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DECLARATION

I, Md. Jahangir Alam, declare that this thesis is the result my own work and that has not been submitted or accepted for a degree in any other University/Institutions. I, hereby, give consent for my thesis, if accepted, to be available for inter-library loans, and for further research.

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06.05.2018

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DEDICATED

TO

MY BELOVED PARENTS

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CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Wood based composites, such as particleboards (PB), medium density fiberboard (MDF), plywood and wood plastic composite (WPC), are wide products used in the buildings, construction industry, and many consumer products. Depending on the desired use of site properties (strength, strong, economy) is able to produce various composites using chip, strands, veneer and fiber (Rowell, 2005). Urea formaldehyde resins have been incredibly used in the production of particleboard and other wood based panels. The use of urea formaldehyde resin as a prime adhesive by the forest products industry is due to water solubility, lack of color, low cost and ease of use under a wide diversity of curing conditions. On the other hand, it has high hydrolysis sensitivity and low water durability (Maminski *et al.*, 2008). The hardener solution is added to catalyze the resin curing reaction and it is presented as a rate of solid hardener substance to solid resin basis. The hardeners are added as late as possible to avoid premature curing due to production line stoppages (Moslemi, 1974).

The use of hexamine as a hardener for a tannin, hence, a tannin-hexamine adhesive, is a very environment-friendly proposition. NMR has confirmed (Pichelin *et al.*, 1999, Kamoun *et al.*, 2003) that the main decomposition of hexamine under such conditions is not directly due to formaldehyde.

With dwindling oil resources and unstable oil prices, the future cost and availability of synthetic adhesives are uncertain. Highly priced synthetic adhesives increase the final cost of wooden panels. There are concern about formaldehyde emissions from the very same adhesives. Research seeking to replace synthetic adhesives is needed to produce quality panels, with lower formaldehyde emissions, at a lower cost. The search for natural adhesives has recently been focused on the use of tar derived from carbonization on lignin, and on the use of tannins. Because it is an economically viable adhesives that uses abundant, renewable natural resources and meets the international standards for performance and emissions (Navarrete *et al.*, 2010). The use of alternative raw materials for the production of cheap and affordable adhesives has discovered tannins (complex poly phenolic compounds), which form insoluble complexes with proteins (Readel *et al.*, 2001).

Tannin-adhesives are industrially and commercially very acceptable they have had little chance to markedly influence the phenol-formaldehyde adhesive market, which was reputed to be in excess of 3 million tons annually worldwide. The total production of wattle and Quebracho tannins has been not more than 150,000 tons/year, while tannin producers do not make available more than (20-30%) of their total production for adhesive production (Pizzi *et al.*, 1993).

Tannin are phenolic compounds. They are secondary metabolites that help defend plants against solar radiation, herbivores, and pathogens. The concentration of phenolic compounds in a plant is influenced by the genetics of the species as a well as the environmental concentrations of the area in which it is located. The nature of phenolic tannins allows them to react with aldehyde under both acidic and alkaline conditions, which allows for their effective use as wood adhesives (Tondi and Pizza, 2009). Condensed tannin formaldehyde wood adhesives have been used industrially since the 1970s for bonding of interior and exterior wood products such as particleboard and plywood (Pizzi, 1994; Pizza, 1983).

One of the major challenges associated with wood-based particleboard is the use of formaldehyde resin. Formaldehyde is a volatile, colorless gas with a strong odor that is commonly used in industrial processes, particularly in manufacturing building materials.

The *A. nilotica* is traditionally used for tanning and retaining in tropical Africa, and is one of the most important tanning materials in Northern India (Sarkar, 1991). It is tree of moderate sized, spiny, and evergreen confined to flooded areas, depressions and river-beds (Thirakul, 1984; EL Amin, 1990). Acacias are established as very important economic plants since early times as source of tannins, gums, timber, fuel and fodder. The bark contains high levels of tannin (12-20%) that is used for tanning leathers. Deseeded pods from *ssp. indica* have 18-27 tannin levels, whereas ssp. nilotica reached up to 50%. The relative tannin levels in *A. nilotica* from least to most are pods (5.4%), leaves (7.6%), bark (13.5%) and twigs (15.8%) (Kiran, Bargali and S. S. Bargali, 2009).

Due to high price of synthetic adhesive and its environment and health hazards for production wood panel product, bio resin will be the alternative source of resin. Since there have no study on tannin based adhesive from *A. nilotica* bark for the production of particleboards. This study will evaluate the extraction of tannin from *A. nilotica* bark that apply to wood composite with determining feasibility of setting agent with bark extraction.

1.2 Objectives of the study

- Develop bio resin from *Acacia nilotica* bark blended with setting agent.
- Manufacture particleboard from setting agents blended *A. nilotica* bark resin.
- Evaluate physical and mechanical properties of setting agent blended *A. nilotica* bark resin blended particleboard.

CHAPTER TWO: LITERATURE REVIEW

2.1 General information about particleboard

A particleboard is a board (or sheet) constituted from fragments of wood and/or other lingo-cellulosic materials (Chips, shaving, flacks, splinters, sawdust, etc.), bonded with organic binders with the help of one or more agents like heat, pressure, humidity, catalyst, etc. (Shrivasta, 1997). It may be classified as a panel product manufactured under pressure and heat from particle of wood or other lingo-cellulosic materials bonded entirely with a binder, generally a synthetic resin, to which other chemicals (e.g., fire retardant, fungicide, water retardant etc.) may be added to improve certain properties (Salehuddin, 1992).

2.1.1 Brief history and development of particleboard

Particleboards are not more than a few decades old production. Before particleboard, modern plywood, as an alternative to natural wood, was invented in the 19th century, but by the end of the 1940s there was not enough lumber around to manufacture plywood affordably. By that time particleboard was intended to be replacement (Sheng, 2004). But before that scarcity in raw materials of plywood, first efforts were made in the early 1920's for manufacturing of particleboard. But it was unsuccessful as for the lack of suitable adhesives. The new technique introduced in the 1930's in the resin application with the growing demand paved the way for the industrial production of particleboard in the early 1940's (Moslemi, 1985). The first commercial pieces were produced during World War II at a factory in Bremen Germany. It used waste material such as planer shavings, off–cuts or sawdust, hammer-milled into chips, and bound together with a phenolic resin. Today's particleboard manufacturer provides high-quality products that consumers require due to up gradation of manufacturing techniques (Moslemi, 1985; Sheng, 2004).

2.1.2 Types of particleboard

Flake board: A particleboard in which the wood is largely in the form of flakes, giving the surfaces of a characteristic appearance (FRI, 1970). A small wood particle of predetermined dimensions specially produced as a primary function of a specialized of equipment of various types, with the cutting action across the direction of the grain (either radially, tangentially, or at an angle between), the action being as to produce a particle a uniform thickness, essentially flat,

and having the fiber direction essentially in the plane of the flakes, in overall character resembling a small piece of veneer (Shrivasta, 1997).

Chipboard: A particleboard made from chips. It is made in varying thickness and may be surface with paper, veneer, plastic materials, etc. (Shrivasta, 1997). Gluing together wood particles with adhesive, under heat and pressure makes chipboard. This creates a rigid board with a relatively smooth surface. Chipboard is available in a number of densities: normal, medium and high density. It is often used for kitchen tops (Which are laminated with melamine) and fine door. Medium density is somewhere between normal and high density. There are exterior grades of chipboard available but most are only suitable for internal use. Chipboard with a veneer surface is widely used as the carcass for kitchen units and worktops and flooring. This type of chipboard is hardwearing, rigid and heavy (Saleuddin, 1992).

Shavings board: A particleboard in which wood shavings are the chief constituent (FRI, 1970).

Wafer board: Rectangular wood flakes are used.

Oriented standard board: Oriented strand board (OSB), also known as flake board, sterling board and aspenite in British English, is a type of engineered lumber similar to particleboard, formed by adding adhesives and then compressing layers of wood strands (flakes) in specific orientations. It was invented by Armin Elmendorf in California in 1963. OSB may have a rough and variegated surface with the individual strips of around 2.5 cm × 15 cm (1.0 by 5.9 inches), lying unevenly across each other and comes in a variety of types and thicknesses.

Cement-bonded particleboards: Cement bonded particleboards are manufacture by weight about (70-75) percent cement and 20-30 percent wood chips, similar to those used in the manufacture of chipboard, the board is heavy with a density of about 1200 gm/m^3.

2.1.2.1 Pressing methods used

- Particleboard manufactured by flat press process, where pressure is applied perpendicular to board surface; particles generally falling flat alone the plane of the board surface.
- Particleboard manufactured by extrusion process, where resin bonded particles are forced between parallel hot plates or dies for consolidation and cure, particles lying largely at right angles to the board surface, and

- Particleboard manufactured by molding process, where product are moulded in to the desired shape with heat and pressure by using specially constructed mould or dies (Banglapedia, 2006).

2.1.2.2 Particle distribution in the thickness of board

- Single layer or homogenous particleboard: Single layer particleboards are made from pressing together wood particle of similar size to form a flat, dense board. No distinct board layers formed.
- Three layer board: three layer particleboard is made of placing finer particles in the face layer and coarse particle in the core. These board are not as dense as single layer boards and tend to split easily.
- Multi-layer or gradated board: graded density are particle similar to three layer particleboards. They have an inner core of coarse particle sandwich between the outer layers of finer particles. However unlike a three layer particleboard, finer particles in the face, slender and flat particles min the intermediate layer, and coarse particles in the core layer. Three layer particleboard is most commonly reported in the literature and utilized in the industry (Wong *et al.*, 1999; Hiziroglu and Holcomb, 2005; Nemli and Dimertal, 2007; Claude *et al.*, 2008).

2.1.2.3 Density of particleboard

- Low density particleboard: Below 640 kg/m^3
- Medium density particleboard: 640-800 kg/m^3
- High density particleboard: above 800 kg/m^3 (ANSI A 208.1-1999)

2.1.3 Uses of particleboard

Particleboard has become a preferable part various wooden composites. Particleboard have several application including floor underlayment, housing, TV and stereo cabinets, shelving table tops, furniture, wall cases, piano and organ parts, mobile homes, flush door cores, sliding doors pool tables and vanities (Bowyer *et al.*, 2007, Maloney, 1993; Nemli *et al.*, 2005). Particleboards are mainly used indoor because they do not have enough water repellency. In the use of particleboard phenol formaldehyde instead of conventional urea formaldehyde resin, could be suitable for outdoor purposes. Bur due to the small particle size, strength may be a problem and

reinforcement of matrix would be useful. Typically, their surfaces are coated or laminated to improve their water repellency and also the formaldehyde emission. In manufacturing of a variety of car case backs, drawer bottoms, and concealed panels, the particleboard is extensively used (Craweford, 1996).

2.1.4 Raw materials for particleboard manufacturing

Mainly two types of raw materials are mainly used in particles manufacturing

2.1.4.1 Ligno cellulosic materials

Woody and non woody materials are under this category

Woody materials: Several particleboard manufacturing use raw for raw materials from industrials wood residues thing (such as saw dust, shavings off cut and slabs) and round wood (logging, residue, thing and non-commercial species) (Lehman and Geimer, 1974; Falk, 1997; Blachet *et al.*, 2009).

Non woody materials: As demand for wood products increase, research look at possible alternative to natural wood such as agricultural residue for the production of particleboard like what straw and corn pith (Wang and Sung, 2002; Boquillon, 2004), waste tea leaves (Shi *et al.*, 2006), Kenaf (Kalaycloglu and Nemli, 2006), egg plant (Guntekin and Karakus, 2008), waste grass (Nemli *et al.*, 2009).

2.1.4.2 Chemical

Various types of chemicals are used as raw materials of particleboard. They are as follows:

Binder or adhesive

An adhesive is a substance capable of holding materials together by surface attachment (ASTM) the wood adhesive can be basically categorized into natural adhesive and synthetic adhesives.

An adhesive is a materials that are adhere to other materials and help attach them together. The state of the attachment is known as adhesion, which is based on the attraction between molecules of the item contact.

The American Society for Testing Materials (ASTM D 907-00, 2002) defines an adhesives as a substance capable of holding materials together by surface attachment. Wood adhesive are

classified into two broad categories: natural and synthetic adhesives. Natural adhesives (Also known as bio adhesives) are made from organic sources like vegetable matter, starch 9 dextrin. Natural resin or from animals e.g. casein animal glues. Animal glues like albumen have been used in the p-plywood industry, but now are largely replaced by synthetic glues. Synthetic adhesive on the other are manmade and further classified into thermoplastic or thermosetting adhesive based on their response when exposed to heat. A thermoplastic adhesive turns soft and formable when heated but regains it rigidity when cooled below it softening points many times with degradation. Example of thermoplastic adhesive used in the wood composite industry include poly (Ethylene-vinyl acetate), poly (vinyl acete) (PVA), Polyacrylate, polyethylene and polyvinyl chloride (PVC) (Ashori, 2007). Upon heating, thermosetting adhesives will become soft, but cannot return to their original state upon cooling. At present, the particleboard industry depend more on synthetic thermosets such as urea formaldehyde adhesive and phenol formaldehyde to manufacture panels. These account for up to 32% of manufacturing costs in the glues-wood composites industry (Sellers, 2000).

2.1.5 Manufacturing process of particleboard

2.1.5.1 Particle preparation

A typical particleboard process being with the preparation of wood particles. Wood or other plant materials are typically processed into particles with appropriate sizes using a hammer mill in a particle plant. The ideal wood particles for making particleboard are long and thin and have similar sizes (Young Quist, 1999). The desirable size of particles normally depend on the types of particleboard. Core particle of three layer particleboard are longer and thicker than surface particles. Graduated particleboard is different from the three layer particleboard and can use diverse sizes of particles.

2.1.5.2 Particle classification/ screening and conveying

After milling, the materials is either screened using vibrating or gyratory screens, or the particles are air classified. The purpose of this step is to remove the fines and separate the core materials from the surface material. A vibrating or gyrating screen is then used to separate finer sized particle from oversized particles into surface and core materials respectively. The screen or classified material then is transported to storage bins (Stark *et al.*, 2006).

2.2 Tannin as adhesive

2.2.1 Tannin

Tannin is another example of such a renewable material and has been used to substitute tannin for the synthetic phenolic in wood adhesives (Pizzi, 2006).

The term "tannin" has been used since the end of the eighteenth century to describe a family of water soluble organic substances present in plant extracts that effect the transformation of animal hide into leather. Vegetable tannins (Scheme 1) are water soluble phenolic rich compounds, one (1) having molecular weights between 500 and 3000 Da, capable of binding water soluble proteins two (2). They can crosslink collagen through a number of hydrogen bonding sites three (3) Vegetable tannins can be classified into hydrolysable and condensed tannins. Four (4) Hydrolysable tannins contain either gallo tannins or ellagi tannins and on hydrolysis Chowdhury, S. A., Vijayaraghavan, R., & MacFarlane, D. R. (2010).

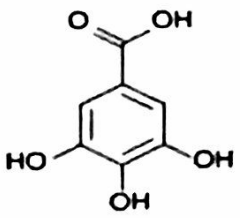
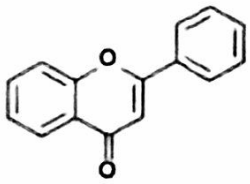
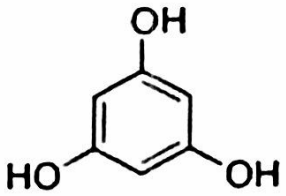
Base Unit:	 Gallic Acid	 Flavone	 Phloroglucinol
Class/Polymer:	Hydrolyzable Tannins	Condensed Tannins	Phlorotannins
Sources	Plants	Plants	Brown algae

Fig: 1. Monomers of tannin and types of tannin based on the monomers (Mole, 1993)

2.3 Babla as source of tannin

The *A. nilotica* is traditionally used for tanning and retaining in tropical Africa, and is one of the most important tanning materials in Northern India (Sarkar, 1991). A mix of equal proportions of spray-dried extracts from *A. nilotica* (garad husks) and *Azadirachta indica* (barks) with a tannin

content of (45–50)%, gave leather comparable with that obtained with *A. mearnsii* (wattle) (Rao, 1967), but this approach has not been adopted commercially.

2.4 General information about *Acacia nilotica*

Acacia nilotica is multipurpose nitrogen fixing tree legume that is widespread in Africa and Asia, and occurs in Australia. It is a complex species with nine subspecies, of which six are native to the African tropics and three others are native to the Indian subcontinent. It occurs from sea level to over 2000 m and can withstand extremes of temperature (>50°C) and air dryness but is frost sensitive when young. It is considered as a very important economic plant since early times as a source of tannins, gums, timber, fuel, fodder and medicine. The main advantage of this genus is its fast biological nitrogen fixation, ability to establish on nitrogen-deficient and drought prone soils and suitability for agro forestry systems and thus can be used in rehabilitation of dry lands. This article briefly reviews the botany, distribution, ecology, uses of the plant and its effect on soil and crops. This is an attempt to compile and document information on different aspect of *A. nilotica* and its potential use in land reclamation (Bargali, K., & Bargali, S. S., 2009).

2.4.1 Botanical classification of *Acacia nilotica*

Domain: Eukaryota

Kingdom: Plantae

Phylum: Spermatophyta

Subphylum: Angiospermae

Class: Dicotyledonae

Order: Fabales

Family: Fabaceae

Subfamily: Mimosoideae

Genus: Acacia

Species: *Acacia nilotica* (http://en **Wikipedia.org/wiki/*Acacia-nilotica*)**

2.4.2 Description

A.nilotica (family Leguminosae, subfamily Mimosoideae) grows to 15-18 m in height and (2- 3) m in diameter. The bark is generally slaty green in young trees or nearly black in mature trees with deep longitudinal fissures exposing the inner grey-pinkish slash, exuding a reddish low quality gum. The leaves are bipinnate, pinnae (3-10) pairs, (1.3- 3.8) cm long, leaflets (10-20) pairs, and (2-5) mm long. Thin, straight, light grey spines present in axillary pairs, usually (3-12) pairs, (5-7.5) cm long in young trees, and mature trees commonly without thorns. Flowers in globulous heads, (1.2-1.5) cm in diameter of a bright golden yellow colour, born either axillary or whorly on peduncles (2-3) cm long located at the end of branches. Pods (7-15) cm long, green and tomentose when immature and greenish black when mature, indehiscent, and deeply constricted between the seed giving a necklace appearance.

2.4.3 Ecology

There is some evidence that *A. nilotica* is a weed in its native habitat e.g. South Africa (Holm *et al.*, 1979), but in other areas it is planted for forestry or reclamation of degraded land (Puri and Khybri, 1975; Shetty, 1979). The ecological implication of using *A. nilotica* as a browse source while maintaining in appropriate stocking rates is land degradation. It grows well in two types of soils i.e. riverine alluvial soil and black cotton soil. This species grow on saline, alkaline soils and those with calcareous pans. *A. nilotica* grows under climatic conditions ranging from sub-tropical to tropical. It can withstand extremes of temperature (> 50°C) and conditions of drought however; adequate moisture is needed for full growth and development. It is frost tender when young and trees of all age classes are adversely affected by conditions of severe frost. It is fire tender and both seedlings and saplings are adversely affected by fire. The average annual rainfall varies from (250-1500) mm.

2.4.4 Economic importance

Acacias are established as very important economic plants since early times as source of tannins, gums, timber, fuel and fodder. They have significant pharmacological and toxicological effects In Africa and the Indian subcontinent; *A. nilotica* is extensively used as a browse, timber and firewood species (Gupta 1970, Mahgoub 1979, New 1980). The bark and seeds are used as a source of tannins (Shetty, 1979; New, 1980) the species is also used for medicinal purposes.

Bark of *A. nilotica* has been used for treating hemorrhages, colds, diarrhea tuberculosis and leprosy while the roots have been used as an aphrodisiac and the flowers for treating syphilis lesions (New, 1980). The gum of *A. nilotica* is sometimes used as a substitute for gum Arabic (obtained from *A. senegal*) although the quality is inferior (Gupta, 1970). Indian Gum is sweeter in taste than that of the other varieties and is used in paints and medicine. The species is suitable for the production of paper and has similar pulping properties to a range of other tropical timbers (Nasroun, 1979).

2.4.5 Effect of *A. nilotica* on soil Characteristics

It was reported that the tree of *A. nilotica* improves soil fertility under its canopy by reducing proportion of sand with simultaneous increase in clay particles, mainly due to protection of soil from the impact of raindrops. Higher nutrient concentration under canopy compared to canopy gap is mainly a consequence of increased above and belowground organic matter input, nutrient cycling through leaf litter and protection of soil from erosion (Pandey *et al.*, 2000, Nair, 1993 Palm, 1995). The decrease in nutrient concentration towards the canopy edge compared to mid canopy position is mainly due to relatively low inputs of leaf litter as the canopy of *A. nilotica* is thin towards canopy edge (Pandey *et al.*, 1999).

2.4.6 Allelopathic effect of *A. nilotica*

El-khawas and Shehata (2005) reported that the leaf leachates of *A. nilotica* inhibited the germination and growth of Zea mays and Phaseolus vulgaris. Duhan and Lakshinarayana (1995) found that the growth of Cyamopsistetragonoloba and Pennisetum growing at distance of (1-2) and (7.5) m from tree of *A. nilotica* was inhibited. Velu *et al.*, (1999) reported that the *Acacia spp.* Have phytotoxic effects on the tree crops of legumes. These results suggested that the inhibitory effect of *A. nilotica* on seed germination and seedling growth is related to the presence of allelechemicals including tannins, flavonoids and phenolic acids. Moreover, the toxicity is caused due to synergistic effect rather than single one (Fag and Stewart, 1994). According to (Stratmann and Ryan, 1997) and El- Khawas (2004) allopathic effect of *Acacia spp.* induced the formation of stress proteins. These proteins are responsible for folding, assembling, translocation and degradation in a broad array of normal cellular processes such as improvement of plant growth, physiological and molecular characteristics (Wang *et al.*, 2004). This allopathic ability

of *A. nilotica* may have the potential as herbicide and can be used in biological control of weeds (Li And Wang, 1998).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Bark collection and preparation

Barks of *A. nilotica* were collected from sawmills located in Krisnagor Bazar, Satkhira. The bark was collected from *A. nilotica* tree having (10-12) years age and (13-14) m stem height. After collection, the barks were dried in air for two weeks. Then it was chopped into small size particles and oven dried at 80°C for 24 hours. After drying samples were grinded with the grinder and blended to powder form and kept in airtight polythane bag.kkkk

3.2 Bark extraction

A. nilotica bark extracts was done by hot water extraction method. The powdered bark was mixed with distilled water at of ratio 15:1 (v/w). The mixer was heated by halogen heater at a temperature of (80±50)°C for 3 hours. The mixture was cool down then filtered by a sieve having 0.1 mm screen opening. The solution was then evaporated until 30% solid content. Then it was stored in refrigerator for further purposes. The bark extract was blended with setting agent as an ammonium chloride (NH_4Cl) and the setting agent ratio was 1%, 2% & 4%. The solution was then stirred in a stirer for 30 minutes. Bark extract blended with setting agents.

3.3 Physical properties of *A. nilotica* bark resin

Physical properties like solid content were measured by standard procedure. To determine the gel time of bark extract, the solution was placed in a test tube and the solution was heated in water bath at 90°C. The solution was stirred with a glass rod until it had formed a gel. Some as earlies writing viscosity and pH was measured by viscometer and pH meter.

3.4 Treatment used for manufacture particleboard

Table 1. Adhesive treatments used for manufacture particleboard

Treatments	Adhesives	Setting agent NH_4Cl (%)
NH_4Cl 1%	Bark extract	1%
NH_4Cl 2%	Bark extract	2%
NH_4Cl 4%	Bark extract	4 %
Bark extract	Bark extract	0%
UF	Urea formaldehyde	0%

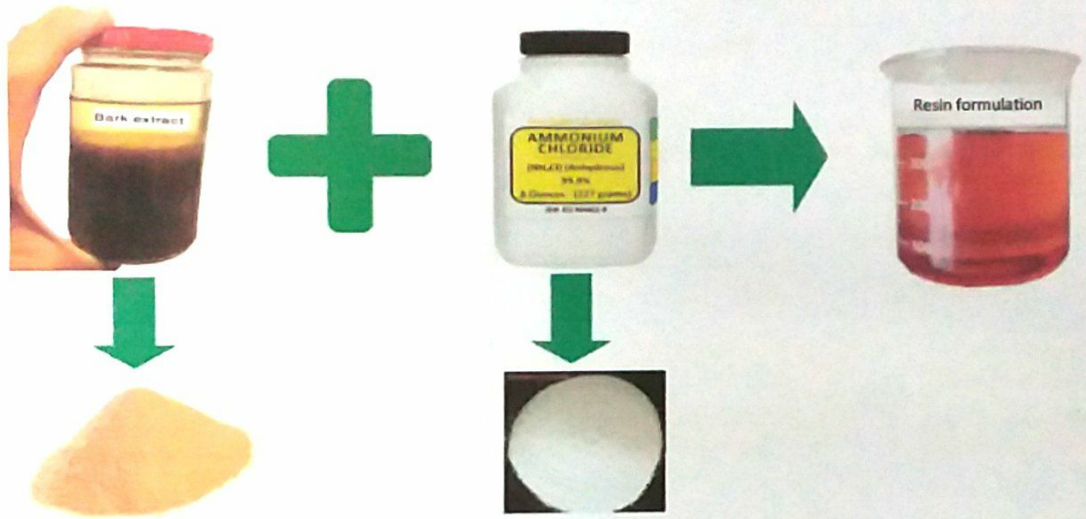


Fig. 2. Resin formulation

- Number of replications: 4
- Number of boards: 5

3.5 Manufacture of particleboard bonded with *A. nilotica* bark resin

The particleboard were manufacturing at Wood Lab., Forestry and Wood Technology Discipline. Jute stick particles were used to manufacture particleboard. Moisture of particles were about 5% before mixing the adhesive with particles. The mat formation of the particleboard were 30×25×0.7cm. The mat was pressed in hot press at temperature 170°C having the pressure 5 MPa and pressing time was 10 minutes. Five different particleboard were prepared with *A. nilotica* bark resin having four (4) concentration of hardener ammonium chloride (NH_4Cl), i.e. (100%

bark extract, 1% NH_4Cl, 2% NH_4Cl and 4% NH_4Cl); One (1) board was prepared with urea formaldehyde (UF, 8%) for the purpose of comparing board properties with the *A. nilotica* bark resin.

- Dimension of the mat: 30×25×.7cm
- Average mat thickness : About 5 times of the targeted board thickness (7 mm)
- Pressure: 5 MPa
- Pressing duration: 10 minutes
- Temperature: 170°C
- Stopping temperature the board was remained fixed for cooling 10 minutes.
- At least 4 replications each treatment were obtained.

Dimensions of the specimen

For the determination of moisture content, density water absorption, thickness swelling and linear expansion: 50 mm x 35 mm (approximately).

3.6 Flow diagrams of particleboard production

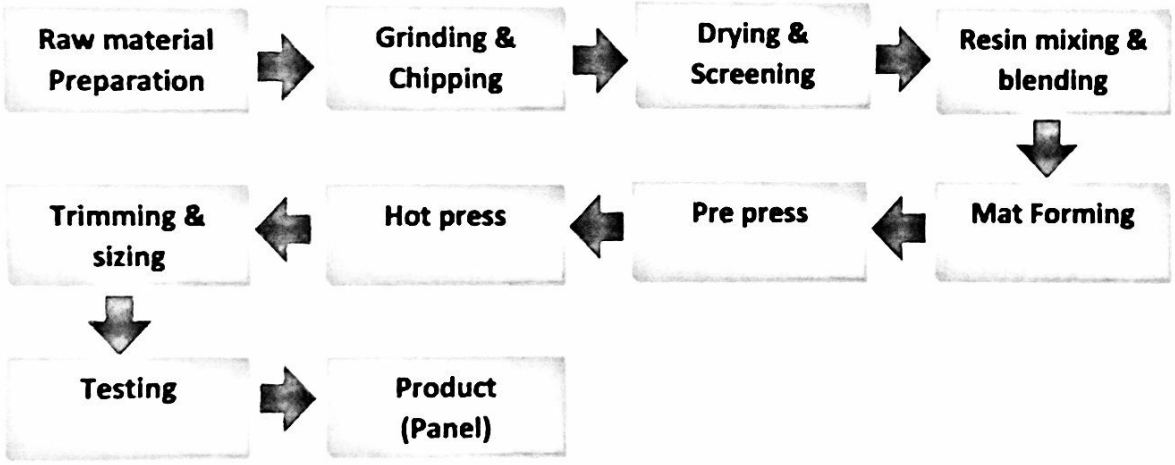


Fig. 3. Flow diagrams of particleboard production

3.7 Determination of Physical and Mechanical Properties

3.7.1 Density

Density is defined as mass as per volume. To determine the density of the particleboards the laboratory test were carried out in the laboratory of Forestry and Wood Technology Discipline in Khulna University. The volume was calculated by measuring length, width with a scale and thickness with a slide clipper.

Then the density of the board was calculated by the following formula-

Density, $\rho = \frac{m}{v}$ .....Equation 1. (Desch and Dinwoodie, 1996)

Where, ρ = Density in gm/cm^3; m = Mass of the sample in gm and v = Volume in cm^3.

3.7.2 Moisture content

The moisture content of wood is the amount of water in wood. To determine the moisture content of the particleboard the weight of the samples before drying in oven and the weight of the samples after oven (24 hours) drying was measured by an electronic balance. Then the moisture content of the board was calculated by the following equation-

$MC\ (\%) = \frac{m_{int} - m_{od}}{m_{od}} \times 100$ ..... Equation 2. (Desch and Dinwoodie, 1996)

Where,

MC = Moisture content (%), m_{int} = Initial mass of the sample (gm), m_{od} = Oven-dry mass of the sample (gm).

3.7.3 Water absorption

Water absorption is expressed as percentage as the difference in weight before and after immersion in water. To determine the water absorption of the particleboard the weight of the sample before immersion in water and the weight of the sample after (24 hours) immersion in water was measured by an electronic balance. Then the water absorption of the board was calculated by the following formula-

$A_w = \frac{m_2 - m_1}{m_1} \times 100$ .....Equation 3. (ASTM, 1997)

Where, A_w = Water absorption (%), m_2 = the weight of the sample after immersion in water (gm), m_1 = the weight of the sample before immersion in water (gm).

3.7.4 Thickness swelling

Swelling is expressed as percentage of the dimension or volume before the change occurred. The thickness of each sample before immersion in water and thickness of sample after immersion (24 hours) in water was measured with a slide clipper. Then the thickness of the board was calculated by the following equation-

$$G_t = \frac{t_2 - t_1}{t_1} \times 100 \quad \text{.....Equation 4.} \qquad \text{(ASTM, 1997)}$$

Where, G_t =Thickness swelling (%), t_2 = Thickness of sample after immersion in water (mm), t_1 = Thickness of sample before immersion in water (mm).

3.7.5 Linear expansion

Linear expansion is the expansion in length of the sample before and after (24 hours) immersion in water and expressed in percentage. Linear expansion was calculated by the following formula-

$$LX(\%) = \frac{L_A - L_B}{L_B} \times 100 \quad \text{.....Equation 5.} \qquad \text{(ASTM, 1997)}$$

Where, L_A = Length of sample after immersion in water (mm), L_B = Length of sample before immersion in water (mm).

3.8 Determination of mechanical properties

The laboratory test for characterized of mechanical properties was carried out using the unconfined compression test apparatus (SIMSUCA-02) according to the D 1037-93 (ASTM, 1995) standard in the laboratory of Akij Particle Board Mills Limited. Samples were cut according to ASTM 1037-93 (ASTM, 1995) standard, with the dimension of 220×180×7 mm.

3.8.1 Modulus of rupture (MOR)

Modulus of rupture (MOR) was measured with the Universal Testing Machine in the Laboratory of Akij Particle Board Mills Limited. The MOR was calculated from the following equation-

$$MOR = \frac{3PL}{2bd3} \quad \text{.....Equation 6.} \qquad \text{(Desch and Dinwoodie,1996)}$$

Where, MOR = the modulus of rupture (N/mm^2), P = Load (N), L = span length (mm), b = width of test sample (mm), d = Thickness of test sample (mm)

3.8.2 Modulus of elastcity (MOE)

The MOE was calculated by Equation 7.

$$MOE=\frac{P'L3}{4\Delta bd3} \quad \text{.....Equation 7.} \quad \text{(Desch and Dinwoodie,1996)}$$

Where, MOE = the modulus of elasticity in (N/mm^2), P = load (N) at the limit of proportionality, L = the span length (mm), Δ = the deflection (mm) at the limit of the propertionality , b = the width of sample (mm), d = the thickness/depth of samle (mm)

3.8.3 Internal bonding (IB)

The Internal bonding (IB) was calculated by Equation 8.

$$\text{Internal bonding (IB)} = \frac{F}{A} \quad \text{.....Equation 8.} \quad \text{(ASTM, 1997)}$$

Where, IB = Internal bonding in (N/mm^2), F = Maximum force calculated at entire area (N), A = Surface area of the specimen (mm^2).

3.9 Analysis of data

The data was analysed by using statistical software Minitab-17. ANOVA (Analysis of Variance) and LSD (Least Significance Difference) were performed at 95% significance level.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Properties of *A. nilotica* bark resin

The data for viscosity, gel time, solids content and pH of the pure bark extraction, *A. nilotica* bark extraction with different concentration of setting agents and urea formaldehyde resin are shown Table 2. The viscosity of the *A. nilotica* bark resin was high in comparison to the other adhesive. Addition of the ammonium chloride (NH_4Cl) to the bark extract reduced it viscosity. Gel time of pure bark extraction was high (180 seconds) but reduced when ammonium chloride (NH_4Cl) was increased in concentration. On the other hand, gel time of UF resin was higher than *A. nilotica* bark resin. In case of solid content of *A. nilotica* bark and resin was similar (26-27)% but lower than UF resin (51%). P^H of bark resin was increased when amount of ammonium chloride (NH_4Cl) was increased in bark extract.

Table 2. Physical properties of *A. nilotica* bark resin

Treatments	Viscosity (cP)	Gel time (s)	Solids content (%)	pH
Bark extract +1% NH_4Cl	342	90	27	7.8
Bark extract +2% NH_4Cl	338	86	27	7.9
Bark extract +4% NH_4Cl	336	84	27	8.0
Bark extract	508	180	26	4.3
Urea formaldehyde	219	118	51	8.8

4.2 Physical properties of the particleboard

4.2.1 Density

Different densities of particleboard were found from the different ratios of ammonium chloride (NH_4Cl) and *A. nilotica* bark extract shown in the Fig. 4. The density of particleboard was increased (0.75 gm/cm^3) when ammonium chloride (NH_4Cl) added to the bark extract but again the density was decreased (0.74 gm/cm^3) with the increase of ammonium chloride (NH_4Cl) proportion. The density of particleboards were even increased in case of *A. nilotica* bark resin than urea formaldehyde resin.

From the statistical analysis, it has been found that there was no significant difference ($P>0.05$) among the densities of different types of particleboard (Appendix 2).

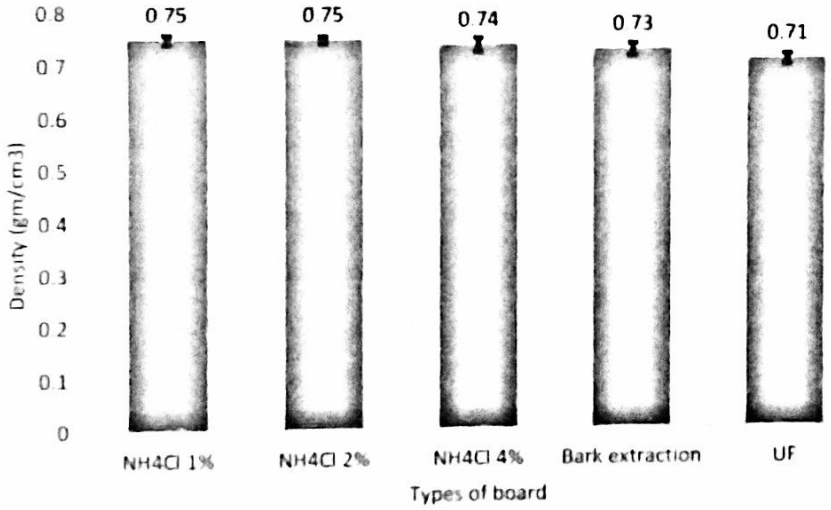


Fig. 4. Density of the different adhesive treatment board

According to melony (1993), the ideal compaction ratio of particleboard is form 1.3 to 1.6 which leads to adequate compaction of particles and consequently good physical and mechanical properties of the boards. All the treatments were within the cited adequate range for compaction ratio.

4.2.2 Moisture content (MC)

Different moisture content (%) of particleboard were found from the different ratios of ammonium chloride (NH_4Cl) and *A. nilotica* bark extract shown in the Fig. 5. The MC (%) of particleboard was decreased with the increase of ammonium chloride (NH_4Cl) proportion in bark extract. The lowest MC (%) was found in case of 4 % ammonium chloride (NH_4Cl) (6.72%). But among the all type of boards UF showed lowest Moisture content (MC) (%) (6.62%).

From the statistical analysis, it has been found that there was no significant difference ($P>0.05$) among the moisture content of different types of particleboard (Appendix 2).

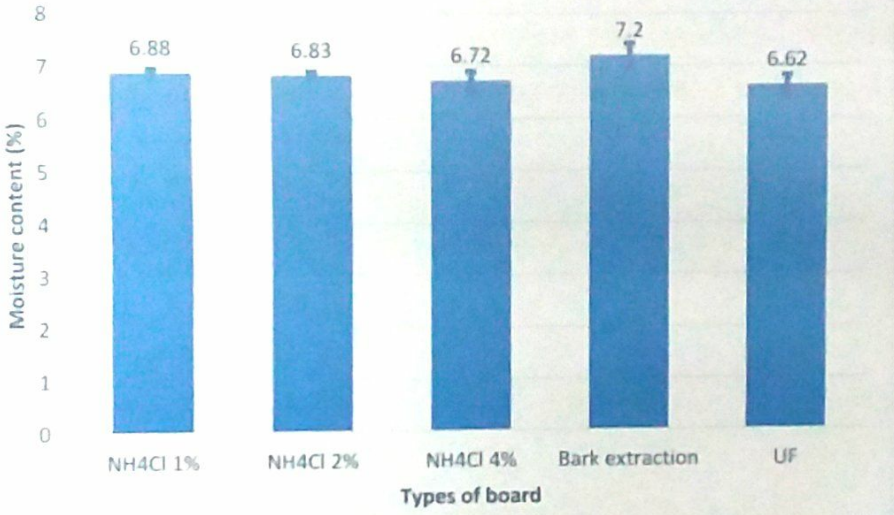


Fig. 5. Moisture content MC (%) of the different adhesive treatment board

Expert *et al.* (2003) stated that wood consists mostly of vessels in which moisture is absorbed. Tannin is also water soluble. Different percentage of tannin and urea-formaldehyde and the different pH values may be the cause of variation in moisture content (%).

According to ANSI (1999) standard, the mean moisture content of particleboard shall not exceed 10% (based on the oven dried weight of the board). All the treatment are within the cited adequate range for moisture content (%).

4.2.3 Water absorption

Different water absorption (%) of particleboard after 2 hours of immersion (WA_2h) and after 24 hours of immersion (WA_24h) were found from the different ratios of ammonium chloride (NH_4Cl) and *A. nilotica* bark extract shown in the Fig. 6. The percentage of water absorption of particleboards were increased due to the addition of ammonium chloride (NH_4Cl) concentration to the bark extract in both 2 hours and 24 hours test duration. But the lowest absorption was found in particleboard made with UF resin for both duration (2 hours and 24 hours). Among the five treatment, the highest mean value of water absorption was found to the particleboard made using 100% bark extract for both duration (2 hours and 24 hours).

From the statistical analysis, it has been found that there was significant difference ($P<0.05$) among the water absorption of different types of particleboard both 2 hours and 24 hours test duration (Appendix 2).

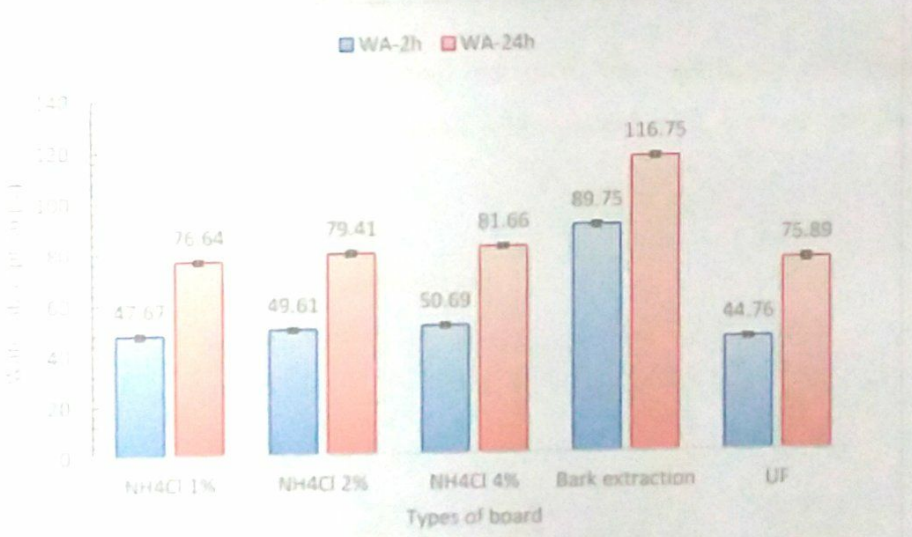


Fig. 6. Water absorption (%) of the boards after 2 and 24 hours of immersion in water

The relation between the percentage of tannin adhesive used and the water absorption of the ply wood after 24 h of immersion (WA_24h). Mixing the adhesive promoted an increase in the water absorption. The treatment with 100% phenol formaldehyde.

Silvia *et al.* (2012) produced plywood with layer of *Pinustaeda* using PF adhesive and tannin adhesive from *Pinus oocarpa* var. oocarap. The adhesive were applied at a grammage of 320

gm/cm^3. The authors determined that the water absorbance values after 24 h of immersion were 107.6 and 63.8% for panels with 100% PF adhesive and 100% pine tannin adhesive, respectly. Thus, the average values obtained in this work were lower for both adhesives than those obtained by Silva *et al.* (2012).

4.2.4 Thickness swelling

Different thickness swelling (%) of particleboard after 2 hours of immersion (TS_2h) and after 24 hours of immersion (TS_24h) were found from the different ratios of ammonium chloride (NH_4Cl) and *A. nilotica* bark extract shown in the Fig. 7. The thickness swelling (%) of particleboard was decreased (23.32 & 33.38%) when ammonium chloride (NH_4Cl) added to the bark extract, but again the thickness swelling (%) was increased (25.34 & 36.33%) with the increase of ammonium chloride (NH_4Cl) proportion in both 2 hours and 24 hours test duration. The thickness swelling (%) of particleboards were almost similar in case of *A. nilotica* bark extract with urea formaldehyde resin in both 2 hours and 24 hours test duration.

From the statistical analysis, it has been found that there was significant difference ($P<0.05$) among the water absorption of different types of particleboard both 2 hours and 24 hours test duration (Appendix 2).

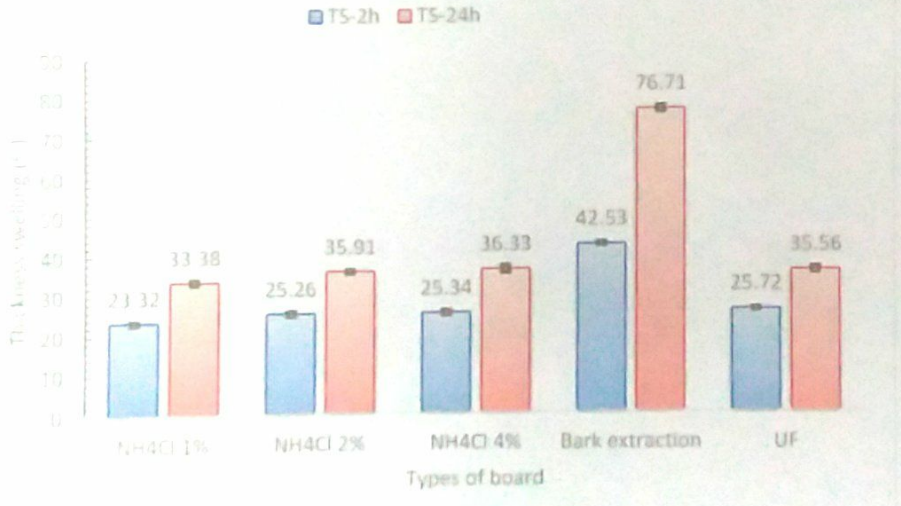


Fig. 7. Thickness swelling (%) of the boards after 2 and 24 hours of immersion in water

Carvalho *et al.* (2014) produced OSB panels with *Pinus oocarpa* wood with 8% adhesive. Urea formaldehyde and tannin from *Stryphnodendron adstringens* in different ratio were used as adhesive and found TS_2h values of 14, 22 and 18% and WA_24h values of 25, 25 and 24% for 25, 50 and 75% tannin content in the adhesive, respectively.

Salari *et al.* (2013) evaluating the quality of OSB [panel produced with 10% urea-formaldehyde adhesive and with apparent density of 0.70 g/cm^3], obtained mean values of 43.2 and 93.5 for TS_2h and TS_24 h, respectively.

4.2.5 Linear expansion

Different linear expansion (%) of particleboard after 2 hours of immersion (LE_2h) and after 24 hours of immersion (LE_24h) were found from the different ratios of ammonium chloride (NH_4Cl) and *A. nilotica* bark extract shown in the Fig. 8. The linear expansion (%) of particleboard was decreased (1.20 & 1.38%) when ammonium chloride (NH_4Cl) added to the bark extract but again the linear expansion (%) was increased (1.41 & 1.55%) with the increase of ammonium chloride (NH_4Cl) proportion in both 2 hours and 24 hours test duration. The linear expansion (%) of particleboards were almost similar in case of *A. nilotica* bark resin than urea formaldehyde resin in both 2 hours and 24 hours test duration.

From the statistical analysis, it has been found that there was significant difference ($P<0.05$) among the linear expansion of different types of particleboard both 2 hours and 24 hours test duration (Appendix 2).

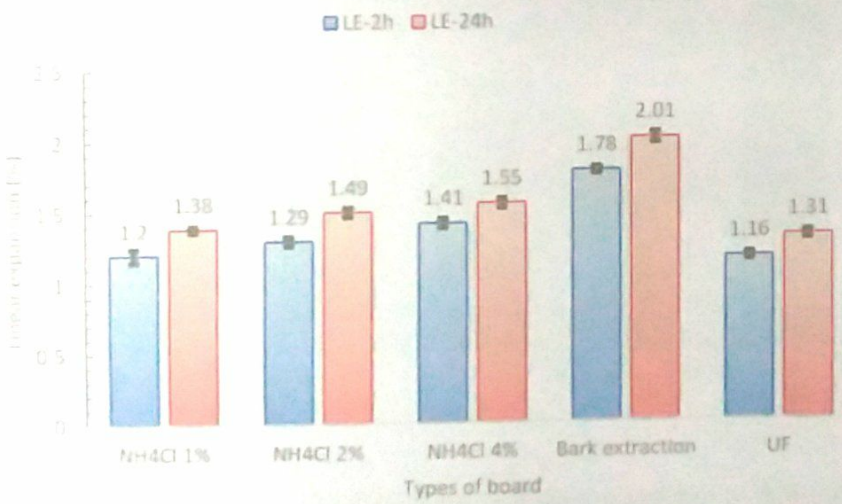


Fig. 8. Linear expansion (%) of the boards after 2 and 24 hours of immersion in water

Salari *et al.* (2013) evaluating the quality of OSB panels produced with 10% urea-formaldehyde adhesive and with apparent density of 0.70 g/cm^3, obtained mean values of 1.2% and 1.85% for LE_2h and LE_24 h, respectively.

4.3 Mechanical properties

4.3.1 Modulus of rupture (MOR)

Different MOR of particleboards were found from the different ratios of ammonium chloride (NH_4Cl) and *A. nilotica* bark extract shown in the Fig. 9. The MOR of particleboard was increased (14.86 N/mm^2) when ammonium chloride (NH_4Cl) added to the bark extract but again the MOR was decreased (10.25 N/mm^2) with the increase of ammonium chloride (NH_4Cl) proportion. The MOR of particleboards were almost similar value in case of *A. nilotica* bark extract with urea formaldehyde resin.

From the statistical analysis, it has been found that there was significant difference ($P<0.05$) among the modulus of rupture of different types of particleboard (Appendix 2).

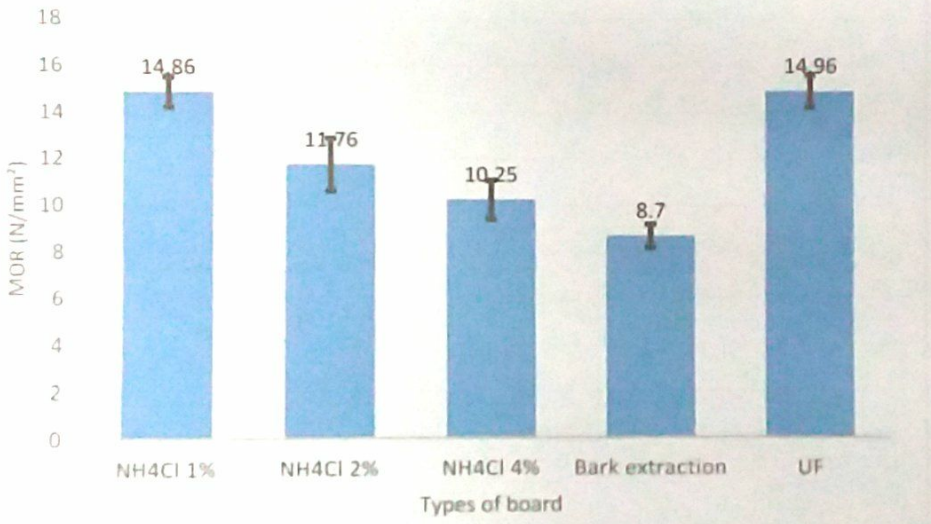


Fig. 9. Modulus of rupture (MOR) of the different adhesive treatment board

Carvalho *et al.* (2014) produced OSB panels with *Pinus oocarpa* wood with 8% adhesive. Urea-formaldehyde and tannin *Stryphnodendron adstringens* in different ratio were used as adhesive. The authors found MOR values of 27.4, 24.4, 12.3, 11.5 and 20.8 MPa for 0, 25, 50, 75 and 100% tannin content in the adhesive, respectively.

According to ANSI (NPA, 1993), the MOR of standard particleboard is 16.5-23.5 N/mm^2 for low density grade. According to IS 3087-1989 (Anon, 1985), the MOR of the standard particleboard is 11.0 N/mm^2. Ugur Arasa and Kalaycioglu (2015), studied urea formaldehyde

(9-10) % particleboard produced with hardener as ammonium chloride (NH_4Cl) and found MOR value 14.26 N/mm^2. Sellers and Miller (2004), studied the quality of OSB panels produced with 10 % tannin adhesives of Acacia, Quebracho and *Pinusradiata*, and apparent density from 0.56 to 0.70 gm/cm^3 obtained mean values from 18.5 to 26.9 MPa for MOR and from 2,754 to 3,802 MPa for MOE. According to EN standard, 11.5, and 1600 N/mm^2 are the minimum requirements for MOR and MOE of particleboard panels for general uses and interior fitments such as furniture (EN 312-2, 1996; EN 312-3, 1996).

In another study, MOR values of the boards manufactured with UF resin and ammonium chloride (NH_4Cl) were defined between 20 and 22 N/mm^2 (Kalaycioglu and Nemli, 2006).

4.3.2 Modulus of elasticity (MOE)

Different MOE of particleboard were found from the different ratios of ammonium chloride (NH_4Cl) and *A. nilotica* bark extract shown in the Fig. 10. The MOE of particleboard was increased (2864.03 N/mm^2) when NH_4Cl added to the bark extract but again the MOE was decreased (1951.11 N/mm^2) with the increase of ammonium chloride (NH_4Cl) proportion. The MOE of particleboards were almost similar value in case of *A. nilotica* bark extract with urea formaldehyde resin.

From the statistical analysis, it has been found that there was significant difference ($P<0.05$) among the modulus of elasticity of different types of particleboard (Appendix 2).

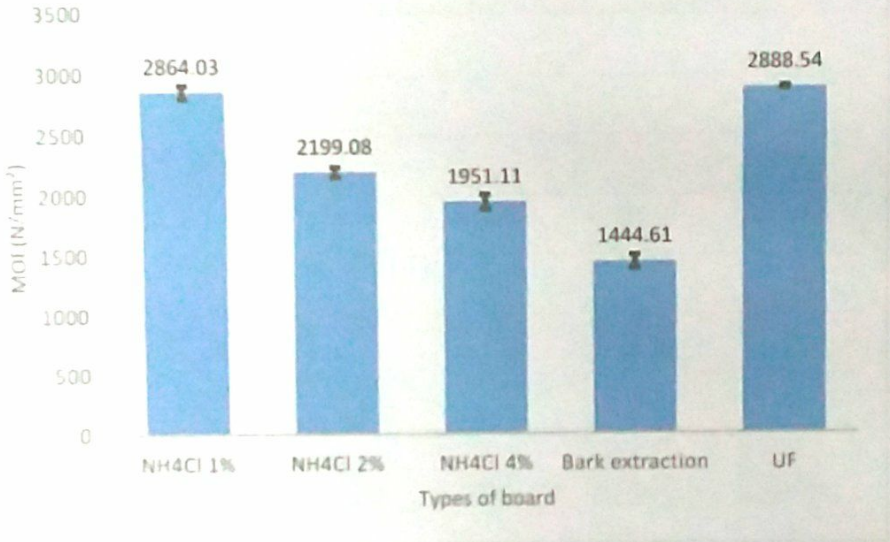


Fig. 10. Modulus of elasticity (MOE) of the different adhesive treatment board

According to ANSI (NPA, 1993), the MOE of standard particleboard is 2400-2750 N/mm^2 for high density grade, 1725-2750 N/mm^2 for medium density grade and 550-1025 N/mm^2 for low density grade.

Ugur Arasa and Kalaycioglu (2015), wood particles used for particleboard manufacturing using ammonium chloride (NH4Cl); concentration (10%) consist of 90% pine (*Pinus sylvestris L.)* and 10% beech (*Fagus orientalis L.*) particles was found MOE value 2615.76 (N/mm^2).

Carvalho *et al.* (2014) produced OSB panels with panels with 8% adhesive. Urea-formaldehyde and tannin from *Stryphnodendron adstringens* in different ratio were used as adhesive. The

authors found MOE values of 1402.1, 1233.6, 1457.5, 1151.1 and 1384.3 MPa for o, 25, 50, 75 and 100% tannin content in the adhesive, respectively.

4.3.3 Internal bonding (IB)

Different IB of particleboard were found from the different ratios ammonium chloride (NH_4Cl) and *A. nilotica* bark extract shown in the Fig. 11. The IB of particleboard was increased (0.52 N/mm^2) when ammonium chloride (NH_4Cl) added to the bark extract but again the IB was decreased (0.38 N/mm^2) with the increase of ammonium chloride (NH_4Cl) proportion. The IB of particleboards were even increased in case of *A. nilotica* bark resin than urea formaldehyde resin.

From the statistical analysis, it has been found that there was significant difference ($P<0.05$) among the internal bonding of different types of particleboard (Appendix 2).

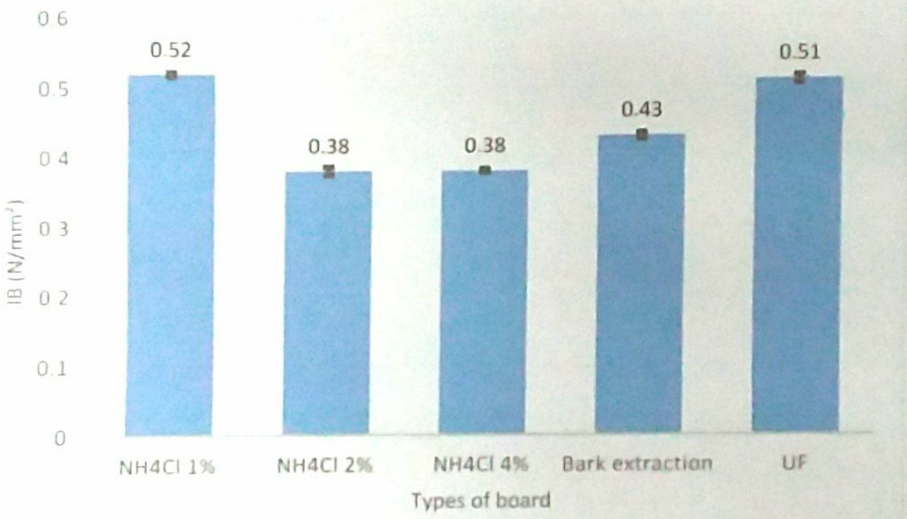


Fig. 11. Internal bonding (IB) of the different adhesive treatment board

According to ANSI (NPA, 1993), the IB of standard particleboard is 0.40 N/mm^2 for medium density grade.

Sellers and Miller (2004) studied the quality of OSB panels produced with 10% tannin adhesives from Acacia, Quebracho and *Pinus radiata*, and apparent density from 0.56 to 0.70 gm/cm^3 obtained internal bond values from 0.16 to 0.35 MPa. Mendes *et al.* (2013), evaluating the effect of thermal treatment on OSB panels produced with phenol–formaldehyde adhesive and mean apparent density of 0.72 gm/cm^3 obtained mean internal bond values ranging from 0.23 to 0.75

MPa. Salari *et al.* (2013) evaluating the quality of OSB panels produced with 10% urea–formaldehyde adhesive and with apparent density of 0.70 gm/cm^3, obtained mean internal bond values of 0.45 MPa. The standard EN 300 (2006) stipulates the minimum value for type 1 OSB panels of 0.30 MPa for the internal bond property.

The minimal requirements of internal bond strength in the EN standard are 0.24 N/mm^2 for general purpose (EN 312-2, 1996), 0.35 N/mm^2 for interior fitments (EN 312-3, 1996) and 0.50 N/mm^2 for heavy-duty load bearing panels (EN 312-4, 1996).

CHAPTER FIVE: CONCLUSION

5 Conclusion

Extractions of *A. nilotica* bark by hot water extraction method produced 26% solid content of the bark extract. At 80°C, water-extracted and 1% ammonium chloride (NH_4Cl) add to bark extract produced the most reactive tannin the gel time of the rich bark resin where was 90 second. Bark extract is mainly influenced by its pH. The pH of the bark extract solution has to be adjusted to the level of the required gel time. Longer gel times (>200 second) were obtained at pH 4.3 and the shortest was at pH 8 (84 second).

For the other properties, the effect of the quantity of tannin rich bark extract used was significant, with the greatest values of the physical properties and the heighest values of the mechanical properties being obtained by the mixture of the adhesives with 1% NH_4Cl as a hardener which means that the use of *A. nilotica* bark extract in a mix form with hardener for the production of panels is more viable. The mixture of bark extract resin and ammonium chloride (NH_4Cl) as a hardener promoted a brittleness of adhesive. One of the factors that affected the reaction could be the broken bonding of adhesive. Where the mixture of the bark extract resin led to a reduction of the pH of the UF adhesive, which probably triggered the beginning of its curing process, since this adhesive cures in an acid medium. The accelerating polymerization of the adhesive also occurs due to tannin based adhesive, once in elevated pH, the accelerating of the curing reaction occurs. However studies on the chemical reactions that occur in the mixture of these two adhesives are necessary for further study.

This study evaluated the effect of ammonium chloride (NH_4Cl) on physical and mechanical properties of particleboard. The results show that ammonium chloride (NH_4Cl) has significant effect on MOR, MOE, TS and WA values. On the other hand, IB and SD were positively affected. All of the result suggest that it is completely feasible to manufacture acceptable and more environmentally friendly particleboard using ammonium chloride (NH_4Cl) as a hardener with tannin rich *A. nilotica* bark resin.

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Appendix I: Laboratory test results

Table A-1. Physical properties of particle board of different adhesive treatment

Treatment	Density(gm/cc)	Moisture content(%)	Water absorption(%)	
			2h	24h
Bark extraction+NH_4Cl 1%	0.75	6.88	47.67	76.64
Bark extraction+NH_4Cl 2%	0.75	6.83	49.61	49.61
Bark extraction+NH_4Cl 4%	0.74	6.72	50.69	50.69
Bark extraction	0.73	7.20	89.75	89.75
UF	0.71	6.62	44.76	44.76

Table A-2. Physical properties of particle board of different adhesive treatment

Treatment	Thickness swelling(%)		Linear expansion(%)	
	2h	24h	2h	24h
Bark extraction+NH_4Cl 1%	24.32	33.38	1.20	1.38
Bark extraction+NH_4Cl 2%	25.26	35.91	1.30	1.49
Bark extraction+NH_4Cl 4%	25.34	36.33	1.41	1.55
Bark extraction	42.53	76.71	1.78	2.01
UF	25.72	35.56	1.16	1.31

Table A-3. Mechanical properties of particle board of different adhesive treatment

Treatment	MOR	MOE	IB
Bark extraction+NH_4Cl 1%	14.86	2864.02	0.52
Bark extraction+NH_4Cl 2%	11.76	2199.08	0.38
Bark extraction+NH_4Cl 4%	10.25	1951.11	0.38
Bark extraction	08.70	1444.61	0.43
UF	14.96	2888.54	0.51

APPENDIX II: ANOVA TEST RESULTS

Table A-4. ANOVA for density

Source	DF	Adj SS	Adj MS	F-value	P-value
Treatment	4	0.004739	0.001185	3.22	0.05
Error	15	0.005526	0.000368		
Total	19	0.010265			

Table A-5. LSD for density

Treatment	N	Mean	Grouping
NH_4Cl 1%	4	0.75	A
NH_4Cl 2%	4	0.75	A
NH_4Cl 4%	4	0.74	A
Bark extraction	4	0.73	A
UF	4	0.71	A

Table A-6. ANOVA for moisture content (%)

Source	DF	Adj SS	Adj MS	F-value	P-value
Treatment	4	0.7804	0.1951	1.86	0.170
Error	15	1.5727	0.1048		
Total	19	2.3531			

Table A-7. ANOVA for water absorption (%) 2h

Source	DF	Adj SS	Adj MS	F-value	P-value
Treatment	4	5609.55	1402.39	3133.38	0.000
Error	15	6.71	0.45		
Total	19	5616.27			

Table A-8. LSD for water absorption (%) 2h

Treatment	N	Mean	Grouping
Bark extraction	4	89.75	A
NH_4Cl 4%	4	50.69	B
NH_4Cl 2%	4	49.61	B
NH_4Cl 1%	4	47.67	C
UF	4	44.76	D

Table A-9. ANOVA for water absorption (%) 24h

Source	DF	Adj SS	Adj MS	F-value	P-value
Treatment	4	4790.82	1197.70	1147.26	0.00
Error	15	15.66	1.04		
Total	19	4806.48			

Table A-10. LSD for water absorption (%) 24h

Treatment	N	Mean	Grouping
Bark extraction	4	116.75	A
NH_4Cl 4%	4	81.66	B
NH_4Cl 2%	4	79.41	C
NH_4Cl 1%	4	76.64	D
UF	4	75.90	D

Table A-11. ANOVA for thickness swelling (%) 2h

Source	DF	Adj SS	Adj MS	F-value	P-value
Treatment	4	1007.30	251.826	522.28	0.00
Error	15	7.23	0.482		
Total	19	1014.54			

Table A-12. LSD for thickness swelling (%) 2h

Treatment	N	Mean	Grouping
Bark extraction	4	42.53	A
NH_4Cl 4%	4	25.72	B
NH_4Cl 2%	4	25.34	B
NH_4Cl 1%	4	25.26	B
UF	4	23.32	C

Table A-13. ANOVA for thickness swelling (%) 24h

Source	DF	Adj SS	Adj MS	F-value	P-value
Treatment	4	5509.96	1377.49	1150.16	0.00
Error	15	17.96	1.20		
Total	19	5527.92			

Table A-14. LSD for thickness swelling (%) 24h

Treatment	N	Mean	Grouping
Bark extraction	4	76.71	A
NH_4Cl 4%	4	36.33	B
NH_4Cl 2%	4	35.91	B
UF	4	35.56	B
NH_4Cl 1%	4	33.38	C

Table A-15. ANOVA for linear expansion (%) 2h

Source	DF	Adj SS	Adj MS	F-value	P-value
Treatment	4	0.99103	0.247758	55.28	0.00
Error	15	0.06722	0.004482		
Total	19	1.05826			

Table A-16. LSD for linear expansion (%) 2h

Treatment	N	Mean	Grouping
Bark extraction	4	1.78	A
NH_4Cl 4%	4	1.41	B
NH_4Cl 2%	4	1.30	B C
NH_4Cl 1%	4	1.20	C
UF	4	1.16	C

Table A-17. ANOVA for linear expansion (%) 24h

Source	DF	Adj SS	Adj MS	F-value	P-value
Treatment	4	1.21743	0.304357	77.61	0.00
Error	15	0.05883	0.003922		
Total	19	1.27625			

Table A-18. LSD for linear expansion (%) 24h

Treatment	N	Mean	Grouping
Bark extraction	4	2.01	A
NH_4Cl 4%	4	1.55	B
NH_4Cl 2%	4	1.49	B C
NH_4Cl 1%	4	1.38	C D
UF	4	1.31	D

Table A-19. ANOVA for MOR

Source	DF	Adj SS	Adj MS	F-value	P-value
Treatment	4	123.50	30.875	12.33	0.00
Error	15	37.56	2.504		
Total	19	161.06			

Table A-20. LSD for MOR

Treatment	N	Mean	Grouping
UF	4	14.96	A
NH_4Cl 1%	4	14.86	A
NH_4Cl 2%	4	11.75	A B
NH_4Cl 4%	4	10.25	B
Bark extraction	4	8.70	B

Table A-21. ANOVA for MOE

Source	DF	Adj SS	Adj MS	F-value	P-value
Treatment	4	6093797	1523449	170.61	0.00
Error	15	133943	8930		
Total	19	6227741			

Table A-22. LSD for MOE

Treatment	N	Mean	Grouping
UF	4	2888.5	A
NH_4Cl 1%	4	2864.0	A
NH_4Cl 2%	4	2199.1	B
NH_4Cl 4%	4	1951.1	C
Bark extraction	4	1444.6	D

Table A-23. ANOVA for Internal bonding (IB)

Source	DF	Adj SS	Adj MS	F-value	P-value
Treatment	4	0.080411	0.020103	248.74	0.00
Error	15	0.001212	0.000081		
Total	19	0.081623			

Table A-24. LSD for Internal bonding (IB)

Treatment	N	Mean	Grouping
NH_4Cl 1%	4	0.52450	A
UF	4	0.51275	A
Bark extraction	4	0.43175	B
NH_4Cl 2%	4	0.37950	C
NH_4Cl 4%	4	0.37625	C

APPENDIX III: LSD TEST RESULTS (MINI TAB)

For Density

One-way ANOVA: NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	0.004739	0.001185	3.22	0.05
Error	15	0.005526	0.000368		
Total	19	0.010265			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0191933	46.17%	31.81%	4.30%

Means

Factor	N	Mean	StDev	95% CI
NH4Cl 1%	4	0.75025	0.01646	(0.72980, 0.77070)
NH4Cl 2%	4	0.74925	0.01284	(0.72880, 0.76970)
NH4Cl 4%	4	0.7393	0.0262	(0.7188, 0.7597)
Bark ex.	4	0.7268	0.0224	(0.7063, 0.7472)
UF	4	0.70925	0.01489	(0.68880, 0.72970)

Pooled StDev = 0.0191933

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
NH4Cl 1%	4	0.75025	A
NH4Cl 2%	4	0.74925	A
NH4Cl 4%	4	0.7393	A
Bark ex.	4	0.7268	A
UF	4	0.70925	A

Means that do not share a letter are significantly different.

For moisture content

One-way ANOVA: NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	0.7804	0.1951	1.86	0.170
Error	15	1.5727	0.1048		
Total	19	2.3531			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.323804	33.16%	15.34%	0.00%

Means

Factor	N	Mean	StDev	95% CI
NH4Cl 1%	4	6.8825	0.1540	(6.5374, 7.2276)
NH4Cl 2%	4	6.8295	0.1397	(6.4844, 7.1746)
NH4Cl 4%	4	6.716	0.360	(6.371, 7.061)
Bark ex.	4	7.202	0.461	(6.857, 7.547)
UF	4	6.622	0.373	(6.277, 6.968)

Pooled StDev = 0.323804

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
Bark ex.	4	7.202	A
NH4Cl 1%	4	6.8825	A
NH4Cl 2%	4	6.8295	A
NH4Cl 4%	4	6.716	A
UF	4	6.622	A

Means that do not share a letter are significantly different.

For water absorption (%) for 2 hours

One-way ANOVA: NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	5609.55	1402.39	3133.38	0.000
Error	15	6.72	0.45		
Total	19	5616.27			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.669002	99.88%	99.85%	99.79%

Means

Factor	N	Mean	StDev	95% CI
NH4Cl 1%	4	47.667	0.754	(46.955, 48.380)
NH4Cl 2%	4	49.610	0.682	(48.897, 50.323)
NH4Cl 4%	4	50.692	0.554	(49.978, 51.403)
Bark ex.	4	89.745	0.760	(89.033, 90.458)
UF	4	44.758	0.564	(44.045, 45.470)

Pooled StDev = 0.669002

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
Bark ex.	4	89.745	A
NH4Cl 4%	4	50.692	B
NH4Cl 2%	4	49.610	B
NH4Cl 1%	4	47.667	C
UF	4	44.758	D

Means that do not share a letter are significantly different.

For water absorption (%) for 24 hours

One-way ANOVA: NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	4790.82	1197.70	1147.26	0.000
Error	15	15.66	1.04		
Total	19	4806.48			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.02175	99.67%	99.59%	99.42%

Means

Factor	N	Mean	StDev	95% CI
NH4Cl 1%	4	76.635	0.727	(75.546, 77.724)
NH4Cl 2%	4	79.405	1.046	(78.316, 80.494)
NH4Cl 4%	4	81.657	0.639	(80.569, 82.746)
Bark ex.	4	116.750	0.677	(115.661, 117.839)
UF	4	75.895	1.653	(74.806, 76.984)

Pooled StDev = 1.02175

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
Bark ex.	4	116.750	A
NH4Cl 4%	4	81.657	B
NH4Cl 2%	4	79.405	C
NH4Cl 1%	4	76.635	D
UF	4	75.895	D

Means that do not share a letter are significantly different.

For thickness swelling (%) for 2 hours

One-way ANOVA: NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	1007.30	251.826	522.28	0.000
Error	15	7.23	0.482		
Total	19	1014.54			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.694385	99.29%	99.10%	98.73%

Means

Factor	N	Mean	StDev	95% CI
NH4Cl 1%	4	23.322	0.723	(22.582, 24.063)
NH4Cl 2%	4	25.255	0.850	(24.515, 25.995)
NH4Cl 4%	4	25.340	0.926	(24.600, 26.080)
Bark ex.	4	42.528	0.467	(41.787, 43.268)
UF	4	25.715	0.298	(24.975, 26.455)

Pooled StDev = 0.694385

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
Bark ex.	4	42.528	A
UF	4	25.715	B
NH4Cl 4%	4	25.340	B
NH4Cl 2%	4	25.255	B
NH4Cl 1%	4	23.322	C

Means that do not share a letter are significantly different.

For thickness swelling (%) for 24 hours

One-way ANOVA: NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	5509.96	1377.49	1150.16	0.000
Error	15	17.96	1.20		
Total	19	5527.92			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.09437	99.68%	99.59%	99.42%

Means

Factor	N	Mean	StDev	95% CI
NH4Cl 1%	4	33.383	0.983	(32.216, 34.549)
NH4Cl 2%	4	35.907	0.544	(34.741, 37.074)
NH4Cl 4%	4	36.332	1.528	(35.166, 37.499)
Bark ex.	4	76.712	1.170	(75.546, 77.879)
UF	4	35.557	1.011	(34.391, 36.724)

Pooled StDev = 1.09437

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
Bark ex.	4	76.712	A
NH4Cl 4%	4	36.332	B
NH4Cl 2%	4	35.907	B
UF	4	35.557	B C
NH4Cl 1%	4	33.383	C

Means that do not share a letter are significantly different.

For Linear expansion (%) for 2 hours

One-way ANOVA: NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	0.99103	0.247758	55.28	0.000
Error	15	0.06722	0.004482		
Total	19	1.05826			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0669453	93.65%	91.95%	88.71%

Means

Factor	N	Mean	StDev	95% CI
NH4Cl 1%	4	1.2025	0.0939	(1.1312, 1.2738)
NH4Cl 2%	4	1.2950	0.0661	(1.2237, 1.3663)
NH4Cl 4%	4	1.4125	0.0650	(1.3412, 1.4838)
Bark ex.	4	1.7775	0.0479	(1.7062, 1.8488)
UF	4	1.1550	0.0520	(1.0837, 1.2263)

Pooled StDev = 0.0669453

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
Bark ex.	4	1.7775	A
NH4Cl 4%	4	1.4125	B
NH4Cl 2%	4	1.2950	B C
NH4Cl 1%	4	1.2025	C
UF	4	1.1550	C

Means that do not share a letter are significantly different.

For Linear expansion (%) for 24 hours

One-way ANOVA: NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	1.21743	0.304357	77.61	0.000
Error	15	0.05883	0.003922		
Total	19	1.27625			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0626232	95.39%	94.16%	91.81%

Means

Factor	N	Mean	StDev	95% CI
NH4Cl 1%	4	1.3825	0.0403	(1.3158, 1.4492)
NH4Cl 2%	4	1.4900	0.0673	(1.4233, 1.5567)
NH4Cl 4%	4	1.5500	0.0678	(1.4833, 1.6167)
Bark ex.	4	2.0125	0.0754	(1.9458, 2.0792)
UF	4	1.3075	0.0562	(1.2408, 1.3742)

Pooled StDev = 0.0626232

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
Bark ex.	4	2.0125	A
NH4Cl 4%	4	1.5500	B
NH4Cl 2%	4	1.4900	B C
NH4Cl 1%	4	1.3825	C D
UF	4	1.3075	D

Means that do not share a letter are significantly different.

For MOR

One-way ANOVA: NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	123.50	30.875	12.33	0.000
Error	15	37.56	2.504		
Total	19	161.06			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.58240	76.68%	70.46%	58.54%

Means

Factor	N	Mean	StDev	95% CI
NH4Cl 1%	4	14.860	1.301	(13.174, 16.546)
NH4Cl 2%	4	11.75	2.27	(10.07, 13.44)
NH4Cl 4%	4	10.253	1.668	(8.566, 11.939)
Bark ex.	4	8.700	0.987	(7.014, 10.386)
UF	4	14.958	1.386	(13.271, 16.644)

Pooled StDev = 1.58240

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
UF	4	14.958	A
NH4Cl 1%	4	14.860	A
NH4Cl 2%	4	11.75	A B
NH4Cl 4%	4	10.253	B
Bark ex.	4	8.700	B

Means that do not share a letter are significantly different

For MOE

One-way ANOVA: NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	6093797	1523449	170.61	0.000
Error	15	133943	8930		
Total	19	622774[illegible]			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
94.4963	97.85%	97.28%	96.18%

Means

Factor	N	Mean	StDev	95% CI
NH4Cl 1%	4	2864.0	105.8	(2763.3, 2964.7)
NH4Cl 2%	4	2199.[illegible]	79.7	(2098.4, 2299.8)
NH4Cl 4%	4	1951.[illegible]	122.8	(1850.4, 2051.8)
Bark ex.	4	1444.6	106.1	(1343.9, 1545.3)
UF	4	2888.5	27.5	(2787.8, 2989.2)

Pooled StDev = 94.4963

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
UF	4	2888.5	A
NH4Cl 1%	4	2864.0	A
NH4Cl 2%	4	2199.[illegible]	B
NH4Cl 4%	4	1951.[illegible]	C
Bark ex.	4	1444.6	D

Means that do not share a letter are significantly different.

For IB

One-way ANOVA: NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	5	NH4Cl 1%, NH4Cl 2%, NH4Cl 4%, Bark ex., UF

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	4	0.080411	0.020103	248.74	0.000
Error	15	0.001212	0.000081		
Total	19	0.081623			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0089898	98.51%	98.12%	97.36%

Means

Factor	N	Mean	StDev	95% CI
NH4Cl 1%	4	0.52450	0.00624	(0.51492, 0.53408)
NH4Cl 2%	4	0.37950	0.01127	(0.36992, 0.38908)
NH4Cl 4%	4	0.37625	0.00562	(0.36667, 0.38583)
Bark ex.	4	0.43175	0.00892	(0.42217, 0.44133)
UF	4	0.51275	0.01127	(0.50317, 0.52233)

Pooled StDev = 0.00898981

Tukey Pairwise Comparisons

Grouping Information Using the Tukey Method and 95% Confidence

Factor	N	Mean	Grouping
NH4Cl 1%	4	0.52450	A
UF	4	0.51275	A
Bark ex.	4	0.43175	B
NH4Cl 2%	4	0.37950	C
NH4Cl 4%	4	0.37625	C

Means that do not share a letter are significantly different.