EVALUATION OF PLYWOOD PROPERTIES MADE USING MODIFIED STARCH AS ENVIRONMENTAL FRIENDLY BINDER

by

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DECLARATION

I declare that this thesis entitled “title of the thesis”is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ______________________________

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Evaluation of Plywood Properties Made Using Modified Starch as Environmental Friendly Binder

ABSTRACT

Common resin system used in wood-based panel preparation was formaldehyde-based glue where they were believed to have fatal effects towards environment and human's health due to the release of free formaldehyde. The objective of the study was to qualify and evaluate physical and mechanical properties of experimental plywood made using sodium hydroxide (NaOH) and hot water gelatinized glutardialdehyde modified starch as environmental friendly binder. Plywood were manufactured using 10%, 20% and 30% of glutardialdehyde percentages based on weight of starch. For physical testing, the range value of density was 0.34 g/cm^3 to 0.38 g/cm^3, moisture content was 19.34% to 23.67%, water absorption was between 24.56% to 71.60%, and thickness swelling between 1.18% to 7.27%. Plywood using NaOH gelatinized glutardialdehyde modified starch binder has higher density, lower moisture content which are advantages for this type of plywood. In mechanical testing, it has been found that plywood using NaOH gelatinized glutardialdehyde modified starch binder has overall higher strength compared to plywood using hot water gelatinized glutardialdehyde modified starch binder, in terms of bending strength (MOR and MOE) and tensile shear strength. Range value of MOR was between 124.88 N/mm^2 to 179.32 N/mm^2, MOE between 8027.50 N/mm^2 to 10603.90 N/mm^2, and tensile shear strength between 651.64 N/mm^2 to 1385.16 N/mm^2. It is also found that highest glutardialdehyde:starch ratio which is 30% of glutardialdehyde used based on weight of starch in environmental friendly binder produced showed better overall plywood physical and mechanical properties. The results showed that glutardialdehyde modified starch can be used as an alternative binder in plywood manufacturing.

Penilaian Sifat-sifat pada Papan Lapis yang Dihasil dengan Menggunakan Kanji yang Diubahsuai sebagai Gam Pengikat Mesra Alam

ABSTRAK

Sistem resin yang biasa digunakan dalam penyediaan panel berasaskan kayu adalah dengan menggunakan gam yang berasaskan formeldehid di mana mereka dipercayai mempunyai kesan merbahaya terhadap alam sekitar dan kesihatan manusia akibat dari pelepasan formaldehid bebas. Objektif kajian ini adalah untuk mengenalpasti dan menilai sifat-sifat fizikal dan mekanikal papan lapis eksperimental yang dibuat menggunakan natrium hidroksida (NaOH) dan air panas yang digelatinkan bersama glutardialdehyde-kanji diubahsuai sebagai gam pengikat mesra alam. Papan lapis dibuat menggunakan 10%, 20% dan 30% daripada peratusan glutardialdehyde berdasarkan berat kanji. Untuk ujian fizikal, nilai julat ketumpatan adalah dari 0.34 g/cm^3 hingga 0.38 g/cm^3, kandungan lembapan adalah dari 19.34% hingga 23.67%, kadar penyerapan air adalah antara 24.56% hingga 71.60% dan pengembangan ketebalan adalah dari 1.18% hingga 7.27%. Papan lapis yang menggunakan gam pengikat NaOH yang digelatinkan bersama glutardialdehyde-kanji diubahsuai mempunyai ketumpatan yang lebih tinggi, kandungan lembapan yang lebih rendah di mana ini adalah kelebihan buat papan lapis ini. Dalam ujian mekanikal, ianya telah dikenalpasti bahawa papan lapis yang menggunakan gam pengikat NaOH yang digelatinkan bersama glutardialdehyde-kanji diubahsuai mempunyai kekuatan yang lebih tinggi secara menyeluruh berbanding dengan papan lapis yang menggunakan gam pengikat air panas yang digelatinkan bersama glutardialdehyde-kanji diubahsuai, dalam terma kekuatan lenturan (MOR dan MOE) dan kekuatan ricih tegangan. Nilai julat MOR adalah dari 124.88 N/mm^2 hingga 179.32 N/mm^2, MOE dari 8027.50 N/mm^2 hingga 10603.90 N/mm^2, dan kekuatan ricih tegangan antara 651.64 N/mm^2 hingga 1385.16 N/mm^2. Kadar tertinggi nisbah glutardialdehyde:kanji iaitu 30% daripada glutardialdehyde yang digunakan berdasarkan berat kanji dalam pembuatan gam pengikat mesra alam menunjukkan sifat-sifat fizikal dan mekanikal papan lapis yang lebih baik. Keputusan kajian menunjukkan glutardialdehyde-kanji diubahsuai boleh digunakan sebagai gam pengikat alternatif dalam pembuatan papan lapis.

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LIST OF ABBREVIATIONS

BC	-	Before Christ
UF	-	Urea-Formaldehyde
MF	-	Melamine-Formalehyde
PF	-	Phenol-Formaldehyde
RF	-	Resorcinol-Formaldehyde
PVAc	-	Polyvinyl acetate
LVL	-	Laminated veneer lumber
WPC	-	Wood-plastic composite
USA	-	United State of America
ASTM	-	American Standard
BS	-	British Standard
EN	-	European Standard
JIS	-	Japanese Standard
Vac	-	Vinyl acetate
SDS	-	Sodium dodecyl sulfate
SiO_2	-	Silicon dioxide
Sdn. Bhd.	-	Sendirian Berhad
NaOH	-	Sodium hydroxide
No.	-	Number
Hr/hrs	-	Hour/hours
i.e.	-	In example

LIST OF SYMBOLS

%	-	Percentage
M	-	Molar
mm	-	Millimetre
g	-	Gram
ml	-	Millilitre
°C	-	Degree Celcius
g/cm^2	-	Gram per centimetre square
kg/cm^2	-	Kilogram per centimetre square
min	-	Minutes
gm^{-2}	-	Gram per metre square
N/mm^2	-	Newton per millimetre square
±	-	Plus minus
x	-	Multiply
>	-	More than
<	-	Less than

CHAPTER 1

INTRODUCTION

1.1 Background of study

Composite materials that are made up of wood elements are known as wood-based composite. The art of veneering and used adhesives to attach decorations to wood has been discovered by the ancient Egyptians 3500 years BC (Eckelman, 1999). There are varies of forms of wood element in wood composites as to different wood composite products to be produced (Shi & Walker, 2006)**.**

Yang *et al.* (2013) stated in thier study that the common resin system used in wood-based panel preparation was the three-formaldehyde glue, which mainly consists of Urea-Formaldehyde (UF) resin adhesive, Phenolic-Formaldehyde resin adhesive (PF) and Melamine-Formaldehyde (MF) resin adhesive. However, they have fatal effects towards environment and human's health due to the release of free formaldehyde. As an alternative, starch has been introduced to become a substitute resin system. Due to its potential, physical and chemical methods could be tested on starch to improve the properties of starch such as, to change the solubility, viscosity and related properties to fulfil the requirements of different application areas of interest. Chemical modification then do play important role in preparation of starch adhesives (Jun-You *et al.*, 2006).

Many studies have been made to use starch as an adhesive. Starch is typically modified to create better properties of the composites such as higher bending strength. Wang *et al.* (2011) had synthesized an environmentally-friendly starch-based wood adhesive by the graft polymerization of vinyl acetate monomer onto waxy corn starch where the shear strength of grafted starch adhesive had increased compared with the blend of commercial polyvinyl acetate (PVAc)/gelatinized starch. Some researchers conducted studies to enhance properties of starch as an adhesive by addition of various chemicals as well as using certain modifications such as corn starch-tannin adhesive (Moubarik *et al.*, 2010), corn starch-tannin mixed with phenol formaldehyde resin (Moubarik *et al.*, 2009), corn starch mixed with sodium dodecyl sulfate (Li *et al.*, 2014) and crosslinked resorcinol‑formaldehyde (Rf) modified starch with reinforcement of *S. spontaneum* fibers (Kaith *et al.*, 2010).

1.2 Problem statement

Over many years, wood composite industries have been uses petroleum-based binder such as urea formaldehyde resin in their production. Formaldehyde is simply said made by the oxidation of methanol. It is sorted differently from other pollutants due to its high danger level and also known as potential human carcinogen substances (Bohm *et al.*, 2012). Thus, there is a pressing demand for the development of environmentally friendly alternative wood adhesives from renewable materials due to limited oil reserve, expanding wood adhesive market and hazardous issues link up with formaldehyde-based adhesives (Huang & Li, 2008)

An effort to reduce the usage of formaldehyde resin had been done by Moubarik *et al.* (2009) by using cornstarch-quebracho tannin-based resins as adhesive in the plywood production. It was found that the performance of plywood panels bonded with cornstarch-quebracho tannin-PF resins in its mechanical properties is better than plywood panels commercial phenol-formaldehyde (PF) made. The characterization of a formaldehyde-free cornstarch-tannin wood adhesive for interior plywood was also studied by Moubarik *et al.* (2010). Currently no investigations on using glutardialdehyde as starch modifying agent for binder production in plywood composite production had been done yet.

Therefore, this study investigated the better solution in overcoming the issue arise from the usage of formaldehyde based resin as binder as well as the possibility of using starch based binder and their effect on the properties of the plywood produced. High demand of plywood as building material then need more improvement in the manufacturing of the plywood itself in order to ensure healthy environment surrounds us.

1.3 Objectives

Following the problem statements previously mentioned in 1.2, the objectives of this research are:

- To determine the properties of plywood using glutardialdehyde modified starch as binder.
- To study the effect of different glutardialdehyde : starch ratio as starch modifier on the plywood properties.

CHAPTER 2

LITERATURE REVIEW

2.1 Wood composite materials

Generally, any wood material that is adhesively bonded together could be translated to the “composite” term. Stark *et al.* (2010) mentioned that the basic element for wood-based composites is the fibre, with larger particles composed of many fibres. Wood elements used in the production of wood-based composites can be made in a variety of sizes and shapes. Typical elements include fibres, particles, flakes, veneers, laminates, or lumber as shown in Figure 2.1. Different form of wood elements then will produced different types of composites products as illustrated in Figure 2.2.

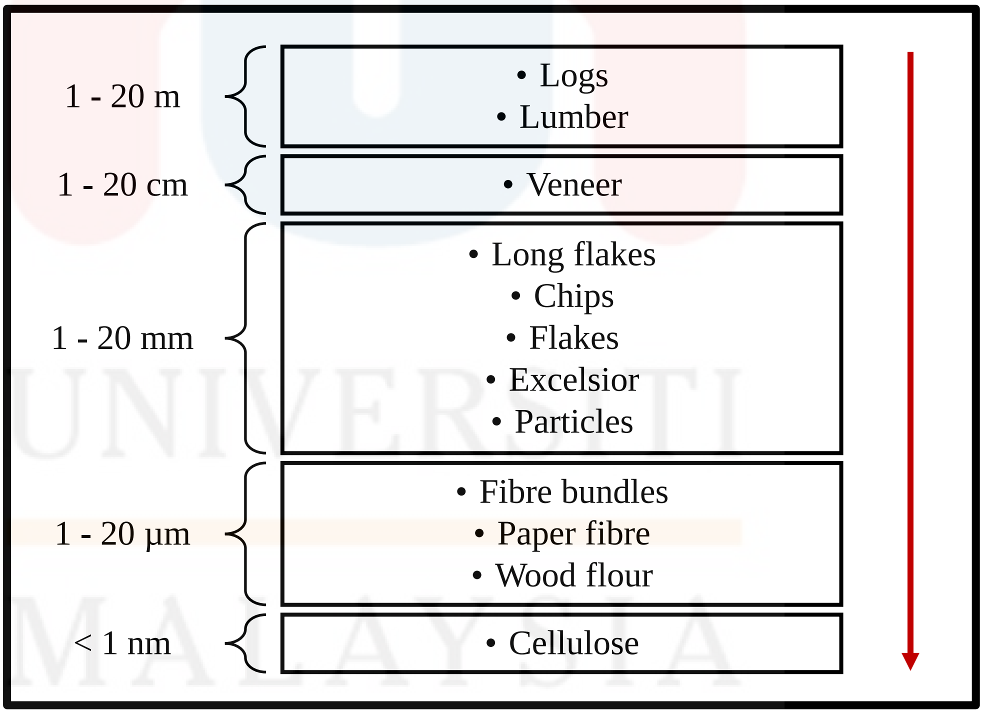

Figure 2.1: Basic wood elements, from largest to smallest (Stark *et al.*, 2010)

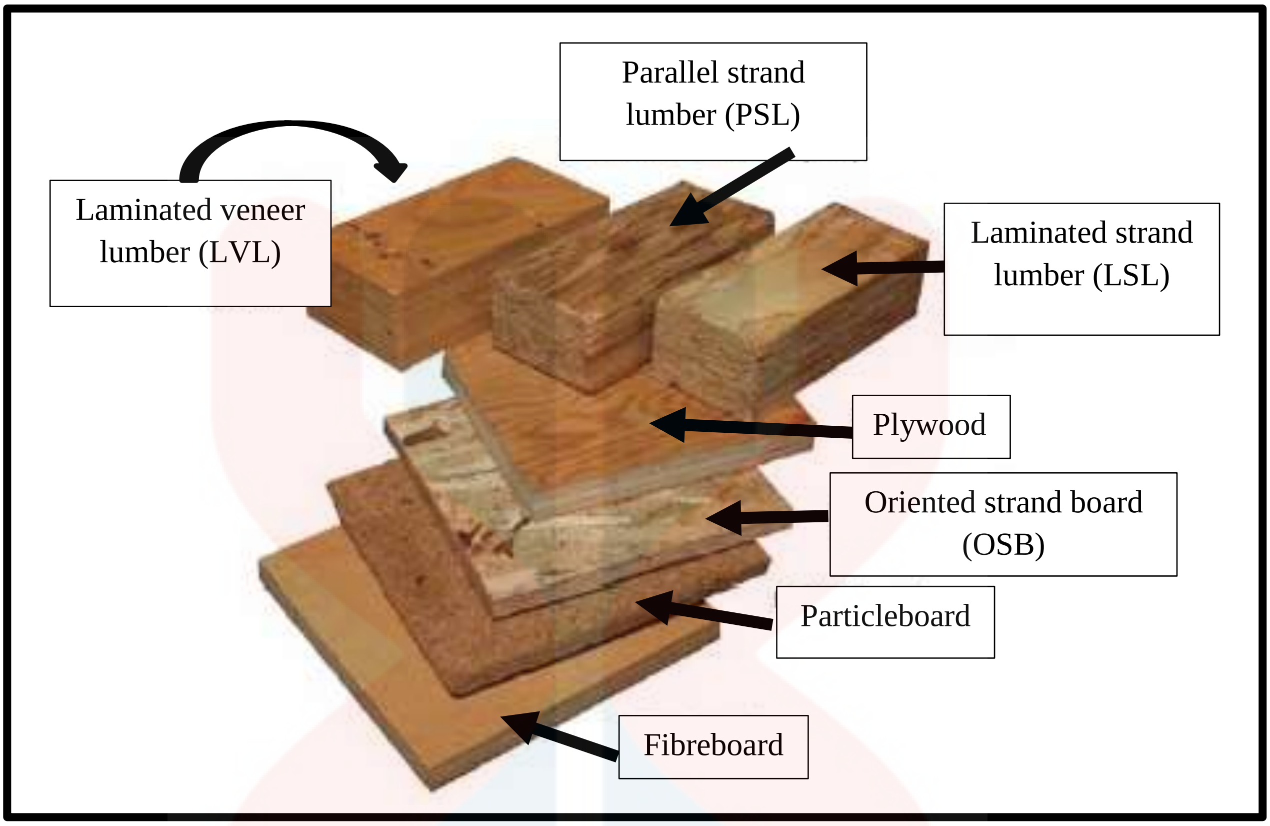

Figure 2.2: Example of various composite products (Stark *et al.*, 2010)

Other than wood-based composites, there are also composites known as polymer composites where the wood elements used in polymer composites have a large shape variation and can be used alone or in combination. The sizes, shapes and characteristics of plant fibre then will determine the properties of the final product such as surface chemistry and fibre aspect ratio in particular (Ashori, 2007).

2.2 Wood composite

Number of wood sources are appropriate and suitable for wood-base manufacturing. Wood with localized defects, knots in example, can often be used efficaciously in wood-based composites. Wood that came from small-diameter timber, forest remainder, or exotic and invasive species and recovered wood from construction waste or industrial manufacturing processes could also be effectively used in wood-based composites (Stark *et al.*, 2010). Developed technologies allow to use low-quality wood and waste from forest and wood industries, peculiarly sawmills, to make value-added products followed with demands of zero-waste principles (Gravitis, 2007).

Generally, wood composites are grouped as shown in Figure 2.3 with few example of each groups listed on (Stark *et al.*, 2010).

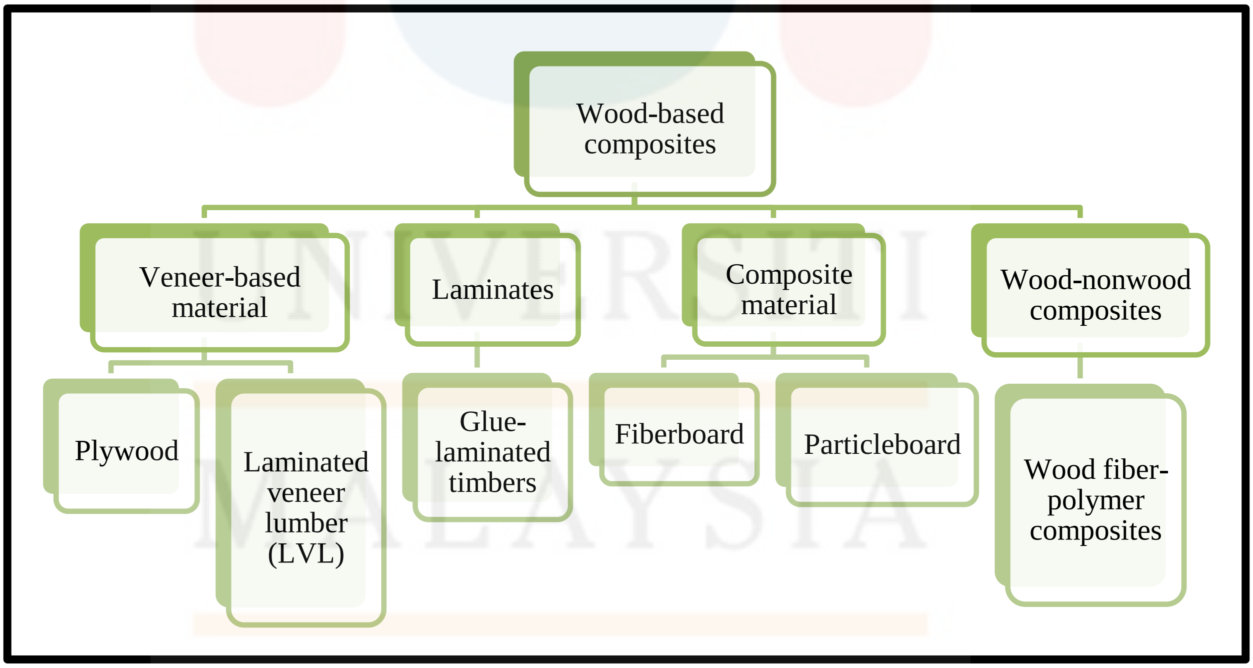

Figure 2.3: Groups of wood-based composites.

Ashori (2007) mentioned in his study that there are another type of composite that is known as wood-plastic composite (WPC) where it contain plant (include both wood and non-wood) fibres and thermosets or thermoplastics. The manufacturing process of WPCs usually begin by mixing plant fibre with polymer, or by addition of wood fibre as filler in a polymetric matrix, and being pressed or moulded under high pressure and temperature. WPCs also helps to offsets the disposal costs of large amount of wood waste generated at different stages of the wood processing (Adhikary *et al.*, 2008). Being widely used in USA, the interaction developed between wood and the thermoplastic material plays a major role in determination of most of the physical and mechanical properties of WPC (Wechsler, 2007).

2.2.1 Plywood

Plywood is an engineered wood which is commercially known as manufactured boards. It is commercially used as constructive material in the manufacturing of furniture, housing, engineered flooring and other relevant industrial products (Gao *et al.*, 2015). Plywood is divided into two general categories, firstly, construction and industrial plywood and secondly, hardwood and decorative plywood. Veneers are known as the main wood element in plywood manufacturing. Plywood is a panel product that is built up of sheets of veneer called plies. It is built up with an odd number of layers with the grain direction of adjacent layers oriented perpendicular to one another. A layer can consist of a single ply or of two or more plies laminated with their grain direction parallel. A panel can contain an odd or even number of plies but always an odd number of layers (Stark *et al.*, 2010). Figure 2.4 illustrated the information given on the plywood structure.

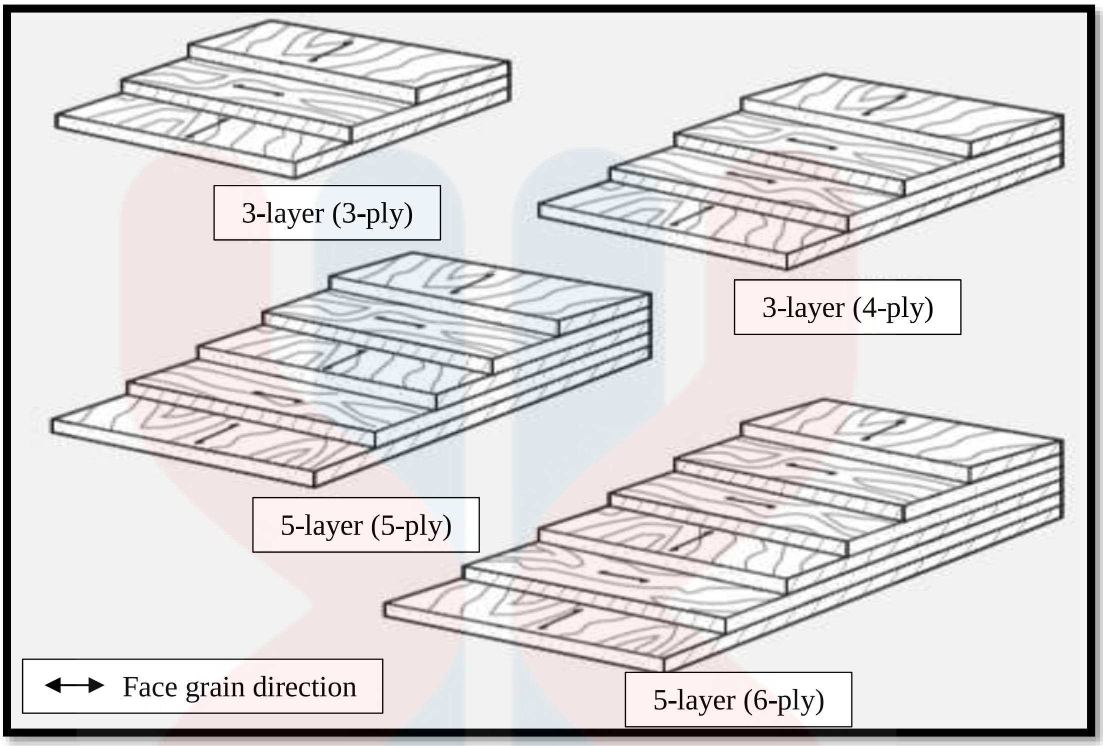

Figure 2.4: Typical three- and five-layer construction with parallel-laminated cross bands in the 4- and 6-ply panels (American Plywood Association, 1997)

It is known that the shortage of wood as a raw material in wood-based industries has led researchers to find alternatives sources of raw materials such as oil palm trunk and pine (Khalil *et al.*, 2010; Ayrilmis *et al.*, 2009). Bekhta *et al.* (2009) in their study stated that plywood produced from compressed birch and alder veneer sheets will have the potential for a variety of construction applications as building materials with better characteristics and lower production costs compared to traditional plywood panels produced.

2.2.2 Testing and plywood properties

Properties of plywood or generally known as wood composite or wood panel, could be separated into two groups, which are physical and mechanical properties. There are four commonly used standards to test these properties namely American Standard (ASTM), British Standard (BS), European Standard (EN) and Japanese Standard (JIS). These standards are differed in their specification of the criteria needed respective to the favourable uses of plywood. Physical properties includes density, moisture content, thickness swelling and rate of water absorption. Meanwhile, mechanical properties are including bending strength and tensile shear strength.

Bending strength determined the Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) of wood composite. Modulus of rupture is an accepted standard of strength, though it is not an actual stress because the formula by which it is calculated is valid only to the elastic limit (Frihart *et al.*, 2010). Modulus of rupture can be used to determine a wood species' overall strength while the modulus of elasticity measures the wood's deflection, but not its supreme strength. This means that some species of wood will bend under stress but not being easily break. According to Liew and Grace (2016), MOR value will be determined during bending process until breakage occurred while MOE is a distorted effect of shear of the load and it is usually determined by the graph.

Tensile shear strength test is conducted to determine the strength of adhesion between the layers of veneers in plywood. It can be done on both parallel and perpendicular surface of sample (Liew & Grace, 2016). Tensile shear strength could be calculated using Equation 2.1;

$$\text{Tensile Shear Strength (MPa or N/mm}^2\text{)} = \frac{Ps}{b\ x\ h} \quad \text{. . . . . Equation 2.1}$$

Where Ps, b and h is the maximum load (N), width of specimen (mm) and distance between notches (mm) respectively (Japanese Agricultural Standards, 2003).

2.3 Adhesives

Adhesive is important in plywood making. Adhesives is a substance that act to join surfaces of objects permanently by an adhesive bonding mechanism after being applied. Adhesives usually required in relatively small quantities compared to the weight of the finished objects (Ebnesajjad, 2008). There are numerous types of adhesives available where they are grouped according to their chemical structure and properties. There are two major group of adhesives identified as thermoplastic and thermosetting adhesives. Thermoplastic adhesives can obtain the adhesiveness required for many uses under normal temperature where it can be softened without undergoing a chemical change. Thermosetting adhesives have the ability to form a permanent solid and heat resistant material and they are mainly used in heavy duty structural applications (Muthike, 2011).

2.4 Wood adhesives

Following the aim of this project, adhesive for wood bonding will be given more attention than adhesive used for other purposes. Wood adhesives uses have been expanded for structural and non-structural purposes for years without major problems. The accent has shifted from evolving new adhesive types and new products to the cultivation and expanded uses of existing ones (Frihart, 2015). Adhesives for wood can be categorized into several groups according to the origin of the primary components. They include natural and synthetic adhesives (Muthike, 2011).

Kaboorani and Riedl (2011) found that, by using adhesives, the wood industry is allowed to use small diameter trees to produce high quality products. Commonly used adhesive in most wood composite manufacturer is formaldehyde based adhesive since it is low cost, fast curing and possess high strength. However, there are serious bad consequences of using this adhesive to public health commonly impacting the eyes, nose, and respiratory system. When high concentration of urea-formaldehyde based adhesives' fumes released to the air, it could lead to cancer risks. Other solution from the researchers is by finding formaldehyde free binders as an alternative (Amini *et al.*, 2015).

2.4.1 Natural origin adhesives

Natural origin adhesives are those having either plant or animal based primary component. Plant-based sources of adhesives include starches, dextrins, natural rubber and vegetables such as soya beans and peanuts. Animal-based sources of adhesives include pelt, tendon, bones, hoofs, horns, fish skin and casein protein from milk curd. Animal-based adhesives were familiar in the past woodworks. They have a wide application but despite their advantages of high initial tack, they are high-priced, uncommon and are now being substituted by synthetic products (Muthike, 2011). Protein polymers and natural polysaccharide-contained biomass already utilized as adhesives for over centenary (Frihart *et al.*, 2010).

Soy-based adhesive was once a main adhesive for plywood preparation. However, it has been replaced by synthetic resin in the 1960s. It then returned to the study area as a wood adhesive in 1990s (Lei *et al.*, 2014). Many efforts in recent years have been carried out to utilize this ample plant protein for fabrication of wood adhesives with improved strength and/or water resistance. Still, very few soya bean adhesives are used commercially in the wood industry due to their disadvantages such as moderate to low dry strength, moderate to low resistance to water and damp atmospheres, and moderate resistance to intermediate temperatures, high viscosity, low solid content, etc. Those disadvantages do highly limit the soy-based adhesive usage to interior applications especially in plywood manufacturing (Lin *et al.*, 2012).

2.4.2 Synthetic origin adhesives

Frihart *et al.* (2010) have mentioned that synthetic organic polymers have overcome the natural wood adhesives. Polymer is known as synthetic compound that consist large molecules that are made up of linked series of repeated simple monomers where they occurred naturally. Petrochemical and natural-gas based system has surmounted the usage of polymers that were commercially produced during the 1930s. Ebnesajjad (2008) in his study stated that synthetic adhesives are structural adhesives which then could be group into three groups which are thermosetting adhesives, thermoplastic adhesives and elastomeric adhesives. Table 2.1 shows examples of thermosetting, thermoplastic and elastomeric adhesives.

Table 2.1: Examples of thermosetting, thermoplastic and elastomeric adhesives (Ebnesajjad, 2008)

Thermosetting Adhesives	**Thermoplastic Adhesives**	**Elastomeric Adhesives**
Urea- formaldehyde	Acrylic	Natural rubber
Melamine-formaldehyde	Phenoxy	Reclaimed rubber
Phenol-formaldehyde	Polyamide	Polyurethane
Polyester	Cellulose acetate	Polysulfide
Epoxy	Polyvinyl chloride	Silicone
	Polyvinyl alcohol	neoprene

Thermosetting adhesives that are widely used nowadays such as urea formaldehyde (UF) and phenol formaldehyde (PF) resins have gave a big impact and contributed greatly to the progress made by the wood industry. Still, the act to decrease the emission levels of formaldehyde fumes from wood-based composites manufactured using UF resins has now become one of the major concerns of the composites and wood adhesives industries (Ayrilmis *et al.*, 2009).

2.4.3 Starch-based adhesives

Being a part of natural origin adhesives, starch can be produced in natural ways, biodegradable, low cost and extravagantly available polysaccharide molecule. Known as the major reserve carbohydrate, it is commonly apportioned in the form of tiny granules in stems, roots, grains and fruits of all forms of green leafy plants (Neelam *et al.*, 2012).

With the objective of producing starch-based adhesives, the attributes of starch could be enhanced by conducting physical and chemical methods, for example, it was an effectual way to change the solubility, viscosity and related attributes to meet the performance requirements of different application areas (Yang *et al.*, 2013). Wang *et al.* (2011) in their study have added silica nanoparticles into vinyl acetate (VAc) grafted starch to produce SiO_2/starch-based wood adhesive in their study where it resulted in incereased bonding strength and water resistance of the starch-based wood adhesive produced. Meanwhile, Li *et al.* (2014) managed to enhance the mobility and storage ability of the starch-based wood adhesive by adding sodium dodecyl sulfate (SDS) in the binder preparation.

2.4.3.1 Gelatinization of starch

Gelatinization of starch implies the reaction of melting of granule in an aqueous medium with heat applied. As temperature increases, the granule will swell and it causes transfer of water in the suspension to water colligated with starch components, the amylose and amylopectin. At temperature of 60-70ºC, insoluble granules are likely to be disrupted by the energy supplied, ensuing a loss of molecular structure and accordingly, loss of its crystallinity. This whole process results in increase of viscosity and starch solubilisation, the outcome of irreversible changes like the breaking of granular and semicrystalline structure where this also consider as a loss of birefringence (BeMiller *et al.*, 2010). Starch granules would be subjected to limited reversible swelling and usually thermal treatment is needed in order to achieve gelatinization of starches. Nevertheless, gelatinization of starches and low-temperature swelling could be brought about by the addition of aqueous alkali such sodium hydroxide, the alkalizing agents (Nadiha *et al.*, 2010). Alkalizing agents are essential in the production of many starch-based food products where such agents are said able to enhance desired product quality such as colour and texture. The products also usually came out with yellowish features with addition of alkali (Lai *et al.*, 2004).

2.4.3.2 Chemical modification of starch

Starch in its natural form is a versatile product and raw materials for production of many modifications, sweeteners and ethanol. Beginning in the 1930s, carbohydrate chemist has developed a range of products that have greatly expanded the use of starch and utilities (Whistler & Schwartz, 2009). Starch present in most green plants and in almost every type of tissue: leaves, fruits, pollen grains, roots, shoots and stems. Starch has a minimal osmotic pressure, which allows plants to store large stockpile of carbohydrates without cutting off cell water relations (Preiss, 2009). Amylose and amylopectin are two major macromolecular components of starch illustrated in the Figure 2.5.

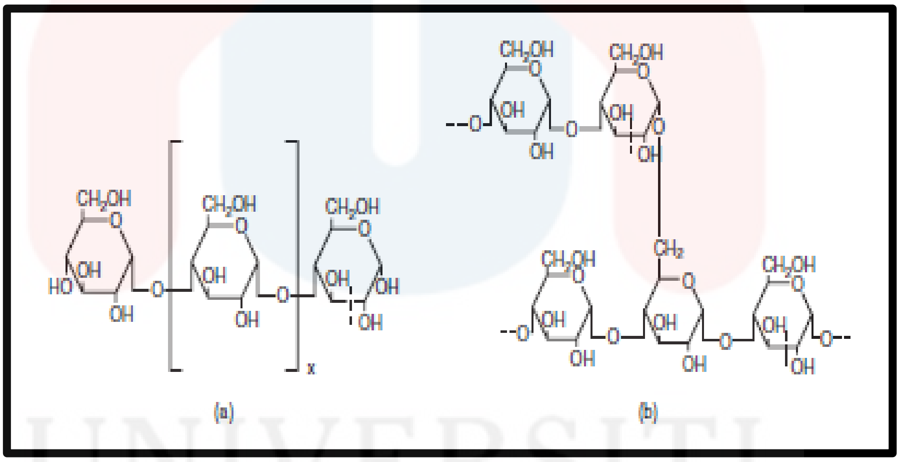

Figure 2.5: Schematic diagram of (a) amylose; and (b) amylopectin with a branch point at O6 position (Perez *et al.*, 2009)

Starch is a component exists in many types of foods such as rice, wheat, tapioca, bread and other bakery items, pasta and potatoes. Other than its criteria of being an essential energy source in human diet, starch also exhibit a splendid raw material for modifying the texture of many processed food items. There are also numbers of non-food use of starch such as in sizing agent, as a fermentation substrate, as a sizing agent agent, as adhesives and binders, etc (Biliaderis, 2009).

Most of available starches in their original form has limitations that make them less than compatible for a variety of applications required. For this reason, most of the starch granules are used as food or industrial ingredient is first need to be modified (chemical and/or physical), while it is still in granular form, to change and improve the physical properties of the starch polymer according to the desired end use (Hubber & BeMiller, 2010). There are several factors need to be considered in selecting a particular native starch for subsequent chemical and/or physical modification such as properties required for a particular application, availability of the starch and economic factors (Chiu & Solarek, 2009).

In accordance to this project, cross-linking is the method chosen to produce the modified starch as binder by using glutardialdehyde solution as the agent in the process. Starch cross-linking reaction works to strengthen the structure of the granules swell when gelatinization occured, increasing resistance to viscosity breakdown due to mechanical shear, acid conditions, or a high temperature (Huber & BeMiller, 2010). Cross-linking strengthen the hydrogen bonds in the granule with chemical bonds that act as a linker between the starch molecules. There are several factors need to be reconsidered in the cross-linking reaction which are, chemical composition of reagent, reagent concentration, pH, reaction time and temperature. However, the extent of reaction and yield of cross-linked starch are arduous to be measured chemically due to the inferior degree of cross-linking for food starch (Neelam *et al.*, 2012).

CHAPTER 3

MATERIALS AND METHOD

3.1 Overall work flow

Overall work flow is illustrated in Figure 3.1.

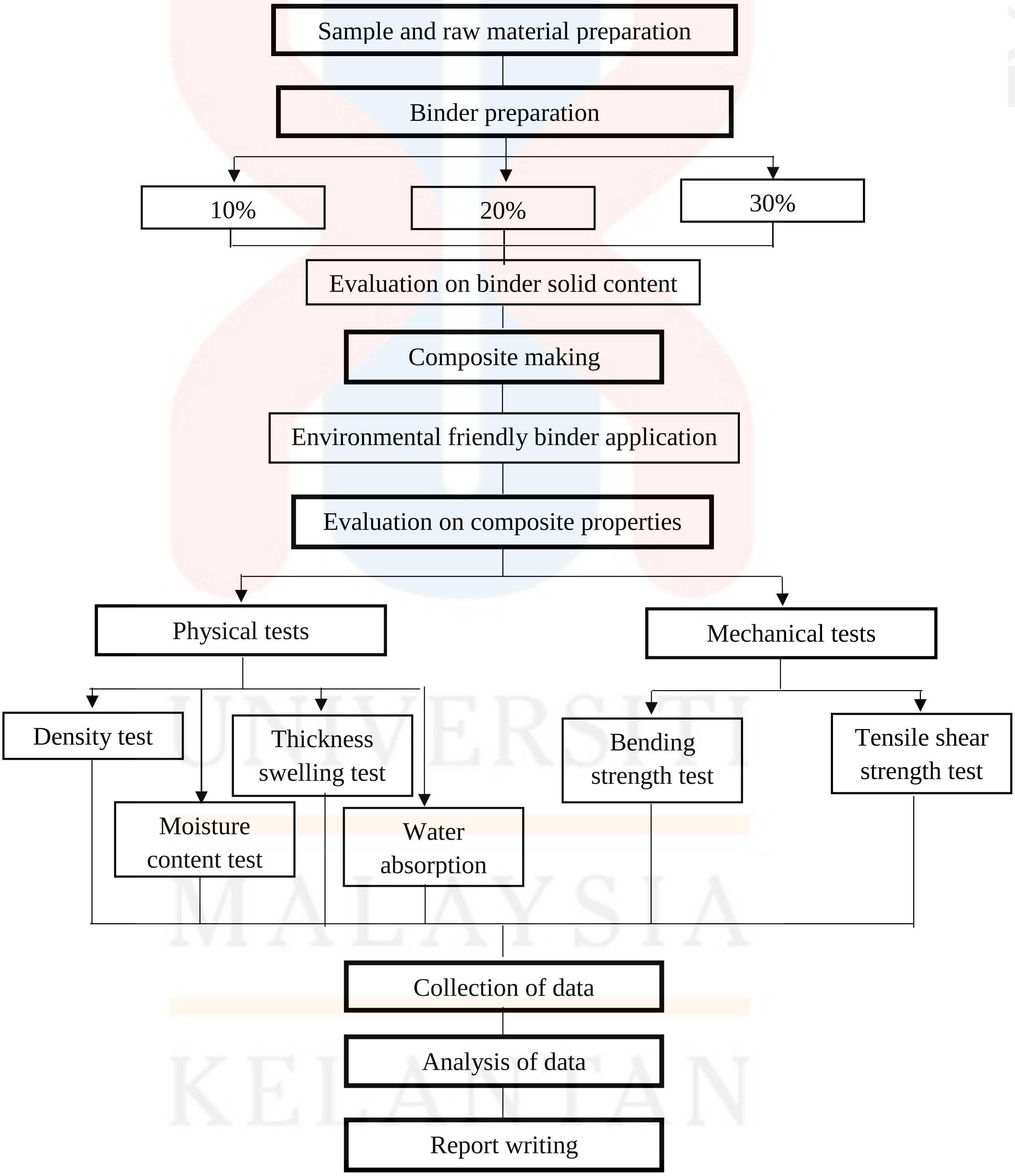

Figure 3.1: Overall work flow.

3.2 Sample and raw material preparation

Wood veneers with dimension of 200 mm x 200 mm were obtained from Syarikat Kilang Papan Bumi Sdn. Bhd. located at Kawasan Perindustrian Jeli, Kelantan, Malaysia. Glutardialdehyde solution and sodium hydroxide (NaOH) crystals were obtained from the Universiti Malaysia Kelantan laboratory and the corn starches were obtained in powder form from Sigma Chemical Company.

3.3 Binder making

100 g of corn starch was dissolved in 300 ml of 1M sodium hydroxide (NaOH) solution. Stirrer was used to continuously stir the mixture, followed by addition of glutardialdehyde solution. Note that three different amount of glutardialdehyde were used which are 10%, 20% and 30% based on weight of starch. Stirring were continued until resinification was attained and starch became well dissolved (Amini *et al.*, 2015). Another type of binder with same three different percentages of glutardialdehyde was made by substituting NaOH solution with hot distilled water as control binder.

Figure 3.2: Produced NaOH gelatinized glutardialdehyde modified starch binder.

3.3.1 Binder solid content test

Approximately 1g of binder sample was taken and dried in an oven at a temperature of 103 °C ± 2 until the sample achieved a constant weight. The solid content of the adhesive was calculated using Equation 3.1 and expressed in a percentage with an accuracy of 0.01%.

$$\text{Solid content (\%)} = \frac{Oven\text{−}dry\ weight}{Initial\ weight} \times 100 \qquad \text{. . . . . Equation 3.1}$$

Figure 3.3: Oven-dried NaOH gelatinized glutardialdehyde modified starch binder.

3.4 Composite making

Plywood was produced by stacking together plies of wood veneers using glues where the layers are rotated up to 90 degrees to one another. Plywood could exist in many different numbers of plies where in this study, three layers with three plies of plywood were produced. The test specimen will be of the full thickness of the material and at least 200 mm × 200 mm in dimension with total of 12 pieces. After applying the binder onto the veneers with loading level of 500 gm^{-2} (Gavrilovic-Grmusa, 2008), those veneers were pressed using cool-presser under pressure of 5 MPa for overnight so as to ensure the layers stacked together firmly (Aydin *et al.*, 2007).

3.5 Evaluation on composite properties

The evaluation of the plywood composite was completed by physical and mechanical testing where physical tests were density and moisture content test, thickness swelling test, water absorption test. Mechanical tests conducted were bending strength test and tensile shear strength test by using appropriate machines. Three replications of test were done for every physical and mechanical tests. All the test methods followed the Japanese Agricultural Standards (JAS) No. 233: 2003 requirements.

3.5.1 Density and moisture content test

The objective of this test is to determine the density of plywood composite which is an indicator of the properties of timber species. The determination of moisture content is crucial since it has a relation with other important mechanical properties of plywood. The sample size was 50 mm x 50 mm. The samples was initially weighed and measured for its dimension using digital vernier caliper in order to determine its density. The samples then were placed in oven at 103±2°C for 24 hours to obtain oven-dry mass of the samples and after that, the samples were left in room temperature for 10 minutes before being weighed (Liew & Grace, 2016).

- The density of the plywood was calculated using Equation 3.2 as follow:

$$\text{Density}\left(\frac{g}{cm^3}\right) = \frac{m}{V} \qquad \text{. . . . . Equation 3.2}$$

Where, m : Mass (g)

V : Volume (cm^3)

- The moisture content then was calculated using Equation 3.3 as follow:

$$\text{Moisture content (\%)} = \frac{(M_1 - M_0)}{M_0} \times 100 \qquad \text{. . . . . Equation 3.3}$$

Where, M_1 : Initial mass of specimen (g),

M_0 : Oven-dry mass specimen (g).

3.5.2 Water absorption and thickness swelling test

Samples with 50 mm x 50 mm in sizes were used in this test. Thickness swelling (TS) and water absorption (WA) were calculated from the difference between specimen thickness and weight before and after immersion in water in 1 hr, 2 hrs, 4 hrs, 12 hrs and 24 hrs. The thickness were measured at three different spots on each samples where the average value was used for determination of TS for each replication. The plywood were weighed using digital balance to determine the weight of plywood after immersion in water. For WA, The percentage of TS or WA were calculated using Equation 3.4 and 3.5, respectively.

$$\text{TS (\%)} = \left(\frac{T_2 - T_1}{T_1}\right) \times 100 \qquad \text{..... Equation 3.4}$$

$$\text{WA (\%)} = \left(\frac{W_2 - W_1}{W_1}\right) \times 100 \qquad \text{..... Equation 3.5}$$

Where T_2 or W_2 is the final thickness or weight after soaking for a certain period of time and T_1 and W_1 is the initial thickness or weight (Fang *et al.*, 2013).

3.5.3 Bending strength test

The plywood with sample size of 163 mm x 50 mm was placed with the surface veneer side up. After putting a weight on the effective length (length or width of the plywood) of the loading rod placed at the centre of the span perpendicular to the span, the defection shall be measured and Bending Young's modulus was calculated by the following equation.

Bending Young's Modulus (MPa or N/mm2) = $\Delta P\ell3/4bh3\Delta y$ ..... Equation 3.5

Where;

ℓ : Span (mm)

b : Width of testing plywood (mm)

(or length of testing plywood, in case of conducting bending stiffness test in width direction)

h : Marked thickness of testing specimen (mm)

ΔP : Difference of upper and lower limit load within the proportional range (N)

Δy : Defection at the centre of span corresponding to ΔP (mm)

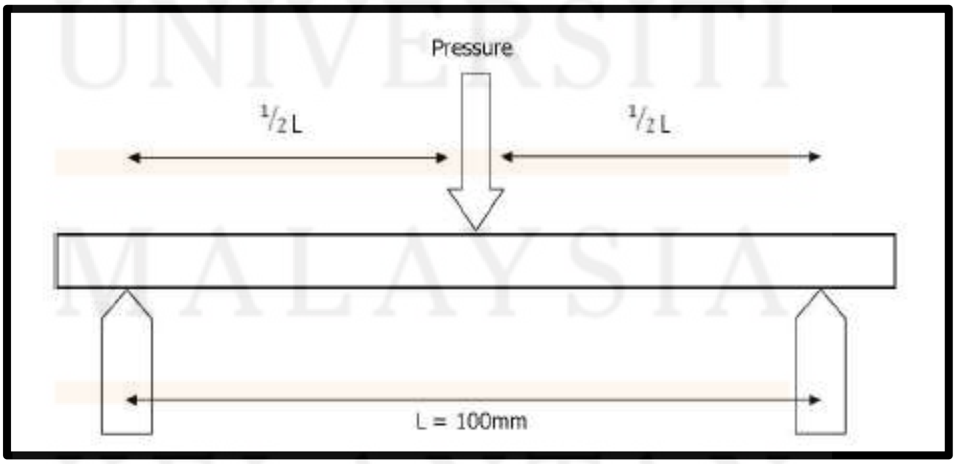

Figure 3.4: Center point loading for bending strength test (Liew & Grace, 2016)

3.5.4 Tensile shear strength test

As mentioned in 2.2.2., tensile shear test was done to identify strength of adhesion between the layers of veneers in the plywood. The veneer layers could slip with each other and apart from the adhesion layer due to shear. To determine shear strength of plywood, prepared size of test piece was 80 mm x 25 mm according to Japanese Agricultural Standards (2003). Before the test was conducted, two notches were done at both upper and lower surface of test sample manually using hand saw. Figure 3.5 showed the cutting of notches on a test piece**.**

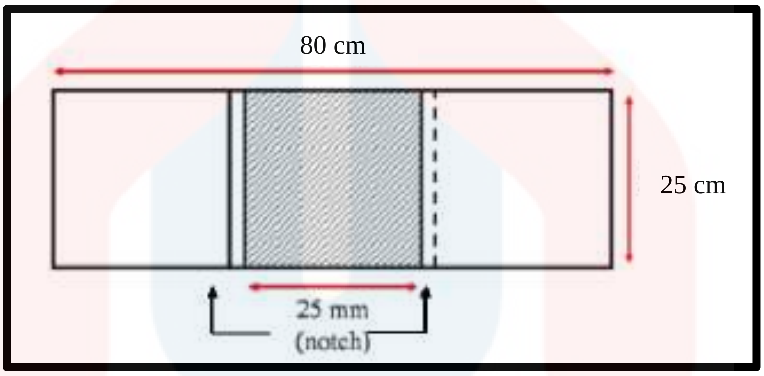

Figure 3.5: Notch cutting on tensile shear test piece (Liew & Grace, 2016)

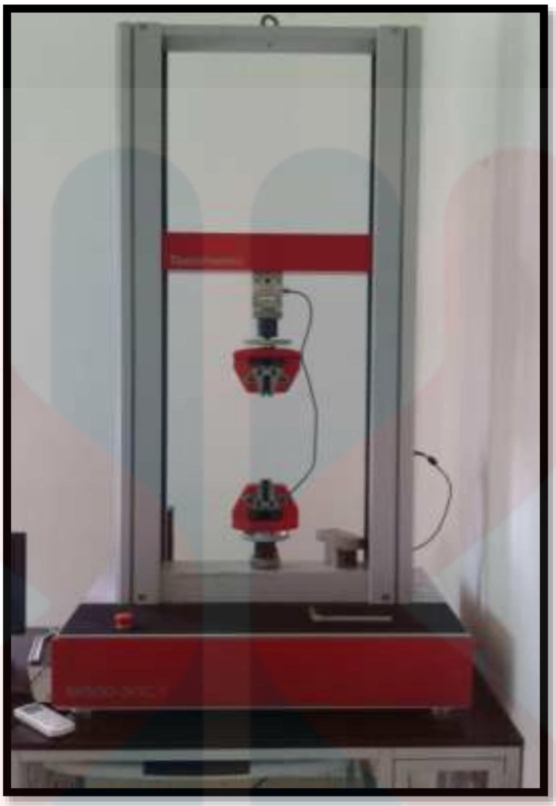

Figure 3.6: Machine used for bending and tensile shear strength test (Isometric machine, M500-50CT)

3.5.5 Statistical analysis

All the data collected were accounted to Analysis of variance (ANOVA). Results will be considered significant at 95% confidence level.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discussed all the results and analyses from the experiment. The results involved both manual calculation from plywood's physical properties tests and results generated from software used for mechanical properties tests. Plywood properties need to be tested on both physical and mechanical properties since both properties may have the probability to affect performances of one and another. For example, results readings of moisture content are able to affect the results readings for bending strength test.

After both physical and mechanical properties tests were done, this study compares results obtained from plywood made using two different types of binder with NaOH solution and hot distilled water as starch modification agents respectively. Varieties of graph were obtained from both of the results and being compared by performing one-way Analysis of Variance (ANOVA) with significance level of 0.05 using SPSS programme (Statistical Package for Social Science) version 21.0 (SPSS Inc., Illinois, USA). In general, all of the graphs and data obtained were discussed in this chapter. The most suitable binder produced also had been identified.

4.2 Binder solid content analysis

Based on Figure 4.1, the mean values of solid content for NaOH binder are 24.43%, 24.81% and 24.99% for 10%, 20% and 30% of glutardialdehyde used in binders respectively. Meanwhile, for hot water gelatinized glutardialdehyde modified starch binder, the solid content are 24.50%, 22.44% and 23.06% for each percentage respectively in increasing orders. It is showed that NaOH gelatinized glutardialdehyde modified starch binder has relatively higher solid content compared to hot water gelatinized glutardialdehyde modified starch binder where the highest solid content is at 30% of glutardialdehyde used in NaOH gelatinized glutardialdehyde modified starch binder that is 24.99%. According to Garcia-Pacios and his colleagues (2011), the binder particle size would increase as the solids content increased and their viscosities were also affected by the percentage of solids content. It was proven that during the binder making process, the NaOH gelatinized glutardialdehyde modified starch binder is noticeably more viscous compared to control binder.

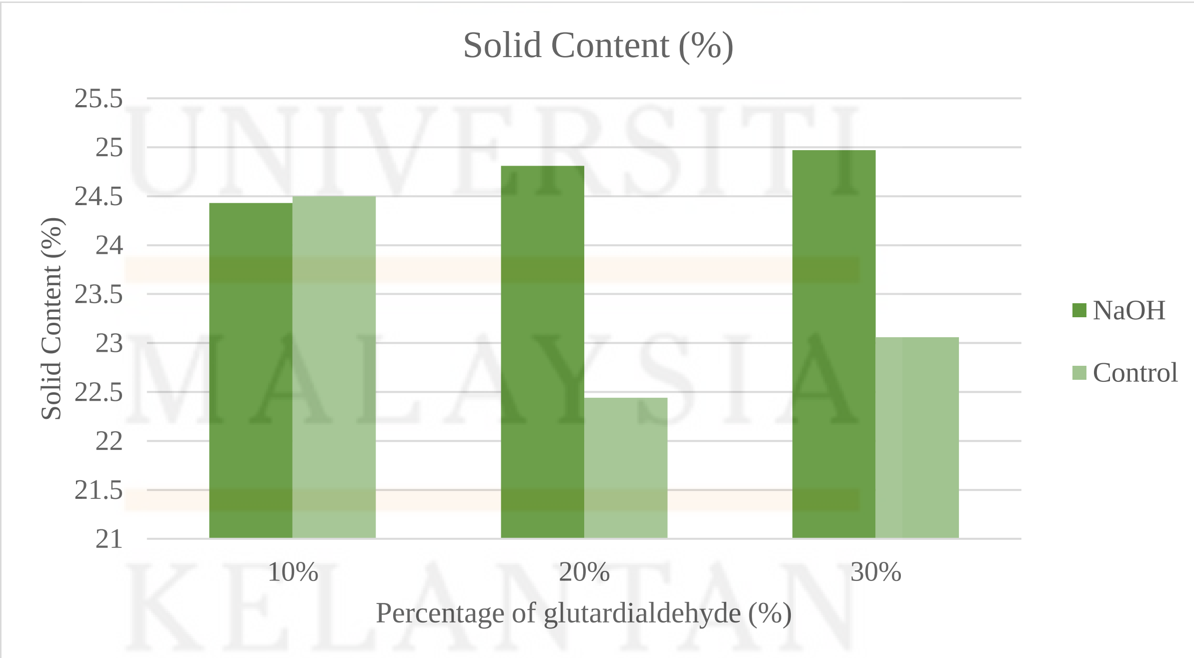

Figure 4.1: Mean of solid content (%) between two types of binder with different glutardialdehyde percentages used.

4.3 Physical properties analysis

In order to utilise wood to its more favourable position and most efficaciously in engineering applications, particular features or physical properties must be considered. The physical properties analysis were conducted in this study where they are density, moisture content, water absorption and thickness swelling of the plywood.

4.3.1 Density and moisture content

According to Frihart and his colleagues (2010), density is the most important physical properties of wood where it is the weight or mass of wood divided by the volume of the specimen at given moisture content. The units for density could vary in expression where the typical units used are pounds per cubic foot (lb/ft^3) or kilograms per cubic meter (kg/m^3). The moisture content also must be take into account when density values are reported in the literature. Table 4.1 shows mean values of density for both plywood using NaOH gelatinized glutardialdehyde modified starch binder and hot water gelatinized glutardialdehyde modified starch binder at three different percentages of glutardialdehyde used respectively.

Density of plywood spread with NaOH gelatinized glutardialdehyde modified starch binder is higher compared to plywood spread with hot water gelatinized glutardialdehyde modified starch binder that is 0.38 g/cm^3 the highest and 0.34 g/cm^3 the lowest. This effect could be due to the raw materials density, where the wood veneer species used were from rubber wood (*Hevea brasiliensis*) which have effect upon the plywood density where adhesive properties of the binder also take into account. This could have relation with the solid content results mentioned previously where NaOH gelatinized glutardialdehyde modified starch binder have higher solid content percentage compared to hot water gelatinized glutardialdehyde modified starch binder. The featured properties for plywood strength is density where higher density will give higher plywood strength (Khalil *et al.*, 2010).

Table 4.1: Density (g/cm^3)

Percentage of glutardialdehyde used (%)	NaOH binder	Control binder
10	0.37±0.02(a)	0.34±0.00(a)
20	0.38±0.03(a)	0.36±0.01(a)
30	0.38±0.02(a)	0.36±0.02(a)

*different letter in a same column and same type of binder showed significant difference at ɑ value of 0.05

Table 4.2 showed mean values of moisture content for all the plywood made for the experiment, after conditioning at 103±2 °C for 24 hours. For plywood spread with 30% NaOH gelatinized glutardialdehyde modified starch binder had the lowest moisture content while plywood spread with 30% hot water gelatinized glutardialdehyde modified starch binder had the highest moisture content of 23.67% This is due to the moisture absorption during the process of making hot water gelatinized glutardialdehyde modified starch binder where the vapour from the water bath absorbed into the binder and thus indirectly causing the plywood made from this binder to have higher moisture content.

Table 4.2: Moisture content (%)

Percentage of glutardialdehyde used (%)	NaOH binder	Control binder
10	21.84±1.70(a)	19.63±1.21(a)
20	21.60±2.12(a)	21.59±0.73(ab)
30	19.34±1.34(a)	23.67±0.61(b)

*different letter in a same column and same type of binder showed significant difference at ɑ value of 0.05

4.3.2 Water absorption and thickness swelling

According to Khalil and his colleagues (2010), the amount of moisture present in plywood would affect many physical properties of plywood. Identification of water absorption and thickness swelling rate were done to study the effect of type of binder on the dimensional stability of the plywood.

Figure 4.2 showed the water absorption rate for both plywood manufactured using NaOH and hot water gelatinized glutardialdehyde modified starch at three different percentages of glutardialdehyde used after 1 hr, 2 hrs, 4 hrs, 12 hrs and 24 hrs immersion of plywood in water. Plywood using NaOH gelatinized glutardialdehyde modified starch binder showed lower water absorption rate after being immersed in water at 1 hr, 2 hrs and 4 hrs compared to plywood using hot water gelatinized glutardialdehyde modified starch binder. However, after being immersed for 12 hrs and 24 hrs in water, plywood using NaOH gelatinized glutardialdehyde modified starch binder showed higher water absorption rate compared to plywood using hot water gelatinized glutardialdehyde modified starch binder.

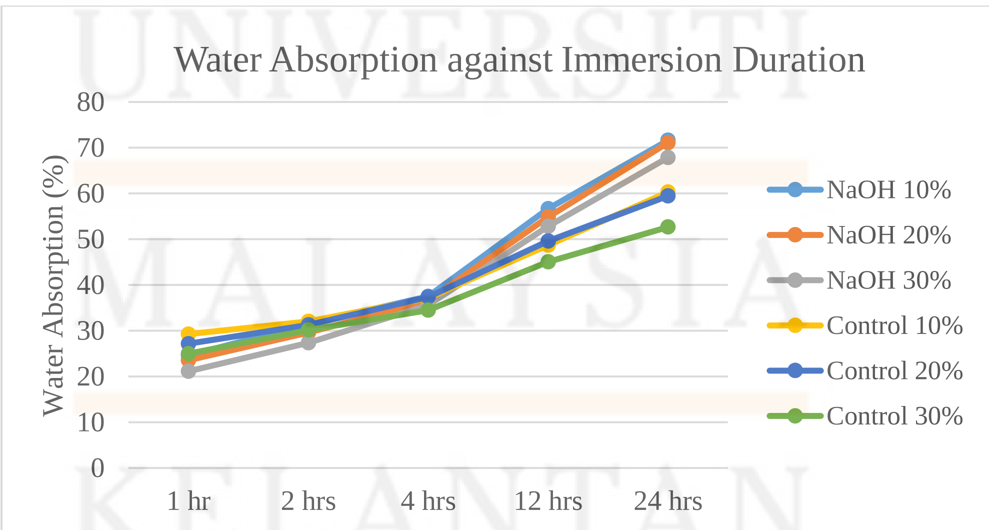

Figure 4.2: Water absorption rate for manufactured plywood.

Table 4.3 showed the statistical analysis of measured water absorption rate for plywood manufactured using NaOH gelatinized glutardialdehyde modified starch binder and hot water gelatinized glutardialdehyde modified starch showing mean values and standard deviations. Three different percentages of glutardialdehyde were used that were 10%, 20% and 30% based on weight of starch. Significant level evaluation using Tukey test done for every type of plywood showed that plywood were not significantly different to each other when compared between different types of binder and percentages of glutardialdehyde used.

Table 4.3: Statistical analysis of measured water absorption rate of the manufactured plywood compared between different types of binder and percentages of glutardialdehyde used.

Hrs. of immersion in water	**Percentages of glutardialdehyde used (%)**	**NaOH binder (%)**	**Control binder (%)**
1	10	24.56±0.75(b)	29.27±2.49(a)
	20	23.56±1.56(ab)	27.17±3.47(a)
	30	21.13±0.52(a)	24.99±0.95(a)
2	10	31.52±0.52(b)	32.03±2.64(a)
	20	29.59±1.00(ab)	31.26±3.00(a)
	30	27.35±1.45(a)	30.16±1.20(a)
4	10	37.49±1.20(a)	37.17±2.56(a)
	20	36.57±0.61(a)	37.34±3.87(a)
	30	35.60±0.13(a)	34.52±0.80(a)
12	10	56.64±0.57(a)	48.67±3.48(a)
	20	54.85±2.16(a)	49.56±3.66(a)
	30	52.85±2.02(a)	45.05±0.90(a)
24	10	71.60±1.48(a)	60.30±3.45(b)
	20	71.09±3.12(a)	59.45±3.14(ab)
	30	67.85±3.16(a)	52.65±1.74(a)

*different letter in a same column and same type of binder showed significant difference at ɑ value of 0.05

Thickness swelling indicates the increment of plywood's thickness after being immersed for a certain period. Figure 4.3 showed the thickness swelling rate for both plywood manufactured using NaOH and hot water gelatinized glutardialdehyde modified starch at three different percentages of glutardialdehyde used after 1 hr, 2 hrs, 4 hrs, 12 hrs and 24 hrs immersion of plywood in water. Plywood with control binder showed higher thickness swelling in overall compared to plywood with NaOH gelatinized glutardialdehyde modified starch binder. Despite of having higher water absorption rate for plywood using NaOH gelatinized glutardialdehyde modified starch binder, it have lower thickness swelling rate which may be due to wood structural panels criteria of being hygroscopic. It will absorb moisture from surroundings if it is dry and simultaneously will release moisture if it is in a dry surrounding and will achieve equilibrium in moisture with the vapour pressure around it (Khalid *et al.*, 2015). This hygroscopic criteria also responsible in the result of water absorption rate mentioned before. However, in overall, the thickness swelling for both plywood showed increasing trend since the particles in the plywood had expanded over immersion period. The geometry of wood particles, their structure and the presence of many voids in the plywood panel allow internal swelling will influence the rate of thickness swelling (Chiang *et al.*, 2012).

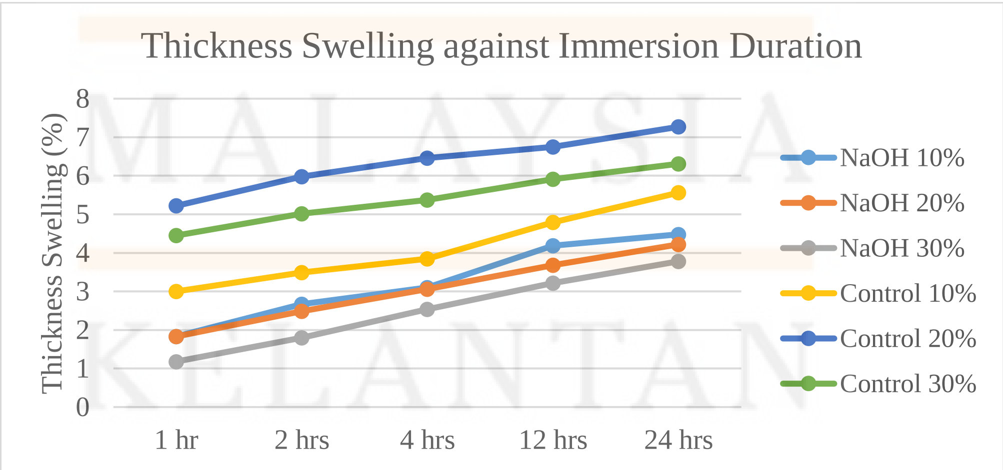

Figure 4.3: Thickness swelling rate for manufactured plywood.

Table 4.4 showed statistical analysis of measured thickness swelling rate of the manufactured plywood compared between different types of binder and percentages of glutardialdehyde used. Results showed that plywood were not significantly different to each other when compared between different types of binder and percentages of glutardialdehyde used except for plywood using hot water gelatinized glutardialdehyde modified starch binder after 4 hrs and 12 hrs of immersion time where when being compared between percentages of glutardialdehyde used, the results are significantly different with each other.

Table 4.4: Statistical analysis of measured thickness swelling rate of the manufactured plywood compared between different types of binder and percentages of glutardialdehyde used.

Hrs. of immersion in water	Percentages of glutardialdehyde used (%)	NaOH binder (%)	Control binder (%)
1	10	1.33±0.55(a)	3.00±0.47(a)
	20	1.83±0.26(a)	5.22±0.46(b)
	30	1.18±0.42(a)	4.45±0.24(b)
2	10	2.67±0.09(b)	3.49±0.27(a)
	20	2.49±0.23(b)	5.98±0.65(b)
	30	1.80±0.36(a)	5.02±0.22(b)
4	10	3.10±0.28(a)	3.85±0.21(a)
	20	3.06±0.42(a)	6.46±0.47(c)
	30	2.54±0.42(a)	5.37±0.22(b)
12	10	4.19±0.40(a)	4.79±0.12(a)
	20	3.68±0.84(a)	6.75±0.46(c)
	30	3.22±0.43(a)	5.91±0170(b)
24	10	4.48±0.40(a)	5.56±0.33(a)
	20	4.22±0.74(a)	7.27±0.54(b)
	30	3.77±0.26(a)	6.31±0.19(ab)

*different letter in a same column and same type of binder showed significant difference at α value of 0.05

4.4 Mechanical properties analysis

The mechanical properties of wood composites depend on many factors where they are wood species, types of adhesives used to bind the wood elements together, geometry of the wood elements and density of the final product or composite produced. The evaluation process of wood-based composites for both structural and non-structural applications use mechanical properties analysis ofttimes (Frihart *et al.*, 2010). The bending and tensile shear strength tests were conducted in this study with the aim to analyse mechanical properties of plywood manufactured.

4.4.1 Bending strength

Bending test generated two results that were modulus of rupture (MOR) and modulus of elasticity (MOE). Results for modulus of rupture were shown in Figure 4.4. Modulus of rupture reflects the strength properties of wood where the maximum load-carrying of a member in bending and is proportional to maximum moment endured by the specimen (Frihart *et al.*, 2010). The results showed that modulus of rupture for both plywood with two types of binder were in increasing trend where it is 152.89 N/mm^2, 174.85 N/mm^2 and 179.32 N/mm^2 for plywood using 10%, 20% and 30% NaOH gelatinized glutardialdehyde modified starch binder respectively and 124.88 N/mm^2, 156.94 N/mm^2 and 175.26 N/mm^2 for plywood using 10%, 20% and 30% hot water gelatinized glutardialdehyde modified starch binder respectively. All of the manufactured plywood passed the Japanese Industrial Standard which required a minimum of 20.0 N/mm^2 of modulus of rupture for plywood with thickness ranging from 12 to 21 mm.

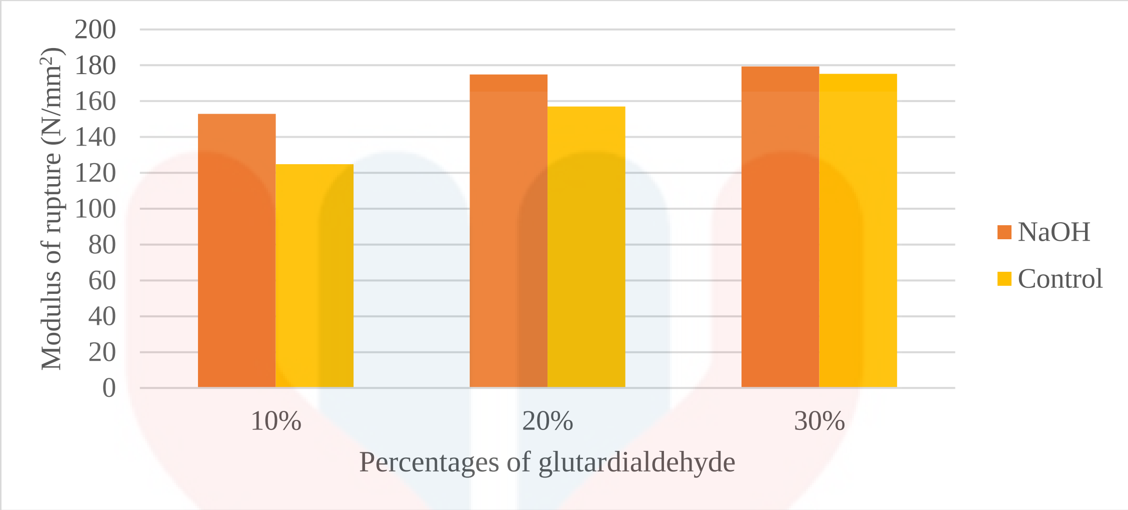

Figure 4.4: Modulus of rupture for manufactured plywood.

Modulus of elasticity indicated the measure of the resistance to bending deflection, which is relative to the stiffness. Elasticity expresses that distortions produced by low stress under the proportional limit are completely recoverable after loads are removed. However, when more stress is loaded beyond the proportional limit, distortion will occur or also called as failure or plastic deformation (Frihart *et al.*, 2010). Figure 4.5 showed the results for modulus of elasticity. The trend was in increasing order for both plywood with NaOH and hot water gelatinized glutardialdehyde modified starch binder where the modulus of elasticity for plywood with NaOH gelatinized glutardialdehyde modified starch binder were 8027.50 N/mm^2, 9689.76 N/mm^2 and 10603.90 N/mm^2 for 10%, 20% and 30% glutardialdehyde used respectively. Meanwhile, for plywood using 10%, 20% and 30% hot water gelatinized glutardialdehyde modified starch binder, the modulus of elasticity were 10214.07 N/mm^2, 10471.45 N/mm^2 and 10540.36 N/mm^2 respectively.

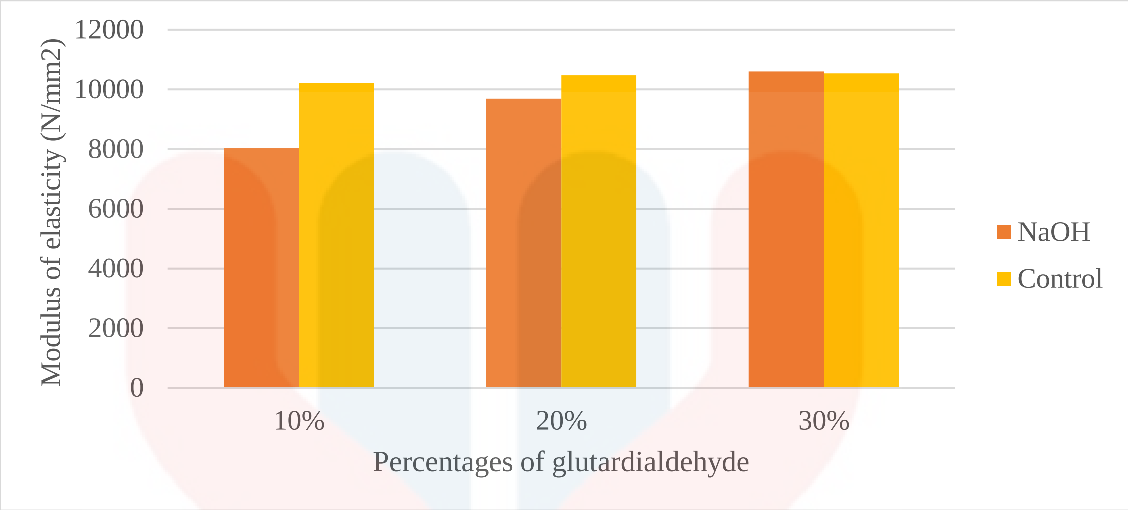

Figure 4.5: Modulus of elasticity for manufactured plywood.

The significant values (p-values) for both modulus of rupture and modulus of elasticity at two different types of binder were shown in Table 4.5. The p-values for MOR at all three percentages of glutardialdehyde used were not significant as $p>0.05$. For MOE, the results were not significant at percentages of 20% and 30% with $p>0.05$, 0.247 and 0.949 respectively but significant at 10% with $p<0.05$, 0.008.

Table 4.5: p-values for MOR and MOE at three different percentages.

Percentages of glutardialdehyde (%)	MOR	MOE
10	0.081	0.008
20	0.368	0.247
30	0.820	0.949

4.4.2 Tensile shear strength

Tensile shear strength or Young's modulus is a measure of resistance to elongation or shortening of a member under tension or compression. Figure 4.6 showed Young's modulus for manufactured plywood. Plywood with NaOH gelatinized glutardialdehyde modified starch binder showed increasing trend of strength as percentages of glutardialdehyde used increased while it became otherwise for plywood with hot water gelatinized glutardialdehyde modified starch. The mean values of Young's modulus for plywood with NaOH gelatinized glutardialdehyde modified starch binder were 709.92 N/mm^2, 772.11 N/mm^2 and 1385.16 N/mm^2 for 10%, 20% and 30% of glutardialdehyde used respectively. Meanwhile, for plywood with hot water gelatinized glutardialdehyde modified starch binder, they were 997.46 N/mm^2, 809.74 N/mm^2 and 651.64 N/mm^2 for 10%, 20% and 30% of glutardialdehyde used respectively. The difference in results could be due to higher moisture content of plywood with hot water gelatinized glutardialdehyde modified starch binder compared to plywood with NaOH gelatinized glutardialdehyde modified starch binder.

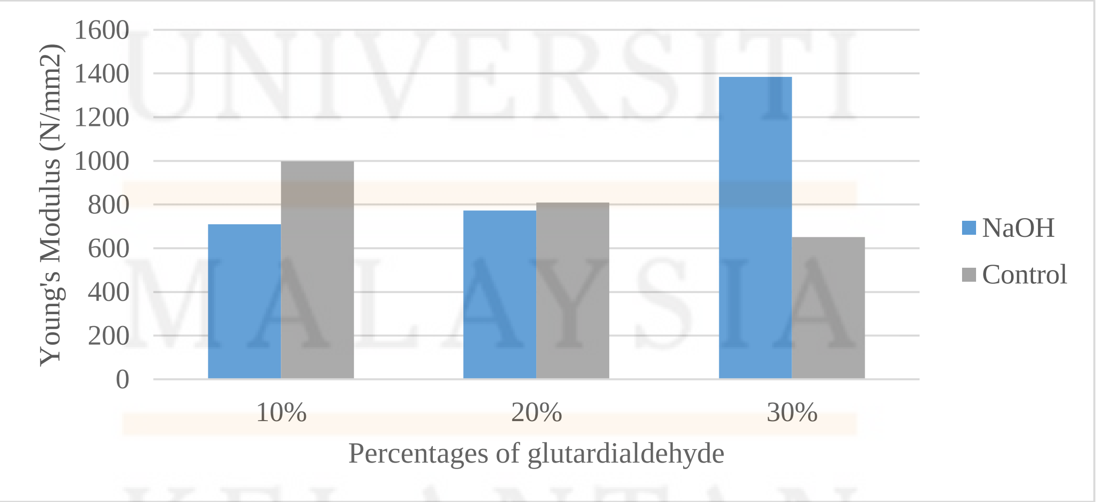

Figure 4.6: Young's modulus for manufactured plywood.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the obtained invigorating results from this research, NaOH and hot water gelatinized glutardialdehyde modified starch are suitable to be used as plywood binder. The strength produced by plywood using modified starch binder had passed the requirements needed by Japanese Agricultural Standards (JAS) No. 233:2003 requirements. Plywood using NaOH gelatinized glutardialdehyde modified starch binder showed better results in most of tests conducted where in tensile shear strength test, the results were comparable to plywood using hot water gelatinized glutardialdehyde modified starch binder with different trend of results obtained.

It is also proven that moisture content showed significant effect on mechanical properties of manufactured plywood where plywood using NaOH gelatinized glutardialdehyde modified starch binder with lower moisture content showed better performance in mechanical testing. Other than that, most of the preferable results obtained were from plywood using 30% NaOH gelatinized glutardialdehyde modified starch binder, indicating that different glutardialdehyde : starch ratio have effect on the plywood properties. Thus, it can be concluded that the objectives of this study were achieved.

5.2 Recommendations

Regardless of the good results obtained with this study, further study should be done to find the optimum parameters to obtain the best in plywood strength and efficient usage of raw materials in ensuring sustainable environment. More tests should be done to identify the effect of different chemical agents used to modifiy starch, different amount of binder loadings and different pressing time. Determination of optimum binder loading will be able to increase the efficiency of raw material usage while determination of different pressing time and temperatures could help cut down the cost of plywood manufacturing. After all the optimum parameters were determined, these plywood made using chemically modified starches can be commercialized for the market and the initial intention of reducing the usage of formaldehyde-based binder could be achieved.

REFERENCES:

Adhikary, K. B., Pang, S., & Staiger, M. P. (2008). Dimensional stability and mechanical behaviour of wood – plastic composites based on recycled and virgin high-density polyethylene (HDPE). *Composites Part B: Engineering*, *39*, 807–815.

Amini, M. H. M., Hashim, R., Sulaiman, N. S., Hiziroglu, S., Sulaiman, O., Mohamed, M., & Mat Rasat, M. S. (2015). Glutardialdehyde modified corn starch – urea formaldehyde resin as a binder for particleboard making. *Applied Mechanics and Materials*, *754-755*, 89–93.

American Plywood Association. (1997). *Plywood Design Specification*. *The Engineered Wood Association*. Washington.

Article, R., Neelam, K., Vijay, S., & Lalit, S. (2012). Various techniques for the modification of starch and the applications of its derivatives. *International Research Journal of Pharmacy*, *3*(5), 25–31.

Ashori, A. (2008). Wood – plastic composites as promising green-composites for automotive industries. *Bioresource Technology*, *99*, 4661–4667.

Aydin, I., & Colakoglu, G. (2016). Variation in surface roughness , wettability and some plywood properties after preservative treatment with boron compounds. *Building and Environment*, *42*(April), 3837–3840.

Ayrilmis, N., Buyuksari, U., Avci, E., & Koc, E. (2009). Utilization of pine (Pinus pinea L.) cone in manufacture of wood based composite. *Forest Ecology and Management*, *259*(1), 65–70.

Bekhta, P., Hiziroglu, S., & Shepelyuk, O. (2009). Properties of plywood manufactured from compressed veneer as building material. *Materials and Design*, *30*, 947–953.

BeMiller, K. C. H. and J. N. (2010). Starches. In A. C. Bertolini (Ed.) (pp. 145–204). CRC Press.

Bohm, M., Salem, M. Z. M., & Srba, J. (2012). Formaldehyde emission monitoring from a variety of solid wood, plywood, blockboard and flooring products manufactured for building and furnishing materials. *Journal of Hazardous Materials*, *221-222*, 68–79.

Chiang, T. C., Osman, M. S., & Hamdan, S. (2014). Water absorption and thickness swelling behaviour of sago particles urea formaldehyde particleboard. *International Journal of Science and Research*, *3*(12), 1375–1379

Ebnesajjad, S. (2008). *Adhesives Technology Handbook*. (S. Ebnesajjad, Ed.) (Second). William Andrew Inc.

Eckelman, C. A. (1999). *Brief survey of wood adhesives*. Purdue University Cooperative Extension Service.

Fang, L., Chang, L., Guo, W., Ren, Y., & Wang, Z. (2013). Preparation and characterization of wood-plastic plywood bonded with high density polyethylene film. *European Journal of Wood and Wood Products*, 1–8.

Frihart, C. R. (2015). Introduction to Special Issue Wood Adhesives : Past , Present , and Future. *Forest Products Journal*, *65*, 4–8.

Frihart, C. R., Hunt, C. G., Stark, N. M., Cai, Z., & Carll, C. (2010). *Wood Handbook: Wood as an Engineering Material*. (R. J. Ross, Ed.) (Centennial).

Gao, W., & Du, G. (2015). Physico-mechanical properties of plywood bonded by nano cupric oxide (CuO) modified PF resins against subterranean termites. *Ciencia Y Technologia*, *17*(1), 129–138.

Garcia-Pacios, V., Iwata, Y., Colera, M., & Martín-Martínez, J. M. (2011). Influence of the solids content on the properties of waterborne polyurethane dispersions obtained with polycarbonate of hexanediol. *International Journal of Adhesion and Adhesives*, *31*(8), 787-794.

Gavrilovic-Grmusa, I., Miljkovi, J., Rado, G., & Diporovic-Momcilovic, M. (2008). Penetration of urea-formaldehyde adhesives in wood tissue. Part 1: Radial penetration of UF adhesives into beech, *98*, 39–48.

Gravitis, J. (2007). Zero techniques and systems - ZETS strength and weakness. *Journal of Cleaner Production*, *15*, 1190–1197.

Huang, J., & Li, K. (2008). A new soy flour-based adhesive for making interior type II plywood. *Journal of the American Oil Chemists' Society*, *85*(1), 63–70.

Japanese Agricultural Standards. (2003). JAS for plywood. *Japanese Agricultural Standards Association, Tokyo*.

Jun-you, S., & Shu-min, W. (2006). Study on modification of API adhesive by corn starch. *China Adhesives*, 35–37.

Kaboorani, A., & Riedl, B. (2011). Improving performance of polyvinyl acetate (PVA) as a binder for wood by combination with melamine based adhesives. *International Journal of Adhesion and Adhesives*, *31*(7), 605–611.

Kaith, B. S., Jindal, R., Jana, A. K., & Maiti, M. (2010). Development of corn starch based green composites reinforced with Saccharum spontaneum L fiber and graft copolymers – Evaluation of thermal , physico-chemical and mechanical properties. *Bioresource Technology*, *101*(17), 6843–6851.

Khalid, H., Ahmad, Z., Tahir, P. M., & Kasim, J. (2016). Investigation on the water absorption characteristics of plywood manufactured using veneers from oil palm stem. *Jurnal Teknologi (Sciences & Engineering)*, *5*, 99–103.

Khalil, H. P. . A., Fazita, M. R. N., Bhat, A. H., Jawaid, M., & Fuad, N. A. N. (2010). Development and material properties of new hybrid plywood from oil palm biomass. *Materials and Design*, *31*(June), 417–424.

Lai, L. N., Karim, A. A., Norziah, M. H., & Seow, C. C. (2004). Effects of Na2CO3 and NaOH on pasting properties of selected native cereal starches. *Journal of food science*, *69*(4), FCT249-FCT256.

Lei, H., Du, G., Wu, Z., Xi, X., & Dong, Z. (2014). Cross-linked soy-based wood adhesives for plywood. *International Journal of Adhesion and Adhesives*, *50*, 199–203.

Li, Z., Wang, J., Cheng, L., Gu, Z., Hong, Y., & Kowalczyk, A. (2014). Improving the performance of starch-based wood adhesive by using sodium dodecyl sulfate. *Carbohydrate Polymers*, *99*, 579–583.

Liew, K. C., & Grace, S. (2016). Engineered Wood Composite of Laminated Veneer Lumber: Physical and Mechanical Properties. In *Materials Science Forum* (Vol. 842, pp. 103-128). Trans Tech Publications.

Lin, Q., Chen, N., Bian, L., & Fan, M. (2012). Development and mechanism characterization of high performance soy-based bio-adhesives. *International Journal of Adhesion and Adhesives*, *34*, 11–16.

Moubarik, A., Allal, A., Pizzi, A., Charrier, F., & Charrier, B. (2010). Characterization of a formaldehyde-free cornstarch-tannin wood adhesive for interior plywood. *European Journal of Wood and Wood Products*, *68*(4), 427–433.

Moubarik, A., Pizzi, A., Allal, A., Charrier, F., & Charrier, B. (2009). Cornstarch and tannin in phenol-formaldehyde resins for plywood production. *Industrial Crops and Products*, *30*(2), 188–193.

Muthike, & Githiomi. (2011). *Choice and utilization of adhesives in wood gluing: Guidelines for users of Wood Adhesives*.

Nadiha, M. N., Fazilah, A., Bhat, R., & Karim, A. A. (2010). Comparative susceptibilities of sago, potato and corn starches to alkali treatment. *Food chemistry*, *121*(4), 1053-1059.

Preiss, J., Solarek, D., Perez, S., Whistler, R. L., Schwartz, D., Biliaderis, C. G., & Chiu, C. (2009). *Starch: Chemistry and Technology*. (J. BeMiller & R. Whistler, Eds.) (Third).

Wang, Z., Gu, Z., Hong, Y., Cheng, L., & Li, Z. (2011). Bonding strength and water resistance of starch-based wood adhesive improved by silica nanoparticles. *Carbohydrate Polymers*, *86*(1), 72–76.

Wechsler, A., & Hiziroglu, S. (2007). Some of the properties of wood – plastic composites. *Building and Environment*, *42*, 2637–2644.

Yang, L., Liu, J., Du, C., & Qiang, Y. (2013). Preparation and properties of cornstarch adhesives. *Advance Journal of Food Science and Technology*, *5*(8), 1068–1072.