



**Addis Ababa University**

**Addis Ababa Institute of Technology**

**School of Chemical and Bio-Engineering**

**Investigating the Potential of Aloe and Sisal Stem Fiber Blends for  
Particleboard Production**

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## ABSTRACT

*Utilization of forest wood raw materials for particle board production has resulted in deforestation, loss of habitat for millions of species, climate change and raw material competition. Therefore, the use of non woody ligno-cellulosic raw materials is a good choice for particle board production. In this study aloe and sisal stem fibers were used as a blend and mixed with urea-formaldehyde (UF) resin for particle board production. First the aloe and sisal stems were collected from Adigrat and sun dried. The dried stems were then crushed into 3mm to 6mm in size. The particles were further reduced in size by grinding (0.5-2.5mm) and classified into different classes, i.e. very fine (250µm-475µm for both aloe and sisal fibers), fine (0.5-1.4 mm for aloe and 0.71-1.4mm for sisal fibers) and coarse (1.4-2.0 mm for aloe and 1.4-2.5 mm for sisal fibers), based on the requirement for production and analysis and stored on different containers until needed. The fibers were then analyzed for their moisture, ash, extractive, hemicellulose, lignin and cellulose content. FTIR analysis was also performed for identification of the functional groups present in the aloe and sisal stem fibers. After analysis of raw materials, three layered particleboards were produced using 22cm by 22 cm mould using coarse particles (60%) as core layers and fine particles (40%) as surface layers. Design expert 11 software was used for design of the experiments and statistical analysis of the results. 17 different boards were produced by varying the aloe to sisal ratio (30-60%), resin loading rate (10-15%) and pressing pressure (150-200 bar) at pressing temperature of 155°C and press time of 14 minutes. The physical (moisture content, water absorption and thickness swelling) and mechanical (Modulus of rupture (MOR), Modulus of elasticity (MOE) and Internal bond (IB)) properties of the boards were investigated and compared with the Ethiopian standards for particle board. The results of the mechanical properties test showed that the particle boards have an average values of 11.267 MPa MOR, 1686.34 MPa MOE and 0.417 MPa IB. The analysis of physical properties also showed that the particle boards have average values of 76.95% water absorption and 62% thickness swelling after 2 and 24hrs of immersion in water bath. The maximum results for MOR, MOE and IB were 12.42MPa, 1830.13MPa and 0.505Mpa, respectively. These values were observed at 45% of aloe to sisal ratio, 12.5% of resin loading and 175 bar pressing pressure. The minimum values for WA and TS were 47.15% and 61.9% , respectively. These values were observed at 45% of aloe to sisal ratio, 15 % of resin loading and 200 bar pressing pressure. The final results of mechanical properties were compared with the Ethiopian standards for particle boards and they were found satisfactory for general purpose use.*

### Key Words

Particle board, Ligno-cellulosic materials, Urea Formaldehyde resin, Mechanical properties, Physical Properties, Aloe fiber, Sisal Fiber

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## ACRONYMS

ANOVA	Analysis of Variance
ASTM	American Society for Testing and Material
ANSI	American National Standards Institute
BBD	Box-Behnken Design
CITES	Convention on International Trade in Endangered species
EN	European Standards
ES	Ethiopian Standards
FTIR	Fourier transform infrared spectroscopy
IB	Internal Bond
ISO	International standards organization
JIS	Japan Industrial standards
MDF	Medium Density Fibreboard
MOE	Modules of Elasticity
MOR	Modulus of rupture
MUF	Melamine Urea- formadehyde
NAUF	No added Urea –Formaldehyde
OSB	Oriented StrandBoard
PB	Particleboard
PF	Phenol Formaldehyde
TS	Thickness swelling
UF	Urea-Formaldehyde
WA	Water absorption

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# 1 INTRODUCTION

## 1.1 BACKGROUND

The construction industry is growing at a rapid pace as a consequence of increasing population and standard of living. High performance synthetic materials for construction such as glass fiber and carbon fiber reinforced composites are available today. However, these materials are mainly used for high-tech applications in aerospace and motor sports due to their high cost. Therefore, lightweight and high-strength wood and wood-based composite boards are still the preferred options for construction due to their reasonable cost (Johnson & Yunus, 2003).

Particleboard, known as chipboard, is wood product manufactured from wood or non-wood materials and a synthetic resin or other suitable binder. The particleboard is made by mixing the raw materials and binder together and forming the mixture into a sheet or a panel (Zhu, 2017). The binder is typically a thermosetting or heat-curing resin often made from toxic formaldehydes. There are two types of adhesives usually used for the production of particle board; formaldehyde based resins and no added urea-formaldehyde (NAUF) resins. Mostly, formaldehyde based adhesives are used for particleboard manufacturing (Kofi, 2014). These toxins will continue to be used unless the supply of petrochemicals is interrupted or a new adhesive system is developed from renewable resources. The major types of particles used to manufacture particleboard include wood shavings, flakes, wafers, chips, sawdust, strands, slivers, and wood wool (Dietenberger et al., 1999).

Particle boards are mainly used as cheaper substitute of wood in building and furniture industries. They are used in the manufacture of various furniture items such as door and window panels; shelves, cabinets, table tops and show cases; cupboards, shutters & ward robes; and various covering of large surfaces such as partitions and side basic floors. As a result they are highly marketed throughout the world (DSA, 2008). According to Nascimento (2003) forest material from pruning and thinning; coarse industrial waste such as slabs, regular and irregular pieces, waste rolls from lamination, etc.; fine industrial waste, such as sawdust, shavings; wood chips of industrial processing of furniture and carpentry; ligno-cellulosic materials such as bagasse, rice straw and other agricultural waste, in pure form or mixed with wood particles are the possible raw materials for particle board production.

All of the particleboard factories in Ethiopia are using eucalyptus tree as a raw material for the production of the particleboards. Although it is abundant throughout the country, utilization of Eucalyptus tree as source of wood has caused various concerns (Alemie, 2009) like high reduction of soil nutrients, impeding the growth and germination of surrounding vegetation by competition for water and release of allelopathic extracts (Shimels & Woldesenbet, 2014). In addition to these problems high dependence on Eucalyptus trees is causing further increase in rate of deforestation which results in global warming (Mamza et al., 2014) and shortage of sustainable raw materials in particleboard production (Nourbakhsh, 2010).

Utilization of aloe and sisal stem fibers is therefore one alternative that reduces concerns related to the above problems. The leaves of aloe vera and sisal have high economic value. Aloes – known as lilies of the desert, plants of immortality, and medicine plants; grow in many parts of the world in diverse habitats including forests, wooded-grass-lands, woodlands, rocky expanses, mountains, cliffs, beaches and waterfalls (Demissew & Nordal, 2010). Aloes are all-purpose plants because their leaves are used for traditional and commercial purposes in producing cosmetic and toiletry products, medicinal and pharmaceutical products, functional foods and ingredients of other foods, and gel-containing health drinks and beverages as well as for ornamental purposes (Christaki & Florou-Paneri, 2010) and large-scale horticulture. But, their stems are disposed having **no economic value except for burning and fencing**. To the best of my knowledge, there is no literature which suggests the utilization of aloe vera stems as an alternative to wood in the manufacture of particleboard.

Fiber from Sisal leaves is also traditionally used for rope and twine, paper, cloth, footwear, hats, bags, carpets, and dartboards (Lok Sanjh Foundation, 2016). The production of particle board from sisal leave fibers is a new technology practiced in the recent years. Gabriel *et al.* (2016) investigated the use of sisal and coir fibers in combination with Eucalyptus particles for the production of particleboard. The particleboards were characterized for their mechanical, physical and thermal properties. The results were not satisfactory for particleboards with sisal. However, for coir particleboards the physico-mechanical properties were very similar to those particleboards produced only with Eucalyptus. But, according to Cabral and Fiorelli (2013) sisal fibers are a promising material for the manufacture of particle boards. **In their study sisal fibers** and wood particles from agro industrial waste were used to produce particle boards with Castor

oil polyurethane resin as an adhesive. The results of the work indicated the viability to produce particleboards using agro-industrial wastes, sisal fiber and castor oil polyurethane resin.

## **1.2 STATEMENT OF THE PROBLEM**

Nowadays, the population size and industrialization is rapidly growing. This resulted in an increase in the demand of using wood and wood products for different activities. Various kinds of plants and plant products are being used as source of food, fibers (for cloths), medicine, energy and other important ingredients. Due to their aesthetic value, plants are the most important elements when we build house and other buildings. The expansion and growth of the building and construction sector together with the above reasons thus resulted in scarcity of plants (deforestation). Therefore, they are very limited in amount and there is high competition for use of plant woods and wood products as construction materials. Besides their scarcity, the direct use of plant woods in construction and furniture work has resulted in different problems like deterioration by fungi, bacteria , insects and fire; lack of uniformity , shrinkage and swelling of the wood, and difficulties in handling, transportation and binding (Ramage et al., 2017).

In order to solve the above problems and to fulfill the huge demand in the plant woods, alternative approaches were chosen and among them is production and use of particle boards. These particle boards are currently produced from flakes, shavings, and fibers of large plants such as eucalyptus and acacia when needed in large scale. They are also produced in small scale from husks and remains of waste materials. The use of forests for such practice causes major problems like loss of habitat for millions of species, climate change and raw material competition etc. Considering the growing concern about the environment and the pressure to decrease the wood dependence, it is must to seek new substitute raw materials for particleboard production hence; there is an interest in renewable materials. Small proportions of the stems of Sisal and aloe vera are traditionally used as fencing material; feed for cattle and fire wood with majority of them simply disposed of no economic value. Utilization of these raw materials for particleboard production is thus one alternative as they contain high percentage of cellulose, lignin and hemicellulose content thus, it seems promising to use these raw materials for such purpose. **The reason for using the blend of aloe and sisal fibers rather than the individual fibers is that the possibility of utilizing both raw materials for particleboard production will be**

investigated concurrently. Additionally it will minimize concerns related to raw material shortage.

### **1.3 OBJECTIVES OF THE STUDY**

#### **1.3.1 General Objective**

The general objective of this study is to investigate the possibility of utilizing aloe and sisal stem fiber blends for particleboard production.

#### **1.3.2 Specific Objectives**

The specific objectives of this study are:

- To investigate the moisture, ash, extractive, hemicellulose, cellulose and lignin contents of aloe and sisal stem fibers
- Investigation of the mechanical and physical properties of the particle boards produced from the sisal and aloe stem blend fiber.
- Investigation of the effects of ratio of aloe to sisal fiber ,pressing pressure and resin loading on mechanical properties (internal bond strength,modulus of rupture and modulus of elasticity) and physical properties (swelling in thickness, moisture content and water absorption) of the particle boards.

#### **1.4 SIGNIFICANCE OF THE STUDY**

Currently there is a rapid development of industrial, commercial and residential buildings in the country. The Ethiopian government has made a number of reforms that can help to increase growth in housing and construction. However, wood and metal processing industries that are producing construction materials are not developing to fulfill demand. In addition to that the use of Eucalyptus for particle board production is causing deforestation. However, Sisal and aloe vera stems are being disposed or used as a fence perhaps burned as a fuel which is not economically viable.

Hence, the significance of this study will be transformation of those fibers into valuable products i.e particle boards without compromising the standards for particleboard properties. This will be highly important when we consider from environmental, economic and societal point of view because the products are biodegradable, the population will be benefited from cultivation of aloe Vera and sisal, and the rate of consumption of eucalyptus will be decreased and thus deforestation can be prevented. Production of particle boards from these plants thus have an economic and ecological advantage which can serve as an initiative (motive) for large scale cultivation, biodiversity conservation and environmental rehabilitation. Additionally, the cost of particle boards will decrease due to an increase in production capacity. This study will also help the policy makers to have awareness on alternative resource for production of wood products and to motivate people to practice effective utilization of resources. So this study will minimize the problems mentioned above and improve the resource use system since an effective and efficient use of resources is very important for development of every country in the world.

## 2 LITERATURE REVIEW

### 2.1 PANEL BOARDS

Panel boards or wood composites is a general term for a variety of board products, which are manufactured on the basis of mechanically chopped, milled and grinded (and refined) wood [veneers, strands, particles, fibers, etc.] bonded by adhesives usually at high temperature and pressure (Youngquist et al., 1997). These products have an impressive range of engineering properties. The distribution of these panel boards in the market is different as some panel types are relatively new on the market but others have been developed and successfully introduced more than hundred years ago (Irle et al., 2010).

The panel boards are produced by forming the homogenized raw material in any direction and amount (Kloeser et al., 2007). Based on the physical configuration of the wood used for their production, conventional wood composite materials fall into five main types i.e. plywood, oriented strand board, particleboard, hardboard, and cellulosic fiberboard (Dietenberger et al., 1999) but the most important panel boards are particle boards, medium-density fiberboards (MDF), oriented strand boards (OSB) and plywood (Youngquist et al., 1997) as shown in Figure 2.1

#### 2.1.1 Plywood

Plywood is the first engineered wood invented and is made from sheets of wood veneer stacked onto each other, crosswise to the directions of their grains. It is made from either softwoods or hardwoods and is always constructed with an alternating odd number of layers with the grain direction of adjacent layers oriented perpendicular to one another (Stark et al., 2010). This improves the strength and minimizes movement in the plane of the board. The main reason for the number of layers being odd usually is that the grain on the outside plies runs in the same direction and so that the properties are balanced about the central veneer or core. The quality and durability of plywood depends on both the timber species and the adhesive used to bond it (Asif, 2009). Phenolic resins serve as the bonding material in these products (Dodiuk & Goodman, 2014). Exterior weather and boil proof (WBP) is constructed with phenol-formaldehyde. Because of its extreme tensile strength across its width and length, it has advantage over solid wood and indeed to an extent over other manufactured boards. Plywood panels have significant bending

strength both along the panel and across the panel, and the differences in strength and stiffness along the panel length versus across the panel are much smaller than those differences in solid wood. Plywood also has excellent dimensional stability along its length and across its width. Minimal edge-swelling makes plywood a good choice for adhesive-bonded tongue- and-groove joints, even where some wetting is expected (Stark et al., 2010).

### **2.1.2 Medium Density Fiber Board (MDF)**

Fiberboard is made from fibers obtained by cooking wood chips, shavings and scraps. Medium density fiberboard has only been widely used in recent years (Ba, 2010). This product can be made as strong as desired even stronger than solid wood. MDF is made from ligno-cellulosic fibers combined with a synthetic resin in a dry process by hot-pressing (Humphrey & Bolton, 1988; Thoemen & Humphrey, 2003). MDF are characterized by their high mechanical resistance and good dimensional stability against temperature variations and moisture in the environment. This property makes them more preferable for a wide range of applications. Thus they are an excellent alternative to solid wood and ideal for furniture, flooring and the building industry.

### **2.1.3 Oriented Strand Board (OSB)**

OSB is produced from wood shredded into rectangular strips of a few centimeters in length, by layering these strands across each other in the direction of their grain, pressing, and binding them with resin adhesives (Brinkmann, 1979; Lee et al., 2006). It is a highly durable product recommended for structural and non-structural applications in the building industry.

OSB panels are usually made up of three layers of strands, the outer faces having longer strands aligned in the long-direction of the panel and a core layer that is counter- aligned or laid randomly using the smaller strands or fines. The orientation of different layers of aligned strands gives OSB its unique characteristics, including greater bending strength and stiffness in the oriented or aligned direction. Control of strand size, orientation, and layered construction allows OSB to be engineered to suit different uses (Falk et al., 2010).

### **2.1.4 Particle Board (PB)**

Particleboard is defined as a composite panel manufactured from small pieces of wood or other ligno-cellulosic materials using an organic resin as a binder by applying one or all of the parameters such as heat, pressure, humidity, a catalyst, etc. (FAO, 2014). It is a structural

material made of wood particles, such as chips, shavings or even sawdust that are mechanically pressed into sheet form and bonded with or without resin (Baharoglu et al., 2014). It is manufactured in wide range of densities but commonly between  $480 \text{ kg/m}^3$  and  $800 \text{ kg/m}^3$ , and is a versatile product recommended for furniture and building industry. Thickness ranges from 2mm up to 30mm, at present, it is made principally from wood chips but work is underway in many research centers for the use of cheaper raw materials.



Figure 2.1: Wood panel products—from top, plywood, OSB, chipboard and MDF (Popescu, 2017)

#### **2.1.4.1 Particle Board Production from Woody and Non-Woody Ligninocellulosic Sources**

Nowadays, the main challenges for particle board production are the increasing material costs (for both wood and resin) and environmental problems associated with depletion of forests used for this purpose. The cost of resin is increasing due to global increase in the prices of oils. The cost of woods is also rapidly increasing which is dependent on different factors such as proximity of the woods to the factories and competition among consumers for different purposes (Sam-Brew, 2017). The wood obtained from forest takes a long time to grow to usable sizes.

Thus, raw wood supply with high demand of wood-based composites causes deforestation (Ashori & Nourbakhsh, 2008).

Ligno-cellulosic materials are the most common form of renewable resources widely used in the world (Nitu et al., 2017). Any substance that contains both cellulose and lignin is a ligno-cellulosic material which indicates the predominance of lignin and cellulose in a natural plant fiber structure (English et al., 1994; Monteiro et al., 2011). Lignocelluloses include wood agricultural crops, like jute or kenaf; agricultural residues, such as bagasse or corn stalks; grasses; and other plant substances. In general, what is true for wood is also true for other ligno-cellulosics even though they may differ in chemical composition and matrix morphology (English et al., 1994).

#### **2.1.4.1.1 Particle Board Production from Woody Ligno-cellulosic Sources**

Wood is a complex composite material, built up of compounds connected with each other by different chemical and/or physical bonds. The quality and quantity of these compounds vary between species, between trees and within the tree itself (Hill, 2006; Rowell et al., 2005). In brief, at the macro level of a tree, wood can be divided in two classes: soft woods-the wood that comes from gymnosperms (mostly conifers) and hardwoods-the wood that comes from angiosperms (deciduous trees). They also differ in terms of their component cells. The structure of softwood is relatively simple. The axial or vertical system is composed mostly of axial tracheids, and the radial or horizontal system is composed mostly of ray parenchyma cells. The structure of hardwoods is more complex, being composed of fibrous elements, vessel elements and axial parenchyma cells (Wiedenhoeft, 2005).

Any type of the biomass consists of three basic plant polymers: cellulose, hemicelluloses and lignin. Their quantity in wood structures varies from species to species as well as among different types of woods as shown in Figure 2.2. All these compounds are more or less permanently bonded between them and fill the inter-fibrillar spaces of cell walls (Popescu, 2017). The other components of the biomass can be mineral substances, organic extractives (waxes, fats, oils), pectin, starch, proteins and some other admixtures (Ioelovich, 2015).

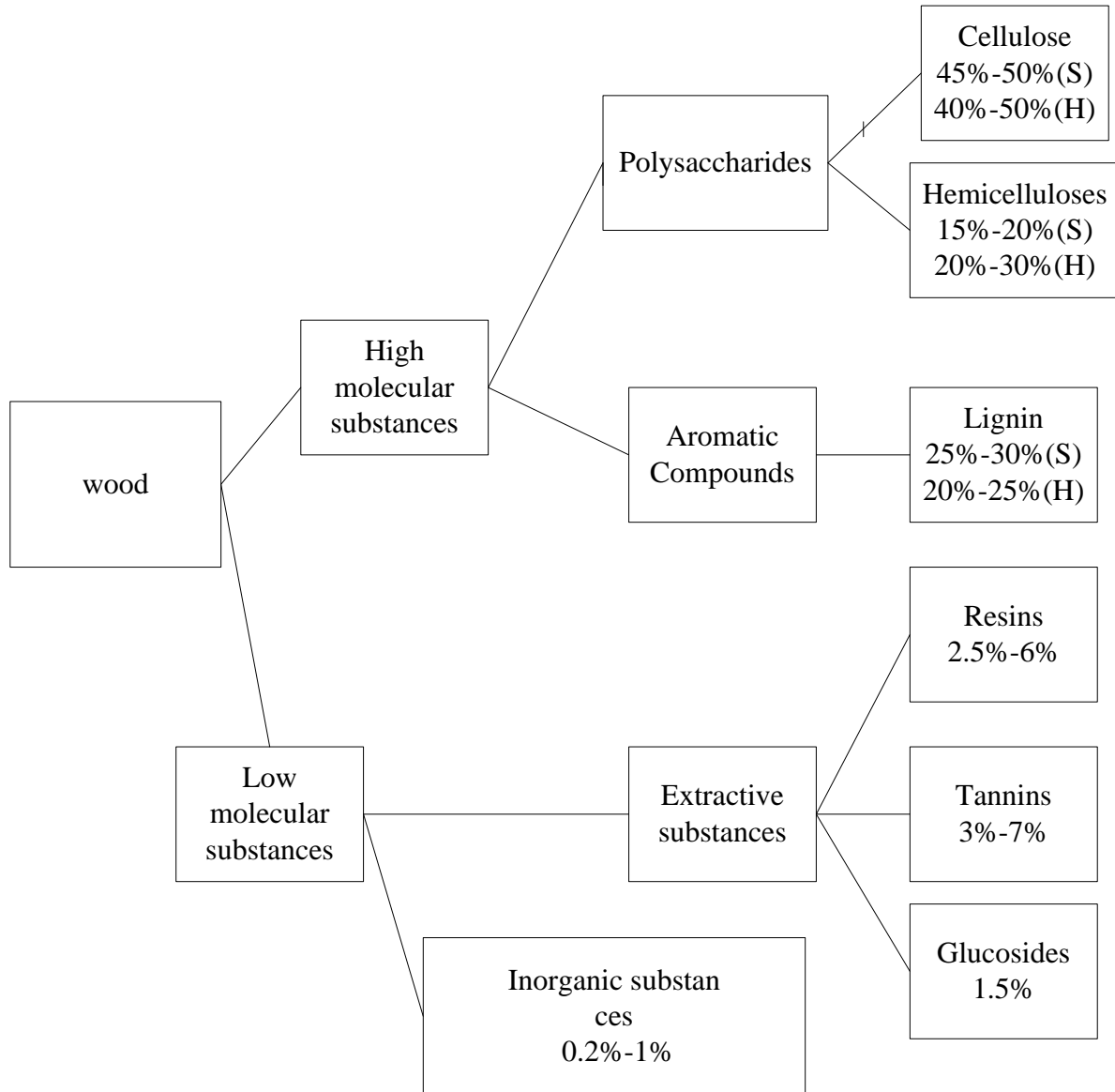


Figure 2.2: Chemical composition of wood(S-soft woods H-hard woods) (Popescu, 2017)

In the past decades, the main raw materials for particleboard production were woods which are obtained from forests (Nitu et al., 2017). Approximately 95 % of the lingo-cellulosic materials used for particle board production is wood and the rest consists mainly of seasonal crops such as flax, bagasse, and cereal straw (Irlé et al., 2010). However, forests are declining at the alarming rate in the world thus; the developing countries have poor wood resources for particleboard manufacturing. In addition to the scarcity, large amount of wood consumptions cause negative impacts on the environment (Mamza et al., 2014).

Particleboard industries consume a significant amount of wood from planted forests, mainly of *Pinus* and *Eucalyptus* genera (Carvalho et al., 2015). In Ethiopia, eucalyptus tree is highly utilized for particle board production. Despite of its abundance throughout the country, utilization of *Eucalyptus* tree as source of wood has caused various concerns (Alemie, 2009) like high reduction of soil nutrients, impeding the growth and germination of surrounding vegetation by competition for water and release of allelopathic extracts (Shimels & Woldesenbet, 2014). In addition to these problems high dependence on *Eucalyptus* trees is causing further increase in rate of deforestation which results in global warming (Mamza et al., 2014) and shortage of sustainable raw materials in particleboard production (Nourbakhsh, 2010).

#### **2.1.4.1.2 Particle Board Production from Non- Woody Ligno-cellulosic Sources**

The term non wood fibers, which also referred to as “alternate fibers”, encompasses range of plants with widely differing characteristics. They are non-woody ligno cellulosic plant materials from which particleboard making fibers can be obtained (Ashori, 2006). The most widely used non-wood materials for particleboard production are corn stalk; wheat straw; rice straw; rice husks; sugarcane/bagasse; pineapple leaf; banana pseudo stem; coconut stem; and oil palm fibers from the stem/trunk, fronds, and empty fruit bunch (Paridah et al., 2015). Most non-wood plants are annual plants that develop full fiber potential in one growing season (Ashori, 2006).

Non-wood ligno cellulosic materials are natural resources which are used as promising alternative material for panel production. Panels made from these sources exhibited equal or better physical and mechanical properties that are comparable to some commercial wood species. They are also economically cheap, renewable and processable. Establishment of sustainable and renewable raw material sources for rapidly growing wood-based industries is thus an important area of focus (Nitu et al., 2017).

There are several classifications for non-wood natural resources which depend on botanical and agricultural grouping, technological processing or the plant part from which they are obtained (bast, leaves, fruits and or seeds) as shown in Figure 2.3 (Anandjiwala & Blouw, 2007; Batra, 2007). Several researches were carried out for production of particleboards from different non-wood ligno-cellulosic sources such as bamboo (Fátima & Araujo, 2015; Xiaobo Li, 2004; Melo et al., 2014; Shimels & Woldesenbet, 2014; Valarelli et al., 2014), corn straw (Wu et al., 2015), corn stalk (Daud et al., 2013), rice husk (Asha, 2017; César et al., 2017; Ciannamea et al., 2017;

Johnson & Yunus, 2003; Melo et al., 2014; Osarenmwinda & Nwachukwu, 2007; Temitope et al., 2015), coconut husk (Greer, 2008; Van Dam et al., 2004), bagasse (Battistelle et al., 2016; Dos Santos et al., 2014; Iswanto et al., 2014; Magzoub et al., 2015; Nonaka et al., 2013; Oliveira et al., 2016; Sanchez, 1968), kenaf (Nayeri, Tahir, Jawaid, Ashaari, et al., 2014; Okuda & Sato, 2004; Widyorini, Higashihara, et al., 2005; Widyorini, Xu, et al., 2005; J. Xu et al., 2003, 2006), banana bunch (Quintana et al., 2009), hemp (Xiaoping Li et al., 2014; Sam-Brew, 2017), jute (Goswami et al., 2008), coir (E. Ahmed et al., 2016; Viswanathan et al., 2000) etc.

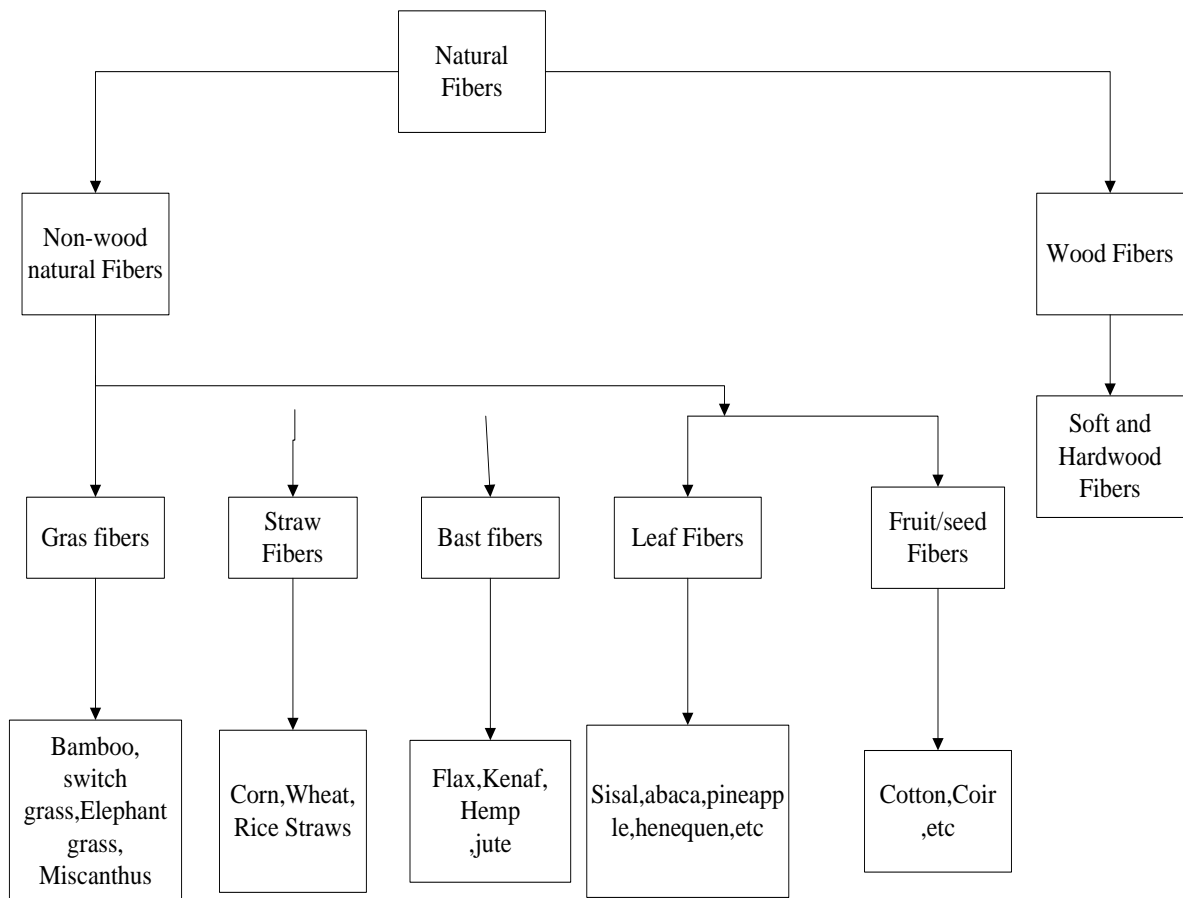


Figure 2.3: Non-wood natural fiber Classification (Anandjiwala & Blouw, 2007)

## 2.1.4.2 Role of Sisal and Aloe Vera as Source of Fibers for Particleboard Production

### 2.1.4.2.1 Aloe Vera

Aloe (>500 species) is by far the most spacious of the six genera known collectively as aloes, which include Aloampelos (7 species), Aloidendron (6 species), Aristaloe (1 species), Gonialoe

(3 species) and Kumara (2 species) (Grace et al., 2015). Aloe Vera is a succulent plant species (W et al., 2017) that is native to southern and eastern Africa along the upper Nile in the Sudan, and it subsequently introduced into northern Africa and naturalized in the Mediterranean region and other countries across the globe. The plant is commercially cultivated in Aruba, Bonaire, Haiti, India, South Africa, the United States of America, and Venezuela (Sahu et al., 2013) for its therapeutic uses, medicinal uses and antimicrobial and antimicrobial activity. Aloes grow in diverse habitats including forests, wooded-grass-lands, woodlands, rocky expanses, mountains, cliffs, beaches and waterfalls (Demissew & Nordal, 2010).

Most are habitat specialists with narrow ranges and extraordinary rates of endemism. Endemism within Ethiopian and Eritrean aloes is high around 75% for the 50 species. This compares with 100% for Madagascar and around 60% for South Africa (Walker, 2017). These centers of diversity coincide alarmingly with Africa's biodiversity Hotspots, where a highly endemic biota is under substantial threat of extinction (Mittermeier et al., 2004). Risks posed by extensive habitat destruction and other threats to their survival are reflected by the inclusion of all aloes, except aloe vera, in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The species-level diversity, ecological importance and threats to aloes place them among the world's most important succulent plant lineages, other examples of which are ice plants (Aizoaceae), cacti (Cactaceae) and Agave (Agavaceae) (Arakaki et al., 2011).

Ethiopian aloes are highly threatened due to limits in their sexual reproduction and natural regeneration, destruction of their natural habitats, unsustainable use or over exploitation for various purposes, destruction of the plants in harvesting, and high degrees of endemism in small restricted areas (Demissew, 1996). The account of family Aloaceae of the Flora of Ethiopia recognized 46 species. They are distributed in all floristic region of the country including: Afar, Arsi, Bale, Gamo Gofa, Gojam, Gonder, Harerge, Kefa, Shewa, Sidamo, Tigray, Wellega and Welo floristic regions (Demissew & Nordal, 2010). Accordingly, majority of Aloe spp. found in Sidamo floristic region (with 14 species) followed by Harerge, Bale, Shewa, Tigray and Welo floristic regions (with 10, 8, 8, 7 and 7 species respectively). Whereas few species found in Afar and Wellega floristic regions (each possess one Aloe species) and one Aloe species (Aloe macrocarpa) found in many floristic regions including Arsi floristic area (Oda & Erena, 2017).

Aloe vera is the most commercialized aloe species and processing of the leaf pulp has become a large worldwide industry. In the food industry, it has been used as a source of functional foods and as an ingredient in other food products, for the production of gel-containing health drinks and beverages. In the cosmetic and toiletry industry, it has been used as base material for the production of creams, lotions, soaps, shampoos, facial cleansers and other products. They are also used for producing medicinal and pharmaceutical products, ornamental purposes and large-scale horticulture (Dessalegn, 2006; Hamman, 2008) .

#### **2.1.4.2.2 Sisal**

Sisal is a succulent perennial crop, whose botanical name is *Agave Sisalana*. It is a drought resistant monocotyledonous plant that can do well in the arid and semi-arid regions and grows best with rainfall of 1,000-1,250 mm per year but can also grow with less rainfall. Excessive rainfall is harmful (Mwaniki, 2018). Sisal can tolerate a temperature of 40-50° C. It was originated from Mexico but now it is mainly cultivated in East Africa, Brazil, Haiti, India and Indonesia (Joseph et al., 1999).It consists of a rosette of sword shaped needle end leaves about 1.5-2 meters tall. Young leaves may have a few minute teeth along their margins, but lose them as they mature. The sisal plant has a 7–10 year life-span and typically produces 200–250 commercially usable leaves. Each leaf contains an average of around 1000 fibers (Michael & Mng’agi, 2017) and is composed of 4% of staple fibers, 0.75% cuticle, 8% dry matter and 87.25% water (Milanese et al., 2011).

The chemical compositions of sisal fibers have been reported by several groups of researchers for example; Barreto et al.,( 2010) found that the content of sisal is cellulose (65.8%), hemicellulose (12%), lignin (9.9%), pectin (0.8%), wax (0.3%) and water soluble compounds. Wilson (1971) also indicated that sisal fiber contains 78% cellulose, 8% lignin, 10% hemicelluloses, 2% waxes and about 1% ash by weight. According to F. de A. Silva et al.( 2010) the chemical composition of the sisal fiber comprehends approximately 54–66% cellulose, 12–17% hemicellulose, 7–14% lignin, 1% pectin and 1–7% ash. These large variations in chemical compositions of sisal fiber are a result of its different source, age, measurement methods, etc.

The main economic application of sisal is in the textile industry, as approximately 75% of all hard natural fibers are produced from sisal (Parsons & Darling, 2000). These fibers are used for making agricultural baler twine and to make carpets, rugs, sacks, yarns, ropes and other

cordage(Akin, 2010). As other natural lignocelulosic fibers, sisal has gained great interest during the last decades in the manufacturing of composite materials, particularly as reinforcement of mortars, concrete and polymer matrices (Bledzki & Gassan, 1999; Y. Li et al., 2000; Satyanarayana et al., 1990).

Production of particle board from sisal fibers is not well studied but there are few researchers who tried some work on production of particle board from a blend of sisal and other raw materials. Gabriel *et al.* (2016) produced particleboards from a combination of sisal and coir fibers with Eucalyptus particle. But the results of mechanical, physical and thermal properties tests were not satisfactory for particleboards with sisal fibers. But, Cabral& Fiorelli (2013) showed sisal fibers are a promising material for the manufacture of particle boards. In their study sisal fibers and wood particles from agro industrial waste were used to produce particle boards with Castor oil polyurethane resin as an adhesive. The results of the work indicated the viability to produce particleboards using agro-industrial wastes, sisal fiber and castor oil polyurethane resin.

## **2.2 PARTICLE BOARD PRODUCTION PROCESS**

Particle boards are usually manufactured in three or multi- layers. The outer layers are referred to as the surface or face layers, and the inner layers are termed the core layers. Face material generally is finer than core material. By altering the relative properties of the face and core layers, the bending strength and stiffness of the board can be increased. But there are also some single layered products throughout the world.

The basic steps in particleboards manufacturing are particle preparation, particle classification and conveying, particle drying, addition of resin and wax, mat formation, pre-pressing, hot pressing ,cooling, finishing and final product storage (Rivela et al., 2006; Youngquist, 1999). Figure 2.4 presents a process flow diagram of a particle board production.

The first step of the process is particle preparation. This step involves the collection of the solid wood ,sun drying, removal of barks and other unwanted parts of the wood and size reduction like chipping and flaking and finally storage until needed in wet bins. Rotary Drum chopper can be used to reduce the original woods in to chips and knife ring flakers are used to further reduce the size of the particles.

Once prepared, the particles are then conveyed to a drier so that the overall moisture level of the particles is reduced to the order of three to eight percent for the purpose of bonding with liquid resin. After being dried the material will be screened and classified using air or vibrating screens. Particles are separated according to size, for the purpose of furnish grading for the board face and core layers. It is essential that the oversized particles be recycled for further reduction and that the fines are screened out, so as to avoid consuming a disproportionate amount of resin.

The furnishes are then transported on conveyor belts to dry storage silos. From the dry storage silos, the core and surface materials are transferred to blenders, in which the particles are mixed with resin (glue), wax, and hardener. Surface and core materials are blended separately as they use two different recipes. The most frequently used resin for particle production is urea-formaldehyde while phenol-formaldehyde, melamine-formaldehyde, and isocyanates are also used sometimes. The choice of the resin type and its quantity depends on the type of product desired. Waxes are added to impart water resistance, increase the stability of the finished product under wet conditions, and to reduce the tendency for equipment plugging. Hardener is blended with the particles to accelerate the resin for curing and to reduce the press time.

After the particles have been mixed, they must be laid into consistent mat before the pressing process takes place. In this process three layers are formed to prepare the particleboard mat for pressing. The mat formed is then pre-pressed manually to consolidate the thickness. The formed mats of glued particles and fibers are transferred to the hot press for pressing and curing. This operation is critical and requires carefully controlled heat, pressure and timing. Typical pressures are 2-3 MPa, temperatures 140-220° C and press times 6-15 seconds per mm of board thickness.

The hot boards are removed from the press and further conditioned to equilibrate moisture content and to stabilize and fully cure the resin. The board temperature must be controlled at 30°C, at which the intensification of resistance is produced. After cooling, the board is trimmed to obtain the desired length and width and finally sanded or planed prior to packaging and shipping. The purpose of sanding is to smooth and make the particle board uniform. Also, sanding or shaving imposes close thickness tolerances and good observation. Particleboards may also be veneered or overlaid with other materials to provide a decorative surface, or they may be finished with lacquer or paint. Particleboards ready to be delivered must be stored under

adequate conditions of temperature and humidity; otherwise their quality can be seriously affected.

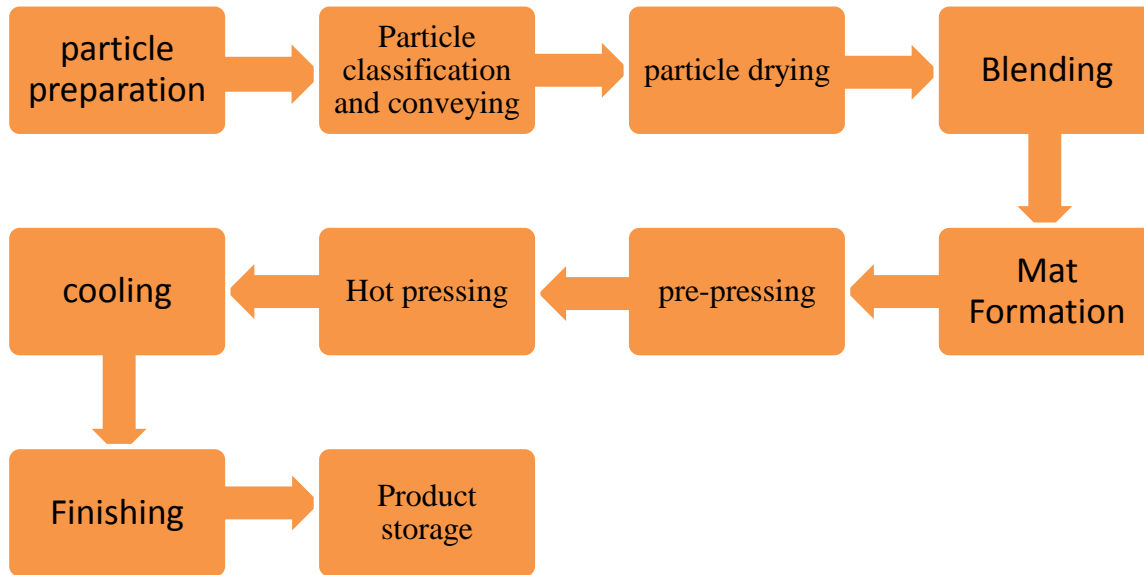


Figure 2.4: Flow chart of particle board manufacture (Sam-Brew, 2017)

### 2.2.1 Factors Affecting Particle Board Production

The properties of particle board depend on many factors. The major factors involve the type and size of particles, kind and amount of resin, raw material (wood) density, board density and profile, furnish moisture content and pressing variables i.e temperature, time and pressure (Wong, 2012).

#### 2.2.1.1 Particle Size

Shape and size of raw material in particleboards are defined as the particle geometry that is one of the main factors which influences the properties of particleboard (Frybort et al., 2008; Nemli et al., 2007). Osarenmwinda & Nwachukwu (2007) studied the effect of particle size on mechanical properties (Modulus of Elasticity, Modulus of Rupture, and Internal Bond) and physical properties (thickness swelling and water absorption) of rice husk particleboard. The study was conducted at fixed resin content (urea-formaldehyde) for different particle sizes. Results of the study showed that as the particle size increased, the particleboard's mechanical

and physical properties decreased. It also showed that particleboard made from rice husk exceeded the European standard for MOE, MOR, and IB, but the thickness swelling values were poor. Thus, according to the study, the smaller the particle size the better the mechanical properties of the particle board.

Viswanathan et al.( 2000) investigated effect of particle size on water absorption and swelling characteristics along the surface and thickness of coir pith particle board produced using phenol-formaldehyde and urea-formaldehyde resins. The water absorption and swelling were least for the board made from largest-size particles and phenol-formaldehyde resin.

Astari et al.( 2018) investigated the physical and mechanical properties of particleboard made from wood waste with several size i.e. coarse, fine and mixed using urea formaldehyde and phenol formaldehyde (at 8%, 10% and 12%) as adhesives. The particleboards were tested for their mechanical and physical properties using Japan Industrial Standard and the results of the study indicated that fine size particle with optimum adhesives both UF and PF give the superior properties among others. It is also reported that board's density and thickness met the standard.

#### **2.2.1.2 Adhesives/ Resin**

Adhesives or resins have played and will continuously play an important role in the efficient utilization of wood resources and in the development and growth of the forest products industry. Bonding between solid wood and wood particles of various sizes by adhesive is key factor in production of modern, functional wood products that are used for different purposes i.e construction, furniture, or other applications (Solt et al., 2019).

About 50% of the final performance of particle boards are related to the application/pressing process parameters and the rest are due to the quality of the adhesive used. A quantity of various categories of resins is used in the particleboard industry, and each has its advantages and disadvantages (Zain et al., 2018). Generally, adhesives can be classified into two categories, i.e. synthetic and natural adhesives. Synthetic adhesives are the petroleum-based adhesive (Zain et al., 2018).

In addition to the production costs (Zain et al., 2018),there are also increasing concerns over the materials of adhesives which are considered as not environmentally benign (McDevitt & Grigsby, 2014). Phenol- formaldehyde and urea-formaldehyde are the two most commonly used

synthetic adhesives in the manufacture of particleboards (Johnson & Yunus, 2003). Urea-formaldehyde (UF) based resins are used extensively in the production of wood-based panels because of their excellent cohesion and adhesion, lack of color in the finished product, and low cost. Nonetheless, formaldehyde can be irritating to the eyes, nose, and throat. The eyes are most sensitive to formaldehyde exposure. Over the past several decades, air pollution in residential buildings has become a matter of increasing concern. Pollutants, such as formaldehyde, are emitted into indoor air from the building materials and the wood-based construction products (Sarı et al., 2012). Phenol-formaldehydes (PF) resin creates strong and water resistant bonds, but requires the longest press times and highest temperatures. Cured PF are inherently dark and are undesirable for decorative products such as furniture and paneling (Johnson & Yunus, 2003).

Natural adhesives are generally extracted from natural resources that commonly obtained from different sort of plants such as tannin, lignin, and starch. Starch and protein-based adhesive were the early natural adhesives for binding materials in particleboard production. The application of soy protein as a binder can be traced back to old time. Still, its early commercial utilization as a wood adhesive started after 1920s (Sarı et al., 2012). The main problem with the use of biodegradable adhesives is that they are predominantly water soluble. This challenge limits their outdoor applications or in a moisture rich environment (Johnson & Yunus, 2003).

N Ayırmis and Nemli (2017) studied the effect of adhesive types on physical and mechanical properties of particleboard. Three types of adhesive i.e. urea-formaldehyde (UF), melamine-urea formaldehyde adhesive (MUF), and acrylic adhesive (AR), were used in the production of lab scale particleboards with three layers. The adhesives were used at 9% UF and 11% MUF based on oven dry weights of particle weight and (AR) with a solid content of 55%. According to the study, minimum formaldehyde emission and improved physical and mechanical properties were observed for the acrylic bonded particleboards, followed by MUF, and UF adhesive bonded particleboards, respectively. The study concluded that the acrylic adhesive can be efficiently used in the production of particleboard.

### **2.2.1.3 Wood Density**

Wood is used in a wide range of conditions and has a wide range of moisture content values in use. Moisture makes up part of the weight of each product in use; therefore, the density must reflect this fact. This has resulted in the density of wood often being determined and reported on

the basis of moisture content in use. The calculated density of wood, including the water contained in the wood, is usually based on average species characteristics. This value should always be considered an approximation because of the natural variation in anatomy, moisture content, and ratio of heartwood to sapwood that occurs. Nevertheless, this determination of density usually is sufficiently accurate to permit proper utilization of wood products where weight is important. Such applications range from the estimation of structural loads to the calculation of approximate shipping weights (Dietenberger et al., 1999).

No single property is known that alone will indicate conclusively the suitability of wood species as a raw material for particleboard manufacture. However, wood density is considered the most important species variable that affects particleboard properties because it affects binder consumption, the bulk of particles to be consolidated and thus strength and the surface smoothness of the board (Vita et al., 1974).

As a general rule, the density of wood used as furnish should be less than that of the resultant particleboard in order to economically produce high quality board (Onuorah, 2011). This is because a low density wood provides a high density compaction rate (Dias et al., 2005) and, therefore, a higher contact surface between the particles than high density wood. This leads to a more uniform product with a greater capacity to transmit loads between the particles, resulting in higher flexural and internal bond properties in particleboards made of low-density wood (Nourbakhsh, 2010). The final board density should be higher than the initial wood species density in order to attain better inter-particle contact and hence sufficient bond between particles by maximizing the usage of resin. Otherwise, most of the resin will polymerize at the void spaces resulting in poor inter-particle bonding (Wong, 2012)

The medium-density woods are used if readily available at a good price and highest-density woods should be avoided. It might seem that high-density woods should produce the strongest particle board. In fact, the lower the wood density; the higher the board strength is at any given density. This is because lighter-weight species have more particles per kg furnish, require higher pressures for proper densification, and thereby achieve better glue line contact. This also indicates that the strength of particleboard is largely determined by glue bond quality, not by wood strength (Shmulsky & Jones, 2011).

#### **2.2.1.4 Board Density**

Panel density is one of the most important properties of wood-based panel products (İstek & Siradağ, 2013). The higher the overall density of particleboard from a given raw material, the greater is the strength. However, other properties such as dimensional stability may be adversely affected by increased density. To assure uniformity, density should be the same through-out the area of a particleboard panel. To produce a board of the highest possible bending strength, at any given board density, the surface layer is made denser than the core (Shmulsky & Jones, 2011).

It is difficult to produce boards with truly uniform density profiles, that is, equal face and core density, because as the press is closed, the surface layers of the mat heat first to a higher temperature than the core. This softens the surface particles and allows them to become more densified than the core. The density profile in a panel can be manipulated in many ways, but, unfortunately, some panel properties of a board are improved by a high contrast density profile, whereas for other properties a uniform density is best. Uniform density is desirable if high internal bond strength is needed or if the edges are to be exposed in use (the edge of a uniform-density board is less porous than one with a high contrast between face and core) (Shmulsky & Jones, 2011)

Lias et al.(2014) studied the effect of board density and particle sizes on properties of homogenous particleboard produced from Kelempayan (*Neolamarckia cadamba*) using Urea formaldehyde (UF) resin. The properties of the particleboards were tested according to Japanese Industrial Standards (JIS) and the results showed that increase in target board density increases MOR, MOE, TS and WA while it decreases IB. It also showed that all particleboards tested met the minimum requirements of the JIS.

Hong et al.(2017) investigated the effect of panel density and resin content on properties of medium density fiberboard (MDF) using urea formaldehyde resin. Results of the study showed that increase in both panel density and resin content led to an increase in internal bonding (IB) Modulus of rupture (MOR), modulus of elasticity (MOE) and screw withdrawal resistance. But the physical properties i.e. thickness swelling (TS) and water absorption (WA) decreased with an increase in both panel density and resin content. According to the study, the panel density of MDF had more significant effect than the resin content in all properties of MDF panels, indicating that it was better to adjust the panel density rather than the resin content for production

of MDF. İstek and Sıradağ (2013) studied the effect of board density on physical and mechanical characteristics of three layered particleboard (PB) produced from mixture of softwood and hardwood chips using Urea formaldehyde (UF) resin as adhesive. This experiment was done by varying the densities of the PB while keeping the other parameters constant. The study showed that an increase in density of PB resulted in improvement of mechanical properties except for thickness swelling and water intake properties. The authors concluded that density change of greater than 10% resulted statistically significant changes on the physical and mechanical properties.

#### **2.2.1.5 Moisture Content**

The effect of moisture in raw materials is also a significant parameter. According to Hidayat et al. (2014), the optimum moisture content of raw materials is 8%. There has been negative impact of higher moisture contents on modulus of binder less particleboard. Mechanical properties of boards are improved with increasing board density where low-density board has high water absorption ability (J. Xu et al., 2003). The effect of moisture content on internal bond strength of bamboo binder less board also investigated by Widyorini & Satiti (2011) and they stated higher moisture content is required to promote the hydrogen bonding and lignin bonding among particles. The authors concluded that 20.2% moisture contents of fine particles gave lower water absorption than air-dried particles. Fiberboard made from 30% moisture content fibers showed higher MOR and MOE values than those of air-dried fibers as stated by Xu & Han (2003). Higher moisture content aids in plasticizing the fibers. It is because of moisture content that enables faster heat transfer to the mat core, thus decreases the melting point of lignin, and therefore creates better contacts among fibers (J. Xu et al., 2003).

Furnish moisture content exerts much influence both on the manufacture and the properties of particleboard. Too high or low levels of furnish moisture result in troublesome operation and produce a poor quality board. The optimum moisture content depends on many factors such as geometry, and wood density, among others, making generalizations difficult. The maximum board strength occurs when the moisture content ranges between 8 to 12 percent at the particle interface. Generally, it is advisable that the boards made from low density woods possess a relatively lower moisture content compared to boards made from denser woods (Abdallah, 2006).

To make a board of a given density and volume using a low density wood species will require a large number of particles. This is conducive to compaction. Thus excessive moisture in mat made up of low density particles is likely to lead to low board strength or, in extreme cases, results in blows and blisters. Moisture differentiation can result in a number of advantages during the hot pressing operation with such as rapidly consolidating the mat surfaces into a dense, strong layer. In order to create moisture differential, either surface particles with higher moisture are used or, just prior to hot pressing, the mat surface is sprayed with a given quantity of water per unit surface area. An optimum exists in the amount of water sprayed, depending on such factors as shape and size, and mat moisture content.

#### **2.2.1.6 Pressing Time**

The function of the hot press in particle- board production is to consolidate the chip mat to the desired thickness and density followed by polymerization of the adhesive between adjacent chips into a cross-linked solid polymer to hold the mat in this consolidated state when removed from the press (Kelley, 1977). Pressing time is the total time taken from when the upper platen first touches the wood mat until it leaves it. Pressing time should be sufficient to consolidate the particle mat into the desired thickness as well as the polymerization of resin into cross-linked solid polymer to hold the mat in a compacted form after removal from the press (Wong, 2012).

Pressing time is an effective factor in the manufacturing of particleboard. Most properties of the particleboard can be positively affected by press time factor (Quintana et al., 2009; Rowell, 1996). The surface quality and physical and mechanical properties of particleboards get significantly improved by increasing the press time (Nonaka et al., 2013). Ashori & Nourbakhsh (2008) investigated the Effect of press cycle time and resin content on physical and mechanical properties of single layer particleboard panels made from underutilized low-quality raw materials. The study reported that all mechanical properties of the panels were improved when the press time was increased from 4 to 5 min which shows that at 4 min press time sufficient heat is not transferred to the core section of the mat (Farrokhpayam et al., 2016).

#### **2.2.1.7 Pressing Temperature**

Hot Pressing temperature is one of the most important parameters influencing board properties. It is determined according to the performance of boards, type of glue, and production efficiency of hot press (Gul et al., 2017b). During hot pressing, heat initially transfers by conduction from the

hot platens to the outer layers of the furnish mat, where it continues to migrate toward the core. As temperature in the outer layers of the mat exceeds 100°C, heat begins to vaporize water. As more water in the mat is converted to steam, the steam pressure begins to build. Elevated steam pressure pushes heat and moisture into the core of the mat, which causes further heating of the wood furnish in the core. This conductive and convective heat energy raises the temperature of the mat, plasticizes the wood furnish, and cures the resin binder. Internal steam pressure increases the rate of heat transfer into the core of the mat, which is critical to mat consolidation, formation of density profile, and overall press- cycle time (Cai et al., 2009).

Higher pressing temperature increases the yield of extractives (Álvarez et al., 2011). The mechanical properties of binder less composites can be changed with various temperature ranges. The chemical changes during temperature application contribute to self-bonding. The reduction in hygroscopicity is attributed to the hemicellulose degradation (J. Xu et al., 2003) because heating wood at high temperatures causes lignin to flow and the hemicelluloses to decompose producing water-insoluble polymers. Okuda & Sato (2004) showed that the mechanical properties and dimensional stability of binder less board manufactured from sugarcane bagasse were improved with increasing the pressing temperature.

Gul et al.(2017b) investigated the impact of hot pressing temperature on medium density fiberboard (MDF) performance produced using wood fiber or other plant fibers as raw materials and applying urea formaldehyde resin. Results showed that increase in hot pressing temperature from 140°C to 160°C improved the strength and water resistance of the product. This increase also resulted in increase in (Modulus of Rupture (MOR), Internal Bonding (IB)) and decrease in both water absorption (WA) and thickness expansion rate. The authors concluded that the increase of hot pressing temperature from 140°C to 160°C improved the performance of the MDF. This is because the rise of hot pressing temperature increased the lapse of the temperature on the surface and core layer of the raw board which accelerates the thermal conduction. This resulted in quick rise of the temperature of the core layer temperature. Thus, glue can flow better and evenly distributed between the fibers and it can be thoroughly solidified. In addition, the rise of temperature may decrease chemical consumption in fiber thus enhances the activity of fiber for easy bonding between the fibers. But, the strength and water resistance of board may

decrease with increase of hot pressing temperature up to 185°C which might be caused by degradation and brittleness of the resin.

#### **2.2.1.8 Pressing pressure**

Pressing pressure plays significant role on internal bond strength and mechanical properties, along with greater dimensional stability of the boards. Wu *et al.*( 2015) investigated the effect of pressure on the strength of bio board and under the pressing pressure of 8 MPa, bio board has bending strength as high as 29.37 MPa. Hydrogen bonding principle is the most important condition in board making. The pressure applied in the process is to press out water from bio board, and the slight temperature is considered to evaporate water molecular between celluloses of bio board (Wu et al., 2015). Cellulose and hemicellulose, which are the two main components of fibers, are covered with hydroxyl groups. Thus, hydrogen bond can be formed between oxygen atoms in these groups and hydrogen atoms on adjacent fibers or water molecules. On drying of bio boards, fiber-to-fiber hydrogen bonds are more favored than fiber-to water hydrogen bonds (Hubbe, 2006).

Gul et al.(2017a) studied the impact of hot pressing pressure on Physical and Mechanical properties of medium density fiberboard (MDF).The results of the study showed that a little but not too much improvement in Physical and Mechanical properties of the products with increase in maximum pressure from 3.5 MPa to 5.5 MPa. It is indicated from the result that addition of the pressure after the hot pressing overcomes the rebound force and the hot press plate contacts the thickness gauge. Only the gauge is subjected to force and the raw board is not affected too much. Therefore, under the above test conditions, a maximum pressure of 3.5 MPa comply the requirement.

### **2.3 PROPERTIES OF PARTICLE BOARDS**

#### **2.3.1 Physical Properties**

##### **2.3.1.1 Moisture Content**

Water content or moisture content is the quantity of water contained in a material such as soil, rock, ceramics, or wood.

### **2.3.1.2 Board Density**

Density of a material is defined as the weight of a material held by a container of unit volume when filled and compacted under a defined condition (Khalilullahi, 1989). It is a measure of the compactness of the individual particles in a board. The average final density of a particleboard is dependent upon the raw material density and the compaction of the mat in the hot press. Any change in one of these factors requires an adjustment of the other if the board density is to remain constant. Therefore, the average board density can be changed by adjusting one of these factors. However, higher density panels produced by increasing the compaction level will not have properties equal to the same density board produced with a higher density wood furnish (Wong, 2012).

### **2.3.1.3 Water Absorption (WA)**

The capacity of a material to absorb and retain water in it is known as water absorption. It is expressed in % of weight of dry material. It depends up on the size, shape and number of pores of material.

### **2.3.1.4 Thickness Swelling**

The effect of thickness swelling in the Particle boards is because of the moisture and absorption properties. Thickness swelling is directly affected by many process variables, but interactions between variables can change basic behavior. Durability depends on low swelling and a high resin content is the best way to control thickness swelling (Halligan, 1970).

## **2.3.2 Mechanical Properties**

Main important mechanical properties of wood based materials are: bending strength (modulus of rupture), stiffness (modulus of elasticity) all calculated from static bending test; and tensile strength perpendicular to the plane of the board (internal bond strength ) (Balama et al., 2012). Strength properties are affected by many factors, such as board density, quantity of adhesive, particle dimensions and orientation, and moisture content (Tsoumis, 1991).

### **2.3.2.1 Bending Strength or Modulus of Rupture (MOR)**

Modulus of rupture (MOR), also known as flexural strength is a mechanical property, defined as the stress in a material just before it yields in a flexure test. By using a three point flexural test

technique, a specimen having either a circular or rectangular cross-section is bent until fracture or yielding for modulus of rupture test. The modulus of rupture represents the highest stress experienced within the material at its moment of failure or breaking. The MOR is very important property that controls the usability of a particleboard as a structural building element. The MOR of a particleboard is dependent on various factors including material type, size and processing conditions (Gamage, 2007).

### **2.3.2.2 Bending Stiffness or Modulus Elasticity (MOE)**

Modulus of elasticity (MOE), also known as tensile modulus, is a number that measures an object or substance's resistance to being deformed elastically when a force is applied to it. The modulus of elasticity of an object is defined as the slope of its stress-strain curve in the elastic deformation region (N Ayrilmis & Nemli, 2017). The higher modulus of elasticity the material has, the stiffer it is.

### **2.3.2.3 Tensile Strength or Internal Bond Strength (IB)**

Internal bond strength (IB) is the best single measure of the quality of manufacture because it indicates the strength of the bonds between particles. The internal bond (IB) strength of particleboard is defined as the tensile strength perpendicular to the panel's plane. A well-cured particleboard will normally fail when stressed in tension perpendicular to the middle of the board which is the lowest density region of the board. The weakest particle interaction and lowest consolidation is found in this region (Wong, 2012).

## **2.4 CLASSIFICATION OF PARTICLE BOARDS**

According to American National Standards Institute(ANSI A 208.1, 1991) standard for particleboard, particleboard includes three board-density classifications: High density: 800 kg/m<sup>3</sup> (50 lb/ft<sup>3</sup>) or greater Intermediate density: 640 to 800 kg/m<sup>3</sup> (40 to 50 lb/ft<sup>3</sup>) and Low density: less than 640 kg/m<sup>3</sup> (40 lb/ft<sup>3</sup>). Most particleboard produced in the low-density category is used for door core, which has only minimal strength requirements. It is not possible to develop structural strength at low densities. Most conventional particleboards range from 670 to 800 kg/m<sup>3</sup> (42 to 50 lb/ft<sup>3</sup>) i.e. intermediate density. In all of these products, board density is higher than that of the constituent raw material.

### 3 MATERIALS AND METHODOLOGY

#### 3.1 MATERIALS AND EQUIPMENT

The basic raw materials used for the production of particle board were sisal and Aloe Vera stems, Urea Formaldehyde resins, paraffin wax and ammonium chloride. The sisal and Aloe Vera stems were collected from villages around Adigrat city, Tigray region. Urea Formaldehyde resin was bought from Addis Ababa merkato “Fitsum wood center”. Paraffin wax, ammonium chloride and other chemicals were purchased from Neway chemical and Laboratory equipment shop in Addis Ababa.

Table 3.1: Materials/Equipment for Particle board production

<b>Materials/Equipment</b>	
Material handling (plastic bag)	Furnace
Grinder machine (WRB80 C/2q)	Fiber flask
Dryer (oven dryer)	Metal plates
Metal mould	Universal Testing Machine
Measuring cylinder(plastics)	Muffle furnace(VF2)
Thermometer (temperature reader)	Caliper
Glove	Autoclave
Sieves of different size (AS 200)	Vacuum filter
Weighing balance (digital)	Mortar
Desiccator	Manually hydraulic press
Crucible	Thermostat water bath

PH Meter( JENWAY 3505)	Knife
------------------------	-------

Table 3.2: Main Chemical Reagents used for Particle board production

Chemicals	Purpose
Urea Formaldehyde	As a resin(adhesive)
Paraffin wax	To provide water resistance and to control swelling caused by temporary wetting
NH <sub>4</sub> Cl	As dehydrator (hardener)
H <sub>2</sub> SO <sub>4</sub>	Determination of lignin content
Distilled water	For raw material tests and particleboard production
Aluminum foil	As sealing or covering for different solutions
NaOH	Determination of hemicellulose Content
Acetone	Determination of extractive Content

## 3.2 METHODS

The basic steps for the production of particle board in this study are raw material preparation and characterization, particle board production and, characterization of particle board. The experimental framework of the whole particle board production process is shown on Figure 3.1.

### 3.2.1 Raw Material Preparation and Characterization

#### 3.2.1.1 Raw Material Preparation

First the main raw materials i.e aloe vera and sisal stems were collected from their sources and the barks of the stems were removed using knife in order to remove the unwanted impurities

such as dirt and stones. The de-barked long woods were chopped into small compartments using chopper and their sizes were reduced further into chips (3-6mm) shown in Figure 3.2 (a &b) so

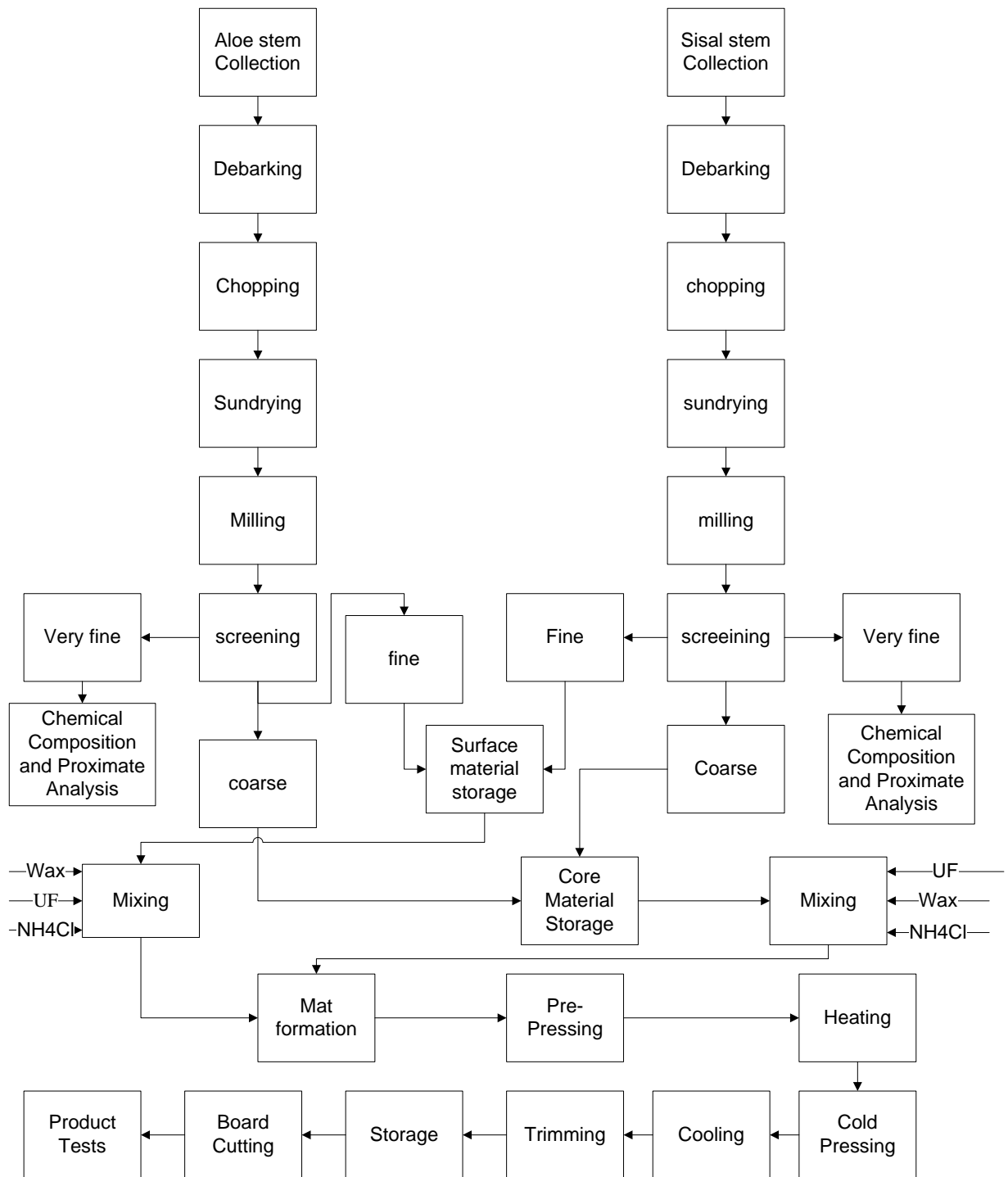


Figure 3.1: Experimental Framework of Particleboard production Process

as to remove the moisture content. The chips were put in thin plastic containers with openings on two sides and allowed to dry on sun for 3 days (8-12% moisture content) with intensive care and intermittent mixing for the difference in light intensity during the day and night times. Once they were dry, the chips were further reduced in size by means of attrition mill and to a size range of (0.5 -2.5) mm as shown in Figure 3.2 (c&d). After milling, the aloe Vera stem fibers were screened using sieve sizes of 250 $\mu$ m, 475  $\mu$ m, 0.5 mm, 1.4mm and 2mm. Similarly, the sisal stem fibers were screened using sieve sizes of 250 $\mu$ m,475  $\mu$ m, 0.71 mm, 1.4mm and 2.5mm.The wood particles were then classified in to different classes i.e very fine (250 $\mu$ m-475  $\mu$ m) for both stem fibers, fine (0.71mm-1.4mm for sisal and 0.5mm -1.4mm for aloe) and coarse (1.4mm-2.5mm for sisal and 1.4mm-2mm for aloe). The different classes of particles were then oven dried on oven at 103°C for 24hrs (to an average moisture content below 5%) on different containers and stored at different plastic bags.

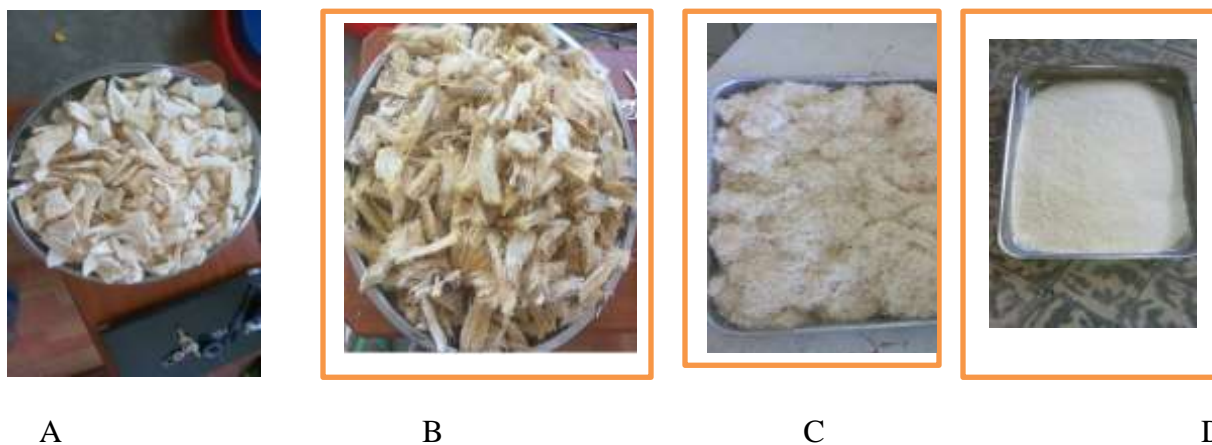


Figure 3.2: Aloe and sisal stem fibers-A. sisal chips B. Aloe chips C. Aloe powder D. sisal Powder

### 3.2.1.2 Raw Material Characterization

For raw material characterization ,samples with size range of 250 $\mu$ m-475  $\mu$ m i.e.( very fine particles ) were taken from each wood fibers (sisal and aloe) and characterized for their moisture content , ash content , lignin content and cellulose content, hemicellulose content and structure of functional groups (FTIR spectroscopy).

#### 3.2.1.2.1 Proximate Analysis of Aloe and Sisal Stem Fibers

##### A. Determination of Moisture Content

This test was done according to (ASTM D 444-92, 2003) and six aluminum foil sample holders were prepared and dried in an oven at 100°C for 3 Hrs. The sample holders were then removed from the oven after 3 hrs and cooled in a desiccator for about 15 minutes. The holders were taken out of the desiccator and weighed. 2 grams of the aloe and sisal fibers were placed in a known weight sample holders (three replicates for each) and transferred into an oven for drying for 24 hrs. at 100°C. After 24 hrs, the samples were removed from the oven and cooled in a desiccator for 30 minutes. Finally, the weight of each sample was recorded and the moisture content was calculated using the formula:

$$MC(\%) = \frac{A - B}{A} * 100 \dots \dots 3.1$$

Where MC=moisture content

A=original mass (g)

B=oven-dry mass (g)

#### **B. Determination of Ash Content**

The ash content was determined according to (ASTM D1102-84, 1984) and six empty and clean crucibles were taken and ignited to a constant weight (0.1mg difference) in a muffle furnace at 600 °c for 30 minutes. After ignition, the crucibles were removed from the muffle furnace and allowed to cool in a desiccator for 30 minutes. When cooled to room temperature, the empty crucibles were weighed on the analytical balance. 2 grams of the oven dried aloe and sisal fibers were placed in a known weight crucibles (three replicates for each) and transferred into muffle furnace and heated slowly to avoid flaming and loss of the specimen until the final temperature of 575 °c for 4 hrs. When ignition was complete, as indicated by the absence of black particles, the samples were removed from the furnace and cooled in a desiccator for 15 minutes. The crucibles with ash were reweighed and heating was repeated for 30 minutes until the weight after cooling is constant to within 0.2 mg. Finally, the weight of each sample was recorded and the Percentage ash content was calculated based on the moisture-free weight of the fiber using the formula:

$$\text{Ash content(\%)} = \left( \frac{W_2}{W_1} \right) * 100 \dots \dots 3.2$$

Where W<sub>1</sub>=weight of oven dry sample

W<sub>2</sub>= weight of ash

### 3.2.1.2.2 Analysis of Chemical Composition

#### A. Determination of Extractive Content

To determine the extractive content of the wood residues, 5 grams of the oven dried raw biomass was placed in to a thimble. 300 ml acetone was measured in 500 ml Erlenmeyer flask as solvent and the Soxhlet extractor was set up with the boiling flask positioned on the water bath set at 70 °C for 4 hrs. After extraction the sample was air dried at room temperature for few minutes and it was placed in an oven at 105°C until the volatile component was removed completely so that the weight of dried biomass is constant. This experiment was repeated six times (three replicates for each sample) and finally, the percentage extractives content was calculated as the difference in weight between the raw extractive-laden biomass and extractive-free biomass using the formula(Blasi et al., 1999; S. Li et al., 2004; Lin et al., 2010):

$$\text{Extractive content, \%} = \frac{e_1 - e_2}{e_1} * 100 \dots \dots 3.3$$

Where e<sub>1</sub>=weight of dry biomass before extraction in grams

e<sub>2</sub>= weight of dry biomass after extraction in grams



Figure 3.3: Experimental setups for extractive content determination

### B. Determination of Hemicellulose Content

To determine the hemicellulose content, 1 g of dried biomass from the extractive analysis was transferred into a 250 mL Erlenmeyer flask and then 150 mL of 0.5 mole/L NaOH solution was added (six samples with three replicates for each). The mixture was boiled for 3.5 hrs with recycled distilled water so as to increase the heating effect and minimize lime scales. After boiling, the mixture was cooled and filtered using vacuum filtration and washed until neutral pH was achieved. The residue was then dried at 105 °C in an oven and cooled in a desiccator and finally weighed until constant weight was obtained (Ayeni et al., 2013; Blasi et al., 1999). The difference between the sample weight before and after this treatment is the hemicellulose and it was calculated as:

$$\text{Hemicellulose content, \%} = \frac{h_1 - h_2}{h_1} * 100 \dots \dots \dots 3.4$$

Where  $h_1$ =weight of dry biomass before analysis in grams

$h_2$ = weight of dried biomass after analysis in grams

### C. Determination of Lignin Content

The determination of lignin was done according to (ASTM D 1106-96, 2001). 0.3 g of extracted dried biomass (that was found from extractive determination) was weighed in glass test tubes and 3ml of 72%  $H_2SO_4$  (mole%) was added and the sample was kept at room temperature for 2hrs by carefully shaking at 30 min intervals to allow for complete hydrolysis. After the initial hydrolysis, 84 mL of distilled water was added to sample to dilute the sample to 4% (mole %) and placed in an autoclave (LAMCS204 LX-B50L) for 1 h at 121 °C. The slurry was then cooled at room temperature and the hydrolysates were filtered through vacuum using a filtering crucible. The acid insoluble lignin was then determined by drying the residues at 105 °C and accounting for ash by incinerating the hydrolyzed samples at 575 °C in a muffle furnace. Finally, the result was calculated using the formula (Sluiter et al., 2008):

$$\text{Lignin, \%} = \frac{L_l}{L_s} * 100 \dots 3.5$$

Where:  $L_l$ = lignin in g and

$L_s$ = weight of extracted air dried sample in g

### D. Determination of Cellulose Content

The cellulose content (%w/w) was calculated by difference, assuming that extractives, hemicellulose, lignin, ash, and cellulose are the only components of the entire biomass.

$$\begin{aligned} \%W \text{ cellulose} &= 100\% - (\%W \text{ ash} + \%W \text{ hemicellulose} + \%W \text{ lignin} \\ &+ \%W \text{ extractives}) \dots \dots 3.6 \end{aligned}$$

### E. Fourier Transform Infrared (FTIR) Spectroscopy

Fourier transform infrared spectroscopy (FTIR) is one of the most commonly used methods for identification different functional groups constituting a compound. FTIR is a rapid and non-destructive technique for the qualitative and quantitative determination of biomass components in the mid-IR region (F. Xu et al., 2013). The wavelength of light absorbed is characteristic of

the chemical bond as can be seen in the annotated spectrum. By interpreting the infrared absorption spectrum, the chemical bonds in a molecule can be determined (Ashokkumar & Ramaswamy, 2014)

The FTIR analysis was done in Addis Ababa University Arat kilo campus. The sample was measured on Spectrum 65FT IR (PerkinElmer) in the range 4000-400  $\text{cm}^{-1}$  using KBr pellets. First, the samples (i.e. aloe vera stem fiber and sisal stem fiber) for the analysis were milled using a ceramic pestle and mortar into powder. The aloe vera stem fiber and sisal stem fiber were then mixed with potassium bromide (KBr) particles (two samples for each fiber) homogenized in an agate mortar to stabilize for infrared analysis. The mixture were then pressed to a small thickness, slightly below 1mm, and were placed into the sample compartment of FTIR attachment of the spectrometer which was continuously purged with dry air required for FTIR analysis. Then the power of the instrument was turned on and the initialization started. Then the sample holders were cleaned by acetone with Kim wipes and the spectrum software was launched. From the window that appeared, the instrument setup button was selected, scans and instrument set up dialog popped up. The sample names scan range, and scan numbers were input. The samples were placed on the sample holder, apply and start button were pressed to collect the spectrum. Finally, the data were saved and the instrument was switched off. The FTIR data were plotted by using origin lab.

### **3.2.2 Design of Experiment (DOE)**

The laboratory experiments were run based on Box –Behnken Design method (BBD) where the three treatment factors are blend ratio of aloe to sisal fiber (30%, 45% and 60%), pressing pressure (150bar, 175bar and 200 bar) and resin content (10%, 12.5% and 15%). The main reason for choosing pressing pressure than temperature is that temperature control is difficult to achieve using manual hydraulic press. High pressure range was chosen to increase the compaction ratio of the board making process and improve the physic-mechanical properties of the boards.

Table 3.3: Experimental Design

Std.	Run	Factor 1 A:Ratio(A/S) %	Factor 2 B:Resin content %	Factor 3 C:Pressing pressure Bar	Response 1 MOR MPa	Response 2 IB Mpa
1	11	30	10	175		
2	17	60	10	175		
3	15	30	15	175		
4	12	60	15	175		
5	7	30	12.5	150		
6	8	60	12.5	150		
7	2	30	12.5	200		
8	4	60	12.5	200		
9	3	45	10	150		
10	5	45	15	150		
11	16	45	10	200		
12	10	45	15	200		
13	6	45	12.5	175		
14	1	45	12.5	175		
15	9	45	12.5	175		
16	14	45	12.5	175		
17	13	45	12.5	175		

Randomization of the experimental runs was done using Design Expert 11 and a total of 17 experiments were run based on the different combinations of their test levels as shown in the Table 3.3. The best combination of the operational factors was determined from Design Expert 11 and Origin lab 2018 soft wares. The Significances of the results were determined from analysis of variance (ANOVA).

### 3.2.3 Particleboard Mix Proportion

The production of particleboards is affected by different variables such as amount of wood particles needed (fine and coarse), amount of adhesive used, amount of wax and hardener and the target density. The calculation of the mix proportions is essential to ensure the appropriate proportions of wood particles, resin, hardener, wax and water needed per board. In this work, the target density of the boards will be taken as 750 kg/m<sup>3</sup> (0.75g/cm<sup>3</sup>) as the intermediate density particle board is 640 to 800 kg/m<sup>3</sup> (ANSI A 208.1, 1991) with thickness of 1.2 cm because it is the most commercially available type of board in markets. Therefore, based on the target density and thickness of the board, length and width of the mould, the total amount of wood material required per board and amount of each component can be calculated as follows.

The volume of the board can be calculated using the formula:

$$V = l * w * t \dots \dots \dots 3.7$$

Where: V=volume of the board in cm<sup>3</sup>, l=length of the mould in cm, w=width of the mould in cm and t=thickness of the board in cm

The total amount of material required before oven drying (labeled as moist) can be calculated as:

$$(MT)_m = v * \rho \dots \dots \dots 3.8$$

Where  $\rho$  is density of the board in g/cm<sup>3</sup> and (M<sub>T</sub>)<sub>m</sub> is total moist mass required in grams per board.

After oven drying, the total amount of material required (labeled as dry) can be calculated as:

$$(MT)_d = v * \rho - (MC)_d \dots \dots \dots 3.9$$

Where (M<sub>T</sub>)<sub>d</sub> is total oven dry mass required in grams per board and (M<sub>C</sub>)<sub>d</sub> is Moisture content .

The total amount of material required after oven drying given in equation (3.9) can be also expressed as:

$$(MT)_d = (W_r)_s + (W_h)_s + (W_p)_s + (W_{wx})_s \dots \dots \dots 3.10$$

Where: (W<sub>h</sub>)<sub>s</sub> is solid weight of hardener in grams, (W<sub>p</sub>)<sub>s</sub> is solid weight of wood particles grams, (W<sub>r</sub>)<sub>s</sub> is solid weight of resin (UF) grams and (W<sub>wx</sub>)<sub>s</sub> is sold weight of wax grams.

Once the solid percentages of the components are known, equation (3.10) can be expressed as:

$$(MT)d = R * W_r + H * W_h + W_p + k * W_{wx} \dots \dots \dots 3.11$$

Where:  $W_h$  is measured weight of hardener in grams,  $W_p$  is measured weight of wood particles grams,  $W_r$  is measured weight of resin (UF) grams,  $W_{wx}$  is measured weight of wax grams,  $R$  is solid content of resin,  $H$  is solid content of hardener and  $K$  is solid content of wax .

Dividing both sides of equation (3.11) by  $W_p$  gives:

$$\frac{(MT)d}{W_p} = R * \frac{W_r}{W_p} + H * \frac{W_h}{W_p} + 1 + k * \frac{W_{wx}}{W_p} \dots \dots \dots 3.12$$

Where:  $W_r/W_p = R_c$  is solid weight ratio of resin to wood particles (rate of loading based on oven dry weight of wood particles specified during mixing),  $W_h/W_p$  is solid weight ratio of hardener to wood particles and  $W_{wx}/W_p$  is solid weight ratio of wax to wood particles.

To calculate the amount of solid wood particles needed, equation (3.12) can be expressed as:

$$W_p = \frac{(MT)d}{(R * \frac{W_r}{W_p} + H * \frac{W_h}{W_p} + 1 + k * \frac{W_{wx}}{W_p})} \dots \dots \dots 3.13$$

If the solid weights of the hardener and wax are given based on the solid weight of resin, equation (3.13) can be expressed as:

$$W_p = \frac{(MT)d}{(R * \frac{W_r}{W_p} * H * \frac{W_h}{W_r} * \frac{W_r}{W_p} + 1 + k * \frac{W_{wx}}{W_r} * \frac{W_r}{W_p})} \dots \dots \dots 3.14$$

Where:  $W_h/W_r$  is solid weight ratio of hardener to resin (loading rate based on solid resin content) and  $W_{wx}/W_r$  is solid weight ratio of wax to resin (loading rate based on solid resin content)

As the Percentage weight of resin needed during mixing based on oven dry mass of wood particles, Percentage weight of hardener based on weight of resin and percentage weight of wax based on weight of resin are specified, the total weight of resin, hardener and wax needed can be calculated respectively as:

$$W_r = R_c * W_p \dots \dots \dots 3.15$$

$$W_h = H_c * W_r \dots \dots \dots 3.16$$

$$W_{wx} = W_c * W_r \dots \dots \dots 3.17$$

The solid weights of the resin, hardener and wax are therefore calculated respectively as:

$$(Wr)_s = R * Wr \dots\dots\dots 3.18$$

$$(Wh)_s = H * Wh \dots\dots 3.19$$

$$(Wwx)_s = k * Wwx \dots\dots\dots 3.20$$

Where Hc is % weight of hardener specified during mixing (based on solid content of resin ) and Wc is % weight of wax specified during mixing (based on solid content of resin)

The amount of water in the wood particles is negligible as they are fully oven dried. But the amount of water in the resin, hardener and wax can be calculated from equations (3.18, 3.19 and 3.20) respectively as:

$$(Wr)_{H2O} = (1 - R) * Wr \dots\dots\dots 3.21$$

$$(Wh)_{H2O} = (1 - H) * Wh \dots\dots\dots 3.22$$

$$(Wwx)_{H2O} = (1 - k) * Wwx\dots\dots\dots 3.23$$

The total weight of water per particle board is the total sum of water in each material and is calculated as:

$$(WT)_{H2O} = n * (MT)_d \dots\dots 3.24$$

Where  $(WT)_{H2O}$  is total weight of water per particle board in grams and n is percentage moisture content of the surface layer of the particleboard

Thus, equation (3.24) is written as:

$$n * (MT)_d = (Wr)_{H2O} + (Wh)_{H2O} + (Wwx)_{H2O} + (W_{dadded})_{H2O} \dots 3.25$$

Rearranging equation (3.25) gives:

$$(W_{dadded})_{H2O} = (n * (MT)_d - ((Wr)_{H2O} + (Wh)_{H2O} + (Wwx)_{H2O})) \dots 3.26$$

For a three layered particle board, according to Gamage (2007) surface layers contribute 40 % (20% for each layer) while the core layer contains 60 % of the total weight of wood particles. Therefore, the weight of core and surface layers can be simply calculated as:

$$W_{core} = 60\% * W_p \dots\dots\dots 3.27$$

$$W_{surface} = 40\% * W_p \dots\dots\dots 3.28$$

The amount of sisal and aloe wood particles needed to make a single particle board will also be calculated based on the conditions for each run i.e the percentage of each wood particle on the individual runs. Let us say if the run is based on 30% of aloe and 60% of sisal, the amount of aloe and sisal wood particles needed for the core and surface layers of the particle board will be calculated as:

$$(W_{\text{core}})_{\text{Al}} = 30\% * (W_{\text{core}}) \dots \dots \dots 3.29$$

$$(W_{\text{surface}})_{\text{Al}} = 30\% * (W_{\text{surface}}) \dots \dots \dots 3.30$$

$$(W_{\text{core}})_{\text{sis}} = 60 * W_{\text{core}} \dots \dots \dots 3.31$$

$$(W_{\text{surface}})_{\text{sis}} = 60\% * (W_{\text{surface}}) \dots \dots \dots 3.32$$

### 3.2.4 Particle Board Production

After appropriate amounts of the main raw materials were determined based on the experimental design and mixing proportionating, Required amounts of aloe and sisal particles were weighted and initially mixed at different proportions (30%- 60%) without binder to enable uniform mixing of the particles .This mixture was blended to a mixture of resin (10%-15% based on the oven dry weight of wood particles)with solid content of 60% given by supplier, 0.7 % paraffin wax emulsion (based on the solid content of resin) with solid content of 32% given by supplier ,2% NH<sub>4</sub>Cl (based on the solid content of the resin) with solid content of 99.5% given by supplier and water. The particles, resin, hardener and wax were mixed manually using plastic bowls for 5 minutes to ensure that the components are evenly mixed with the resins.

After blending, the particles were spread evenly in to into a 22 x 22 x 1.4 cm (Pereira et al., 2018) metal mould with rectangular metal plates at the top and base. Aluminum foil was used as a cover for the mould to prevent the panel from sticking to the plate during hot pressing. Three layered mats were formed using the fine particles as surface layers i.e bottom and top layers and the coarse particles as core layer in the middle of the surface layers. The mats formed were pre-pressed in a cold hydraulic press at a pressure of 100 bar for 2 minutes(Lias et al., 2014) to consolidate the thickness. The mould with the pre-pressed mats was removed after two minutes and placed in a heater until a temperature of 155<sup>o</sup>c was attained on all sides of the mould .After the desired temperature was attained, it was removed from the heater and pressed in hydraulic

press at a pressure of 150 bar-200 bar (Ota & Okamoto, 2015)for 14 minutes to achieve target thickness of 1.2cm.

The hot boards were then removed from the press and conditioned at 25° C to equilibrate moisture content and to stabilize and fully cure the resin. Finally, the cooled boards were trimmed to final dimensions of 21 x 21cm and stored prior to characterization.

### **3.3 PHYSICAL AND MECHANICAL PROPERTIES TEST OF PARTICLE BOARD**

The tests for physical and mechanical properties of the final particle boards were done on Maichew particle board factory. Among the physical properties that were investigated were bulk density, moisture content, water absorption and thickness swelling. The mechanical properties i.e Modulus of rupture, modulus of elasticity and internal bond strength were done using universal testing machine (Zwick/Roell ZMART.PRO Germany).

#### **3.3.1 Physical Property Tests**

##### **3.3.1.1 Moisture Content**

After the boards were trimmed and stored for some time, they were prepared for moisture content test. The specimens were prepared according to the Ethiopian standard (ES ISO 16979, 2016). Three specimens with dimensions of 5cm by 5cm were cut from different locations of each particle board, coded and their weights were measured and recorded before they were dried in an oven (NPFE 141 Memmert Germany) for 16 hrs at a temperature of 110 °c. Finally, the specimens were taken out from the oven and their weights were recorded. Their moisture contents were calculated using the formula given in equation 3.33.

$$MC(\%) = \frac{\text{Wt of air dry sample} - \text{Wt of oven dry sample}}{\text{wt of oven dry sample}} * 100 \dots 3.33$$

##### **3.3.1.2 Water Absorption and Thickness Swelling**

For this test, the specimens were prepared according to the Ethiopian standard (ES ISO 16979, 2016). Three specimens with dimensions of 2.5 cm by 2.5cm were cut from different locations of each particle board, coded and their weights and average thicknesses were measured and

recorded before they were immersed in water bath for 2 hours at room temperature. After 2 hours, the samples were taken out of the water bath their mass and average thicknesses were recorded. The samples were also immersed in the water bath for another 22 hours and their masses and average thicknesses were recorded after 24 hours of immersion. Finally, percentage water absorption and percentage thickness swelling were calculated using the formulas given in equation 3.34 and 3.35.

$$\text{WA after } y \text{ hours}(\%) = \frac{\text{Weight after } y \text{ hours} - \text{starting weight}}{\text{starting weight}} * 100 \dots \dots \dots 3.34$$

$$\text{TS after } y \text{ hours}(\%) = \frac{\text{thickness after } y \text{ hours} - \text{starting thickness}}{\text{starting thickness}} * 100 \dots 3.35$$

### 3.3.2 Mechanical Properties Test

#### 3.3.2.1 Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)

The tests for MOR and MOE were done according to the Ethiopian standard(ES ISO 16978, 2016) and for both tests, two specimens of known moisture content with dimensions of 5 cm by 20 cm Were cut from different locations of each particle board, coded and their weights and average thicknesses were measured. The distance between the grips of the bending tester was set as 15cm for standard test specimen and the specimens were put above the grips. The average thickness, average moisture contents and the average density of the specimens were fed to a computer system and the system was started on the computer to apply a Pressure load at the center of the support. Finally, the average values for MOR and MOE, which can be calculated from equations 3.36 and 3.37 respectively were read from the computer and recorded.

$$\text{MOR} = \frac{3 * F_{\text{max}} * l}{2 * b * t^2} \dots \dots \dots 3.36$$

Where  $F_{\text{max}}$  is the maximum load(N),  $l$  is the distance between the centers of the supports (mm),

$b$  is the width of the test piece (mm),  $t$  is the thickness of the test piece(mm)

$$\text{MOE} = \frac{l_3 * (F_2 - F_1)}{4 * b * t^3 * (a_2 - a_1)} \dots \dots \dots 3.37$$

Where  $F_2 - F_1$  is the increment of load (N) on the straight- line portion of the load deflection curve.  $F_1$  shall be approximately 10% and  $F_2$  shall be approximately 40% of the maximum load  $a_2 - a_1$  is the increment of deflection at the mid length of the test piece (corresponding to  $F_2 - F_1$ )

### 3.3.2.2 Internal Bond Strength (IB)

The internal bond (IB) strengths of the particleboards were determined according to the Ethiopian standard (ES ISO16984, 2016). Four specimens of known moisture content with dimensions of 5 cm by 5 cm were cut from different locations of each particle board, rubbed on their plane surfaces, coded and their weights and average thicknesses were measured. The plane surfaces of the square test specimens were glued to metal loading blocks using glue stick chemicals which were melted in an oven at a temperature of 90 ° C for about 15 minutes. The metal blocks were attached with the grips of the test device and average thickness, average moisture contents and the average density of the specimens were fed to a computer system. The specimens were then subjected to tensile force perpendicular to the particleboard surface until rupture occurred. Finally, the average values of IB, which can be calculated from equation 3.38 were read from the computer and recorded.

$$IB = \frac{F_{\max}}{a * b} \dots \dots \dots 3.38$$

Where IB is tensile strength perpendicular to the plane of the panel of each test piece (MPa),

$F_{\max}$  is the breaking load (N), a is the length of the test piece (mm) and b is the width of the test piece (mm)

## 4 RESULTS AND DISCUSSION

### 4.1 PROXIMATE AND CHEMICAL ANALYSIS OF RAW MATERIALS

#### 4.1.1 Proximate Analysis

##### 4.1.1.1 Ash and Moisture Content

Ash is a general term which refers to inorganic substances such as silicates, sulfates, carbonates, or metal ions (Rydholm, 1965). The ash and moisture contents of the aloe and sisal fibers were calculated using the formula given in equation 3.1 and 3.2 and the results which are shown on Table A.1 and Table A.2 of appendix part were a moisture content of 4.8% and 4.2 % for aloe and sisal respectively while the ash contents were 3.93% and 0.94% for aloe and sisal fibers respectively. According to (Nitu et al., 2017; Tajuddin & Ahmad, 2016), the ash content for sisal leave fiber was in the range 0.6 to 1% which complied with this result. There is no reference on the amount of ash in aloe stem fiber but according to the studies conducted on aloe vera leaves by (M. Ahmed & Hussain, 2013) and (Haque et al., 2014), the amount of ash was 16.88% and 19.5%. The result of this experiment which is lower compared to the study is reasonable because the leaves of aloe Vera contain high mineral contents than the stems. Various literatures on ash content of aloe vera leaves showed that aloe vera has high mineral content such as magnesium, zinc, chromium, selenium, sodium, iron, potassium, copper, manganese etc.

##### 4.1.2 Fourier Transform Infrared (FTIR) Spectroscopy

Generally, the peaks at around 3400  $\text{cm}^{-1}$  and around 2927  $\text{cm}^{-1}$  which are attributed to O-H stretching absorption and C-H absorption bands respectively, have contributions from all the three main wood cell chemical components i.e. cellulose, hemicellulose and lignin (Shi et al., 2012). As shown from Figures 4.1 and 4.2, there are broad peaks at 3422.16  $\text{cm}^{-1}$  for aloe and at 3414.7  $\text{cm}^{-1}$  these are attributed to O-H stretching vibrations in all the three components. The peaks at 2925.58  $\text{cm}^{-1}$  and 2929.26  $\text{cm}^{-1}$  also belong to the C-H stretching vibrations in all the three components. For sisal fibers (Figure 4.2), the band at 1742.62  $\text{cm}^{-1}$  corresponded to C=O stretching of carbonyl groups and ester groups in hemicellulose. The peaks at 1621.34  $\text{cm}^{-1}$  for aloe fiber and at 1624.54  $\text{cm}^{-1}$  for sisal fiber are attributed to the stretching vibration of C=C plus the asymmetric-stretching vibration of COOH in the aromatic ring that is associated with

cellulose, hemicellulose, and lignin (Xiaoli Li et al., 2018). The absorption peaks at 1411.21  $\text{cm}^{-1}$  for aloe and 1424.54  $\text{cm}^{-1}$  for sisal also belong to  $\text{CH}_2$  asymmetric stretching vibrations in lignin (K et al., 2012). The peaks at 1320.93  $\text{cm}^{-1}$  and at 1331.52  $\text{cm}^{-1}$  of aloe and sisal fibers respectively belong to the  $\text{CH}_2$  wagging mode in cellulose. The absorption band at 1058.19  $\text{cm}^{-1}$  for sisal fiber is characteristic for C-O stretching vibration in cellulose while the band at 1049.25  $\text{cm}^{-1}$  for aloe fibers is characteristic for C-O vibrational stretching in esters in hemicellulose (Adapa, 2009).

The FTIR results of this experiment showed comparable values with the natural ligno-cellulosic sources of wood fibers used for particle board production. Therefore, utilization of these raw materials as alternative source is good choice that should be practiced.

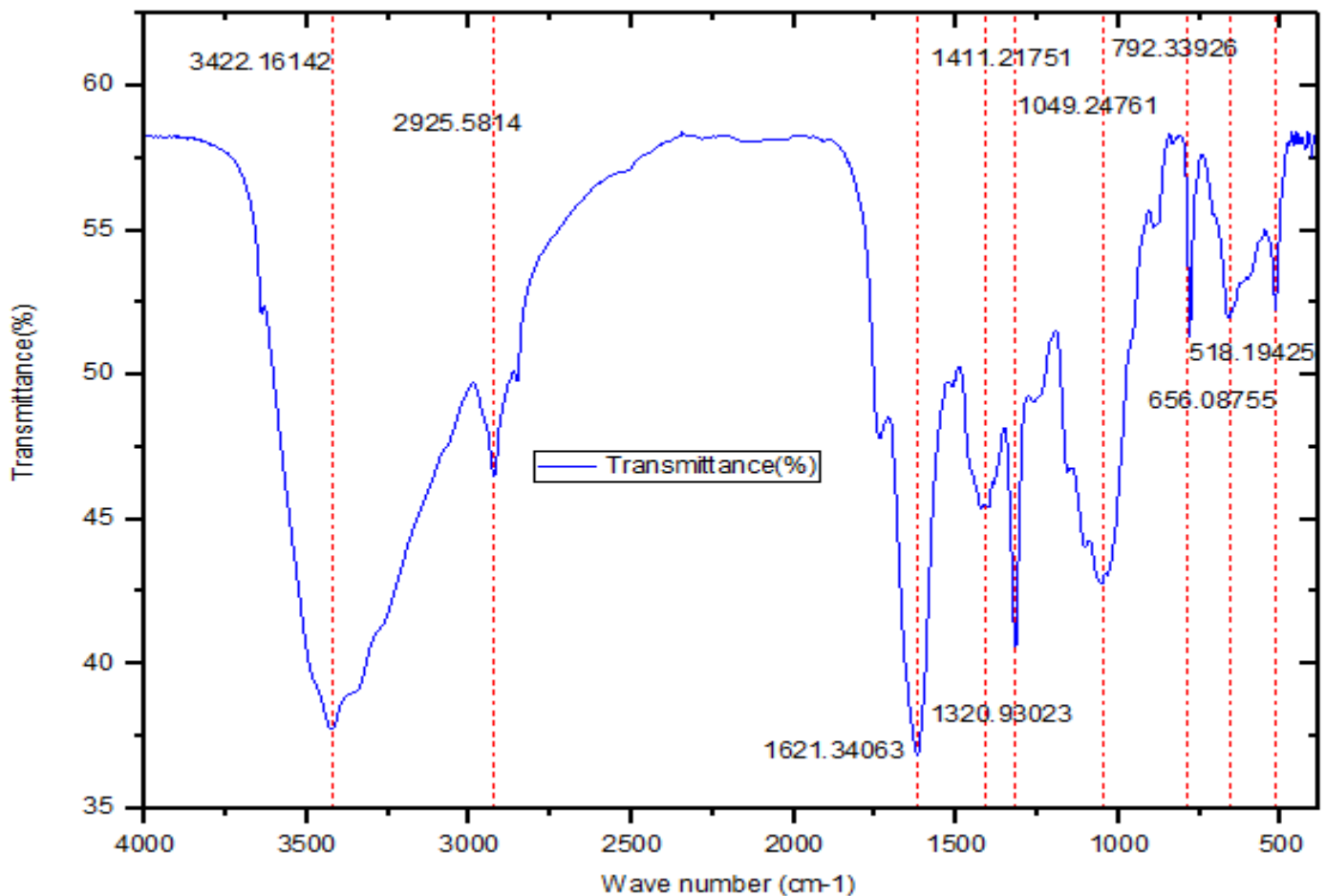


Figure 4.1: Fourier transform infrared (FTIR) spectrum for aloe Vera stem fiber

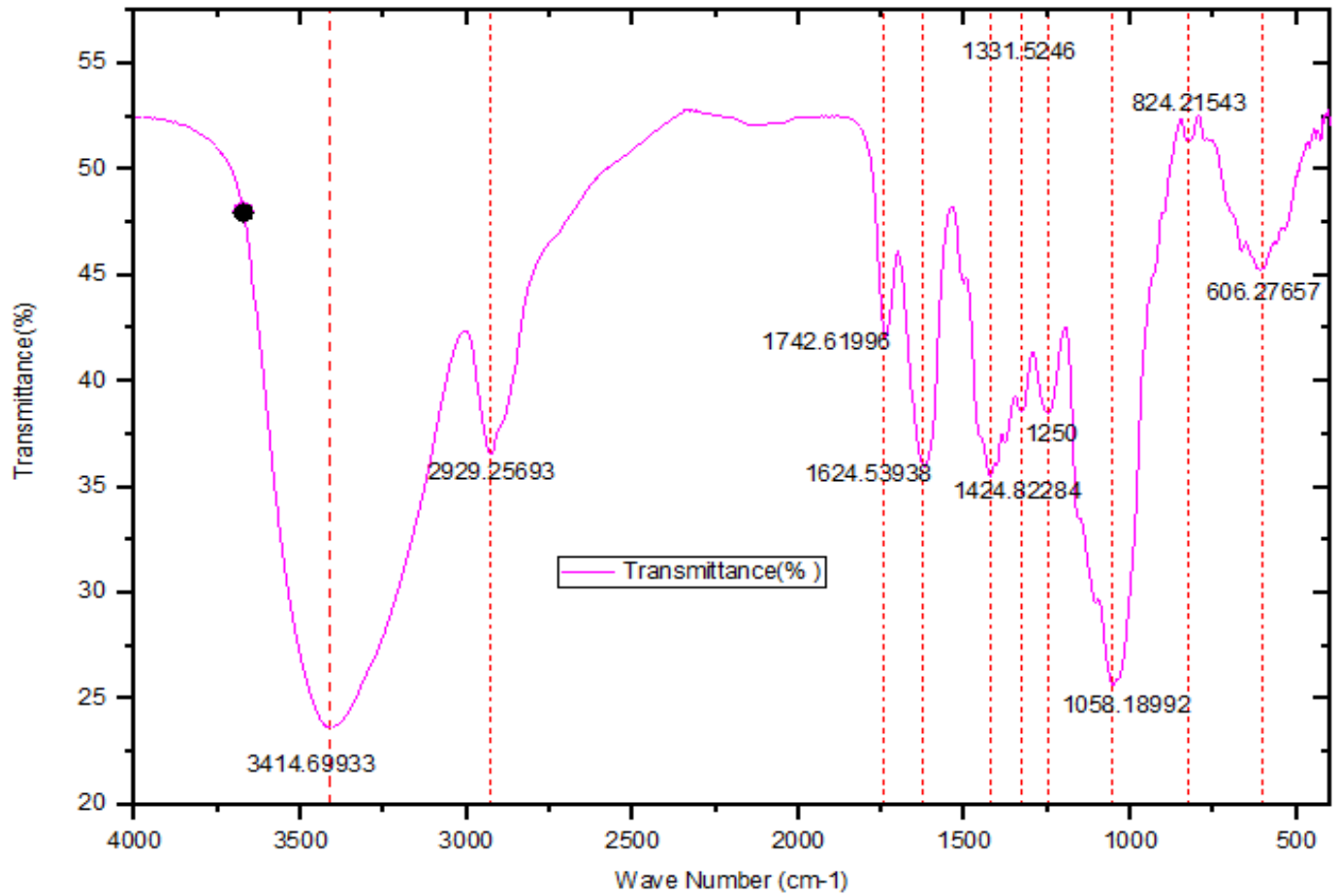


Figure 4.2: Fourier transform infrared (FTIR) spectrum for sisal stem fiber

#### 4.1.3 Chemical Composition Analysis of Raw Material Fibers

As shown in Figure 4.3 and Tables B.1 to B.3 in appendices part, the extractive, hemicellulose, Klason lignin and cellulose content were 4.57, 13.9,22 and 55.6 % respectively for aloe stem fiber and 2.87, 16.43, 24.89 and 54.87 wt % respectively for sisal stem fiber.

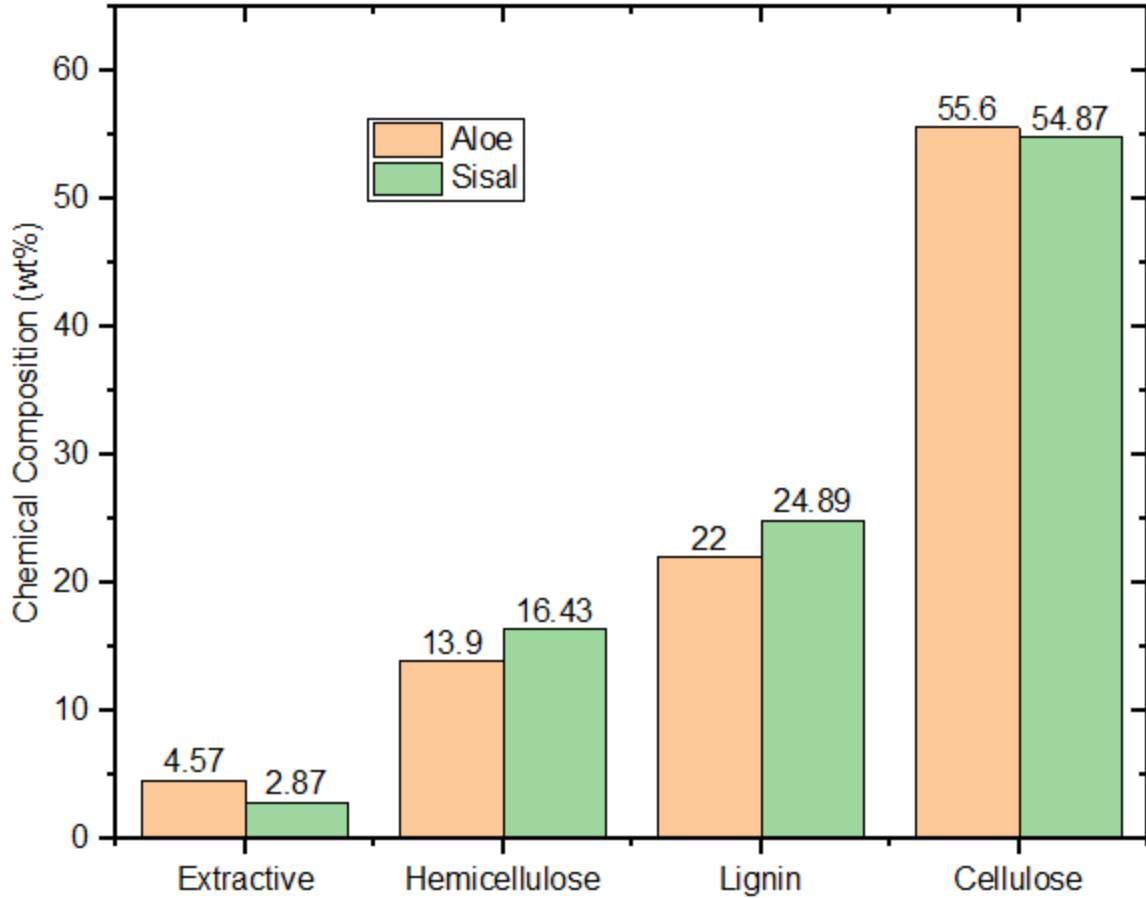


Figure 4.3: Chemical composition of Aloe and Sisal Fibers

According to Thomas (2009), the cellulose, hemicellulose, lignin and extractive content of hardwoods are 43-47, 28-32, 16-24 and 2-8% respectively. The study also revealed that softwoods have a composition of cellulose (40-44%), hemicellulose (25-29%), lignin (26-31%) and extractive (1-5%) contents. Silva et al. (2010) also showed that sisal leaf fibers contain 54-66% cellulose, 12-17% hemicellulose and 7-14% lignin. The results of this work as compared to the literature values are comparatively good because the cellulose and lignin contents are high; thus, the fibers from aloe and sisal stems can serve as alternative sources of wood particles for particleboard production.

## **4.2 PHYSICAL AND MECHANICAL PROPERTIES OF PARTICLE BOARDS**

### **4.2.1 Physical Properties**

#### **4.2.1.1 Moisture Content**

Moisture content of a particleboard is an important property that has determinant impact on properties and uses of the particleboard. Sensible Changes in moisture caused reduction in particle board strength and unreliable life which prevented the wide spread use of particle boards for exterior and structural uses (Halligan,1970). As shown on Table 4.1, moisture content of the particle boards varied from 5.09 % to 9.15% and the average value is 7.4%. The highest moisture content was observed at low pressure and low resin content while the lowest moisture content was observed at high pressure and high resin contents. The variation in moisture content is due to variation in the amount of resin used during production. It may also be due to variation in pressing pressure and environmental exposure after production. According to Ethiopian standard ES ISO 16893( 2018), the moisture content of particle boards can vary from 5 to 14%. Therefore, this result is generally in line with the limits specified in the Ethiopian standards.

Table 4.1: Average moisture contents of the particle boards

Sample No.	Sample Code (A/S Resin P)	Average Air dried mass (g)	Average oven dried mass (g)	Average moisture content (g)	Average Moisture content (%)
1	30 10 175	16.09	14.62	1.46	9.14
2	60 10 175	17.04	15.59	1.45	8.50
3	30 15 175	19.38	18.07	1.31	6.78
4	60 15 175	16.58	15.52	1.06	6.35
5	30 12.5 150	17.41	16.00	1.41	8.10
6	60 12.5 150	18.43	17.25	1.18	6.41
7	30 12.5 200	16.08	15.02	1.06	6.54
8	60 12.5 200	18.39	17.19	1.21	6.70
9	45 10 150	18.82	17.10	1.72	<b>9.15</b>
10	45 15 150	17.34	16.20	1.14	6.56
11	45 10 200	16.73	15.34	1.39	8.22
12	45 15 200	20.44	19.44	1.01	<b>5.09</b>
13	45 12.5 175	17.97	16.53	1.44	7.96
14	45 12.5 175	17.41	16.10	1.31	7.51
15	45 12.5 175	19.29	17.77	1.52	7.93
16	45 12.5 175	18.93	17.53	1.40	7.40
17	45 12.5 175	18.07	16.71	1.36	7.52
				<b>Average</b>	<b>7.40 %</b>

#### 4.2.1.2 Water Absorption and Thickness Swelling

As shown on Table 4.2, the water absorption of the particle boards varied from 60.6% to 84.21% and from 63.74% to 92.18% after 2hrs and 24hrs of immersion respectively. The thickness swelling also varied from 43% to 67.1% and from 51.3% to 79.89% after 2hrs and 24hrs of immersion respectively. The average values for water absorption were 71.75% and 82.15% after 2hrs and 24hrs of immersion respectively and for thickness swelling the average values were 55.85% and 68.38% at their corresponding immersion times. The lowest and highest values for both WA and TS were observed at aloe to sisal ratio of 45 %, resin content of 15% and Pressing pressure of 200 bars and aloe to sisal ratio of 60%, resin content of 10% and Pressing pressure of 175 bars respectively.

The Ethiopian standard (ES ISO 16893, 2018) has no reference value for maximum requirement in water absorption of all grades of particle boards. It also has no reference value for maximum requirement in thickness swelling of general purpose and furniture grade particle boards. But, for load bearing particle boards, the maximum limit in thickness swelling after 24hrs of immersion is 19% with thickness range of 6mm to 13 mm. According to the **European standard EN 312 (2005)**, the maximum values of TS a particle board should have after 2h and 24 h of immersion are **8% and 15%** respectively.

The results of this work for WA and TS as compared to the standards are not satisfactory because there is a high increase from the maximum limits. Thickness swelling and water absorption of the particle boards decreased when the resin content and pressing pressure were increased. As pressure increases, the compaction ratio increases and this decreases the internal void volume which can reduce the migration of water inside the particleboards (Nadir Ayrilmis et al., 2017). As resin content was increased, Water absorption and thickness swelling decreased. This may be due to the cross-linking property of the chemical components of the resin with the hydroxyl groups of aloe and sisal fibers which reduces the hygroscopicity of the boards (Saad & Kamal, 2012). Slight increase in both WA and TS were also observed as the aloe to sisal ratio was increased, this may be due to an increase in the contents of cellulose and hemicellulose that are hydrophilic. Thus particleboards attract water molecule resulting in WA and TS upon immersion in water (Jr et al., 2016).

Table 4.2 : Average results for water absorption and thickness swelling of the boards

Sample No.	Sample Code (A/S Resin P)	Average WA@2hrs (%)	Average WA@24hrs (%)	Average TS@2hrs (%)	Average TS@24hrs (%)
1	30 10 175	80.64	87.43	63.6	75
2	60 10 175	<b>84.21</b>	<b>92.18</b>	<b>67.1</b>	<b>79.89</b>
3	30 15 175	70.05	79.91	48	54.1
4	60 15 175	65.05	66.41	53	67.32
5	30 12.5 150	76.78	87.11	59.73	74.7
6	60 12.5 150	77.19	86.42	60.14	73.97
7	30 12.5 200	69.64	77.53	52.6	65.14
8	60 12.5 200	71.96	83.24	54.9	70.8
9	45 10 150	81.05	87.69	64	75.26
10	45 15 150	73.85	85.12	56.8	72.6
11	45 10 200	82.42	91.14	65.3	78.73
12	45 15 200	<b>60.06</b>	<b>63.74</b>	<b>43</b>	<b>51.3</b>
13	45 12.5 175	69.35	81.73	52.3	64.32
14	45 12.5 175	68.85	79.85	51.8	63.5
15	45 12.5 175	70.22	81.26	53.16	68.81
16	45 12.5 175	66.29	82.76	49.24	56.43
17	45 12.5 175	71.75	83.03	54.7	70.6

## **4.2.2 Mechanical Properties**

### **4.2.2.1 Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)**

Modulus of elasticity in bending and bending strength are the two important properties of particle board that should be studied thoroughly. Bending strength is the measure of load necessary to break a board in bending and it is very important property that controls the usability of a particleboard as a structural building element. Modulus of elasticity in bending is a measure of resistance offered by the board to the deflection under a load and is an indication of the stiffness of the board. Generally, boards tend to be more brittle when the MOE value is high and tend to be more ductile or flexible when the MOE value is low (Yang et al., 2003).

The measured values of MOR and MOE in this experiment are shown in Table 4.3 below. As observed from the Table, the results of this experiment range from 9.832-12.42 Mpa and from 1551.32-1830.12 Mpa for MOR and MOE respectively. These ranges are indications of significant differences among the particleboards produced at different operating conditions. The average results are 11.267 Mpa for MOR and 1686.34 Mpa for MOE. The maximum values of MOR and MOE for the particle boards were 12.42 and 1830.12 Mpa respectively. These maximum values were observed at aloe to sisal ratio of 45 %, resin content of 12.5% and Pressing pressure of 175 bars. The minimum value for MOR (9.832 Mpa) was observed at aloe to sisal ratio of 45%, resin content of 10% and Pressing pressure of 150 bars and the minimum value for MOE (1551.32 Mpa) was observed at aloe to sisal ratio of 60 %, resin content of 10% and Pressing pressure of 175 bars. Based on the Ethiopian standard (ES ISO 16893, 2018), 10.5, 11 and 15 Mpa are the minimum requirements of MOR for general purpose, furniture grade and load bearing particle boards respectively with thickness of 6 to 13 mm. As observed from the MOR results, about 88.23% of the particle boards satisfied the minimum requirement for general purpose particle boards.

Table 4.3: Final average result for MOR and MOE tests

Sample No.	Sample Code (A/S Resin P)	Average thickness (cm)	Support separation (cm)	Average moisture content (%)	Average density (g/cm <sup>3</sup> )	MOR (Mpa)	MOE (Mpa)
1	30 10 175	1.10	15	9.14	0.68	10.455	1562.845
2	60 10 175	1.19	15	8.50	0.64	10.71	<b>1551.32</b>
3	30 15 175	0.91	15	6.78	0.77	11.517	1599.89
4	60 15 175	0.97	15	6.35	0.74	11.574	1582.18
5	30 12.5 150	1.03	15	8.10	0.72	10.068	1613.75
6	60 12.5 150	1.00	15	6.41	0.78	10.37	1607.71
7	30 12.5 200	0.96	15	6.54	0.75	10.75	1630.95
8	60 12.5 200	1.10	15	6.70	0.68	10.863	1625.863
9	45 10 150	1.12	15	9.15	0.66	<b>9.832</b>	1604.15
10	45 15 150	1.06	15	6.56	0.69	11.148	1722.574
11	45 10 200	1.02	15	8.22	0.77	10.9545	1734.73
12	45 15 200	0.94	15	5.09	0.76	11.75	1751.75
13	45 12.5 175	0.99	15	7.96	0.71	12.23	1801.67
14	45 12.5 175	1.02	15	7.51	0.72	<b>12.42</b>	<b>1830.12</b>
15	45 12.5 175	1.01	15	7.93	0.71	12.27	1817.31
16	45 12.5 175	1.05	15	7.40	0.713	12.3	1824.34
17	45 12.5 175	1.03	15	7.52	0.716	12.34	1806.27

#### **4.2.2.2 Internal Bond (IB)**

Internal bond is a measure of bonding strength between the individual particles within the board and it indicates the force required to pull apart a board in a direction perpendicular to the surface. As shown in Table 4.4, the maximum and minimum values for IB of the particle boards were 0.505 MPa and 0.338 MPa respectively and the average value was 0.417 MPa. The minimum value for IB was observed at aloe to sisal ratio of 45%, resin content of 10% and Pressing pressure of 150 bars and the maximum value for IB was observed at aloe to sisal ratio of 45 %, resin content of 12.5% and Pressing pressure of 175 bars. According to the Ethiopian standard (ES ISO 16893, 2018), 0.28, 0.40 and 0.40 Mpa are the minimum requirements of IB for general purpose, furniture grade and load bearing particle boards respectively with thickness of 6 to 13 mm. All the particle boards tested met the minimum requirement of IB stated on the Ethiopian standards for general purpose.

Table 4.4: Final average result for IB tests

Sample No.	Sample Code (A/S Resin P)	Mass (g)	Average Thickness (cm)	Volume(cm <sup>3</sup> )	Average moisture content (%)	Average density (g/cm <sup>3</sup> )	IB (Mpa)
1	30 10 175	13.66	0.84	21.08	9.14	0.65	0.362
2	60 10 175	13.09	0.84	20.94	8.50	0.63	0.369
3	30 15 175	14.57	0.79	19.77	6.78	0.74	0.425
4	60 15 175	14.96	0.82	20.61	6.35	0.73	0.439
5	30 12.5 150	15.65	0.91	22.69	8.10	0.69	0.343
6	60 12.5 150	16.05	0.84	21.09	6.41	0.76	0.345
7	30 12.5 200	16.51	0.90	22.56	6.54	0.73	0.361
8	60 12.5 200	13.12	0.78	19.54	6.70	0.67	0.371
9	45 10 150	15.18	0.97	24.18	9.15	0.63	<b>0.338</b>
10	45 15 150	12.95	0.77	19.31	6.56	0.67	0.419
11	45 10 200	14.79	0.80	19.92	8.22	0.74	0.39
12	45 15 200	15.05	0.81	20.32	5.09	0.74	0.431
13	45 12.5 175	14.09	0.84	20.89	7.96	0.67	0.502
14	45 12.5 175	13.93	0.81	20.18	7.51	0.69	0.497
15	45 12.5 175	13.52	0.77	19.21	7.93	0.70	<b>0.505</b>
16	45 12.5 175	14.57	0.86	21.51	7.40	0.68	0.503
17	45 12.5 175	14.05	0.81	20.36	7.52	0.69	0.494

### **4.3 STATISTICAL ANALYSIS OF THE MAIN FACTORS AFFECTING PARTICLE BOARD PRODUCTION**

In order to investigate the effect of different processing variables on the quality of particle boards produced, the experimental design chosen was Box Behnken design (BBD). The main processing variables were aloe to sisal fiber ratio, resin content, and pressing pressure while the response variables studied were modulus of rupture (MOR) and internal bond (IB) of the boards and design expert 11 was used for analysis of Variance (ANOVA).

#### **4.3.1 Analysis of Variance (ANOVA) For Modulus of Rupture (MOR) and Internal Bond (IB)**

The ANOVA for MOR and IB are shown in Tables 4.5 and 4.6 shown below. This was done to investigate the effect of aloe to sisal ratio, resin content and pressing pressure on modulus of rupture and internal bond strength of the boards. As shown from the Tables, the Model F-values of 140.23 and 308.55 for MOR and IB respectively imply the models are significant. There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, BC, A<sup>2</sup>, B<sup>2</sup>, C<sup>2</sup> are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The Lack of Fit F-values of 2.74 and 1.24 implies the Lack of Fits are not significant relative to the pure errors. There is a 17.72% chance for MOR and 40.43 % chance for IB that a Lack of Fit F-value this large could occur due to noise. Non-significant lacks of fits are good -- we want the models to fit.

Table 4.5: ANOVA for quadratic model of MOR

**Response 1: MOR**

Source	Sum of Squares	df	Mean Square	F-value	p-value	
<b>Model</b>	11.62	9	1.29	140.23	< 0.0001	Significant
A-Ratio(A/S)	0.0661	1	0.0661	7.18	0.0316	Significant
B-Amount of resin	2.04	1	2.04	221.31	< 0.0001	Significant
C-Pressing pressure	1.05	1	1.05	114.14	< 0.0001	Significant
AB	0.0098	1	0.0098	1.06	0.3365	Not Significant
AC	0.0089	1	0.0089	0.9699	0.3575	Not Significant
BC	0.0677	1	0.0677	7.36	0.0301	Significant
A <sup>2</sup>	2.89	1	2.89	313.66	< 0.0001	Significant
B <sup>2</sup>	0.7421	1	0.7421	80.60	< 0.0001	Significant
C <sup>2</sup>	3.97	1	3.97	431.22	< 0.0001	Significant
<b>Residual</b>	0.0645	7	0.0092			
Lack of Fit	0.0434	3	0.0145	2.74	0.1772	not significant
Pure Error	0.0211	4	0.0053			
<b>Cor Total</b>	11.68	16				

Table 4.6: ANOVA for quadratic model of IB

**Response 2: IB**

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.0635	9	0.0071	308.55	< 0.0001	Significant
A-Ratio aloe to sisal (A/S)	0.0001	1	0.0001	6.10	0.0429	Significant
B-Resin content	0.0082	1	0.0082	356.52	< 0.0001	Significant
C-Pressing Pressure	0.0015	1	0.0015	63.75	< 0.0001	Significant
AB	0.0000	1	0.0000	0.5986	0.4644	Not Significant
AC	0.0000	1	0.0000	0.6996	0.4305	Not Significant
BC	0.0004	1	0.0004	17.49	0.0041	Significant
A <sup>2</sup>	0.0209	1	0.0209	913.11	< 0.0001	Significant
B <sup>2</sup>	0.0040	1	0.0040	176.07	< 0.0001	Significant
C <sup>2</sup>	0.0235	1	0.0235	1029.40	< 0.0001	Significant
<b>Residual</b>	0.0002	7	0.0000			
Lack of Fit	0.0001	3	0.0000	1.24	0.4043	not significant
Pure Error	0.0001	4	0.0000			
<b>Cor Total</b>	0.0637	16				

### 4.3.1.1 Model Adequacy Checking

As shown in Tables 4.7, the values of regression coefficients ( $R^2$ ) which quantitatively evaluates the correlation between the experimental data and the predicted response are 0.9945 and 0.9975. Since the  $R^2$  values are closer to 1.0 it indicates that the regression lines perfectly fit the data. This implies that 99.45% of the total variation in the modulus of rupture and 99.75% of the total variation in the internal bond were attributed to the experimental variables studied.

The Predicted  $R^2$  of 0.9378 and 0.9785 are also in reasonable agreement with the Adjusted  $R^2$  of 0.9874 and 0.9943 respectively; i.e. the differences are less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratios of 32.450 and 43.9293 indicate an adequate signal. These models can be used to navigate the design spaces.

Table 4.7: Fit statistics of the models for MOR and IB

Std. Dev.	0.0960	$R^2$	0.9945	Std. Dev.	0.0048	$R^2$	0.9975
Mean	11.27	Adjusted $R^2$	0.9874	Mean	0.4173	Adjusted $R^2$	0.9943
C.V. %	0.8516	Predicted $R^2$	0.9378	C.V. %	1.15	Predicted $R^2$	0.9785
		Adeq Precision	32.4500			Adeq Precision	43.9293

The final equations in terms of the coded factors are given as:

$$\text{MOR} = +12.31 + 0.0909 * A + 0.5047 * B + 0.3624 * C - 0.0495 * AB - 0.0473 * AC - 0.1301 * BC - 0.8282 * A^2 - 0.4198 * B^2 - 0.9711 * C^2 \dots\dots\dots 4.1$$

$$\text{IB} = 0.5002 + 0.004175 * A + 0.031925 * B + 0.0135 * C + 0.00185 * AB + 0.002 * AC - 0.01 * BC - 0.070425 * A^2 - 0.030925 * B^2 - 0.074775 * C^2 \dots\dots\dots 4.2$$

The final equations in terms of the actual factors are also given as:


$$\text{MOR} = -64.84131 + 0.375883 * \text{Ratio (A/S)} + 2.30487 * \text{Amount of resin} + 0.589988 * \text{Pressing pressure} - 0.001320 * \text{Ratio (A/S)} * \text{Amount of resin} - 0.000126 * \text{Ratio(A/S)} * \text{Pressing pressure} - 0.002082 * \text{Amount of resin} * \text{Pressing pressure} - 0.003681 * \text{Ratio(A/S)}^2 - 0.067170 * \text{Amount of resin}^2 - 0.001554 * \text{Pressing pressure}^2 \dots\dots\dots 4.3$$

$$\begin{aligned}
 IB = & -5.11762 + 0.0268983 * \text{Ratio aloé to sisal (A/S)} + 0.16225 * \text{Resin content} + 0.044174 * \\
 & \text{Pressing Pressure} + 4.93333e-05 * \text{Ratio aloé to sisal (A/S)} * \text{Resin content} + 5.33333e-06 * \\
 & \text{Ratio aloé to sisal (A/S)} * \text{Pressing Pressure} - 0.00016 * \text{Resin content} * \text{Pressing Pressure} - \\
 & 0.000313 * \text{Ratio aloé to sisal (A/S)}^2 - 0.004948 * \text{Resin content}^2 + -0.00011964 * \text{Pressing} \\
 & \text{Pressure}^2 \dots\dots 4.4
 \end{aligned}$$

The normal probability plots shown in Figures 4.4 and 4.5, indicate the residuals following by the normal % probability distribution, in the case of this experimental data the points in the plots shows fitted to the straight line in the Figure, this shows that the quadratic polynomial models satisfies the assumptions analysis of variance (ANOVA) i.e. the error distribution is approximately normal.

Design-Expert® Software

MOR

Color points by value of MOR:  
 9.832  12.42

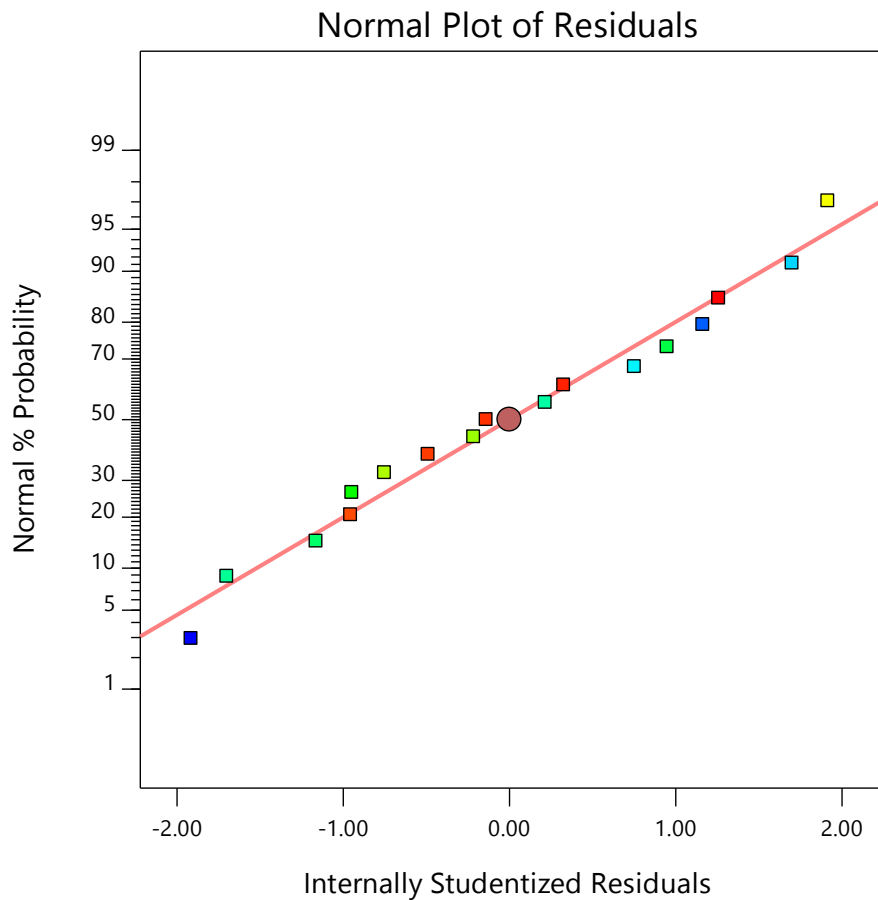


Figure 4.4: Normal probability plot of Residuals for MOR

IB

Color points by value of

IB:

0.338 0.505

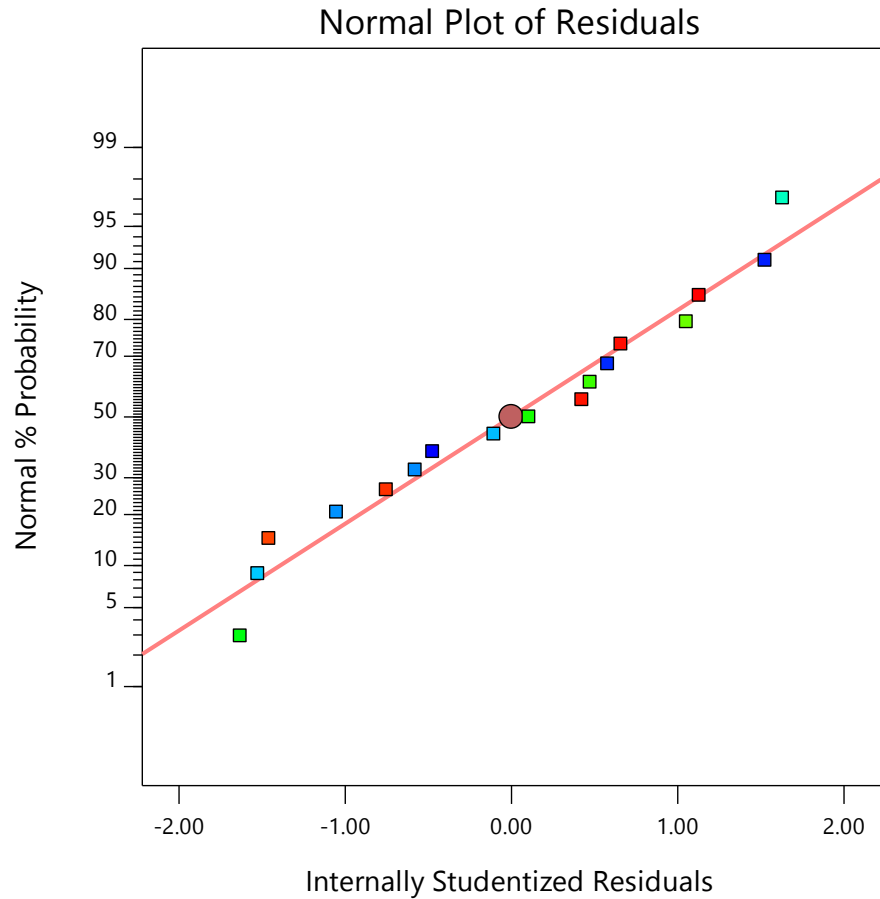


Figure 4.5: Normal probability plot of residuals for IB

The plot of predicted versus actual value is also important criteria to check the adequacy of the model. If the scatter of the plot lies almost on the diagonal line, this shows that the model is designed very well i.e the experimental data is closely related to the data predicted from the model. As shown on Figure 4.6 and 4.7, almost all of the data points are close to the lines of perfect fit. This demonstrates that the models were described well i.e. the regression model equations provided accurate description of the experimental data under the specified conditions.

MOR

Color points by value of

MOR:

9.892 12.42

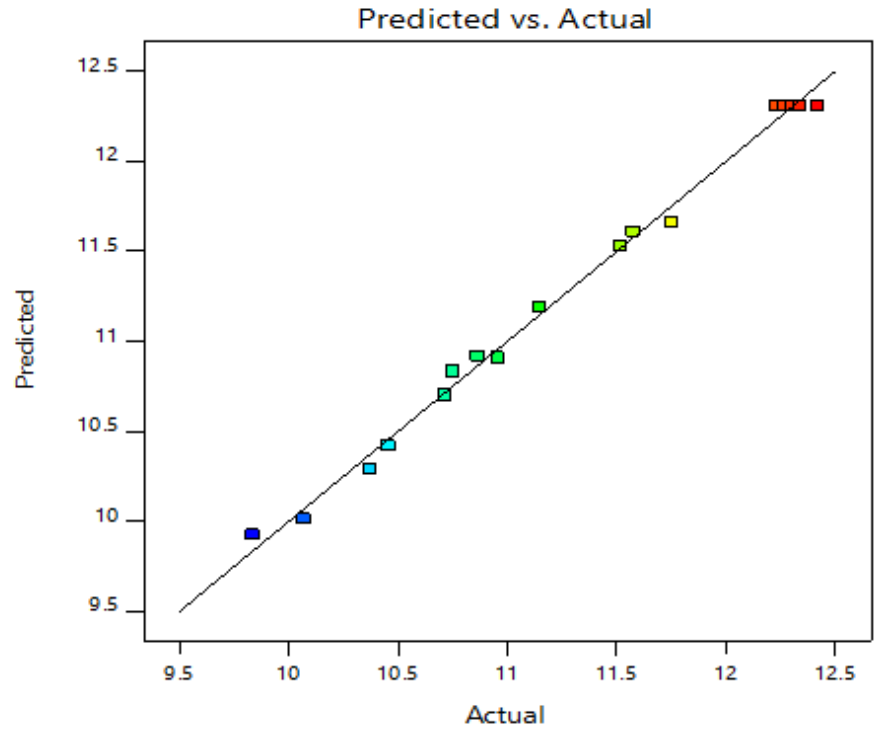


Figure 4.6: Predicted versus Actual plot of MOR

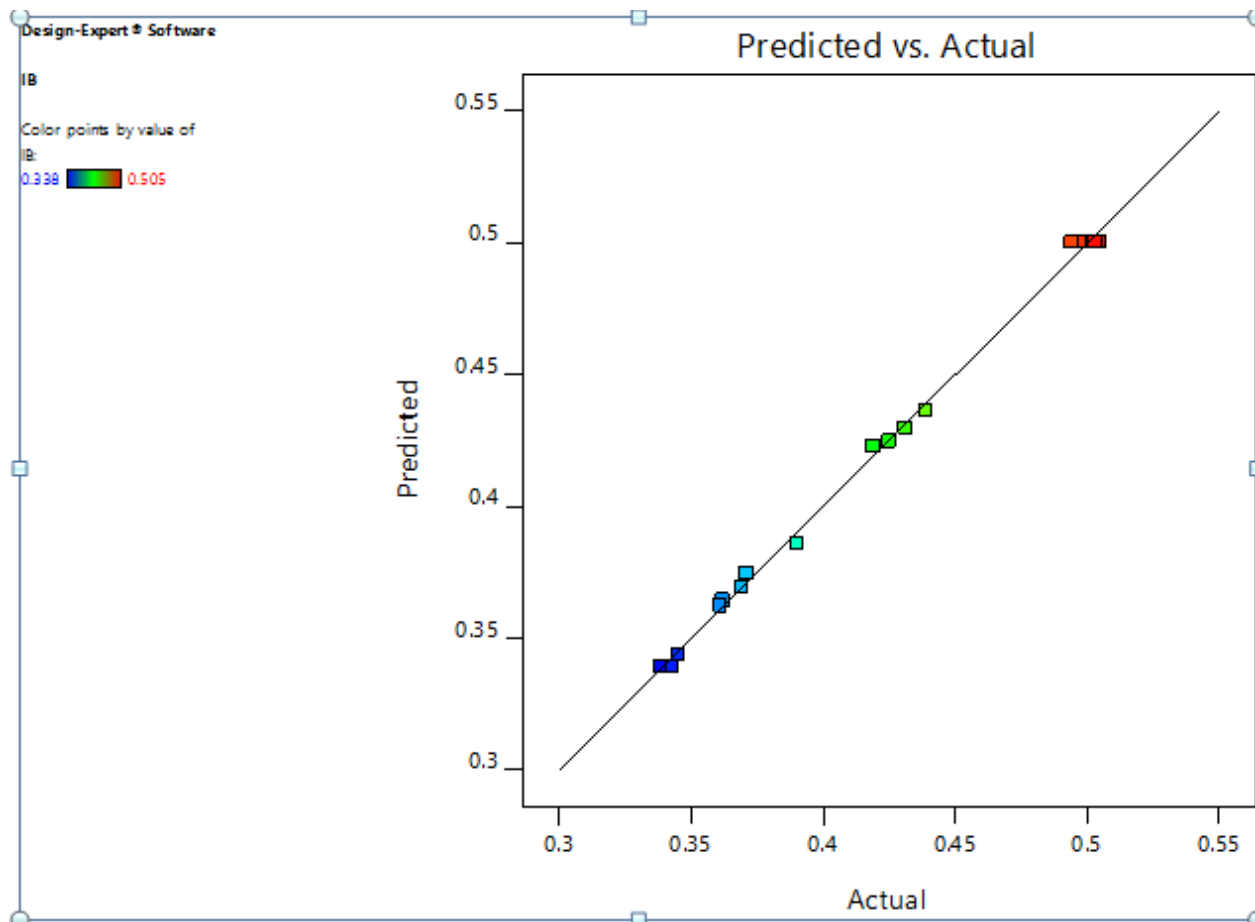


Figure 4.7: Predicted versus Actual plot of IB

## 4.4 EFFECTS OF THE PROCESSING CONDITIONS ON QUALITY OF THE BOARD

### 4.4.1 Effects of Single Factor

#### 4.4.1.1 Effect of Aloe to Sisal Fiber Ratio

The effects of aloe to sisal ratio on MOR and IB of the particle boards are shown Figures 4.8 and 4.9 respectively. As observed from the Figures, maintaining the pressing pressure and resin content constant respectively at 175 bar and 12.5% and changing the aloe to sisal ratio from 30% to 45% rapidly increased the value of MOR and IB. However, when this ratio was increased in the range of 45 % to 60%; the MOR and IB were observed decreasing. The decrease in mechanical properties of the particle boards may be due to an increase in extractive content of the mixture as the aloe fibers have higher extractive content than sisal fibers. It also may be due

to increase in pore amounts when aloe fibers were increased because an increase in a less denser fibers increases the voids which are the causes for fracture in the particleboard. The other reason that could be is an increase in moisture content of the mat. As the ratio of aloe to sisal is increased, the moisture content in the mat also increases. This is because the moisture content of aloe fibers were higher than sisal fibers. With increase in temperature of outer layers of the mat beyond 100 °C, heating results in vaporization of water. Therefore, more water in the mat will be converted into steam inside the mould. The rise in steam which rise steam pressure may cause expansion in particleboards as well as cracks (Ota & Okamoto, 2015).

**Design-Expert® Software**

Factor Coding: Actual

**MOR (Mpa)**

● Design Points

-- 95% CI Bands

Std # 15 Run # 4

X1 = A: Ratio(A/S) = 45.00

**Actual Factors**

B: Amount of resin = 12.50

C: Pressing pressure = 175.00

Y = MOR (Mpa) = 12.27

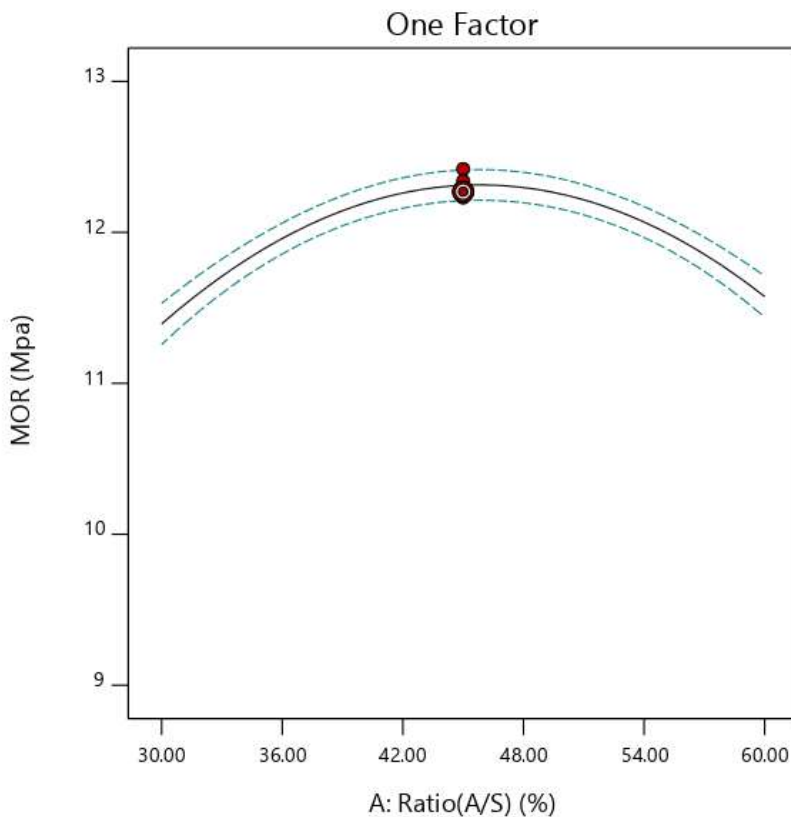


Figure 4.8: Effect of aloe to sisal ratio on MOR

Design-Expert® Software  
Factor Coding: Actual

IB (Mpa)

● Design Points  
-- 95% CI Bands

Std # 13 Run # 4  
X1 = A: Ratio(A/S) = 45

Actual Factors

B: Amount of resin = 12.5  
C: Pressing pressure = 175

Y = IB (Mpa) = 0.502  
CI = (0.418835, 0.432365)

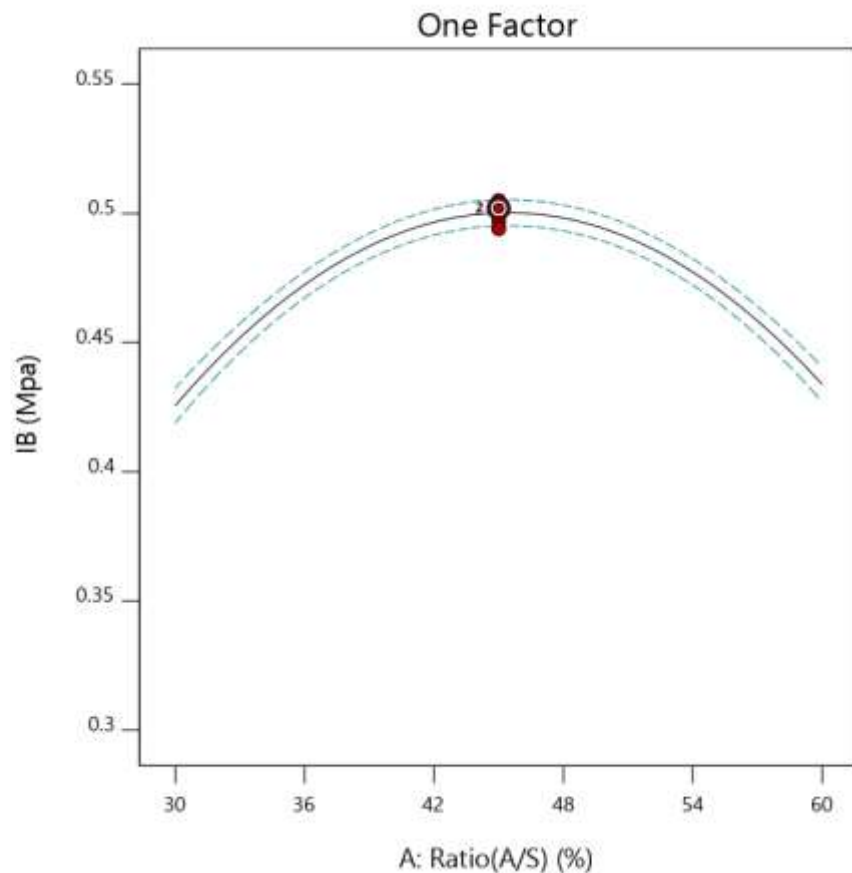


Figure 4.9: Effect of aloe to sisal ratio on IB

#### 4.4.1.2 Effect of Resin Content

It has been indicated that resin content is an important factor in improving the strength properties and dimensional stability of particleboards. According to Hong et al.( 2017) and (Nadir Ayrilmis et al., 2012), an increase in resin content increased the MOR,MOE and IB of the particle boards. But as resin content increased beyond the optimum value, the MOR value started to decrease because the agglomeration of wood particles at higher loadings of matrix had decreased the reinforcement-matrix bond hence lowering the magnitude of MOR(Ishak et al., 2010).

In this study, the effects of resin content on MOR and IB of the particle boards are shown Figures 4.10 and 4.11 respectively. These effects were investigated by varying the resin content while keeping the other two variables i.e aloe to sial ratio and pressing pressure constant in order

to avoid the interaction effects caused due to variation. These variables were set at their optimum values and the effects were visualized using plot as indicated in Figures 4.10 and 4.11.

As shown in the Figures, the modulus of rupture and internal bond strength of the boards increased gradually with rise in resin content in the range 10% to 12.5% and then remained almost constant in the range 12.5% to 15% with only slight decrease. This may be due to the high moisture content in the particle boards which can demolish the adhesive linkages(Nemli et al., 2007). It may also be due to decrease in viscosity of the resin which reduces the flow rate inside the mat.

Kimoto et al.( 1964) produced particleboards by using urea formaldehyde resin at 8%, 10% and 15% and the study concluded that at 15% there is only slight improvement in strength properties % as compared to 10 % urea formaldehyde. Lehmann (1970) investigated the resin efficiency of UF at 2, 4 and 8 % resin contents for particle board production .According to the study, only a small increase in MOR and MOE and substantial increase in IB when adhesive content increased from 4% to 8%.There are no consistent data available which indicate a particular adhesive level is optimum(Wong, 2012).

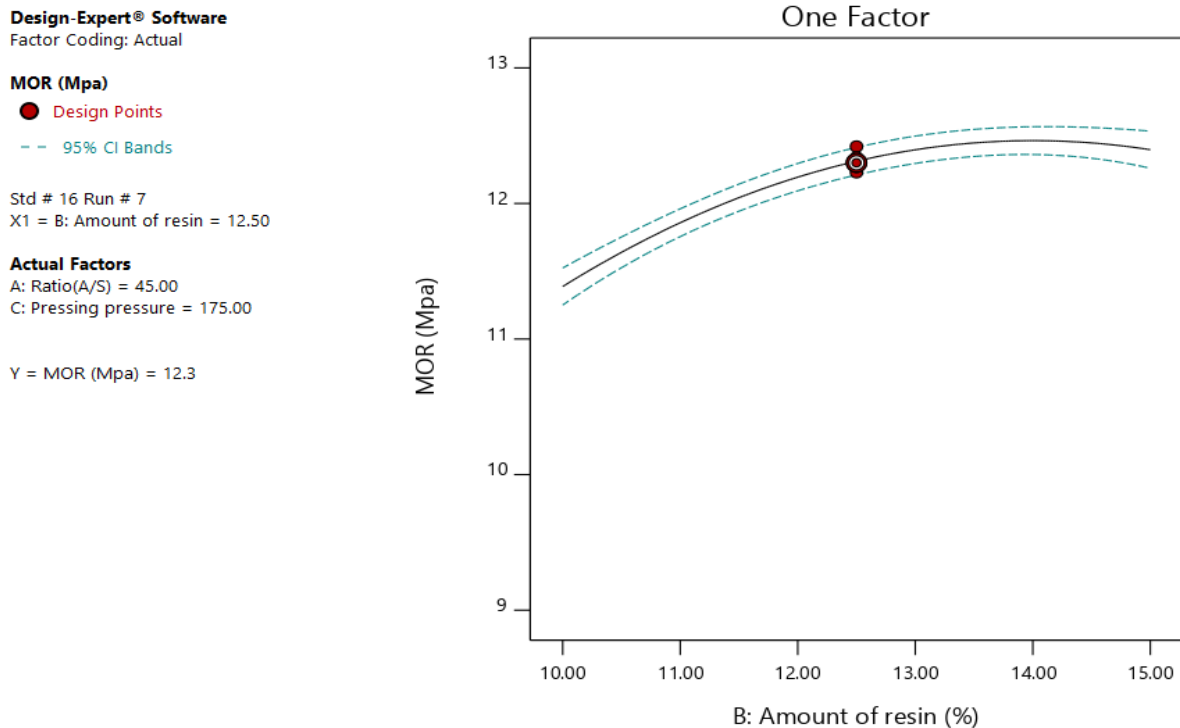


Figure 4.10: Effects of resin content on MOR

Design-Expert® Software  
 Factor Coding: Actual

**IB (Mpa)**  
 ● Design Points  
 - - 95% CI Bands

Std # 13 Run # 4  
 X1 = B: Amount of resin = 12.5

**Actual Factors**  
 A: Ratio(A/S) = 45  
 C: Pressing pressure = 175

Y = IB (Mpa) = 0.502  
 CI = (0.430585, 0.444115)

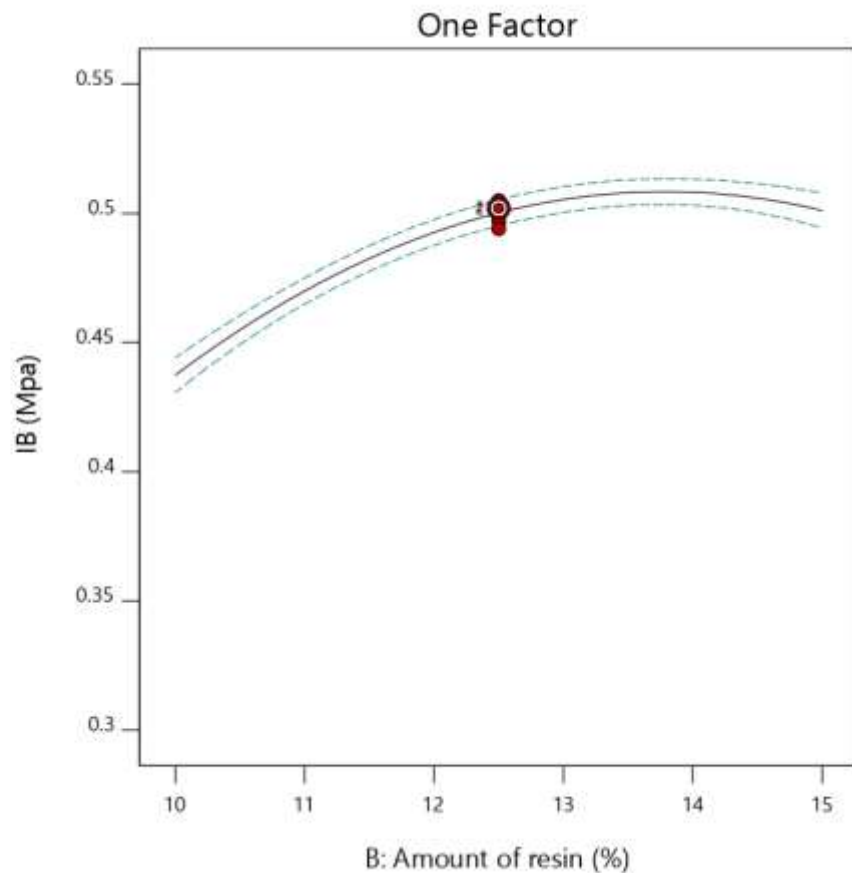


Figure 4.11: Effects of resin content on IB

#### 4.4.1.3 Effect of Pressing Pressure

Pressing pressure is an important parameter to assess changes of resin impregnation among particles and the change of apparent density of particleboard. Figure 4.12 and 4.13 showed that maintaining the Aloe to sisal ratio and resin content constant respectively at 45% and 12.5% and changing the pressing pressure from 150 to 175 bars rapidly increased the value of MOR and IB. This may be due to an increase of the board density as the compaction ratio is increased. This may also reflect that the spread of the binder is greater with increasing molding pressure and that particles are bonded strongly. However, when the pressure was increased in the range of 175 to 200 bars; the MOR and IB were observed rapidly decreasing. This may be due to the higher stress levels that cause plastic deformation on the cells of the wood that reduce the mechanical properties of the wood (Popescu, 2017).

Design-Expert® Software  
Factor Coding: Actual

**MOR (Mpa)**

- Design Points
- 95% CI Bands

Std # 16 Run # 7  
X1 = C: Pressing pressure = 175.00

**Actual Factors**

A: Ratio(A/S) = 45.00  
B: Amount of resin = 12.50

Y = MOR (Mpa) = 12.3

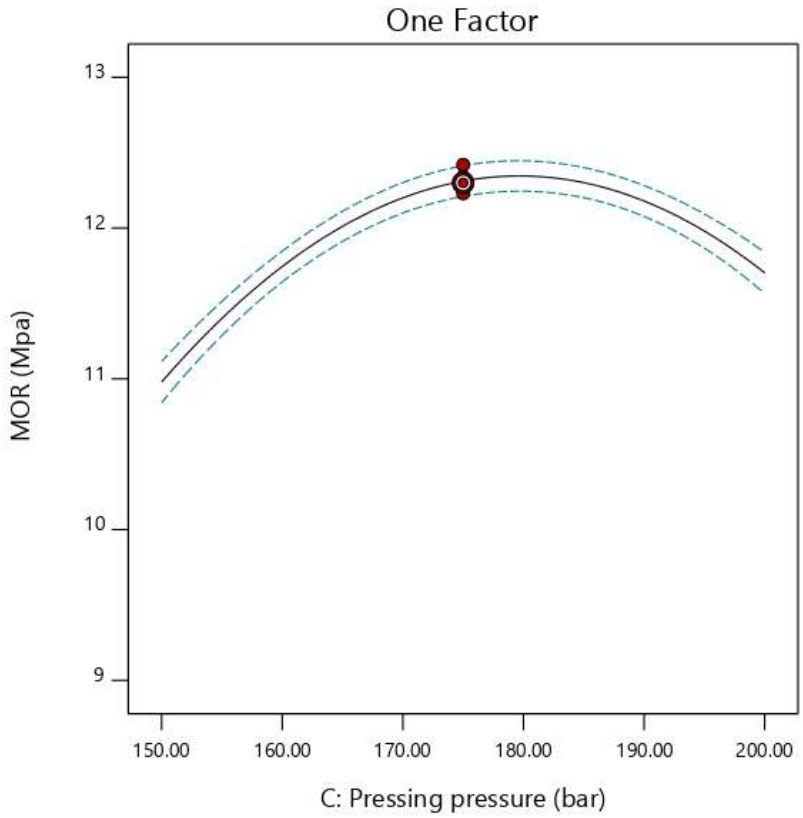


Figure 4.12: Effects of Pressing pressure on MOR

Design-Expert® Software  
Factor Coding: Actual

IB (Mpa)

● Design Points  
-- 95% CI Bands

Std # 13 Run # 4  
X1 = C: Pressing pressure = 175

Actual Factors

A: Ratio(A/S) = 45  
B: Amount of resin = 12.5

Y = IB (Mpa) = 0.502  
CI = (0.40521, 0.41874)

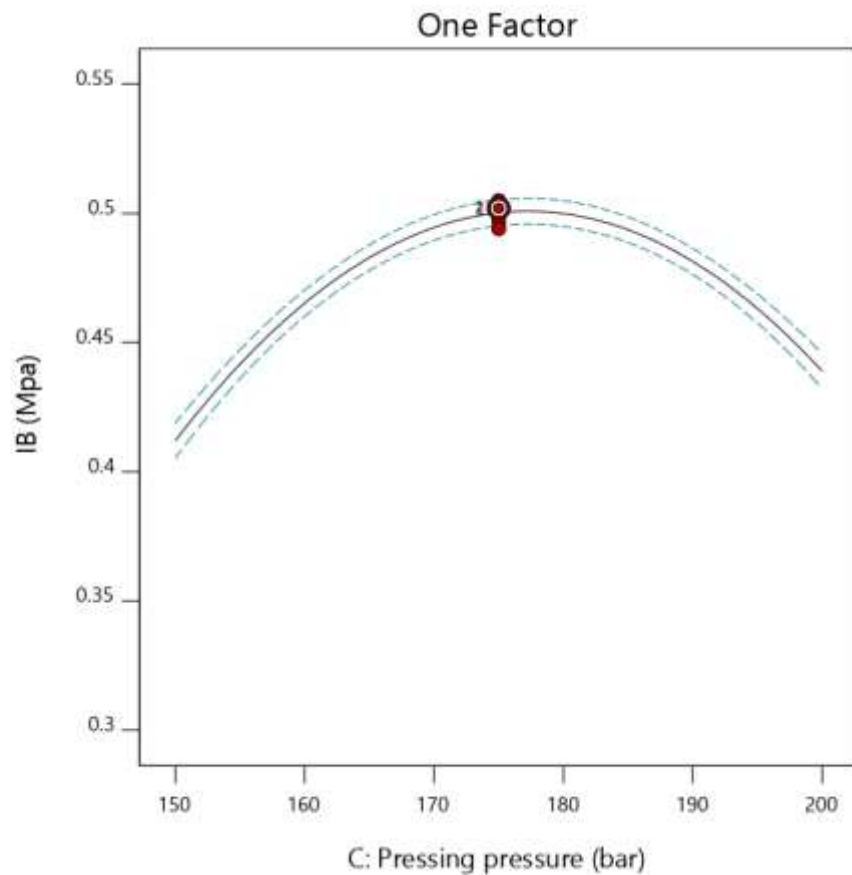


Figure 4.13: Effects of pressing pressure on IB

#### 4.4.2 Interaction Effects of Factors

The possible interactions that can affect MOR and IB are between aloe to sisal ratio and resin content, aloe to sisal ratio and pressing pressure and between resin content and pressing pressure. Figures 4.14 and 4.15 and Tables 4.5 and 4.6 from analysis of variance, demonstrate the significant interaction effects that exist between the processing variables. As observed from the Figures and Tables, the only significant interaction that affects both modulus of rupture and internal bond is between resin content and pressing pressure. In this study, both the modulus of rupture and internal bond increased with increase in both resin content and pressing pressure.

Nayeri et al.(2014) investigated the effect of resin content and pressing pressure on the Performance Properties of rubber wood-kenaf composite board Panel. According to the study,

interaction between resin content and pressure, have increased the MOR and IB of the particle boards with increase in both parameters.

Design-Expert® Software  
Factor Coding: Actual

**MOR (MPa)**  
 ● Design points above predicted value  
 ○ Design points below predicted value  
 9.832 12.42

X1 = B: Resin content  
X2 = C: Pressing Pressure

**Actual Factor**  
A: Ratio alou to sisal (A/S) = 45

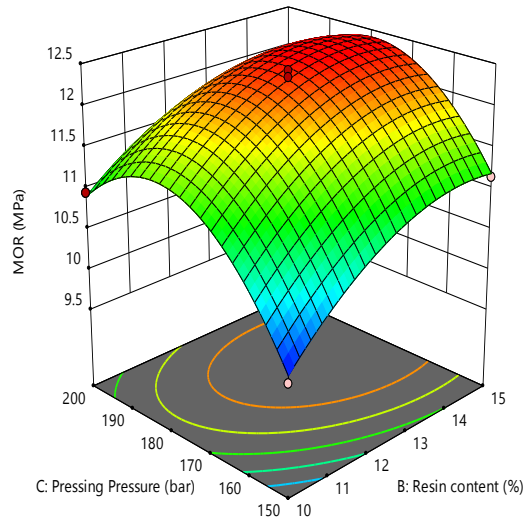


Figure 4.14: Interaction effect of resin content and pressing pressure on MOR

Design-Expert® Software  
Factor Coding: Actual  
**IB (MPa)**  
 0.320 0.490  
 X1 = B: Resin content  
 X2 = C: Pressing Pressure  
**Actual Factor**  
 A: Ratio alou to sisal (A/S) = 45

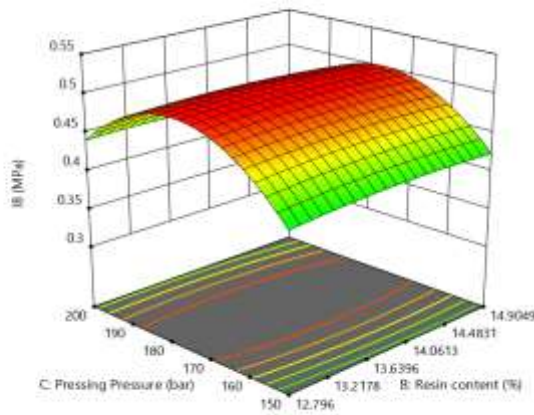


Figure 4.15: Interaction effect of resin content and pressing pressure on IB

## 5 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 CONCLUSIONS

In this study, the potential for using aloe and sisal stem fibers as a raw material for non-wood bio-based particleboard was investigated based on the physical and mechanical properties test of particle board produced from milled blend of aloe and sisal stem fibers and Urea- formaldehyde resin.

This study also investigated the effects of the Aloe to sisal ratio, resin content and pressing pressure on MOR and MOE of the particleboards. The results of the analysis showed that aloe to sisal ratio, resin content and pressing pressure were the most important factors which affect MOR and MOE particleboards. An increase in aloe to sisal ratio from 30% to 45% rapidly increased the value of MOR and IB. But, further increase of this ratio from 45 % to 60% decreased the MOR and IB of the particleboards. The possible reasons for the decrease could be increase in one or all of extractive content, pore size and moisture content. The MOR and IB of the boards also showed gradual increase with increase in resin content in the range 10% to 12.5% and then remained almost constant in the range 12.5% to 15% with only slight decrease. This could be due to high moisture content in the particle boards which can demolish the adhesive linkages and/or increase in viscosity of the resin which reduces the flow rate inside the mat. Similarly, increase in pressing pressure from 150 to 175 bar rapidly increased the value of MOR and IB. But, with further increase of pressing pressure up to 200 bar; the MOR and IB were observed rapidly decreasing. This could be due to the higher stress levels that cause plastic deformation on the cells of the wood that reduce the mechanical properties of the wood

The minimum values for mechanical properties of the particleboards, MOR, IB and MOE, found in this work are in line with the Ethiopian standards requirement for general purpose use. But, the physical properties like WA and TS which need further investigation did not satisfy the maximum limit set by the standard. WA and TS of the boards were slightly affected by the aloe to sisal ratio but they were highly affected with resin content and pressing pressure. Based on the results of this work, resin content and pressing pressure were the most important factors for production of good quality particleboards. The mechanical and physical properties of the particle boards were highly dependent on these factors. Therefore, too much focus should be made on the situation of these factors while producing particleboards of desired quality.

The chemical composition analysis of the aloe and sisal fibers also showed high similarity with fibers of other non-woody and woody lingo-cellulosic source materials. This finding together with the acceptable mechanical properties of the particleboards produced from blend aloe and sisal stem fibers, proved that utilization of these fibers for production of particle boards is good choice which should not be ignored. Some of the importance of this work are; cost minimization, environmental rehabilitation, biodiversity conservation and reduction in global warming.

## 5.2 RECOMMENDATIONS

The following recommendations are made based on the general review of particleboard production from different raw materials and different operating parameters as well as the findings of this research.

- Uniformity of the aloe and sisal fiber blend and resin mixture is an important factor during particleboard production because it provides an improved bond strength between fibers and effective stress transfer from fiber to fiber. Therefore, automatic mixing equipment should be used to ensure uniform distribution of components of the mixture.
- In this study, the pre-pressed mats were heated manually on electric heater before transferring to cold hydraulic press for final pressing. This process is not effective in terms of temperature control and heat transfer from surface layers to the core layers of the particleboards as it reduces the effectiveness of the resin curing. Thus, hot hydraulic press should be used to avoid such problems.
- The water absorption and thickness swelling of the particle boards were not consistent with reference values in the Ethiopian standards. In order to solve this, the spring back effect should be decreased by reducing the density of particle boards. The final pressure load applied during pressing should not be released quickly in order to prevent backward movement of the particles.
- Optimization of the blend ratio, resin content and pressing pressure is an important for finding the appropriate conditions to improve the mechanical and physical properties of the particleboard. Therefore, Optimization of these pressing parameters should be done on future work.
- The effects of pressing temperature and press time on the physical and mechanical properties of particleboards are not investigated in this work. Further studies should be done on future work.
- Utilization of wood chips for particle board manufacture is uneconomical and it causes depletion in forests throughout the world. There is an increasing trend of using alternative sources such as those investigated in this study. Therefore, governmental authorities should implement laws that enforce the populations to be aware of the status of aloe and sisal plants on their environment and increase cultivation of these plants. These plants are good choice for environmental rehabilitation; resource conservation and protection

because they can be cultivated in small areas, do not need too much water and easily grow at any part of the world.

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## APPENDICES

### APPENDIX A: Proximate Analysis of Aloe and Sisal Fibers

Table A.1: Ash content of aloe and sisal fibers

	Aloe fiber			Sisal fiber		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
Weight of empty crucible(g), Wc	28.53	28.69	28.21	20.89	20.51	23.43
Weight of wood powder(g) , W1	2.00	2.00	2.00	2.00	2.00	2.00
wight of crucible with ash(g), Wf	28.60	28.75	28.31	20.91	20.53	23.44
Weight of ash(g), W2=Wf-Wc	0.07	0.06	0.11	0.02	0.02	0.02
Ash content(%), AC(%)=(W2/W1)*100	3.54	3.01	5.25	0.99	1.03	0.80
Average Ash content(%)	3.93			0.94		

Table A.2: Moisture content of aloe and sisal fibers

	Aloe fiber			Sisal fiber		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
Weight of air dry sample(g) ,Ws	2.00	2.00	2.00	2.00	2.00	2.00
Weight of air dry sample with crucible(g) ,Wi	36.76	34.86	35.28	36.37	38.41	36.14
Weight of oven dry sample with crucible(g) ,Wf	36.65	34.77	35.20	36.30	38.32	36.04
Moisture content(g), MC=W <sub>i</sub> -W <sub>f</sub> =mc	0.11	0.10	0.08	0.08	0.08	0.09
Moisture content(%), MC(%)=(mc/W <sub>s</sub> )*100	5.36	4.83	4.22	3.80	4.09	4.71
Average moisture content (%)	4.80			4.20		

## APPENDIX B: Chemical Composition Analysis of Aloe and Sisal Fibers

Table B.1: Extractive Content of Aloe and Sisal Fibers

	Aloe fiber			Sisal fiber		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
Weight of empty crucible(g), $e_c$	34.571	32.913	35.8362	51.5814	45.8379	47.4702
weight of dry biomass before, $e_1$	5	5	5	5	5	5
wight of crucible with extracted wood residue(g), $e_f$	39.413	37.595	40.627	56.4401	50.718	52.3015
weight of dry biomass after extraction , $e_2=e_f-e_c$	4.842	4.682	4.7908	4.8587	4.8801	4.8313
Extractive content (%), $EC(\%)=(e_1-e_2)/e_1*100$	3.16	6.36	4.184	2.826	2.398	3.374
Average extractive content (%),Ave EC(%)	4.57			2.87		

Table B.2: Hemicellulose Content of Aloe and Sisal Fibers

	Aloe fiber			Sisal fiber		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
Weight of empty crucible(g), $h_c$	53.389	35.4425	54.4514	24.5129	27.8475	23.9175
weight of dry biomass before analysis, $h_1$	1	1	1	1	1	1
wight of crucible with extracted wood residue(g), $h_f$	54.2441	36.2878	55.334	25.3517	28.6723	24.7609
weight of dry biomass after analysis , $w_2=h_f-h_c$	0.8551	0.8453	0.8826	0.8388	0.8248	0.8434
Hemicellulose content(%), $HC(\%)=(h_1-h_2)/h_1*100$	14.49	15.47	11.74	16.12	17.52	15.66
Average Hemicellulose content (%), $Ave HC(\%)$	13.9			16.43		

Table B.3: Lignin Content of Aloe and Sisal Fibers

	Aloe fiber			Sisal fiber		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
Weight of empty crucible(g), $lc$	53.3894	48.9016	50.7410	34.6822	32.1061	35.5714
weight of dry biomass before analysis, $L_s$	0.3	0.3	0.3	0.3	0.3	0.3
wight of crucible with extracted wood residue(g), $L_f$	53.4534	48.9636	50.8130	34.7582	32.1751	35.6504
weight of dry biomass after analysis , $L_l=L_f-lc$	0.06400	0.06200	0.07200	0.07600	0.06900	0.07900
Lignin content(%), $LC(\%)=(L_l)/L_s*100$	21.3333	20.6667	24.0000	25.3333	23.0000	26.3333
Average Lignin content (%), $Ave LC(\%)$	22.000			24.89		

APPENDIX C: Some photos of the experiments during the particle production and Testing



Final Particle boards



Samples for MOR and MOE Test



MOR and MOE Test



Samples for IB Test



Ash



Cold Hydraulic pressing



Samples for WA and TS tests