figure 4.2, different densities of particleboards are exhibited where density increases with the quantity of resin (resin content of 60% had lowest value of 1089 kg/m³ while 90% had highest value of 1216 kg/m³). The reason behind this phenomenon could be attributed to increase in solid content of the adhesive. According Rachtanapun et al., (2012) the possible contribution of density increase is from resin polymer. The most controlling factors of density are raw material density, binder density, pressing pressure, particle quantity in the board and other additives (Iswanto, Febrianto, Hadi, & Ruhendi, 2013; Rachtanapun et al., 2012). Another possible reason for increase in density with increase in resin content could be due to reduction in porosity in the particleboard resulting from lower particle fraction.

In the case of the treated sample, the same trend is observed. However, the densities are higher than those of untreated samples. This could be attributed to the fact that, the treated sample had good bonding between the particles and resin thus amount of pores available in the board were reduced hence boosting the densities (Nurul, Mohammad, & Julkapli, 2019). Treatment of leather with fat-liquor converts the hydrophilic nature of leather to a hydrophobic state thus boosting interfacial bonding with hydrophobic polyester resin. This results in a less porous product and hence higher densities. Based on JIS A 5908-2003 standard, the minimum and maximum requirements for density is 400 kg/m³ and 900 kg/m³ respectively. The test results of density showed that it was above the requirements.

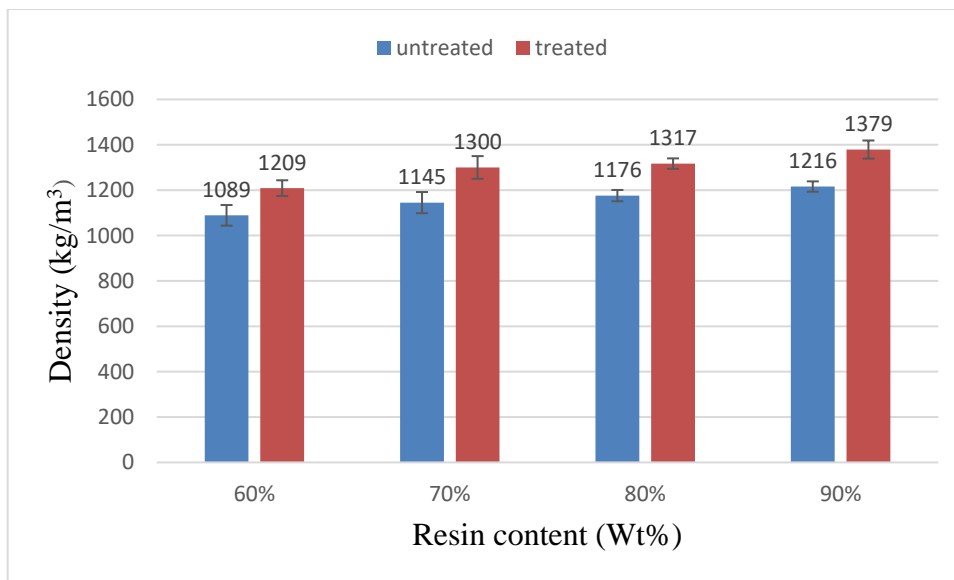


Figure 4.2: Effects of resin content on density of particle board

An analysis of variance (Regression) for density of particleboard with varying matrix fractions is shown in Table 4.6 and from the analysis, it can be seen that resin content had significant effects on the density (p-value was less than Alpha (α) value, $P < 0.05$).

Table 4.6: Analysis of Variance (Regression) for density of particleboard from leather shavings and varying matrix weight fraction

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	8487.2	8487.20	139.36	0.007
Resin	1	8487.2	8487.20	139.36	0.007
Error	2	121.8	60.90		
Total	3	8609.0			

From Table 4.7, the obtained t-value (T-value) of 15.37 and statistical significance (2-tailed p-value) of paired t-test (p-value), which is 0.001. As the p-value is less than 0.05 (i.e., $p < 0.05$), it can be concluded that there is a statistical difference between the mean values of treated and untreated particleboards.

Table 4.7: Paired T-test analysis for density of particleboard from leather shavings and varying matrix weight fraction from 60%-90%.

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	4	1301.3	70.2	35.1
Untreated	4	1156.5	53.6	26.8
Difference	4	144.75	18.84	9.42
95% CI for mean difference: (114.77, 174.73)				
T-test of mean difference =0 ($V_s \neq 0$):T-value =15.37 p-value=0.001				

4.3.2 Effects of blend ratio on density of the particleboard

Figure 4.3 shows the results of board density with respect to the blend ratio. In the case of untreated samples, it was observed that the density of the particleboard decreases with an increase in leather ratio. According to Nurul et al.,(2019) a low density composite is one with more voids, pores and spaces within its structure. Therefore, decrease in density with addition of leather could be attributed to increase porosity and voids in the particleboard. There is a

high negative correlation between the density of a material and porosity which implies that the higher the density the lower the porosity (Anthony & Adeyinka, 2012).

On the other hand, the treated samples exhibited higher densities compared to untreated samples. The highest density of treated board is 1374 kg/m³ while that of untreated board of the same blend ratio is 1320 kg/m³. The differences in the densities between the treated and untreated sample can be explained by the fact that, the treated one resulted in superior interfacial bonding with the resin thus reducing formation of voids. Fewer voids and less porosity of the treated composites resulted in high densities (Anthony & Adeyinka, 2012). The densities of particleboard produced with blended ratios also showed higher densities than the JIS standard.

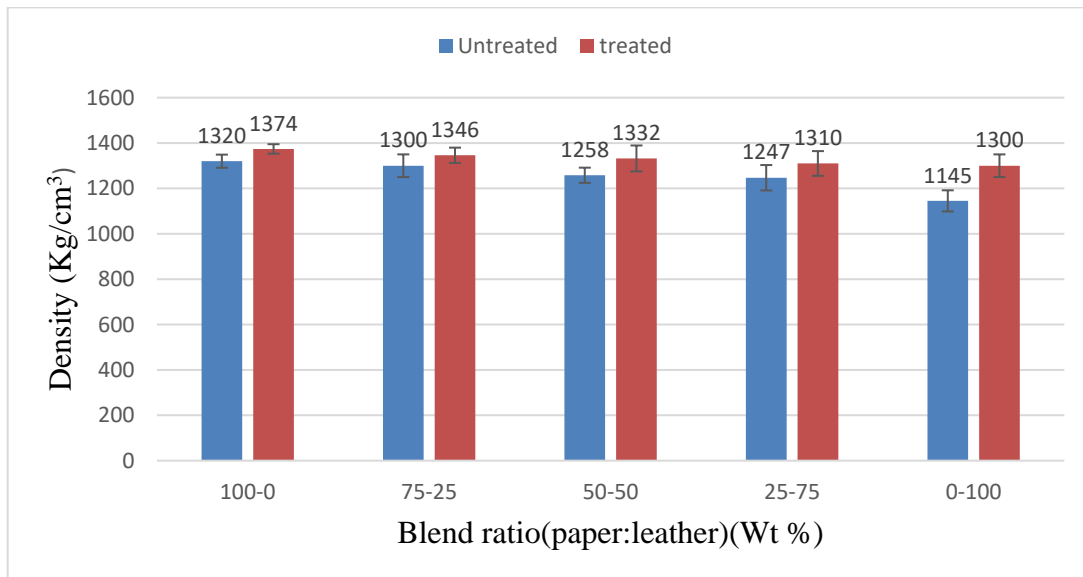


Figure 4.3: Effects of blend ratio on the density of particleboard

An analysis of variance (Regression analysis) for particleboard made from a constant matrix fraction of 70% and varying blend ratio is presented in Table 4.8. From this analysis the p-

value was 0.018 and this indicated that there was significant difference among varying blending ratios since $p < 0.05$.

Table 4.8: Analysis of variance for particleboard manufactured from 70% matrix weight fraction at varying blend ratio.

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	16241	16240.9	22.38	0.018
Resin	1	16241	16240.9	22.38	0.018
Error	3	2177	725.7		
Total	4	8609.0			

The paired t-test for treated and untreated particleboard is exhibited in Table 4.9. The result shows that the computed value of P two-tail (0.016) was less than the Alpha (α)-value ($P < 0.05$), suggesting a significant difference in densities between treated and untreated particleboard.

Table 4.9: Paired T-test analysis for density of particleboard manufactured from 70% matrix fraction with varying blend ratio

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	5	1332.4	29.4	13.2
Untreated	5	1254.0	67.9	30.3
Difference	5	78.4	44.1	19.7

95% CI for mean difference: (23.7, 133.1)
T-test of mean difference = 0 (vs \neq 0): T-Value = 3.98 P-Value = 0.016

4.3.3 Effects of resin content on moisture content of the particleboard

The humidity response of particleboard depends on its ability to retain moisture or its water absorptivity. This property depends on the manner the sample is composed and processed rather than the properties of the constituents (Abdulkareem, Raji, & Adeniyi, 2010). The

results of the moisture content of the particleboards with change in resin content is presented in Figure 4.4. It can be seen that the moisture content decreased with increasing resin content. This is in agreement with the study by Harshavardhan & Muruganandam, (2017) where moisture content decreases with increase in resin content. According to this author, factors contributing to high moisture content include; volume of empty space that can accommodate water particles, the presence of a capillary channel connecting empty spaces together and broad particle surface area. The particleboard made with lower resin content (60%) had lower density thus higher moisture absorption while the one with the highest resin content (90%) had high density leading to the lowest moisture value (Nurul et al., 2019). The moisture content of lowest resin panel was 5.5% and that of highest resin content was 3.0%. Similar results were obtained by Harshavardhan, (2017) in the production of particleboard from mushroom waste and polyester resin. The results of moisture content conform to Japanese industrial Standards (5%-13%) in that it does not exceed the maximum value required by the standard.

The results of moisture content for treated samples also decreased with increasing resin content as shown in Figure 4.3. It is shown that the moisture values of these boards are lower than those of untreated ones. The reason behind this could be as a result of good cohesion bonding between the particles and the matrix after converting leather into hydrophobic nature similar to that of resin. Good bonding between the reinforcement and the matrix can reduce pores in the particleboard thus lowering the moisture values of respective composites.

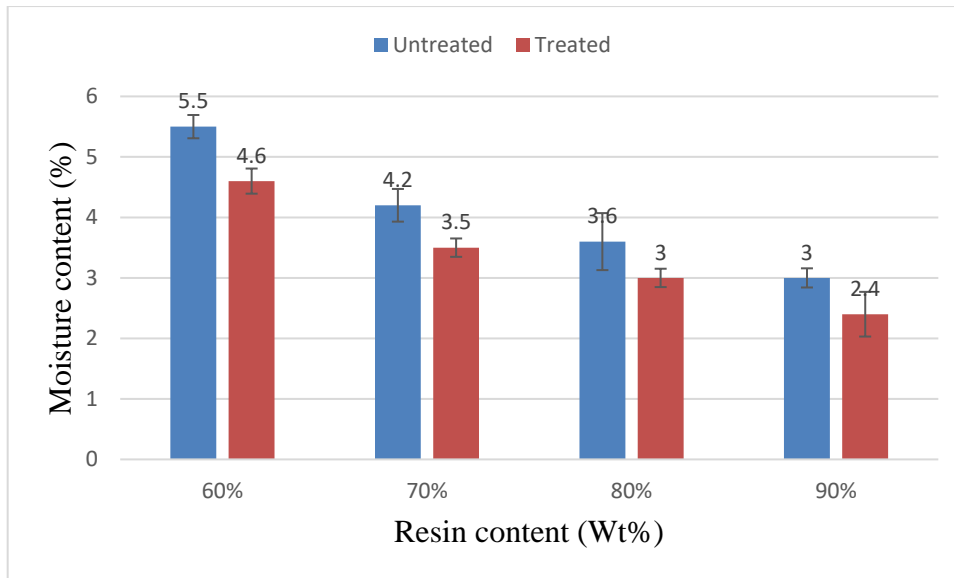


Figure 4 4: The effects of resin content on the moisture content of particleboard

Table 4.10 shows the results of analysis of variance for the moisture content of a particleboard manufactured from leather shavings at varying resin weight fraction (60%-90%). This analysis indicated that there was a significant difference in moisture content of boards made from various matrix fractions since the P-value obtained was 0.022 and was less than α -value (0.05). The matrix weight fraction had impacts on moisture content of the particleboard.

Table 4.10: Analysis of variance for moisture content of particleboard manufactured from leather shavings at varying matrix weight fraction.

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	3.2805	3.2805	44.63	0.022
Resin	1	3.2805	3.2805	44.63	0.022
Error	2	0.1470	0.07350		
Total	3	3.4275			

The paired t-test for particleboard produced from treated and untreated leather shavings is shown in Table 4.11. The value of computed P-value was 0.002 which was less than the α -value (0.05) indicating a significant difference between the moisture content of treated and untreated particleboards. Therefore, particle treatment had an impact on the moisture content of the boards.

Table 4.11: Paired T-test analysis for moisture content of particleboard from leather shavings and varying matrix weight fraction from 60%-90%.

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	4	3.375	0.932	0.466
Untreated	4	4.075	1.069	0.534
Difference	4	-0.7000	0.1414	0.0707
95% CI for mean difference: (-0.9250, -0.4750)				
T-test of mean difference = 0 (vs \neq 0): T-Value = -9.90 P-Value = 0.002				

4.3.4 Effects of blend ratio on moisture content of particleboards

The effects of blend ratio on the fabricated boards is depicted in Figure 4.5 and as the leather ratio is increased, the moisture absorption increases. Considering the untreated samples, the blend ratio of 100:0 had the lowest moisture value of 1.8% while that of 0:100 had the highest moisture value of 4.2%. The high value of moisture content with increase in leather ratio could be attributed to the fact that leather shavings had higher moisture content than waste papers thus a high ability to retain moisture during formation. In addition to this, 100% leather has high density thus a high ability of moisture absorption (Nurul et al., 2019). The lower value of moisture content with 100% waste papers can be linked to fewer pores in the particleboard resulting from high density of waste paper.

The same trend is observed with treated samples where moisture content increases with increase in leather ratio. When compared with untreated samples the values of moisture

content were lower. This could be due to the fact that the number of pores (voids) available were limited by good bonding between fibre and matrix.

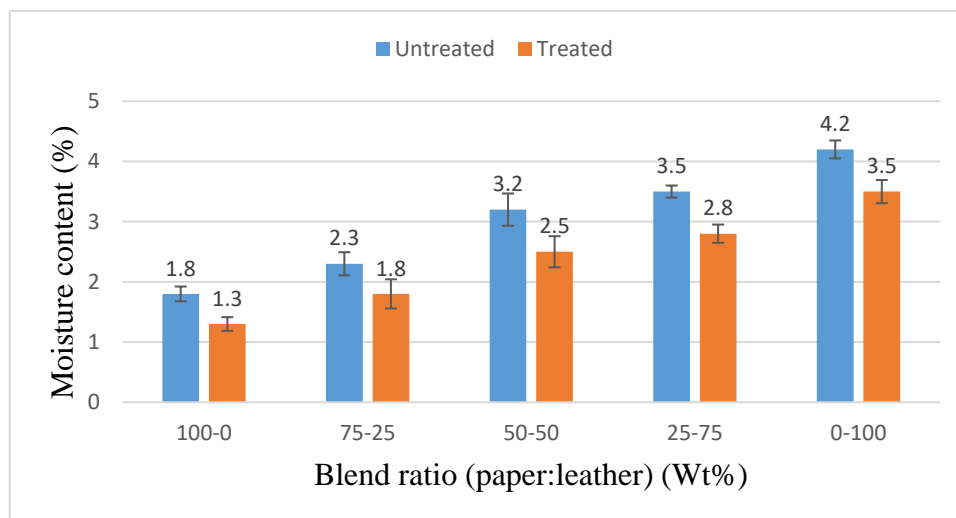


Figure 4.5: The blend ratio effects on the moisture content of board

Table 4.12 presents the result of analysis of variance for moisture content of particleboard manufactured from consistent matrix weight fraction at varying blend ratio. From this analysis the difference in blend ratio on the board's moisture content was significant. This is because the computed P-value (0.001) was lower than the Alpha value (0.05).

Table 4.12: Analysis of variance for particleboard manufactured from 70% matrix weight fraction at varying blend ratio

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	3.60000	3.60000	180.00	0.001
Resin	1	3.60000	3.60000	180.00	0.001
Error	3	0.06000	0.02000		
Total	4	3.66000			

A paired t-test for untreated and treated particleboard made from varying blend was done and the result is depicted in Table 4.13. The computed P-value was 0.000 suggesting a significant

difference in the moisture content of particleboard ($P < 0.05$). Treatment of the particles had effects on the moisture content of the boards.

Table 4.13: Paired T-test analysis for moisture content of particleboard manufactured from 70% matrix fraction with varying blend ratio

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	5	2.380	0.858	0.384
Untreated	5	3.000	0.957	0.428
Difference	5	-0.6200	0.1095	0.0490

95% CI for mean difference: (-0.7560, -0.4840)
T-test of mean difference = 0 (vs \neq 0): T-Value = -12.66 P-Value = 0.000

4.3.5 The effects of resin content on water absorption of particleboard

The water uptake in composites depends on the weight fraction of the reinforcement as a result of increased voids, polar content and poor interfacial bonding between the fibre and the matrix. The swelling effect caused by water intake is not significant in good fibre/matrix interfacial adhesion systems (Abdulkareem et al., 2010 ;Wong & Jye, 2014).

It is observed from Figure 4.6 that the moisture absorption percentage for the particleboard made of 60%, 70%, 80% and 90% resin content are 6.3%, 5.2%, 4.8% and 3.3% respectively. It can be seen that the water absorption decreased with increase in resin content of the particleboard. These results agree with the study by Rachtanapun et al., (2012). This could be as a result of the hydrophobic nature of polyester brought about by the strong intermolecular cohesive bonding within the molecule of the polyester resin which prevented water penetration to the composite. According to Jankauskaitė, Jiyembetova, & Gulbinienė (2016) and Das, (2017) the collagen molecule found in leather contains hydroxyl groups which attracts water molecules through hydrogen bonding causing water absorption in composites. Different mechanisms of water absorption that occur in the polymer matrix

include; diffusion of water molecules into the fibre structure, diffusion of water molecules into gaps between the polymer molecule chains, migration of water molecules into gaps and flaws at fibre/matrix interface as well as capillary transport into micro cracks in the matrix as a result of fibre swelling.

The decrease in water absorption with an increase in resin content could also be explained by the fact that the polar group of leather responsible for water intake was reduced by an increment of polyester resin. It was also due to the reduction of gaps and flaws at the fibre/matrix interface resulting from a good bonding system. According to Cruz et al., (2011) water absorption of composites decreases with the matrix content and it is higher than that of the matrix alone. In the study by Asha, (2017) the values of water absorption of a particleboard made from rice husk and polyester resin ranged between 2.63% and 6.67%. On the case of treated samples, the same pattern of water absorption decrement with an increase in resin content was noted. Based on JIS A 5108 (2003) standards, particleboard should have a maximum absorption value of 12% after 24 hours immersion. All the boards with various resin content satisfy the swelling requirements for general uses and as a result, the boards can be used as a stable product.

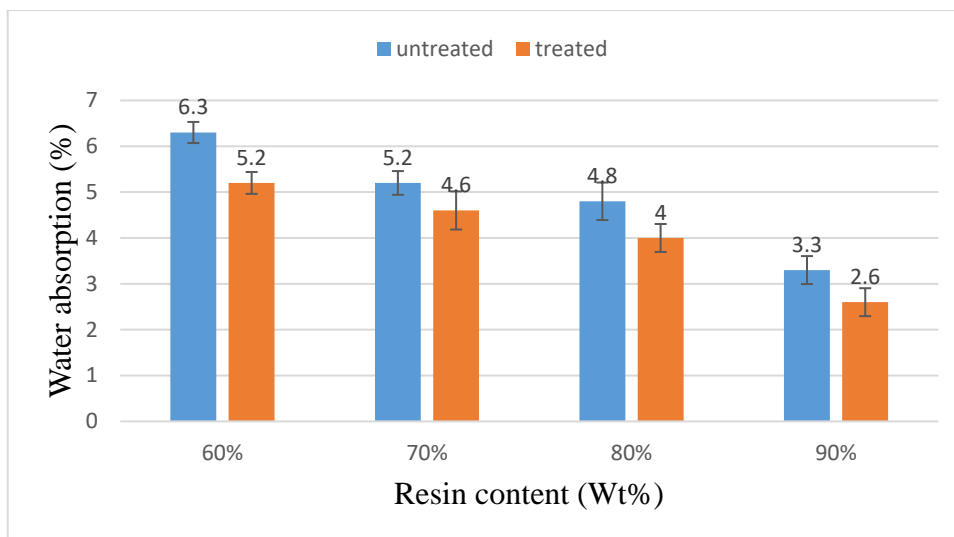


Figure 4.6: Effects of resin content on water absorption of particleboard

Analysis of variance of particleboard was done to investigate if resin weight fraction had an impact on the moisture content and the output is depicted in Table 4.14. From this analysis, the computed P-value (0.022) was lower than the α -value ($P < 0.05$) and this indicated that there was a significant difference on varying resin content.

Table 4.14: Analysis of variance for water absorption of particleboard manufactured from leather shavings at varying matrix weight fraction.

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	4.4180	4.4180	43.74	0.022
Resin	1	4.4180	4.4180	43.74	0.022
Error	2	0.2020	0.1010		
Total	3	4.6200			

Paired t-test for particleboard made from treated and untreated particles was done and the results are shown in Table 4.15. The P-value of 0.005 was obtained and this suggested that there was significant difference between the treated and untreated particleboards. ($P < 0.05$).

Table 4.15: Paired T-test analysis for water absorption of particleboard from leather shavings and varying matrix weight fraction from 60%-90%.

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	4	4.100	1.114	0.557
Untreated	4	4.900	1.241	0.620
Difference	4	-0.800	0.216	0.108
95% CI for mean difference: (-1.144, -0.456)				
T-test of mean difference = 0 (vs \neq 0): T-Value = -7.41 P-Value = 0.005				

4.3.6 The effects of blend ratio on water absorption property of particleboard

Studies by Khazaeian, Ashori, & Yahyavi (2015) show that water absorption increases with increase in polar groups and void/pores present after fabrication since it helps in build-up of moisture in reinforcement-resin interface. The effects of blend ratio on water absorption are shown in Figure 4.7. The water absorption of untreated samples increases with increase in leather ratio from 2.3% to 5.2% and this trend could be as a result of increase in polar groups from leather which acted as attraction sites of water. Since there was an increase in the densities of the boards, the water absorption decreases respectively (Abdulkareem & Adeniyi, 2017). On the other hand, the treated samples had lower values than those of untreated samples. Modification of the particles could have led to a reduction in porosity since interfacial bonding between the particles and the matrix was boosted.

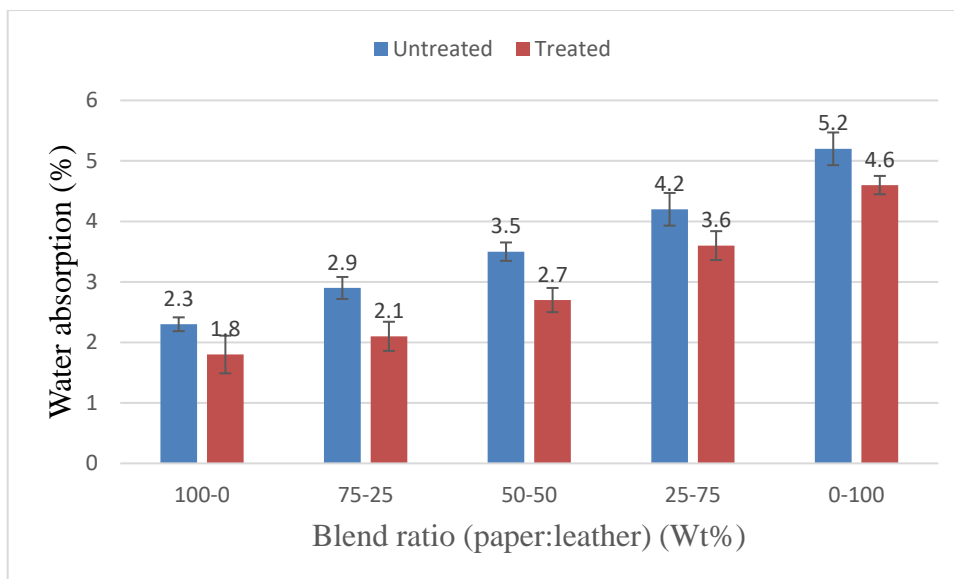


Figure 4.7: Water absorption property of particleboard and blend ratio

Table 4.16 presents the analysis of variance for water absorption of particleboards manufactured from varying blend ratio. It can be seen that there was significant difference in water absorption when the blend ratio was varied. The computed P-value was 0.001 and this value was less than the Alpha value (0.05).

Table 4.16: Analysis of variance for water absorption of particleboard manufactured from 70% matrix weight fraction at varying blend ratio

Analysis of variance						
Source	DF	Adj SS	Adj MS	F-value	p-value	
Regression	1	5.04100	5.04100	225.72	0.001	
Resin	1	5.04100	5.04100	225.72	0.001	
Error	3	0.06700	0.02233			
Total	4	5.10800				

As shown in Table 4.17, a paired t-test was done to compare the effects of treated and untreated particles on the water absorption property of the particleboard. This analysis shows

a P-value of 0.000 indicating that treating of particles had significant impact on the property of fabricated boards. The null hypothesis was rejected since $P < 0.05$.

Table 4.17: Paired T-test analysis for water absorption of particleboard manufactured from 70% matrix fraction with varying blend ratio

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	5	2.960	1.146	0.512
Untreated	5	3.620	1.130	0.505
Difference	5	-0.6600	0.1342	0.0600

95% CI for mean difference: (-0.8266, -0.4934)
T-test of mean difference = 0 (vs \neq 0): T-Value = -11.00 P-Value = 0.000

4.3.7 Internal bond strength of the particleboard and resin content

Figure 4.8 shows the graph of ultimate tensile strength of the particleboard sample against its corresponding resin content. For the untreated sample, it was observed that the tensile strength decreases with an increase in resin content from 6.46MPa (60% resin) to 2.82MPa (90% resin). In other words, the highest tensile strength corresponded to 40% particle weight fraction. Several studies have shown that tensile strength of a composite is dependent on the weight fraction of the reinforcement and its strength. However, there is a level over which increase in fibre fraction decreases the strength due to poor bonding (Limited, 2012; Tezara, Siregar, Moey, & Wei, 2016; Njoku, Okon, & Ikpaki, 2011; Madueke & Bolasodun, 2017)

From literature, the internal bond strength of neat cured polyester is 5.11 MPa (Daramola, Adediran, & Omotayo, 2017) but when compared with composite reinforced with particles, the strength decreased (Rodrigues, Maia, & Mulinari, 2011). Similar results were obtained in this study. The decrease in internal bond strength of the particleboard as resin content was increased could be attributed to poor stress transfer between the filler and matrix, poor dispersion of reinforcement in polyester resin matrix and poor interfacial bond since the

particle mass fraction was reduced. On the contrary, the internal bond strength values of the treated samples were higher than those of untreated ones. The difference could be as a result of better bonding between the particles and the polyester resin since treatment of the particles converted the hydrophilic nature of the particles to hydrophobic state which is also found in the matrix. The general minimum requirement of Japanese Industrial Standards type 8 boards is 0.15MPa and all the boards fabricated with varying resin content were above this value.

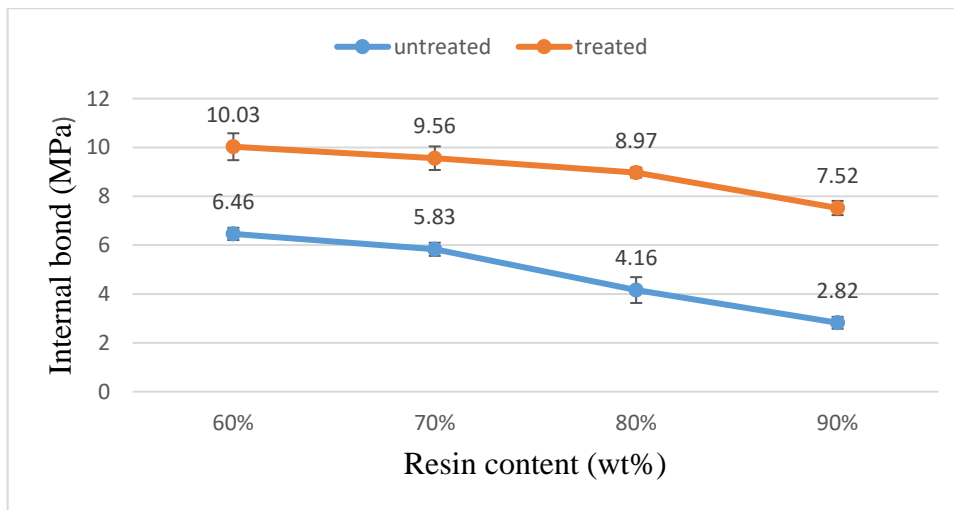


Figure 4 8: Internal bond strength of particleboard with varying resin content

An analysis of variance for the internal bond of a particleboard manufactured from leather shavings with varying resin weight fraction of 60%-90% is shown in Table 4.18. From this analysis, the value of computed P-value was 0.014 and this was lower than α -value (0.05) indicating a significant difference in the internal bond of the particleboards. This means that resin increment had effects on the internal bond.

Table 4.18: Analysis of variance for internal bond of particleboard manufactured from leather shavings at varying matrix weight fraction.

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	7.9254	7.9254	72.09	0.014
Resin	1	7.9254	7.9254	72.09	0.014
Error	2	0.2199	0.1099		
Total	3	4.6200			

The effects of treating the particles on the internal bond strength of particleboard was done using paired t-test analysis and the results are exhibited in Table 4.19. The analysis suggested that there was significant difference between treated and untreated particleboards. This is indicated by the low P-value of 0.001 as compared to α -value of 0.05.

Table 4.19: Paired T-test analysis for internal bond of particleboard from leather shavings and varying matrix weight fraction from 60%-90%.

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	4	9.020	1.090	0.545
Untreated	4	4.817	1.648	0.824
Difference	4	4.202	0.643	0.321
95% CI for mean difference: (3.180, 5.225)				
T-test of mean difference = 0 (vs \neq 0): T-Value = 13.07 P-Value = 0.001				

4.3.8 Internal bond strength of particleboard and sample mixing ratio

The results of internal bond strength against untreated blend ratio of waste paper to leather (see Figure 4.9) indicated that 100% waste papers had the highest strength (13.61 MPa) and 100% leather wastes had the lowest (5.83 MPa). The reason behind these values could be due to good bonding with the resin where waste papers bonded well with polyester resin compared to the leather shavings. From raw material values, the moisture content of waste papers was much lower than those of leather shavings thus this could also have contributed

to poor bonding in the case of leather wastes. This is in agreement with a study by Daramola et al.,(2017). When paper was mixed with leather shavings, 75:25 paper to leather ratio exhibited the highest tensile strength and could be attributed to high bonding sites with the polyester resin as leather particles were in low levels.

The tensile strength of treated samples had higher values of strength than untreated ones. This could be due to good bonding between the particles and the resin resulting in good bonding and strong material. 25:75 blend ratio had higher internal strength and could be due to random and systematic errors in the measurements. The boards satisfied the minimum requirement of JIS A5803 standard type 8 (0.15 MPa)

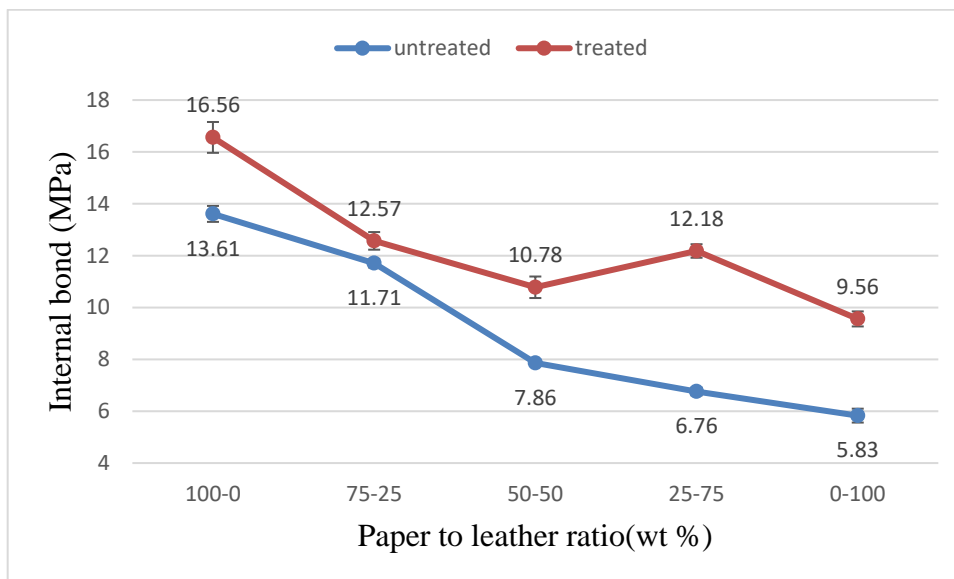


Figure 4.9: Effect of mixing ratio on internal bond strength of particleboard

The effects of varying blend ratio of leather shavings and waste paper on the internal bond strength of particleboard was done using regression analysis (see Figure 4.20). From this

analysis the P-value of 0.007 was obtained. This value was lower compared to α -value (0.05), thus suggesting significant impact on the particleboard.

Table 4.20: Analysis of variance for internal bond of particleboard manufactured from 70% matrix weight fraction at varying blend ratio

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	42.0660	42.0660	45.43	0.007
Resin	1	42.0660	42.0660	45.43	0.007
Error	3	2.778	0.9259		
Total	4	44.844			

Table 4.21 shows paired T-test analysis between treated and untreated particles on internal bond strength of particleboard at varying blend ratios. The internal bond difference between the two was significant since the computed P-value (0.015) was lower than the Alpha-value (0.05).

Table 4.21: Paired T-test analysis for internal bond of particleboard manufactured from 70% matrix weight fraction with varying blend ratio

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	5	12.13	2.93	1.31
Untreated	5	9.15	3.35	1.50
Difference	5	2.980	1.621	0.725

95% CI for mean difference: (0.968, 4.992)
T-test of mean difference = 0 (vs \neq 0): T-Value = 4.11 P-Value = 0.015

4.3.9 Resin content and Modulus of Rupture (MOR) of particleboard

The outcome of modulus of rupture (flexural strength) with resin content is displayed in Figure 4.10. The maximum bending strength (14.32 MPa) of the particleboard was at 60wt% resin content after which it continually dropped because of a decrease in particle mass

concentration. This is in agreement with Shamszadeh et al. (2013) who mentioned that reinforcement quantity is the main cause of dissimilar flexural strengths in composites. The composites with higher particle weight fraction showed higher flexural strength.

In a study by Madueke & Bolasodun (2017) the maximum bending strength was noted at 20 wt.% reinforcement concentration and the reduction of this strength was caused by controlled mobility of matrix by the particles. Also according to Al-mosawi, Rijab, Abdullah, & Mahdi (2014) and Durowaye et al. (2014) the flexural strength increased with increased fibre addition until a maximum level where further increase caused reduction in bending strengths. The flexural properties of composites depend mainly on the interfacial bonding and microstructure between the matrix and reinforcement. The decrease in flexural strength in this study could be attributed to the fact that there was a reduction in the total surface area available for matrix-filler interaction leading to a poor load transfer between the matrix and the reinforcement. As the resin content was added the number of particles responsible for load bearing were reduced thus causing a reduction in flexural strength.

In the case of the treated sample the maximum bending strength was 14.5 MPa at 60 wt% resin content and the lowest was 11.58 MPa at 90wt% resin content. These values were higher than those of the untreated samples. The difference between the strengths could be due to strong interfacial adhesion between the particles and the polyester resin after surface modification.

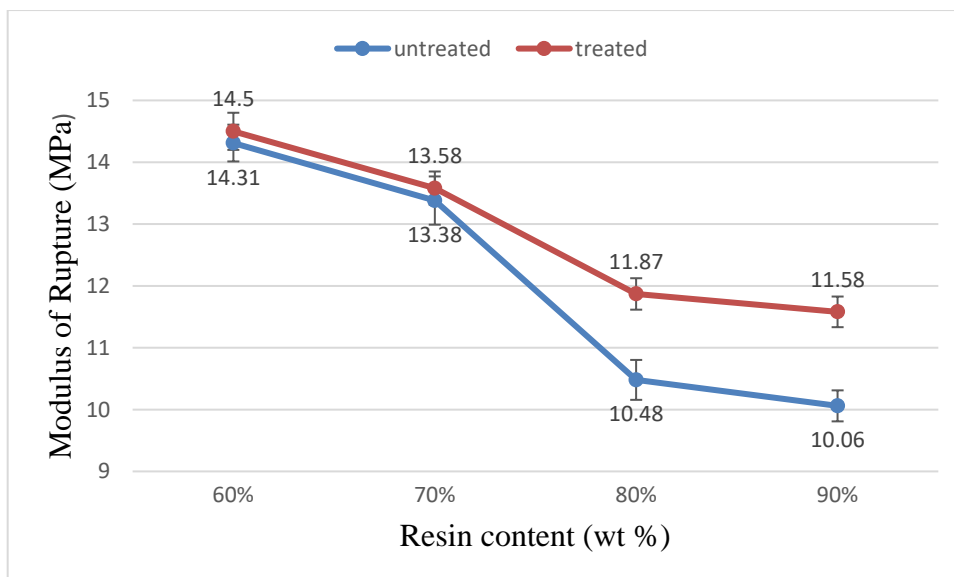


Figure 4.10: Relationship between the resin content and bending strength of particleboard

Analysis of variance for MOR manufactured from leather shavings at varying matrix weight fraction is shown in Table 4.22. The P-value was 0.040 which was lower than α -value thus indicating a significant difference in MOR at varying resin weight fractions. The null hypothesis was thus rejected and other alternatives were accepted.

Table 4.22: Analysis of variance for MOR of particleboard manufactured from leather shavings at varying matrix weight fraction.

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	12.2461	12.2461	23.21	0.040
Resin	1	12.2461	12.2461	23.21	0.040
Error	2	1.055	0.5276		
Total	3	13.301			

From Table 4.23, the calculated absolute P-value (0.109) is higher in modulus of rupture than the two tailed P- values (0.05), thus suggesting that there was no significant difference between the mean values for treated and untreated particleboards. The null hypothesis was

accepted. There was no significant difference between the two and this could be due to random and systematic errors in the measurements.

Table 4.23: Paired T-test analysis for MOR of particleboard from leather shavings and varying matrix weight fraction from 60%-90%.

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	4	12.88	1.39	0.7
Untreated	4	12.06	2.11	1.05
Difference	4	0.825	0.729	0.365

95% CI for mean difference: (-0.336, 1.986)
T-test of mean difference = 0 (vs \neq 0): T-Value = 2.26 P-Value = 0.109

4.3.10 Relationship between the mixing ratio of particles and bending strength of particleboards

Figure 4.11 shows the values of modulus of rupture (bending strength) of particleboards against the mixing ratio of the particles. Considering the untreated sample, the highest value (20.11MPa) was at 100 wt% waste papers while the lowest value (11.44 MPa) was at 50 wt% waste papers. The high value of bending strength at 100 wt% waste papers could be explained by the reason that good bonding between the particles and polyester resin was experienced. The fact that the waste papers had lower moisture could have contributed to less defects such as warping, splitting and cracking in the board resulting in greater adhesion (Nurul et al., 2019) . At 50 wt% level there was poor bonding between the two types of particles and polyester resin due to incompatibility resulting in lower bending strength. The increase in strength at 25wt% waste paper content could be due to random and systematic errors during measurement.

The maximum bending strength of treated samples was 21.05 MPa and the minimum was 14.44 MPa. When these values are compared with the untreated sample, the treated ones have

the highest values. The reason for this increase could be due to an increase in total surface area available for particle-matrix interaction. Due to good bonding between the less hydrophilic particles with polyester matrix, efficient stress transfer in the composite was achieved leading to higher flexural strengths (Daramola et al., 2017) .

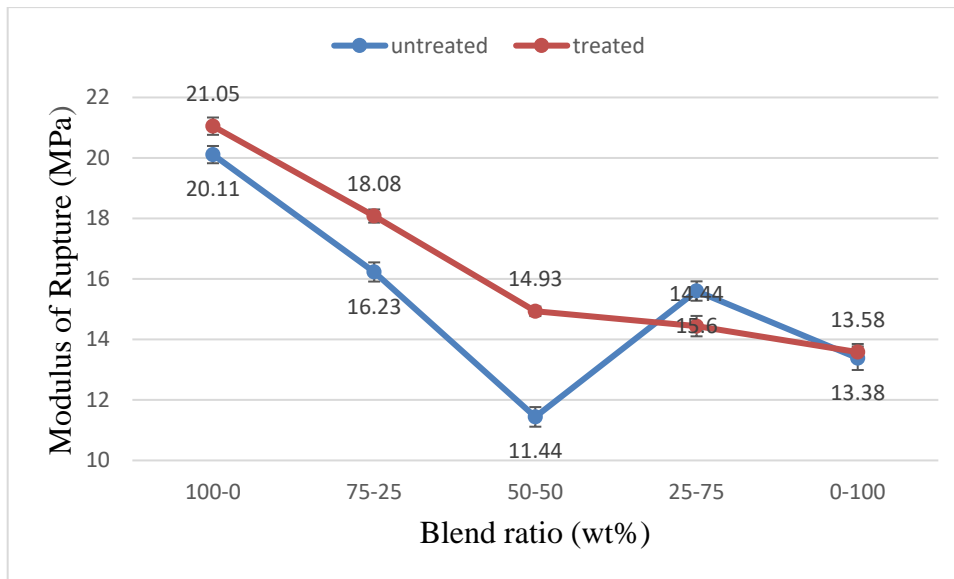


Figure 4.11: Effects of blending ratio on bending strength of particleboard

Table 4.24 presents the analysis of variance for MOR of manufactured boards at varying blend ratio. There was no significant difference on blend ratio on the MOR of particleboard since the P-value was higher than the α -value. This insignificant difference could be due to errors in measuring and testing.

Table 4.24: Analysis of variance for MOR of particleboard manufactured from 70% matrix weight fraction at varying blend ratio

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	18.742	18.742	2.43	0.217
Resin	1	18.742	18.742	2.43	0.217
Error	3	23.17	7.722		
Total	4	41.91			

The difference between treated and untreated MOR of particleboard made from varied blend ratios had no significant difference as shown in Table 4.25. The paired t-test P-value was higher than the alpha value and null hypothesis was accepted. This insignificance could be due to errors during measurements.

Table 4.25: Paired T-test analysis for MOR of particleboard manufactured from 70% matrix weight fraction with varying blend ratio

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	5	16.42	3.10	1.39
Untreated	5	15.39	3.24	1.49
Difference	5	1.024	1.774	0.793

95% CI for mean difference: (-1.179, 3.227)
T-test of mean difference = 0 (vs \neq 0): T-Value = 1.29 P-Value = 0.266

4.3.11 Modulus of elasticity of particleboard and resin content

The effects of resin content on modulus of elasticity of the particleboard is depicted in Figure 4.12. From the graph, the MOE decreased with increase in resin content. Factors which affected the flexural strength also affected the flexural modulus in the same manner since flexural modulus is a function of flexural strength (Durowaye et al., 2014). Therefore, as the resin content was increased from 60 wt% to 90 wt% the flexural modulus was reduced from

5.032 GPa to 3.554 GPa. Increase in resin content could have created defects due to an incomplete cure of the matrix and void (places unfilled by matrix and particles) reducing restrain strength thus leading to lower modulus of elasticity (Nurul et al., 2019).

When the particles were modified with fat liquor, the bending modulus of the particleboards were raised to 5.325 GPa and 4.040 GPa maximum and minimum respectively. Modification of the particle by fat imparted hydrophobic coating on the particles resulting into increase bonding sites with hydrophobic polyester resin. The higher modulus values of treated samples could have therefore been attributed to greater adhesion between the particles and the matrix (Daramola et al., 2017).

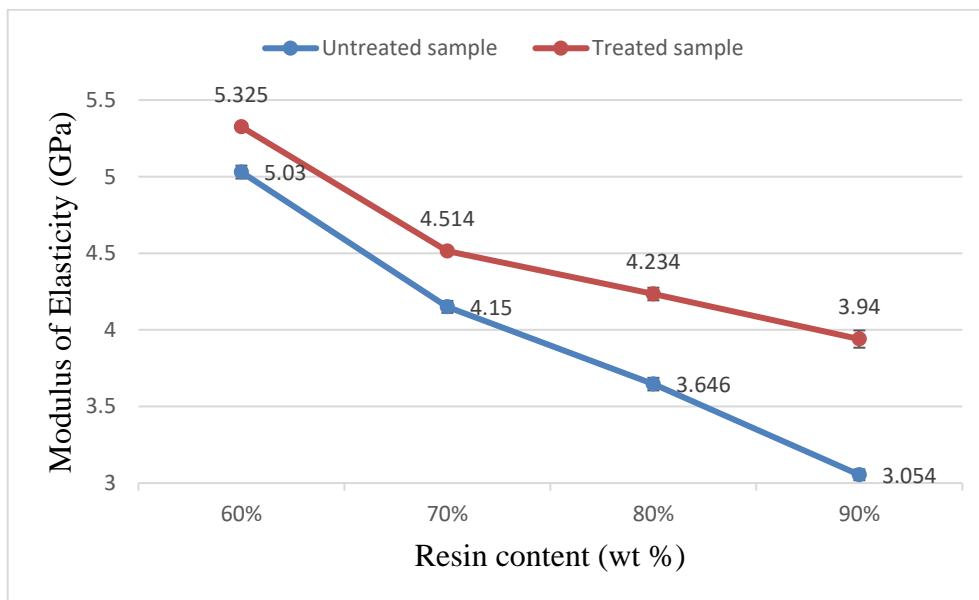


Figure 4.12: Relationship between the resin content and MOE of particleboard

An analysis of variance for modulus of elasticity of particleboard produced from leather shavings at varying resin fraction of 60% -90% is shown in Table 4.29. From this analysis, the computed P-value was 0.008 showing that there was a significant difference in modulus

of elasticity. Resin weight fraction had effects on the MOE property of the particleboard and the null hypothesis was rejected.

Table 4.26: Analysis of variance for MOE of particleboard manufactured from leather shavings at varying matrix weight fraction.

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	2.0685	2.0685	131.33	0.008
Resin	1	2.0685	2.0685	131.33	0.008
Error	2	0.03150	0.01575		
Total	3	2.10003			

Table 4.27 is a paired T-test analysis between treated and untreated particles on the MOE property of the particleboard at different matrix weight fractions. There was a significant difference between mean value of treated and untreated particleboards since the computed P-value (0.028) was less than α -value (0.05)

Table 4.27: Paired T-test analysis for internal bond of particleboard from leather shavings and varying matrix weight fraction from 60%-90%.

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	4	4.503	0.596	0.298
Untreated	4	3.970	0.837	0.418
Difference	4	0.533	0.266	0.133

95% CI for mean difference: (0.109, 0.957)
T-test of mean difference = (vs \neq 0): T-Value = 4.00 P-Value = 0.028

4.3.12 Correlation of board bending modulus and blending ratios of particles

Figure 4.13 shows the bending modulus of fabricated boards with change in blend ratio of paper and leather waste. At 100 wt% untreated paper waste the particleboard had maximum bending modulus of 5.474 GPa while at 100 wt% leather ratio the modulus value was

minimum at 4.150 GPa. 100 wt% waste paper had a high value and this could be due to good adhesion between the resin and particles. Since waste papers had lower moisture content, less moisture could have been trapped during pressing resulting in a strong particleboard (Nurul et al., 2019). The low modulus value at 100% leather could be due to low density and high moisture content since low density causes reduction in MOE (Mehdi, Maraghi, Tabei, & Madanipoor, 2018). Similar results were obtained by Wieland et al., (2020) in assessment of mechanical properties of wood-leather panel.

The treated sample followed the same trend as the untreated sample but its values were higher. The leather/paper wastes have hydrophilic dominance but when they are modified by fat, hydrophilicity reduces and a hydrophobic nature is created. Since polyester resin is a hydrophobic polymer, the interaction between modified particles and polyester is higher and this could have been the reason for increase in bending modulus in the case of the treated sample.

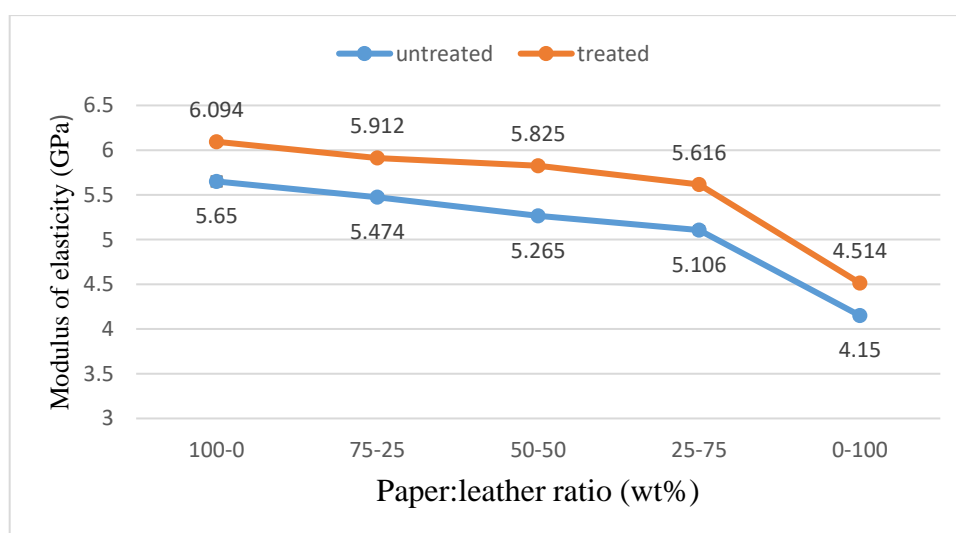


Figure 4.13: Correlation between the blending ratio and flexural strength of fabricated particleboard

The results of varying blend ratio of waste paper and leather shavings on MOE property of particleboard was significant as exhibited in Table 4.28. Compared to α -value, the computed P-value was lower (0.032) indicating rejection of null hypothesis.

Table 4.28: Analysis of variance for MOE of particleboard manufactured from 70% matrix weight fraction at varying blend ratio

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	1.13434	1.13434	14.57	0.032
Resin	1	1.13434	1.13434	14.57	0.032
Error	3	0.2336	0.07786		
Total	4	1.3679			

Paired T-test for MOE of particleboard produced from constant matrix fraction with varying blend ratio is depicted in Table 4.29. The P-value is 0.000 which is lower than α -value (0.05) thus suggesting a significant difference between treated and untreated particleboards. Modification of particles with fat treatment had effects on the board's properties.

Table 4.29: Paired T-test analysis for MOR of particleboard manufactured from 70% matrix weight fraction with varying blend ratio

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	5	5.592	0.627	0.280
Untreated	5	5.129	0.585	0.262
Difference	5	0.4632	0.0748	0.0335

95% CI for mean difference: (0.3703, 0.5561)
T-test of mean difference = 0 (vs \neq 0): T-Value = 13.84 P-Value = 0.000

4.3.13 Compression strength of particleboard and resin content

The compression strength of fabricated particle board with change in resin content is displayed in Figure 4.14 and from the graph, the compression strength decreases with

increase in resin content up to 80% resin content where it starts to rise again. 60% resin content had compressive strength of 18.57 MPa while that of 90% had 13.41 MPa.

According to Wu, Wang, & Li (2018) the reinforcement and resin in the composite assumes the force when subjected to a compression loading thus this strength is determined by both reinforcement and the matrix. The most common failure mode under compression force in a composite is kinking of load bearing reinforcement. This kinking mode involves buckling of fibres over a small region causing instability and fibre fracture. The instability which is created by voids and resin-rich regions will provide insufficient restraint to fibres under compression loading (Limited, 2012).

The decrease in compression strength with decrease in resin content could be attributed to an unfavourable deformation process aided by filler reduction in the matrix (Bhagyashekar, 2014). In addition, the fact that in the compression test, any crack or flaws introduced by dispersion of particles will be closed and made ineffective resulted in this trend. Therefore 60% resin content had the highest value because of higher particle content which provided sufficient restraint to compression loading. Increase in compression strength at 90% resin content could be due to errors during manufacturing and measurement processes.

When values of treated and untreated samples were compared, the treated samples depicted higher compression strength. Since the treated sample was modified on the surface by fat coating, the bonding between the resin and particles was improved and defects were less. This could be an explanation for the exhibited trend. The minimum requirement by ASTM for compression strength for load bearing concrete is 4.14 MPa and all the boards met this requirement.

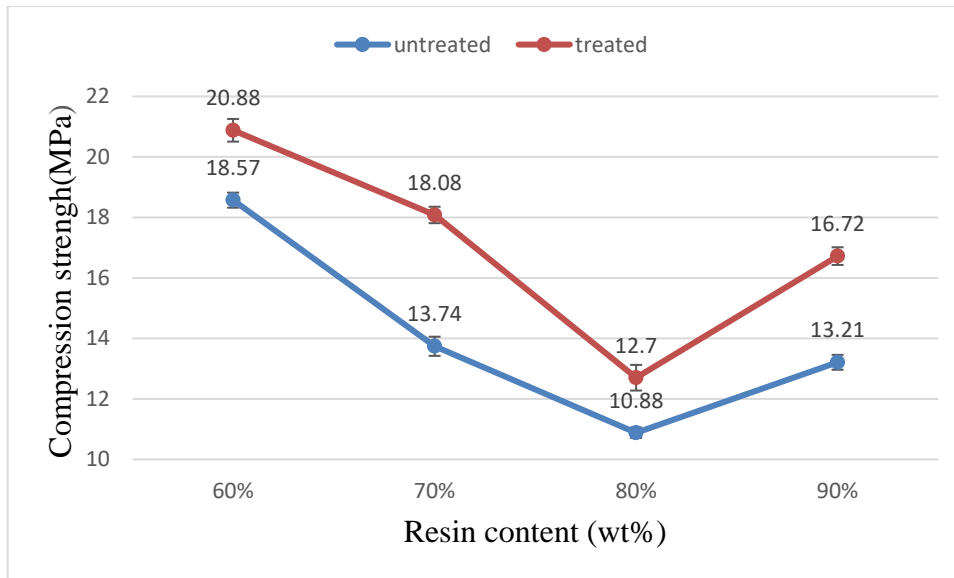


Figure 4.14: Compression strength of particleboard and resin effects

The effects of varying matrix weight fraction on the compression property of particleboard were analysed using regression method and values obtained are presented in Table 4.30. The computed value was higher than the Alpha value and null hypothesis was accepted. Insignificant differences exhibited could be due to random and systematic errors during measurements.

Table 4.30: Analysis of variance for compression strength of particleboard manufactured from leather shavings at varying matrix weight fraction.

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	18.51	18.509	2.86	0.233
Resin	1	18.51	18.509	2.86	0.233
Error	2	12.95	6.474		
Total	3	31.46			

The difference between treated and untreated particleboard in terms of compression strength was significant as shown in Table 4.31. This is indicated by the P-value (0.0140) being lower than α -value (0.05) after paired T-test analysis.

Table 4.31: Paired T-test analysis for compression strength of particleboard from leather shavings and varying matrix weight fraction from 60%-90%.

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	4	17.09	3.40	1.70
Untreated	4	14.08	3.24	1.62
Difference	4	3.020	1.160	0.580

95% CI for mean difference: (1.175, 4.865)
T-test of mean difference = 0 (vs \neq 0): T-Value = 5.21 P-Value = 0.014

4.3.14 Blend ratio and compressive strength of fabricated board.

Figure 4.15 shows the compressive strength of the particleboard against the paper-leather blend ratio. It can be observed that the compression strength of 75:25 untreated paper to leather waste (30.61 MPa) was the highest while 25:75 ratio was the lowest (10.71MPa). The high values in 75:25 blend ratios could be due to crack deflection by the particles thus providing great restraint to compression loading hence resulting in higher values. On the other hand, combining 25% waste paper and 75% leather waste could have resulted in the creation of voids and instability in the composite thus lower restraint to particles during loading hence low compressive strength values (Limited, 2012).

The treated samples exhibited the same trend; however, the values were much higher than untreated samples 33.7 MPa and 15.57 MPa respectively. This increase in compressive strength could be attributed to increase in adhesion between the resin and particles resulting from increased bonding sites. Also, the reason could be due to less voids present in the composites resulting in an increase in restraining capacity of fibres.

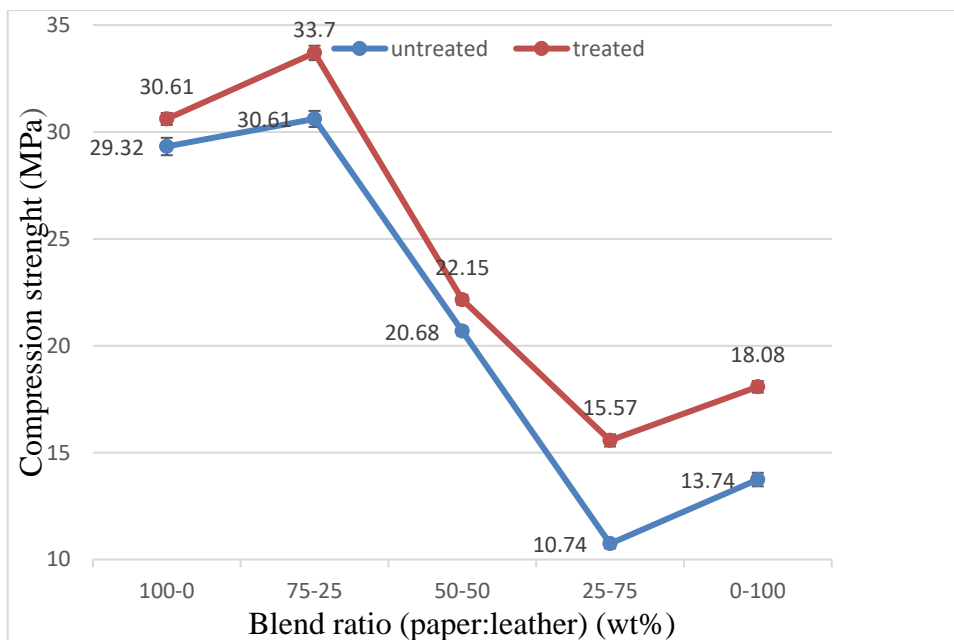


Figure 4.15: The effects of blend ratio on compressive strength of particleboard

Table 4.32 shows the results of analysis of variance for compression strength of particleboard at varying blend ratio of leather shavings and waste papers. From this analysis, a significant difference in compression strength at different blend ratios was noted ($P < 0.05$).

Table 4.32: Analysis of variance for compression strength of particleboard manufactured from 70% matrix weight fraction at varying blend ratio

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	260.41	260.41	13.19	0.036
Resin	1	260.41	260.41	13.19	0.036
Error	3	59.24	19.75		
Total	4	319.65			

As shown in Table 4.33, the difference between treated and untreated particleboards was significant. From paired T-test analysis, computed P-value (0.033) was less than the α -value

indicating the difference and null hypothesis was rejected. This means that treatment of the particles had impacts on compression strength of particleboards.

Table 4.33: Paired T-test analysis for MOR of particleboard manufactured from 70% matrix weight fraction with varying blend ratio

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	5	24.62	7.40	3.31
Untreated	5	21.02	8.94	4.00
Difference	5	3.60	2.53	1.13

95% CI for mean difference: (0.46, 6.75)
T-test of mean difference = 0 (vs \neq 0): T-Value = 3.18 P-Value = 0.033

4.3.15 Correlation between the resin content and impact strength of fabricated board

The amount of energy that the fabricated sample absorbed before fracture is shown in Figure 4.16. It was observed that the particleboard absorbed maximum energy at 80wt% resin content (64 KJ/m²) and minimum energy at 60 wt% resin content (48.33 KJ/m²). There was an increase in impact energy as resin content was increased up to 80 wt%. Similar results were obtained by Madueke & Bolasodun (2017) and Durowaye et al. (2014) where impact strength was reduced by high reinforcement content. Increase in impact strength with increase resin content could be attributed to addition of elasticity of the material due to particle reduction increasing deformability of the matrix. The matrix was able to absorb energy thereby increasing the toughness and hence impact strength increased.

At lower resin content, there is poor interfacial adhesion between the polymer matrix and the reinforcement and this would cause occurrence of micro cracks at impact point thus decreasing the impact strength. The reinforcement will not be able to block the propagation of cracks leading to lower impact strength (Durowaye et al., 2014).

Fat treated particles showed higher impact strength 67 KJ/m^2 for maximum and 47.67 KJ/m^2 . This increment could be as a result of improved bonding between the particles and matrix resulting from surface modification and thus less crack initiation sites are present in the particleboard. Therefore, fewer defects in the composites lead to improvement of board impact strength.

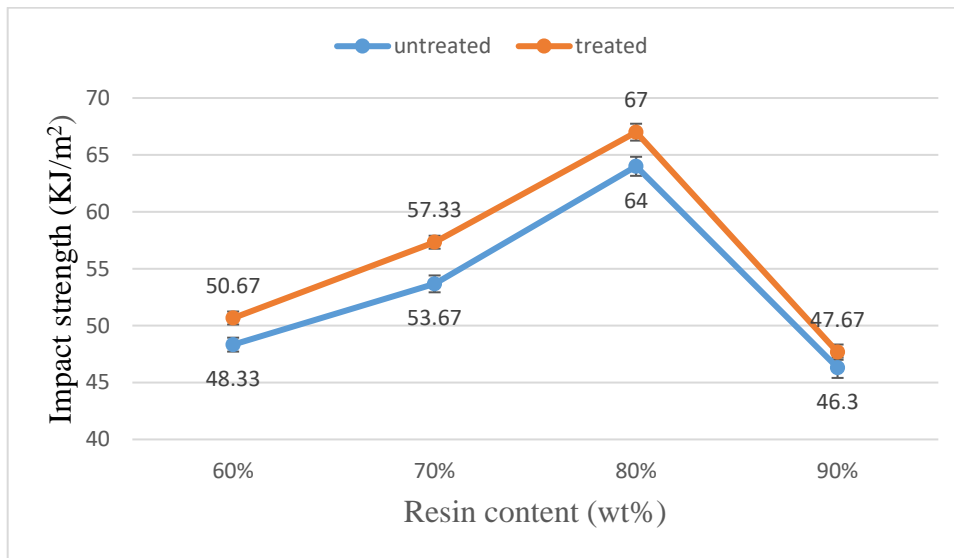


Figure 4. 16: Relationship between resin content and board impact strength

The effects of varying matrix weight fraction on the impact strength of particleboard is depicted in Table 4.34. Analysis of variance showed that there was no significant difference in impact strength when resin content was varied and this could be due to errors during measurements.

Table 4.34: Analysis of variance for impact strength of particleboard manufactured from leather shavings at varying matrix weight fraction.

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	0.077	0.0769	0.00	0.980
Resin	1	0.077	0.0769	0.00	0.980
Error	2	198.368	99.1842		
Total	3	198.445			

Paired T-test between treated and untreated particleboard from leather shavings with varying resin fraction is presented in Table 4.35. The computed P-value (0.038) was lower than Alpha value thus a difference in impact strength between the two types was significant ($P < 0.05$).

Table 4.35: Paired T-test analysis for impact strength of particleboard from leather shavings and varying matrix weight fraction from 60%-90%.

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	4	55.67	8.57	4.28
Untreated	4	53.83	8.13	4.07
Difference	4	1.843	1.034	0.517

95% CI for mean difference: (0.197, 3.488)
T-test of mean difference = 0 (vs \neq 0): T-Value = 3.56 P-Value = 0.038

4.3.16 Effects of blend ratio on impact strength of particleboard

The impact strength of particleboard against blend ratio of raw materials is illustrated in Figure 4.17. In the case of untreated samples 100 wt% leather waste had the highest impact strength while 50 wt% leather had the lowest impact value. Maximum impact strength in leather particleboard could be explained by the fact that leather fibres promoted deformation and ductile mobility of polyester molecules which increased the capability of composites to absorb energy during crack propagation. When the ratio was reduced to 50-50 ductile

mobility of the polymer and energy absorption during crack propagation was reduced (Durowaye et al., 2014).

The values of impact strength of treated samples were 57.33 KJ/m² and 47.67 KJ/m² for maximum and minimum strength, respectively. Comparing these strengths with untreated samples, the treated ones had superior strength values. Modification of particles with fat treatment could be the reason why the strength values increased since bonding between the particles and matrix was boosted.

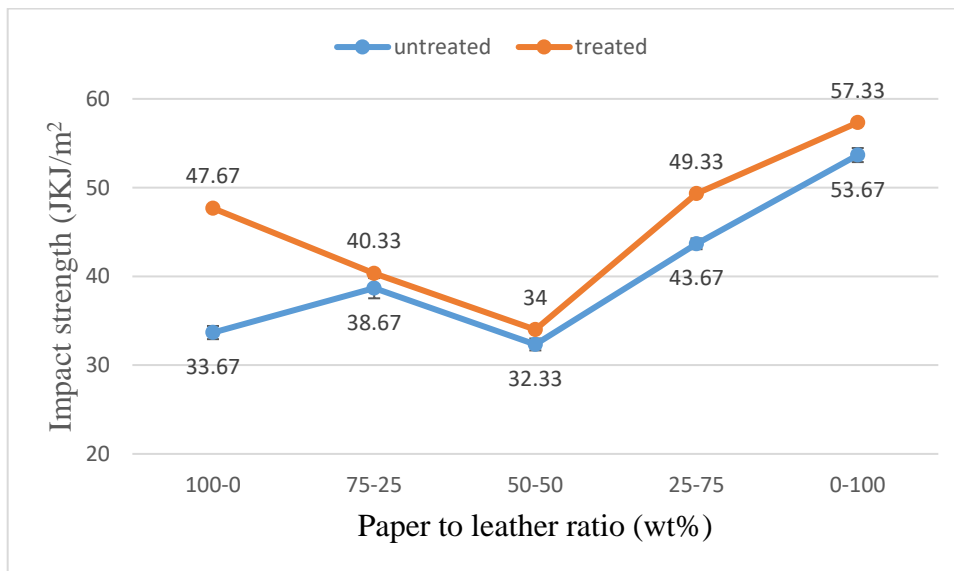


Figure 4.17: Effects of blend ratio on impact strength of particleboard

As shown in Table 4.36, analysis of variance shows that there was no significant difference in impact strength of particleboards produced from varying blend ratios of leather and paper. The P-value of 0.075 was obtained which was higher than the α -value. Systematic and random errors could have occurred during measurements resulting in the observed output.

Table 4.36: Analysis of variance for impact strength of particleboard manufactured from 70% matrix weight fraction at varying blend ratio

Analysis of variance					
Source	DF	Adj SS	Adj MS	F-value	p-value
Regression	1	230.40	230.40	7.15	0.075
Resin	1	230.40	230.40	7.15	0.075
Error	3	96.60	32.20		
Total	4	327.00			

Table 4.37 represents paired T- test analysis for impact strength of particleboard produced from different blend ratios. There was no significant difference between treated and untreated composites and this could be due to errors. The null hypothesis was accepted.

Table 4.37: Paired T-test analysis for impact strength of particleboard manufactured from 70% matrix weight fraction with varying blend ratio

Paired T-Test and CC: treated, untreated				
	N	Mean	StDev	SE Mean
Treated	5	45.53	8.87	3.97
Untreated	5	41.00	9.04	4.04
Difference	5	4.53	4.81	2.15

95% CI for mean difference: (-1.44, 10.50)
T-test of mean difference = 0 (vs \neq 0): T-Value = 2.11 P-Value = 0.103

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSIONS

The aim of this work was to produce a particleboard from leather shavings and waste paper using the compression method and to investigate the effects of resin content and blend ratio on the properties of the fabricated board. Based on the results of this study, the following conclusions can be drawn.

Utilization of leather shavings and waste papers in particleboard production is an alternative solution to waste management. This is ascribed by the particulars of raw materials in that leather shaving contained chromium which is dangerous to the environment when it is disposed. In addition, the amount of volatile present in these wastes helps in stabilizing chrome in the environment.

The physical tests carried out in this work included; density, moisture content and water absorption using various proportions of resin and blend ratio. It was observed that the physical properties can be greatly improved by using a higher amount of resin content and blending with higher proportions of waste paper. The implication is that the polyester resin of high quantity can be used in a place where high density and resistance to moisture is a major consideration. The value of water absorption and moisture content of the board were low because the hydrophobic resin was used during manufacturing thus relating to high dimensional stability.

The mechanical tests which were carried in the current study include; Modulus of rupture, Modulus of elasticity, Internal bond strength, compression strength and impact strength. From the results it can be concluded that unsaturated polyester resin of 60 wt% and higher amount of waste paper in the blend showed the highest resistance before failure by bending, tensile loading and compression. The suggestion is that the resin content of 60 wt% and higher substitution of waste paper can be used for application where flexibility is a major consideration and where resistance to higher tensile and compression loading is needed.

The particleboard sample made from 100% leather with 80 wt% and 70 wt% resin content had the capacity to absorb higher amounts of energy before crushing relative to other samples tested. Therefore, the particleboard from leather shavings bonded with 80% and 70% resin content can be utilized in areas where impact strength is the major factor.

The study also showed that treatment of particles had significant difference on the physical and mechanical properties of the particleboards. This implies that modification of particles can result in superior properties of the particleboard and that the properties of the board can be improved by treating the samples before use.

5.2 RECOMMENDATIONS

Research on possibility of blending leather shavings with other materials should be done in order to provide boards of varying properties and applications.

Baseline studies should be conducted to determine the range of resin content applicable for particleboard production.

Optimization studies need to be done in future to establish optimal resin content and blend ratio in particleboard production.

Further studies should be done to determine the best processing parameters to produce a very good board with improved properties. Parameters such as such as pressing pressure, resin type and pressing temperature should be studied. This will ensure a good adhesion, short processing time as well as the best binder for the board.

Additional tests such as microscopy, hardness and abrasion should also be done on the particleboard to see the bonding between particles and to better understand the properties of materials for other possible end uses.

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