



Faculty of Engineering

**Physical, Mechanical and Thermal Properties of Sago Fiber Reinforced  
Composite Particleboard**

**Tay Chen Chiang**

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# Physical, Mechanical and Thermal Properties of Sago Fiber Reinforced Composite Particleboard

Tay Chen Chiang

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## **DECLARATION**

This is to certify that, the thesis work entitled “ physical, mechanical and thermal properties of sago fiber reinforced composite particleboard ” has been done by the candidate himself and does not contain any material extracted from elsewhere or from a work published by anybody else. The thesis has not been accepted for any degree and is not concurrently submitted in candidature for any other degree.

.....

Tay Chen Chiang  
Matric Number: 14010091  
Faculty of Engineering  
Universiti Malaysia Sarawak  
Date : 12/12/2017

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## ABSTRACT

In this research, sago particles with adhesive of low emission Urea Formaldehyde (UF) resin with 51.6% solid content are the main focus. The optimum performance of sago urea formaldehyde composite particleboard is determined. The fabrication process is based on JIS A 5908 standard. Sago residues have chemical reactivity with the matrix such as UF or phenol formaldehyde (PF) due to the lignocellulose composition. They are able to be hot-pressed into particleboard. The feasibility of hybrid particleboard made from sago mixed with waste wood was investigated. The processing and material parameters for an optimized board were identified based on the right particle size, weight fraction, density, matrix and hybrid while the effect of parameter was investigated through mechanical, physical and thermal analysis. The results showed composite particleboard with  $800 \text{ kg/m}^3$  exhibited the optimum strength. The optimum mechanical properties were achieved at 80wt% of sago particles with particles size 1.18mm. Hybrid composite particleboard fabricated with ratio sago 25wt% and waste wood 75wt% able to improve the mechanical and physical properties. The board performance was determined by the strength of the material, chemical bonding and its density. The interaction between particles depends on the particle and matrix bonding. The structure of the sago particleboard depends on the particle size, packing and the relative ratio. The sago particleboard met the requirement for ANSI A208.1-2009 as the door core, industrial and commercial purpose. The percentage of water absorption and thickness swelling increased with the weight fraction of particles. Composite particleboard made by PF has higher water absorption and thickness swelling compared with composite particleboard made by UF. The percentage of thickness swelling and water absorption can be reduced by impregnating higher loading of UF and PF. Sago UF/PF composite particleboard decomposed in single stage decomposition. The first step of decomposition is determination of moisture content while the

second step is dehydration reaction on the polymer chain and final step is residues conversion to carbon. Differential Scanning Calorimetry (DSC) showed an endotherm peak between 50 °C – 100 °C which indicates the high amount of water molecules in the board. Generally, sago particles decomposed at 230 °C to 350 °C which indicated the loss of amorphous structure like hemicellulose, cellulose and lignin. The double endothermic peaks were due to the thermal decomposition of sago particles and filled with UF. Starch in the particleboard had contributed the high melting temperature due to cross-linking reaction between starch granules. Sample with single exotherm was found to be more thermally stable than those with multiple exothermal peaks. In hybrid particleboard, the addition of waste wood has improved the curing speed and better bonding between particles. Fourier transform infrared spectroscopy (FTIR) showed the bonding between functional group of sago particles and UF as well as the chemical interaction, which confirmed that the reactions between all the components in the composite system and thus, enhanced the mechanical strength of hybrid particleboard. A stable hydrogen bond was formed between UF and starch through chemical reaction. The scanning electron microscope (SEM) images showed that excellent dispersion of sago particles with matrix was important for stronger bonding. The better interfacial bonding and adhesion as well as reduction of micro-voids at the filler matrix interface occurred upon increasing of the matrix. SEM also showed the interaction between the sago particles and UF matrix was unsatisfactory due to particles debonding, particles pull-out, matrix fracture and particles damage occurred in sago UF particleboard.

**Keywords:** Sago composite particleboard, urea formaldehyde, physical and mechanical properties, thermal analysis.

## ***Kestabilan Termal, Sifat-sifat Mekanikal dan Fizikal Komposit Papan Partikel Sagu***

### **ABSTRAK**

*Dalam kajian ini, partikel sagu dengan pelekat resin urea-formaldehid (UF) dengan kandungan pepejal 51.6% adalah fokus utama dan prestasi optimum papan partikel sagu urea -formaldehid dikenalpastikan. Proses fabrikasi adalah berdasarkan Piawaian JIS A 5908. Sisa sagu yang mempunyai komposisi lignoselulosa bertindak balas secara kimia dengan matriks seperti UF atau PF (fenol-formaldehid) dan boleh menjalani proses “hot press”. Kesesuaian sisa sagu dan kayu dicampur aduk menjadi papan hibrid telah dianalisis. Pemprosesan dan parameter bahan untuk papan yang mempunyai prestasi optimum telah dikenal pasti berdasarkan saiz partikel, pecahan berat, ketumpatan, matriks dan hibrid manakala kesan parameter diujikaji melalui analisa mekanikal, fizikal dan terma. Hasil kajian menunjukkan papan partikel dengan 800 kg/m<sup>3</sup> mempamerkan kekuatan optimum. Sifat mekanikal yang optimum dicapai pada kadar 80% berat zarah sagu dengan partikel bersaiz 1.18 mm. Papan partikel komposit hibrid yang dihasilkan dengan nisbah sagu 25% berat dan sisa kayu 75% berat mampu meningkatkan sifat mekanikal dan fizikal. Prestasi papan dipengaruhi oleh kekuatan bahan, komposisi kimia dan ketumpatan. Interaksi antara partikel bergantung kepada ikatan partikel dan matriks. Struktur papan partikel sagu bergantung kepada saiz partikel, kepadatan dan nisbah relatif. Papan partikel sagu telah memenuhi syarat piawaian ANSI A208.1-2009 sebagai teras pintu untuk tujuan industri dan komersial. Keputusan ujikaji menunjukkan bahawa peratusan penyerapan air dan pengembangan ketebalan bertambah dengan peningkatan pecahan berat partikel. Partikel yang diperbuat daripada PF mempunyai penyerapan air dan pengembangan ketebalan lebih tinggi berbanding partikel diperbuat daripada UF. Peratusan pengembangan ketebalan dan*

penyerapan air boleh dikurangkan dengan menggunakan peratusan UF dan PF yang lebih tinggi. Papan sago UF/PF mereput dalam penguraian peringkat tunggal. Langkah pertama penguraian adalah penentuan kandungan lembapan manakala langkah kedua adalah tindak balas dehidrasi pada rantai polimer dan langkah terakhir melibatkan penukaran sisa kepada karbon. Kalorimetri Imbasan Perbezaan (DSC) menunjukkan puncak endotermik pada 50 °C-100 °C yang menunjukkan papan partikel sago UF/PF mengandungi jumlah molekul air yang banyak. Secara umumnya, partikel sago mereput antara 230 °C-350 °C dan ini menunjukkan bahawa kehilangan struktur amorfus seperti hemiselulosa, selulosa dan lignin. Puncak gandaan endotermik adalah disebabkan oleh penguraian terma zarah sago dan dipenuhi oleh UF. Sampel dengan eksotermia tunggal lebih stabil daripada sampel yang mempunyai pelbagai puncak eksotermia. Penambahan sisa kayu dalam papan hibrid telah meningkatkan kelajuan pengawetan dan ikatan antara partikel. Spektroskopi Inframerah Fourier (FTIR) menunjukkan ikatan antara kumpulan berfungsi partikel sago dan UF serta interaksi kimia. Ini mengesahkan tindak balas antara semua komponen dalam sistem komposit dan ini meningkatkan kekuatan mekanikal bagi papan partikel jenis hibrid. Mikroskop Pengimbasan Elektron (SEM) menunjukkan bahawa penyebaran partikel sago dengan matriks adalah penting untuk pembentukan ikatan yang kuat dalam sistem komposit. Ikatan dan lekatan antara permukaan papan menjadi lebih baik dan lebih banyak pengurangan ruang kosong mikro di pengisi matriks apabila peratusan matriks ditingkatkan. SEM juga menunjukkan interaksi antara partikel sago dan UF matriks adalah kurang memuaskan disebabkan oleh zarah nyahikatan, partikel tercabut, kerosakkan matriks dan partikel yang telah wujud dalam komposit.

**Kata kunci:** Papan komposit sago, urea-formaldehid, sifat-sifat fizikal and mekanikal, analisis haba.

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## LIST OF ABBREVIATIONS

|                    |                                            |
|--------------------|--------------------------------------------|
| OSB                | Oriented Strand Boards                     |
| NH <sub>4</sub> Cl | Ammonium Chloride                          |
| UF                 | Urea Formaldehyde                          |
| PF                 | Phenol Formaldehyde                        |
| PRF                | Phenol Resorcinol Formaldehyde             |
| MF                 | Melamine Formaldehyde                      |
| MOR                | Modulus Of Rupture                         |
| MOE                | Modulus Of Elastic                         |
| IB                 | Internal Bonding                           |
| ASTM               | American Society for Testing and Materials |
| FTIR               | Fourier Transforms Infrared                |
| TGA                | Thermo Gravimetric Analysis                |
| DSC                | Different Scanning Calorimetry             |
| NH <sub>4</sub> Cl | Ammonium Chloride                          |
| Ø                  | Diameter                                   |

# CHAPTER 1

## GENERAL INTRODUCTION

### 1.1 Introduction

Nowadays, wood products are important due to the growing population that enlightened the challenges for forestry and forest to source the specific type of trees with good qualities and properties. Therefore, researchers are trying to look for alternative ways to reduce full dependence on natural resources. The scientists sought for new resources like agro-residues materials mixed with thermoset resin as composite particleboard to substitute the wood resources application. The demand for composite particleboard from lignocellulosic fiber has been increasing as timber resources in natural forests decline. Researchers are highly interested in utilization of lignocellulose residues for manufacturing of composite particleboard due to naturally abundant (Salem *et al.*, 2014). It is easily adapted to various types and forms of panel. In addition, lignocellulose residues are excellent in physical and chemical properties which make it more effective in the development of composite particleboard and reduced the wood consumption (Salem *et al.*, 2015). However, the application of the lignocellulose fiber is limited to the furniture industries. In furniture industries, it is difficult to look for the right lignocellulose material as particleboard due to the structural and non-structural application. To obtain excellent properties of composite particleboard, preparation and the structural relationships between the matrix and lignocellulose materials should be highly studied.

The interest using composite particleboard in the furniture industries has increased dramatically during the last few years. During 2012, China, India, Malaysia, Vietnam and South American countries had showed the high consumption of composite particleboard for

the furniture and cabinet making and this increase slightly by 2017 (Sawmillers 2016). The production of composite particleboard can replace a variety of wood base products due to the simple manufacturing method and cost effective.

Composite particleboard is described as board manufactured by hot compression of dry wood particles that have been sprayed with binder resin and compress under the pressure and heat (Enayati *et al.*, 2013). Usually the composite particleboard are made from wood chips, sawmill shavings or saw dust with synthetic resin.

The process of making composite particleboard usually consists of gluing fiber pieces together with a binder, forming them into a mat and pressing them into the final product. The binder is typically a thermosetting or heat-curing resin often made from formaldehydes. The advantages of composite particleboard are low cost, light weight, perfect for ready-made furniture and easily to machine (cut, drilled and milled). The major disadvantages of particleboard is low strength and prone to getting damaged because of moisture and humidity (Sari *et al.*, 2012). In this study, the mechanical and physical properties will be the major concern for the particleboard application.

An emphasis on ecological development by government, new methods involving sago usage re being explored in the furniture industries. Mukah-Sarawak Malaysia and Province of Sulawesi Tenggara are the biggest sago starch processing industries and rich in agricultural residues from sago starch processing industries are abundant and readily available (Awg-Adeni *et al.*, 2010; Aripin *et al.*, 2007). Based on the research done by scientists, about 7 tons (t) of sago pith waste has been produced daily from a single sago starch processing mill (Awg-Adeni *et al.*, 2010). The residues from its production tend to be discharged to rivers, burnt in field deposited in the factory compound (Toh *et al.*, 2011; Aripin *et al.*, 2007). Improper disposal of sago waste had become an issue for public society because of the health

risk. The proper disposal system or converting the sago waste into useful product is the possible way for controlling the environment pollution like contamination of water sources and health risk to public. Scientist had emphasis on the bioconversion products by turning the waste into the added value products like ceramic (sago waste/clay) for effective waste management purposes (Aripin *et al.*, 2007). The exploitation of these residues from sago starch processing industry such as sago bark and residues can be used for global environmental conservation and is sustainable for research and development. Using the sago residues into the composites industry will help saving the cost and creating a market value product such as particleboard, low density fibreboard, decking, desks, shelves, cabinets and fencing. New types of particleboard (sago) should be investigated to get the optimal properties to substitute the virgin material.

Sago palm also known as *Cycas revoluta* belonged to the *Palmae* family. The palm can reach a maximum height of 25 m with 40 cm diameter (Hairul *et al.*, 2016). It consists of leaflets, rachis, trunk cortex and pith. Sago palm was used as monosodium glutamate, glucose, paper products, yeast, textiles and laundry industries. The pith was used as animal feed and the trunk cortex, which were full with fibres, became the waste material (Hairul *et al.*, 2016). Therefore, it was interesting to investigate the sago residues to become a useful raw material as composite particleboard. According to Evi *et al.* (2008) sago provided various advantages of the crop, such as economically acceptable, relatively sustainable, environmentally friendly, uniquely versatile, vigorous and promotes socially stable agro-forestry systems. According to Bhupinder *et al.* (2008) Sarawak government had carried the research and development work on the sago palm since 1987 on the application.

Besides, urea-formaldehyde was chosen as binder in the particleboard industries due to advantages such as high reactivity, excellence performance and low cost. Urea-formaldehyde

is a non-transparent thermosetting resin, which are made by the combination of urea and formaldehyde heated with ammonia or pyridine. The properties of Urea-formaldehyde are high tensile strength, flexural modulus, high heat distortion temperature, low water absorption, high surface hardness and higher stability. Conner *et al.* (1996) had mentioned that more than 70% of urea-formaldehyde resin is used in forest industry products, which are particleboards (61%), hardwood plywood (5%) and medium density fiberboards (27%). However, UF has limited usage like higher water absorption, formaldehyde emission, decomposes and mould shrinkage (Dunky *et al.*, 2015).

In this study, urea formaldehyde adhesives act as matrix and used to bond the sago particles as reinforcement. The reinforcing particles is the main load carrying component in the composite particleboard. It provides high strength and stiffness as well as resistance to bending and breaking under the applied stress. The interface adhesion between the urea formaldehyde and sago particles will be major concern for improved compatibility and developing a mechanical or chemical bonding.

Many research works have been carried out to identify the parameters that influence the mechanical and physical properties of the particleboard. One of the important parameters is that the particle size should be well determined during the particleboard fabrication. This is because the properties of the particleboard depend on the inter-particle bonding. The particle size strongly influenced the availability of particle surface for gluing. The number and area of inter-particle contact will contribute to the overall final panel strength (Emmanuel *et al.*, 2008). The optimum particle size had enhanced the stress transfer from matrix to fibers for improving the mechanical properties of the board (Cezary *et al.*, 2011). Generally, it has been found that the reinforcement effect was influenced by the particle size.

It was found that better physical and mechanical properties was influenced by the board density and matrix. The higher density of the composite particleboard is usually associated with higher mechanical properties. Therefore, density was major concern for this study. The performance of bonding between adhesive types and matrix loading need to be consider during the particleboard fabrication because it will affect the overall particleboard strength.

This research had proved hybrid composite particleboard showed better physical and mechanical properties due to the consistent performance and higher mechanical strength. The properties of the hybrid composite particleboard will improved the final performance of board and resulting in positive effects to the wood-based industry (Zeki, 2015).

In this research, new sustainable bio-based composite particleboard have been studied as alternative for the furniture application. Their performance in furniture application has been demonstrated, including physical properties, mechanical properties, thermal properties, morphological and properties.

## **1.2 Problem statement**

Nowadays, Sarawak furniture manufacturers faced a shortage of timber supplies and most of the high quality tropical timber produced in Sarawak was export to Japan, South Korea and China. This had caused the furniture manufacturers in Sarawak face the shortage of high quality timber materials in domestic market for the furniture application. Industrialists and researchers have been looking for an alternative to replace the wood materials using the agro-residues in the furniture industries.

Composite particleboards are materials with high demand due to their unique characteristics. However, the composite particleboard cannot be applied widely due to the limitation of their properties to certain extend and environmental concern. Composite

particleboards are in hydrophilic nature and their drawbacks are low thermal resistance, low mechanical properties and poor adhesion. The presence of hydroxyl groups as indicated by the void spaces can be observed in composite particleboard.

In Sarawak, it has been approximated that 7 tons(t) of sago pith waste was generated daily from a single sago starch processing factory (Awg-Adeni *et al.*, 2010). Those residues from production was discharged to rivers, deposited in factory compound and cause the health risk for public society and environment pollution. According to Toh *et al.* (2011), huge amounts of sago waste were decomposed naturally in the farmland or burned after the sago starch extraction. This had caused the serious environmental problem and health hazards. The sago residues is selected to become the raw material for the composite particleboard is an alternative to solve this problem. This leads to growing tendency of recycling of sago residues and using them as production of composite particleboard.

Therefore, a study on the characteristics of composite particleboard on thermal analysis, physical and mechanical properties was conducted in this research to determine whether the sago urea formaldehyde can substitute the wood and widely applied in furniture industries.

### **1.3 Research hypothesis**

The sago composite particleboard with thermal stability, physical and mechanical properties will be established in this research. It is speculated that the thermal stability, mechanical and physical properties are related to the parameter like particle size, weight fraction, matrix and density. The particleboard morphology is related to the matrix and type of lignocellulosic fibres, density set up and weight fraction of particles with matrix. In this study, the type of constituent-morphology-properties relationship of sago composite particleboard

can be well investigated by studying the effect of particle size, weight fraction, density, matrix and hybrid properties.

#### **1.4 Research gap**

In recent years, there is a growing interest in development of new materials enhances optimal utilization of natural resources on the lignocellulosic composite particleboard. It is speculated that the type of matrix, density, weight fraction and lignocellulosic fibers will affect the morphology of the composite particleboard. To date, there is no study on the mechanical and physical properties on sago urea formaldehyde composite particleboard. Furthermore, the potential of using sago residues as composite particleboard has not been explored by researchers. There are the gaps in literature for lignocellulosic fiber for composite particleboard and these gaps have posed significant limitations to the furniture industry application. Hence, focus will be emphasize on the characterization and properties of the sago composite particleboard.

Without a well-established processing-morphology-properties, the materials and manufacturing engineers are not able to predict the final performance of the composite particleboard. In addition, properties like mechanical, physical and thermal analysis will be studied along with the characterization of the sago composite particleboard. In the point of manufacturing cost, the lignocellulosic residues are used in the composite particleboard fabrication and the cost can be reduced as the expensive matrix can be saved up in the particleboard formulation. Since the target application of new composite particleboard is for furniture application, the key properties hat determine the performance of composite particleboard. More emphasis will be placed on these properties. Parameter like particle size, density, matrix to be used and hybrid composite particleboard should be studied for better mechanical and physical performance at composite particleboard.

## **1.5 Research objectives**

The aim of this research is to study the thermal, physical and mechanical properties of lignocellulosic residue fibers reinforced with urea formaldehyde matrix as composite particleboard. The research focuses on environmental friendly and making use of the waste material such as sago. Application of lignocellulose materials will give better mechanical performance for the composites particleboard. Besides, it is more environmentally friendly, cheaper and denser than hardwood. Waste from the natural resources can be recycled into valuable products and reduce the environmental stress. In order to achieve this aim, the following objectives were fulfilled:

The main objectives include:

- a. To fabricate the sago composite particleboard with various parameters and investigate optimal parameters for better sago composite particleboard.
- b. To determine and analysis the physical, mechanical and thermal analysis of the sago composite particleboard through characterization respect to the effect of different parameters and compare with the existing particleboard for industrial application.
- c. To evaluate the feasibility of producing hybrid particleboard made from various ratios of sago and waste wood particles for improvement.

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.0 Introduction**

The demand for composite wood products such as plywood, oriented strand board (OSB), hardboard, particleboard, medium density fiberboard and veneer board has been increased throughout the world (Eslah *et al.*, 2012). As demand for wood-based products increased substantially worldwide, wood-based industry in some countries including Malaysia are heading towards a looming shortage of wood. Malaysia is the largest timber producer and wooden product exporter in the world. The demand for wood products had exceeds the timber supply resulting in continued cutting without replacement (Sotannde *et al.*, 2012). The over demand will have serious impacts on economic, social and environmental implications.

#### **2.1 Sago**

In Sarawak, it has been approximated that 7 tons(t) of sago pith waste was generated daily from a single sago starch processing factory (Awg-Adeni *et al.*, 2010). Those residues from production was discharged to rivers, deposited in factory compound and cause the health risk for public society and environment pollution. According to Toh *et al.* (2011), huge amounts of sago waste were decomposed naturally in the farmland or burned after the sago starch extraction.

#### **2.2 Composite particleboard**

Composite particleboard is defined as a panel manufactured from small pieces of wood or other lignocellulosic materials bonded together with the binder like thermoset or

thermoplastic with the following agents heat, pressure, humidity and catalyst (Elbadawi *et al.*, 2014).

Ayrilmis (2008) mentioned that manufacturing parameters and the properties of the raw materials such as wood, binders and additives have effect on the physical and mechanical properties. When the lignocellulose material is considered as raw material, the properties like, anatomical of fiber structure and strength, chemical bonding between fiber and matrix, composition of fiber are considered to be basic characteristic that influenced the particleboard.

Over the years many different lignocellulosic materials had been used in the composite particleboard production such as coconut chips, paper sludge, waste tea leaves, castor stalks, wheat straw, flax shiv, kenaf stalks, needle litter, waste grass clippings, bagasse, saline creeping wild rye, peanut hull, cotton carpel, vine prunings, kiwi prunings, waste tissue paper, corn peel and almond shell (Cuk *et al.*, 2011).

### **2.3 Effect of the pressing temperature, time & pressure on composite particleboard**

Cuk *et al.* (2011) produced composite particleboard using different pressing temperature. The optimal properties were obtained at 180 °C while 140 °C was too low to achieve required strength. The particleboard strength will reduce at 200 °C due to higher temperature degraded the material and created the coking phenomenon. Hence, this had embrittlement of the surface (Yang *et al.*, 2014 ; Cuk *et al.*, 2011). Yang *et al.* (2014) and Apri *et al.* (2014) stated that by increasing the pressing temperature between 150 °C to 180 °C increased the MOE and MOR. This was due to increase of plasticizing and adhesive curing during the hot press process. Low viscosity of adhesive and softening of particles in the mat had increased the contact area between resin and particles.

Apri *et al.* (2014) reported that increasing of pressing temperature, time, pressure and resin content had significantly improved the internal bonding. By increasing the pressing

temperature will increase the MOE value of the adhesives. The high temperature had increased the resin bonding between the particles. At low temperature with short time of pressing will caused the pre-curing of adhesive while at high temperature for longer time will caused over curing. Pre and over curing will reduced the bonding strength of particleboard. Cuk *et al.* (2011) had mentioned that high pressure and temperature during the hot press process will increased the strength of the composite. Elbadawi *et al.* (2015) had mention that increased press time resulted an improvement in all the mechanical properties while decreasing the physical properties.

## **2.4 Matrix**

The matrix in composite particleboard was used to bind the fibers and transmit the loads to the fibers through chemical or mechanical bonds. The binder are usually low in strength and modulus compared to the fibers. As stated by Cuk *et al.* (2011) the commonly binder used for particleboard manufacturing were melamine-modified urea-formaldehyde resin, phenol - formaldehyde resin, melamine-urea-phenol-formaldehyde resin, Soy-protein adhesive, cement and 4,4'-methylenediphenyl isocyanate (MDI) resin. PF and UF were applied at medium density particleboard for general purpose requirement like paneling, ceiling, partitioning in the interior decoration (Bhaduri *et al.*, 2008). Resin content has an important effect on final price of products and accounts for 35% of production cost (Eslah, 2012).

According to Gassan *et al.* (2000) the interfacial behavior between the fibers and polymer matrices has great influence on the overall properties of composite particleboard. The influences was due to the stress transfer between fiber and matrix, stress redistribution as well as mechanisms of destruction increased and propagation. Composite materials with poor interfaces have low strength and stiffness but high resistance to fracture as the crack growth

perpendicular to the fibers. On other hand, materials with strong interfaces have high strength but brittle. The low mechanical strength of composites may due to the unbonded or debonded regions of fiber-matrix interface and non-completely energy dissipation occurred at cracks or delaminations in composites particleboard.

The curing rates of formaldehyde-based resins were dependent on the pH of the lignocellulose materials. If the pH of lignocellulose is low, pre-curing may result. When an adhesive is pre-cured, the board will be weak and flaky. This was due to the binder cures before the particles have been compressed. During the hot press process, the pre-cured resin bonds were broken due to the heat. Decreasing the pH of particles is needed for good adhesion and successful curing. This will result in better physical and mechanical properties of the board (Elbadawi *et al.*, 2015). High viscosity of resin had slower the wetting and penetration process into the fiber surface, hence created the poor dimensional stability (Abdullah *et al.*, 2012).

Bhaduri *et al.* (2008) had studied the mechanical properties of the khimp particleboard bonding with the PF and UF. The mechanical properties like impact strength, tensile strength ,flex modulus and modulus of rupture of the board increased with the resin content of the board and density.

#### **2.4.1 Phenol Formaldehyde (PF)**

According to Izreen *et al.* (2011) understanding the heat for curing the Phenol Formaldehyde (PF) is important in order to provide tremendous enhancement in properties like mechanical strength, dimensional stability and durability against decay and termite attack. This is to increase the physical and biological properties of particleboards. PF resin consist of high quantity of water than UF resin (Apri *et al.*, 2014). Therefore, during the hot press process, the moisture in PF resin evaporated more slowly. This had make the solid content of

PF resin need higher heat to impregnation the resin into the composite particleboard structures. Bhaduri *et al.* (2008) compared between the PF and UF resin. PF resin exhibited better mechanical properties to the particleboard. This may due to three dimensional bonding effect of the binder.

#### **2.4.2 Urea Formaldehyde (UF)**

Urea formaldehyde resin is a major type adhesives used to produce particleboard and the wood based panels (Elbadawi *et al.*, 2015). Eslah *et al.* (2012) reported that over 90% of wood-based panel product in the world were manufactured with UF resin due to the advantages including low cost, non-flammability, very rapid curing rate and light colour.

Singha *et al.* (2009) had studied the mechanical properties of composite particleboard based on the Pine needle particles reinforced UF matrix. The strength of the composite structure depend on the bonding between the hydroxyl / methylol from matrix and the cellulosic from fiber. The bonding strength between matrix and lignocellulose relied on the surface geometric of particles. Good wetting of particles by the matrix with the formation of chemical bond increased the bonding strength.

According to Zhongli *et al.* (2007) lower pH of particle is better for UF bonding because UF is pH sensitive resin. During the UF resin application, the moisture content of the particles and pH need to be considered. Elbadawi *et al.* (2015) had mention that UF adhesives is good in the application of particleboard with the condition of environment and acidic wood because it can affect the hardening of the UF. According to Izreen *et al.* (2011) the presence of urea will limit the penetration of UF into the cell wall of the particle and resistance against fungal decay in the particleboard.

## **2.5 Factor influencing the physical properties of composites particleboard**

### **2.5.1 Moisture content**

Natural fiber are hygroscopic material and this characteristic affects the overall performance of the composites particleboard. If the fiber content higher moisture content during fabrication, the bonding between the particles will be weaker due to the poor wetting surface. Dhakal *et al.* (2006) had mention that all polymer composites absorb moisture when immersed in water and in humid atmosphere. The effect of moisture will lead to the degradation of fiber-matrix interface. Such degradation creates poor stress transfer leading to reduction of mechanical and dimensional properties. In general, moisture diffusion in a composite is affected by the volume fraction of fiber, voids, viscosity of matrix, humidity and temperature. Apri *et al.* (2014) and Butylina *et al.* (2011) had mention that the moisture absorption ability of composites was influenced by density and particle porosity. Butylina *et al.* (2011) stated that composites made by wood pellets has higher moisture content compared with the wood flour. The moisture content served as an indicator of porosity.

Moisture diffusion in polymeric composite are governed by three different mechanisms which are the diffusion of water molecules inside the micro gaps between polymer chains, capillary transport into the gaps and flaws at the interfaces between fiber and matrix (Dhakal *et al.*, 2007). This leads to poor wetting and impregnation during manufacturing stage, transport of microcracks in the matrix arising from the swelling of fiber composites.

As the moisture content increased the mechanical properties decreased. This was due to the formation of hydrogen bonding between the water molecules and cellulose fiber. Lignocellulose fibers are hydrophilic in properties which has formed a large number of hydrogen bonds between macromolecules of the cellulose and polymer. This had caused the

composite particleboard has weak interfacial adhesion between the fiber and matrix. Hence, decreased the mechanical properties (Dhakal *et al.*, 2007).

### **2.5.2 Density profile of composite particleboard**

The density of a composite particleboard is not uniform along its thickness and this is referred to as vertical density profile (VDP). Most of the mechanical properties like MOE, MOR, Screw test, IB and tensile-strain are affected by the VDP in a particleboard. VDP formation is influenced by press duration, moisture distribution in the board and hot-press temperature, particle arrangement, types of resin and wood. The VDP of a composite particleboard can provide information on the average raw density, maximum raw density of top and bottom layer and actual position of sanding surface. Cai *et al.* (2004) reported that the three-layer board showed the U shape of density profile. This was due to the fine particles on the board surface pressed with high temperature and formed a higher density on the board. Hence, the U-shape density profile lead to good bending properties. According to Wu *et al.* (2001), composite particleboard show the M-shape of density profile which indicates the regular density gradient across the panel thickness. The skewed density profile was due to uneven sanding of the panel after manufacturing.

### **2.5.3 Water absorption and thickness swelling on composite particleboard**

Water absorption is used to determine the amount of water absorption under specified condition for consider in furniture industry application. The dimension of composite particleboard always changes with moisture content effect. The study of the water absorption by particleboard during soaking is crucial because it affected the mechanical properties of the end product and negative effect like microorganisms attack. Samariha *et al.* (2011) stated that, for lignocellulose composite exposed to environment conditions, the most important physical

characteristics were the water absorption and thickness swelling. These characteristics determine the end use application of the composite particleboard. Water absorption can deteriorated both mechanical strength and dimensional stability in composites particleboard. According to Khazaei *et al.* (2008), mechanical strength decreased up to 4-6 percent for every percent of moisture content increment. Therefore, hygroscopic characteristics must be taken into consideration during the design of lignocellulose composite and its final application. Abdullah *et al.* (2012) mentioned that water uptake is affected by several factors, namely, the type of matrix and fiber, the orientation and distribution with respect to direction of water transport and the chemical reacted between water and matrix. Factors such as porosity, void content, lumen size, density and water diffusivity of the natural fibers, resin with water-resistant and fiber-matrix adhesion affect the water absorption behaviour of the composites particleboard (Khalil *et al.*, 2011; Khazaei *et al.*, 2008). Thickness swelling of the particleboard depend on the behavior of lignocellulosic panel exposed to moisture, low UF resin content, exposure condition and the particle geometry (Cai *et al.*, 2004).

#### **2.5.4 Behaviour of water absorption and thickness swelling on composite particleboard**

Butylina *et al.* (2011) mentioned that the rate of water absorbed by composite particleboard depend on the type of fiber and matrix, temperature, difference in water distribution within the composite particleboard and the reaction between the water and matrix. Uncompleted encapsulation of matrix on the fibers will caused the fiber aggregates and porosity to lead to water absorption. Alizera *et al.* (2010) explained that the low swelling rates for polymer matrix composites particleboard during the initial stages of moisture absorption is caused by the viscoelasticity of the polymer matrix. Finding from Kumar *et al.* (2006) showed that the behaviour of water absorption by the wood composite particleboard demonstrated the moisture absorption has high rate initially and slower rate at later stages ( the relaxation phase

). The high initial water absorption rate was due to the diffusion phenomenon where the water penetrated and dispersion through capillaries, vessels and cellular wall of wood. As absorption proceeds, the capillaries and cavities near the surface will be covered up to achieve equilibrium condition follow by the slow water uptake due to the trapped air bubbles which affect the water migrated inside the material. The water will spread from the more concentrated medium towards the lesser concentrated slowly.

Ajayi *et al.* (2008) explained that the TS and WA value increased after submersion of water because the compression stress released will caused the degradation of bonds, destruction of the binder, wood flakes delaminating, weakness and fragility of boards. The stable flakeboards can be produced using the higher level of curing agent to resist hydrostatic force against the bonds. High concentration of curing reagent speed-up the exothermic reaction of the board and caused the binder to achieve formation and stronger bonds.

#### **2.5.5 Characteristic of lignocellulose composite particleboard against water absorption (WA) and thickness swelling (TS)**

Ahmed *et al.* (2010) stated that composite particleboard consist of cellulose, hemicellulose and lignin with hydroxyl group. Hydroxyl group forms hydrogen bond with water molecule and absorb more water. Higher proportion of hemicellulose in the natural fiber reinforcement composite will caused the water uptake increased (Abdul Khalil *et al.*, 2011). Hemicellulose are hydrophilic in nature and this contributes to higher water absorption compared with cellulose and lignin (Apri *et al.*, 2014). Hydrophilic nature of fiber in the cellulose and lignin structures had resulted in poor compatibility between fiber and matrix and this increases the water absorption. Rafael *et al.* (2014) reported that the water absorption for these particleboards can be due to high content of silica. This will affects the particles adhesion and gluing process. Better adhesion between matrix and filler contributes to the

decrease of velocity of the diffusional processes due to smaller gaps in the interfacial area. Hence, more hydrophilic groups of OH are blocked (Alireza *et al.*, 2011).

#### **2.5.6 Effect of parameter (weight fraction, particles size, density, matrix and hybrid) on the thickness swelling (TS) and water absorption (WA) of composite particleboard**

As part of the investigation, physical properties of the particleboard were affected by the fiber weight fraction. Sufficient matrix is needed to bond the particles and matrix well. By increasing the fiber content from 60 to 80% increased, WA is increased as it is directly proportional to the increase of hydrophilic property of natural fibers (Chaharmahali *et al.*, 2010). Shakeri *et al.*, (2010) stated that the higher content of fiber had increased the number of micro voids due to the improper bonds between the hydrophilic filler and the hydrophobic matrix polymer. The presence of OH groups had increased the water absorption by forming the hydrogen bonding with water molecules.

Water absorption and thickness swelling was significantly decreased in the composite particleboard with UF content (Zhongli *et al.*, 2007). Increasing the resin content will limit the water penetration. This is due to the higher amounts of resin had filled up the lumen and formed inter coating in the composite particleboard which had reduced the water absorption (Izreen *et al.*, 2011). Jani saad *et al.* (2012) reported that the chemical composition in matrix is efficient to cross-link with the hydroxyl groups of natural fibers. Hence, this leads to reduction of the hygroscopicity of the boards. The hygroscopic was influenced by the factors of resin such as the monomer, polymerization rates, cross-linking and pore size of the polymer network, bond strength, the interaction between polymer and water, the filler and the resin- filler interface. Abdullah *et al.* (2012) explained that higher loading of resin had showed greater stability against water. The sufficient bonding strength between the matrix and

particles resist the water. There were similar result appeared on the composite particleboard impregnated with PF resin which decreased the degree of water absorption because the hydroxyl group were replaced by the carbon atoms in the PF chains (Abdul Khalil *et al.*, 2010).

The higher resin content in the composite particleboard had reduced the water absorption because the parenchyma tissues was covered by the resin which had reduced the water uptake capacity. Besides, the voids spaces in parenchyma and cell wall will be penetrated by the resin (Abdullah *et al.*, 2012). Fauzi *et al.* (2012) mention that the higher resin content had resulted in the lower moisture content, TS and WA value . This is due to the resin formed the hydrophobic sheet on the board surface and restricted the board to absorb the water vapor.

A study done by Hassine *et al.* (2009), larger particles size had caused composite particleboard has higher water absorption. This was due to larger particles leading to greater hydrophilic exposed surface and poor adhesion between particles and polymer matrix. Such large particles contribute to the void spaces which are readily filled with water.

Rokiah *et al.* (2010) reported that increasing the particle size from 1mm to 2mm will increased the water absorption and thickness swelling. This was due to the densification of fiber created the swelling pressure at the same time. Insufficient of matrix to cover the bigger surface of particle had caused an inability of bonding between the particles. Hence, all of those factor had increased the WA and TS.

According to Chanakan *et al.* (2010) the coarse particles have low water resistance properties compared with boards prepared from fine particles sizes. Fine particles size offer denser packing, more uniform grain sizes and easier penetration of adhesive compared to the course particle sizes, hence reduced the water absorption.

Aripin *et al.* (2007) claimed that WA decreased with the board density. At higher density, the pores inside the composite particleboard became smaller. Hence, resulted in decreasing WA. Low density board with the presence of voids inside the composite particleboard contributes to higher water absorption (Abdul Khalil *et al.*, 2011). The formation of micro-channels leads to more water absorption because the water pass through the pores on the fibers surface.

Abdullah *et al.* (2013) claimed that TS and WA decreased with density was due to the voids inside of particles decreased. Hence, increase water resistance of the composite particleboard. Wu, (2001) and Apri *et al.* (2014) mention that the lowest density had the largest WA. This is due to the water or water vapor are more easily absorbed or released into composite particleboard. The panel at 8% resin content with higher densities had the smallest WA. As reported by Jani Saad *et al.* (2012) at low density board, the highly porous structure of the board enables water to penetrate into the board and increased the WA and TS.

Cai *et.al.* (2004) stated that high-density boards has more compression set than lower density. The presence of high density zone and fine particles had increased the TS . As mention by Kasim *et al.* (2001) increasing board density leads to higher TS since a higher compressive set exists in higher density boards resulting in higher swelling as stresses are relieved.

Ihak *et.al.* (2014) and Jani saad *et al.* (2012) same view on panel with higher density gave higher compaction ratios. This implied that more consolidate deformity has been exposed onto the particles during hot pressing. Hence, this had reduced porosity in the high-density boards. The diffusion rate of water into the individual component flakes and board were reduced.

Paul *et al.* (2014) stated that composite particleboard made from Phenol Formaldehyde (PF) has better resistance to water and dimensional stability compared to Urea

Formaldehyde (UF). This indicates that the cohesive and binding forces of PF resin are stronger and sustainable with water. Composite particleboard impregnated with PF resin will have lower degree of water absorption because the hydroxyl group were replaced by the carbon atoms in the PF chains (Abdul Khalil *et al.*, 2010). Abdullah *et al.* (2012) found that UF have higher water absorption compared with PF. The ability of UF to release and absorb moisture is high. While PF have better interfacial contact between fiber-matrix bonding led to better dimensional stability. According to Chai *et al.* (2009), water absorption remain constant as increased the soaking time. This was due to the hydrophilic nature and high porosity of the fibers had improved the water diffusion process to achieve saturation.

According to Apri *et al.* (2014) UF has low resistant to weather and moisture. 130 °C for 10 minutes hot press process will caused the over curing on UF resin. Hence, this had resulted weak bonding strength between the particles and matrix. Hence, the TS values increased. TS of lignocellulose panel were influenced by the quantity and distribution of adhesive, moisture content, compatibility and chemical composition of mat.

Othman *et al.* (2016) reported that urea formaldehyde composite particleboard are less stable and when exposed to moisture, it tends to spring back. This was due to low dimensional stability and weathering resistance of UF properties.

Experiment done by Abdul Khalil *et al.* (2011) showed hybrid composites particleboard uptake water rapidly during the first few hours due to the hydrophilic nature of the cellulosic materials, enabling the water to penetrate into the composites particleboard. The water molecules remains in the inter-fibrillary space of cellulosic structure and causes the cracks and micro voids at the surface of composites particleboard. This resulted in the interfacial de-bonding. Besides, the porous tubular structures presented in fiber had increased the penetration of water uptake by capillary. The formation of void structures within the composites particleboard due to weak compatibility between the particle surface and adhesive

in the hybrid composite particleboard, which facilitates the water absorption (Hamid *et al.*, 2015). Water absorption was controlled by wood cell wall collapse during consolidation and density distribution in the board. Hybrid composite particleboard made from particle with diameter bigger than 1 mm had significantly higher water absorption than those less than 1mm. The larger particle size generally had larger voids and space between the particles. Hence, more moisture accommodation in the board.

Hybrid composite particleboard has higher water absorption and thickness swelling (Hasan *et al.*, 2015). This was due to the presence of free -OH group in the molecular structure, holocellulose especially hemicelluloses occurred in the lignocellulose material, size of raw material and its ratio. The hygroscopicity of hemicelluloses was higher than the cellulose and lignin as it contained higher number of free-OH.

A study was done by Othman *et al.*, (2016) on hybrid composite particleboard using bamboo (B) and rubber wood (RW) with different ratio. The physical qualities of bamboo which are typically longer, thinner and narrower than wood chips had resulted higher TS value as the higher ratio of bamboo applied in hybrid board. During the mixing and hot press process, the particles will overlapped each other and created voids between the particles. The high values of TS was obtained due to these voids increased the ability of water absorption and weakened the bonded particles. The rubber wood particles have better TS and WA performance compared to bamboo particles. This was due to rubber wood particles have better gap-filling properties, more compact in particles packing and better bonding between the particles.

### **2.5.7 Effect of temperature on thickness swelling (TS) and water absorption (WA) for composite particleboard**

Yang *et al.* (2014) stated that 150 °C will give higher TS values compared with 180 °C and 200 °C. This was due to less resin had been cured at lower temperature. Higher compression temperature could provide better TS result as the steam at surface was transferred into the core of the mat and accelerated the curing process. Higher temperature could compress the material easily and performance better in TS value.

## **2.6 Factor influencing the mechanical properties of composites particleboard**

### **2.6.1 Effect of natural fiber on mechanical properties of composites**

In general, the properties of composite particleboard were greatly influenced by the following factors: the species of lignocellulose materials, fiber structure, density, hardness, compressibility, type and size of lignocellulose materials, method of particle drying, particle screening and separating, type and amount of binding, method of mat formation, structure of particleboard, curing condition, thickness of the board and the moisture of the particles and board (Cuk *et al.*, 2011). According to Eslah *et al.* (2012) composite particleboard properties were greatly affected by the panel compaction rate, particle geometry, composition of adhesives and types, density, press conditions and other process variables.

Mechanical properties of composites particleboard relied on the nature of the matrix, differences in morphology, density, dispersion and orientation of the material, fiber aspect ratio, stress transfer at the interface, mixing temperature, the nature of the fiber-matrix consolidated and the interphase region (Nourbakhsh *et al.*, 2010; Singha *et al.*, 2009). Ahmed *et al.* (2013) mention that the performance of reinforcement relied on compound interaction like fiber structure, size, shape, dispersion, surface area, surface sensitivity and binding quality between fiber and adhesives. Rafael *et al.* (2014) had mention that physical-

mechanical properties depend on the particles and adhesive interaction performance. Singha *et al.* (2009) had mention that mechanical properties of composites particleboard relied on the fiber-matrix bonding, load transfer from matrix to reinforcement and surface area of reinforcement. The higher magnitude of bonding and large surface for reinforcing material have created better interaction between the matrix and reinforcement. Hence, this resulted in better mechanical properties.

Chemical composition of plant fiber have greatly influenced the mechanical properties (Ishak *et al.*, 2010). Plant fiber consist of three components like cellulose, hemicellulose and lignin which strongly influenced the mechanical properties. Cellulose is the main structural component that contributes strength and support the plant cell walls and the fibers. It is one of the stiffest and strongest organic constituents in a natural fiber.

#### **2.6.2 Effect of parameter (weight fraction, density, particle size, matrix and hybrid) on modulus of rupture (MOR) for composite particleboard**

According to Hazwani *et al.* (2014), MOR increased when the composite particleboard density increasing from 500 kg/m<sup>3</sup> to 700 kg/m<sup>3</sup> due to the higher compaction ratio in the board. MOR increased linearly with the board density (Yang *et al.*, 2014). The higher density is usually associated with higher mechanical properties (Akgul *et al.*, 2007; Kasim *et al.*, 2001).

The MOR of kenaf particleboard increased with board density (Jani Saad *et al.*, 2012). The better uniformity of fiber dispersed had cause the composite particleboard has increased the compatibility, hence resulted better flexural strength (Chai *et al.*, 2009). The composite particleboard density is determined by the quantity of particles applied on the board. The density increased as the larger quantity of particles applied and expected to reduce voids in the board and enhance the MOR.

The density effect on the MOR and has high correlations between density and mechanical properties (Cai *et al.*, 2004). The three-layer particleboard showed the greater bending properties than the single layer. This was due to higher density on the surface layer. There was no significant effect on MOR values by using low quality particle, less desirable geometry and low percentage on husk and leaves in the chips.

According to Kociszewski *et al.* (2012) MOR for wood plastic composite particleboard increased with increasing the particles size and drop after reaching certain limit. Using the large-sized particles at core particleboard with small-sized particles at face of board can provided better properties.

Sotannde *et al.* (2012) had done the research on Afzelia Africana wood residues bonded with cement, smaller wood particles have better bonding than bigger particles in wood-cement composites. When the flakes-sawdust particle were mixed in particleboard, it had attributed the highest MOR than those using flake particles only. The flakes-sawdust has random distribution in the particleboard and the heterogonous particles size tend to enhance the bending strength of the particleboard.

Kimoto *et al.* (2015) mention that boards made from medium and coarse particle show higher MOR. The coarse needle like particles do not provide an advantages for MOR due to higher local compression stresses and accompanying compression deformation on the thicker particles. Apri *et al.* (2014) stated that one of the factors that influence the MOR value is particle geometry. Particle with high slenderness ratio will be easier to orient to increase the board strength.

Nourbakhsh *et al.* (2010) and Ishak *et al.* (2010) had studied the bending strength on fiber/PP composite particleboard and kenaf reinforced unsaturated polyester composites respectively. The MOR increased with weight fraction of fiber until an optimal value and then steep decline beyond after that due to excessive fibers reduced the interfacial bonding

between the fiber and matrix. The flexural stress drop as the fiber volume fraction raised due to the moisture uptake increased. (Dhakal *et al.*, 2007). Chaharmahali *et al.* (2010) had stated that the excessive fiber were not fully bonded by the matrix and caused the strength reduced.

Singha *et al.* (2009) and Ahmed *et al.* (2010) studied the natural fiber-reinforced composite particleboard by adding the fiber up to 25% which increased the flexural strength, and then decreased at 30% fiber loading. Excessive of fiber will caused inefficiency of stress transfer from matrix to fibers, reduced the reinforcement-matrix contact and created weak dispersion force in the composite (Chai *et al.*, 2009). The accurate amount of particles is needed for transferring the stress from matrix to fiber in order to achieve good bending strength. Nourbakhsh *et al.* (2010) had mention that better bending strength can be achieved by uniform fiber distribution in the composite.

Cai *et al.* (2004) mention that the MOR could be improved by adjusting the pressing condition at the early stage to densification at the face and using the high volume of matrix at the face layers. Jani Saad *et al.* (2012) had done the experiment on kenaf particleboard, the result show MOR value increased with loading.

An experiment conducted by Abdul Khalil *et al.* (2010) showed that the flexural strength increased with the resin content up to 15% but decreased with excessive resin loading. The excessive resin will reduced the lumber strength. This had resulted the composite materials become brittle and not manage to withstand greater loads. The low resin content had influenced the stiffness, increased the deformability of matrix interface between the fiber. This had caused the inconsistency of matrix distributed in composite to form agglomerates and the loads were ineffectively transmitted between fibers.

Izreen *et al.* (2011) had done a research by impregnation of low density wood with PF at high temperature which enhance the bending strength. At lower PF concentrations, more resin would penetrate into the cell wall and resulted in higher anti swelling in the composite

particleboard. This is because the resin had successfully penetrated into the cell wall upon heating and formed an insoluble polymer which bulked the cell wall. PF resin had improved the lignocellulosic materials strength and served as a boundary to resist or block the water molecules to penetrate into cell wall and cell lumen (Dungani *et al.*, 2014). When the fiber was penetrated with PF, the fiber become more rigid and stiff, resulted in fiber brittleness. The high polarity of PF resin created the strong hydrogen bonds with the hydroxyl groups, which increased the flexural properties.

According to Hamid *et al.* (2015) hybrid composite particleboard with 40:60 ratio shows the lowest MOR. This was due to the composite particleboard fabricated by particle with diameter less than 1mm and has the lower density on it.

Hasan *et al.* (2015) reported that hybrid composite particleboard produced from 50% kenaf and 50% kadam showed the highest MOR value. Higher bending strength of fabricated composites particleboard resulted from the higher density of raw materials, board density, surface density, surface particle alignment, adhesive content and its higher fiber length of raw materials.

Othman *et al.* (2016) manufactured the hybrid composite particleboard with bamboo (B) & rubber wood (RW). The MOR results show the 70B: 30RW has the highest MOR while 30B: 70RW was the lowest in MOR. The higher portion of bamboo particles performed higher MOR value due to the bamboo which has higher strength in structure compared with rubber wood.

### **2.6.3 Effect of parameter (weight fraction, density, particle size, matrix and hybrid) on modulus of elasticity (MOE) for composite particleboard**

Hazwani *et al.* (2014) and Jani saad *et al.* (2012) reported that higher density had increased the MOE value and made the composite particleboard to be more brittle. In most

cases, panel have tendency to be brittle when the MOE value is high and ductile or flexible when the value is low.

The density effect on the MOE of eastern red cedar particleboard (Cai *et al.*, 2004). The board was fabricated from two different wood chips had resulted high interaction between density and mechanical properties. There was no significant effect on MOE values by increasing density, particle quality, less desired geometry and small portion of husk and leaves in the chips.

The MOE of composites particleboard have great influenced by the factor such as fiber dispersion, fiber concentration, fiber orientation, fiber aspect ratio, fiber stiffness, and fiber intrinsic rigidity (Lopez *et al.*, 2012).

Increasing the length of particles and slenderness ratio had increased the MOE (Arabi *et al.*, 2011). The particles size have great effect on macro-voids in particleboard, macro-voids increased with fiber thickness but decreased with increasing fiber length and width. The bonding strength of the particleboard can be increased using coarse particles in board core. According to Apri *et al.*, (2014) fiber length could influenced the MOE value.

As mentioned by Navdeep *et al.* (2012) the MOE of composite particleboard increased with fiber weight fraction until an optimum value at 50% of fiber loading. An experiment done by Randa *et al.* (2013), MOE for particles reinforced epoxy matrix composites particleboard can be increased by the filler concentration. This will cause the absence of voids in board and good mixing of the filler in matrix. MOE decreased due to decrease of availability of epoxy material to bond all the filler particles in matrix. In eastern white cedar particle-based composites particleboard, the MOE increased as wood fiber content increased (Hassine *et al.*, 2009).

Several factors that could influenced the MOE values are resin type, resin content and adhesive bonding (Apri *et al.*, 2014). A studied carried out by Lopez *et al.* (2012) showed that

the MOE of natural composites particleboard are greatly influenced by the matrix. Addition of resin increased the MOE value which made the board more brittle (Jani saad *et al.*, 2012). Generally, boards have tendency to be brittle when the MOE value is high while ductile or flexible when the value is low. Another finding of PF was the acidic properties of lignocellulose material which weaken the bonding strength in PF hence resulted in the lower value in MOE (Apri *et al.*, 2014).

Hybrid composite particleboard bamboo: rubber wood at 30:70 shows the lowest MOE value due to the higher portion of rubber wood particles which are shorter than bamboo particles. During the test, the strength reduced due to the shorter particles unable to transfer the stress from one particles to other. The MOE can be increased by applying the higher ratio of bamboo in the board. The longer and thinner bamboo particles had produced the stronger and stiffer composite particleboard (Othman *et al.*, 2016).

According to Liliana *et al.* (2013), a unique combination of sisal and oil palm fiber with rubber had resulted in increased modulus. As stated by Hamid *et al.* (2015) hybrid composite particleboard does not improved the MOE compared with the single raw material for the composite particleboard fabrication.

#### **2.6.4 Effect of parameter (weight fraction, density, particle size, matrix and hybrid) on internal bonding (IB) for composite particleboard**

According to Hazwani *et al.* (2014), IB increased when the composite particleboard density increase due to the higher compaction ratio in the board. As mention by Abdullah *et al.* (2013) the IB strength increased with particleboard density. Panel with the higher density had significant effected on the mechanical characteritis (Akgul *et al.*, 2007). By increasing the density increased the IB strength within the particleboard (Yang *et al.*, 2014; Kasim *et al.*, 2001).

An observation done by Sotannde *et al.* (2012) flake-sawdust boards with higher density due to the heterogeneous nature of particles which enhanced bonding between particles by filling up the void spaces in the boards. The higher density and chemical additives had increased the internal bonding strength of the board.

According to Pan *et al.* (2007), particles with 20-40 mesh had performed at highest IB values. Particles with this size bind better by the matrix and had tighter bonds. Smaller particles with 40-60mesh particles were not covered by the matrix well when the same ratio of matrix and particles was used. Bigger size of particles, 10-20 mesh have largest surface. This has resulted weak contact between particles and created the pores. This had caused the particles not bonded well by the resin. Hence, reduced in mechanical strength.

The IB values increased with resin loading (Jani Saad *et al.*, 2012). This is because higher volume of resin had better interfacial bonding between fibers in the panel, thus increased the ability for the boards to withstand the pulling force during the test. Eslah *et al.* (2012) mention that increased resin content will increased the bonding between the resin and wood particles which led to the improvement of internal bond strength.

Ebewele *et al.* (2004) mention that the internal bonding strength of UF-bonded particleboard depends on the strength of adhesive and its bonding to lignocellulose material. The internal bonding strength increased with the degree of hydrogen bonding between molecules and condensation reaction between methylol and amide groups during the hot press.

Hamid *et al.* (2015) manufactured the hybrid composite particleboard using two different size particles. The result showed that oil palm empty fruit bunch (EFB) and Merpauh (wood) ratio 60:40 with particle less than 1 mm and ratio 80:20 with particles more than 1mm have the highest IB.

High internal bonding value can be achieved by hybrid composite particleboard with bamboo and rubber wood. The presence of small rubber wood particles had tighten the particleboard with high compatibility of packing. The combination of rubber wood with bamboo resulted in higher compaction of fiber arrangement. This has leads to better binding between the particles and contributed to higher IB. The rubber wood particles have desired geometries for better bonding quality (Othman *et al.*, 2016).

Hybrid composite particleboard with wood : bamboo have higher internal bonding strength compared with wood : rice husk. The lower internal bonding was due to the cylindrical and hollow structure of rice husk particles, created the boundary which may act as a barrier during resin application. The low internal bonding influenced by the particles and matrix bonding (Rafael *et al.*, 2014).

#### **2.6.5 Effect of parameter (weight fraction, density, particle size and hybrid) on screw withdrawal test for composite particleboard**

Cai *et al.* (2004) and Jani saad *et al.* (2012) mention that screw withdrawal resistance highly depend on the panel density. The ability of boards to hold the screw increased as the board density increased. This had improved the efficiency of the interfacial bonding of the fibers, indirectly increased the capability of the boards to grip the screws being withdrawal. Vanchai *et al.* (2010) reported that screw holding strength were found to increase with density ratio from 600 kg/m<sup>3</sup> to 800 kg/m<sup>3</sup>. A study shown by Vassiliou *et al.* (2005) showed better withdrawal strengths could be achieved by selecting the correct panel density for screw fitting.

Jani saad *et al.* (2012) mention that particles geometry had great effect on screw test. Increasing the particle dimension improve the screw withdrawal resistance. Board made from

coarse particle has large screw withdrawal resistance due to existence of moderate void spaces for screwing.

According to Jani saad *et al.* (2012) resin loading had great effect on screw test. The ability of boards to hold the screw increase with resin loading. This had increased the interfacial bonding of the fibers and the ability of the boards to grip the screws being withdraw. An experiment conducted by Kimoto *et al.* (2015) showed increased resin content improve the screw withdrawal resistance except for the saw dust at 8 and 10 percent resin content due to weakness of mutual bond of particles.

According to Othman *et al.* (2016) high screw withdrawal value can be attributed to the geometrical properties of bamboo and rubber wood particles. The bamboo particles are coarse in their geometrical properties compared with rubber wood particles. During the mixing process, the smaller rubber wood particles will fill up the voids between the bamboo particles. Hence, this had increased the compatibility of the board. When a screw is driven into a particleboard, board with more compacted particles has more surface area in contact with the screw thread and thus produces more resistance to withdrawal force. According to Rafael *et al.* (2014) hybrid composite particleboard with wood: bamboo has the highest screw withdrawal strength compare with the wood : rice husk.

#### **2.6.6 Effect of parameter (weight fraction, particle size, matrix and hybrid) on impact strength for composite particleboard**

Impact strength were affected by the fiber size, fiber distribution, fiber orientation relative to the impact load and fiber-polymer adhesion (Butylina *et al.*, 2011). The composite particleboard made of the smallest particles showed the lowest value (Kociszewski *et al.*, 2012).

Increasing the fiber content from 60 to 80% will significantly decreased the impact strength (Chaharmahali *et al.*, 2010). High loading of fiber will counterbalance the defects and improved the toughness of composites (Gilles *et al.*, 2000). Ishak *et al.* (2010) had studied the mechanical properties of kenaf reinforced unsaturated polyester composites particleboard. Impact strength increased until an optimal value of fiber weight fraction but decline beyond after optimal. This is because higher fiber content lead to poor interfacial adhesion between the fiber and matrix hence declined the impact properties. Nourbakhsh *et al.* (2010) had mention that by increasing the lignocellulosic fiber will declined the impact strength of the composite particleboard due to its stiffness.

Gilles *et al.* (2000) mentioned that low loading of fibers introduces the critical defects to the board structure and form voids due to poorly bonded interface regions occurred. The defects act to reduce impact strength. Excessively low toughness was partly ascribed by the presence of many pre-existing micro compressive defects along the fibers which act as loci of failure in the composite particleboard structure.

The impact strength of the Phenol Formaldehyde (PF) Empty Fruit Bunch (EFB) increased linearly with addition of 20% of EFB fibers. The presence of EFB fiber as fibrous reinforced agent in the PF matrix has strengthened the composite particleboard (Chai *et al.*, 2009). Impact strength decreased after 30% of loading because higher fiber loading caused poor distribution of fibers in matrix. The stress transfer between matrix and fibers became weak (Chai *et al.*, 2009; Chang *et al.*, 2004). Incorporation of particle fillers reduce the fracture in particleboard. Besides, the quality of natural fibers and its strength had great influenced on impact strength (Oksman, 2000). The fiber bundles have lower mechanical properties than individual fibers due to low bonding strength between the individual fibers.

Gassan *et al.* (2000) mention that low impact strength in composite particleboard were due to matrix cracking, fiber-matrix debonding and delamination at low impact strength. At

greater impact energies, the deterioration on fiber fracture and being withdraw, whereas the low velocity impact loadings, the fiber-matrix adhesion can affect the failure. Impacts on composites particleboard with low levels of fiber-matrix adhesion had generate large areas of splitting and delamination with severe effects on the compressive properties.

Increasing the resin content from 5% to 15% had increased the impact strength and the impact strength decreased beyond 15% (Abdul Khalil *et al.*, 2010). The good impact strength was due to better interfacial interaction between the fiber and matrix. The resin penetrated within the pits or pores of the composite particleboard well. Therefore, during the impact test, the fibers within 15% matrix has higher efficiency to absorb the impact force. Excessive matrix will caused the composite particleboard become brittleness and not be able to resist fracture under high speed of impact test.

Using jute and hemp in the hybrid composite paprovide better results in impact properties (Liniana *et al.*, 2013). According to Jawaid *et al.* (2011) impact strength of the tri-layer hybrid composite particleboard with oil palm empty fruit bunches (EFB)/ woven jute fiber ( $J_w$ )/(EFB) is comparatively high. Oil palm EFB fiber has high fracture toughness compared to  $J_w$  fiber. The high impact strength was due to the high porous nature of lignocellulose fiber. The impact strength of EFB/ $J_w$  hybrid epoxy composite particleboard is lower compared with EFB/glass hybrid polyester composites particleboard. Hybridization of  $J_w$  fibers with the oil palm EFB fiber composite decreased the impact strength. In  $J_w$ /EFB/ $J_w$  hybrid composites particleboard with laminated, the fracture appeared due to poor interaction between the matrix and fibers. Besides, the impact toughness of the hybrid composite particleboard was mostly affected by the  $J_w$  fiber at the surface layer.

### **2.6.7 Effect of parameter (weight fraction, particle size, matrix and hybrid) on tensile strength for composite particleboard**

Toh *et al.* (2011) had mention that highly packed structure of composites particleboard can be produced by using the powder-powder system and pellet-pellet system which had attributed the good results in tensile strength. In the powder-powder system, the sago pith waste (SPW) and poly vinyl alcohol (PVA) were prepared in the form of powder in order to achieve better mixing. Pellet-pellet system were prepared by using both the PVA and SPW powder were plasticized individually using the twin screw extruder. The SPW was more compatible when mixing using similar system due to the raw material have similar geometry. The similar geometry of SPW and PVA had created the hydrogen bonds formation or chemical reaction between the OH group of PVA and starch from SPW. The better interaction had resist and prevent the slippage of molecular chains over lapping each other during stretching in tensile test. Tensile strength will reduce in the pellet-powder system due to SPW was prepared in powdery form and incorporate with the pre plasticized PVA which had created the macromolecules and form the loosely packed structure in composites particleboard.

Hassine *et al.* (2009) and Kociszewski *et al.* (2012) reported that tensile modulus showed a steady increased with the particles size up to certain limit with higher filler content. According to Stark *et al.* (2003) wood plastic composites particleboard strength can be improved using higher aspect ratio of wood fibers compared to the larger size of fibers. This is due to the larger particle that decreased the tensile properties. Nourbalhsh *et al.* (2010) mention that high aspect ratio of fibers improved the stress transfer between the matrix and fibers. Migneault *et al.* (2008) and Nourbalhsh *et al.* (2010) stated that constant fiber diameter with increased fiber length improved the strength and elasticity of composites particleboard. Kociszewski *et al.* (2012) mention that using large-sized particles at core particleboard and

the small-sized particles at surface of board provided better properties. Li *et al.* (2009) mention that optimal tensile properties of hardwood fibers reinforced with HDPE can be achieved using the particles size with 40 mesh compared with 20 mesh.

According to the research done by Navdeep *et al.*, (2012) the effect of high fiber weight fraction is required to obtain better performance natural composites particleboard. The tensile properties of composites particleboard was enhanced by increasing the fiber to a polymer matrix due to the fiber higher stiffness and strength than the matrices. The composite particleboard strength increased as the fiber or other reinforcement applied in the polymer matrix. According to Nourbakhsh *et al.* (2010), tensile strength of wood fiber/PP composites particleboard raised with increasing fiber weight fraction. This behavior was due to interfacial adhesion between the matrix and fibers.

Ishak *et al.* (2010) studied the kenaf reinforced unsaturated polyester composites particleboard. The results showed that the weight fraction of fibers have great influenced on tensile properties by increasing the weight fraction. The tensile strength increased until an optimal value and decline beyond after that due to poor interfacial adhesion between the fiber and matrix.

Singha *et al.* (2009) and Ahmed *et al.* (2010) reported that the tensile strength of composites particleboard increased with fiber particle until 30% weight fraction but drop after that. This was due to lack of stress transfers from matrix to fibers therefore limited to weak dispersion forces. As mention by Fakhrul *et al.* (2013) decrease in tensile strength was due to the poor interfacial bonding between the hydrophobic polymeric matrix and the hydrophilic lignocellulosic fibers, which had reduced the efficient stress transfer between the two phases of the material.

Toh *et al.* (2011) work on sago pith (SPB)/poly(vinyl alcohol) (PVA) composite particleboard. The result shown that tensile strength increased as sago pith increased from 50

to 80 wt% which created an optimum interaction between the fiber and matrix. When the PVA is mixed with a starch and lignocellulose SPB, large number of hydroxyl groups remain mixed with each other by intermolecular and intramolecular hydrogen bonding with PVA and SPB. Tensile strength reduced after the 80 wt% due to the PVA embrittled by incorporation of SPB. The higher amount of SPB had declined the efficiency of polymer-chain sliding when external forces are enforced. Tensile strength reduce due to shortness of entanglement and crystallization, poor interfacial adhesion of components, variations of filler geometry such as lengths and irregularly shaped particles which had reduce the compatibility of the composite particleboard.

The hybrid composites particleboard showed a positive effect on tensile strength when the composite having a ratio 4:1 banana and sisal (Liliana *et al.* 2013). The maximum stress transfer for the hybrid composites particleboard can be obtained in composites having volume ratio of banana and sisal at 3:1. The study have proof that incorporation of fibers increased the mechanical properties.

## **2.7 Characterization of composites particleboard**

### **2.7.1 Thermo-gravimetric analysis (TGA) for composite particleboard**

Thermo-gravimetric analysis (TGA) measures the weight loss as a function of temperature. It is an analytical technique used for determining temperature as material is heated. Thermal analysis is an important analytical method in understanding the structure-property relationship and thermal stability of composite particleboard. Thermal analysis is used to determine the moisture content and volatile component in composite particleboard because it effect on the overall of particleboard properties. The structural constituents of natural fibers such as cellulose, hemicellulose and lignin are sensitive with different range of temperatures.

Singha *et al.* (2009) has study the effect of heating on the composite particleboard by TGA. For the cellulose fibers, depolymerization, dehydration and glucose formation took place at 26 °C to 190 °C. Urea formaldehyde matrix had an initial decomposition at 238 °C while the final decomposition was at 995 °C. Degradation temperatures for natural fiber reinforced composites occur between the degradation temperatures for matrix and fibers. The polymer composites have initial decomposition temperature at 231 °C and final decomposition at 815 °C, which indicated the existence of cellulose fibers had great effect on the thermal stability of polymer matrix. This indicates that composites are less stable than the matrix.

Chai *et al.* (2009) carry out the thermogravimetric studies on PF-EFB (Empty fruit bunch). The samples undergo three main degradation stages. The first stage of degradation at 80-100 °C was due to evaporation of moisture from the composite panel. The second stage of degradation at 200-350 °C was associated to the degradation of EFB fiber correlated with the lignocellulosic components. The third stage of degradation at 400-600 °C was due to the decomposition of phenol formaldehyde components as a result of broken cross-linking network.

A study done by Sulaiman *et al.* (2013) showed oil palm starch undergo TGA have weight loss in three steps. A minor decrease in weight at 29 °C in the first stage was due to evaporation of water and easily volatile materials. The second and third stages comprised of the dehydration of polymer chains and complete decomposition of samples residues.

TGA curves showed that chemical components affect the thermal stability and degradation. Dungani *et al.* (2014) mention that the weight loss below 100 °C has attribute to the evaporation of water. Amini *et al.* (2013) reported that 6% of weight loss between 30 °C and 100 °C was due to moisture loss. Woraphot *et al.* (2009) studied the behaviour of

parawood strands by TGA. The finding was 0 °C-100 °C belong to the moisture release with small percentage of weight loss.

Dungani *et al.* (2014) showed degradation of lignin pyrolysis at 300 °C-340 °C. Islam *et al.* (2012) mention that the pyrolysis of wood components like hemicellulose, lignin and cellulose usually occur at 200 °C, 220 °C and 250 °C. As mentioned by Amini *et al.* (2013) 66% of weight loss between 250 °C and 425 °C was due to the thermal decomposition of hemicellulose, carbon dioxide and water. Woraphot *et al.* (2009) found that the loss of amorphous structure from the cell wall like hemicellulose and lignin was at 160 °C-305 °C. Disintegration and evaporation of cell wall structure like cellulose and lignin was found at 305 °C-370 °C. Cellulose will not decompose until the temperature reached 340 °C. Further pyrolysis of the remaining cell wall structure was at 370 °C-475 °C.

There are several attempts to explain the thermal degradation mechanism of Phenol formaldehyde adhesives. According to Emmanuel *et al.* (2011) , the peak temperature 230 °C was attributed to additional cross link that are formed due to condensation reactions between phenol and methylene group to form a carbon-hydrogen crosslink. The second peak 430 °C was attributed to the second stage where methylene bridges decompose or broken into methyl groups with formation of both phenols and cresols. The third stage at 530 °C involved the discharge of hydrogen atoms from the ring structure and transformation of hydrogen gas. Chai *et al.* (2009) mentioned that degradation at 400-600 °C refer to the decomposition of phenol formaldehyde components due to the broken cross-linking network. In the case of urea formaldehyde matrix, initial decomposition took place at 238 °C and final decomposition at 995 °C (Singha *et al.*, 2009).

### 2.7.2 Differential Scanning Calorimetry (DSC) for composite particleboard

Chemical reactions and physical changes such as melting occur due to absorption or release of heat energy. Heat given off during a reaction is called an exotherm. The absorption of heat by a material is called an endotherm. The exotherms and endotherms were used to determine the chemical and physical state change in the specimen.

Sulaiman *et al.* (2013) had done the analysis on oil palm starch using DSC. Oil palm starch shows the melting temperature at 77.88 °C. The composite particleboard fabricated with modified starch had a higher melting temperature due to the cross linking reaction with epichlorohydrin that occurred in starch. Hence, this had attributed better interaction between starch and particles in the board fabricated and required higher temperature to go through the melting process. Amini *et al.* (2013) mention that endothermic peak at 92 °C due to the melting temperature of the composite particleboard made from rubber wood with modified starch. Degradation of lignocellulose fibers like hemp and flax are reported at 230 °C, pine at 256 °C while the jute and wheat straw flour were 190 °C (Faith *et al.*, 2008).

Islam *et al.* (2012) mention that an endotherm peak was observed between 50 °C to 150 °C indicates a high amount of water molecules in the wood fiber. Endothermic peaks at 228 °C and 275 °C were due to the thermal decomposition of wood fibers and filled polymer in the wood. This observation can be illustrated on the physical foundation of prominent changes happen in the structure. Mohamad Amini *et al.* (2013) reported that two exothermic peaks were found at 32 °C and 172 °C due to moisture loss and the reaction of unreacted glutardialdehyde or chemical compound.

Mariko *et al.* (2009) stated that endothermic reaction at 70 °C to 100 °C in composite was due to evaporation of moisture while 190 °C was due to the decomposition of PF. The decomposition of hemicellulose and lignin is an exothermic reaction. There is no endothermic

reaction in a cellulose with PF samples at 325 °C because PF inhibits the endothermic reaction of cellulose.

Zhang *et al.* (2011) had modified the urea-formaldehyde by EPU ( Emulsifiable polymeric methane diphenyl diisocyanate ). When the EPU applied with urea formaldehyde resin, it will speed up the curing process. There was no exothermic peak in DSC curve when 70/30 UF/EPU ratio applied. The isocyanate had accelerated the chemical reaction with the water than urea-formaldehyde resin. This had cover up the UF resin characteristics peak, thus giving rise to a wide exothermic peak.

### **2.7.3 Fourier transform infrared (FTIR) spectroscopy analysis for composite particleboard**

FTIR was used to determinate and verify the functional groups presents in organic and inorganic structure. Chemical bonds in different environments absorb varying intensities at varying frequencies. Thus Infrared radiation (IR) spectroscopy include absorption information and analyzing it in the form of a spectrum. The frequencies at which absorptions of IR radiation “peaks” or “signals” occur are associated directly to binding inside the mixture.

Izreen *et al.* (2011) had mention that spectral 3700-3000  $\text{cm}^{-1}$  spectral indicates the O-h stretching in free or weakly H-bonded hydroxyls. The formation of cross-linked polymer of PF was at the absorbance peak of 1234  $\text{cm}^{-1}$  for the asymmetric stretch phenolic C-C-OH. Excess free formaldehyde indicated by the absorbance peak 2890-2914  $\text{cm}^{-1}$  is the characteristic peak of methyl group C-H.

Islam *et al.* (2012) mention that absorption band at 3407  $\text{cm}^{-1}$ , 2917  $\text{cm}^{-1}$ , and 1736  $\text{cm}^{-1}$  are due to O-H, C-H and C=O stretching vibration respectively. These absorption bands are due to hydroxyl groups in cellulose, carbonyl groups of acetyl ester in hemicellulose and carbonyl aldehyde in lignin.

#### 2.7.4 Scanning electron microscopy (SEM) analysis for composite particleboard

Scanning electron microscopy (SEM) is used to examine the surface morphology of lignocellulose fibers and the fracture surface of natural fiber-reinforced polymer matrix composites. The SEM images show two opposite morphological situations: (a) domains of fibers dispersed in composite particleboard and the interaction between the fiber and matrix and (b) poor interfacial interaction between fiber and matrix.

Butylina *et al.* (2011) studied the deformation behaviour of wood-polymer composites particleboard fabricated by various wood sources. The fibers were randomly dispersed and randomly located in longitudinal and transverse direction. Aggregation of fibers and existence of voids strongly influence the fracture behaviour. Broken wood fibers are visible due to poor adhesion between the wood and matrix. Hence, the fibers were being extracted. Othman *et al.* (2000) mentioned that fiber pull-outs were due to poor adhesion between the fiber bundles and matrix. Voids were created due to improper bonding between the fiber and matrix.

SEM micrograph shows the oil palm trunk (OPT) polymer composites filled up the void in the fiber (Abdullah *et al.*, 2012). The parenchyma tissues in the fiber were found to be in bowl-shaped and easier for matrix to fill it up. The PF resin penetrated in parenchyma cells presented weak bonding hence resulted in the reduction of dimensional stability in physical properties. The SEM micrograph shows size and shape of cell wall structures, cell walls and cell lumens of fiber are coated with the PF resin which restricted the absorption and penetration of water into cells (Dungani *et al.*, 2014). However, there are some voids and water domains formed in the composite due to the condensation of PF during the fabrication process (Chai *et al.*, 2009).

## CHAPTER 3

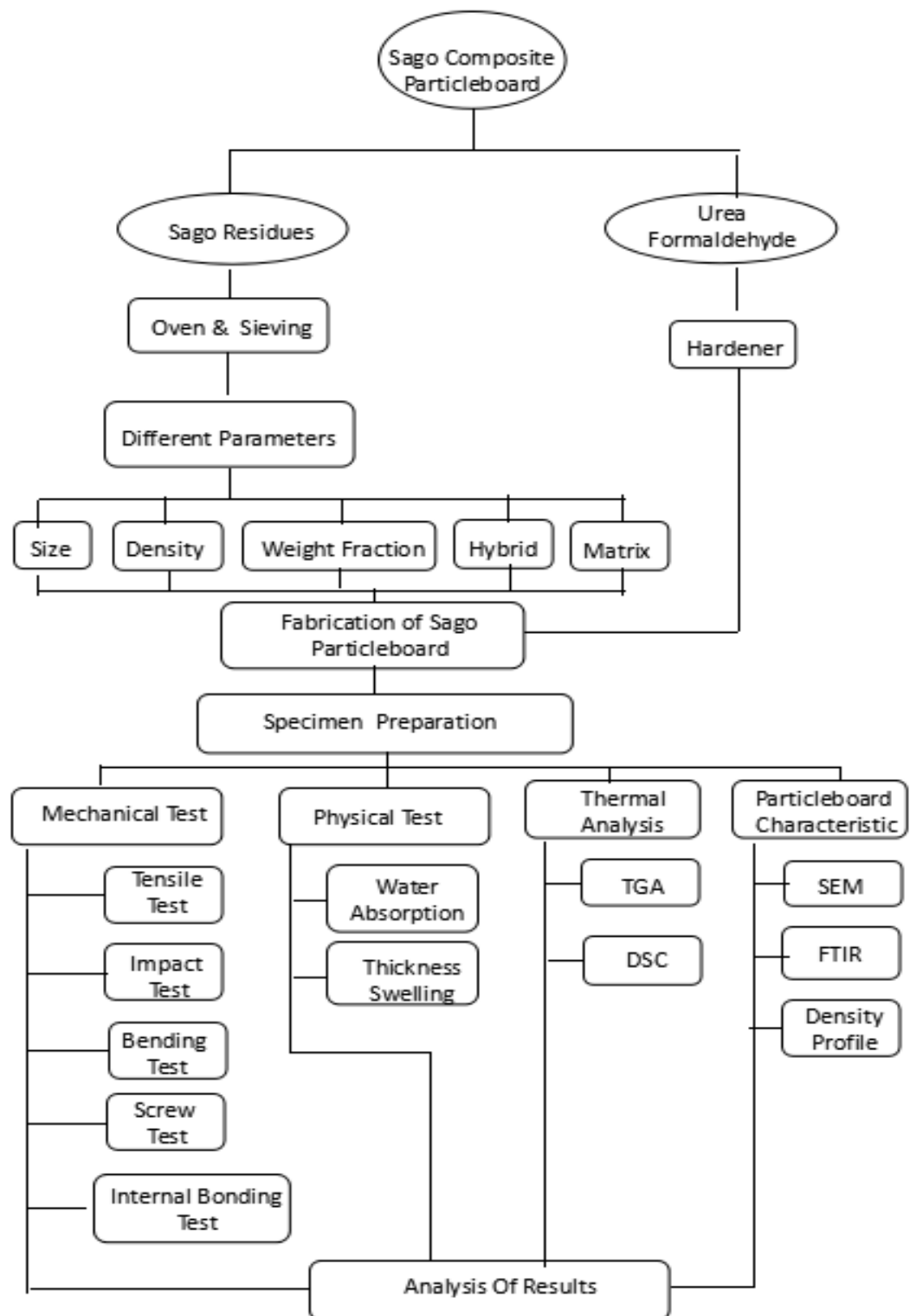
### MATERIALS AND METHODS

#### 3.1 Experiment overview

The purpose of this study is to investigate the mechanical and physical properties of sago composite particleboard. A thermal analysis was performed on the sago composite particleboard to study the gravimetric response and specific heat capacity at elevated temperature. Thermogravimetric analysis (TGA) was used to analyse the thermal stability of materials and examine the kinetics of physico-chemical processes occurring in the sample. The thermal expansion or contraction was due to moisture content. Differential scanning calorimetry (DSC) provides the quantitative and qualitative data on endothermic and exothermic process of materials during physical transitions that are caused by phase change, melting, glass transitions, thermodynamic process, kinetic events, crystallization and oxidation. These properties were optimized by various composite parameters such as particle size, weight fraction, density, matrices and hybrid. In order to achieve this objective, a single layer panels were manufactured using sago particles, Urea Formaldehyde (UF) or Phenol Formaldehyde (PF) and ammonium chloride.

This chapter describes the materials and methods used in this research project. The experimental work was divided into four stages. The first stage involved the preparation of sago particles with urea formaldehyde. The second stage determined the physical properties of sago particles such as moisture content and the particle dimension. The third stage characterized using Fourier transform infrared spectroscopy (FTIR), Scanning electron microscopy (SEM) and the profile density of sago composite particleboard. The last stage evaluated the thermal analysis, mechanical and physical properties of sago composite particleboard.

### 3.2 Process Flow Chart



### **3.3 Preparation of sago particles**

Sago particles were obtained from Mukah, Sarawak, Malaysia. The particles went through the sieving process for separation of particle size. < 0.6 mm, 1.18 mm and 2 mm sieving size of the particles were used in the experiment. After the sieving process, the particles were subjected to drying under the sun. The particles were dried in the oven at 105 °C for 24 hours to achieve moisture content of less than 5% before fabrication. The sieving vibrator HK-DUAL-DRIVE-LAB-SHAKER used in the sieving process. The round vibratory sieves were used to separate the desired particles. The separation time for sieving is about 10 minutes for each operation. The output cross checked by the HIROX KH-8700 microscope.

### **3.4 Preparation of waste wood particles for hybrid composite particleboard**

The waste wood particles obtained from the Seven Seas Trading Company (Sarawak). It was dried under the sun followed by an oven drying at 105 °C for 24 hours. This is to achieve the moisture content of 5% or less for better bonding during the fabrication process.

### **3.5 Preparation of Matrices**

#### **3.5.1 Urea Formaldehyde (UF)**

Urea formaldehyde (UF) resin at 51.5% solid content that serves as particle binder was supplied by Hexzachem Sarawak Sdn Bhd (Kuching). UF was used as binder together with 1% NH<sub>4</sub>CI solution which acts as a hardener. UF is one of the most commonly used resin in composite particleboard manufacturing due to the positive aspect like rapid cure rate, cost-effective, non-flammable and light in colour. The viscosity of UF is 168CPS and the PH is 8.

### **3.5.2 Phenol Formaldehyde (PF)**

Phenol Formaldehyde (PF) was obtained from Bintulu Adhesive & Chemicals Sdn. Bhd (Bintulu). PF with 41% solid content was used as an adhesive to bind the wood particles and widely used in the plywood and firewood industries. The viscosity for PF is 90 pulse and the PH is 13.

### **3.6 Ammonium chloride (NH<sub>4</sub>Cl)**

NH<sub>4</sub>Cl solution which acts as a hardener and was applied with the UF to accelerate the curing process and shorten the press time. The hardener was obtained from Hexzachem Sarawak Sdn Bhd (Kuching). The main purpose is to accelerate the polymerisation process. 1% of NH<sub>4</sub>Cl will be added together with UF during the fabrication process.

### **3.7 Manufacturing Apparatus**

This section explains the equipment used in the particleboard preparation.

#### **3.7.1 Mixing drum**

The normal mixing drum with a cover used to mix particles with resin. The cover was designed to have few small holes, each with a diameter of 1 mm. The holes released pressure during the mixing process. The capacity of the mixture was 3 m<sup>3</sup> with rotating speed of 800 rpm. The main purpose of using the mixing drum was to have homogenous mixture of particles with matrix.

### **3.7.2 Spray**

A spray gun with high pressure to spray the resin into the mixer while mixing with the particles. The pressure gun had a 1.5 mm nozzle for controlling the resin flow. A constant pressure was maintained during the mixing process.

### **3.7.3 Mold/ silicon glass mat/ steel plate/ steel bar**

A particleboard mold made by wood. The dimensions of the mold was 300 mm X 300 mm X 120 mm. Silicon glass mat was used to release the particleboards after the hot press process. Steel plate with dimension of 500 mm X 500 mm X 3 mm was placed at the bottom of the raw materials for transferring the raw material to the hot press machine and to ensure consistent heat transmission from bottom. A 10 mm steel bar was used to set the thickness of the sago composite particleboard.

### **3.7.4 Hot press**

The Kobayashi hot press machine used to manufacture particleboards. The machine was used to perform hot pressing and cold pressing. It took approximately 1 hr to reach 180 °C and ½ hr to cool to room temperature 25 °C. The maximum press area for the hot press was 500 mm x 500 mm. The maximum pressing capacity of the hot press machine was 150 tons.

### **3.7.5 Cutting machine**

Panel saw SZIII was used for cutting process. Samples were prepared and cut from each test board according to the Japanese Industrial Standard, *JIS A 5908-1994*.

### **3.7.6 Chamber**

The chamber used for the curing process. The sago composite particleboards were stored in the chamber at a temperature of 25 °C and 65% humidity until the constant mass was achieved. This process usually took 2 days to complete.

## **3.8 Sago Composite Particleboard Production Process**

This section outlines the general methodology for the sago composite particleboard production process. The experiments were conducted with different parameter with different mixture proportions of residues and matrix. The composite particleboards were made by using the sago particles and waste wood as the raw materials. The amount of adhesives, hardener and raw materials were calculated by considering the target density of the composite particleboards. In this work, the parameters such as matrices used, ie Urea Formaldehyde and Phenol Formaldehyde, various particles sizes, densities, weight fraction and hybrid composite particleboard were investigated and analysed.

The first step of the process was particle preparation. The particles were collected from Mukah sago mill plant. The particles was dried under the sun for two days followed by oven drying at 105 °C for 24 hours. This was to ensure that they were dried and the moisture had evaporated completely. The moisture level of particles must be kept in the range of 3 to 8 % for the purpose of better bonding with liquid resins. Immediately after drying, the particles were screened for desired size in the vibrating screens. The particles were separated according to size i.e. 0.6 mm, 1.18 mm and 2 mm. The amount of particles were measured in accordance with the calculated amount ( refer to the calculation at part 3.15 ). For the hybrid particleboard, Sago : Waste wood were prepared based on the ratios : 25 wt%:75 wt%, 50 wt%:50 wt% and 75 wt%: 25 wt%. Urea Formaldehyde (UF) or Phenol Formaldehyde (PF) are generally used to bind the particles. 1% of  $\text{NH}_4\text{Cl}$  was added during the mixing process to

make the UF become hard. Adhesives for both the matrices depend on the weight fraction of resin : 10 wt% , 15 wt% and 20 wt% to be used with the raw material. For eg. 10 wt% of adhesive mixed with 90 wt% of sago particles.

While mixing the particles, the calculated amount of matrices and hardener were measured and then mixed in a small bottle. Figure 3.1(a) shows the particles were placed into the mixing drum. Figure 3.1(b) and Figure 3.1(c) show that the raw materials were mixed at a constant speed and the resin was sprayed on the surface of the particles at the same time. Figure 3.1(d) shows the mixture was collected and placed into a pail for weighing. The weight loss was calculated. Next, the mixture was transferred into a wood mold for molding before pressing.

Once the molding was done, the mold was compressed manually by body weight, as shown in Figure 3.1(e). The mixture was manually compressed in a wood mold and the thickness of the mixture was constantly checked to ensure even mixing and ensure that the sago composite particleboard have a square shape when removed from the wood mold. Two pieces of silicon glass mat were used as a release agent for the sago composite particleboard.

The molded mat was transferred into the press machine for consolidation process. Figure 3.1(f) shows the two steel bars at 10mm thickness placed on both the sago composite particleboard sides to maintain the thickness of the mat. Figures 3.1(g) and 3.1(h) show the mat was transfer to the hot press machine to go through the hot press process. Figure 3.1(i) shows that the mat was compressed at selected temperature with specified pressing time. The temperature was set at 180 °C and the pressure was initially set to 40 tons for 2 minutes and then gradually decreased to 20 and 10 tons where each pressure lasted for 2 minutes. The main purpose of reducing the pressure was to avoid a build-up of steam pressure within the board that could potentially lead to blistering if the steam was not released effectively.

After the hot pressing process, the sago composite particleboard was removed and left to cool down to room temperature as shown in Figure 3.1(j). Figure 3.1(k) shows the sago composite particleboard undergo the side trimming. Next, the particleboard were kept in the chamber for 2 days curing process as shown in figure 3.(l). The temperature of the chamber was set at 25 °C with a humidity of 65%. This is to avoid the sago composite particleboard from swelling and also to stabilise the particleboard. After 2 days, the sago composite particleboard was cut into specimen sizes for the purpose of thermal analysis, mechanical and physical tests.



(a)

(b)

(c)



(d)

(e)

(f)



**Figure 3.1:** Sago composite particleboard production process (a) Mixing preparation of sago particles (b) Mixing process of sago and with (c) Adhesive spraying process (d) The mixture of sago composite (e) Mixture was manually compressed (f) Steel bars with 10mm thickness for setting (g) Transferring the mixture from mold (h) Sago composite mixture for hot press process (i) Mixture being compressed as sago composite particleboard (j) Heat released after the fabrication (k) Cutting process for sago composite particleboard (l) Curing process for sago composite particleboard.

### 3.9 Specimens Preparation

The particleboard was cut into the specimen size for testing. Each of the tests has different specimen dimension. Specimens for flexural test, screw withdrawal, internal bonding, tensile test, water absorption and thickness swelling were prepared and tested according to the *JIS A 5908* and *ASTM D 638* standards. All the specimens were prepared following the guidelines as shown in the Figure 3.2 and 3.3

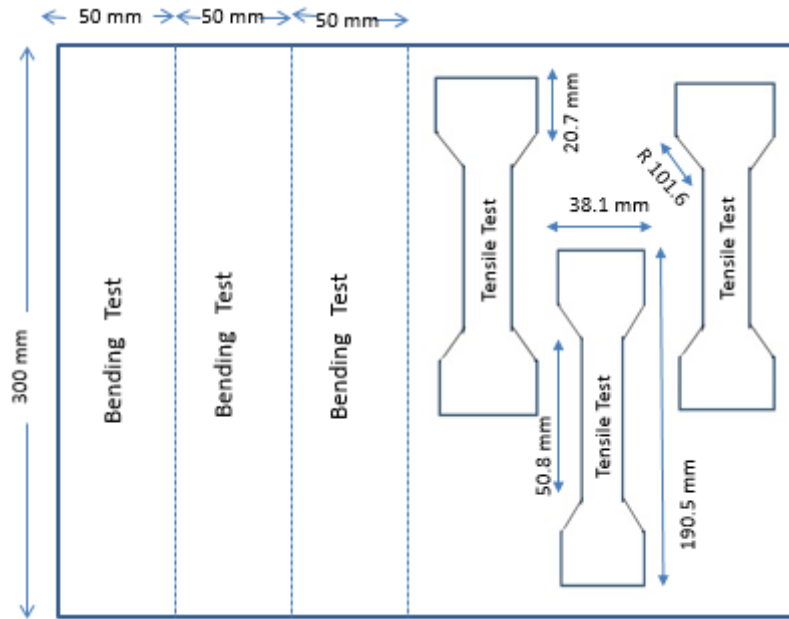


**Figure 3.2:** Cutting diagram of particleboard specimens for bending and tensile specimens (mm).

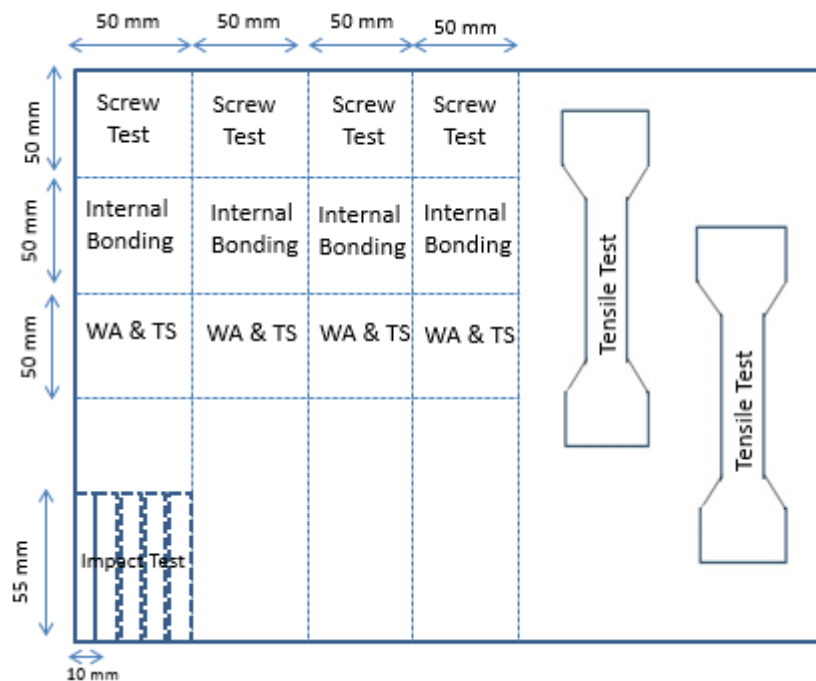


**Figure 3.3:** Cutting diagram of particleboard specimens for internal bonding, screw test, tensile test, water absorption and thickness swelling specimens (mm).

### 3.10 Characterisation of the sago composite particleboard

#### 3.10.1 Mechanical test of sago composite particleboard

##### 3.10.1.1 Bending test of sago composite particleboard

Bending strength is as an ability of a material to resist deformation under load applied perpendicular to its longitudinal axis. The size of specimens used in the test was prepared based on the *JIS A 5908* standard. The specimens were prepared with specific dimensions; width of 50 mm, length of 300 mm, thickness of 10 mm. The test was carried out using a three-point loading system applied on a supported beam. The maximum load was measured by applying a load approximately 10 mm/min from the surface of the test piece. The distance of two supports span ( $L$ ) was fixed at 150 mm and the load was applied at the middle points of two supports ( $L/2$ ). The bending strength was obtained using the formula below:

MOR = Modulus of rupture (MPa)

$$\text{MOR} = \frac{3PL}{2bt^2} \quad \text{Eqn.1}$$

MOE = Modulus of elasticity (MPa)

$$\text{MOE} = \frac{L^3}{4bt^3} \times \frac{\Delta W}{\Delta S} \quad \text{Eqn.2}$$

Where  $P$  = load at a given point on the load deflection curve (N),  $L$  = support span (150 mm),  $b$  = width of beam tested (50 mm),  $t$  = depth of beam tested (10 mm),  $\Delta W$  = Increment in load (N),  $\Delta S$  = deflection with the load.

##### 3.10.1.2 Tensile test of sago composite particleboard

The purpose of a tensile test is to investigate the breaking tensile stress. The test was conducted at room temperature 20 °C with 65% relative humidity test at 4 mm/min. The specimens were prepared based on the dimensions in Figure 3.4 under *ASTM D 638* standard.

$$\text{Tensile strength} = \frac{\text{Force (load)}}{\text{Cross section area}} \quad \text{Eqn.3}$$

$$\text{Tensile stress at yield} = \frac{\text{Yield load}}{\text{Cross section area}} \quad \text{Eqn.4}$$

$$\text{Tensile stress at break} = \frac{\text{Load at break}}{\text{Cross section area}} \quad \text{Eqn.5}$$

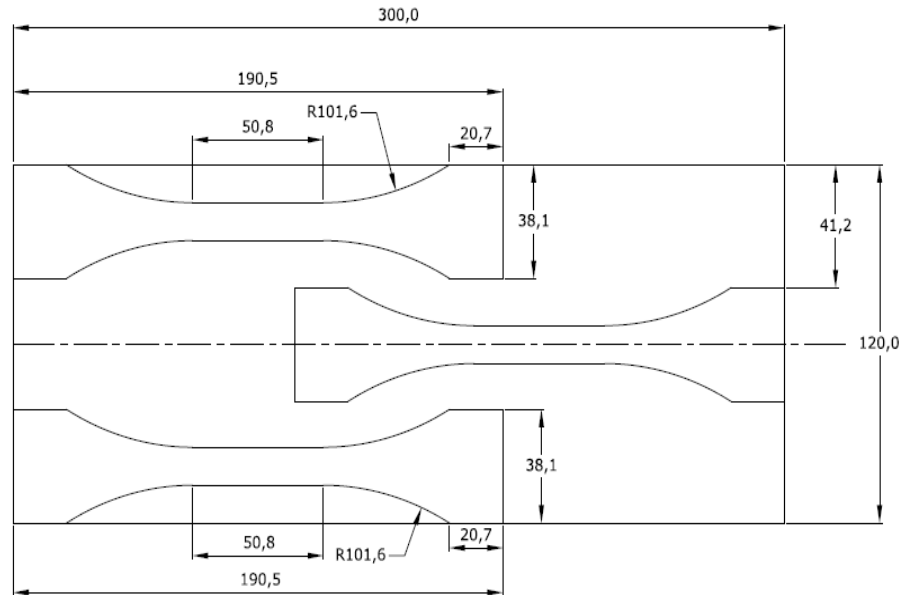


**Figure 3.4:** Detail of tensile test specimen's dimensions (mm).

### 3.10.1.3 Internal Bonding of sago composite particleboard

The specimens were prepared based on the JIS A 5908 with 50 mm width, 50 mm length and 10 mm thickness. The specimens were first glued to the aluminium blocks on both surfaces using hot melt glue and go through the cooling for 24 hours. This procedure ensured that the glue would fully stick on the aluminium blocks. A tension load was applied perpendicular on the surface of each specimen at 2 mm/min until failure occur. The maximum load of every specimen was recorded and then divided by the sample's cross section area. This test determine the shear properties that would be applied perpendicular on the surface of a test board and to measure the performance of an adhesive in wood composites.

$$IB = \frac{F_{max}}{A B} \quad \text{Eqn.6}$$

Where  $F_{max}$  = breaking load (N),  $A$  = width (mm),  $B$  = length (mm), IB= Internal bonding (N/mm<sup>2</sup>)

#### 3.10.1.4 Screw Test of sago composite particleboard

The specimens were prepared based on the JIS A 5908 standard with the dimensions; 50 mm width, 50 mm length and 10 mm thickness. The centre of each specimen was identified using intersection method and a guide hole 3 mm depth and 2 mm diameter was drilled. A 2.7 mm diameter screw was driven into the pilot hole until the head of the screw is parallel to the surface of the specimen. The specimen was then fitted into the holder and tensile force was applied to the screw at a rate of 2 mm/min and the maximum force in N was recorded by the system.

#### 3.10.1.5 Impact Test of sago composite particleboard

The Charpy impact test is used to test the ability of an object to resist high-rate loading. The test helps to determine the amount of energy absorbed in fracturing a test piece at high velocity. This absorbed energy is a measure of a given material's toughness. Specimens were prepared based on the ASTM A370 standard with 10 mm width, 55 mm length and 10 mm thickness. There are two types of failure modes : brittle and ductile.

$$\text{Impact strength} = \frac{\text{Energy absorption}}{\text{Cross Section}} \quad \text{Eqn.7}$$

Where Energy absorption(J), Cross section ( m<sup>2</sup> ), Impact strength = J/m<sup>2</sup>

### 3.10.2 Physical test of sago particleboard

#### 3.10.2.1 Water Absorption (WA) and Thickness Swelling (TS) of sago composite particleboard

Water absorption test is used to determine the amount of water absorbed under specific conditions. The main purpose of the test is to check the behaviour of a particleboard

and the effects of the absorbed water on the dimensions of the affected particleboard. The water absorption (WA) and thickness swelling (TS) tests were performed according to ASTM D-1037. Water absorption tests were conducted by immersing the Sago-UF specimens in a de-ionised water bath at 25 °C for different time durations. The water absorption and thickness swelling specimen were prepared with the dimension of 50 mm X 50 mm X 10 mm with smooth and squarely trimmed edges. The side of each specimen were glued tightly to prevent water from being absorbed through the sides of the surface when they were immersed in water. The specimens were horizontally submerged 3 cm below the water surface. After 2 hours, 24 hours, 48 hours, and 72 hours immersion process, the specimens were taken out from water and the surfaces were dried using a clean dry cloth. The specimens were reweighed to the nearest 0.1mg within 1 min of removing them from the water. The specimens were weighed regularly at 2 hours, 24 hours, 48 hours and up to 72 hours exposure. The water absorption and thickness swelling of each specimen was calculated by the weight thickness difference respectively.

**Water absorption (%) =**

$$\frac{W_f - W_i}{W_i} \times 100\% \quad \text{Eqn.8}$$

Where  $W_i$  = initial weight,  $W_f$  = final weight

**Thickness swelling (%) =**

$$\frac{T_f - T_i}{T_i} \times 100\% \quad \text{Eqn.9}$$

Where  $T_i$  = initial thickness,  $T_f$  = final thickness

### **3.10.2.2 Moisture for the Raw Materials**

Natural fibres are hygroscopic material and this characteristic affects the overall performance of the composites. If the fibres with higher moisture content during fabrication, the bonding between the particles will be weaker due to the wet surface. Therefore, the moisture content should be kept to the lowest during the fabrication process. Fibers with higher moisture content were dried in an oven. The apparatus and material in this test included an oven and a balance weighing machine. About 10 grams of fibres were picked randomly. Each specimen was weighed and the reading was recorded. The specimens were dried in the oven at 105 °C for 24 hours. After the heating process, the specimens were weighed after they become stable and the reading of each specimen was recorded.

### **3.10.2.3 Density Profile of the composite particleboard**

The vertical density profile (VDP) was used to measure the density profile of sago composite particleboard, oriented strand board (OSB) or medium density fiberboard (MDF) samples along the thickness of particleboard. This variation of density along the thickness direction of a particleboard is referred to as vertical density profile (VDP). The VDP in a particleboard has a significant influence on most of the mechanical properties like modulus of rupture (MOR), modulus of elastic (MOE), screw test, internal bonding (IB) and tensile-strain. VDP formation is influenced by the press time, moisture distribution in the mat and hot- press temperature, particle configuration, wood and resin type. The VDP of a particleboard can provide information on the average raw density, maximum raw density of top and bottom layer and actual position of sanding surface. The measuring principle of raw density is based on a combination of x-ray transmission and forward scatter. The imaging geometry will be shown on the screen.

### **3.11 HIROX KH-8700 Digital Microscope**

The HIROX digital microscope was used to measure the sago particles size like length and surface area. Natural fiber are discontinuous fiber and come with different diameter. The size of natural fiber have great influence on the final product. Before a sago composite particleboard is manufactured, the physical properties of the fiber should be study.

### **3.12 Fourier transform infrared spectroscopy (FTIR)**

The functional groups and chemical characteristics of Sago/UF particleboards were obtained using a Fourier Transform Infrared Spectroscopy (Shimadzu - IRAFFINITY-1) with a resolution of  $4000\text{-}600\text{ cm}^{-1}$  using 20 scans per sample.

### **3.13 Scanning Electron Microscopy (SEM)**

The Scanning Electron Microscopy (SEM) JSM-5300LV technique was used to study the fracture surface of the specimens. The SEM was operated at an accelerating voltage of 1-5 kV and emission current of  $47\text{ }\mu\text{A}$ . The fracture surface were sputter-coated with gold 50 nm in thickness. The scanning data were analyzed at magnifications of 100X and 200X. Approximately 8-10 SEM images were taken. In addition, the SEM technique was used to study the cross section of the fibers. The failed specimens were examined to observe the morphology of fracture surface of the sago composites particleboard, such as the interfacial interaction between the Sago particles and Urea Formaldehyde.

### **3.14 Thermal Analysis**

#### **3.14.1 Thermogravimetric Analysis (TGA)**

The thermogravimetric analysis of the sample was carried out using TGA/DSCI STAR System, Mettler Toledo thermal analyser according to ASTM E1131. Approximately

10mg of the powder sample was placed in an aluminium pan and heated constantly at a rate of 10 °C/min from 50 °C to 800 °C under 30 mL/min of nitrogen gas atmosphere. The weight loss and temperature were recorded and analysed to determine the following TGA Parameters: weight loss %, initial degradation temperature, volatiles in sample, and the residual weight %.

### **3.14.2 Differential Scanning Calorimetry (DSC)**

The differential scanning calorimetry analysis was carried out by using the same machine TGA/DSCI STAR System and 10mg of the powder sample was prepared. The powder sample heated constantly at a rate of 10 °C/min from 50 °C to 800 °C under 30 mL/min of nitrogen gas atmosphere. For DSC, the heat given off during a reaction was called an exotherm while the heat absorbed by material is called an endotherm. By measuring the exotherms and endotherms, it is possible to determine all the chemical and physical state changes that occurred in the sample.

### 3.15 Calculations For Particleboard

1. Setting the dimensions or volume of Fibre board which is:

$$V = 30 \text{ cm} \times 30 \text{ cm} \times 1 \text{ cm} = 900 \text{ cm}^3$$

$$\text{Percentage of resin or UFR solid content} = 52.8\% = 0.528$$

$$\text{Density of fibre board} = \rho = 600 \text{ kg/m}^3 = 0.6 \text{ g/cm}^3$$

2. Mass (fibres + UFR which is including moisture content) ,

$$m = \rho V = 900 \text{ cm}^3 \times 0.6 \text{ g/cm}^3 = 540 \text{ g}$$

3. By setting 90% of mass is fibre weight and 10% of mass of UFR(including moisture content):

$$\text{Amount of fibres} = 540 \text{ g} \times 0.9 = 486 \text{ g}$$

$$\text{Amount of UFR (including moisture content)} = 540 \text{ g} \times 0.1 = 54 \text{ g}$$

$$\text{Amount of UFR (without moisture content)}$$

$$= \frac{\text{Amount of UFR (including moisture content)}}{\text{Percentage of UFR solid content}} \quad \text{Eqn.10}$$

$$= 54 / 0.528$$

$$= 102.273 \text{ g}$$

4. Amount of  $\text{NH}_4\text{Cl}$  hardener, measured by taking 1% of UFR (including moisture content)

$$= 54 \text{ g} \times 0.01 = 0.54 \text{ g}$$

5. By adding up all of the component's amount,

$$= \text{Fibres} + \text{UFR (without moisture content)} + \text{NH}_4\text{Cl}$$

$$= 486 \text{ g} + 102.273 \text{ g} + 0.54 \text{ g} = 588.813 \text{ g}$$

After adding up, put into the mixing machine for components mixing process. After finishing the process, the mixing taken out and reweight again, it is observed that total weight reduced. There are 5% of weight loss created by mixing process, therefore for other experiment or mixing process, 5 % will be added for fibres, UF and  $\text{NH}_4\text{Cl}$ .

## CHAPTER 4

# EFFECTS OF PARTICLES SIZE OF SAGO/UREA FORMALDEHYDE COMPOSITE PARTICLEBOARD ON PHYSICAL, MECHANICAL AND THERMAL PROPERTIES

### 4.1 Introduction

The production of composite particleboard has been constantly increasing due to its several advantages compared to solid wood and other composite materials. Composites particleboard is fabricated by changing the wood into particles, bonded with resin together with pressure and heat into panel product (Hazwani *et al.*, 2014).

Mechanical properties of composite particleboard were depending on few factors. The most important factor is the wood particle size. Emmanuel *et al.* (2011) mentioned that the size of particles strongly affecting the particle packing efficiency and bond strength. Composite particleboard required the bulk mass of particles and the number of inter particle contact to achieve effective inter-particle bonding (Onuorah *et al.*, 2011). Greater particle contact promoted the resin efficiency.

In order to achieve the better mechanical and physical properties, the optimal particle size must be selected during the board fabrication. Emmanuel *et al.* (2012) mentioned that better mechanical and physical properties of composite particleboard could be achieved by controlling the particle size during the board fabrication. According to Cezary *et al.* (2011), better performance of mechanical properties could be achieved by using the particles with great length and a high length-to-thickness ratio. The internal bonding strength of composite particleboard was increased when the fines and wood dust were applied in the core of boards. However, the bending and modulus of elasticity (MOE) reduced. The was due to the filling of void spaces between the larger particles with fines to produce a higher degree of inter particle

contact. The optimal particle size had increased the mechanical properties such as tensile, bending and impact strengths (Cezary *et al.*, 2011).

Researchers have reported that the critical particles size, particle-matrix interface adhesion, and particles loading on composite particleboard had notable effects on the mechanical properties (Fu *et al.*, 2008). Although natural fibers are frequently used as reinforcement, there are some drawbacks namely poor compatibility with thermoplastic matrix, high moisture absorption, high probability of deterioration by biological organisms, and low thermal stability to be concerned (Islam *et al.*, 2012).

Particle size had great influence on the physical properties of composite particleboard. Thickness swelling and water absorption test were used in the composite particleboard to determine the dimensional stability and the ability of water absorb caused the material decay or damage. However, natural fiber undergoes changes in its moisture content and the water absorption properties significantly affect the mechanical properties of a product (Khazaei *et al.*, 2008).

Mechanical properties of composite particleboard are generally dependent on the properties of their components and the inter facial bonding of fiber and matrix (Chandra *et al.*, 2014; Anupama *et al.*, 2012). The chemical bonding plays an important role in the bonding process between the matrix and fiber in a composite particleboard (Chandra *et al.*, 2014). In this work, Fourier Transform Infrared (FTIR) spectra are used to characterize the Sago/urea formaldehyde composite particleboard in terms of their functional group and bonding.

A thermal analysis was performed on the sago composite particleboard to qualify the gravimetric response and specific heat capacity at elevated temperature. DSC provides the quantitative and qualitative data on endothermic and exothermic process of materials during physical transitions. The thermal stability studies indicated that particle size and

particle/matrix interface adhesion have great influence on the thermal properties of the composite particleboard.

The purpose of this study is to evaluate the effect of particles size on the thermal, mechanical and physical properties throughout the composite particleboard performance. A single-layer particleboard by using the sago particles has been established at targeted density level  $600 \text{ kg/m}^3$ .

## **4.2 Results and Discussion**

### **4.2.1 Sago particles sorting**

The particles were sorted by the vibration sieve to the desired particle size. There are less than 0.6 mm, 1.18 mm, 2 mm and  $> 2 \text{ mm}$ . The particles size was cross checked by the HIROX KN – 8700 ( 3D Digital Microscope ). The dimension of the particles has a great influence on the final product. The sorting process gave particular effect when applied as raw material for the particleboard production. High mechanical and physical performance of the particleboard were achieved by an optimal size of the particles. The data were taken from a random selection with 200 units of particles for each size

**Table 4.1:** Percentage of particles and the dimensions.

| Particles size | Group | Range           | Count | Percentage % |
|----------------|-------|-----------------|-------|--------------|
| 0.6mm          | G1    | 0.01 mm-0.10 mm | 56    | 28.0         |
|                | G2    | 0.11 mm-0.20 mm | 119   | 59.5         |
|                | G3    | 0.21 mm-0.30 mm | 19    | 9.5          |
|                | G4    | 0.31 mm & above | 6     | 3.0          |
| 1.18mm         | G1    | 0.40 mm-0.50 mm | 65    | 32.5         |
|                | G2    | 0.51 mm-0.60 mm | 70    | 35.0         |
|                | G3    | 0.61 mm-0.70 mm | 52    | 26.0         |
|                | G4    | 0.71 mm & above | 13    | 6.5          |
| 2.00mm         | G1    | 0.20 mm-0.30 mm | 14    | 7.0          |
|                | G2    | 0.31 mm-0.40 mm | 119   | 59.5         |
|                | G3    | 0.41 mm-0.50 mm | 40    | 20.0         |
|                | G4    | 0.51 mm & above | 27    | 13.5         |

#### 4.2.2 Moisture content of sago particles

Moisture content is a critical parameter for developing vertical density profile and a very significant parameter in particleboard production. High moisture content of natural particles reduced the bonding of particles and matrix due to poor surface wetting. The moisture content was maintained at the lowest during the fabrication process. Poor surface wetting for hydrophobic resin may cause interfacial shear bond and thus, lowered the strength of a composite particleboard. When excessive moisture migrated to the particleboard core, it requires additional pressing time to exit through the edges of the board to prevent delamination and spring-back condition when the press is open. Excessive moisture caused rapid densification of the surface and loosen the core, hence, resulting in poor mechanical test and may interfere with the polymerization of resin. The results of moisture content test in Table 4.2 shows that the smallest size particle possessed higher moisture content than the biggest size. The size and shape of the individual particles in a furnace are significant factors that influence on the particles drying. The total drying time increased with the chip thickness. The over pressure in the centre of material was higher in the thinner particles. This was due to

the distance for transport the heat from surface was halved and the main pressure release in longitudinal direction. When the longitudinal and latitudinal dimension was doubled, the maximum overpressure increased by a factor of more than two because of the larger length of longitudinal and latitudinal flow necessary for pressure equalization. The total drying time was longer in order to achieve the equal volumes, a smaller particle is better for drying purpose than a bigger one, due to the highest resistance to flow in the thickness direction. The fine particle consisted of numerous pores than coarse particles. The coarse particles have less porosity or overall pore space. The water could be held tighter in small pores than in larger pores, so fine particles could hold more water than coarse particles.

**Table 4.2:** Moisture content of the natural particles.

| Particles Size   | Moisture Content (%) |
|------------------|----------------------|
| Less than 0.6 mm | 9.486                |
| 1.18 mm          | 8.248                |
| 2 mm             | 7.595                |
| >2 mm            | 7.519                |

#### **4.2.3 The effect of particle size on thickness swelling (TS) of sago composite particleboard**

Figure 4.1 shows the effect of sago particles size on thickness swelling of the sago composite particleboards. Thickness swelling increased with the immersion time and become constant after 24 hours.

Sago composite particleboard with 0.6 mm size achieved the lowest thickness swelling. This was due to the low diffusion rate in a particleboard with higher compaction that had reduced the porosity and thus lowered the capacity of a particleboard in absorbing water due to its limited surface area. Higher compaction reduced water penetration into the

particleboard and consequently, the water needed longer time to diffuse into the particles and panel.

Sago composite particleboards with 2 mm particles size had the highest thickness swelling value at the beginning until 24 hours where the water increment rate started to slow down. During the soaking process, the TS value increased again because the particles had expanded and some particles were released from the particleboards.

Thickness swelling is also influenced by the geometry of particles, their structure and the presence of many voids in the boards that allow internal swelling as well (Olufemi *et al.*, 2012).

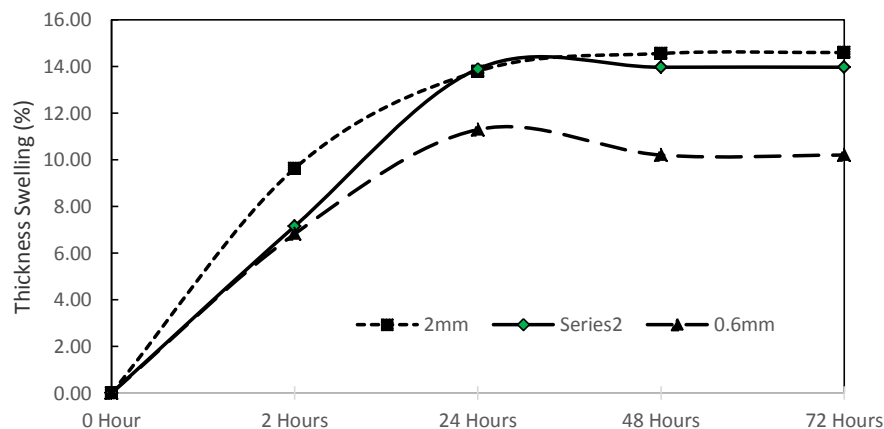


**Figure 4.1:** Particles size affected the thickness swelling on sago composite particleboard.

#### 4.2.4 The effect of particle size on water absorption (WA) of sago composite particleboard

Figure 4.2 shows the results of water absorption (WA) of the sago composite particleboards against the soaking time. There were two-step processes for the water uptake patterns. During the first two hours, more than half of the final absorbed water occurred. The trend of the water uptake began to saturate after 24 hours (Khazaei, 2008). Fick's law was used to determine the moisture absorption of sago composite particleboard where the mass of

water absorbed linearly with square root of time until it reached an equilibrium state (Vilay *et al.*, 2008).

The higher initial water absorption rate can be explained by the diffusion phenomenon, like a fluid migration, where the water spreads itself through the capillaries, vessels and cellular walls of the sago particles. Two forms of water up-take patterns were present which were interstitial water and bound water. The interstitial water was contained in the cellular cavities and bound water was retained in the cellular walls. The rate of water absorption depended on the difference between the saturation water content and the water content at a given time, which was called the driving force. The moisture diffusion into the particles took place because of moisture gradient between the surface and the centre. As sorption proceeded, the water content increased, diminishing the driving force and consequently the absorption rate. Generally, the interstitial water molecules were relatively weaker than the bound water molecules, thus, water migrated from the more concentrated medium towards the less concentrated one.

The size and shape of the individual particle furnish are significant factors that influence the water absorption process. The water absorption rate increased in thinner particles. This was due to the maximum over pressure in the centre of thinner particles was higher. The distance for transporting the water from surface was halved compared with bigger particles and main pressure release in the longitudinal direction. When the longitudinal and latitudinal dimension was doubled, over pressure increased by a factor of more than two due to the larger length of longitudinal and latitudinal flow for water absorption to be stable. The total time was longer in order to achieve the equal volumes, smaller particles would achieve faster than the bigger one due to the highest resistance to flow in the thickness direction. The ability of composites to absorb water is an indicator of their porosity (Svetlana *et al.*, 2011). 1.18 mm particle had the least porosity when applied in composite. As a result, it had the least

water absorption compared to the smallest and biggest particles. During the particleboard fabrication, small size of particles that had bigger spaces between each other caused the water molecules to easily substitute the spaces in between. On the other hand, 2 mm particles having the same problem just slightly different than 0.6 mm. 1.18 mm particles were the optimum for the particleboard fabrication and the spaces between the particles made it difficult for the water molecules to penetrate into the particleboard. 1.18 mm particles showed good inter-particle bonding between the particles and matrix during the hot-press process and had reduced the porosity of the boards which made the boards to become water repellent.

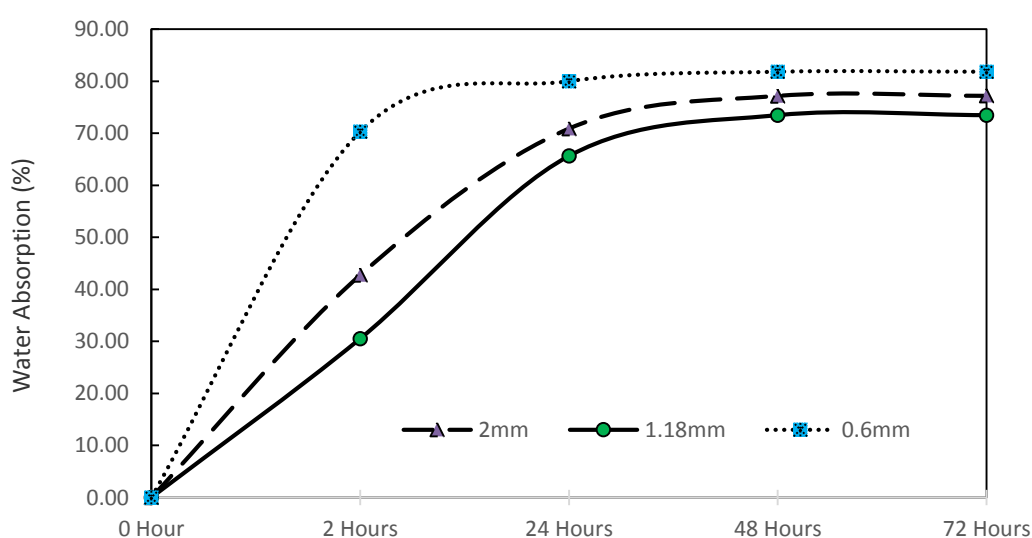


**Figure 4.2:** Water absorption affected by particles size on sago composite particleboard.

#### 4.2.5 Effect of particles size on bending strength of sago composite particleboard

The results in Figure 4.3 show bending properties gradually decreased with particle size from 0.6 mm to 2 mm. The 0.6 mm sieving size of sago particles had the highest bending strength compared to the other specimens. This could be due to the interferences of deformability of the matrix. This interference was created through the physical interaction and immobilization of the matrix by the presence of mechanical restraints, thereby increased the bending strength. The smaller particles had higher surface area than larger ones, with

higher interaction with matrix at lower concentration of particles. There was sufficient matrix to bond the particles and this reduced the voids resulting in better bending strength. Based on the statistics, it could be seen that about 60% of particles in the range of 0.11 mm to 0.20 mm shared geometrical similarity and this resulted in better bonding with each other and reduced voids (Toh *et al.*, 2011).

Coarse particles with 2 mm sieving size had the lowest bending strength because the particles were too big and not able to transfer the stress during the test. Poor adhesion between the UF matrix and sago particle had caused the voids occurred due to the particle which could be pulled out easily. Failure occurred because the surface of the particles was not filled by the matrix. The large particles were de-bonded more easily from the matrix and led to void formation. The presence of voids that resulted from processing abnormalities and porosity of sago composite particleboard had reduced the bending test (Svetlana *et al.*, 2011). Particle geometry is an important factor that affects their mechanical properties. Particles with a higher aspect ratio enhanced stress transfer from the polymer matrix to the particles and finally improved the mechanical properties of sago composite particleboard (Marek *et al.*, 2012).

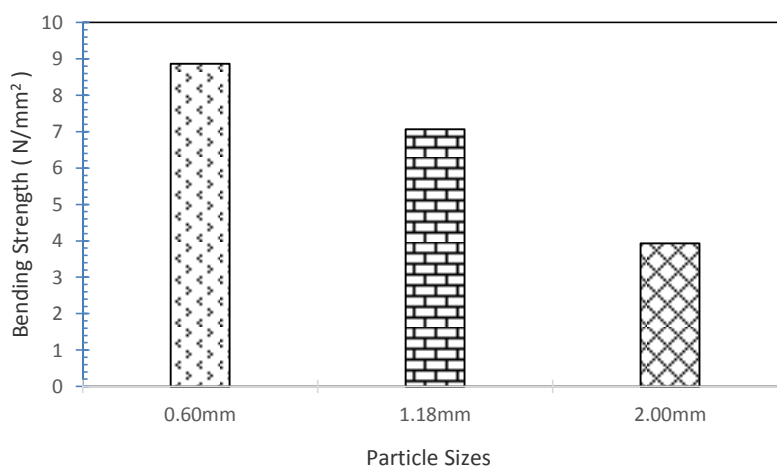


**Figure 4.3:** Particles size effect on bending strength on sago composite particleboard.

#### **4.2.6 Effect of particles size on internal bonding (IB) of sago composite particleboard**

Figure 4.4 showed the internal bonding test results. The particleboard with 1.18 mm fiber size had the highest internal bonding strength compared with 0.6 mm and 2 mm fiber sizes. The 1.18 mm particles had better bonding between the particles and matrix. Particles 1.18mm had higher specific surface area and had better adhesion strength with matrix. Hence, this provided better inter-particle contacts, which was improved internal bonding property compared to 0.6mm and 2mm. As a result, the matrix filled the gaps inside the core and increased the tension resistance.

The main reason that 0.6 mm had the lowest internal bonding because the matrix did not flow smoothly between the particles and they were not fully penetrated by the matrix. The internal bonding specimens failed at the core of sago composite particleboard because of improper bonding between particles. The lowest density at the middle core could lead to the specimen to fail easily. The particle size and shape of fibers affected the internal bonding process. Fine and coarse particles would not contribute better strength to sago composite particleboard. The internal bonding strength could be improved by using the optimal particles size that was 1.18 mm.

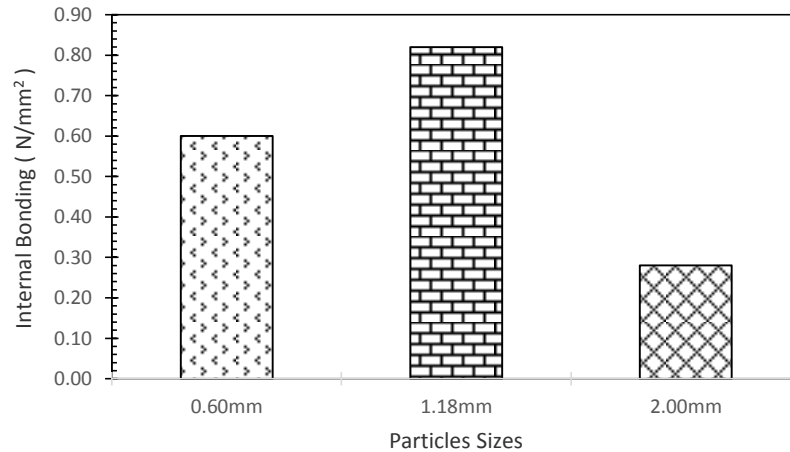


**Figure 4.4:** Particles size affected the internal bonding on sago composite particleboard.

#### 4.2.7 Effect of particles size on screw test of sago composite particleboard

Figure 4.5 shows that 1.18 mm particles achieved the highest screw strength. The 1.18 mm particle possessed good structure in the particleboard and the particles were sufficiently bonded by the matrix. The effective binding had increased the compatibility and enabled a screw to be fixed securely on the sago composite particleboard and resulted in better screw withdrawal reading.

Particles with 0.6 mm sieving size had the lowest value in screw test because the small particles had weak support structure and the matrix did not flow smoothly through the particles as the small particles were compacted together. The 2 mm particles were not bonded effectively during the fabrication and this created voids that caused failure in specimens during the test.

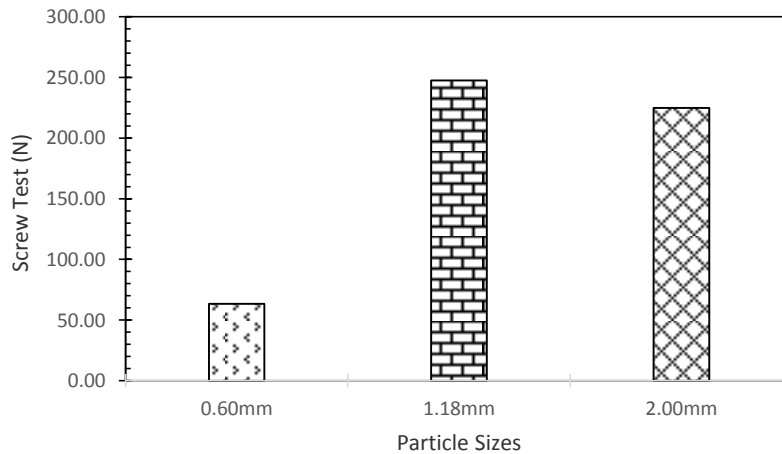


**Figure 4.5:** Screw test affected by particles size on sago composite particleboard.

#### 4.2.8 Effect of particles size on modulus of elasticity (MOE) of sago composite particleboard

Figure 4.6 shows the MOE of particleboards was significantly affected by the particles size. Based on the result, 1.18 mm samples showed the highest MOE value due to the particles had enough matrix to cover and increased the contact between the particles.

Porosity of the composite was inheritable due to the combination of particles with difference in size and matrix. Researchers had mentioned that geometrical variables such as pore size, shape, micro structural characteristic and location need to be considered as these had great effects on the MOE (Anupama *et al.*, 2012). By using the 2 mm particle size in the particleboard, voids were created due to the space created by the particles without fully bonded by the matrix and has the lowest value on MOE.

Smaller particle size such as 0.6 mm had lower value on MOE compared to 1.18 mm because it was not fully bonded with the matrix due to the arrangement of compact packing between the particles. This had caused inhomogeneity of particles and matrix and decreased the matrix coverage in the sago composite particleboard. The particles tend to agglomeration

and reduced the strength of whole composite particleboard. The agglomerates were the weak point in the board and break easily when a stress was applied. Besides, the matrix was hard to flow through the specimen and it evaporated during the hot press process. Additionally, smaller particle had weaker structure characteristics compared to the 1.18 mm.

Based on the FTIR result, 1.18 mm particles showed the higher starch characteristic compared to 0.6 mm and 2mm particles. The higher volume of starch created better bonding between the UF matrix and particles. The MOE increased because of the stiffening effect of the granules and incorporation of the sago fillers with the UF matrix. Hence, this had increased the modulus of the composites because starch granules are stiffer than the UF matrix in which they were dispersed (Toh *et al.*, 2011).

Improper bonding of 2mm particles with UF matrix had created the flaw where stresses were easily concentrated. This had enabled a relatively low level of energy to initiate cracks and causing the board to fail.

As a conclusion, there was a critical particle size on the sago/UF particleboards that affected the MOE. When the particle size was below and above the critical value, the effect on composite was more significant. Other factors included particle, matrix and particle / matrix adhesion (Fu *et al.*, 2008).

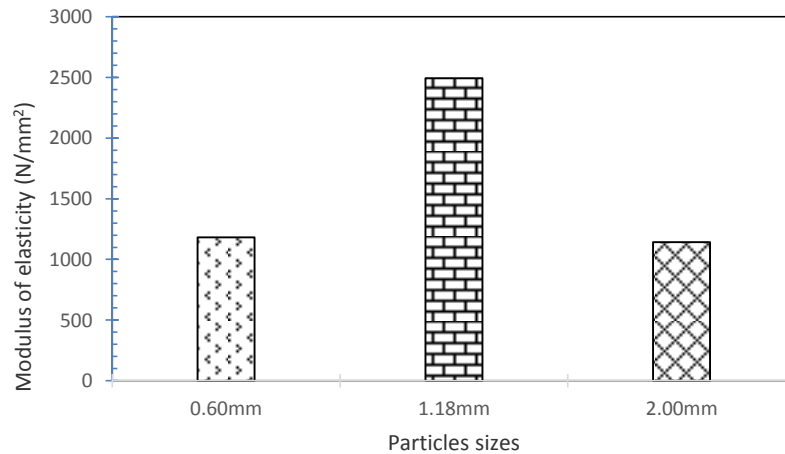


**Figure 4.6:** Particles size affected the modulus of elasticity on sago composite particleboard.

#### 4.2.9 Effect of particles size on tensile strength of sago composite particleboard

The effects of particle size on the tensile strength of sago/ UF composite are shown in Figure 4.7. The results showed that 1.18 mm sago composite particleboard had the highest tensile strength. The tensile strength increased when the particle size increased from 0.6 mm to 1.18 mm.

The quality of adhesion at the interface is important for the sago composite particleboard. The adhesion strength at the interface determines the load transfer between the components (Fabrice *et al.*, 2012; Fu *et al.*, 2008). The compaction of 1.18 mm particles had increased the adhesion quality. The 1.18mm particles had better adhesion strength at the interface between particles and matrix and between particles and interphase compared to 0.6 mm and 2 mm particles. This enabled the stress to be transferred effectively between the fibers and matrix (Randa *et al.*, 2013).

High percentage of same range of filler had increased the reinforcement effect. In this study, 1.18mm particle had showed 61% of geometrical similarity compared to 0.6 mm and 2 mm. The same range of particles size had led to better bonding between each other and high

packed structure for interaction. The effectiveness of stress transferred from the UF matrix to filler particles strongly depended on sago-filler interaction (Khalil *et al.*, 2013). Therefore, the particleboards with 1.18 mm sieving size had better stress concentration and managed to withstand higher stress when specimens were stretched or pulled before the failure. 1.18 mm particles had a higher total surface area for a given particle loading compared to 2 mm size and had increased the efficient stress transfer (Fu *et al.*, 2008). This had indicated that the strength increased with increasing surface area of the filled particles through a more efficient stress transfer mechanism. Tensile strength strongly depended on the hydrogen bond and the chemical interaction between –OH group of urea formaldehyde and –OH group of starch from sago (Toh *et al.*, 2011). FTIR showed the 1.18 mm sago composite particleboard consist of cellulose and the interaction between the UF matrix. UF matrix had better bonding with cellulose structure.

The high compaction of 0.6 mm particles had lead to agglomerate. This had caused the inhomogenous mixing between the particles and UF matrix. The particles were not fully bonded with UF had reduced the strength in sago composite particleboard and inefficiency of stress transfer (Randa *et al.*, 2013).

The 2 mm particles had poor surface area for bonding between the particles and matrix. Therefore, a lot of voids between the particles in the specimen were created and when the specimen began to pull, they tend to fail (Fu *et al.*, 2008). This had caused the sago composite particleboard strength reduced due to the larger space created between the particles and not fully bonded in the specimen. Exstence of larger and more voids 2 mm particleboard had caused increased the moisture absorption. FTIR showed 2 mm sago composite particleboard had higher percentage of OH group compared to 0.6 mm. The higher percentage of OH group in board had reduced the strength.

The tensile strength of sago /UF composite could be enhanced by adding the particles with 1.18 mm size and the results imply that particle size had significant effect on the strength and created ductile properties on the composite.

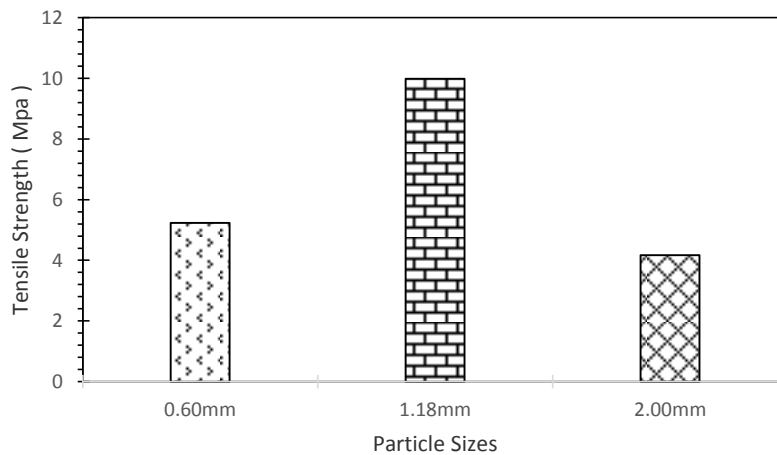


**Figure 4.7:** Particles size affected the tensile strength on sago composite particleboard.

#### 4.2.10 Effect of particle size on impact strength of sago composite particleboard

It was found that 0.6 mm samples had the highest impact strength. The smallest particles had higher compaction and agglomeration that increased the energy absorptance. The smaller particle size in the particleboard was able to withstand fast impact load which was better than the bigger particle size because the particle would slip from matrix and left weak points or stress on concentrated area. This remarkable performance indicated that 0.6mm particles were more effective in distributing the applied stress over a large volume at the sago composite particleboard and which helped to prevent propagation of cracks by carrying large part of the load in the area under the crack.

Particleboards made from 2 mm particles tend to fail easily during the test because the loose structure prevented them from absorbing the energy effectively. The bigger particles could not give better impact strength as its size could cause poorer particles dispersion as well

as the presence of sand particles in the particleboard. Hence, the interaction between the particles and matrix became poorer due to lack of interfacial bonding between the particles and matrix and existence of some porosity (Hornsby *et al.*, 2007). The introduction of bigger particles into the UF acted as flaw where stresses were easily concentrated, thus, enabling a relatively low level of energy to initiate cracks and causing the composites to fail. Different sizes of particles affected the interfacial shear, normal stresses and fracture characteristic (Ishak *et al.*, 2009).

Particle geometry (fiber length to thickness ratio) is one of the factors that affect the impact strength. Particles with higher aspect ratio managed to transfer the stress from polymer matrix to the particles and finally improved the particleboard strength (Marek *et al.*, 2012; Chang *et al.*, 2004).

This study proved that impact strength of the particleboard was greatly influenced by the particle size, fiber distribution and particle-polymer adhesion (Svetlana *et al.*, 2011; Chang *et al.*, 2004).

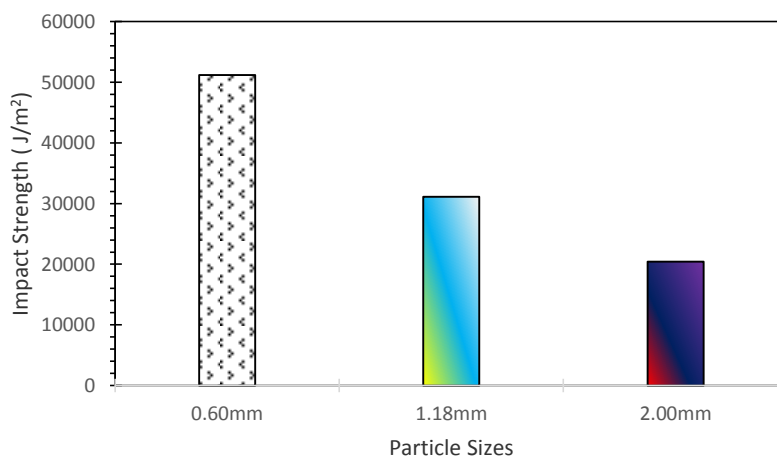


**Figure 4.8:** Particles size affected the impact strength on sago composite particleboard.

#### 4.2.11 Thermo-gravimetric analysis (TGA) of sago composite particleboard

The results obtained by TGA are presented in Figure 4.9. Evaluation of the thermal behaviour of sago composite particleboard were important in the determination of the limit of their service temperature under environment condition and its strength unaffected. The TGA curve for sago composite particleboard implied that the sample subjected to heat, first loses weight slowly and then sharply over a narrow range. Finally, the curve returned to a slope of zero as the reactant was exhausted. The TGA curves were used to determine weight loss and to identify the decomposition of material at certain temperature (Azwa *et al.*, 2013). Temperature played a significant role in the dimensional stability of nature fiber composites particleboard where it caused direct thermal expansion or contraction by affecting the rate and the amount of moisture absorption which led to fiber swelling (Wang *et al.*, 2005). The thermal behavior is practical interest for conditions associated with temperatures above the ambient, as in fire damage, curing or process involving heating.

It could be seen that sago composite particleboard with 2 mm particle size has the highest weight loss initially, which is about 9%. This is attributed to the higher moisture content trapped in the particleboard. The moisture evaporated from the particles starting earlier than other samples around 55 °C–175 °C with longer time and higher temperature (Chandra *et al.*, 2014). The 2 mm particles had bigger surface area to trap more moisture compared to smaller size particles and the presence of hemicelluloses has caused higher moisture absorption of the sago composite particleboard (Chandra *et al.*, 2014).

It was observed that the thermal stability of sago composite particleboard decreased as the particles size increased. This was because the addition of surface area caused reduction in the thermal stability of composite due to the influence of less stable particles (Chandra *et al.*, 2014). The gaps between the particles in 2mm sago composite was more and bigger compared to 0.6mm and 1.18mm and did not fully bond with the matrix. This had increased the -OH

groups in sago attracted water molecule through hydrogen bonding, thus making it dimensionally unstable, which had caused physical, mechanical, and chemical properties changes (Islam *et al.*, 2012).

Sago composite particleboard with 0.6 mm particle size had better thermal stability compared to sago composite particleboard with 2 mm particle size. This was because reducing the size could help the particles to bond well with UF and improve the decomposing process (Goodrich *et al.*, 2009). This was due to the higher amount of UF coating on the optimal particle surface. Smaller particles have optimal surface area for higher amount of UF to cover their surface (Bawornkit *et al.*, 2014). Smaller particles will caused the  $\text{NH}_4\text{Cl}$  easy to lower the surface tension between the UF matrix and particles. This caused the smaller particles to increase the surface area by leaving the OH group easily. The smaller particles have altered the bond energy distribution of the particles and matrix and the bonds usually broken easily by high temperatures compared with large particles. Bigger particles will require high temperature for melting and chemical process. Smaller size of particles allowed covalent bonds to form easily in the composite systems. The dispersion of particles in the particleboard was also an important factor that contributed to the enhancement of thermal stability (Hatakyama *et al.*, 1994). Besides, smaller particles had optimum surface-to-volume ratio and this caused decomposition temperature to be greater than the larger particle size. Therefore, smaller particle size had greater equilibrium temperature extension (Hatakyama *et al.*, 1994). Sago composite particleboard with small particle size had lower percentage of weight loss initially due to small area of surface trapping small amount of moisture. There was a marginal improvement in thermal behavior of sago composite particboard by using the small size of particles.

Lignocellulosic constituents in the sago fiber were chemically active and decomposed thermo-chemically between 200 °C to 250 °C. Hemicellulose, cellulose and lignin

decomposed at 200 °C, 220 °C and 250 °C respectively, with carbon dioxide and water (Islam *et al.*, 2012). There are three steps in the thermal decomposition of sago composite particleboard. Initial temperature of every step was defined as moisture loss or evaporation of trapped solvent. According to the TGA thermograph, the weight loss at first step was about 3%, 2% and 9% for 0.6 mm, 1.18 mm and 2 mm sago composite particleboard respectively. Different weight losses were visible due to the removal of moisture. For second step degradation, the weight loss was due to the restriction of mobility of UF matrix and sago fiber to different weight loss during the decomposition. The specimen continued to degrade until a fixed carbon content with 27%, 25% and 15% for 0.6 mm, 1.18 mm and 2 mm particles of sago composite particleboard at 800 °C is obtained.

The choice of particles size plays a very important role in the preparation of sago composite particleboard. In order to prevent aggregation of microemulsion UF in reaction process, the film formation performance of selected particles size must be suitable for UF intercalation, otherwise interfacial film formed by UF will reduce the TGA (FU *et al.*, 2013).

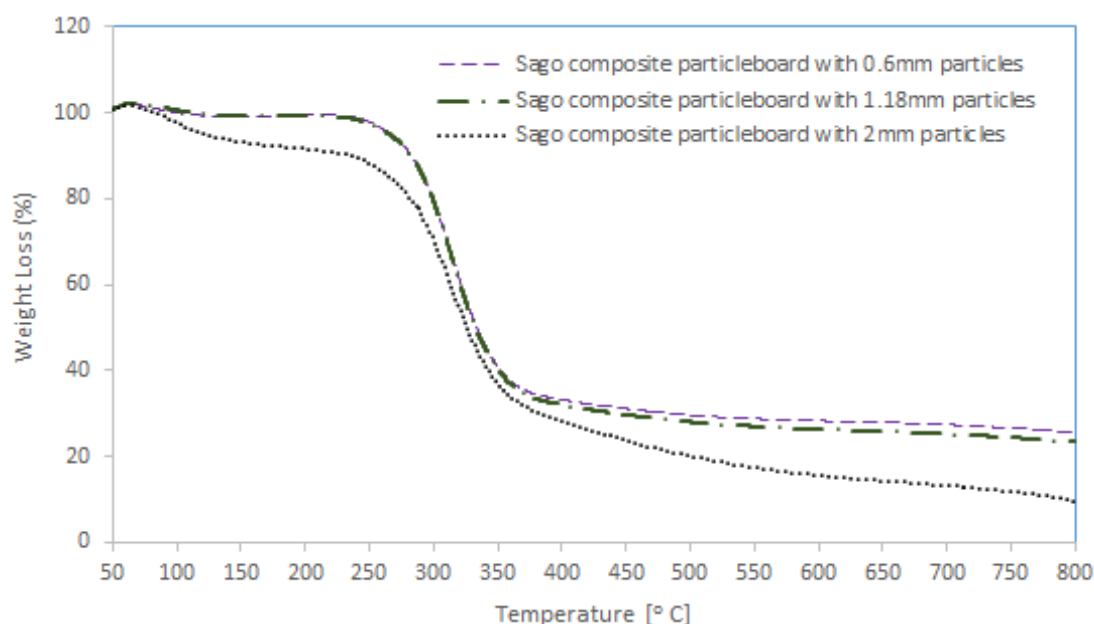


**Figure 4.9:**Sago composite particleboard with different size of particle analysis by TGA.

**Table 4.3:** Results for sago composite particleboard with different particle size analysis by TGA.

| Sample :                                           | Temperature (°C) | Weight Loss (%) | Residue (%) |
|----------------------------------------------------|------------------|-----------------|-------------|
| Sago composite particleboard<br>(0.6mm particles)  | 75<br>312        | 3<br>71         | 27          |
| Sago composite particleboard<br>(1.18mm particles) | 82<br>311        | 2<br>73         | 25          |
| Sago composite particleboard<br>(2mm particles)    | 86<br>311        | 9<br>76         | 15          |

#### 4.2.12 Differential scanning calorimetry (DSC) of sago composite particleboard

The DSC thermograms of sago particleboard with different particle size are shown in Figure 4.10. DSC was performed to check the moisture content and volatile component present in samples. The result showed that as the temperature increased, the chemical activity showed that moisture content and volatile components had greater effect on the properties of particleboard (Islam *et al.*, 2012).

Sago composite particleboard with 0.6 mm cured more compared sago composite particleboard with 2 mm. The smaller particles 0.6 mm accepted a higher charge relative to their weight than larger particles. The smaller particles were easily explored with UF due to smaller surface area. This caused the smaller particles to have better bonding compared with the bigger particles. Smaller particles that bonded with UF also possessed better curing characteristic, thus improving the thermal stability properties of the particle. Covalent bonds could be formed in the composite systems, although the dispersion of particles was an important factor for contributing to the enhanced thermal stability (Chandra *et al.*, 2014). As the UF became cross-linked the residual heat of curing becomes smaller and was causing the

sample to cure more (Melter, 2000). The attractive force between the charged particle and being coated by matrix is greater, which usually led to preferential deposition and wrap-around with smaller particles. It seemed that the particles size played a synergistic role in improving the thermal resistance of the composite.

Based on the result, all the endotherm peak was within the temperature range between 50 °C to 200 °C. The endotherm peak occurred at 88 °C, 82 °C, and 76 °C for sago composite particleboard with particles 2 mm, 1.18 mm and 0.6 mm respectively. Sago composite particleboard with 2 mm showed higher amount of water molecules in the sample compared with board fabricated by 0.6 mm and 1.18 mm; this was proved by TGA. The small reduction on endotherm peak was observed in both 2 mm and 1.18 mm sago composite particleboard. This indicated a smaller amount of water molecules in the samples (Islam *et al.*, 2012).

The result showed that higher melting temperature occurred on bigger particles. The higher melting temperature was found at 88 °C for sago composite particleboard 2 mm and the lowest was found at 76 °C for sago composite particleboard 0.6 mm. Bigger particles contained more starch compared to smaller particles and with their bigger surface were exposed to more matrix. This was contributed by the cross-linking reaction between the starch granules and led to better interaction between starch, UF, and the particles in the panel (Sulaiman *et al.*, 2013). Hence, this would contribute to higher strength of panel and required more heat to complete the melting process (Sulaiman *et al.*, 2013).

Generally, decomposition of the natural fiber began between 200 °C and 360 °C (Islam *et al.*, 2012; Ahmad *et al.*, 2002). Based on the result, sago composite particleboard 2mm showed a single endothermic peak at 263 °C due to thermal decomposition of sago particles. Sago composite particleboard 0.6 mm exhibited two endothermic peaks at 263 °C and 322 °C; Sago composite particleboard 1.18 mm exhibited two endothermic peaks at 262

°C and 318 °C. The double endothermic peaks obtained in DSC thermograms were due to the thermal decomposition of sago and sago filled with UF.

Sago composite particleboard 2 mm exhibited a second exotherm peak at 303 °C, whereas no extra exotherm peak was observed in particleboard 0.6 mm and 1.18 mm. Sample with single exotherm was found to be more thermally stable than those with double exotherm peak.

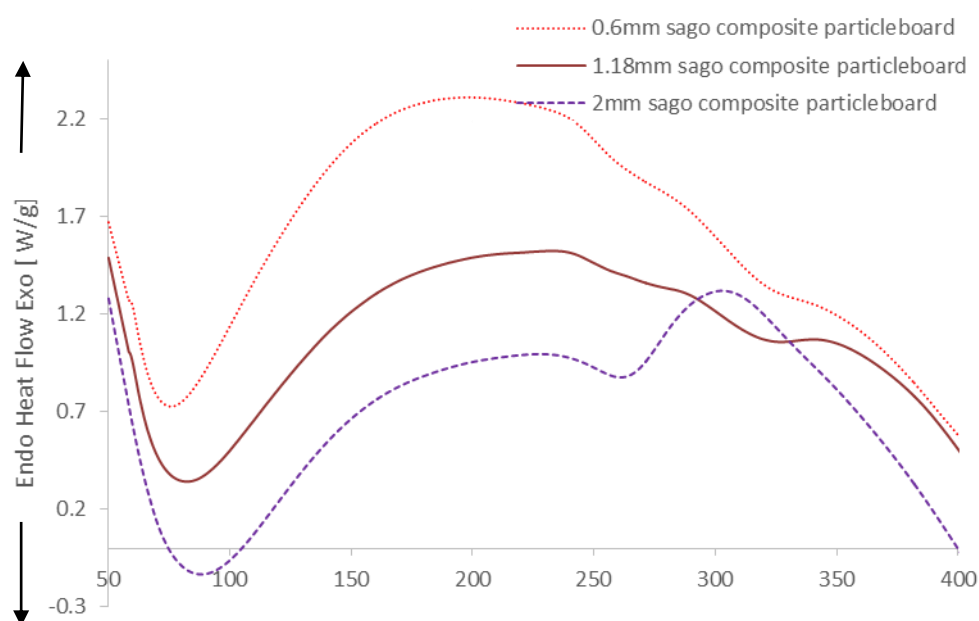


**Figure 4.10:** Sago composite particleboard with different size of particle analysis by DSC.

#### 4.2.13 Fourier Transform Infrared Spectroscopy Analysis (FTIR) OF Sago Composite Particleboard

The IR spectra of sago composite particleboard with different particles size are shown in Figure 4.11, 4.12 and 4.13. Investigation on these chemical reaction, lignocellulose components, hydroxyl group, bonding information and carbonyl group on the sago composite particleboard are important for establishing correlations between interface characteristics and the particleboard properties.

There was absorption of moisture in sago composite particleboard. The band at 3331  $\text{cm}^{-1}$ , 3288  $\text{cm}^{-1}$ , 3749  $\text{cm}^{-1}$ , 3259  $\text{cm}^{-1}$ , and 3759  $\text{cm}^{-1}$  were attributed to hydroxyl group, O-H stretching in H-bonded hydroxyls. This indicated that sago particles were hydrophilic and easily absorbing water. The O-H groups were significantly reduced when better bonding was formed between matrix and sago particles. The sago composite particleboard with 1.18 mm particle size had better bonding between the particles and matrix compared to 0.6 mm and 2 mm. This had reduced the pores which prevented water molecules to be penetrated the sago composite particleboard. 2mm particles had penetrated the most moisture due to bigger and more voids in the board. High moisture content in sago composite particleboard could caused swelling or dimensional defect and this would be affected the physical and mechanical property of the board.

The chemical reaction between sago and UF matrix was showed at the peak 1022  $\text{cm}^{-1}$ , 1028  $\text{cm}^{-1}$  and 1149  $\text{cm}^{-1}$ . This was associated with bending and stretching vibration of C-O and ether vibrations of C-O-C (Gurses *et al.*, 2013). This showed that there were both the cellulosic material and smaller oligomeric structures in matrix. The N-H bending vibration appeared at 1541  $\text{cm}^{-1}$  and 1537  $\text{cm}^{-1}$  were related to sago and UF reinforced composite particleboard. This had proved that the sago and UF have intermolecule reaction.

The superiority of mechanical propeties of sago composite particleboard was related with the high content of  $\alpha$ -cellulose. The  $\alpha$ -cellulose was observed at 3331  $\text{cm}^{-1}$ , 3288  $\text{cm}^{-1}$ , 3749  $\text{cm}^{-1}$ , 3259  $\text{cm}^{-1}$ , and 3759  $\text{cm}^{-1}$  in the sago composite particleboard (Sim *et al.*, 2012). The cellulose had better bond between the urea formadehyle compared to lignin and hemicelluloses and improved the mechanical bond strength of the particleboard (Eike *et al.*, 2016). The peak 1624  $\text{cm}^{-1}$ , 1647  $\text{cm}^{-1}$  and 1633  $\text{cm}^{-1}$  corresponded to C=O stretching

vibration in conjugated carbonyl of lignin. Improper bonding between the matrix and lignin reduced the mechanical strength.

These studies confirmed the reduction of mechanical properties was due to the penetrated of O-H groups. The similar pattern of FTIR spectra had proved that the sago composite particleboard had same component but the particles size had great influenced on the mechanical, physical and thermal properties.

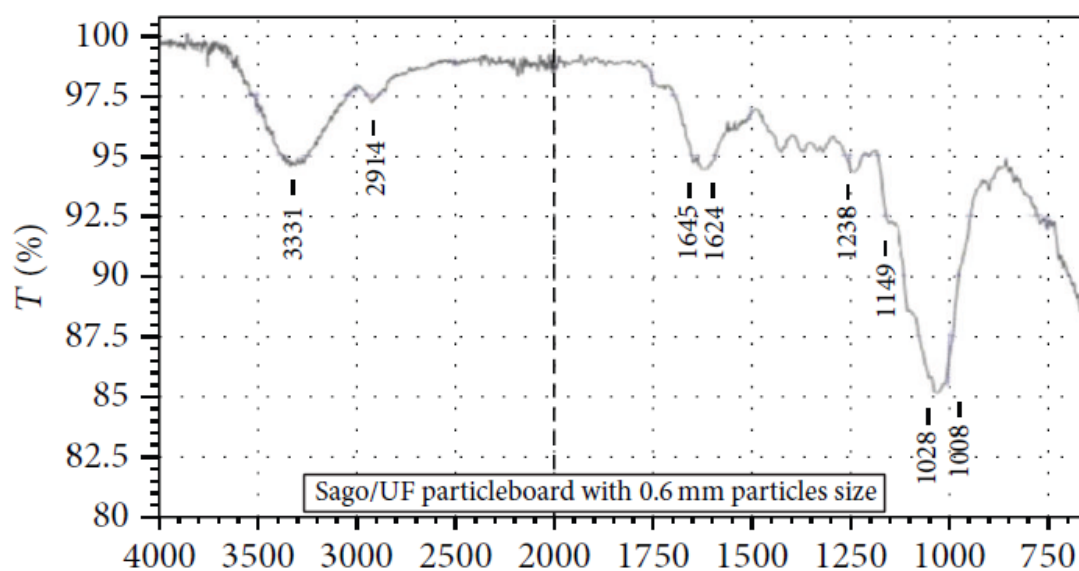


**Figure 4.11:** FTIR of sago composite particleboard with 0.6 mm particle size.

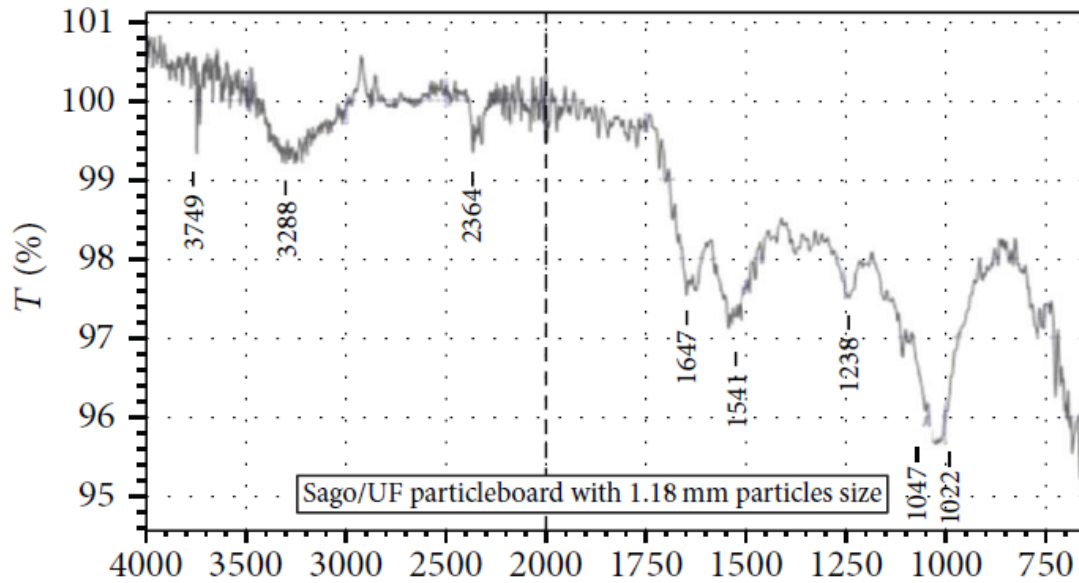


**Figure 4.12:** FTIR of sago composite particleboard with 1.18 mm particle size.

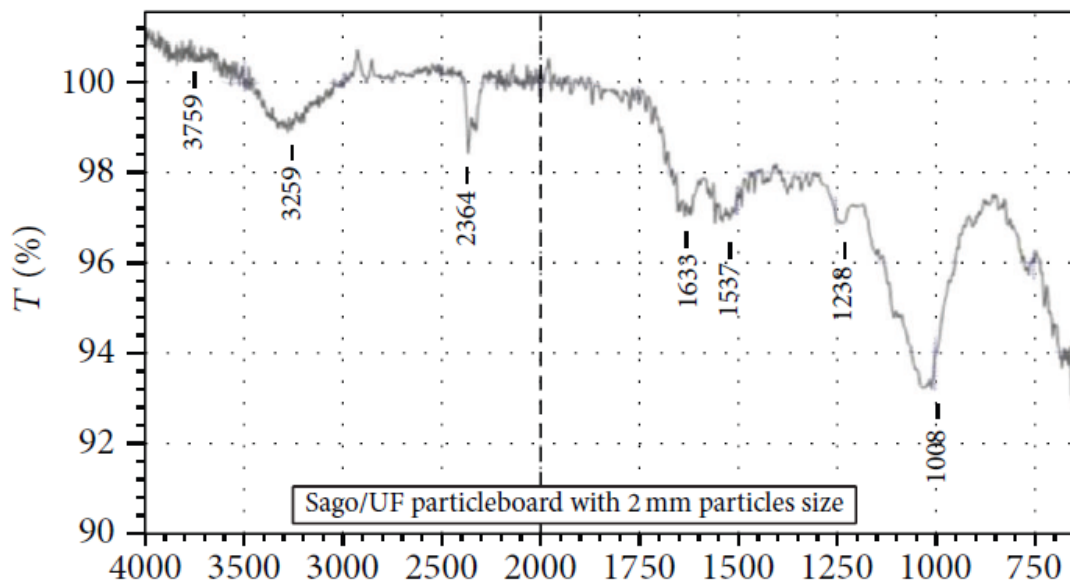


**Figure 4.13:** FTIR of sago composite particleboard with 2 mm particle size.

#### 4.2.14 Scanning Electron Microscopy (SEM) Analysis Of Sago Composite Particleboard

The SEM micrographs of UF matrix distribution on the sago composite particleboard are shown in Figure 4.14 (a) and (b). Figure 4.14(a) showed that the UF matrix were dispersed unevenly on sago composite particleboard. The poor interfacial adhesion had

resulted poor mechanical strength. Figure 4.14(b) presented the uniform distribution of matrix at sago composite particleboard due to the well intercalation between particles and matrix. The presence of UF matrix within the composite particleboard was seen to have a good contact with the sago particles. The balanced interaction between the adhesive and sago particles consequently enhanced the mechanical properties of the particleboard (Omar *et al.*, 2017). This indicated better interfacial adhesion and further supported higher mechanical properties of sago composite particleboard.

The SEM micrographs of sago composite particleboard are shown in Figure 4.15 (a), (b) and (c). Figure 4.15(b) indicated that 1.18 mm particle size have better bonding between sago particles and UF matrix. This indicated better interfacial bonding and strong compatibility which was reflected in improvement of the mechanical and physical properties. 1.18 mm particles give better stress distribution than 0.6 mm this was because the higher amount resin contained per unit area it created better glue line between the particles (Hazwani *et al.*, 2014). The homogenous blend of network with small amount of void spaces equivalently scattered throughout the surface, hence indicating a compact distribution within the board (Omar *et al.*, 2017). Figure 4.15 (a) and (c) showed surfaces with cracks between the particles and matrix in sago composite particleboard, indicating that there was no bonding between particles and matrix. The poor adhesion between matrix and particles caused agglomerates on the sago composite particleboard surfaces (Luo *et al.*, 2012). The agglomeration between 0.6 mm particles and UF shown in Figure 4.15(a) indicated the weak adhesion and compatibility. The microstructure revealed that there was small discontinuities distribution of sago particles and UF matrix (Idris *et al.*, 2011). This had reduced the whole mechanical properties of sago composite particleboard. Figure 4.15(c) showed the 2 mm particles were not detached from the matrix as the size of particles increased in sago composite particleboard. Improper bonding between the particles and matrix had reduced the strength of the board. Sago composite

particleboard fabricated with 2 mm particles had more and larger voids compared with 0.6 mm and 1.18 mm. The more and larger voids appeared had caused the moisture easy to penetrate in the board and resulted in low strength. The SEM micrographs confirmed the effect of particle size had great influenced on physical, mechanical and thermal properties.

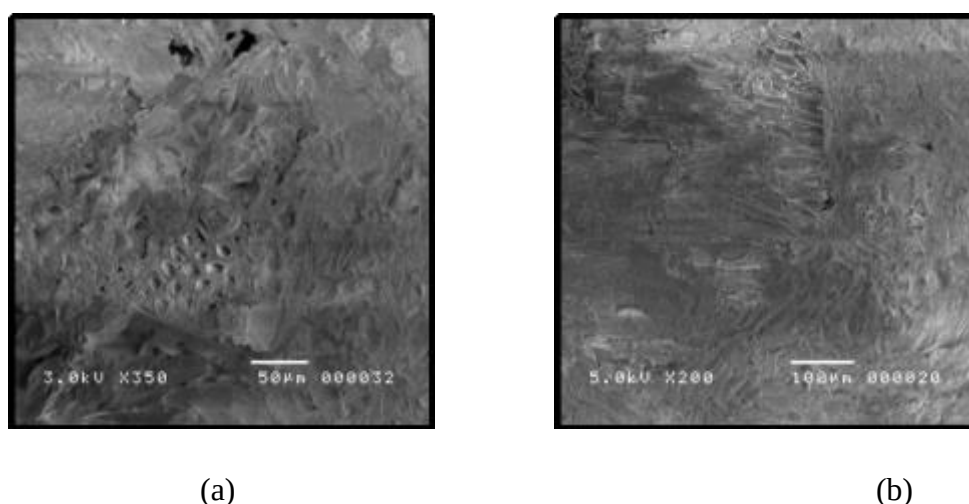


**Figure 4.14:** SEM micrographs of matrix distribution on the sago composite particleboard (a) Uneven of matrix distribution and (b) uniform distribution of matrix

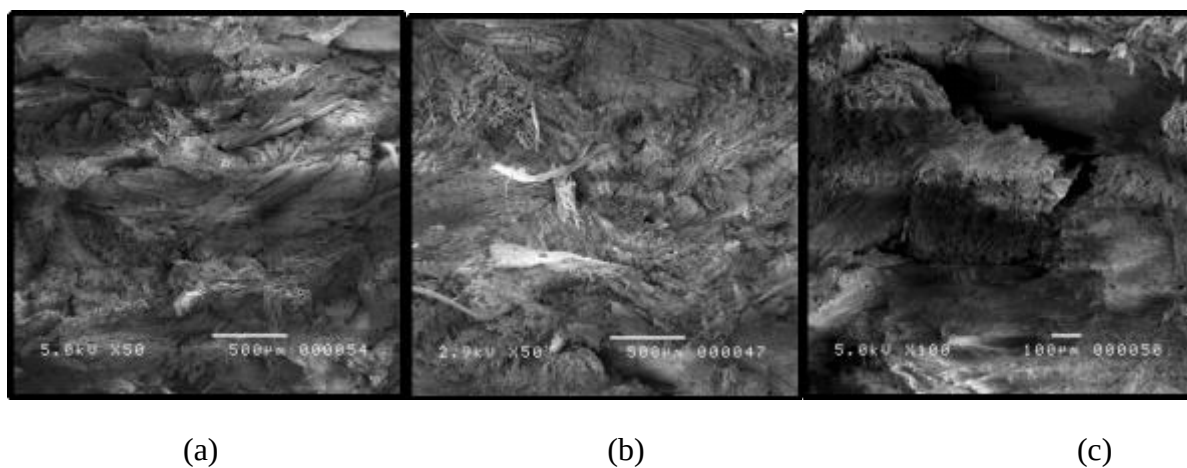


**Figure 4.15 :** SEM micrographs of fiber matrix bonding (a) 0.6 mm particles size, (b) 1.18 mm particles size (c) 2 mm particles size

### 4.3 Summary

From the results, it is clear that sago particleboards size had an impact on the board performances. The analysis of particleboard through physical, mechanical and thermal

stability showed a little difference by changing the size of particles. The boards' strength was enhanced when the particle size was increased but this was only applicable to certain limit. High quality of mechanical properties for sago/UF particleboard were obtained by using particles of 1.18 mm. High impact strength could be achieved using the 0.6 mm particle size. 0.6 mm and 2 mm particle sizes had poor adhesion with the UF matrix, giving rise to water absorption and thickness swelling. From the TGA/DSC study, 0.6 mm particle had better thermal stability and curing properties. The samples were fully bonded by the UF matrix. Based on the TGA, the degradation of hemicellulose, cellulose, and lignin could be observed followed by a further slow degradation until a fixed carbon was achieved at 800 °C. FTIR analysis showed the bonding between functional groups of sago fiber and UF, which confirmed that the reactions occurred between all the components in the composite system. The findings showed that the new application for sago composite particleboard was viable for furniture industry.

## CHAPTER 5

# EFFECTS OF WEIGHT FRACTION OF SAGO/UREA FORMALDEHYDE COMPOSITE PARTICLEBOARD ON PHYSICAL, MECHANICAL AND THERMAL PROPERTIES

### 5.1 Introduction

Nowadays, the demand of composite particleboard applications had recently increased substantially throughout the world. Resin costs is a major portion of total manufacturing expense of composite particleboard. Consequently, optimum board properties with minimum adhesive consumption is the goal of particleboard fabrication. Therefore, it is important to understand the effect of adhesives and particle sizes on the characteristics of composite particleboard before the furniture industry application. The good balance between mechanical properties and the cost of production is the key point in the successful development of composite particleboard.

There are many factors affecting the properties of the composite particleboard. The most important factors namely fiber structure, type and amount of binder, form and size of natural fiber, method of mat formation and the final moisture content of the board (Natasa *et al.*, 2011).

Fu *et al.* (2008) proved that the mechanical properties greatly affected by the particle-matrix interface adhesion and particle loading. The strength of the composites strongly depending on the stress transfer between the particles and matrix. For well-bonded particles, the applied stress can be effectively transferred to the particles from the matrix. This clearly improved the mechanical strength.

The properties of composite particleboard are influenced by the fiber content (Navdeep *et al.*, 2012). Raghavendra *et al.* (2014) mentioned that the mechanical property of

the composite particleboard like strength and stiffness were found to improve with variation in the reinforcement weight fraction. The composite particleboard strength, stiffness and toughness were affected by reinforcement particle size, particle adhesion and particle loading.

Thickness swelling and water absorption test are important parameter and durability of the particleboard to determine the end use application. The main concern for the composite particleboard was their susceptibility to moisture absorption and the effect on physical, mechanical and thermal properties (Dhakal *et al.*, 2007). Fourier Transform Infrared (FTIR) spectra were used to characterize the sago/urea formaldehyde composite particleboard in terms of their functional group and bonding.

This research is an attempt to study the effect of weight fraction on the thermal, mechanical and physical properties of composite particleboard made from sago particles and UF resin as an alternative of raw material in the furniture industry.

## **5.2 Result and Discussion**

### **5.2.1 Effect of weight fraction on thickness swelling (TS) of sago composite particleboard**

Figure 5.1 shows the results of thickness swelling (TS) of particleboards affected by the weight fractions. The results indicated that a decrease in the weight fraction of fiber (increase in UF content) affect the thickness swelling (Olufemi *et al.*, 2012). This was because sago was less repellent to water as more resins were incorporated into the sago composite particleboard (Jani *et al.*, 2012). The thickness swelling could be affected by the bonding quality between the particles and the adhesive properties (Wang *et al.*, 2005). An increase in adhesive created better bonding quality compared with small amount of UF. This was because better surface properties and hardness provided by higher amount of UF (70 wt%) on the outer surface had resist the moisture to penetrate into sago composite particleboard through

the irregularities surface and voids (Gagan *et al.*, 2016). The presence of sago bark in the particleboards resulted in higher water resistance. This was due to polyphenolic extractives in the barks reacted with the UF and improved the water resistance properties (Zhongli *et al.*, 2007).

The high percentages of TS tests were due to the high percentage of highly absorbent particles in the panels. Sago composite particleboard with 90wt% of particles had the highest of TS compared to 70 wt% particleboard. This was due to improper coating of UF which allowed the water to penetrate into the board. The water filled the voids and intermolecular spaces that rose the linear dimension of the board. The particles were very short and constituted a high percentage of total fiber content, thus, creating a very large and highly absorbent surface area. The highly porous structure of the board allowed the water molecules to penetrate into the board and increased the water uptake, resulting in high water absorption and caused the board to swell and subsequently led to an increase in the TS (Jani *et al.*, 2012).

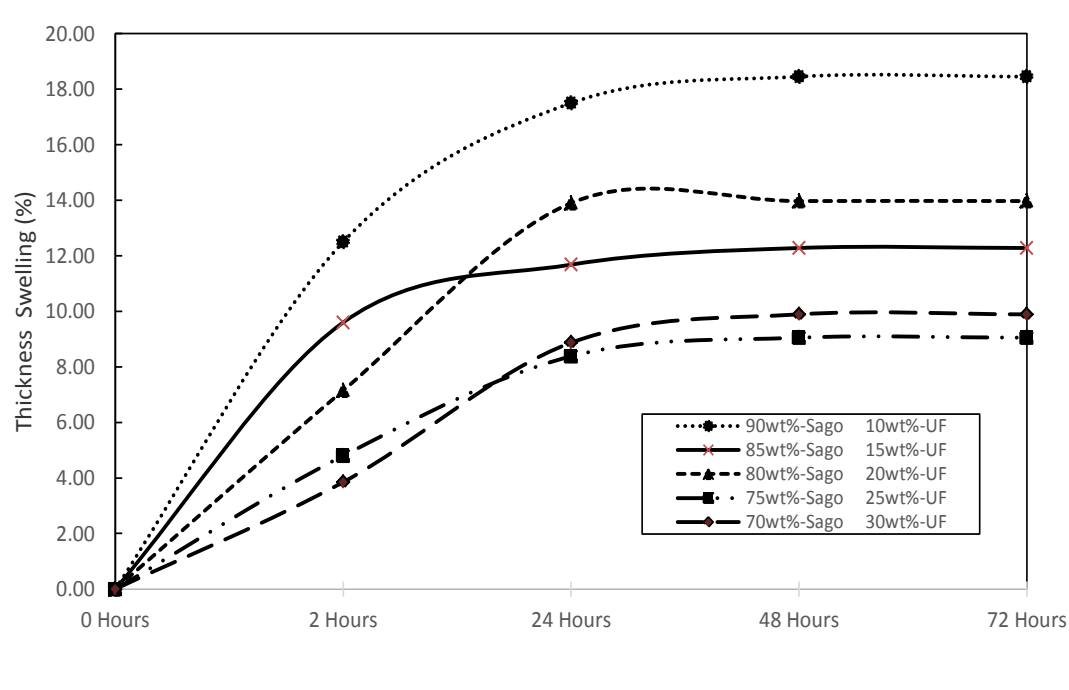


**Figure 5.1:** Thickness swelling VS soaking time affected by weight fraction of sago composite particleboard.

### 5.2.2 Effect of weight fraction on water absorption (WA) of sago composite particleboard

Figure 5.2 shows the results of water absorption (WA) of particleboards which is affected by the weight fraction. The results showed that the resin content had a significant effect on the water absorption. The trend of the water uptake process was linear in the beginning, then slowed down and reached saturation after prolonged time (Dhakal *et al.*, 2007). The long-term water absorption of sago composite particleboard maintained relatively stable dimensions after 72 hours (Wang *et al.*, 2005). Generally, water absorption increased with immersion time until equilibrium condition is reached. Fick's law was used to determine the moisture absorption of sago composite particleboard where the mass of water absorbed linearly with square root of time until it reached an equilibrium state (Vilay *et al.*, 2008).

Sago composite particleboard with 30 wt% of matrix had better covered surface area than the 10 wt% of matrix. The addition of UF in the particleboard, caused the formation of hydrogen bonds, increased the water binding sites and reduced the particleboard's capacity of absorbing water (Zhongli *et al.*, 2007). Water absorption decreased with increased the resin content due to the chemical components in the resin that was capable of cross-linking with the hydroxyl group of the fibers, hence the hygroscopicity of the boards reduced. Hygroscopic expansion could be affected by various factors of the resin such as the monomer, the polymerization rates, the cross-linking and pore size of the polymer network, the bond strength, the interaction between polymer and water, the filler and the resin-filler interface (Jani *et al.*, 2012).

Water absorption increased as the particles loading increased. The reason was due to sago particles contained more polar hydroxide groups, which resulted in a high moisture absorption. This could be explained by the theory of void over volume of the board where the particles were not fully bound by the UF and hydroxyl properties by the fiber. FTIR showed

sago particles is extremely hydrophilic in nature due to the presence of the hydrophilic hydroxyl group of cellulose, hemicelluloses and lignin that was responsible for water absorption (Takian *et al.*, 2013). Therefore, higher content in fiber lead to a higher amount of water absorbed. When the particles content was increased in the particleboard, the number of free OH group of sago cellulose also increased. Hence, the water absorption increased (Alireza *et al.*, 2010). The 90 wt% of sago particles were incomplete encapsulation of UF and probable occurrence of sago particles aggregated and led to the high penetration ability due to the porosity.

The hydrophilic sago particles/fiber swelled when the particleboard was exposed to moisture. As a result of fiber swelling, micro cracking of the brittle thermosetting resin occurred. The high cellulose content in sago fiber further contributed to more water penetrating the interface, through the micro cracks induced by swelling of fibers, creating swelling stresses leading to particleboard failure. The water molecules actively attacked the interface, resulting in debonding of fiber and matrix (Dhakal *et al.*, 2007).

Therefore, the weight fraction of particles and matrix had great influence on the physical properties of the sago composite particleboard. High moisture content in the sago composite particleboard would cause swell, provided fertile ground for mold and mildew, lose the strength of the board and deform quickly.

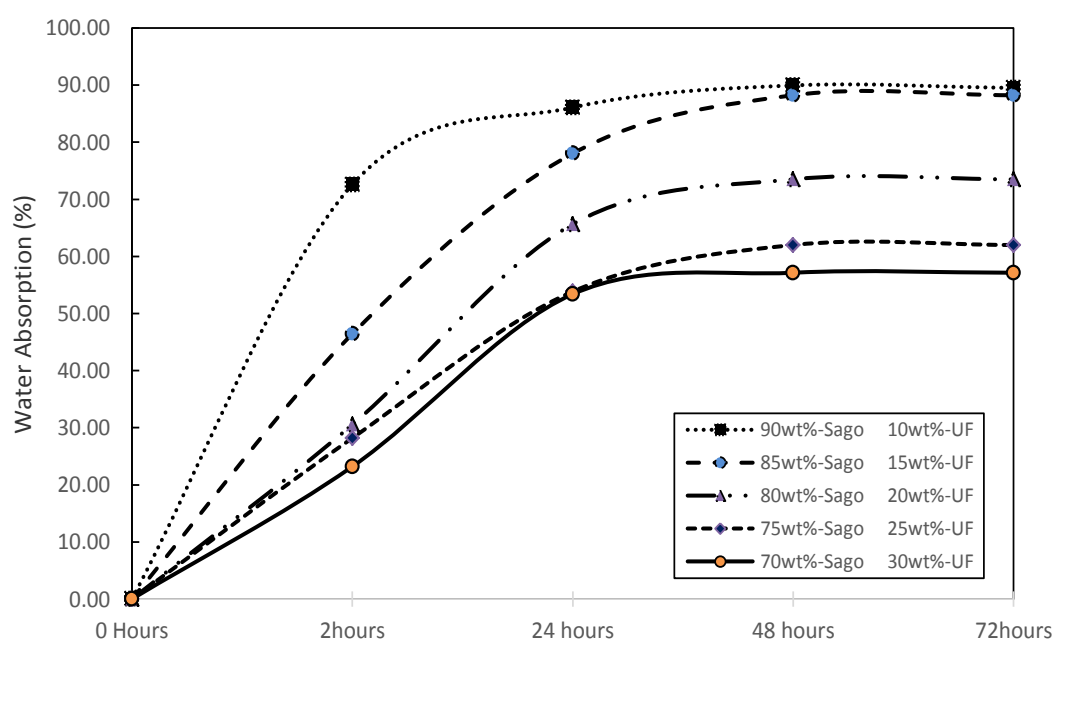


**Figure 5.2:** Water absorption verses soaking time affected by weight fraction of sago composite particleboard.

### 5.2.3 The effect of particles size and weight fraction on bending strength of sago composite particleboard

Figure 5.3 shows the relationship between bending strength and particle weight fractions with the size of 0.6, 1.18 and 2 mm respectively. It was clear that the board containing 85 wt% sago particles for both 0.6 mm and 1.18 mm sizes had the highest value of bending strength. The bending strength of 85% weight fraction of sago particles with the size of 0.6 mm is 8.86 N/mm<sup>2</sup> while the bending strength for the 1.18 mm was 7.06 N/mm<sup>2</sup>. The changes in bending strength against the particles size with different weight fraction could be seen at the Figure 5.3.

It could be seen that the particles with the size of 0.6 mm with different weight fraction of urea formaldehyde (UF) matrix had better bending strength compared to the particles with the 1.18 mm with different UF matrix. This was due to deformability of the UF

matrix had created the physical interaction and immobilization of the matrix by the presence of mechanical restraints, which had increased the bending strength. The 0.6 mm particles with 15 wt% of UF matrix had more exposure of the surface between the particle/matrix interaction in reinforced composite particleboard. There was sufficient matrix to bond the particles and this reduced the voids resulting in better bending strength.

The result showed 2 mm particles with 20 wt% UF matrix had higher bending strength compared with 0.6 mm and 1.18 mm with same loading of UF matrix. This might be due to more exposure of the surface between the particle/matrix interaction in the particle composite particleboard. The reason for this behaviour was attributed to the strength of course particles and the high adhesion between course particles with matrix (Chanakan *et al.*, 2010). The 2 mm particles with 20 wt% of UF matrix were tightly interlocked and oriented randomly in three dimensions which had increased in the strength of the composite particleboard. The chemical bonding accounts for adhesion between UF and the natural fibrous material. The higher bond strength obtained for UF matrix was due to the possible reaction between the methylol groups of resin with hydroxyl group of cellulose (Singha *et al.*, 2009).

The highest percentage of particles weight fraction for the samples did not show higher bending strength value because there was insufficient resin to wet all the fibers in the sago composite particleboard. The MOR of samples with UF resins increased significantly at the interval of 90 wt% to 85 wt% for 0.6 mm and 1.18 mm while 90 wt% to 80 wt% for 2 mm. This showed that the presence of resins resulted in improved bending strengths. At higher resin content, more bonding sites were available. During hot pressing, bonding between the particles and efficiency of resin hardening had increased (Dahmardeh *et al.*, 2011). Thus, the strength properties and the dimensional stability were improved.

The result showed the particles size with different weight fraction of matrix had affected the compressive structure in the sago composite particleboard (Xu *et al.*, 2006).

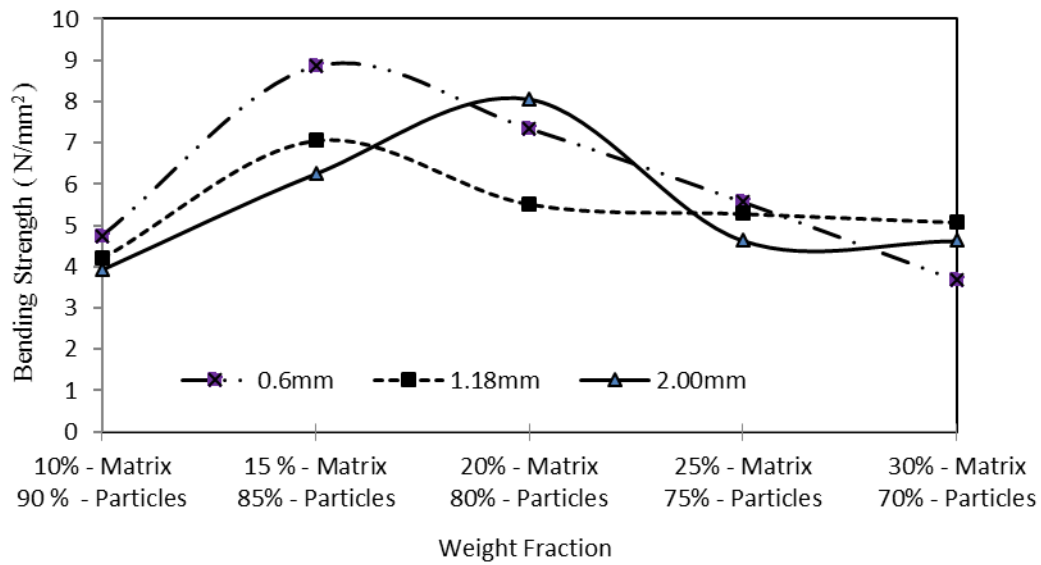


**Figure 5.3:** Bending strength of sago composite particleboard affected by weight fraction and particles size.

#### 5.2.4 The effect of particles size and weight fraction on internal bonding (IB) of sago composite particleboard

The internal bond test results were showed in Figure 5.4. In general, sago composite particleboard 1.18 mm with 80 wt% of particles had the highest internal bonding strength with the value of 0.82 N/mm<sup>2</sup>. The particles with this size were covered better with resin and had tighter bond. The IB strength increased when increased resin loading. This was due to better adhesive binding between the binder and particles; resulting in a greater ability to withstand the perpendicular forces. The results of the test showed a trend that IB strength improved with higher resin loading (Jani *et al.*, 2010). The results also showed that there was an increase on internal bonding up to a certain limit as the fiber weight fraction decreased but these values decreased due to the evaporation of excessive matrix as steam (Jani *et al.*, 2010; Grigoriuo *et al.*, 2000). The reductions of the IB values for sago composite particleboards might be attributed to insufficient or over sufficient of the resin applied. This were showed at 1.18 mm with 85 wt% of particles and 75 wt% of particles respectively. Insufficient of matrix

had caused the particle coated with UF matrix well. Hence, the adhesive bonding between particles were reduced. Over sufficient of resin would caused the resin evaporated as steam during the hot press process.

It was found that different weight fractions of particles with resin affected the glue line either slowed down or intensified the polymerization reaction rate. Thus, modification on the hot pressing time and temperature were required to fully cure the resin so that compact particleboards could be produced (Izrad *et al.*, 2009). From the experiment, it was observed that some of the cured resins were retained on the particles surface which indicating insufficient penetration of resin. There were some areas on the particles surface without any trace of resin adhesive. The effects of interaction between the resin and particles were clearly showed in the experiment. The bonding strength between polymer matrix and lignocelluloses depended on the surface topology of the particles (Singha *et al.*, 2009).

Increment on the weight fraction of matrix on 2 mm of sago composite particleboard did not improved the internal bonding. This was due to larger surface area of particles not covered adequately by the adhesives when same mass ratio of adhesive and particles were used (Zhongli *et al.*, 2007). This had resulted in weak contact between the particles so that the pores between particles could be easily seen at SEM which were not bonded well by resin. On the other hand, a higher proportion of 2mm particles would result in a lower bulk density due to the abundance of coarse particles, which made looser structures between particles (Morteza *et al.*, 2011).

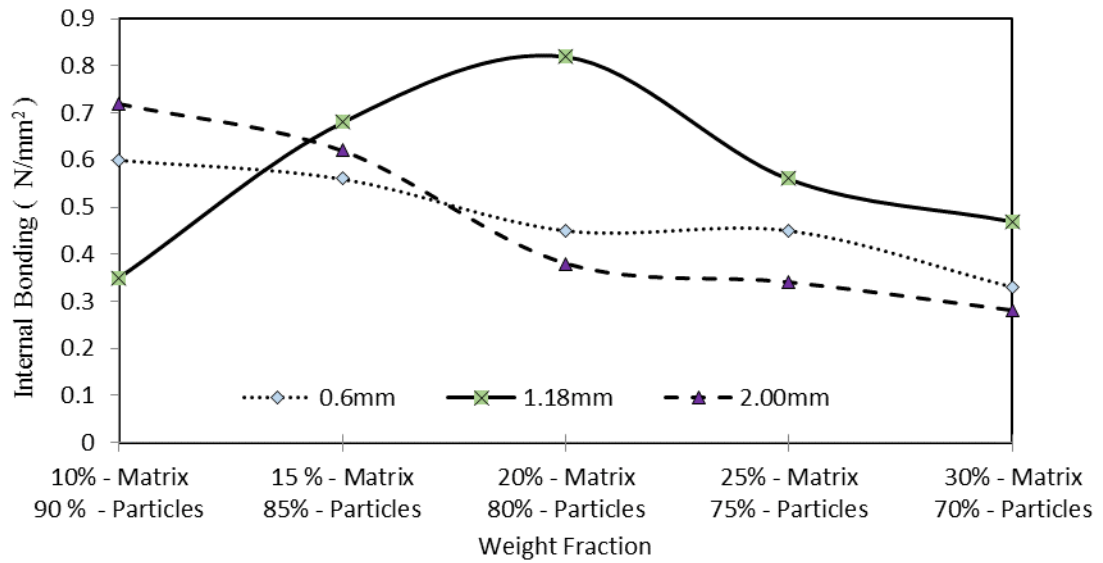


**Figure 5.4:** Internal bonding of sago composite particleboard affected by weight fraction and particles size.

### 5.2.5 The effect of particles size and weight fraction on screw test for sago composite particleboard

As shown in the Figure 5.5, the optimal value of screw test for all the sizes of the particles was 80 wt%. From the observation, it was found that withdrawal strength improved at different levels as the resin content increased until certain value of weight fraction. All the sago composite particleboard with excessive matrix would cause the withdrawal strength drop due to the matrix evaporation as steam during the hot press process without bonding the particles. The results showed that 1.18 mm with 80 wt% could withstand the highest load of 247.49 N and had the highest screw withdrawal strength.

Decreasing the weight fraction of particles from 90 wt% to 80 wt% had increased the screw withdrawal load. This had increased the bonding between particles and the ability of a board to bear the pulling force after being resinated with high resin dosage. The boards with optimal resin 20 wt% caused the screw to be embedded tightly and resulted in better screw withdrawal strength. Sago composite particleboard with 20 wt% matrix had created better

bonding between particles and the particles were packed together with higher strength. Hence, this created high compaction of a composite particleboard and increased the withdrawal strength.

Among the sago composite particleboard with 20 wt% matrix, particleboard with 1.18 mm particles had better screw test compared with 0.6 mm. This was due to lower relative surface area of particles size 1.18 mm has higher resin-spread-rate on coarse particles compared with fine particles 0.6 mm. This had increased the bonding between particles and able to bear the pulling force better.

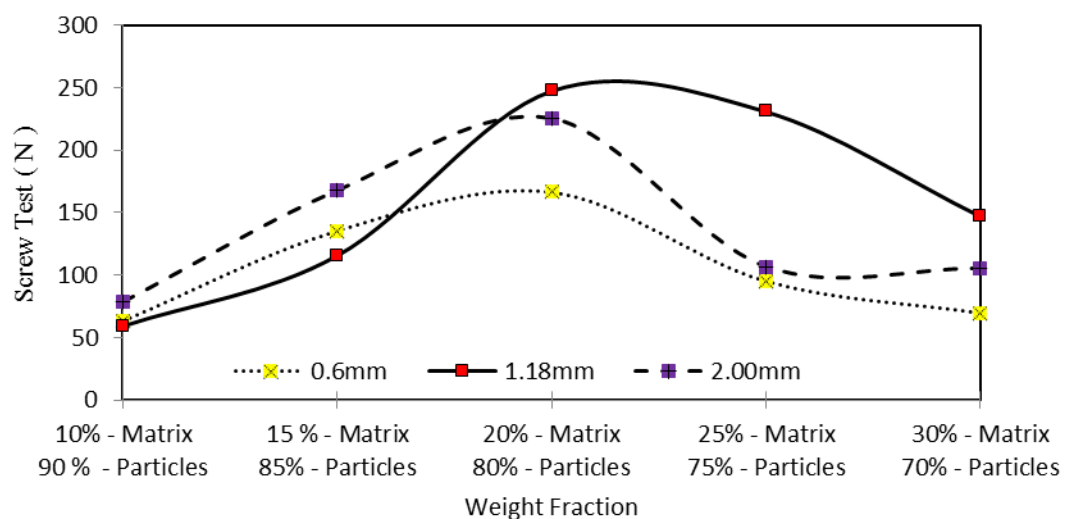


**Figure 5.5:** Screw test of sago composite particleboard affected by weight fraction and particles size.

### 5.2.6 The effect of particles size and weight fraction on modulus of elasticity (MOE) for sago composite particleboard

The modulus of elasticity (MOE) for sago composite particleboard was shown in Figure 5.6. The results showed MOE were strongly dependent on the particle loading with the particles size. Particleboard fabrication depended on chemical and mechanical bonds of the materials because the matrix needed to bind with the particles well between each other during the fabrication process. During the mechanical test, the applied stress could be effectively

transferred between the particles and matrix due to the well bonded particles (Fu *et al.*, 2008). The results showed that the addition of matrix on the sago composite particleboard did not improve the MOE. Excessive of matrix had caused the imperfect adhesion between fiber-matrix due to shortage of particles bonding with matrix.

Decreasing the weight fraction of the particleboard with particle size of 0.6 mm and 1.18 mm, decreased the MOE. This was due to the space between the particles had increased. This could be the fiber-matrix interface bonding quality which became weak when the matrix increased and particles decreased at the same times. According to Amer *et al.* (2009), the inter connectivity of each phase in a composite became the main consideration during the test and the bonding characteristics of interface could affect the elastic modulus of the whole composite. Elastic properties of individual phase and their concentration in a composite should be considered for the elastic properties of the composite materials (Amer *et al.*, 2009).

Particles 1.18 mm showed the highest MOE at 90 wt% due to better fiber-matrix bonding. The 1.18 mm particles had better covered surface by the UF matrix with perfect particles dispersion and the higher compaction of particles had reduced the voids in boards. Hence, this had increased the contact area between particles and resulted better stress transfer. Particles 0.6 mm had lower MOE compared to 1.18 and 2 mm because it was difficult for the excess matrix to flow through the particles of the smaller size specimen. The particles tend to agglomeration and reduced the strength of whole composite particleboard. The agglomerates were weak point in the board and broke easily when a stress was applied.

The superiority of mechanical properties of sago composite particleboard was related with the high content of cellulose. The cellulose was observed at FTIR under chapter 4 in the sago composite particleboard (Sim *et al.*, 2012). Sago composite particleboard with of 0.6 mm particles size had smaller amount of cellulose compared with 1.18 mm and 2 mm. Hence this had reduced the whole specimen strength. The cellulose had better bond between the urea

formaldehyde compared to lignin and hemicelluloses and improved the mechanical bond strength of the particleboard (Eike *et al.*, 2016).

For the coarse particle with 2 mm size, MOE increased with UF, reaching a maximum weight fraction at 80 wt% because the absence of voids in the composite created good bonding between the particles and matrix. The MOE dropped after that due to the decreased of sago particles that created the void between each other and the excess matrix evaporated during the hot press process. The poorly bonded particles, had caused inefficient of stress transfer between the UF and particles. This had caused debonding because of non-adherence of particles with UF. Thus, the particle could not carry any load. Therefore, when the specimen began to pull, it tended to fail easily

These results implied that weight fraction and particles size had great influence on composite stiffness and specimens required higher volume of particles to substitute the voids (Fu *et al.*, 2008). The results proved the elasticity of the sago composite particleboard was strongly influenced by the fiber and matrix composition, fiber morphology, perfect fiber dispersion of individual particles in a specimen, fiber volume ratio, porosity and perfect adhesion between fiber-matrix (Fabrice *et al.*, 2012; Fu *et al.*, 2008).

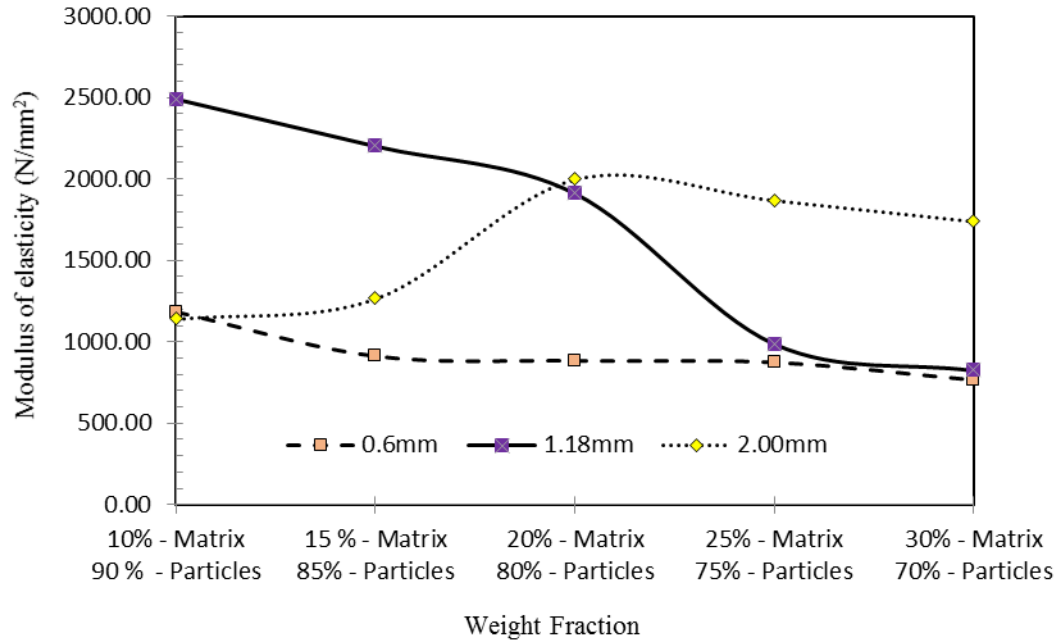


**Figure 5.6:** Modulus of elasticity of sago composite particleboard affected by weight fraction and particles size.

### 5.2.7 Effect of particles size and weight fraction on impact strength for sago composite particleboard

Figure 5.7 shows the impact strength of sago composite particleboard with different sizes at different weight fraction. The impact strength for 0.6 mm and 1.18 mm sieving size of particleboard increased linearly with decreasing the weight fraction of particle until 75 wt%. However, the excessive matrix would reduce the impact strength. Impact strength for 2 mm sieving size increased until 80 wt% as optimal strength and then decreasing. The excessive matrix will not improve the impact strength due to the low particles content created the poor interfacial adhesion. Hence, this had caused the composite particleboard not to manage to dissipate the energy effectively. Chaharmahali *et al.* (2010) mentioned that increasing the fiber content in the sago composite particleboard would significantly decrease the impact strength due to the poor interfacial adhesion not be able to cover the particles well.

The optimal value to obtain the highest impact strength for 0.6 mm was 70 wt% while 1.18 mm and 2 mm were 75 wt% respectively. 0.6 mm sieving size had better impact strength compared to 1 mm and 2 mm sieving size because 0.6 mm sieving size was more compactly filled in composite particleboard that provided a large region for stress concentration due to the smaller surface area.

The 2 mm particleboard showed steep decline beyond their optimal values. This was due to higher particles content that led to poor interfacial bonding between the particles and matrix and hence decreased the mechanical properties. Coarse particles with poor interfacial bonding caused the sago composite particleboard breaking easily. The coarse particles tend to agglomerate and not efficient in absorbing energy.

Beyond the optimal weight fraction, the mechanical properties for all the sizes were experiencing steep decline (Ishak *et al.*, 2010). According to Ishak *et al.* (2010), the size of the particles affected the interfacial shear, normal stresses and fracture characteristics dramatically.

The most important factor that influenced the mechanical properties of the sago plant was its chemical composition. According to Habibi *et al.* (2008), sago particles contained cellulose, hemicellulose and lignin and were found to have a strong influence on the mechanical properties to the particles itself and the particleboard especially the cellulose content. Cellulose is the main structural component that provides strength and stability to the plant cell walls and particles. Cellulose is one of the stiffest and strongest organic constituents in the natural fibers. It played an important role in the impact resistance of fiber-reinforced composites as they interacted with the crack formation and acted as stress transferring medium (Jawaid *et al.*, 2011).

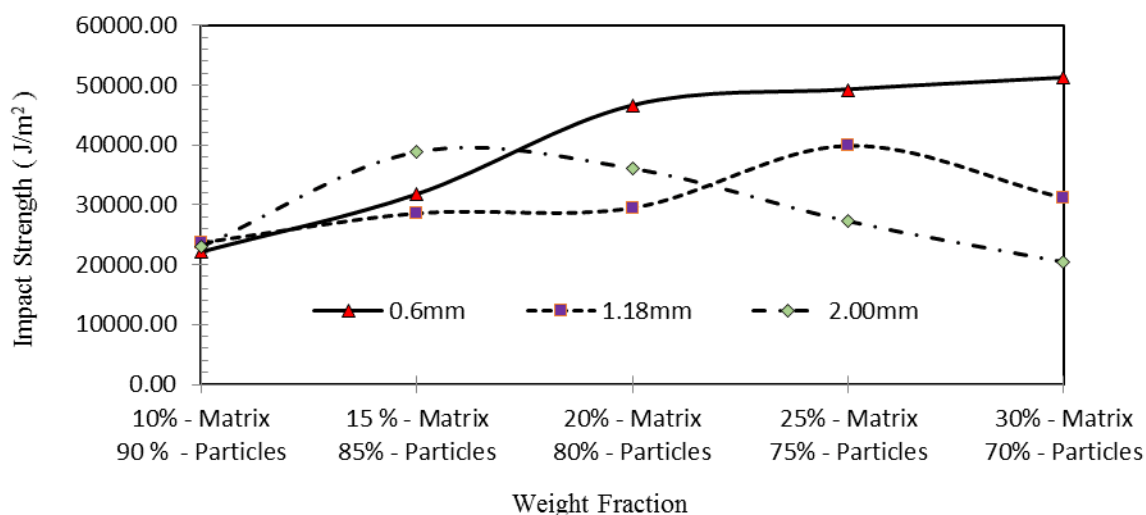


**Figure 5.7:** Impact Strength of sago composite particleboard affected by weight fraction and particles size.

### 5.2.8 Effect of particles size and weight fraction on tensile strength for sago composite particleboard

Based on the results shown in Figure 5.8, 0.6 mm and 1.18 mm particles had similar trend for the tensile strength, which slightly decreased by decreasing the weight fraction of sago. This showed that the weight fraction had great influence on the tensile performance.

The results showed that 1.18 mm particles size at 90 wt% had the highest tensile strength. In order to achieve the homogeneously dispersed in the composite, the particles and matrix needed to mix with the correct amount. This was to create good chemical bonding between the particle and matrix. The performance of composites was determined by the particle/matrix interfacial adhesion and created a good polymerization. This indicated that the incorporation of sago granules into the UF matrix introduced a new interfacial region that affected the stress transfer (Toh *et al.*, 2011). The dispersion of the networked UF with the sago particles was expected to be good because its surface was covered with organic materials and created better reinforcement on the board. As in fiber-reinforced composite particleboard, the quality of adhesion at the interface was crucial importance for the behavior for composite

particleboard. The openings formed in the networked contributed to improve its dispersion by penetration of UF matrix into the particles and enhanced the tensile strength at the same time (Khalil *et al.*, 2013).

The properties of the particle/matrix interfacial adhesion had great influence on the tensile strength performance and affected the stress transfer effectively (Amer *et al.*, 2009). The 0.6 mm and 1.18 mm particles had similar trend for the tensile strength, which slightly decreased by decreasing the weight fraction of sago. Increasing the matrix would cause the tensile strength to reduce due to the poorly bonded particles between the hydrophobic polymeric matrix of urea formaldehyde and the hydrophilic lignocellulose fillers that led to inefficient stress transfer (Takian *et al.*, 2013). Decreasing the weight fraction of particles caused the discontinuity of debonding that existed between the non-adherence of particle to polymer and caused the particle not to be able to transfer the load during the test (Fu *et al.*, 2008). Excessive matrix did not improve the tensile strength because it caused the composite to become wet due to too much moisture content in the composite and reduced the strength of bonding during the hot process. The high amount of water from matrix caused swelling of fibers and created gaps between the fiber and polymer-matrix that led to a decrease in tensile properties. Based on the FTIR, sago composite particleboard consisted of high amount of OH group. The high OH group reduced the strength of the board. Sago composite particleboard with 30 wt% of UF matrix consisted of high OH group and reduced the strength.

FTIR showed sago composite particleboard with 20 wt% of matrix had high amount of cellulose compared with the board with 10 wt%. The interaction of cellulose particles with UF resin was excellent due to the hydrophilic nature of cellulose with UF matrix. The cellulose hydroxyl group and lignin hydroxyl groups are the major components of the fiber and both components played an important role on hydrophilicity (Sreekala *et al.*, 2000). Hydrophilicity had great influence on the polymerization. FTIR showed sago composite

particleboard with 30 wt% has the lignin hydroxyl group and this had caused the UF not bonded well. UF matrix had better interaction with cellulose which resulted the high tensile strength.

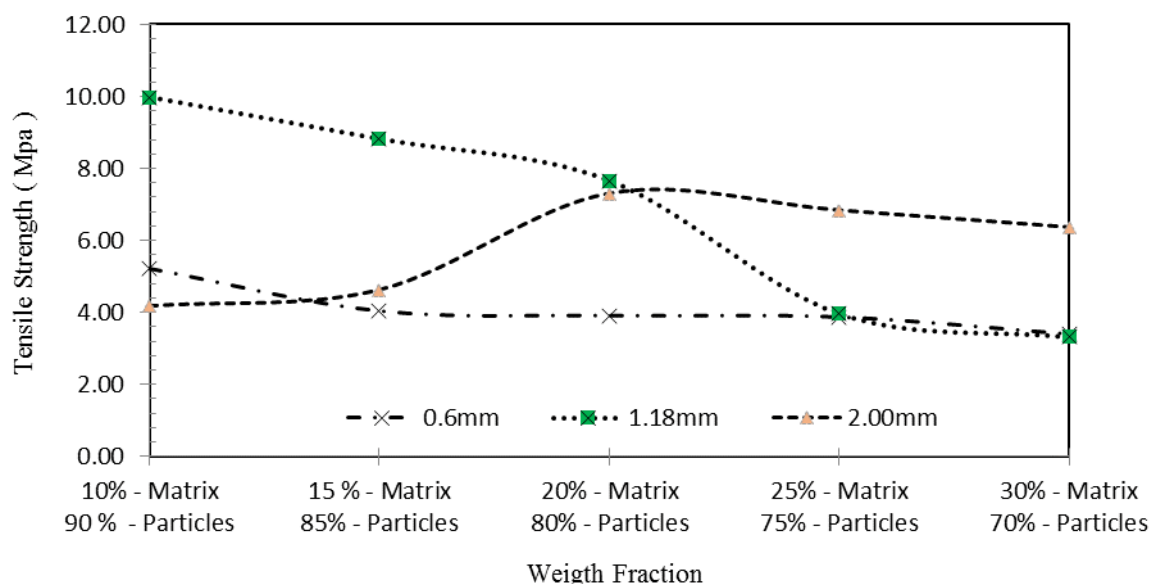


**Figure 5.8:** Tensile strength of sago composite particleboard affected by weight fraction and particles size.

## 5.2.9 Sago composite particleboard with different weight fraction of UF matrix

### analysis by TGA

Thermal stability is one of the most important parameters for sago composite particleboard to determine their suitability in actual applications. The thermal stability of particleboards by using different weight fractions of matrix was shown in Figure 5.9 and the details of decomposition were shown in Table 5.1. It showed that increased the weight fraction of matrix in particleboard will lead to different level of thermal stability. All the specimens were decomposed in a single stage of decomposition. The first step was associated with the moisture loss or the evaporation of trapped solvent. The second step was associated with the weight loss process corresponding to dehydration reaction on polymer chain which

usually occurred from 180 °C to 570 °C. The final step was associated with the residues at 450 °C in order to produce the carbon.

There were three thermogravimetric regions that appeared on sago composite particleboard with 20 wt% matrix. In the first region (60 °C–136 °C), there was a small peak due to loss of water absorption. In the second region (207 °C–534 °C), formation of volatile combustible compounds and high loss of weight took place. In the third thermogravimetric region, it belonged to residue and formation of char. Based on the TGA curve, the decomposition rate was around 305 °C to 312 °C. According to the thermal behaviour of the sago composite particleboard, hot pressing temperature at 160 °C was suitable for the UF and sago to react without thermal decomposition (Corcione *et al.*, 2012). Sago composite particleboard with 30 wt% UF matrix was decomposed with 3% of mass loss was observed from 55 °C to 167 °C followed by the major weight loss of 71% at the second stage. Then, at the final stage, the residues were found to be 27%. Sago composite particleboard with 10 wt% matrix decomposed into three steps, that was, 3% of mass loss in the first step, 71% of mass loss in second step, and 27% of mass loss in the last step.

The pyrolysis of sago composite particleboard took place below 250 °C. Result showed that the pyrolysis of hemicellulose, lignin and cellulose usually occurred at 200 °C, 220 °C and 250 °C respectively, with carbon dioxide and water (Islam *et al.*, 2012; Corcione *et al.*, 2012). Sago composite particleboard with 20 wt% of UF matrix had strong interaction between sago particles in the composite particleboard. UF matrix acted as across-linker that reacted with the cell wall hydroxyl group of sago and created a rigid linking bridge with sago particles. Hence, the thermal stability of sago particle was enhanced (Islam *et al.*, 2012).

Sago composite particleboard with 20 wt% of UF matrix was more thermally stable because the weight loss percentage was low during the degradation process compared to other specimens. It is apparent that the incorporation of UF matrix improves its thermal stability.

The thermal stability increased when the percentage of UF reached its maximum 20wt% created the better dispersion of the UF and better inter chain network between particles and matrix (Grich *et al.*, 2014). The uniform dispersion of sago particles and matrix had improved the thermal properties. However, sago composite particleboard with 10 wt% of matrix and sago composite particleboard with 30 wt% of matrix did not show good thermal stability properties. This was due to 10 wt% is not sufficient for particles bonding and not enough to enhance the thermal stability through residue formation (Carola *et al.*, 2012). While the 30 wt% is excessive for particle bonding. The high amount of UF content in sago composite particleboard produced less stable charred during the decomposition due to the high amount of moisture content as major bearing on the end use properties (Krishna *et al.*, 2013).

Better thermal stability could be attained by introducing optimum weight fraction of matrix into the particleboard. In this study, 20 wt% of matrix was the optimum weight fraction for particleboard fabrication. Hence, 20 wt% matrix could lead to better bonding between the matrix and particles (Corcione *et al.*, 2012). The strong interaction between particles and polymer matrix had caused the motions of polymer chains to be limited and increased the stabilization in the sago composite particleboard (Corcione *et al.*, 2012). Excessive matrix had evaporated during the hot press process and would reduce the strength for the whole specimen. The 20 wt% of matrix increased the resistance of particleboards to thermal degradation, alter their pyrolysis route, and increased the amount of char produced (Karastergiou *et al.*, 2000). The strength of the composite reduced by the presence of numerous hydroxyl groups (-OH) in the sago components. The OH groups in sago attracted water molecule through hydrogen bonding, thus causing it to be dimensionally unstable and physical, mechanical and chemical properties changed (Islam *et al.*, 2012).

Sago composite particleboard with 20 wt% of UF matrix had the lowest percentage of weight loss at the first stage due to the composite being trapped by small amount of water.

This had caused the sago particles to have better bonding between each other without hydroxyl groups.

The different observations in these three particleboards were probably due to the different weight fraction used to manufacture the boards which indicated that the weight fraction was significant to thermal stability behavior. Better thermal stability would caused the particleboard had better stable dimensionality and the strength properties were unaffected. This implied that optimal weight fraction of matrix loaded on sago composite particleboard had higher thermal stability.

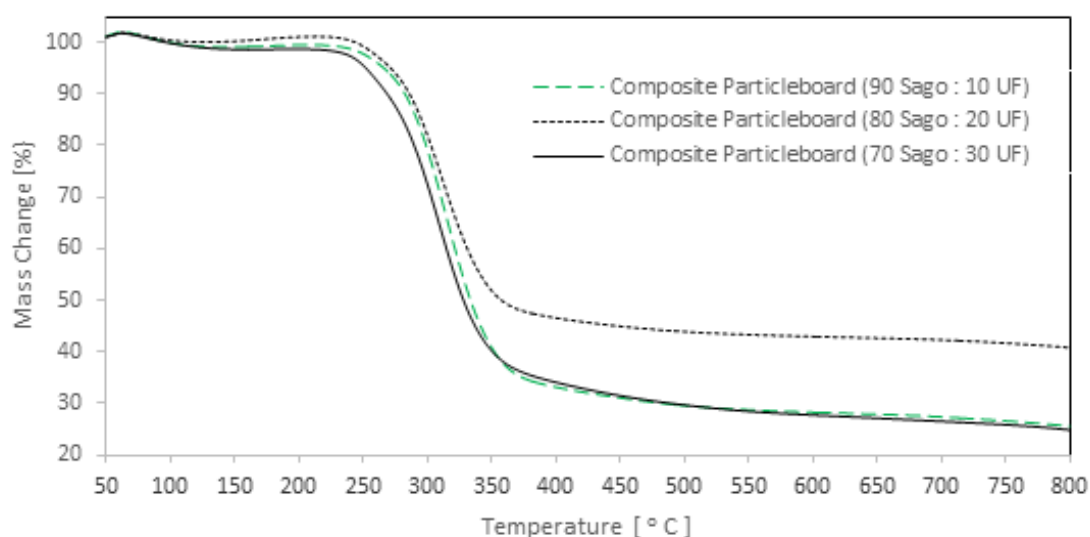


**Figure 5.9 :** Sago composite particleboard with different weight fraction of matrix analysis by TGA

**Table 5.1:** Results for Sago composite particleboard with different weight fraction of matrix analysis by TGA.

| Sago composite particleboard :<br>Weight fraction (wt% ) | Temperature Peak<br>(°C) | Mass Loss<br>(%) | Residue<br>(%) |
|----------------------------------------------------------|--------------------------|------------------|----------------|
| 90wt% Sago : 10wt% UF                                    | 75                       | 3                | 27             |
|                                                          | 312                      | 71               |                |
| 80wt% Sago : 20wt% UF                                    | 74                       | 2                | 41             |
|                                                          | 308                      | 58               |                |
| 70wt% Sago : 30wt% UF                                    | 76                       | 3                | 27             |
|                                                          | 306                      | 71               |                |

#### 5.2.10 Sago composite particleboard with different weight fraction of UF matrix

##### analysis by DSC

Figure 5.10 shows the DSC thermogram of sago composite particleboard with different weight fraction of matrix. The organic compound had melted and decomposed with the pattern as shown in the thermogram in Figure 5.10 (Melter, 2000). This showed that amorphous structure occurred in the particleboard and the liquid crystals remained anisotropic after the melting peak (Melter, 2000). Sago composite particleboard had reached the melting peak at 80 °C, 78 °C and 77 °C at 30 wt%, 20 wt% and 10 wt% of matrix respectively. The lower temperature peak was caused by the structural reorganization and amorphous portion that developed in to crystallinity (Chung *et al.*, 2000).

Sago composite particleboard with 20 wt% of UF matrix showed better curing properties than the board with 10 wt% of matrix. This was due to the sufficiency of UF applied on sago particles, which had created homogeneous dispersion in the particleboard and improved the cross-linking reaction between the starch granules (Sulaiman *et al.*, 2013).

Sago composite particleboard with 30 wt% of UF matrix with largest area showed the least curing properties compared other samples moreover consume maximum of heat release due to the sago particles, UF curing and water reaction (Hassine *et al.*, 2009). This could be the excessive matrix where there was little change of the crystal perfection or degree of crystallinity by increasing the weight fraction during manufacturing process (Chung *et al.*, 2000). Hence, the curing period became longer. The increase in the melting temperature could be attributed by two factors: incomplete curing reaction and increase in the free volume of the system (Azwa *et al.* 2013). The decrease in the free volume was proposed to be responsible for increasing the melting temperature due to the addition of matrix in the particleboard. The particleboard with different loadings of sago particles and matrix had higher melting

temperature which might be attributed to the reinforcement effect and restricted the motion between sago particles and matrix that led to increase in  $T_m$  (Chandra *et al.*, 2014).

Sago composite particleboard with 30 wt% of matrix had the compact packing in structure order while sago composite particleboard with 20 wt% of matrix of the particleboard had looser packing in the structure order which required smaller amount of heat to achieve curing and melting. Sago composite particleboard with 30 wt% of UF matrix showed exothermic peak with lower temperature of 201 °C compared to board with 10wt% of matrix which was 208 °C. This was due to additional sago particles that shifted the exothermic peak toward the higher temperature and the nucleating of the sago particles in the crystallization of UF matrix (Hassine *et al.*, 2009). Sago particles acted as heterogeneous nucleation agents for UF.

Sago composite particleboard with 30 wt% of UF matrix showed a single endothermic peak between 200 °C and 350 °C due to thermal decomposition of sago particles. The samples were reduced to fibers and char in an inert atmosphere (Chung *et al.*, 2000). Sago composite particlesboard with 10 wt% and 20 wt% of UF matrix exhibited multi endothermic peak due to thermal decomposition of sago particles and filled polymer UF in the sago particles (Islam *et al.*, 2012). This was shown based on the prominent changes occurring in the structure and the chemical reaction with secondary reaction (Islam *et al.*, 2012; Melter, 2000).

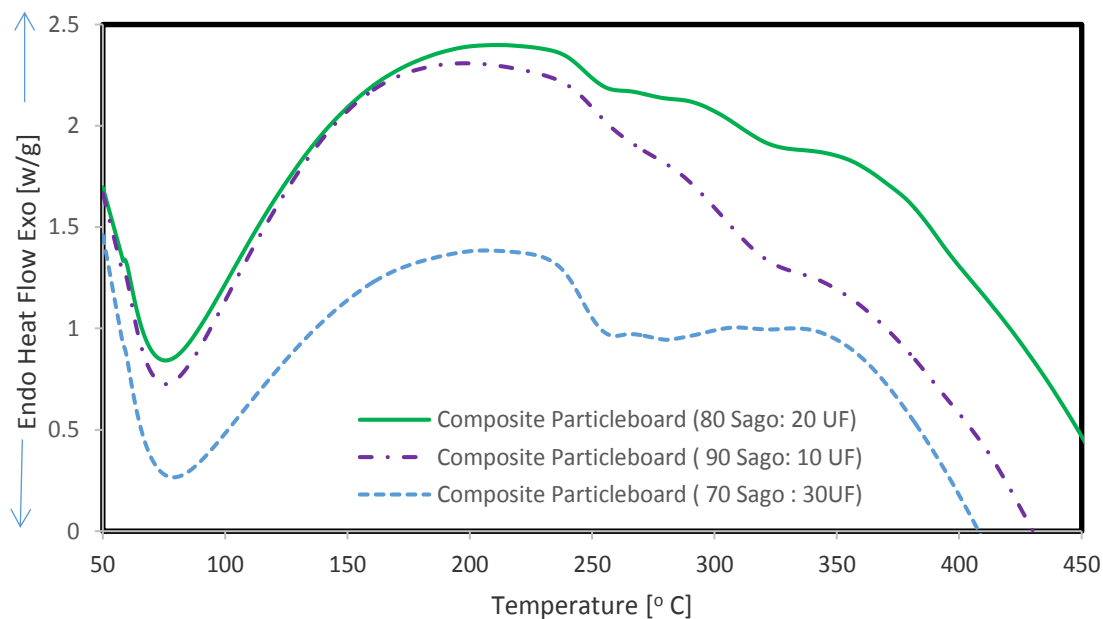


**Figure 5.10:** Sago composite particleboard with different weight fraction of UF matrix analysis by DSC.

#### 5.2.11 Fourier transform infrared (FTIR) spectroscopy analysis sago composite particleboard

The FTIR were used to character the interactions and explain the effects of urea formaldehyde on the lignocellulose constituents (cellulose, hemicellulose and lignin). An IR spectrum is a very characteristic feature of a substance and therefore it can be treated as an analytic tool for identifying structural groups present in the investigated compounds, as well as for studying the occurring chemical process. FTIR spectra of sago composite particleboard with different loading of urea formaldehyde are presented in the region  $4000\text{ cm}^{-1}$  to  $600\text{ cm}^{-1}$  in Figure 5.11, 5.12 and 5.13.

FTIR spectra in Figures 5.11, 5.12 and 5.13 showed that sago composite particleboard was fabricated with same chemical component. However, only sago composite particleboard with 30 wt% of urea formaldehyde matrix showed a significant different pattern. The peaks  $2704\text{ cm}^{-1}$ ,  $2848\text{ cm}^{-1}$  and  $2918\text{ cm}^{-1}$  showed the C-H stretching of lignocellulose component and aldehyde at the 30 wt% of sago composite particleboard. The 3 peaks showed that high

concentration of UF penetrated into the sago composite particleboard compared to sample with 10 wt% at  $2920\text{ cm}^{-1}$  and sample with 20 wt% at  $2924\text{ cm}^{-1}$ . The increased absorption band due to impregnation of urea formaldehyde inside the cell wall void spaces of sago (Islam *et al.*, 2012). This confirmed that UF was successfully impregnated inside the particleboard as confirmed by FTIR spectroscopic analysis. This result proved that higher loading of UF matrix does not proposed better mechanical strength of the particleboard due to the free hydroxyl groups at higher loading of UF matrix.

The chemical reaction between sago and UF matrix were showed at the peak  $1260\text{-}900\text{ cm}^{-1}$  and  $1250\text{-}1000\text{ cm}^{-1}$  for C-O group and C-O-C stretching, respectively (Yaacob *et al.*, 2011; Sarifuddin *et al.*, 2013). This had proved that cellulosic material and smaller oligomeric structures in matrix. The N-H bending vibration appears at  $1629\text{ cm}^{-1}$  and  $1631\text{ cm}^{-1}$  were related to sago and UF reinforced composite particleboard. This had indicated that cellulose was interaction between hydroxyl groups and amino group (Gurses *et al.*, 2013). This confirmed that the incorporation of urea formaldehyde into sago particles that created strong covalent bond between polymer matrix and fillers led to the significant reduction of the hydroxyl groups and increased the mechanical strength of composite particleboard.

The presence of OH group peaks at  $3261\text{ cm}^{-1}$ ,  $3574\text{ cm}^{-1}$ ,  $3726\text{ cm}^{-1}$ ,  $3228\text{ cm}^{-1}$  and  $3726\text{ cm}^{-1}$  were related to the presence of amylose and amylopectin in sago starch (Sarifuddin *et al.*, 2013). The characteristic peaks appeared due to the intermolecular hydrogen bond formation that occurred when starch and UF were incorporated into the sago composite particleboard. This had proved that sago composite particleboard is hygroscopic nature. High moisture content in the sago composite particleboard had affected the physical, mechanical and thermal stability. SEM proved that there are voids occurred in the sago composite particleboard had add advantages for moisture to penetrated into it. Sago composite particleboard with 10 wt% of urea formaldehyde matrix have increased the moisture

sensitivity due to the presence of hydroxyl group with the higher weight fraction of sago particles which were hydrophilic in nature. The presence of hydroxyl groups in sago composite particleboard with 30 wt% of urea formaldehyde were due to matrix in hydrophobic nature which was not be able to absorb by the sago particles. Both of this reason had caused the poor interfacial adhesion between particles and matrix. Hence, both the 10 wt% and 30 wt% of matrix in composite particleboard had reduced the mechanical strength.

The mechanical properties of sago composite particleboard were related with interfacial adhesion. The cellulose had better bonds between the urea formaldehyde compared to lignin and hemicelluloses and improved the mechanical bond strength of the particleboard (Eike *et al.*, 2016).

High content of cellulose in the sago composite particleboard had created better bonding with matrix. The common glycosidic linkages explained that the presence of the absorption band at  $1020\text{ cm}^{-1}$ ,  $1029\text{ cm}^{-1}$ ,  $1114\text{ cm}^{-1}$ ,  $1149\text{ cm}^{-1}$ ,  $1236\text{ cm}^{-1}$ , and  $1244\text{ cm}^{-1}$  was attributed to C-O-C ring vibrational stretching of  $\beta$  for cellulose I and cellulose II sago residues (Sim *et al.*, 2012). Sago composite particleboard with 20 wt% matrix had higher content of cellulose compared with the board with 10 wt% and 30 wt% matrix. Sago composite particleboard with 30wt% showed the C=C stretching vibrations of the aromatic rings of lignin at  $1519\text{ cm}^{-1}$  (Sim *et al.*, 2012). The had caused the mechanical strength reduced due to improper bonding between the matrix and lignin.

These studies confirmed the reduction of mechanical properties due to the penetration of O-H groups. The similar pattern of FTIR spectra proved that the sago composite particleboard had same component with different weight fraction of matrix that greatly influenced on the mechanical, physical and thermal properties.

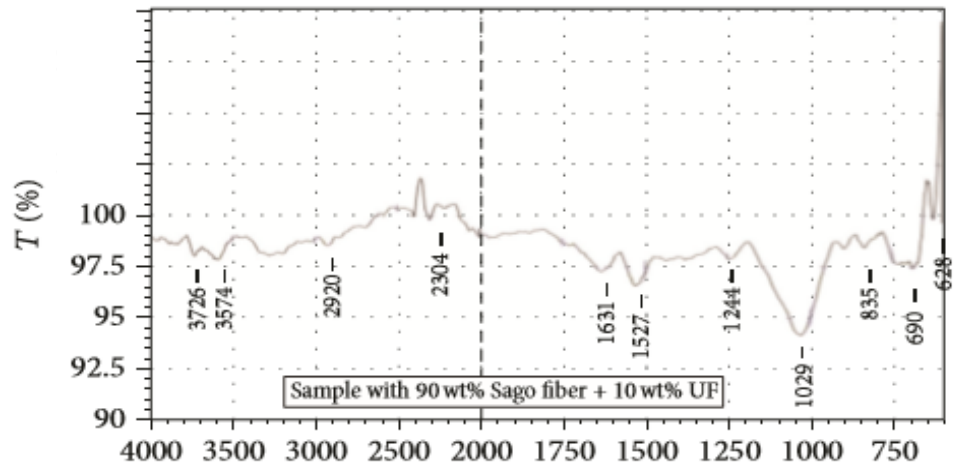


**Figure 5.11:** FTIR of sago composite particleboard with 90wt% sago +10wt% UF.

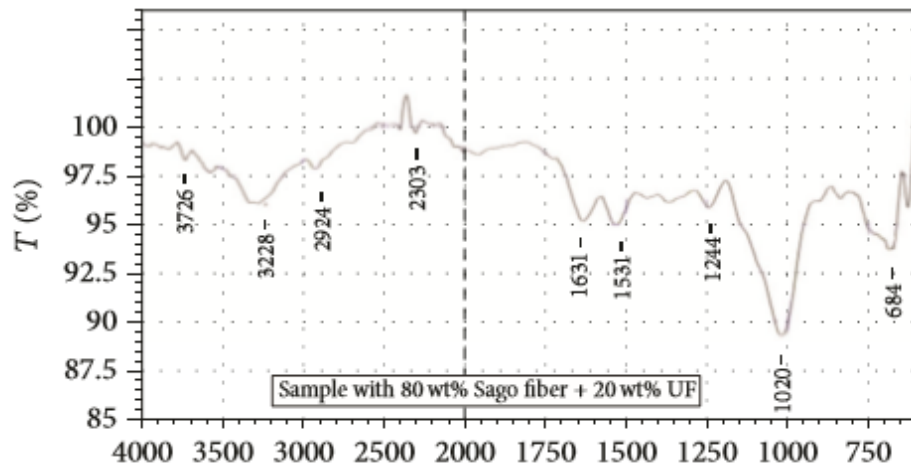


**Figure 5.12:** FTIR of sago composite particleboard with 80wt% sago + 20wt% UF.

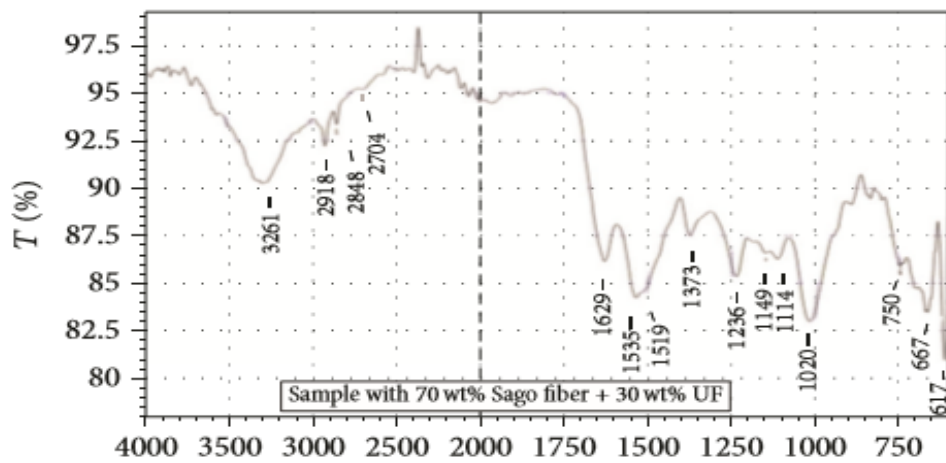


**Figure 5.13:** FTIR of sago composite particleboard with 70wt% sago + 30wt% UF.

### 5.2.12 Scanning electron microscopy (SEM) analysis of sago composite particleboard

Figure 5.14 (a) showed the sago particles were coated with urea formaldehyde well and this had created the better adhesion between matrix and particles which was increased the efficient load transfer. Mechanical properties of sago composite particleboard could enhance by using the optimal particles size with optimal weight fraction of matrix (Njoku *et al.*, 2011). This had attributed to increase in surface area which enhanced load transfer between the matrix and particles. Figure 5.14 (b) showed the typical fractography feature of fracture behavior due to improper bonding between the particles and matrix. Hence, existing of voids occurred had reduced the efficient of load transfer. The strength of sago composite particleboard decreased due to poor interfacial bonding resulting in spaces between particles and matrix had by generating a weak structure (Suvarna *et al.*, 2015). Existing of voids in the composite particleboard had penetrated the moisture. High moisture, adequate and excessive matrix applied on the sago composite particleboard had caused the mechanical strength reduced.

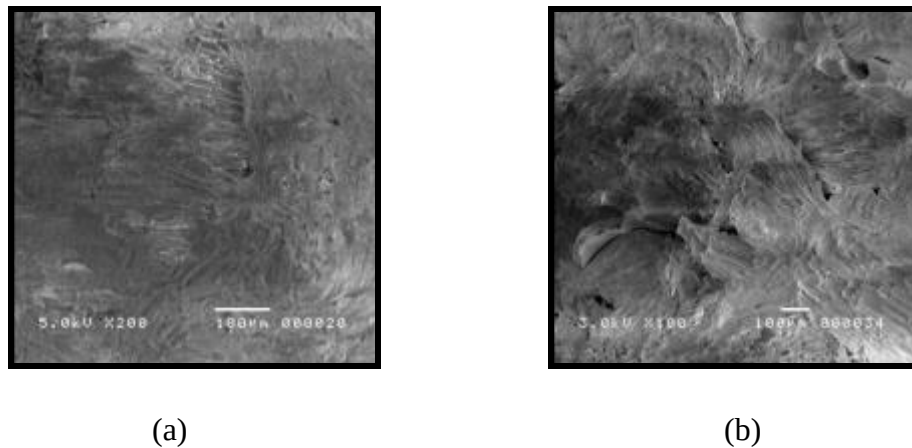


**Figure 5.14 :** (a) Better adhesion between matrix and particles and (b) weak adhesion between matrix and particles

### 5.3 Summary

From the results, it is clear that sago composite particleboards with the size and weight fraction had great impact on the board performances. The boards' strength was enhanced when the resin loading was increased to certain percentage of resin loading and beyond that weight percentage, the strength would drop. The mechanical strength of the sago composite particleboard reduced as inadequate or excessive adhesive was applied due to improper adhesive bonding between particles. From the TGA/DSC study, it could be concluded that sago composite particleboard with 20 wt% matrix had better thermal stability and better curing properties. This was because the samples were fully bonded by the UF matrix. Based on the TGA, the degradation of hemicellulose, cellulose and lignin could be observed followed by a further slow degradation until a fixed carbon was achieved at 800 °C. FTIR analysis showed the correspondence of bonding between functional groups of sago fiber and UF which confirmed that the reactions between all the components had been taking place in the composite particleboard. FTIR proved that OH group in the sago composite particleboard had reduced the mechanical strength. SEM proved the voids had encouraged the OH group to penetrate in the board. Besides, the weight fraction has significant effects on the water adsorption and thickness swelling expansion.

## **CHAPTER 6**

### **EFFECTS OF UREA FORMALDEHYDE AND PHENOL FORMALDEHYDE OF SAGO COMPOSITE PARTICLEBOARD ON PHYSICAL, MECHANICAL AND THERMAL PROPERTIES**

#### **6.1 Introduction**

Research showed that a large amount of binder is being used in particleboard fabrication which accounts for up to 32% of the manufacturing cost (Mamza *et al.*, 2014). Various types of binders have been used in the manufacture of composite particleboards. The binders are classified as interior or exterior use based on the requirement and their response to moisture and temperature.

One of major challenges associated with composite particleboard is the use of matrix resin. Factors that influence the selection of adhesive include cost, assembly process, strength of bonded assembly and durability.

The bonding strength depended on efficient distribution of applied forces between the matrix and particles phase. The interfacial behavior between the fibers and polymer matrices had great influenced on the overall properties of composite particleboard due to the stress transfer occur between fiber and matrix, stress redistribution as well as mechanisms of damage accumulation and propagation (Gassan *et al.*, 2000). The low mechanical strength of composite particleboard might be due to the unbonded regions of fiber-matrix interface and incompletely energy dissipation occurred at cracks or delaminations.

The quality of composite particleboard depended on the performance of glued joints upon good glue bond formation. Good interface adhesive formation required good interlinks between matrix and particles. An adhesion implied a formation of interface by penetration of matrix into the particles by mechanical interlocking, thermodynamic adsorption of the glue on

the wood or chemical (covalent) bonding (Anwar *et al.*, 2012). Indira *et al.* (2013) mentioned composites particleboard exhibited superior mechanical property and less water adsorption was due to good fiber/matrix interaction that resulted low void content and good fiber wetting.

Over 90% of wood-based panel product in the world were manufactured with UF resin due to the advantages including low cost, non-flammability, very rapid curing rate and light colour (Elbadawi *et al.*, 2015; Eslah *et al.*, 2012). The disadvantages of urea formaldehyde were far too hard and brittle to be use alone as coating material (Osemeahon *et al.*, 2014).

Phenol formaldehyde was widely used in the manufacturing and possessed various advantages over other resins, such as low cost, high rigidity, good dimensional stability, better flame retardation and chemical reactivate (Chai *et al.*, 2009). This was attributed to its highly cross-linked aromatic structure and greater number of resonance-intensifying hydroxyl groups. However, PF has limited usage due to its brittleness and poor adhesion properties (Inamdar and Rathod, 2013)

The objective of this work was to investigate the effectiveness of UF and PF matrix as potential reinforcing agents on physico-mechanical and thermal properties of sago composite particleboard. The combination of sago particles with UF/PF could be utilized for general indoor application purposes such as furniture manufacturing due to the advantages like optimized performance, minimized weight and volume, cost effectiveness, chemical resistance, and resistance to biodegradation. Scanning electron microscopy (SEM) studies had been carried out to get an insight into fiber/matrix interaction and fiber breakage.

## 6.2 Results and Discussion

### 6.2.1 The effect of matrix with different loading on thickness swelling (TS) for sago composite particleboard

Figure 6.1 shows the effect of UF and PF resin on thickness swelling. It was observed that, by increasing resin loading in both particleboards, resistance against water being absorbed was developed. The swelling percentage of particleboard was slightly reduced after being impregnated with higher loading of UF or PF resin and led to better dimensional stability. This could be explained by high resin content 20 wt% for both UF and PF which had better cover the parenchyma tissues, reduced the ability of parenchyma to absorb water. Both resins loading had reduced the porosity and minimized the dimensional changes.

Both the 10 wt% of UF and PF sago composite particleboard had the highest thickness swelling compared with 20 wt% of UF and PF particleboard. Natural fiber-based polymer composites had poor water resistance due to the presence of polar groups, which attracted water molecules through hydrogen bonding (Abdullah *et al.*, 2012). This phenomenon led moisture to build up in cell walls and at the fiber/matrix interface. The polar hydroxyl groups in sago form hydrogen bonds with water molecules. This had been attributed to the water being absorbed through the formation of hydrogen bonds which increased with weight fraction and parenchyma tissue (Abdullah *et al.*, 2012). The presence of OH groups enhanced the water absorption by forming hydrogen bonding with water molecules that caused the particleboard dimensional changes.

UF sago composite particleboard had better dimensional stability than PF sago particleboard. This could be attributed to the strong UF resin properties with stable adhesive forces (Malhotra *et al.*, 2012). Hence, UF resin provided better water resistance than the PF resin. Besides, UF had better resistance against the water due to the sufficient bonding strength with reduction in internal force generated by water (Abdullah *et al.*, 2012; Abdul

Abdul Khalil *et al.*, 2011). UF had better bonding with sago particles to form stable solids which occupied void spaces in the parenchyma and penetrated the cell wall. On the other hand, PF required higher temperature and press time compared with UF to achieve better bonding strength for better interfacial contact between fiber-matrix bonding (Apri *et al.*, 2014). UF adhesive had better bonding than PF because the  $\text{NH}_4\text{Cl}$  was applied during the fabrication process which increased the bonding quality compared with noncatalyst on PF (Ravindra *et al.*, 2017). The catalyst had improved the sago particles acidity. The low and high pH could cause precuring and over curing to happen. This will caused the board become weak and flaky because the binder cured before the particles had been compressed or resin bonds broke due to over curing (Elbadawi *et al.*, 2015; Iswanto *et al.*, 2012).

PF sago composite particleboard had shown poorer thickness swelling properties compared to the UF. This was because PF resin contained a higher amount of water and low viscosity and low solid content compared with UF. PF needed higher temperature or longer time for the hot press process due to the PF properties which was more liquid. During the hot press process, the moisture in PF evaporated more slowly compared to UF and caused the PF located in the parenchyma cells. Hence, poor bonding between the particles had caused the dimensional stability to be reduced (Abdullah *et al.*, 2012). TS of composite panel was influenced by the quality and distribution of adhesive, moisture content, compatibility, and chemical composition of furnish (Iswanto *et al.*, 2014).

Sago composite particleboard with PF 15 wt%, UF with 15 wt%, and UF 20 wt% had met the minimum TS requirement of JIS A 5908 Standard by not exceeding 16% of thickness swelling. Based on the result, all the sago composite particleboard continued increasing with in thickness swelling until it reached saturation after 48 hours with stable dimensions. The result showed UF have better cohesive and binding forces compared with PF.

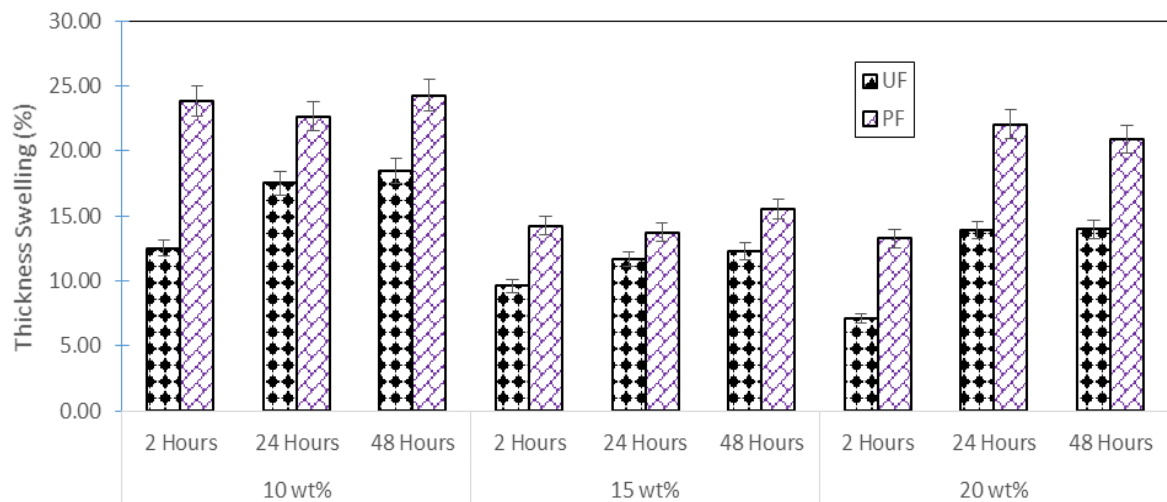


**Figure 6.1:** Thickness swelling of sago composite particleboard versus matrix with different load.

### 6.2.2 The effect of matrix with different loading on water absorption (WA) for sago composite particleboard

Figure 6.2 showed that both sago composites particleboard had the same pattern of water uptake where most of the water was absorbed in the first 2 hours. Higher initial water absorption rate might be due to diffusion phenomenon as fluid spreads through the capillaries, vessels, and cellular walls of sago. Capillaries and cavities on the surface were filled up by water instantaneously; hence water concentration on the surface saturated rapidly, and moisture movement was restricted to the inner of composites. Water moved easily into large cavities instead of in small cavities due to the presence of air bubbles trapped inside small cavities (Khazaei *et al.*, 2008).

The result illustrated the water absorption of UF and PF particleboards with different fiber content. It could be clearly seen that water absorbed increased with the fiber content. The highest water uptake was found in 10 wt% of matrix in particleboard for both UF and PF. This was due to the presence of more hydroxyl groups in the parenchyma tissue that enabled more hydrogen bonding to be formed and the parenchyma behaved like a sponge with which

it was easier to absorb water (Abdullah *et al.*, 2012; Abdul Khalil *et al.*, 2010). There was more surface area on sago particles and parenchyma tissues to absorb moisture (Abdullah *et al.*, 2012; Chaharmahali *et al.*, 2010). On the other hand, the porous structure of sago particleboard led to large initial uptake. The presence of free hydroxyl group and other polar groups in sago results in poor compatibility between the fiber and matrix. Hence, this caused the sago particleboard to take up the high amount of water which was trapped into the interfibrillar space of cellulosic structure and micro voids (Abdul Khalil *et al.*, 2011). When the specimens were immersed in the water for longer time, the water molecules entered the particleboard through the voids and absorbed by the polar OH groups of sago particles and caused interfacial debonding at the same time.

The hydrophilic nature and high porosity of sago content enhanced the water diffusion process and took a longer time to achieve saturation (Chaharmahali *et al.*, 2010; Chai *et al.*, 2009). This was observed by other researchers that the water uptake capacity of the particleboard decreased with the increment of resin loading. Both matrices UF and PF showed that the water absorption decreased with resin content. This could be explained by high resin content 20 wt% for both UF and PF with better covered on the parenchyma tissues, which reduced the ability of parenchyma to absorb water. By increasing the resin content had caused the chemical components in the resin to have better crosslink with hydroxyl groups of the sago and hence reduced the hygroscopic of the boards. Hygroscopic expansion was affected by monomer, polymerization rate, cross-linking and pore size of polymer network, the bond strength, interaction between polymer and water, and filler resin interface (Saad *et al.*, 2012).

UF had better water resistance compared with PF as the cohesive and binding force of UF resin were stronger and more sustainable (Abdul Khalil *et al.*, 2011; Awg-Adeni *et al.*, 2010). The reason for less water absorption of particleboard with UF resin loading compared to PF resin loading was due to better interfacial contact between fiber-matrix bonding in UF

(Abdullah *et al.*, 2012). UF matrix had better bonding properties to cover the parenchyma tissues from absorbing the water. By increasing the resin loading in the UF particleboard, the void spaces in the parenchyma were reduced and penetrated into the cell wall of sago. The presence of urea in UF increased the molecular weight of resin system and thus limited the penetration into the cell wall of the sago and filled up the lumen which formed an internal coating and reduced the water absorption (Nur *et al.*, 2011).

The results showed that sago impregnated with higher loading of PF reduced the degree of water absorption. This reflected the replacement of hydroxyl group with carbon atoms in the PF chains (Abdul Khalil *et al.*, 2010). The molecular weight distribution of resin significantly influenced the viscosity and the ability of resin to penetrate the cell wall (Nur *et al.*, 2011). PF had higher amount of water compared to UF. This caused the moisture in PF took a longer curing time to achieve curing. Incomplete polymerization of matrix might occur in the lumen making the solid content of PF located fully in the parenchyma cells thus leaving more air spaces for moisture uptake (Abdullah *et al.*, 2012; Nur *et al.*, 2011).

All the UF/PF sago particleboards were not applicable in the industry usage due to the requirement that they should be less than 60%. The particleboard might improve by adding some wax for water resistance or laminated with PVC sheet.

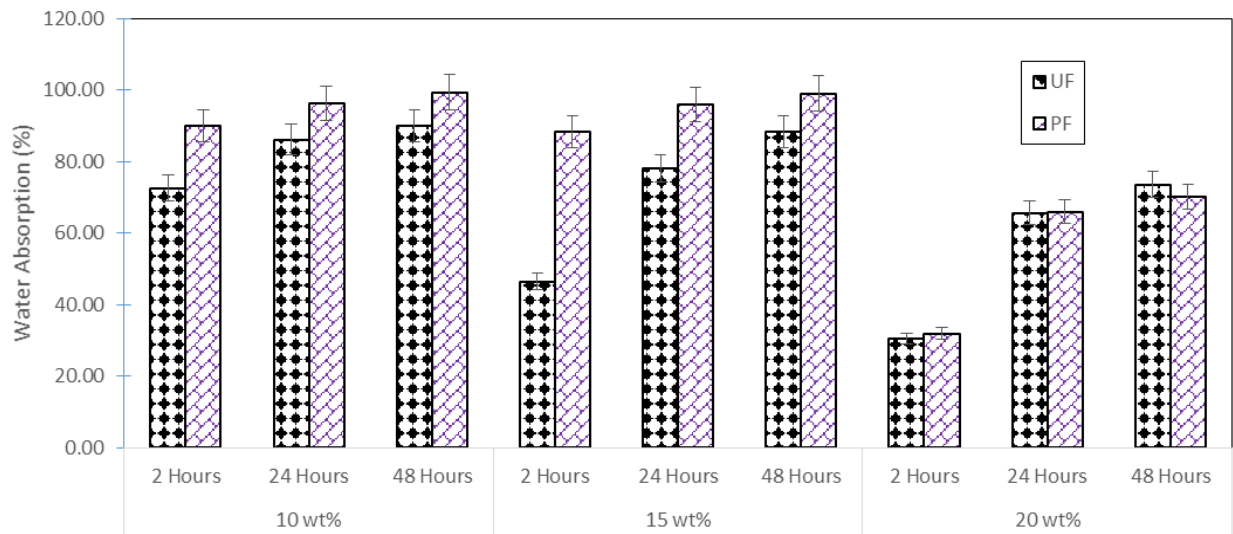


**Figure 6.2:** Water absorption of sago composite particleboard versus matrix with different loading.

### 6.2.3 Bending strength of sago composite particleboard with different loading of UF and PF matrix

Figure 6.3 illustrates the relationship between the bending strength of different types and loading of matrices applied to the sago composite particleboard. The results showed that urea formaldehyde (UF) and phenol formaldehyde (PF) improved the bending strength when applied to the particleboard. The MOR of sago UF/PF strongly depending on the bonding strength between the polymer matrix, surface topology, and lignocellulosic of sago particles (Singha *et al.*, 2009).

The bending strength of UF particleboards increased with the resin content up to 15 wt% but decreased beyond their optimal value (Abdul Khalil *et al.*, 2010). This was because at high of UF loading more particles were well-bonded with the matrix which reduced the voids between sago particles (Wong *et al.*, 2010). Due to the good intercalation of UF matrix and sago particles, the stress transfer between the matrix and fibers increased and, therefore, the bending strength improved especially at 15 wt% (Ozturk, 2010). The excess resin beyond 15 wt% loading reduced the strength and made the particleboard brittle (Abdul Khalil *et al.*,

2010). The agglomeration of sago particles at higher loadings of matrix had decreased the reinforcement-matrix bond hence lowering the magnitude of MOR (Ishak *et al.*, 2010; Singha *et al.*, 2009). As a result, it led to poor interfacial bonding between the fiber and matrix hence decreasing the MOR.

The 10 wt% of PF had better bonding between the matrix and sago due to surface morphology which decided the interfacial matrix-fiber adhesion. The good wetting of the sago particles by the PF matrix had formed good chemical bond between the particles and matrix, which resulted in better bending strength (Singha *et al.*, 2009). The sufficiency and effectiveness of the matrix in covering the surfaces of the particles had created the cross-link between the matrix and particles for better mechanical bonding throughout the hydrogen and covalent bonds (Saad *et al.*, 2012). PF created a better mechanical interlock between the particles and matrix. When PF was applied on the sago particles, the matrix penetrated easily into them and filled up the pores of the substrate. This led to better impregnation process that forced the PF to locate in particles structure and provided more resistance to shear forces. Sago composite particleboard with 10 wt% of UF matrix had lower result on bending strength. As the fiber concentration increased, the hydrophobic polymer finds it difficult to wet the hydrophilic particles which caused improper bonding and reduced the strength of whole composite particleboard. Sago composite particleboard with 10 wt% matrix had higher loadings of agglomerate particles caused poorer transfer of load and stresses by particles agglomerated to matrix which decreased the mechanical properties of composites particleboard.

The 20 wt% of PF did not improve the bending strength because the excessive matrix was evaporated during the hot press and the lower viscosity (90 CPS) and solid content 41% of PF caused the matrix to flow through rather than bond with the particles. Higher volume of sago particles was covered by PF. PF resin contained higher amount of water compared to UF

resin. In this case, higher temperature or longer heating time was needed for better bonding strength between particles and matrix.

Sago composite particleboard with 15 wt% of UF had higher bending strength than the board with 15 wt% of PF. PF had lower viscosity in properties and required higher volume of particles to adsorb the matrix for better bonding. It was due to the poor fiber-matrix interfacial adhesion and caused failure of the fibers in the load distribution. The 15 wt% of UF was the optimal matrix loading for sago composite particleboard and the high viscosity of UF had caused the particles were well-bonded with the matrix which reduced the voids between sago particles. This had created good intercalation of UF matrix and sago particles had increased the stress transfer between the matrix and fibers.

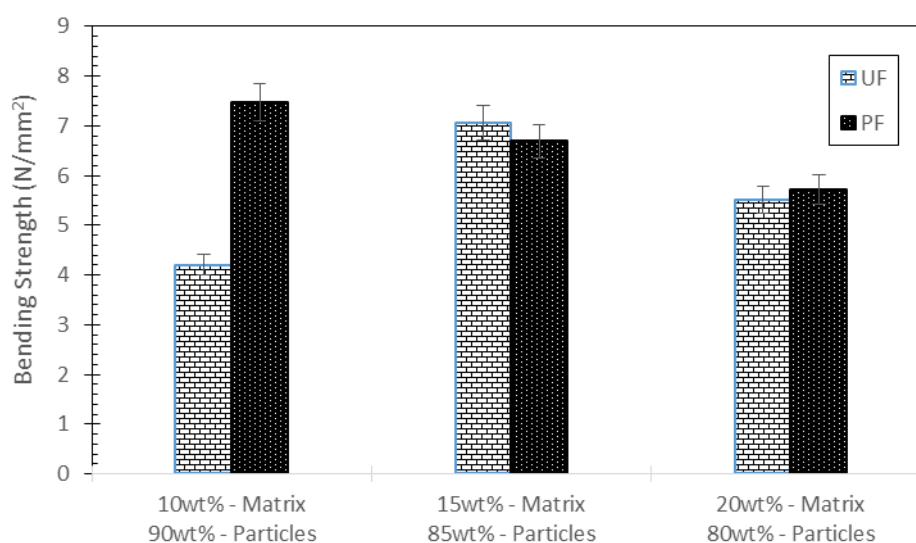


**Figure 6.3:** Bending strength of sago particleboard versus matrix and different loading

#### 6.2.4 Modulus of elasticity (MOE) of sago composite particleboard with different loading of UF and PF matrix

Figure 6.4 illustrates the effect of UF and PF with different weight fraction on MOE. It was observed in Scanning Electron Microscopy that MOE were influenced by particles and

matrix interface bonding, transverse cohesion, and the perfect dispersion of individual particles (Fabrice *et al.*, 2012; Fu *et al.*, 2008).

Sago composite particleboard with UF had better MOE compared to PF. This was due to higher viscosity in UF with shorter time to complete polymerization during the hot pressing (Pan *et al.*, 2007). Based on the results, sago composite particleboard with UF exhibited higher MOE. The inter particle bonds formed by the resins showed greater tendency of stretching due to slippage in PF resin. This indicated that more energy was required to deform sago composite particleboard with UF compared to PF particleboard (Mamza *et al.*, 2014). The UF filled the lumen and wall, hence forming a rigid cross-linked polymer which resulted in the increment of strength and stiffness (Nur Izreen *et al.*, 2011). MOE had increased the stiffening effect of the granules from sago (Yee *et al.*, 2011). Further increasing in UF loading reduced the MOE because the sago residues had reduced. The starch granules from sago were stiffer than the matrix when dispersed at sample (90 wt% sago + 10 wt% UF matrix).

Sago composite particleboard with 10 wt% of UF had the highest MOE value. The presence of polar group in the UF contributed to electrostatic absorption between the UF and sago particles. Higher electrostatic charges acting on UF or sago surface strengthened the UF and sago interface by holding them together and increased their resistance to deform (Abdul Khalil *et al.*, 2010; Idris *et al.*, 2011). The modulus increased with the particles concentration. This was due to deduction of the voids in the particleboard and created better bonding of particle with matrix in the board (Hussain *et al.*, 2013). Besides, high content of particles reduced the porosity between particles and resulted in a lower specific surface area for better stress transfer (Reza *et al.*, 2015).

The MOE reduced with the weight fraction of UF. This was due to the stress transfer between particles and matrix interface which reduced due to high moisture content when the

matrix loading increased (Dhakal *et al.*, 2007). This had proved by the FTIR due to the high content of OH groups.

The 10 wt% of PF showed the lowest MOE and tended to be ductile. This was due to shortage of PF matrix to bond all the particles in the board (Hussain *et al.*, 2013). The MOE increased with the weight fraction of PF. This is due to the covalent bonds acting to connect the PF into the sago which helped to fill the gap between sago particles (Wong *et al.*, 2010).

PF resin had lower MOE value compared to UF because of the acidic properties of sago which resulted in weakening in adhesive bonding strength (Iswanto *et al.*, 2014). The average pH of sago was between 3 and 5.5 (Rowell *et al.*, 2012). The strength of bonding reduced as the temperature and chemical reaction between PF and sago particles decreased. In general, with natural fiber exposed to an acid or base for a longer time or higher temperature, the strength could be degraded. Sago particles with high amount capacity required the addition of catalyst to bring the pH to the level (acidic or alkali) for optimum resin curing. This would increase the good interlinks between matrix and particles (Anwar *et al.*, 2012). UF adhesive had better bonding than PF because the  $\text{NH}_4\text{Cl}$  was applied during the fabrication process which increased the bonding quality compared with non-catalyst on PF. The catalyst and sago particles acidity increased the curing rate (Elbadawi *et al.*, 2015). The curing rates of formaldehyde-based resins were dependent on the pH of the catalyst. The low pH could cause precuring and the board became weak and flaky because the binder cured before the particles had been compressed and when the press was closed the precured resin bonds broke (Elbadawi *et al.*, 2015; Iswanto *et al.*, 2012). Besides, using the coupling agent ( $\text{NH}_4\text{Cl}$ ) had improved the mechanical performance of sago composite particleboard structure and enhanced the resistance to thermal deformation and water absorption properties (Reza *et al.*, 2015).

From the study, the effect of matrix with different loading was importance for good dispersion of particles in sago composite particleboard which would affect the performances on physical and mechanical properties. Good interface bonding had indicated the particles were perfectly attached with matrix and were strongly imbedded with matrix, efficiency of mixing and attributed a good interfacial interaction between particles and matrix.

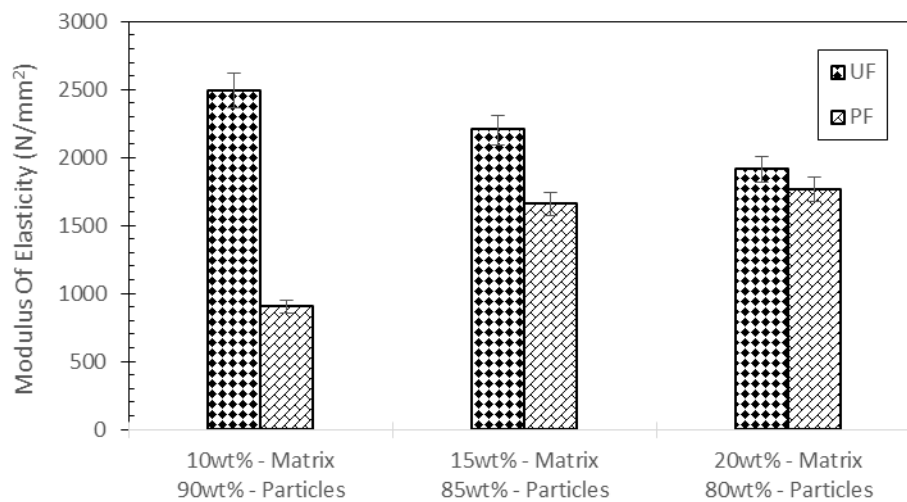


**Figure 6.4:** Modulus Of Elasticity sago particleboard versus matrix with different loading.

### 6.2.5 Internal bonding (IB) of sago composite particleboard with different loading of UF and PF matrix

Figure 6.5 shows that there was slight difference in the IB value for both the UF and the PF sago composite particleboard. Sago composite particleboard with PF matrix showed increment in IB value by increasing the weight fraction of matrix until 15 wt% of PF content. The IB value increased due to the matrix that held the fiber firmly and increased the interfacial bonding between the particles in the particleboard (Ishak *et al.*, 2010). The higher amount of resin, the stronger interfacial bonding between particles in the boards was formed, thus prolonging the ability of the boards to withstand the pulling force during the test (Saad *et*

*al.*, 2012). The wetting properties from PF matrix caused it to easily penetrate the particles and created better mechanical interlock. At the same time, the matrix filled up the voids and created better bonding between each particle. Another possible explanation for the superior performance of PF at 10 wt% and 15 wt% was related to its high mobility on sago particles (Papadopoulos, 2006). FTIR showed that PF had better bond between lignin and cellulose. When the PF droplets were placed on the sago particles, they spread out spontaneously without the need of any external forces. The high mobility of PF had caused the matrix to penetrate deep into compressed particles and repaired the weak zones in the particleboard (usually damaged by cracks and tissues) by sticking them together. The 20 wt% of UF sago composite particleboard showed the highest internal bonding because there was sufficient resin to wet all the sago particles in the composite specimens. The  $\text{NH}_4\text{Cl}$  that acted as catalyst in UF had increased the bonding strength compared with the PF with no catalyst applied (Sotande *et al.*, 2012). This occurrence could accelerate curing process which influenced the change of methylene-ether bridges (low cohesive strength, low resistance to hydrolytic degradation and less dimensional stability) to the methylene bridges (high cohesive strength, high resistance to hydrolytic degradation and best dimensional stability) (Jirapat *et al.*, 2014). The high content of methylene bridges could improved board strength.

Sago composite particleboard with 10 wt% and 15 wt% of UF matrix lowered the IB value compared with the PF sago composite particleboard with the same amount of matrix to be used. This was due to the insufficient UF for the particle bonding and, thus, affected the wetting properties. High viscosity of UF caused slow resin diffusion in sago lumen and decreased in mechanical interlocking (Iswanto *et al.*, 2014). This reduced the mobility of polymer hydroxyl group and caused the unstable methyl ether bridge not able to change to methylene bridge; consequently the bonding strength became weak (Iswanto *et al.*, 2014). The internal bonding strength of UF-bonded particleboards depended largely on the strength

of adhesive and its bonding to particles. It had great influence on the degree of hydrogen bonding between molecules and condensation reactions between the methanol and amide group (Charles *et al.*, 2007).

Sago composite particleboard with 20 wt% of PF content did not show better IB performance because PF had lower flow rate with low solid content 41% on the physical properties and required higher temperature and longer pressing time to cure the core mattress. The higher water molecules in core mattress had reduced the internal bonding strength. At low temperature, resin diffusion in wood became lower that it would decrease mechanical interlocking and reduced the mobility of polymer hydroxyl group. This had caused unstable methyl ether bridge did not change to methylene bridge, consequently the bonding strength value is lower and reduced the glue bond formation at the core mattress (Papadopoulos, 2006). Excessive PF matrix did not improve the IB because the matrix would evaporate during the hot press and did not bond well with the particles. Excessive formaldehyde scavenger at PF led to some changes in fiber structure, and thus the mechanical properties of sago composite particleboard were decreased (Elbadawi1 *et al.*, 2015).

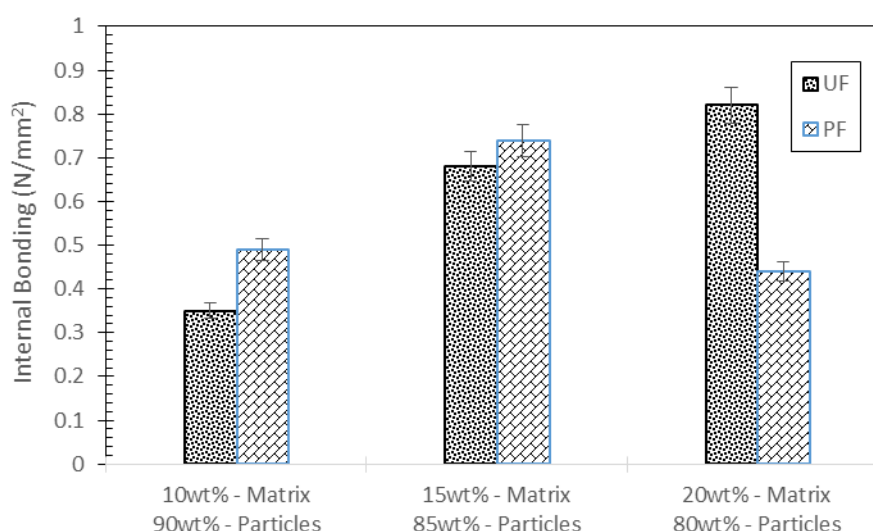


**Figure 6.5:** Internal bonding of sago particleboard versus matrix and different loading.

### **6.2.6 Screw test of sago composite particleboard with different loading of UF and PF matrix**

Figure 6.6 illustrates the screw test of different types of matrix applied to the sago composite particleboard. The results showed that UF had shown the highest screw test at 20 wt% of matrix.

The screw test value increased when the UF matrix increased up to 20 wt%. The UF matrix bonded well with the particles and reduced the existence of voids. Hence, this had improved the ability of boards to hold the screw being pull-out (Saad *et al.*, 2012). The efficiency of interfacial bonding between particles indirectly increased the ability of boards to hold the screw being pull-out, and hence the screw test value increased (Saad *et al.*, 2012). Particleboard filled with higher dosage of UF resin caused the matrix to flow across surface, transfer to substrate, and penetrate into the cell wall. When the screw was embedded tightly into the particleboard, it was difficult to extract during the test.

The PF matrix only bonded well at higher weight fraction of particles. Sago composite particleboard with 20 wt% PF matrix proved that high loading of matrix with low volume of particles had reduced the screw test result. This was due to low viscosity of PF allowed it to flow easily through the sago particles and managed to bond well between the particles. By increasing the dosage of PF into the sago particleboard, the embedded strength did not improve because the PF matrix flowed over or evaporated during the fabrication process. The high moisture content of PF matrix had caused improper bonding between particles and this had influenced the bond formation and performance. The PF sago composite particleboard required the optimal pressure of compression for high volume PF with low content of particles. Too high pressure led to non-reliable glue line because it pressed so much glue out of the bond line. It caused thin glue line and inadequate of matrix to penetrate into the

particles. On the other hand, low pressure caused decreased in shear strength and did not provided close contact between the surfaces and the bond line that might remain partly poor.

The UF matrix interacted with sago specimens better than the PF matrix. Sago particles had hydroxyl groups in their three main components like cellulose, hemicellulose, and lignin while the UF matrix could react with hydroxyl groups better than the PF matrix. PF did not show better screw test results because the sago particle absorbed water and lose some of its strength when it was wet. Hence, the PF matrix had weakened hydrogen bonds with the sago particles and created the failure zone (Charles *et al.*, 2007).

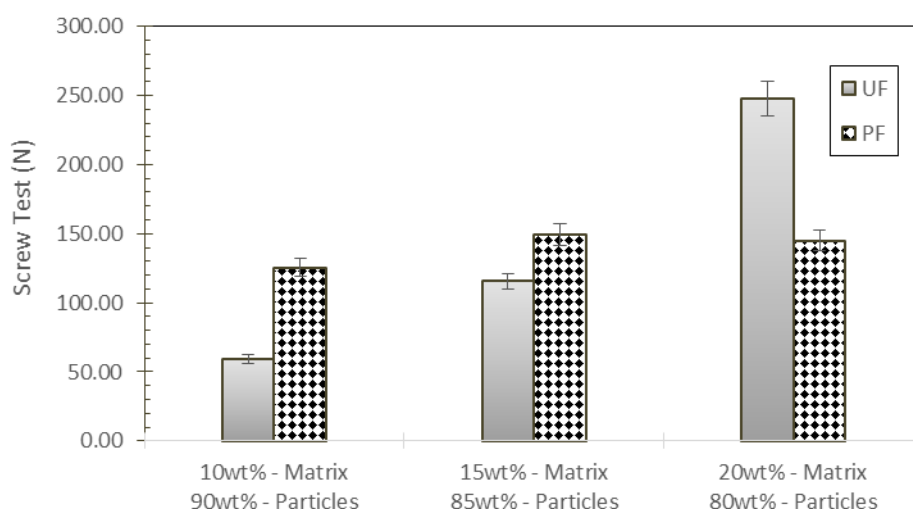


**Figure 6.6:** Screw test of sago particleboard versus matrix and different loading.

### 6.2.7 Tensile strength of sago composite particleboard with different loading of UF and PF matrix

Figure 6.7 shows that the tensile strength greatly affected by UF and PF matrix with different dosing. The bonding strength were strongly dependent on the interaction between polymer matrix and sago, surface topology and lignocellulosic of sago particles (Singha *et al.*, 2009). The result showed that UF had better bonding between polymer matrix and sago. This

was due to the good wetting of the sago particles by the UF matrix that formed a chemical bond between particles and matrix (Singha *et al.*, 2009). FTIR proved that UF have better bonding with cellulose and this had increased the strength.

The UF sago composite particleboard exhibited better tensile strength than the PF particleboard. This could be attributed to the strong binding force and compaction strength of UF resin at the resin-sago interface. The high tendency of the resin penetration into the pores and crevices of the sago besides the three-dimensional bonding effect resulted in better mechanical interlocking and increased the efficiency of stress transfer along the interface (Mamza *et al.*, 2014).

Sago composite particleboard with 10 wt% of PF showed the lowest tensile strength. This was due to inefficient stress transfer at the particle/matrix interface and had created the debonding between the particle and matrix (Fu *et al.*, 2008). The viscous resin could not allow the matrix to penetrate into the pores and crevices of the sago, and hence the tensile strength reduced (Mamza *et al.*, 2014).

The tensile strength increased with the PF loading. This was because PF had better interfacial adhesion and improved strength of lignocellulosic materials (Dungani *et al.*, 2014). Hydroxymethyl phenols would crosslink on heating to 120°C to form methylene and methyl ether bridges through eliminating water molecules (Jin *et al.*, 2014). At this point the PF adhesive with higher loading had created better 3-dimensional rigid network, which was typical of polymerized phenolic and make the sago composite with higher loading of PF had better strength.

On the other hand, UF bonded composite particleboard swelled more when the matrix loading increased. This had showed at 30 wt% of UF sago composite particleboard with increased the UF loading had decreased the tensile strength due to high content of OH group at board. High loading of UF had caused amino methylene linkages were susceptible to

hydrolysis (Jin et al., 2014). Therefore, the UF adhesive was not stable at high humidity and temperature. Poly condensation of urea with formaldehyde usually resulted in hydrolytically sensitive bonds and lowered the cross-link between particles and matrix. This had increased to lose in stress-bearing application. The incorporation of cellulosic or lignocellulosic particles with UF matrix decreased the tensile strength of the sago composite particleboard (Yee *et al.*, 2011). The interfacial interaction of sago and UF matrix introduced a new interfacial region that affected the stress transfer in the sample. During the tensile test, the plasticizer molecules might allow the macromolecular chains to undergo stretching and slippage.

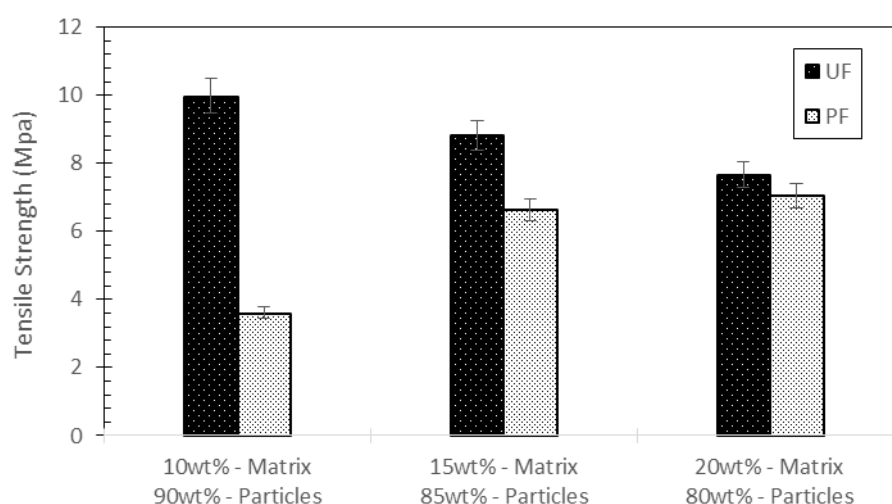


**Figure 6.7:** Tensile strength of sago particleboard versus matrix with different loading.

### 6.2.8 Impact strength of sago composite particleboard with different loading of UF and PF matrix

Figure 6.8 represents the impact properties of UF and PF sago composite particleboard. The result showed that UF had better impact strength than PF. This was because UF had better fiber-matrix bonding compared with PF (Dungani *et al.*, 2014). UF had better interfacial interaction between the fiber and matrix. Hence, this reduced the pores in the

UF sago particleboard and enhanced the impact properties. This showed that UF penetrated well into the sago particles and caused the material better resistance to withstand fracture when undergoing stress at high speed.

UF showed better impact strength properties compared with PF. The increment of UF loading into the sago composite particleboard had strengthened the particleboard. This was due to impregnation of UF into the cell membrane resulted harder structure in composite particleboard (Yue *et al.*, 2016).

UF did not show high impact strength at 90wt% sago loading. This was due to the poor dispersion of particles in the matrix which led to weak stress transfer from matrix to particles when load was applied. High fibers loading caused difficulties for matrix in flowing through and led to weak stress transfer from the matrix to the fibers (Charles *et al.*, 1977). According to Dungani *et al.* (2014), the impact failure of the composite might be caused by matrix fracture, fiber/matrix bonding, and fiber pull-out (Dungani *et al.*, 2014).

PF showed the decreasing impact strength due to the increased resin loading. At 10 wt% loading of PF, it showed the highest value of impact strength due to the high interfacial interaction between the fiber and matrix. This caused the greatest impregnation of PF within the pits or pores in the particleboard and enhanced the impact properties (Abdul Khalil *et al.*, 2010). The higher resin loading of PF did not promote better impact strength because it imparted brittleness to the composite material and caused the material not able to resist the fracture under the stress applied with high speed efficiently. Besides, there were disruptions in the homogeneity of matrices such as a tendency to form agglomerates and this caused the loads could not transmit effectively between particles. Moreover, low loading levels of fiber at 80 wt% fiber + 20 wt% PF matrix had higher degree of critical defects to the composite structure with voids and poor bonded interface region (Sebe *et al.*, 2000). Such defects had reduced the impact strength.

PF matrix with higher loading of fiber had better impact strength. This was because higher loading of fiber could reinforce cellulose, counterbalances the defects, and improved the toughness (Sebe *et al.*, 2000). On the other hand, PF at higher loading of fiber repaired the weak boundary between the particles and increased the ability of absorption energy.

Besides, the stress transfer in the sago particleboard depended on the physical and chemical bonding of the matrix and fibers (Dungani *et al.*, 2014). Factors such as nature of the constituent materials, fiber-matrix interface, construction and geometry of particles highly influenced the impact properties (Jawid *et al.*, 2011). Low impact strength could be due to the presence of many preexisting micro compressive defects along the fibers (Sebe *et al.*, 2000). These defects would form small kinks in the microfibrillar structure and the presence of crystalline regions in the cell wall (Sebe *et al.*, 2000). The internal voids and local defects in the particles had caused the weak bonds between the particles and matrix. This had introduced the delamination and reduce the energy absorption.

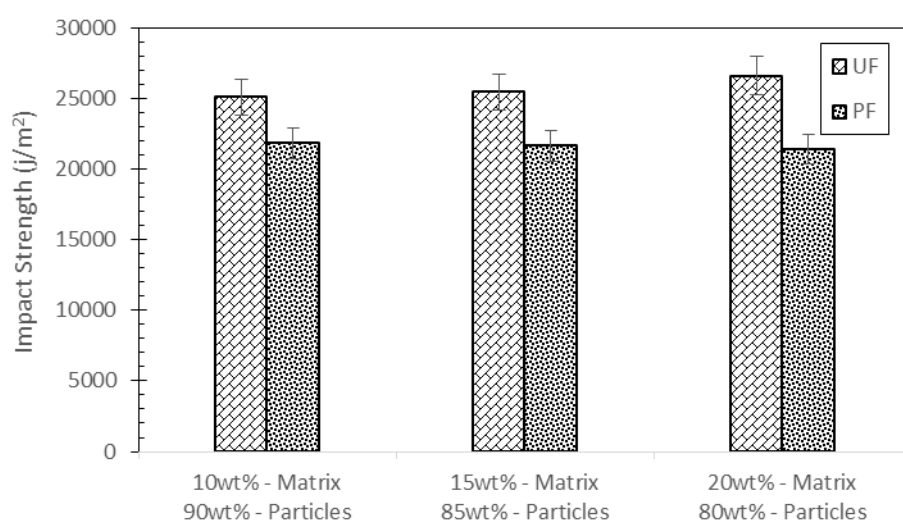


**Figure 6.8:** Impact strength of sago particleboard versus matrix with different loading

### 6.2.9 Thermogravimetric Analysis (TGA) of sago composite particleboard

The evaluations of thermal behavior of sago composite particleboard with different matrix were important in the determination of the limit of their service temperature under environmental condition. Figure 6.9 and Table 6.1 showed the details of the decomposition of the sago composite particleboard. Sago composite particleboard with PF showed the highest weight loss initially compared to sago composite particleboard with UF because of its fixed moisture. Since PF matrix had lower percentage of the solid content from the original, it took longer time than UF matrix to remove the moisture. PF sago particleboard involved the evaporation of water and had high volatility at around 53.5 °C-166.7 °C, while the water evaporated from the UF sago composite particleboard at around 53.5 °C-158.7 °C.

The second step of the PF sago composite particleboard decomposition was produced at 295.4 °C within the temperature range of 170.4 °C to 594.9 °C, with 60.45% of weight loss. The pyrolysis of sago as well as PF components was completed at about 595 °C. It was believed that the pyrolysis residue of sago particles and PF decomposed slowly until the end of the process (Adachi *et al.*, 2009). PF sago composite particleboard corresponded to degradation, where sago degraded to hemi- cellulose, cellulose, and lignin while PF degraded to carbon, hydrogen, and oxygen. The second peak temperature in this study at 295.4 °C was attributed to the cross-links that were formed and small exposed groups of the cured resin were removed. The condensation reactions between functional groups of the cured PF adhesive could cause additional cross-links. The condensation reaction was between phenol and methylene group to form a carbon- hydrogen cross-link. The methylene bridges were decomposed or broken into methyl groups with the formation of both phenols and cresols (Emmanuel *et al.*, 2011).

For UF sago composite particleboard, levoglucosan is the main constituent of decomposed products besides water, urea, and formaldehyde (Moubarik *et al.*, 2010). The

thermal degradation began at 174.5 °C to 544.4 °C, after the materials had absorbed certain amounts of heat energy. The heat initiated the degradation process which broke down the structure and caused the molecular chain ruptures (Moubarik *et al.*, 2010). For the UF, the most probable phases formed during the second step of decomposition were water, carbon dioxide, and carbon (Moubarik *et al.*, 2013).

PF sago composite particleboard had higher thermal stability than UF sago particleboard. This was related to high crystallinity index and the characteristic structure of layers in a polymer matrix which were close to molecular level that possessed high thermal stability (Chaharmahali *et al.*, 2010; Amini *et al.*, 2013). PF sago particleboard took longer heating time and higher temperature to increase the decomposition without changing the structure or losing strength (Amini *et al.*, 2013). PF sago particleboard had higher percentage of residue compared with UF sago particleboard. The residues of PF and UF sago particleboard were 34.66% and 19.92%, respectively. PF adhesive was slightly more resistant to extreme temperature at 800 °C (Emmanuel *et al.*, 2011). The highest weight loss temperature of PF and UF sago particleboard was 295.4 °C and 311 °C in which UF was lower than PF by 15.7 °C.

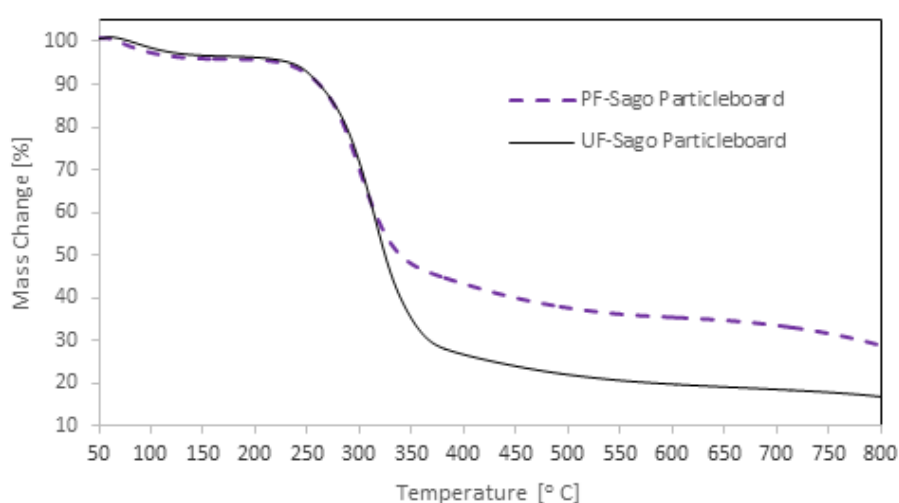


**Figure 6.9:** TGA of PF and UF sago composite particleboard.

**Table 6.1:** Results for sago composite particleboard with different matrix analysis by TGA.

| Matrix | Temperature peak (°C) | Weight loss (%) | Residues (%) |
|--------|-----------------------|-----------------|--------------|
| PF     | 69.58                 | 4.89            | 34.66        |
|        | 295.39                | 60.45           |              |
| UF     | 80.40                 | 4.25            | 19.92        |
|        | 311.04                | 75.83           |              |

#### 6.2.10 DSC of Sago Composite Particleboard

Figure 6.10 shows the DSC thermogram of sago composite particleboard with different matrix. Sago composite particleboard with PF matrix had the highest melting temperature of 75.5 °C compared to particleboard with UF matrix that was only 73.3 °C. The particleboard manufactured with PF matrix had a higher melting temperature due to the cross-linking reaction with epichlorohydrin that occurred in sago particles (Sulaiman *et al.*, 2013). This led to better interaction between sago particles with the PF matrix. Thus, more heat was needed to complete the melting process.

Sago composite particleboard with UF had higher curing characteristics peak, thus giving rise to a wide exothermic peak (Singha *et al.*, 2008). Research had found that sago composite particleboard with UF required a low curing temperature and short press time. PF required a higher curing temperature and long pressing time (Wood Utilization , 2012).

Sago composite particleboard made by UF matrix showed multi exothermic peaks and these could be due to the methylation and condensation reaction (Emmanuel *et al.*, 2011). Methylation is a nucleophilic which involved the addition of formaldehyde to urea ring while the condensation was the cross-link (cure) reaction by methylolated urea into polymer molecules.

PF matrix had the highest viscosity compared to UF and was difficult to achieve an efficient distribution in the particleboard. According to Emmanuel *et al.* (2011), PF with higher viscosities could be warmed at 40 °C to give acceptable spraying properties on particles.

During the manufacturing process, the phase change for the PF matrix from homogenous to heterogeneous occurred when it was mixed with cellulose from sago particles. The cellulose from the sago particles change the PF matrix from a continuous phase to a dispersive one. In a homogenous PF curing system, the PF molecules formed a large cross-linked network. However, it was possible that the addition of cellulose to PF system resulted in a barrier to the PF cure. This caused the PF oligomers molecules to have unrestricted space to polymerize completely and achieved the maximum reaction enthalpy. With addition of cellulose, the polymerization might be restricted by the distance between cellulose polymers resulting in lower reaction enthalpy and maximum curing temperature (Emmanuel *et al.*, 2011).

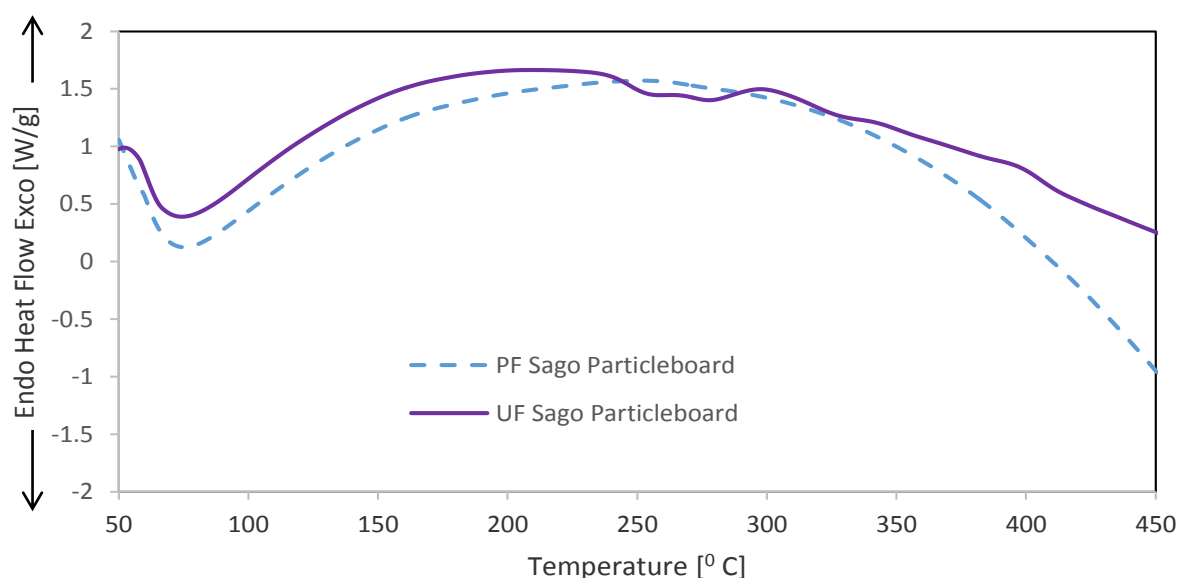


**Figure 6.10:** DSC of PF and UF sago composite particleboard.

### 6.2.11 Fourier Transform Infrared (FTIR) Spectroscopy Analysis Of Sago Composite Particleboard

The formulation of UF sago composite particleboard was analyzed using FTIR. Figure 6.11 depicted the infrared (IR) spectra of sago particles and Figure 6.12 was the urea formaldehyde. Figure 6.13 showed the combination sago with urea formaldehyde. The FTIR had proved that sago composite particleboard had better bond between sago and UF. The C-O-C vibration stretching of  $\beta$  for cellulose I and II at  $1026\text{ cm}^{-1}$ ,  $1149\text{ cm}^{-1}$  and  $1238\text{ cm}^{-1}$ , OH stretching in cellulose at  $1546\text{ cm}^{-1}$  and OH bond stretching vibration of  $\alpha$  - cellulose at  $3743\text{ cm}^{-1}$  (Sim *et al.*, 2012). This had proved high content of cellulose in sago composite particleboard. The cellulose had better bonding between the urea formaldehyde compared to lignin and hemicelluloses and improved the mechanical bond strength of the particleboard (Eike *et al.*, 2016). The mechanical properties of sago composite particleboard were related with the high content of cellulose. The absorption bands of sago composite at  $1462\text{ cm}^{-1}$  had proved  $\text{CH}_2$  methylene bridge to be reflection of cellulose to UF polymer interaction (Emmanuel *et al.*, 2011). The interaction between cellulose and UF caused the sago composite particleboard to have better mechanical properties. In sago composite particleboard, the peak  $1425\text{ cm}^{-1}$ ,  $1462\text{ cm}^{-1}$ ,  $1514\text{ cm}^{-1}$  were attributed as lignin. UF did not formed better bond with lignin.

Figure 6.12 shows the OH group at  $2800\text{-}3800\text{ cm}^{-1}$ . In the sago composite particleboard with UF, the OH peak had been reduced by chemical reaction between sago particles and UF. This reduction may be ascribed to the consumption of OH groups during condensation reaction. The C=C, C=O, N-H, C-O-C, C-H and  $\text{CH}_2$  band of sago and UF all shifted to different frequency, because of poly condensation. These observations indicated a chemical reaction between sago particles and UF matrix. As results, the OH groups in sago composite particleboard had been reduced and increased the mechanical strength.

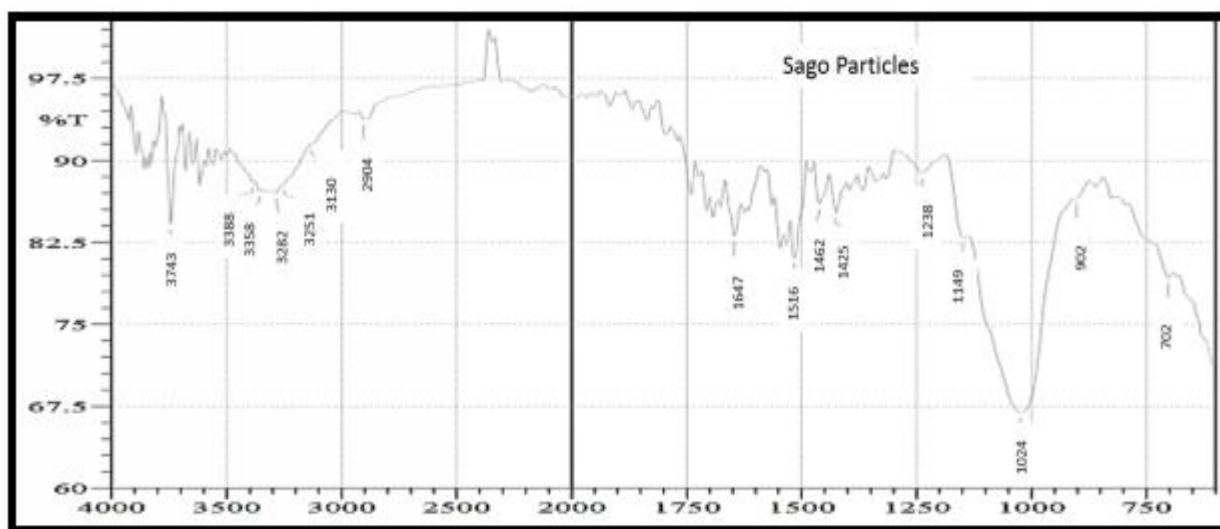


Figure 6.11: FTIR of sago particles.

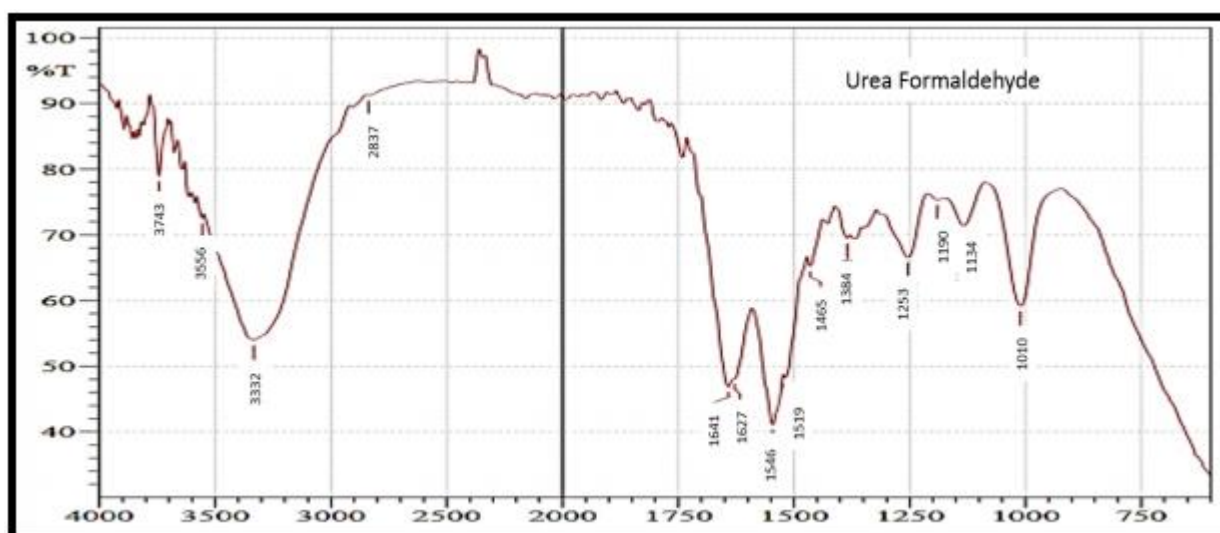


Figure 6.12: FTIR of urea formaldehyde.

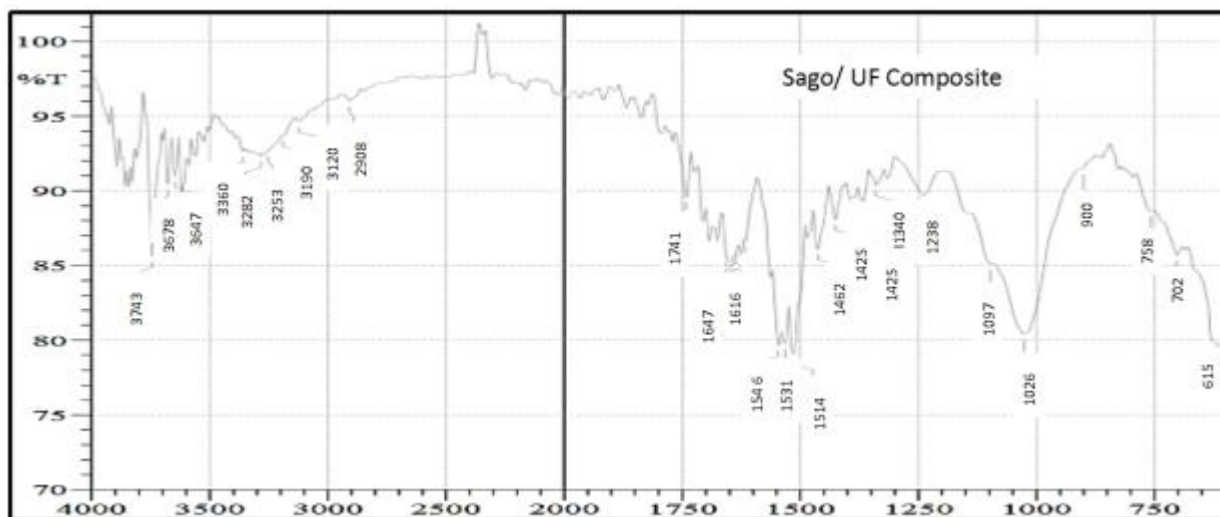


**Figure 6.13:** FTIR of sago composite particleboard.

Figure 6.15 shows the interaction between sago and phenol formaldehyde in sago composite particleboard. Sago composite particleboard with 10 wt% and 15 wt% of phenol formaldehyde had better bending strength, internal bonding and screw test compared with urea formaldehyde. This was due to phenol formaldehyde had better bonding with cellulose and lignin. The interaction between cellulose and PF were associated with CH<sub>2</sub> and CH functional groups. This reflected that the interaction between cellulose and PF at 1327 cm<sup>-1</sup>, 1425 cm<sup>-1</sup>, 1693 cm<sup>-1</sup> and 2906 cm<sup>-1</sup>.

The peak at 1425 cm<sup>-1</sup>, 1462 cm<sup>-1</sup>, 1517 cm<sup>-1</sup> were attributed as lignin. The ability of phenol formaldehyde to capture more loads before the adhesive broken apart was probably due to the presence of lignin and phenol. Lignin had an aromatic and highly cross-linked structure, similar to the network of PF adhesive (Ibrahim *et al.*, 2007). During the reaction, some ortho or para-hydroxymethyl phenol would react with ortho hydroxymethyl lignin to produce a network polymers of lignin-phenol-formaldehyde (Emmanuel *et al.*, 2012). Further reaction would lead to the formation of methylene bridges and water elimination. The

addition of cellulose and lignin to PF was attempted to increase sago composite particleboard elastic modulus and strength (Emmanuel *et al.*, 2012).

Figure 6.14 showed phenol formaldehyde with the OH group at 2800-3800  $\text{cm}^{-1}$ . In the sago composite particleboard with PF, the OH peak had been reduced by chemical reaction between sago particles and PF. This reduction might be ascribed to the consumption of OH groups during condensation reaction. As results, the OH groups in sago composite particleboard had been reduced and increased the mechanical strength.

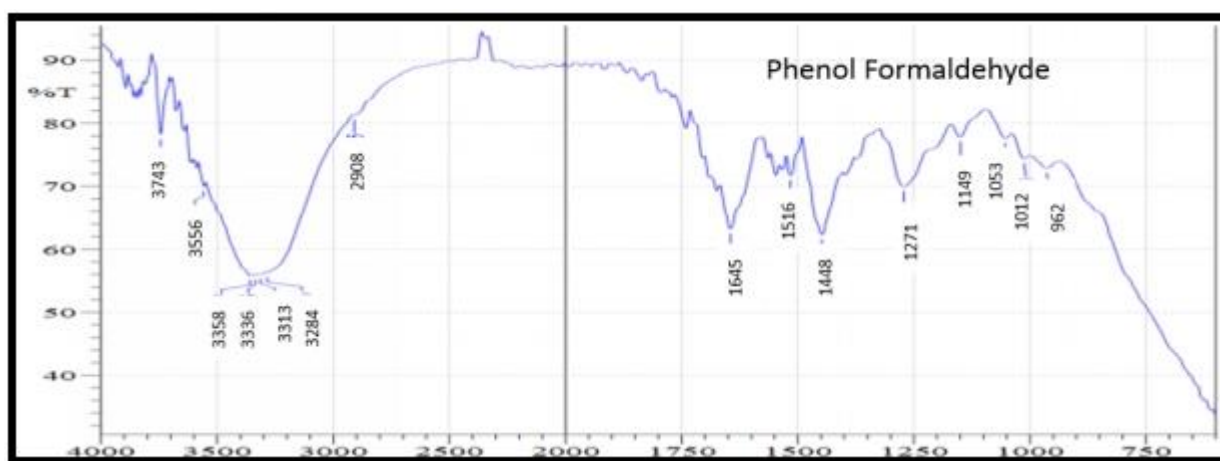


**Figure 6.14:** FTIR of phenol formaldehyde.

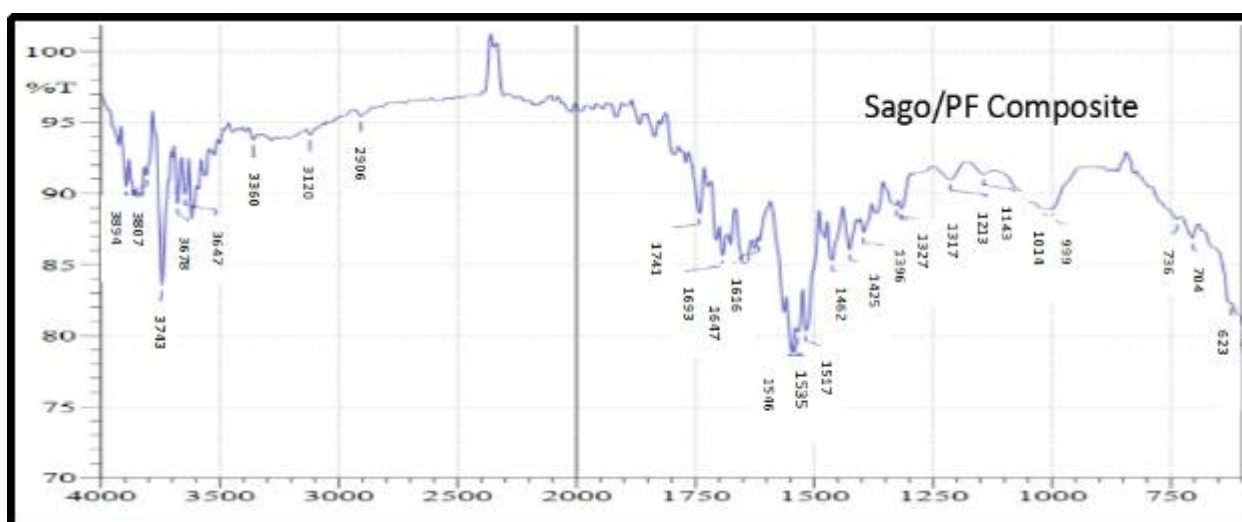


**Figure 6.15:** FTIR of sago composite particleboard with PF.

### 6.2.12 Morphological Study

The morphological analysis of tensile fracture surface of sago composite particleboard was shown in Figure 6.16. The SEM image of sago composite particleboard showed agglomeration of sago particles and could be seen clearly that the roughness and void existed between particles and UF. The debonding had indicated that there was no bonding between the particles and matrix and created the voids between the particles (Sarifuiddin *et al.*, 2013). Improper bonding formed due to the surface roughness from the incompatible blend of different size of the particles. The features indicated that there were poor dispersion and weak interfacial bonding between the matrix and particles which confirmed that the interfacial bonding between the particles and matrix was poor and weak. The immiscibility of the particles caused the weak interfacial adhesion and starch granules tend to agglomerate and resulted in low strength. Exist of voids had caused the moisture to penetrate in to the sago composite particleboard and reduced the mechanical strength.

The best dispersion and interfacial bonding was observed in the Figure 6.16 (a). The incorporation of UF binder strongly reduced the surface roughness and voids spaces in sago composite particleboard. This had increased the phase compatibility and adhesion between the particles and UF matrix, thus significantly increased the surface morphology and affected the mechanical behaviour of final product.



(a)

(b)

(c)

**Figure 6.16:** UF sago particleboard (a) Particle bond with the UF matrix (b) and (c) Boundary of the particles/void/de-bonding

### 6.3 Summary

In this study, it was clear that sago composite particleboards with different matrix and loading had an impact on the mechanical, physical, and thermal performances. The boards' strength was enhanced when the resin loading increased, but this was only applicable to certain percentage where the strength would drop after the optimum. From the TGA/DSC study, it could be concluded that sample with PF sago particleboard had better thermal stability and denser in structure while the UF sago particleboard had better curing properties. The results showed that the resin content had significant effects on the water adsorption and thickness swelling expansion. The findings showed that the new application for sago composite particleboard could be utilized as a raw material in particleboard manufacturing.

## CHAPTER 7

# SAGO/UREA FORMALDEHYDE COMPOSITE PARTICLEBOARD: EFFECT OF DENSITY TOWARDS ITS PHYSICAL, MECHANICAL AND THERMAL PROPERTIES

### 7.1 Introduction

Composite particleboard is a panel product manufactured under pressure from particles of ligno-cellulosic materials with an adhesive (Enayati *et al.*, 2013). It is widely used for construction, furniture, and interior decoration. Composite particleboard properties are strongly influenced by structural factors such as the board compression ratio, board density, adhesives type and content, and others.

Board density is one of the most important factors affecting the properties of particleboard (Mehanička *et al.*, 2016). It is known that an increase in board density leads to improved mechanical properties of particleboards. There is a high correlation between board properties and the density

Onuorah *et al.* (2011) mentioned that board density is the most important furnish variable to control the property of particleboard. Higher compression leads to greater contact between particles and more efficient adhesive utilization. This leads to a greater capacity to transmit loads between the particles, resulting in higher mechanical properties. According to Ajayi *et al.* (2008), the greater compression ratio and bonding within high density board enable the high strength to be achieved. By Increasing the board density, compression rate and contact between lignocellulose materials is increased (Eslah *et al.*, 2012). Chai *et al.* (2009) stated that board with higher density contains more particles which reduces voids due to compaction and thus, enhance the mechanical strength.

A panel with the higher density had significant effects on the mechanical properties (Akgul *et al.*, 2007). The board properties are greatly dependent on the board density. The higher density is usually associated with higher strength properties (Kasim *et al.*, 2001). Yang *et al.* (2014) proved that the effect of density and structure had great influence on MOR where MOR increased with density. According to Hazwani *et al.* (2014) and Abdullah *et al.* (2013), IB will increase with board density due to the higher compaction ratio in the board. Cai *et al.* (2004) and Jani saad *et al.* (2012) stated that face screw withdrawal resistance was highly associated with panel density. The ability of boards to hold the screw improved as the board density increased due to better interfacial bonding of the fibers. Furthermore, hydrophilic properties of sago will cause the problem in dimensional stability, lower durability to termite attack, and lower mechanical properties of the board that made up by sago residues.

Therefore, the objective of this work is to investigate the effect of board density on the morphological, thermal stability, mechanical and physical changes of a composite particleboard.

## **7.2 Results and Discussion**

### **7.2.1 Density Profile of Sago Composite Particleboard**

The density profiles along the thickness of new panels made from sago particles with urea formaldehyde, obtained from X-ray attenuation, showed variations in the structure of the panel, at different levels, depending on the sample thickness. This provides important information on quality and mechanical properties of panels, leading to the knowledge of the setting of the pressing conditions and indications of its technological performances, expanding the possibilities of diagnostic parameter of raw materials and new panel manufacturing process (Belini *et al.*, 2014).

Figure 7.1 shows different density gradients observed for panels with different mean densities. It is understood that the density profile of a board strongly influenced the mechanical, physical and thermal properties. Based on the density profile, the density of a mat-formed particleboard is not uniform throughout the board itself. The skewed density profiles were due to uneven sanding of the board after manufacturing (Wu *et al.*, 2001). Density profile of a board was highly dependent on the particle configuration, moisture distribution, pressing time, temperature of the hot press, reactivity of the resin and the compressive strength of the component of the sago particles (Cai *et al.*, 2004). Most of the particleboards have higher density at the top and bottom regions compared to the core as these regions were exposed directly to the heat from hot-press plates (Ihak *et al.*, 2014). When the rate of heat conduction from top and bottom plates is controlled, moisture dried up and hardens the sago particles especially on the surface of the board. This produced a layer with higher densities at the top and bottom of the board as there is less compression in the core layer. At the same time, the initial rapid press closing speed generated a higher pressure to the mat, which only allows a shorter time of heat and moisture to be transferred into the core layer resulting in a lower density of the core.

Sago composite particleboard with density  $800 \text{ kg/m}^3$  has a uniform density profile and was found to possess homo-profile properties. Wong *et al.* (1999) explained that homo-profile boards have a significant influence on the mechanical test and correlated with the board mean density. This can be due to a higher density closer to the surface that increases the flexural strength.

Sago composite particleboard with density  $500 \text{ kg/m}^3$  was found to have a U shape density profile (Cai *et al.*, 2004). This is due to higher moisture content within the fine particles on the panel surfaces. Moisture in the top and bottom of the board dried up

completely by the hot-press heat. The higher initial pressure with short closing time during the hot pressing process resulted in higher face of density (Nirdosha *et al.*, 2006).

Sago composite particleboard with 600 kg/m<sup>3</sup> and 700 kg/m<sup>3</sup> have an M shape profile and categorised as a conventional particleboard (Wu *et al.*, 2001). The M shaped density profile is produced when the closing speed decreased. A long press closing time helps to facilitate stress relaxation in a board before the final thickness is achieved. With a longer press closing time, the adhesive will polymerize on the surface before sufficient inter-particle contact occurs inside the board. Other factors such as heat, moisture transfer and resin cure are also affected by the change in press closing speed (Miyamoto *et al.*, 2002).

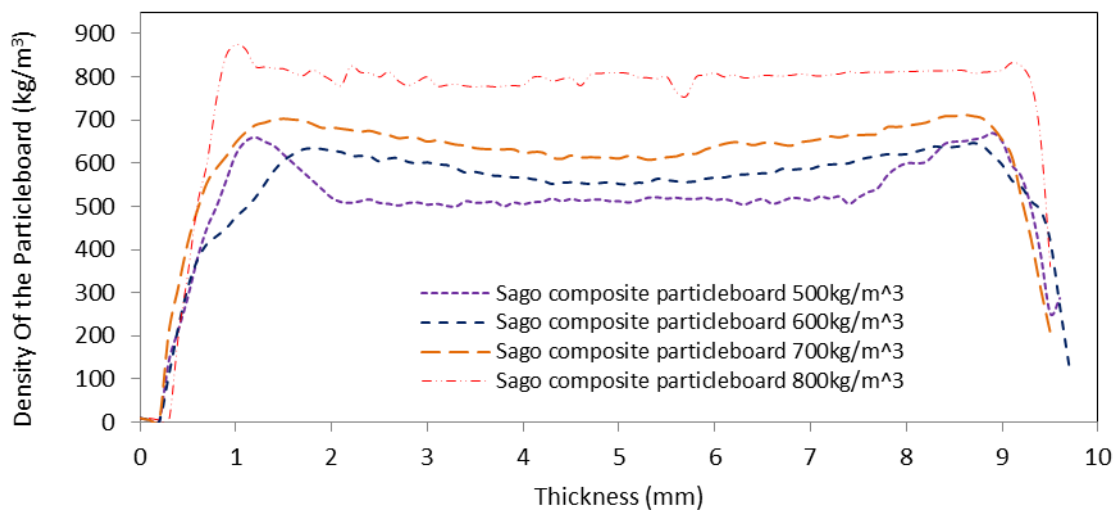


**Figure 7.1:** Density profile of the sago composite particleboard with different density.

### 7.2.2 The effect of density on water absorption (WA) of sago composite particleboard

Figure 7.2 showed the effect of density with rapid uptake of water over the first 2 hours due to the hydrophilic nature of the cellulosic materials, enabling the composites to take up a high amount of water. Water absorption increased with the immersion time.

The highest water absorption was obtained in sago composite particleboard with 500 kg/m<sup>3</sup> while board with 700 kg/m<sup>3</sup> had the least. The highest percentage of water absorption in board with 500 kg/m<sup>3</sup> is attributed to loosen packing in particleboard and created void in the boards which allowed more water intake compared to board with 700 kg/m<sup>3</sup> (Sotannde *et al.*, 2012). In low density particleboard, the highly porous structure of the board allows water to penetrate into the board and increased the water uptake, resulting, in high water absorption at the same time and caused the board to swell (Jani *et al.*, 2012). This had caused higher water absorption in low density particleboard than the high density particleboard due to the presence of voids inside the particleboard (Ihak *et al.*, 2014). The formation of micro-channels, which contribute to the high water absorption, provide a way for water to pass through pores on the surface of the particles. This had caused the water to enter the particleboard easily through the pores and absorbed by polar OH groups of sago particles. This leads to a rise of water absorption and weight gain in the particleboard. The water absorption behaviour of natural fibres also depends on free hydroxyl groups present in cellulose and hemicelluloses, which are accessible by water (Khalil *et al.*, 2011).

Sago composite particleboard with 700 kg/m<sup>3</sup> was compressed in good order with high compatibility had reduced the voids content which caused the least water uptake and has better barrier for water entry. This shows that the packing and arrangement of particles limit the absorption of moisture into the particleboard, because the voids have been filled up during the formation of composite particleboard (Khalil *et al.*, 2011). Higher compaction ratio implies that more compressive deformation has been imparted onto the particles during hot

pressing. Particles were under greater compressive set and caused the void formation to be reduced. Hence, lessening the water absorption property (Jani *et al.*, 2012).

Sago composite particleboard with 800 kg/m<sup>3</sup> had the highest water absorption compared to board with 700 kg/m<sup>3</sup> because more water aborted by its large volume of particles which is to equalize the target board density (Nurhazwani *et al.*, 2016; Juliana *et al.*, 2012). A board that are not properly bonded with UF and particles will expand further and allow the water penetration and absorption increased when submerged in water (Nurhazwani *et al.*, 2016; Juliana *et al.*, 2012).

Based on the report by Jani and Kamal (2012), hygroscopic expansion can be affected by various factors of the resin, such as the monomer, polymerization rate, cross-linking and pore size of the polymer network, bond strength, interaction between polymer and water, filler and resin filler interface (Jani *et al.*, 2012).

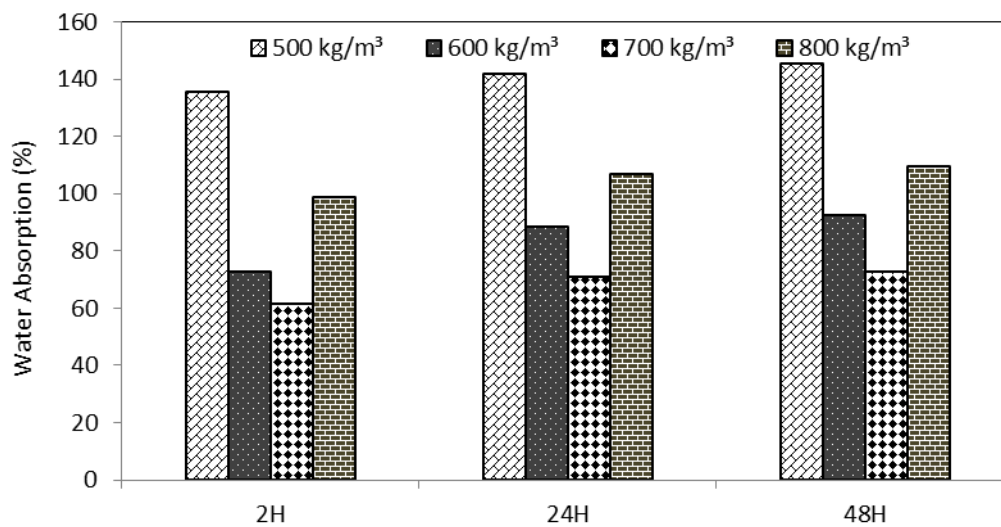


**Figure 7.2:** Effect of density on water absorption of sago composite particleboard.

### 7.2.3 The effect of density on thickness swelling (TS) of sago composite particleboard

Figure 7.3 shows the thickness swelling of sago composite particleboard at different density with immersion time. The highest thickness swelling (TS) was found in sago composite particleboard with 500 kg/m<sup>3</sup>. Sago composite particleboard with 700 kg/m<sup>3</sup> had the lowest thickness swelling compared to the other specimens.

The presence of more irregular void spaces in board with 500kg/m<sup>3</sup> had enhanced water absorption and thickness swelling (Sotannde *et al.*, 2012). Uncompacted particleboard has developed a lot of voids in between the particle during the formation. Thus, this will increase the number of micro voids caused by the large amount of poor bonded area between the hydrophilic filler and the hydrophobic matrix polymer and weaken the particle/matrix adhesion in nature (Alireza, 2010).

When density increased, the porosity decreased. This had proven at particleboard with 700 kg/m<sup>3</sup>. In addition, when particleboard's density increased from 500 kg/m<sup>3</sup> to 700 kg/m<sup>3</sup>, stronger connections are produced due to the higher contact area between the particles and their higher overlap (Morteza *et al.*, 2016). This increased the internal bonding strength and finally, the particleboard's thickness swelling decreased. The thickness swelling of sago composite particleboard was influenced by the quantity and distribution of adhesive and panel compatibility (Apri *et al.*, 2014)

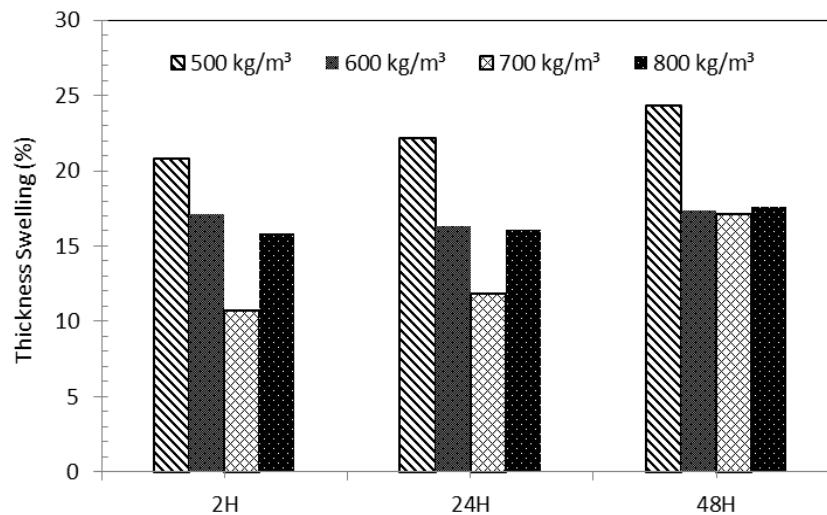


**Figure 7.3:** Effect of density on thickness swelling of sago composite particleboard.

#### 7.2.4 The effect of density on bending strength of sago composite particleboard

Figure 7.4 shows the effects of board density on the bending strength of sago particleboards. Based on the experiments, the bending strength shows a significant increase when the board density increased from 500 kg/m<sup>3</sup> to 800 kg/m<sup>3</sup>. The results show sago composite particleboard with 800 kg/m<sup>3</sup> had the highest bending strength, whereas sago composite particleboard with 500 kg/m<sup>3</sup> shows the lowest bending strength.

Sago composite particleboard with 800 kg/m<sup>3</sup> shows the highest bending strength value because the particles and the matrix of the board have a better bonding. Therefore, the number of void spaces of sago composite particleboard at 800 kg/m<sup>3</sup> is reduced and resistance to rupture is enhanced. This can be attributed to the greater compression ratio and better particles bonding within boards, leading to a better contact area between the resin and sago particles which had resulted in high strength properties (Hazwani *et al.*, 2014; Eslah *et al.*, 2012; Ajayi *et al.*, 2008). This had caused the higher packing of particles available to distribute stresses well.

Sago composite particleboard 500 kg/m<sup>3</sup> has the lowest bending strength value due to the porous structure of the specimen and the reduction in the inter particles contact area which had resulted in the formation of weaker bonds (Ajayi *et al.*, 2008). The voids had increased the hydroxyl groups to penetrate into the sago composite particleboard and reduced the bending strength (Leng *et al.*, 2017).

The bending strength value increases when the density increased from 500 kg/m<sup>3</sup> to 800 kg/m<sup>3</sup>. This is because the areas of stress concentration around the component particles are more diffused when the sago particles occupy more volume in the board which resulted in increased applied stress (Sotannde *et al.*, 2012). The molecules have less room to displace with the same force as the material becomes denser thus, leading to a higher stiffness (Paul *et al.*, 2006). An increase in the bending strength may be due to the higher density in the face layer compared to others (Cai *et al.*, 2004).

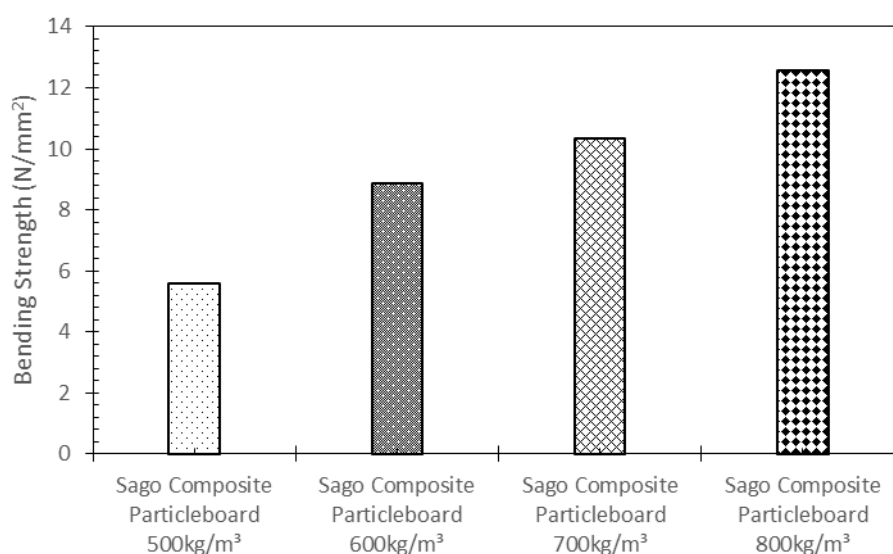


**Figure 7.4:** Effect of density on bending strength of sago composite particleboard.

### 7.2.5 The effect of density on internal bonding of sago composite particleboard

Figure 7.5 shows that density has significant effects on the internal bonding strength. Sago composite particleboard with  $800 \text{ kg/m}^3$  has the highest internal bonding strength while sago composite particleboard with  $500 \text{ kg/m}^3$  has the least. The internal bonding of particleboard is directly influenced by board density.

Sago composite particleboard with  $800 \text{ kg/m}^3$  had proved that by increasing the board density, the internal bonding strength also increases and this is similar to observations made by other researchers (Kasim *et al.*, 2001). The higher compaction ratio at higher density had increased the strength and resulted in harder panels (Akgl *et al.*, 2007; Kasim *et al.*, 2001). This was due to the increase of the compaction of sago composite particleboard which created better contact and stronger connections between particles. Besides, the empty spaces decreased and particles are more connected to each other; therefore, more heat transfer to the core of the board. This had caused the particles to become softer and compact due to increase in the heat transfer rate and the resin is polymerized well in the core. Thus, the internal bonding increased due to effective bonding to resist begging pull apart.

According to Eslah *et al.* (2012), board density is one of the important factors which will affect the properties of particleboards; denser panel results in higher mechanical properties (Eslah *et al.*, 2012; Akgl *et al.*, 2007). Furthermore, it provides better quality of inter-particle contacts under compression (Arabi *et al.*, 2011).

Sago composite particleboard with  $500 \text{ kg/m}^3$  causes the internal bonding strength to reduce because of low compaction leading to the formation of voids. The low density had caused insufficient contact area for effective bonding to resist the tensile forces applied during the internal bonding test. Low density of sago composite particleboard causes the internal bonding strength to reduce because the availability of adhesive per particles in the board had

reduced (Scatolino *et al.*, 2013). The matrix failed to wet the particles for bonding and resulted in the strength reduction of the board.

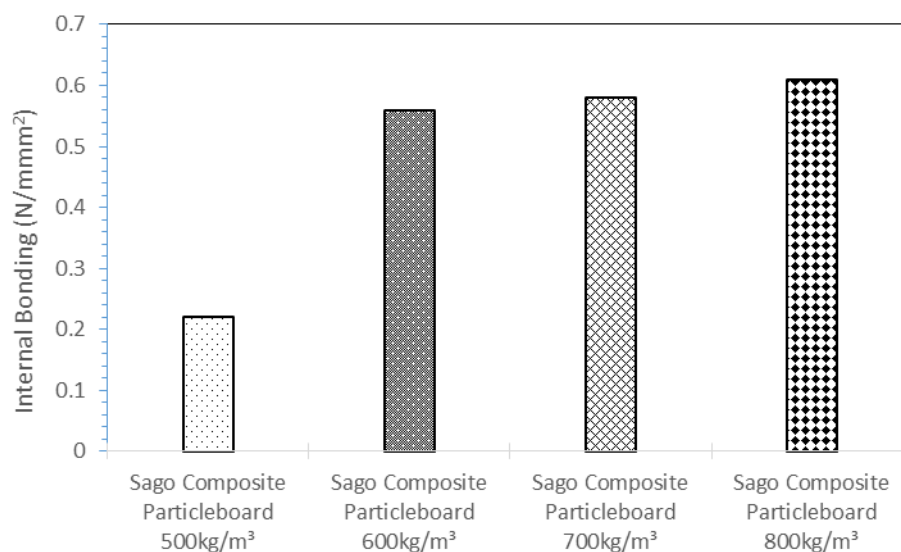


**Figure 7.5:** Effect of density on internal bonding of sago composite particleboard.

#### 7.2.6 The effect of density on screw withdrawal of sago composite particleboard

The screw withdrawal test is commonly used to determine the fastening quality of the composite particleboard. Figure 7.6 shows the screw strength of the particleboards at different density. Overall, sago composite particleboard with 800 kg/m³ has the highest screw holding ability. The experiment shows that panel density has a significant impact on the performance of the screw holding power (Cai *et al.*, 2004). The screw holding ability increased with the density of the panel (Vassilion *et al.*, 2005; Kasim *et al.*, 2001). Sago composite particleboard with 800 kg/m³ had better performance on screw holding ability compared to the particleboards with the lower density. This is due to the particleboard with higher density had formed a good structure order. The structure of the panel was the most important factor in the fastener holding capacity. The high compatibility caused the sago particles to bond well with the UF matrix in a more effective way and had increased the bonding strength between the particles and matrix for uniform density distribution. The efficient of uniform density

distribution indirectly increased the densification of core panel which increased the ability of the boards to hold the screw securely when the screw was being pulled out (Jani *et al.*, 2012). It was discovered that the screw withdrawal resistance is strongly associated with the board density. As the density increased, the particles and matrix loading had strengthened the mechanical performance of the board (Jani *et al.*, 2012).

Sago composite particleboard with  $500 \text{ kg/m}^3$  has lowest screw strength due to the loose packing structure in board and reduced the ability of boards to hold the screw securely. Generally, fasteners driven in low density zones easily to fail at lower load levels than those driven in high density zones.

The screw withdrawal is affected by other factors such as screw geometry, depth of penetration into particleboards, particle grain direction, moisture content, raw material and rate of loading during the test (Jani *et al.*, 2012; Vassilion *et al.*, 2005; Cai *et al.*, 2004).

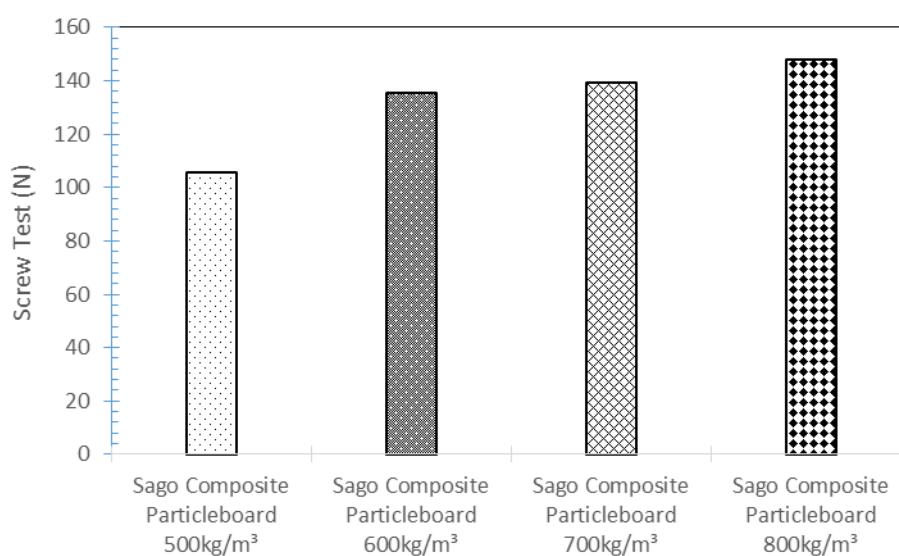


**Figure 7.6:** Effect of density on screw test of sago composite particleboard.

### **7.2.7 The effect of density on modulus of elasticity (MOE) of sago composite particleboard**

The MOE result for each of the sago composite particleboard with different density is summarized in Figure 7.7. Based on the result, the MOE increased linearly with particleboard density. The increase in strength properties is associated with a higher compaction ratio at higher density which had created well-bonded boards and resulted in harder panels (Cai *et al.*, 2004 & Kasim *et al.*, 2001). Sago composite particleboard with 800 kg/m<sup>3</sup> has the highest MOE while 500 kg/m<sup>3</sup> shows the least.

Sago composite particleboard with 800 kg/m<sup>3</sup> has better MOE compared with the others. This was due to higher volume of resin applied leading to increased resin bonding for better strength and increased the interfiber bonding. The presence of polar group in the resin may contribute to electrostatic adsorption between resin and particles. This had strengthened the board interface and hold them together and increased their resistance to deformation during the test. The contact area between the particles increased and the performance of the connection area of glue improved which had created higher crosslink density compared to lower density in the particleboard (Morteza *et al.*, 2016). On the other hand, the additional volume of sago particles increased the stiffness of the composite particleboard and has better distribute stresses during the test. According to Jani and Kamal (2012), the higher stiffness will lead to higher MOE of the boards. Particleboards tend to be brittle when the MOE value is higher due to the higher addition of resin into the board and tend to be ductile or flexible when the value is low. This is expected to influence the overall stiffness of the board.

Low density particleboard has lower MOE strength because the bonding between particles and matrix was weaker due to the loose structure in the board (Leng *et al.*, 2017).

MOE is also influenced by factors like fibre composition, fibre morphology, fibre dispersion, distribution of fibre in the whole volume of the material and fibre-matrix interface quality in the whole composite (Fabrice, 2012).

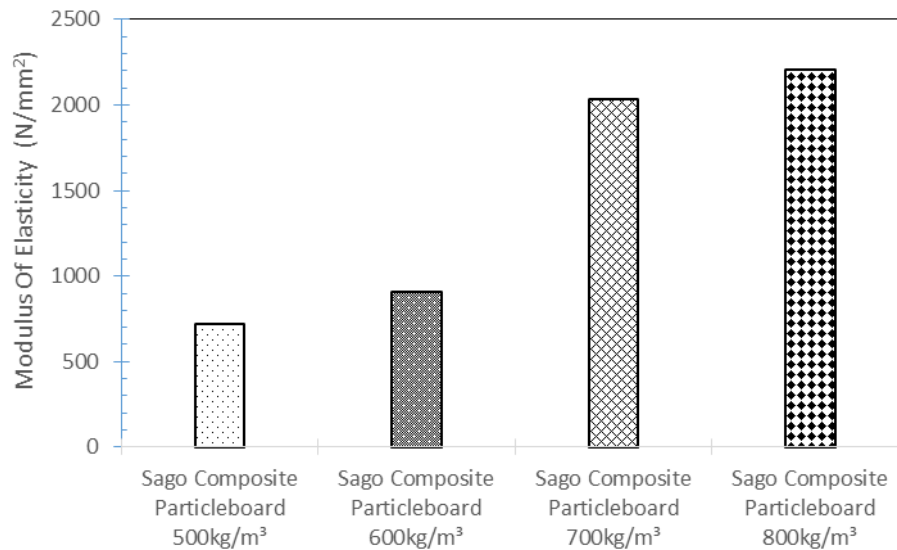


**Figure 7.7:** Effect of density on modulus of elasticity of sago composite particleboard.

### 7.2.8 The effect of density on tensile strength of sago composite particleboard

Figure 7.8 shows the density had great influence on the tensile strength. The tensile strength increased with the density of the particleboard from 500 kg/m³ to 800 kg/m³. Nwanonenyi *et al.*, (2013) also reported that increased density of composite led to increase in tensile strength.

Sago composite particleboard with 800 kg/m³ had the highest tensile strength performance while board with 500 kg/m³ had the least. When density increased, the compatibility between the fibre and matrix was increased and led to an increase in the strength of composite particleboard. When the density increased, it was found that the average pore size decreased. The number of pores per unit area increased slightly and the pores became less interconnected. The high compatibility caused the fibre to transfer the stress between the matrix more effectively. Therefore, the particleboards had better stress

concentration and managed to withstand higher stress while being stretched or pulled before failure. Besides, the high compression had strengthened the interfacial bonding between the particles and matrix, which resulted in good stress propagation and improved the tensile strength (Atuanya *et al.*, 2011).

Lower density particleboards have high level of porosity. The pores were exerted by stress-concentrating influence and consequently reduced the load bearing (Fleck *et al.*, 1981). Cracking easily occurred on particleboards with lower compatibility. This is due to the closely spaced particles, causing high strain magnifications between the particles. As the strain increases, cracking occurs in the bundles oriented at other angles to the tensile axis as predicted from the orientation. Shear cracking and resin fracture had caused the specimen to fail as the load increased (Fabrice *et al.*, 2012).

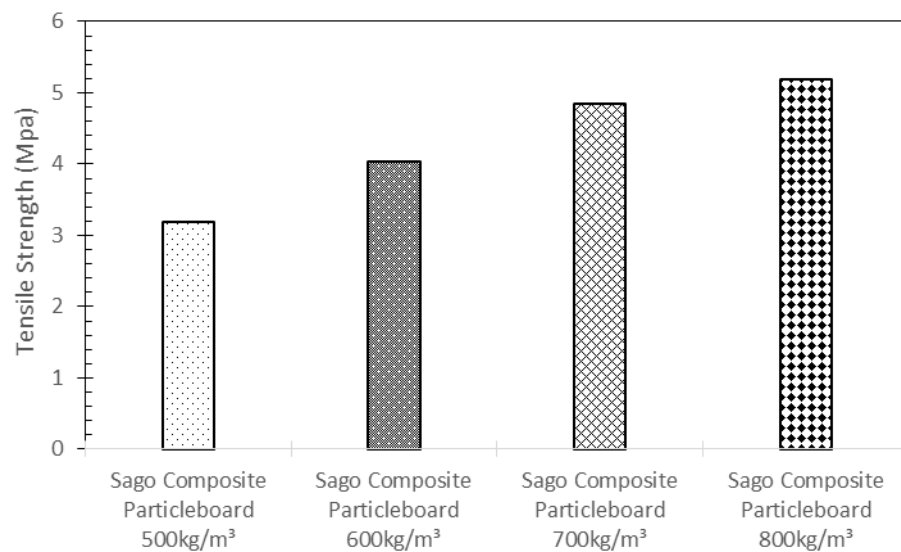


**Figure 7.8:** Effect of density on tensile strength of sago composite particleboard

### 7.2.9 The effect of density on impact strength of sago composite particleboard

The performance of UF-sago particleboard with different densities is shown in Figure 7.9. The best performance of impact strength was achieved by sago composite particleboard with  $700 \text{ kg/m}^3$  while the sago composite particleboard with  $500 \text{ kg/m}^3$  achieved the least. Increasing the particleboard density increase the impact strength up to a certain limit then drops after that. Sago composite particleboard with  $700 \text{ kg/m}^3$  was found to have perfect compatibility to achieve the highest impact strength. This is due to space within the composite was filled with compatible particles and matrix which created a good interconnection and absorbed energy more efficiently during the test. The improvement in impact strength could be due to the amount of matrix that allowed the applied stress to be transferred more effectively due to increment in total fibre surface in contact with the matrix. High compaction packing had increased the particle surface area for good adhesion with matrix. This improved the interlocking at the interface and provided better adhesion with UF resin. The impact strength increased with density up to  $700 \text{ kg/m}^3$  but decreased as density is increased beyond  $700 \text{ kg/m}^3$ . It was due to the high fiber content which increased the probability of fiber agglomeration and stress concentration. Thus, the board requires less energy for crack propagation (Geetanjali *et al.*, 2016). The reasons are that the fiber is capable of absorbing energy and compression pressure which removes the voids contents in the composite particleboard because of appreciative mix-up fiber and matrix. As fiber loading increased in high density particleboard, more force is required to pull out the fibers, thereby increasing the impact strength (Dhanalashmi *et al.*, 2015). The reinforcing effect on impact strength was enhanced due to the higher volume of the spongy nature of natural fiber. These structures absorb more impact loads compared with loose structure packing (Siva *et al.*, 2013).

Sago composite particleboard with  $500 \text{ kg/m}^3$  has the porous structure and had less ability to absorb energy due to ineffective energy dissipation mechanism at the interface.

Irregular hole size could be attributed to voids and air entrapment, which led to poor interface between the particles and matrix with internal defect in composite. Part of the low impact strength was also attributed to poor fibre dispersion, which resulted in weak interfacial bonding between the fibre and matrix that consequently, created potential sites for crack growth.

The impact properties of composite materials are directly related to the nature of the constituent materials, fibre-matrix interface, construction and geometry of the composites and the test conditions (Jawaid *et al.*, 2011).

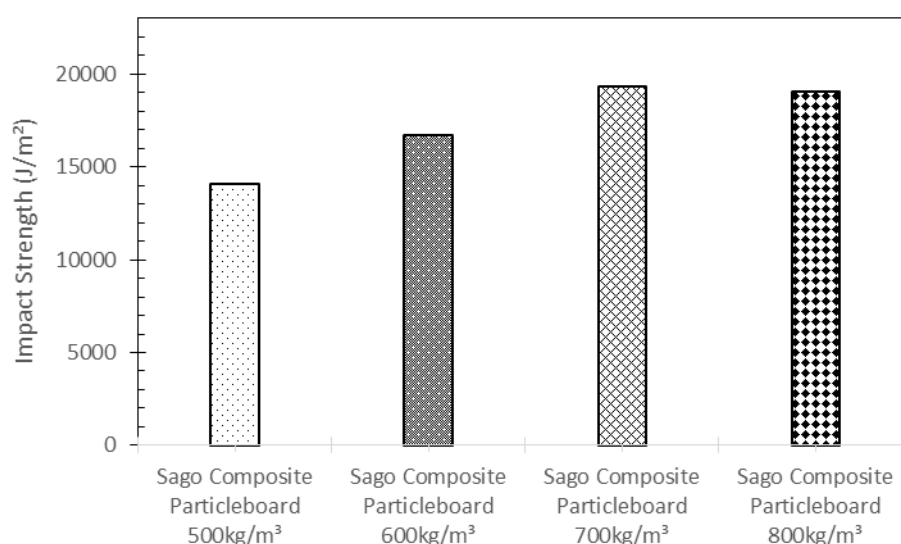


**Figure 7.9:** Effect of density on impact strength of sago composite particleboard.

#### 7.2.10 Thermogravimetric Analysis (TGA) of sago composite particleboard with different density

Thermal analysis is a technique in which a physical property of a substance measured as a function of temperature, while the substance is subjected to the controlled temperature. Knowledge of thermal behaviour is not only essential for proper processing and fabrication, but also to complete the characterisation of materials especially for thermal stability and for selection of appropriate end users. Figure 7.10 shows the TGA curves of different densities

and the results obtained with different density analysis are tabulated in Table 7.1. All the specimens showed a single stage decomposition reaction, where they are decomposed into three steps, which are water absorption, volatile and char. Increasing density not only improve the resistance of particle boards to thermal degradation but also alters their pyrolysis route and thus increasing the char produced.

The TGA curve shows that all the specimens have the same characteristics where a change in mass for all specimens were observed at temperatures from 50 °C to 200 °C. This is because the specimens have a higher moisture content at this stage (Karastergiou *et al.*, 2000).

Sago composite particleboard with 800kg/m<sup>3</sup> has the highest compatibility in structure because it is associated with the highest level of the curve compared to board with 500 kg/m<sup>3</sup>. Sago composite particleboard with 500 kg/m<sup>3</sup> has the least density in structure order (Hatakeyama, 1999). The results show that better thermal stability can be achieved with a denser packing due to the high compaction in sago composite particleboard. Sago composite particleboard with higher density had more interactions between the sago particles and UF matrix compared with low density. The interactions between sago particles and UF matrix resulted in increased physical and chemical cross-linking in the board structure which prevented the degradation of the polymer chains and prevented the decomposition at high temperatures by resisting molecular mobility (Javad *et al.*, 2015). This had increased the thermal stability due to low migration characteristics (Carola *et al.*, 2012). Besides, this had indicated that sufficient uniform and fine dispersion of the sago particles and UF matrix improved the interfacial adhesion between each other led to higher stability (Samie *et al.*, 2015). The stability may be also attributed to the barrier effect of high compaction, which hindered the diffusion of the decomposition products from the UF to the gas phase. Another reason could be the higher thermal conductivity of the sago composite particleboard that made heat dissipation within the specimens.

The decomposition peak for all specimens occurred in between 308 °C- 311 °C. Based on the thermal behaviour of the particle board, a hot pressing temperature of 160 °C is suitable for the sago fibres to react with UF without thermal decomposition. Degradation of hemicellulose, cellulose and lignin can be observed at temperatures between 245 °C – 364 °C, 241 °C – 354 °C, 243 °C-350 °C, 241 °C-344 °C with mass loss of 70.88%, 69.06%, 68.30% and 66.61% for sago composite particleboard with 500 kg/m<sup>3</sup>, 600 kg/m<sup>3</sup>, 700 kg/m<sup>3</sup> and 800 kg/m<sup>3</sup> respectively. Degradation continues slowly until a fixed carbon content at 800 °C. The range of decomposition temperature decreased with increasing density which may be caused by a more homogeneous dispersion of fibres and UF in the particle board.

Sago composite particleboard with 800 kg/m<sup>3</sup> have the least mass loss with 2.76% at 63.52 °C because it has the lowest moisture content of sago fibre incorporated in the composite (Azwa *et al.*, 2013). Higher compaction facilitates bonding and resistance to moisture trapping on the specimen which resulted in reducing the voids between the particles. Sago composite particleboard with 800 kg/m<sup>3</sup> undergoes degradation with a mass loss of 66.61% at 311.64 °C. The specimen will degrade further until 30.63% of char is formed. The decomposition reaction kinetics can be significantly altered with a denser packing. A denser packing can also inhibit the diffusion of evolved gases through the sample (Hatakeyama, 1999). Thermal stability can be improved with good compatibility because of low migration characteristics and homogeneous dispersion of the particles and matrix (Esposito, 2012).

Sago composite particleboard with 500 kg/m<sup>3</sup> initially has the highest weight loss which is about 3.88% at 86.79 °C due to the high moisture content within the particleboard and the presence of hemicellulose had improved the moisture absorption in the composite (Azwa *et al.*, 2013; Vanreppelen *et al.*, 2013; Chai *et al.*, 2009). The moisture in board with 500 kg/m<sup>3</sup> start to evaporate earlier than other samples at around 54.67 °C-220 °C with longer time and higher temperature (Chai *et al.*, 2009). The degradation of hemicelluloses, cellulose

and lignin in the second region at 310.62 °C with mass loss of 70.88 % (Vanreppelen *et al.*, 2013). The specimen continues to degrade until a fixed carbon content with 25.24% of mass loss at 800 °C is obtained. Char is formed when the specimen undergoes continuous degradation until a constant carbon content is obtained. The conductivity of a loosely packed specimen is low due to the fact that the air between the particles has poor conductivity.

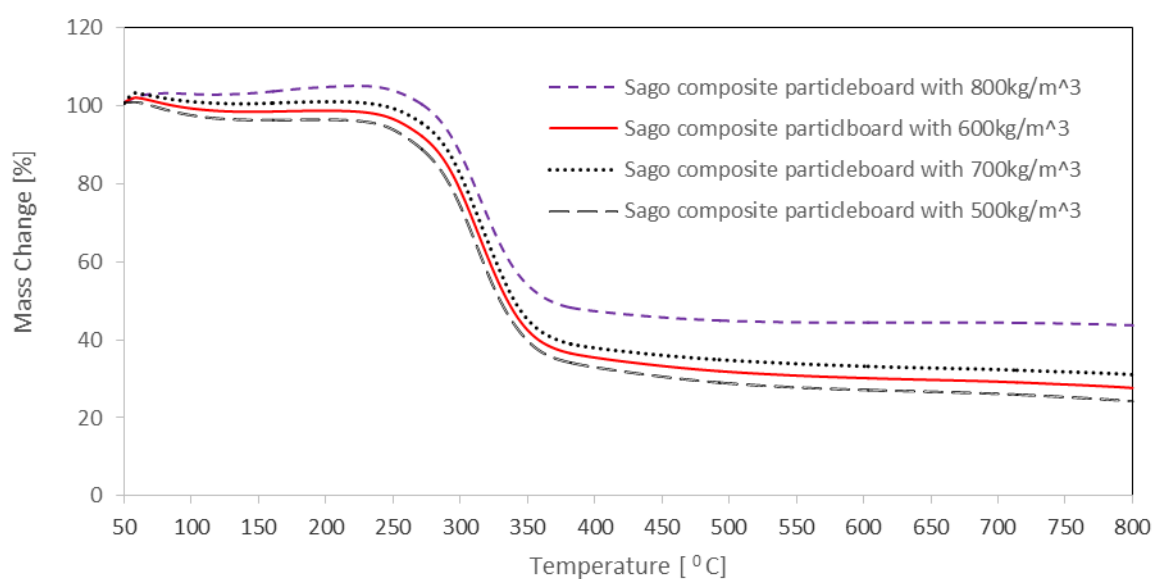


**Figure 7.10:** Mass change (%) versus temperature at various density of sago composite particleboard.

**Table 7.1:** Results for Sago / UF sample with different density analysis by TGA

| Sample                                                        | Temperature<br>Peak ( ° C) | Mass loss<br>(%) | Residues<br>(%) |
|---------------------------------------------------------------|----------------------------|------------------|-----------------|
| Sago composite<br>particleboard with<br>500 kg/m <sup>3</sup> | 86.79 ° C<br>310.62 ° C    | 3.88%<br>70.88%  | 25.24%          |
| Sago composite<br>particleboard<br>with 600 kg/m <sup>3</sup> | 71.03 ° C<br>308.77 ° C    | 3.56%<br>69.06%  | 27.38%          |
| Sago composite<br>particleboard with<br>700 kg/m <sup>3</sup> | 69.28 ° C<br>309.16 ° C    | 3.12%<br>68.30%  | 28.58%          |
| Sago composite<br>particleboard with<br>800 kg/m <sup>3</sup> | 63.52 ° C<br>311.64 ° C    | 2.76%<br>66.61%  | 30.63%          |

#### 7.2.11 Different Scanning Calorimetry (DSC) of sago composite particleboard with different density

The thermogram in Figure 7.11 shows the organic compound melt with decomposition (Vanreppelen *et al.*, 2013). All the specimens showed an endotherm peak between 50 °C to 100 °C which indicates a high amount of water molecules in sago/UF particleboard (Alireza, 2010). Sago composite particleboard with 800 kg/m<sup>3</sup> and 500 kg/m<sup>3</sup> have the highest amount of water molecule in sago fibres compared with sago composite particleboard with 600 kg/m<sup>3</sup> and 700 kg/m<sup>3</sup>. The higher amount of water molecules in sago composite particleboard with 500 kg/m<sup>3</sup> was due to low compatibility of the particleboard structure and trapped more moisture from the surrounding. Sago composite particleboard with 800kg/m<sup>3</sup> had higher moisture due to the higher amount of UF applied on the particleboard.

Generally, decomposition for sago fibre begin at 230 °C – 350 °C and indicates a loss of amorphous structure of cell wall like hemicellulose, cellulose and some portion of lignin. The cellulose did not decompose until 340 °C (Chai *et al.*, 2009).

From the DSC thermogram, sago composite particleboard with 800 kg/m<sup>3</sup> showed a single endothermic peak at 265 °C due to thermal decomposition of sago fibres (Hatakeyama, 1999). Sago composite particleboard with 500 kg/m<sup>3</sup> and 600 kg/m<sup>3</sup> exhibited two endothermic peaks which are at 260 °C and 340 °C for sago composite particleboard with 500 kg/m<sup>3</sup> and 260 °C and 325 °C for board with 600 kg/m<sup>3</sup>. The double endothermic peaks obtained in DSC thermogram were due to the thermal decomposition of Sago fibres and filled with UF (Vanreppeien *et al.*, 2013). This observation can be explained on the basis of prominent changes like the evaporation of moisture, decomposition of hemicellulose, cellulose and lignin that occur in the structure and morphology of sago fibre components (Hatakeyama, 1999). The second exotherm peak at 287 °C may be due to further pyrolysis of the remaining cell wall structure (Chai *et al.*, 2009).

The thermogram shows the area under the curve for sago composite particleboard with 500 kg/m<sup>3</sup> is smaller compared to board with 800 kg/m<sup>3</sup>. It had shown that sago composite particleboard with 500 kg/m<sup>3</sup> was less compact in the structure and easy to cure compared with board 800 kg/m<sup>3</sup> (Hatakeyama, 1999). This may be due to the particleboard which was fabricated with smaller amount of UF and sago particles hence having a better curing properties. The addition of fibre to the UF system results in barriers to the UF cure. The UF oligomers molecules have unrestricted space to polymerize for complete cure and increased the enthalpy reaction (Emmanuel, 2011).

According to the thermogram, the higher melting temperature of starch was found on the higher density board. Based on the thermogram, the peak of melting for sago starch fall at 72.66 °C, 73 °C, 74 °C and 76 °C for sago composite particleboard with 500 kg/m<sup>3</sup>, 600

kg/m<sup>3</sup>, 700 kg/m<sup>3</sup> and 800 kg/m<sup>3</sup> respectively (Emmanuel, 2011). It was attributed to the structure perfection or degree of crystallinity at this stage (Islam *et al.*, 2012). The higher density of particleboard has higher melting temperature due to the crosslinking reaction with epichlorohydrin and leads to better interaction between starch and particles in panel manufactured. The reinforcing of starch granules through crosslinking reaction with epichlorohydrin contributes to higher strength of panel where more heat is required for melting process to complete (Nurul *et al.*, 2013). As a result, higher density particleboard had a higher melting enthalpy. Sago composite particleboard with 500 kg/m<sup>3</sup> and 800 kg/m<sup>3</sup> showed that UF have crucial reaction during the thermal degradation at 274 °C and 267 °C respectively. The higher temperature had caused the chain rupture in UF molecule (Feng *et al.*, 2012).

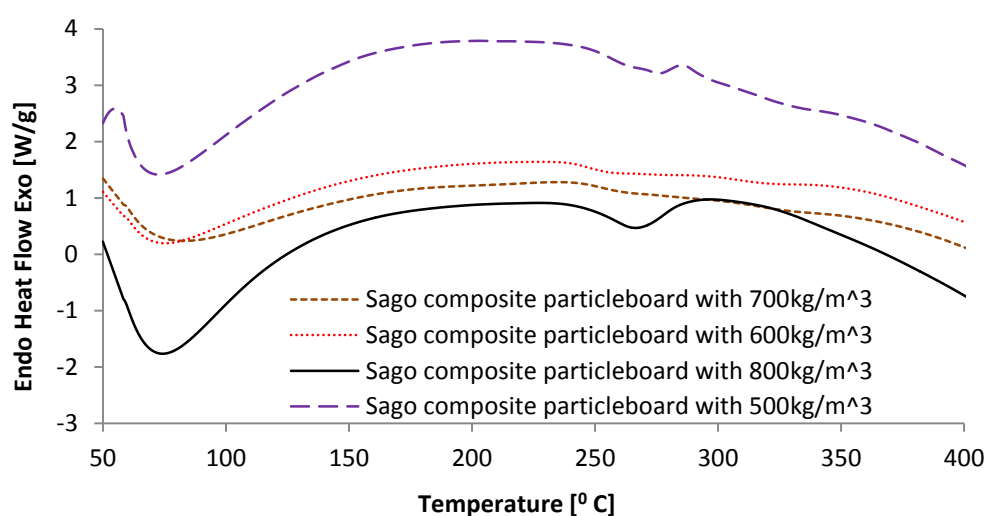


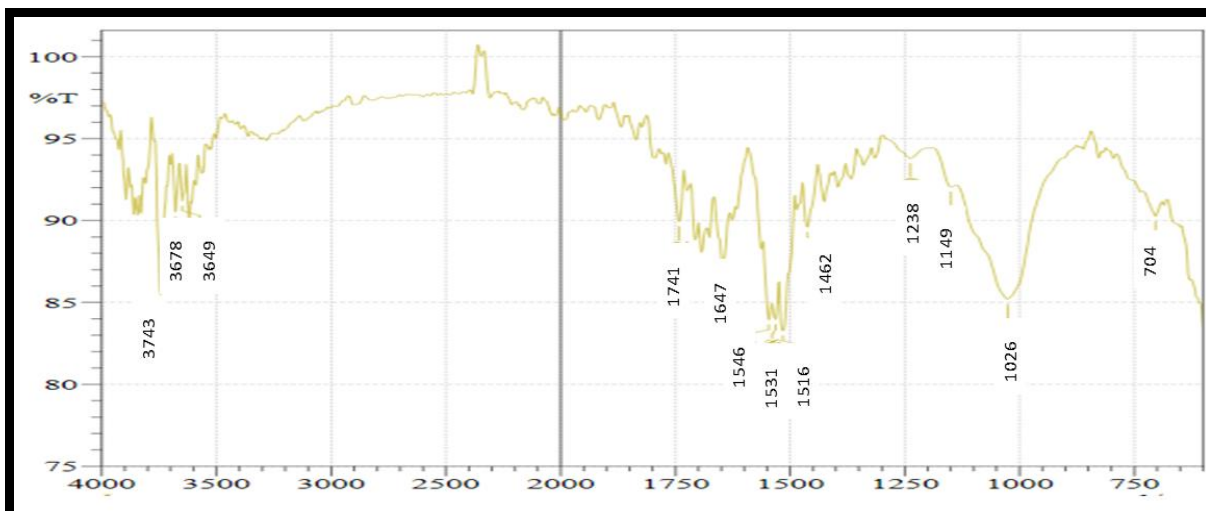
**Figure 7.11:** Thermogram of sago/UF sample with different density analysis by DSC.

## 7.2.12 Fourier Transform Infrared (FTIR) Spectroscopy Analysis Of Sago Composite

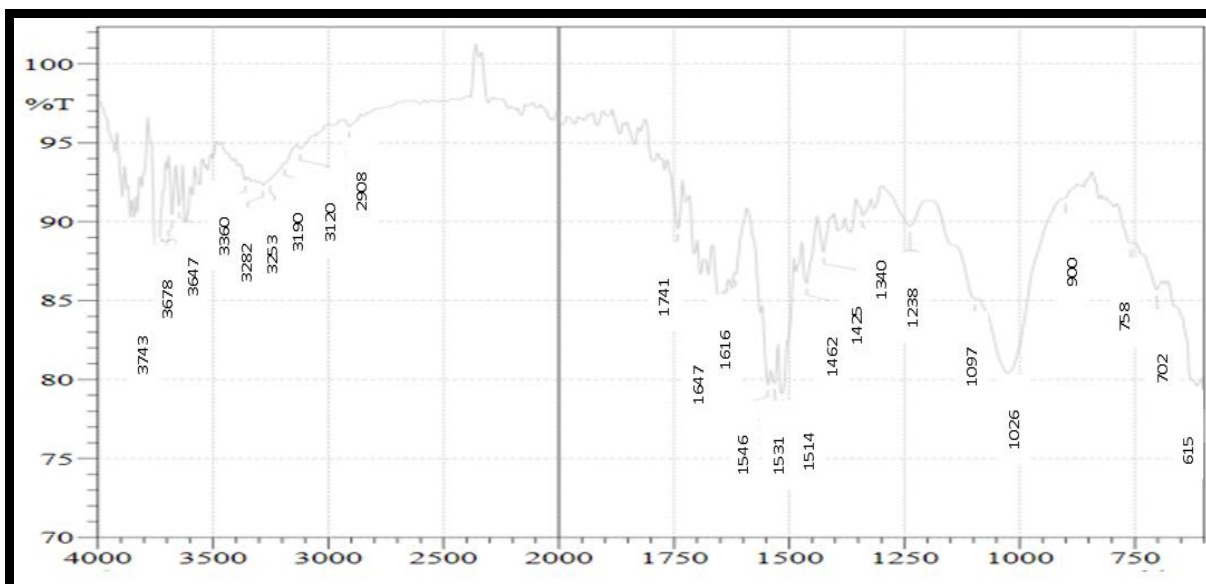
### Particleboard with Different Density

The sago composite strength had great influenced by the OH groups. High volume of voids had caused the moisture to penetrate into the board and reduced the whole properties. Figure 7.12 showed the Sago composite particleboard with density (a) 800 kg/m<sup>3</sup> and (b) 500 kg/m<sup>3</sup>. The band at 3000 cm<sup>-1</sup> to 4000 cm<sup>-1</sup> is caused by OH vibrations and can be treated as a measure of hydrophilicity. The peak 3000 cm<sup>-1</sup> to 4000 cm<sup>-1</sup> is the characteristic of hydroxyl (-OH) stretching of the methyl group (Izreen *et al.*, 2011). The 'free' water is present largely as monomeric H<sub>2</sub>O molecules and its fundamental OH stretching band was observed near 3649 cm<sup>-1</sup> and 3647 cm<sup>-1</sup> (Sarifuiddin *et al.*, 2013). When the water entrapped in sago composite particleboard, the strength of the hydrogen bond may vary, depend on the nature of the UF, the functional group of lignocellulose and porosity. By analysing the positions of the stretching or bending bands, it is possible to elucidate the state of water; this has a direct effect on transport (diffusion) and the absorption properties of the membrane. SEM proved that there are voids occurred in the sago composite particleboard had add advantages for moisture to penetrate into it.

Based on the FTIR result, sago composite particleboard with high compaction 800 kg/m<sup>3</sup> has less OH group compared with sago composite particleboard with 500 kg/m<sup>3</sup>. This was due to the high compatibility particles and matrix had resisted the moisture to penetrate into the board. Hence, the OH group reduced had increased the board properties. The high compaction of arrangement in sago composite particleboard had reduced the voids and had enhanced the mechanical, physical and thermal properties. This proved that sago composite particleboard is hygroscopic nature. High moisture content in the sago composite particleboard had affected the physical, mechanical and thermal stability.



(a)



(b)

**Figure 7.12 :** Sago composite particleboard with (a)800kg/m<sup>3</sup> and (b)500kg/m<sup>3</sup>

### 7.2.13 Scanning Electron Microscopy (SEM) Analysis of Sago Composite Particleboard with Different Density

The morphology of the fracture surface of sago composite with density  $800\text{kg/m}^3$  and  $500\text{kg/m}^3$  were presented in Figure 13 (a) and (b). Figure 13 (a) indicated high compaction of sago composite particleboard with better interfacial adhesion and further supported higher mechanical properties. Based on Figure 13(a), the sago composite particleboard with high compatibility due to heavy bonding and tightly arranged structure. The fiber were tightly connected with the UF matrix, which indicated better interfacial bonding between the fiber and matrix. This tightly connected fiber and matrix led to an increased in mechanical properties of particleboard(Suvarna *et al.*, 2015). Therefore, it can be deduced from the SEM micrograph that the function of UF binder had increased the phase compatibility and adhesion between the particles and UF matrix, thus significantly increased the surface morphology of sago composite particleboard. It can be observed that the dispersion of particles was uniform which greatly affects the mechanical behaviour of composite particleboard. Mechanical interlocking is one of the bonding mechanisms that occur between fiber and polymer matrix in sago reinforced composite particleboard. This mechanism of mechanical interlock involves diffusion of UF matrix into the porous fiber surface. Thus, the UF matrix will flow into the porous fiber surface and the embedded UF will solidify in the pores and become in extractable.

Figure 14(b) showed that low compaction of sago composite particleboard with existence of voids, which is an indication of poor adhesion between particles and matrix. There were many micro pores in the sago composite particleboard. The pores will absorb moisture and reduced the whole properties of the board. Figure 14(b) this feature indicated that there are poor dispersion and weak interfacial bonding between the matrix and

particles in the sago composite particleboard. These reasons led to the mechanical strength reduced and physical properties increased.

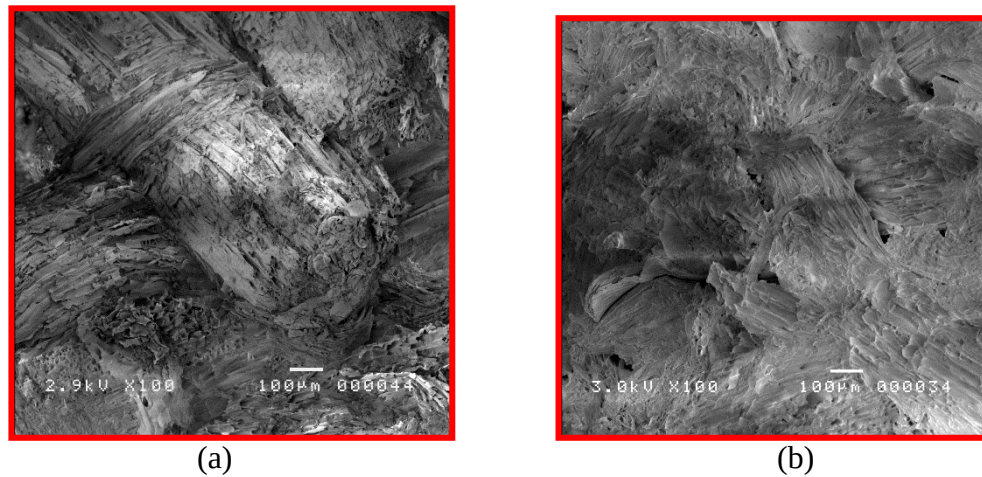


**Figure 7.13 :** Particles arrangement in sago composite particleboard (a) High compaction 800 kg/m<sup>3</sup> (b) Low compaction 500 kg/m<sup>3</sup>

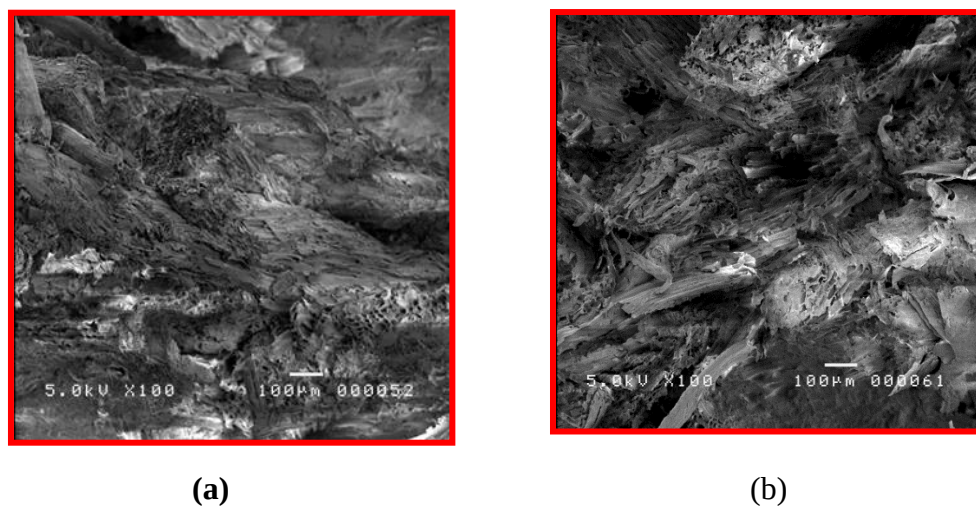


**Figure 7.14 :** Voids at (a) High compaction 800 kg/m<sup>3</sup> (b) Low compaction 500 kg/m<sup>3</sup>

### 7.3 Summary

The results show that increasing the density will affect the mechanical, thermal stability and physical properties of a particleboard. It can be seen that the compatibility of the particleboard has a significant effect on the performance of a board. Sago composite particleboard with  $500\text{kg/m}^3$  particleboard has better curing properties due to the small amount of fibres and UF applied during the fabrication. Sago composite particleboard with  $800\text{ kg/m}^3$  has the smallest weight loss of moisture content in the board and has better thermal properties. Low compaction of the board had reduced the strength properties due to high penetrated of moisture through the voids. High compatibility of particleboard had improved the bonding between particles and surface contact. This had reduced the spaces between the particles and increased the strength property.

## CHAPTER 8

### EFFECTS OF HYBRID COMPOSITE PARTICLEBOARD ON PHYSICAL, MECHANICAL AND THERMAL PROPERTIES

#### 8.1 Introduction

The development of particleboard based on natural fiber is rapidly increasing. Furthermore, the advances in technology have enabled agricultural wastes and other industrial by products to be utilized as well. Researchers had come up with an idea by creating the hybrid composite particleboard using the different types of lignocellulosic mixed together with the adhesive in order to meet the high demand of wood industry.

Hybrid composite particleboard is the combination of two or more types of different fibers in a single matrix (Abdul Khalil *et al.*, 2011). There are numerous factors that influence the final mechanical and physical properties of the composite particleboard such as raw material, density of the board, compaction ratio, types and contents of the matrix, humidity of the particles, pressing temperature and specific pressure (Rafael *et al.*, 2009)

From hybrid composite particleboard, a new property or characteristic that is not in a single type of reinforcement can be obtained. Basically, the hybrid composite material is one of the ways for one material to be reinforced with another material, resulting in enhancement of the mechanical and physical properties. The properties of the hybrid composite particleboard did not follow the independent properties of individual components. Hybrid particleboard had better performance in the physical and mechanical properties and mainly used in cabinets, floor, wall, furniture, desk, counter top, ceiling panels and office dividers (Salem *et al.*, 2015).

In the hybrid composites particleboard, urea formaldehyde acts as a matrix and sago residues mixed with waste wood were the reinforcement. The reinforcing of sago and waste

wood are the main load-carrying component in the hybrid composites particleboard. It provides high strength and stiffness as well as resistance to bending and breaking under the applied stress. Interface bonding between the particles and the matrix is the key to transfer the stress from the matrix into the particles across the interface (Maneesh *et al.*, 2012).

Improving the final performance of composites particleboard is important and had brought the positive effect to the furniture industry (Zeki *et al.*, 2015). Therefore, the objective of this study was to evaluate the feasibility of producing hybrid composite particleboard made from various ratios of sago and waste wood particles. In order to achieve the best performance in the furniture industries, the dimension and stability of a particleboard need to be studied. The thermal stability, mechanical and physical change of a hybrid composite particleboard need to be evaluated before to be used in the furniture industries.

## **8.2 Results and Discussion**

The samples are prepared for mechanical, physical and thermal stability analysis.

Sample prepared according to the weight fraction of the material. S = sago, W = waste wood , 25 = 25 wt%, 50 = 50 wt%, 75 = 75 wt% & 100 =100 wt%

### **8.2.1 Density of Hybrid Particleboards, Sago and Waste Wood Particles**

Table 8.1 shows the density of the sago and waste wood particles. Table 8.2 showed the density of hybrid particleboard made from sago and waste wood were 600 -758.5 kg/m<sup>3</sup>. Factors like wood density, pressing pressure, particle quantity in mat and resin content had great influenced on the board density (Apri *et al.*, 2014). Apri *et al.* (2014) stated that the density of hybrid particleboard is higher than the original material components due to resin weight and pressure during manufacturing.

**Table 8.1:** Density of Sago and Waste wood.

| Lignocellulose Material | Density (kg/m <sup>3</sup> ) |
|-------------------------|------------------------------|
| Sago Particles          | 645.00                       |
| Waste wood Particles    | 725.00                       |

**Table 8.2:** Density of the particleboard.

| Particleboard    | Density (kg/m <sup>3</sup> ) |
|------------------|------------------------------|
| Sago             | 600.00                       |
| Hybrid (75W:25S) | 758.50                       |
| Hybrid (50W:50S) | 700.00                       |
| Hybrid (25W:75S) | 725.00                       |

### 8.2.2 Moisture of Sago and Waste Wood Particles

Table 8.3 shows the moisture content of sago and waste wood particles. The moisture content should be maintained less than 5% before the fabrication process because it will reduce the bonding of fibers and matrix due to poor surface wetting. Poor surface wetting for hydrophobic resin may cause interfacial shear bond and thus, lower the strength of a composite. When excessive moisture migrated to the particleboard core, it requires additional pressing time to be removed through the edges of the board. This is to prevent de-lamination and spring-back condition when the press is opening. Excessive moisture may cause rapid densification of the surface and loosen the core. Hence, resulting in poor mechanical test and may interfere with the polymerization of resin.

**Table 8.3:** Moisture content of the natural fibers.

| Natural Fibers                          | Moisture content % |
|-----------------------------------------|--------------------|
| Waste wood with 1.18mm sieving size     | 12.3 %             |
| Sago particles with 1.18mm sieving size | 16.2%              |

### 8.2.3 Water absorption (WA) of hybrid composite particleboard

Figure 8.1 shows the results of water absorption of hybrid particleboard against the soaking time. The water absorption for hybrid (50S:50W) particleboard was significantly higher than other particleboard made from different ratios of sago and waste wood. Hybrid (50S:50W) showed the highest water absorption follow by the hybrid (75S:25W), Hybrid (25S:75W) and sago particleboard. It may due to the differences in hemicelluloses content of raw materials. The sago particles increase the moisture absorption, however, it decreased when mixed with the waste wood. The presence of free –OH group in the molecular structure, holocellulose (especially hemicelluloses) is responsible for water absorption. The hygroscopicity of hemicelluloses was higher than the cellulose and lignin.

The Hybrid (50S:50W) particleboard shows the highest water absorption because the compatibility of the board was lowest among the hybrid board. It shows only 700 kg/m<sup>3</sup> of the density compared with other hybrids which were higher. Hamid *et al.* (2015) mentioned that a weak compatibility between the particle surface and adhesive could lead to the formation of void structure within the particleboard which facilitates water absorption (Noral *et al.*, 2015). The weak compatibility between the particle surface and the adhesive could lead to the formation of void structures within the hybrid composite particleboard, which facilitated water absorption. Water absorption is probably controlled by the structure related factors such as the collapse of the particles cell wall during consolidation, the vertical density distribution and horizontal density distribution in the panel. The loosely packed architecture of the hybrid

composite particleboard resulted in the formation of entrapped air pockets in the mat. Hence, this leads to a higher void content of hybrid (50S:50W) composite particleboard and created space for moisture accommodation (Jawid *et al.*, 2011). Therefore, when the board was submerged in water, they have more surface area exposed to water, allowing increased water penetration and absorption.

Hybrid (25S:75W) composite particleboard showed the lowest water absorption compared to hybrid (50S:50W) and (75S:25W) because it is more compatible with its mat. Hybrid (25S:75W) showed the density  $758.5 \text{ kg/m}^3$ . The hybrids are influenced by the nature of constituent materials, fiber-matrix interface, construction and the geometry of the particles. At hybrid (25S:75W) particleboard, 75 wt% waste wood will be substituted with the sago particles in order to be compacted in structure. The high compatibility of mat will have high resistance of water uptake compared with the loosely packed hybrid particleboard. The reason for this decrease is probably due to the lessening of specific surface of the particles with the increased of the density resulting in less water or moisture absorption (Cai *et al.*, 2010). Low porosity on the board resulting from the higher density made diffusion of water difficult and higher resistance to absorption properties.

Sago composite particleboard (100S: 0W) has shown the better water absorption at 2 and 24 hours because it was fabricated by the same material and particle size which has low potential for water absorption. The particles have better bonding with matrix compared with hybrid particleboard.

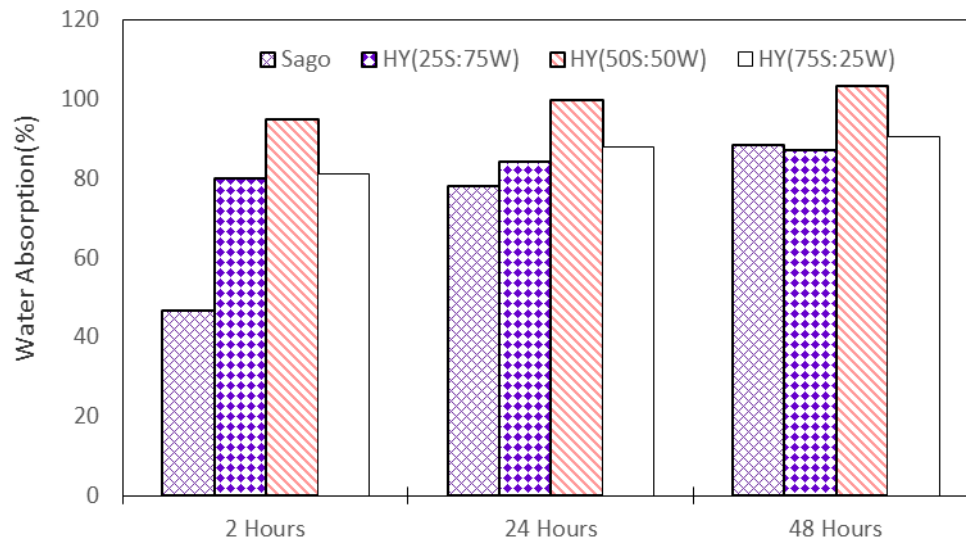


**Figure 8.1:** Water absorption verse soaking time for hybrid composite particleboard.

#### 8.2.4 Thickness swelling (TS) of hybrid composite particleboard

The response of thickness swell of hybrid composite particleboard sample immersed in water is shown in Figure 8.2. The water was absorbed by a high amount initially, then slows and approaches saturation over a prolonged time. The TS values ranged from 11.68% to 16.93% for the first 24 hours. The lowest TS was recorded in the sago particleboard (100S:0W) follow by the hybrid (25S:75W) and hybrid (50S:50W) while hybrid (75S:25W) showed the highest TS. A lower percentage is better for dimensional stability. A high ratio of sago resulted in a high TS value, which might be due to the physical qualities of sago (Othman *et al.*, 2016). Sago particles are typically smaller and narrower than waste wood. Hence, when the particles were mixed together and pressed, the particles overlapped each other, creating voids between the particles. These gaps may have increased the water uptake and weakened the bonded particles, resulting in the high TS value. When the amount of sago particles was reduced from 75% to 25%, the TS value decreased. The hybrid (25S:75W) showed the decreasing on TS after 48 hours due to the particle which was not bonded well with the UF matrix and easily release from the particleboard (Ricardo *et al.*, 2014).

The thickness swelling of hybrid (50W:50S) particleboard showed a high increase at the beginning and stabilized nearly the same value after 48 hours. The board was fabricated by two difference hemicelluloses namely Sago and waste wood along with the size of raw materials and its ratio (Salem *et al.*, 2015). The hygroscopic nature of lignocellulosic materials is contributed by the presence of free -OH group in the molecular structure of cellulose, hemicellulose and lignin. Among those three organic compounds, hemicellulose contained the most free -OH and has higher hygroscopicity.

The sago composite particleboard (100S:0W) has better gap-filling properties than hybrid particleboard, resulting in more compact and better joined particles that minimize the swelling and water uptake.

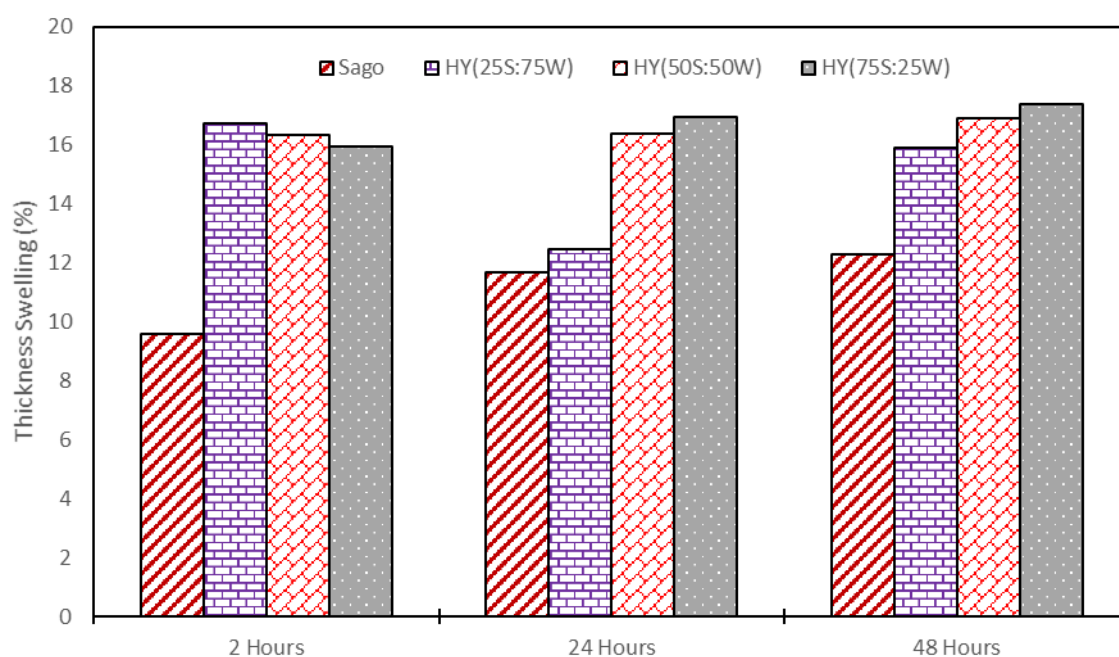


**Figure 8.2:** Thickness swelling verses soaking time for hybrid composite particleboard.

### 8.2.5 Bending strength of hybrid composite particleboard

Figure 8.3 showed the bending strength of hybrid sago waste wood particleboard. Hybrid particleboard 25S:75W had the highest bending strength value, followed by 75S:25W and 50S:50W. While board made from 100% sago had the lowest bending strength value.

Hybrid composite particleboard (25S:75W) consisted the highest portion of waste wood particles resulted in highest bending strength value. One of the most important parameters affecting the bending strength of composites is fiber dimension; waste wood has bigger particles size, which will support greater stresses and provide greater strength (Othman *et al.*, 2016). Waste wood has a better slenderness ratio of the particles size, which had resulted in a stiffer and stronger board in bending (Suffian *et al.*, 2009). On the other hand, hybrid composite particleboard (75S:25W) has lowest bending strength compared with other hybrid composite particleboards. In general, sago particles have a lower aspect ratio than waste wood. High portion of sago particles used in hybrid composite particleboard had reduced the strength due to the lower aspect ratio (Ramadan *et al.*, 2014). The large amount of smaller sago particles and total surface area in hybrid composite particleboard had an adverse effect on the bending strength (Yong *et al.*, 2012).

Hybrid (25S:75W) particleboard had the highest bending strength value because the board have the highest density  $758.5 \text{ kg/m}^3$  compare with others (Noral *et al.*, 2015). On the other hand, hybrid (75S:25W) and hybrid (50S:50W) have the density  $725 \text{ kg/m}^3$  and  $700 \text{ kg/m}^3$  respectively. The high density had created highly packed structure in particle board. Therefore, the high compatibility of the board had reduced the number of void spaces at hybrid (25S:75W) and enhance the resistance to rupture. This can be attributed to the greater compression ratio and better particle bonding within boards, leading to a better contact area between the resin and the sago/waste wood particles which had resulted in high strength properties (Hazwani *et al.*, 2014; Eslah *et al.*, 2012; Ajayi *et al.*, 2008). Besides, the adequate

resin to form better bonding with particles under high degree of compaction had created a better internal bond within the board. In addition, the lowest density indicated the presence of void space or micro cracks present in the hybrid composite particleboard had reduced the bending strength due to penetrate of moisture.

The reason why hybrid composite particleboard (25S:75W) has the highest bending strength was due to the raw material density itself. Hasan *et al.* (2015) reported that a higher density of raw materials affected the corresponding higher bending strength of manufactured board. Density of waste wood is  $725 \text{ kg/m}^3$  whereas sago is  $645 \text{ kg/m}^3$ ; as well as the difference in the percentage of waste wood and sago particles was used within in the particleboard. This had contributed the higher portion of waste wood used in hybrid (25S:75W) have higher density and created higher bending strength (Salem *et al.*, 2015).

Hybrid composite particleboard (50S:50W) and (75S:25W) showed the lower bending strength compared with (25S:75W). Hybrid composite particleboard was greatly affected by the moisture content of the particles. Sago particles consisted higher moisture content compared with waste wood, hence the high portion of sago in hybrid composite particleboard had increased the moisture absorption and reduced the bending strength.

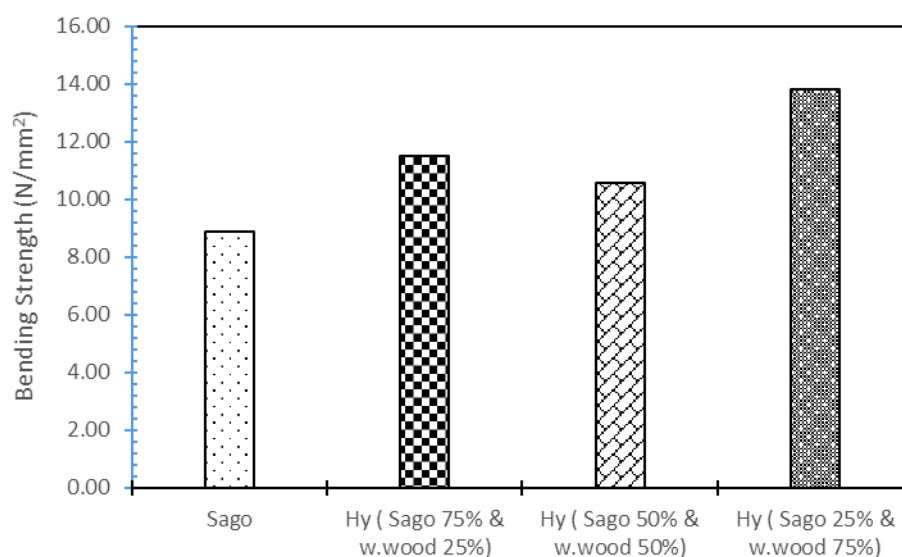


**Figure 8.3:** Bending strength of hybrid composite particleboard.

### 8.2.6 Internal Bonding (IB) of hybrid composite particleboard

Figure 8.4 shows the relationship between hybrid particleboard and internal bonding strength. Hybrid (25S:75W) particleboard showed the best internal bonding values compared to other specimens. This indicated that the composite with particleboard with 75 wt% waste wood have better interaction with 25 wt% of sago.

The compaction of hybrid has great influence on internal bonding value. Hybrid (25S:75W) had shown higher density compared with others. These results were attributed to the use of waste wood particles in manufacturing of hybrid composite particleboard, which resulted in improving the compatibility between the waste wood particles, sago and matrix. The small particles of sago that were employed in the sago composite particleboard composition were directly attributed to a better composition of the panels. The higher compaction had led to better joinery and bonding between the particles and thus contributes to high IB. The presence of a high portion of waste wood particles in the sago particleboard had compact and tighter the structures of the board (Othman *et al.*, 2016). The voids in the particleboard were reduced by substituting the small particle size of sago. Hence, this had increased the mechanical properties.

Generally, particleboard made from larger particles has better mechanical properties. Based on the observation, waste wood was bigger in size compared with sago. Hybrid composite particleboard (25S:75W) consisted of higher portion of waste wood and this indirectly increased the internal bonding. The adequate resin to form better interaction between the bigger particles and adhesive under a high degree of compaction ratio had created better internal bond strength within the board (Rusli *et al.*, 2013).

Hybrid (50S: 50W) did not show better result compared to others because the same portion of waste wood and sago did not employ well in composite particleboard. Both the waste wood and sago particle were filtered on the same sieving size but the output of particles

was different. Dissimilar of particle geometry caused the particles between sago, waste wood and matrix to poorly bond. The surface area had reduced contact between the matrix and the particles (waste wood and sago); resulting in a weak glue line and low bonding strength properties of the core panel. Hence, this had attributed the particleboard failed to bear the shear force during the test. Besides, the inhomogeneous mixing of the sago and waste wood had reduced the compaction of the particleboard.

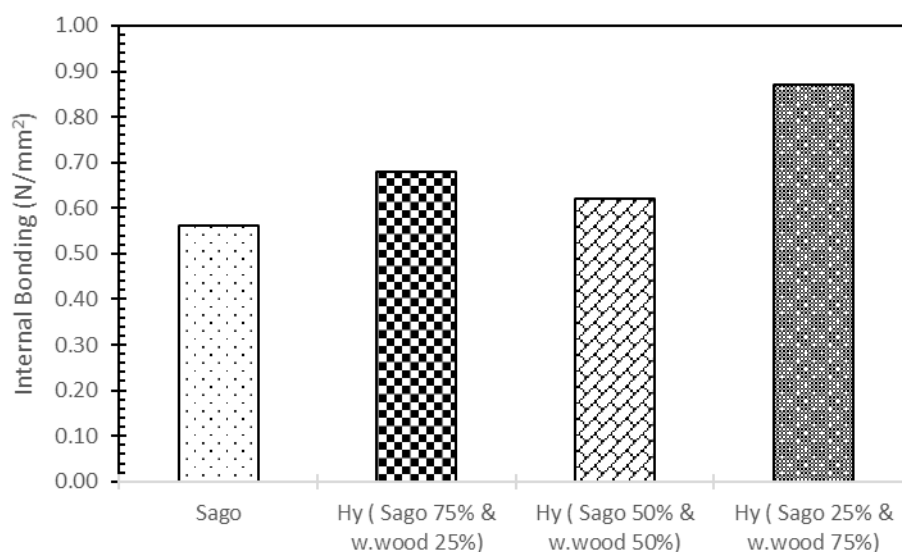


**Figure 8.4:** Hybrid particleboard have great influence on IB.

### 8.2.7 Screw withdrawal test of hybrid composite particleboard

Figure 8.5 shows the screw test for various hybrid particleboard with the screw withdrawal. The screw withdrawal values for all hybrid particleboard were higher than the boards made from 100% sago. The hybrid (25S: 75W) showed the highest screw withdrawal. The high screw withdrawal value indicates a good bonding between particles. This result also agreed with the finding by Nurhazwani *et al.*, (2016) that screw holding strength is strongly related to the internal bond strength of the board (Othman *et al.*, 2016). High screw withdrawal value can be attributed to the geometrical properties of sago and waste wood particles. Waste wood particles are more elongated and larger than sago particles, which are

grainy. When both sago and waste wood particles mixed with UF, the smaller particles will fill the voids between the sago particles, making the hybrid boards more compact than boards made solely of sago. When a screw is driven into a particleboard, the more compact board has more surface area in contact with the screw thread and thus produces more resistance to withdrawal force (Jovan *et al.*, 2007).

According to Jonathan *et al.* (2009), the screw withdrawal is greatly affected by the moisture content of the raw material. Hybrid (75S:25W) and (50S:50W) composite particleboard did not attribute higher screw withdrawal strength because the board was fabricated by high amount of sago particles which has higher moisture content. Moisture content has great influence on bonding between the particles and the matrix. Hence, the weak bonding interface between particles and matrix had reduced the screw withdrawal strength.

Hybrid (50S:50W) had the lowest screw withdrawal because the board has the lowest density (Jonathan *et al.*, 2009). As the board with the loose structure order is easy to be pulled out and resulted in lower values of screw withdrawal strength. Hybrid (25S:75W) had the highest density, which had attributed the higher screw withdrawal strength compared to others. The high compaction of the board caused the screw embedded tightly in the board and resist began to pull, as result in better screw withdrawal strength during the test.

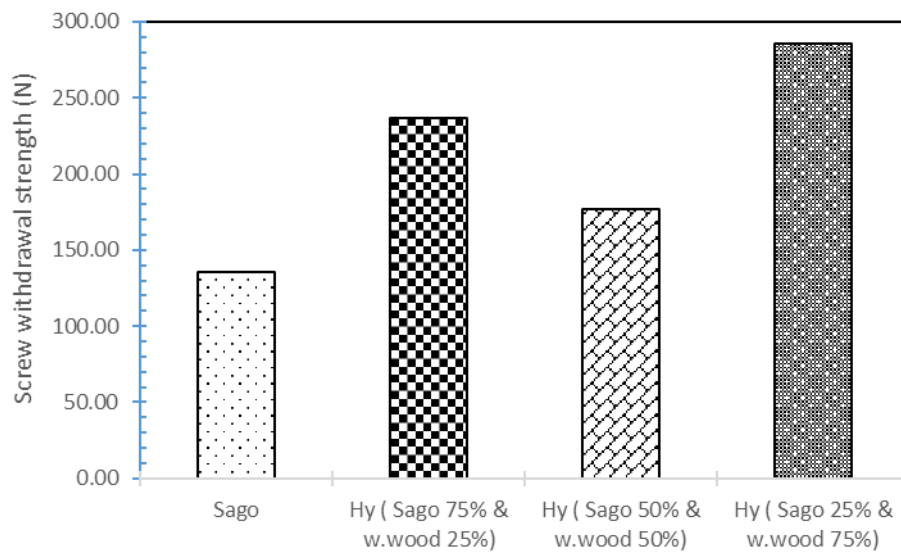


**Figure 8.5:** Hybrid particleboard have great influence on screw test.

### 8.2.8 Modulus of Elasticity (MOE) of hybrid composite particleboard

Figure 8.6 illustrates that the Modulus of elasticity (MOE) of the hybrid particleboard was influenced by the properties of the fiber component. This finding showed the highest MOE was recorded by boards made from hybrid (25S:75W) particleboard, followed by hybrid (50S:50W) and hybrid (75S:25W), particlesboard made from 100% sago had the lowest MOE value. The presence of waste wood particles increased the stiffness of the board and resulted in a higher MOE value.

The lowest MOE observed in 100% sago board due to the smaller size of particles applied on board (Salem *et al.*, 2015). Sago particles are smaller than waste wood. Therefore, when force is applied perpendicular to the board surface, the smaller particles do not sufficiently overlap to transfer the applied stress. This result agrees with other studies indicating that particles must be big enough to transfer stress from one particle to another (Othman *et al.*, 2016). Longer and thinner particles produce stronger, stiffer particleboard.

MOE value varied among the different types of particleboard due to the density of raw materials as well as percentage of particle within the board (Salem *et al.*, 2015). Waste wood

particles have higher density compared with sago particles. Hybrid (75W:25S) composite particleboard consisted of higher percentage of waste wood and this will indirectly increase the MOE. Hybrid (75W:25S) composite particleboard has the highest density  $758.5 \text{ kg/m}^3$  while the lowest density was made by 100% sago with  $600 \text{ kg/m}^3$ . As reported by researchers, the higher density resulted the higher MOE (Salem *et al.*, 2015). By increasing the waste wood in hybrid particleboard, the performance will improve.

MOE value decreased when the proportion of sago in particleboard increased which caused a decrease in resistance and rigidity parameters of these materials (Abdul Khalil *et al.*, 2011). This happened on hybrid (50S:50W) and (75S:25W) due to smaller sago particles employed in the hybrid composite particleboard had lower the MOE.

Other studies of natural fiber-reinforced composites particleboard have shown that the decreasing of MOE was probably due to the decrease of the fiber geometry (length/diameter ratio) and flake geometries (Ramadan *et al.*, 2014; Li *et al.*, 2010). Hybrid (75S:25W) and (25S:75W) have better substitution for the void in hybrid particleboard. Better compatibility had caused the un-split particles in mat increased and the contact area between the resin and particles increased which leads to increasing of MOE. The rough and fine particle from the waste wood and sago had caused the better bonding between the particles and matrix.

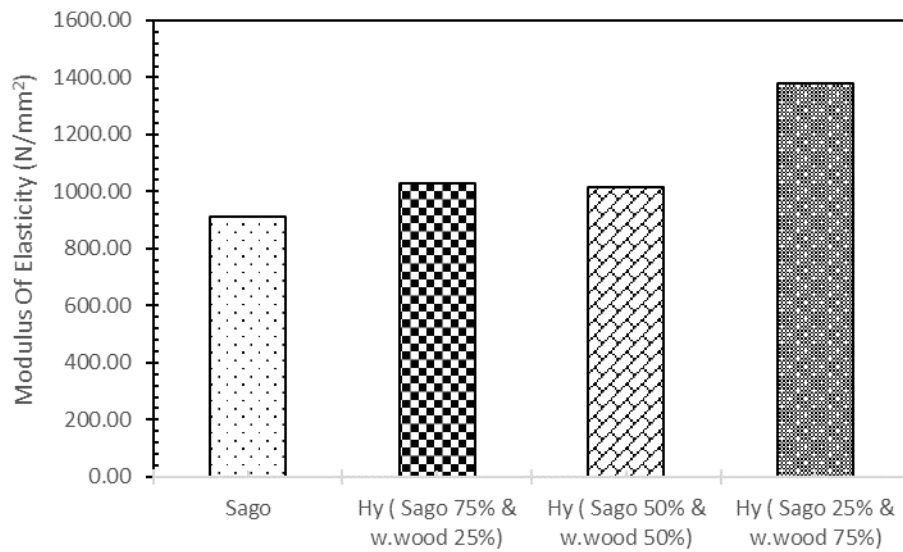


**Figure 8.6:** Hybrid particleboard have great influence on MOE.

### 8.2.9 Tensile strength of hybrid composite particleboard

Figure 8.7 shows the tensile strength of the hybrid composite particleboard. Hybrid (25S:75W) show the highest tensile strength follow by hybrid (50S:50W) and (75S:25W) particleboard, while sago composite particleboard made by 100% sago has the lowest tensile strength.

The tensile strength of the hybrid composite particleboard is generally affected by the bonding quality between particles and matrix, particles structure and size, surface area and reactivity, particle loading, perfect dispersion of individual particles and aspect ratio of the particles (Khalil *et al.*, 2013; Fabrice *et al.*, 2012; Fu *et al.*, 2008).

Hybrid composite particleboard was fabricated by mixing the particles (sago and waste wood) and matrix with the correct amount to create a good chemical bonding to achieve the homogeneously mixing in the board. This had created good match within the particleboard and increased the reinforcement effect. Hence, this will increase the particle/matrix interfacial adhesion and creates a good polymerization. This may indicate that the incorporation of sago granules and waste wood with UF matrix had introduced a new interfacial region that affects

the stress transfer (Toh *et al.*, 2011). The dispersion of the networked UF with the sago and waste wood particles is expected to be good because its surface is covered with organic materials. The openings formed in the networked contributed to improve its dispersion by penetration of the UF matrix into the particles and enhance the tensile strength at the same time (Khalil *et al.*, 2013).

Hybrid (75W:25S) composite particleboard has highest tensile strength because the board has the highest compatibility compared to others and enabled the stress to be transferred effectively between the particles and the matrix (Randa *et al.*, 2013). The tensile strength showed improvement with increasing picks densities due to increasing the amount of waste wood sharing the load which leads to lacking of air spaces between them, increased the friction areas and their resistance to tensile load. The good match of sago and waste wood within the particleboard had created better bonding between the particles and the matrix. This had created the high packed structure for interaction. The effectiveness of stress transferred from the UF matrix to particles strongly depend on particle interaction (Khalil *et al.*, 2013) . The combination of sago and waste wood allows to impregnate well with the UF, resulting in good adhesion at core interface and able to withstand the forces applied to it. The presence of hydroxyl and ether groups from UF had lead to good interfacial bonding between the fibers and matrix. This interaction will inevitably alter the properties of the fiber, increased the board stiffness and resistance to delamination. Therefore, the composite particleboards with 75% waste wood and 25% sago had better stress concentration and managed to withstand higher stress when specimens were stretched or pilled before the failure.

In hybrid (75S:25W) composite particleboard, high percentage of sago particles did not perform better on tensile strength because it reduces the stress concentration and inefficiency of stress transfer hence reduced the composite strength (Randa *et al.*, 2013). Sago

particles were high absorption of moisture. The high percentage of sago had reduced the whole strength of hybrid composite particleboard.

Composite particleboard made by 100% sago has the lowest strength due to the high content of moisture in the board and it reduce the strength of bonding during the hot process. This could be due to the fact that high amount of water from the matrix causes fibers swelling and creates gaps between the fiber and polymer-matrix and lead to a decrease in tensile properties.

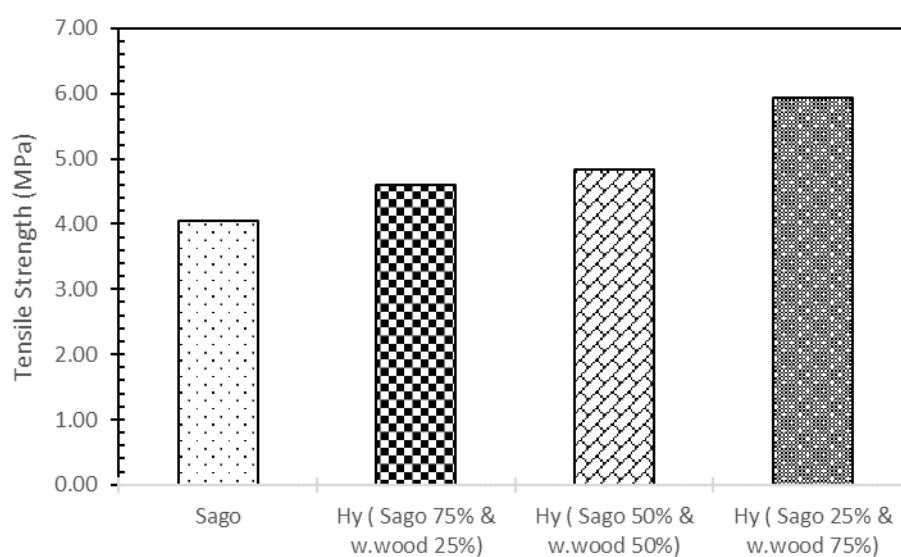


**Figure 8.7:** Tensile Strength of hybrid composite particleboard.

#### 8.2.10 Impact Strength of hybrid composite particleboard

Figure 8.8 illustrates the impact strength of the hybrid particleboard. This result shows the highest impact strength was recorded by boards made from 100% sago (100S:0W), followed by hybrid (25S:75W) and hybrid (75S:25W), while board made from hybrid (50S:50W) had the lowest impact value.

Particleboard made by 100% sago showed the highest impact strength which is attributed to the presence of the same type and size of particles. This factor leads to increased impact energy (Idris *et al.*, 2011). Sago particles have high tenacity of absorption energy. The

most important factor that influences the mechanical properties of the particleboard is its chemical composition. Sago contain cellulose, hemicellulose and lignin and are found to have a strong influence on the mechanical properties especially the cellulose content (Habibi *et al.*, 2008). Cellulose is the main structural component that provides strength and stability to the plant cell walls and particles. The cellulose is one of the stiffest and strongest organic constituents in the natural fibers. It plays an important role in the impact resistance of fiber-reinforced composites as they interact with the crack formation and act as stress transferring medium (Jawaid *et al.*, 2011).

Hybrid (50S:50W) particleboards had the lowest impact strength. This was due to the lack of interfacial bonding between the particles and the matrix (Hprnsby *et al.*, 1997). Hence, the existence of some porosity in the particleboard. The board from 50% of sago and waste wood had caused the loose structure occurred in the board and prevented them from absorbing the energy effectively. The poorer particle dispersion as well as the presence of smaller size particles in the particleboard will cause the impact strength to decrease.

Hybrid (25S:75W) has better impact strength than hybrid (75S:25W) and (50S:50W). This could be due to the hybrid particleboard contained high portion of bigger waste wood particles than smaller size of sago particles. Research had found that larger particles and higher compaction of particleboard manage to dissipate the energy effectively and able to withstand fast impact load better (Cezary *et al.*, 2011). The high compatibility of the board had increased the ability of energy absorption.

The impact strength of a hybrid particleboard is directly related to its overall toughness that is highly influenced by the nature of the constituent materials, fiber-matrix interface, construction and geometry of the composites (Jawaid *et al.*, 2011). The hybrid particleboard was manufactured by different portion of sago and waste wood. The sago and waste wood play an important role in improving the impact resistance of fiber-reinforced

particleboard as they interact with the crack formation in the matrix and act as a stress transferring medium (Jawaid *et al.*, 2011).

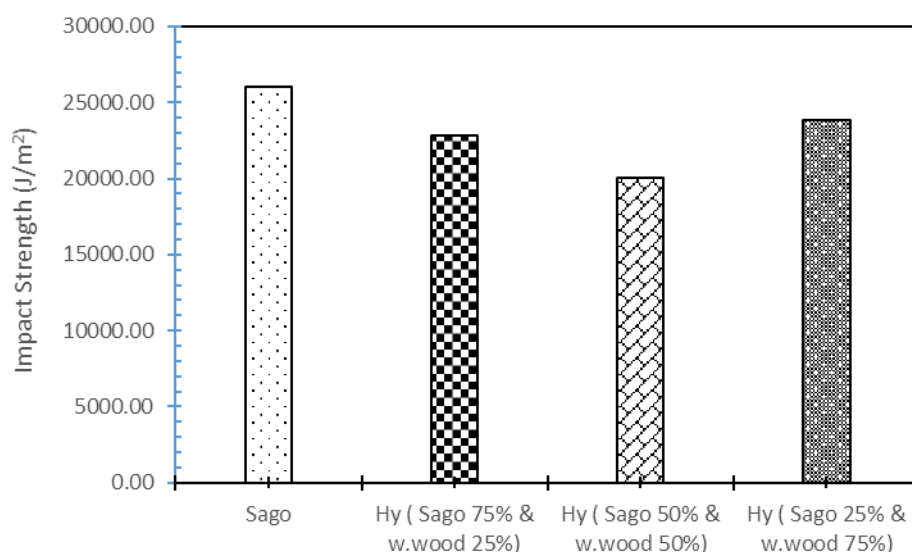


**Figure 8.8:** Impact strength of hybrid composite particleboard.

### 8.2.11 Thermogravimetric analysis (TGA) of hybrid composite particleboard

The thermal behaviour of hybrid composite particleboard is shown in Figure 8.9 and Table 8.4. All the samples have gone through the single decomposition stage. Based on the result, hybrid composite particleboard (25S:75W) has the best thermal stability compared to other samples. By increasing the percentage of waste wood in hybrid particleboard, the improvement of its thermal stability and the higher proportion of waste wood appeared to increase the overall resistance of thermal degradation.

At the first stage, pure sago composite particleboard has the highest weight loss which is about 3.56% at 71.03 °C. This indicates that the sago composite particleboard has higher moisture content which is associated with higher moisture loss or evaporation of trapped solvent (Karastergiou *et al.*, 2000). The presence of hemicelluloses in the sago particle also causes higher moisture absorption of the composite (Azwa *et al.*, 2013). Besides, the porous nature of sago has resulted in higher weight loss and tends to trap moisture more easily

(Thomas *et al.*, 2009). In contrast, the hybrid (25S:75W) does not show any weight loss in the first stage. This is because the waste wood which act as filler are fully bonded with the sago particles and has substituted the void between particles during fabrication. Good compatibility structural order has effectively resisted the moisture trapped by the particleboard.

The thermal degradation occurs after the particleboard have absorbed sufficient amounts of heat energy. The heat will break down the structure and cause the molecular chain to rupture at this stage (Amine *et al.*, 2013). In the second stage, the decomposition weight loss 68.25% with (75S:25W), 70.29% with (50S:50W) and 57.41% for (25S:75W). According to the tabulated TGA results of decomposition in table 8.4, the waste wood 25 wt%, 50 wt% and 75 wt% has a peak temperature of 313.45 °C, 327.01 °C and 351.59 °C respectively. The difference is probably due to different loading of waste wood. Some researcher had mentioned that the addition of natural fibers (sago) will cause a reduction in thermal stability of the composites due to instability of fibers. Theoretically, the waste wood plays a role in improving the thermal resistance of the composites (Azwa *et al.*, 2013). Furthermore, there will be no degradation up to 160 °C and the thermal stability will gradually decrease (Rezaur *et al.*, 2011). The TGA curve also implies that the decomposition rate of hybrid particleboard is around 313.45 °C to 351.59 °C. Therefore, hot pressing temperature at 180 °C is suitable for the hybrid particleboard without thermal decomposition (Jia *et al.*, 2014).

In other studies, initial degradation of natural fibers is around 190 °C to 230 °C. It is believed that low temperature degradation is associated with the degradation of hemicelluloses (Faith *et al.*, 2008). The pyrolysis of wood components take place below 250 °C, 200 °C for hemicelluloses, 220 °C for lignin and 250 °C for cellulose (Saiful *et al.*, 2012).

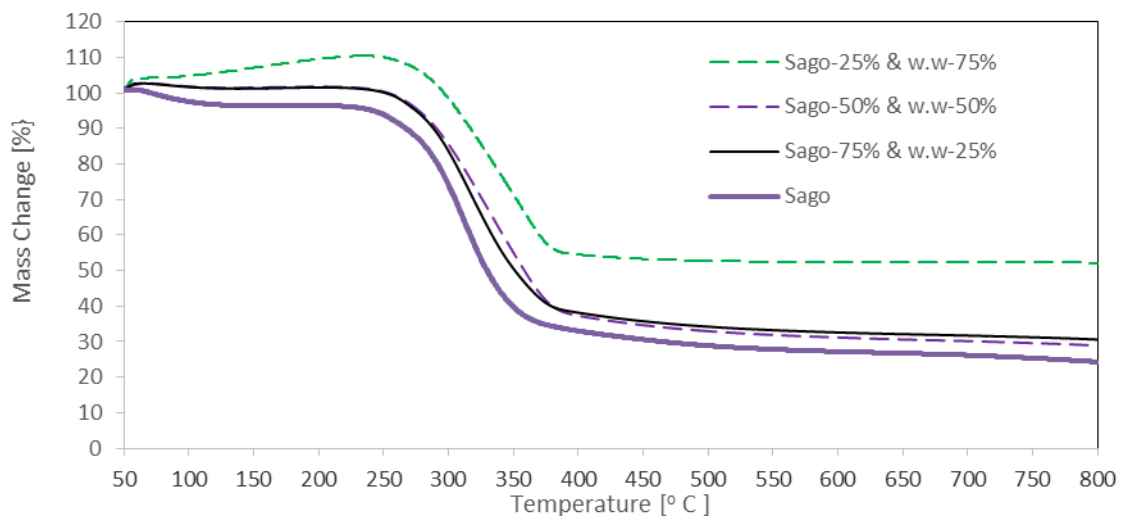
Hybrid particleboard (25S:75W) has the best interaction between sago and waste wood, and hence lead to the enhancement of thermal stability (Saiful *et al.*, 2012). This may be due to waste wood and sago component that causes the formation of cross linking which

act as an infusible support to provide thermal resistance. Hybrid composite particleboard (25S:75W) with higher density has more interactions between the particles and UF matrix compared with low density. The interactions between particles and UF matrix resulted in increased physical and chemical cross-linking in the board structure which prevent the degradation of the polymer chains and prevent the decomposition at high temperatures by resisting molecular mobility (Javad *et al.*, 2015). This had increased the thermal stability due to low migration characteristics (Carola *et al.*, 2012).

The major sources of stability are the fiber orientations, cross-linking and new chemical bonding, which allow thermal energy to be distributed over many bonds (Saiful *et al.*, 2012). Thus, the covalent bonds formed can enhance the thermal stability (Melter, 2000). The small differences seen in the hybrid composite particleboard are probably due to the different wood species that being chosen as waste wood, as well as the manufacturing conditions used to manufacture the boards. In short, the thermal stability of particleboard will differ as the wood chosen as material composite is different (Karastergiou *et al.*, 2000).

**Table 8.4:** Results for hybrid particleboard analysis by TGA.

| Particleboard                                  | Temperature Peak<br>[ °C ] | Weight Loss<br>[ % ] | Residue<br>[ % ] |
|------------------------------------------------|----------------------------|----------------------|------------------|
| Sago -25wt%<br>Waste Wood – 75wt%<br>(25S:75W) | 351.59                     | 57.41                | 52.90            |
| Sago -50wt%<br>Waste Wood – 50wt%<br>(50S:50W) | 76.97<br>327.01            | 0.67<br>70.29        | 31.40            |
| Sago -75wt%<br>Waste Wood – 25wt%<br>(75S:25W) | 74.08<br>313.45            | 1.41<br>68.25        | 33.21            |
| Sago – 100wt%<br>(100S:0W)                     | 71.03<br>308.77            | 3.56<br>69.06        | 27.38            |

**Figure 8.9:** TGA of hybrid composite particleboard.

### 8.2.12 Different scanning calorimetry (DSC) of hybrid composite particleboard

The thermogram in Figure 8.10 shows an organic compound melting with endotherm (Amer *et al.*, 2009). It was attributed to the little change of the crystal perfection or the degree of crystallinity during the hybrid composite particleboard fabrication. The hybrid composite

particleboard started loss of amorphous structure of cell wall like hemicellulose and lignin at the 240 °C to 350 °C (Wanchai *et al.*, 2009).

The thermogram showed that hybrid composite particleboard (50S:50W) has the largest peak area and need more heat to achieve curing. The largest heat was released due to the fiber and UF resin or water reaction (Zhang *et al.*, 2011). The melting temperature increased can be attributed to two factors, the incomplete curing reaction and the increase in the free volume of the system. The decrease in the free volume is responsible for the increase  $T_m$  because of the addition of 50 wt% of the sago particles (Chandra *et al.*, 2014). In addition, the particleboard with similar loadings of sago and waste wood particles had a higher melting temperature. This may be attributed to reinforcement effect and the segmental level restriction of the motion by incorporation of waste wood with the matrix which leads to increase of the temperature (Chandra *et al.*, 2014). This could be contributed by crosslinking reaction that occurs between the epichlorohydrin that occurred in starch from the sago particles (Nurul *et al.*, 2013). The interaction between sago particle, waste wood and UF in the panel had cause higher temperature needed to complete the melting process. Hybrid composite particleboard with 50 wt% sago and waste wood has higher melting temperatures compared to others. This is caused by sago particles which absorb the surrounding moisture and matrix into the particles easily, requiring higher temperature for melting. According to Hassine *et al.* (2009), the addition of wood particles to the matrix will result in an increase in melting temperature. This was due to the nucleating of wood particles in the crystallization of the matrix. During non isothermal crystallization, the heterogeneous nucleation activity of wood shifts the DSC exothermic peak toward a higher temperature 256 °C. The exotherm peak had shown the samples was more thermally stable compared with other.

Hybrid particleboard (75W:25S) had the most curing properties with better result of mechanical properties. The additional wood had improved the curing speed and have better

bonding between the sago particles. The second endothermic at 370 °C indicates the disintegration and evaporation of the majority of cell wall structure like cellulose crystallites and lignin (Wanchai *et al.*, 2009). On the other hand, hybrid particleboard (75S:25W) has large melting area and less cure compared to hybrid particleboard (75W:25S).

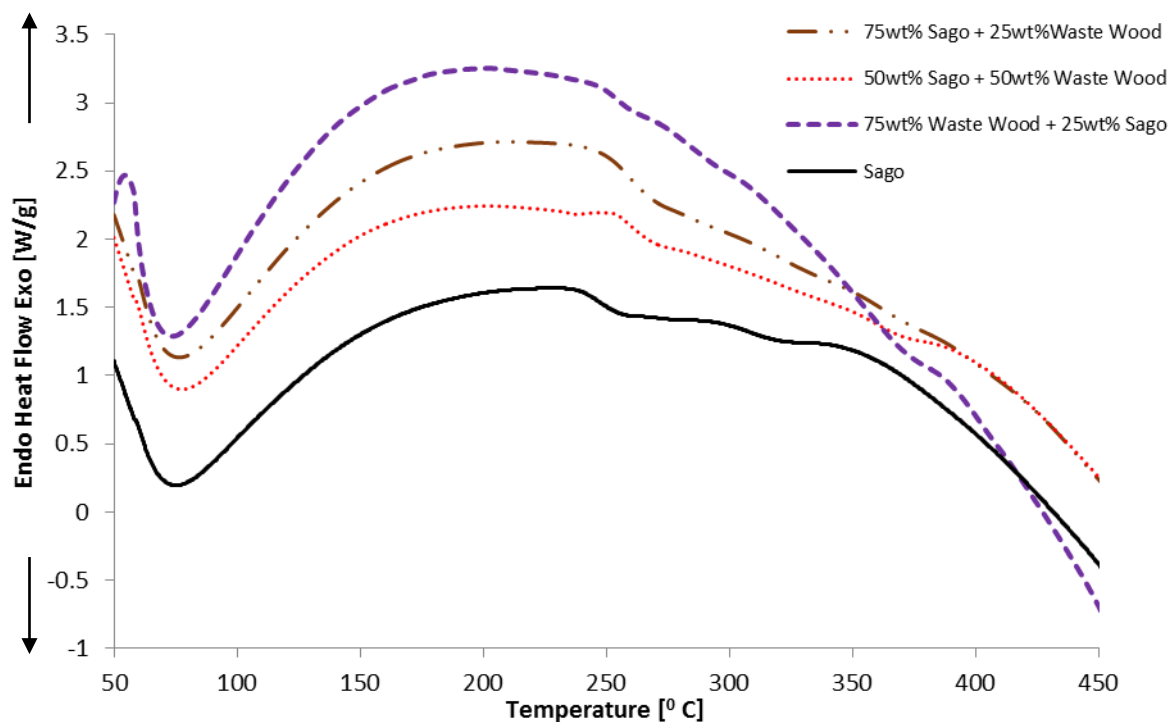


**Figure 8.10:** Hybrid particleboard analysis by DSC.

### 8.3 Summary

Hybrid particleboard produced from sago and waste wood showed better physical, mechanical and thermal properties than sago composite particleboard. Among the hybrid composite particleboard, hybrid (25S:75W) showed the best performance due to the particle ratio (sago or waste wood) have significant influences on it. Hybrid (25S:75W) produced from a mixture of 25 wt% of sago and 75 wt% of waste wood showed higher density of the board. The mechanical and physical properties increased with the density of the board due to

the increased compatibility of the board. High compatibility had caused the pore size between the particles decreased, reduced the moisture penetration, and created better contact between particles. This had increased the effectiveness of stress transfer during the mechanical test.

## CHAPTER 9

### CONCLUSION AND RECOMMENDATIONS

#### 9.1 Comparative Results through the Findings

According to the experimental results in this research, the overall performance of sago composite particleboard were investigated and summarized as in Table 9.1.

**Table 9.1:** Sago composite particleboard overall performance

| Parameters         | Particleboard                                          | Overall Performance |
|--------------------|--------------------------------------------------------|---------------------|
| By Particles Size  | Sago composite particleboard with 0.6mm                | Moderate            |
|                    | Sago composite particleboard with 1.18mm               | Excellent           |
|                    | Sago composite particleboard with 2mm                  | Poor                |
| By Weight Fraction | Sago composite particleboard with 1.18mm + 90wt%       | Poor                |
|                    | Sago composite particleboard with 1.18mm + 80wt%       | Excellent           |
|                    | Sago composite particleboard with 1.18mm + 70wt%       | Moderate            |
| By Density         | Sago composite particleboard with 500kg/m <sup>3</sup> | Poor                |
|                    | Sago composite particleboard with 600kg/m <sup>3</sup> | Satification        |
|                    | Sago composite particleboard with 700kg/m <sup>3</sup> | Good                |
|                    | Sago composite particleboard with 800kg/m <sup>3</sup> | Excellent           |
| By Matrix          | Sago composite particleboard with PF                   | Poor                |
|                    | Sago composite particleboard with UF                   | Excellent           |
| By Hybrid          | HY(25S : 75W)                                          | Excellent           |
|                    | HY(50S : 50W)                                          | Moderate            |
|                    | HY(75S : 25W)                                          | Poor                |

In this study, different type of sago composite particleboard were produced by using different parameters to achieve the optimum properties. Particles size, weight fraction and density were the parameters that greatly affect the performance of sago composite particleboard mechanical strength. The trend of the mechanical strength usually goes up to a certain limit and drop after reaching the optimum performance. The trend goes down due to the voids within the board penetrated by moisture content. Hence, mechanical strength is reduced.

## **9.2 Conclusion**

This thesis investigated the performance of sago composite particleboard. From this study, the successful fabrications of lignocellulos material mixed with adhesive have been carried out. A better understanding of parameters such as particle size, weight fraction, density, matrix and hybrid effects on the thermal analysis, mechanical and physical properties had been studied. From these investigations, several conclusions can be drawn from the experiment.

The mechanical properties were positively correlated with the particle size, weight fraction and density. The increased of the density from  $500 \text{ kg/m}^3$  to  $800 \text{ kg/m}^3$  had increased the mechanical strength except the impact strength. High compatibility had caused the pore size between the particles to decrease and enhanced the stress transfer between matrix and fiber.

Particles size 1.18 mm and weight fraction have great impact on mechanical strength. 1.18 mm particles have better mechanical bonding between particles and matrix compared to 0.6 mm and 2 mm. This was due to sufficient matrix to bond the particles and reduced the voids; resulting in better mechanical strength.

It was found that the mechanical strength improved at different levels as matrix increased until a certain limit of weight fraction. Excessive matrix will cause the densification

and polymerization on the particleboard surface. Hence this will reduce the whole particleboard strength. The higher moisture content will cause the “explode/ blistering” problem due to the high steam pressure had generated within the board during the hot pressing and not be able to escape when the press opens.

In this study, sago particles were mixed with waste wood at ratio 1:3 with urea formaldehyde and converted into hybrid particleboard. This show that the effect of hybrid improved the mechanical strength of whole hybrid composite particleboard.

Water absorption and thickness swelling were affected by the parameter such as density, size of particle, weight fraction of fibers, resin and hybrid condition. High percentage of water absorption was due to higher weight fraction of lignocellulose materials used in the particleboard. Particles with size 1.18mm have better performance on water absorption due to better bonding between the particles and the matrix. Hence, this had caused the high resistance of water to penetrate the particleboard. Smaller particles will cause the highest water absorption due to the more surface area to absorb the water. Urea formaldehyde has better bonding between the sago particles compared to the Phenol formaldehyde. By increasing the matrix loading for both the matrix, this had increased the water resistance.

Scanning electron microscope (SEM) showed weakening in the interface bonding between the sago particles and matrix with intact fiber being pulled out from the matrix or fiber breakage. Besides, existing of voids occurred can be seen from SEM. The breakage and voids at the composite particleboard are the main reason to reduce the whole mechanical strength of particleboard and had reduced the efficiency of load transfer.

Fourier transform infrared (FTIR) spectroscopy allowed the investigation of fibers incorporated with the adhesive. Based on the FTIR, these absorption bands are associated with lignocellulosic components, starch, functional groups and UF feature. FTIR had proof that the sago particles have physical and chemical interaction with the UF and enhance the

mechanical strength. It showed the chemical interaction between UF and starch. Existing of OH group had reduced the mechanical strength of the composite particleboard.

Thermogravimetric (TGA) showed the sago composite particleboard had gone through single decomposition reaction. The sample was decomposed into three steps. Sample with the higher percentage of residues possesses higher thermal stability and achieves high crystallinity.

Differential scanning calorimetry (DSC) result showed sago urea formaldehyde particleboard decompose the lignocellulose fiber into hemicellulose, cellulose, lignin and pyrolysis of cell wall structure. Higher melting temperature occurred on the bigger particles which contain more starch and penetrated by adhesive. Hence, this required more heat to complete the melting process. It may due to the cross-linking reaction with epichlorohydrin that appeared at sago particles. The melting and curing temperature depend on the adhesive and lignocellulose fiber applied on particleboard.

The sago composite particleboards that were produced in this project which had fulfilled the American National Standard ANSI A208.1-2009 and JIS A 5908 Japanese standard. The findings show that the new application for sago composite particleboard is viable for furniture industry ( refer appendix A ). The sago composite particleboard is more environmental friendly, cheaper and denser than hardwood.

### **9.3 Recommendations**

Based on the experiment conducted, the following further studies are recommended in more detail for further improve the lignocellulose fibers as raw materials in the furniture and composite industry.

- 1 Environmental degradation under various weather conditions is required to study the effect of heat and humidity on the particleboard. Bio-deterioration should be carried out

to investigate for susceptible attack and deterioration by fungi and termites, post treatment against the growth of molds on the particleboard surface. Environmental factors such like moisture resistance, sunlight and UV index will influence the interface bonding strength of particleboard through mechanical property analysis.

- 2 Different types of manufacturing process of particleboard should be studied. Manufacturing process such as injection moulding, and extrusion in order to reduce the waste during fabrication can be used and comparison of the properties of the particleboard can be performed.
- 3 Theoretical modeling would be beneficial in analyzing parameters which can be used to improve and optimize the mechanical strength of the particleboard. This is to find the optimized parameter to be applied on the particleboard for superior quality and light weight properties.

## **REFERENCES**

- Abdul Khalil, H. P. S., Jawaid, M. & Abu Bakar, A. (2011). Woven hybrid composites: water absorption and thickness swelling behaviours. *BioResources*, 6(2):1043-1052.
- Abdul Khalil, P. S., Bhat, A. H., Jawaid, M., Amouzgar, P., Ridzuan, R. & Said., M. R. (2010). Agro-wastes: mechanical and physical properties of resin impregnated oil palm trunk core lumber. *Polymer Composites*, 31(4):638-644.
- Abdullah Istek. & Huseyin, S. (2013). The effect of density on particleboard properties. *International Caucasian Forestry Symposium*, PP: 932-938.
- Abdullah, C. K., Jawaid, M., Abdul Khalil, H.P.S., Zaidon, A. & Hadiyane, A. (2012). Oil palm trunk polymer composite : Morphology, water absorption and thickness swelling behaviours. *Peer-Review Article, Bioresources*, 7(3):2948-2959.
- Adachi, S. S., Haing, Z. Z., Nagase, M. & Nakagome, H. (2009). Influence of contained adhesive on the pyrolysis characteristics of wood biomass. *Proceedings of the 5th ISFR*, PP: 29-34.
- Ahmad, H., Kasim, J. & Mohmod, A. L. (2002). Properties of single-layer urea formaldehyde particleboard manufactured from commonly utilized malaysian bamboo (*Gigantochloa scortechinii*). *Journal of Bamboo and Rattan*, 1(2):109–117.
- Ahmed, A. S., Alam, M. A., Piee, A., Rahman, M. R. & Hamdan, S. (2010). Study of physical and mechanical properties of oil palm empty fruit bunch fiber reinforced polypropylene composites. *Journal of Energy & Environment*, 12(1): 16-21.
- Ajayi, B., Olufemi, B., Fuwape, J. A. & Badejo, S.O. ( 2008). Effect of wood density on bending strength and dimensional movement of flake boards from *gmelina arborea* and *leuceana leucocephala*. *IIBCC ,11<sup>th</sup> Int. Inorganic-Bonded Fiber Composite Conference*, PP :260-266.
- Ajayi. B. & Badejo, S.O.O. (2005). Effects of board density on bending strength and internal bond of cement-bonded flakeboards, *Journal of Tropical Forest Science*, 17(2): 228-234.
- Akgul, M., Yalcin, C., Cengiz, G., Ayhan, T. & Unmit, B. (2007). Medium density fiberboard from *Quercus robur*. *Journal of Applied Sciences*, 7(7): 1085-1087.

- Alireza, S. & Ghasemian, A. (2010). Water absorption and thickness swelling behavior of polypropylene reinforced with hybrid recycled newspaper and glass fiber. *Applied Composite Material*, 17:183-193.
- Amer, S., Singha. & Vijay, K. T. (2009). Study of mechanical properties of urea-formaldehyde thermosets reinforced by pine needle power. Peer-reviewed article, *Bioresources.com* 4(1): 292-308.
- American Society for testing and Materials. Standard test method for charpy impact test. A370
- American Society for testing and Materials. Standard test method for water absorptin of plastic. D570  
Philadelphia PA: ASTM,1998
- Amine, M., Antonio, P., Ahmed, A., Fatima, C. & Bertrand, C. ( 2013 ). Polenta cornstarch-mimosa tannin-based urea formaldehyde adhesives for interior grade particleboard. *Journal of Materials and Environmental Science*, 4(4) :496-501.
- Amini, M. H., Rokiah, H., Salim, H. & Nurul, S. S. (2013). Properties of particleboard made from rubberwood using modified starch as binder. *Composite Part B*, 50:259-264.
- Anupama, U. & Ramvir, S. (2012). Prediction of effective elastic modulus of biphasic composite materials. *Modern Mechanical Engineering*, 2(1) : 6-13.
- Anwar, M. K., Paridah, M. T., Hamdan, H., Zaidon, A., Roziela, H . A. & Nordahlia, A. S. (2012). Adhesion and bonding properties of low molecularar weight phenol formaldehyde- treated plylybamboo. *Journal of Tropical Forest Science*, 24(3):379-386.
- Apri, H. I., Irawati, A., Supriyanto. & Susilowati, A. (2014). Effect of resin type, pressing temperature and time on particleboard properties made from sorghum bagasse. *Agriculture, Forestry and Fisheries*, 3(2): 62-66.
- Arabi, M., Faezipour, M. & Gholizadeh, H. (2011). Reducing resin content and board density without adversely affecting the mechanical properties of particleboard through controlling particle size. *Journal of Forestry Research*, 22(4): 659-664.

- Aripin., S. T., Mitsudo, S., Saito, T. & Idehara, T. (2007). Fabrication of unglazed ceramic tile using dense structured sago waste and clay composite. *Indonesia Journal of Materials Science*, 2(2):79-82.
- Atuanya, C.U., Ibhadode, A.O. A. & Igboanugo, A.C. (2011). Potential of Using Recycled Low-Density Polyethylene in Wood Composites Board. *Tribology in Industry*, 33(1):11-17.
- Awg-Adeni, D. S., Abd-Aziz, S., Bujang, K. & Hassan, M. A. (2010). Bioconversion of Sago Residue into Value Added Products. *African Journal of Biotechnology*, 9(14): 2016-2021.
- Azwa, Z. N. & Yousif, B. F. (2013). Thermal Degradation Study of Kenaf Fibre/Epoxy Composites using Thermogravimetric Analysis. 3rd Malaysian Postgraduate Conference (PPC 2013), PP: 256-264.
- Azwa, Z. N., Yousif, B. F., Manalo, A. C. & Karunasena, W. (2013). A review on the degradability of polymetric composites based on natural fibres. *Materials & Design*, 47(1):424-442.
- Bejan, A. & Nield, D.A. (2013). Chapter 2. Heat transfer through a porous medium, Springer, Convection in porous media, P.P:31-46.
- Belini, U. L., Fiorelli, J., Savastano, J. H. & Tomazello, F. M. (2014). Density profile as a tool in assessing quality of new composite. *Materials Research*, 17(1): 138-145.
- Bhaduri, S. K. & Mojurnder, P. (2008). Medium density particleboard from khimp plant. *Natural Product Radiance*, 7(2):106-110.
- Bhupinder, K. (2008). Development and physico-chemical characterization of granular cold water soluble sago starch, Doctor of Philosophy Thesis, Universiti Sains Malaysia.
- Bouafif, H., Ahmed, K., Patrick, P. & Alain, C. (2009). Effects of fiber characteristics on the physical and mechanical properties of wood plastic composites. *Composites: Part A* 40 (2009):1975–1981.
- Butylina. S., Ossi, M. & Timo, K. (2011). Properties of wood fibre-polypropylene composites: effect of wood fibre source. *Applied Composite Material*, 18:101-111.
- Cai, Z., Qinglin, W., Jong, N. L. & Salim, H. (2004). Influence of board density, mat construction and chip type on performance of particleboard made from eastern redcedar. *Forest Products Journal*, 54(12): 236-232.

- Cai, Z., Xianjun, L., Jerrold, E. W. & Altaf, H. B. (2010). Selected properties of particleboard panels manufactured from rice straws of different geometries. *Bioresource Technology*, 101 (2010):4662-4666.
- Carola, E. C. & Mariaenrica, F. (2012) Characterization of Nanocomposites by Thermal Analysis, *Materials*, 5(0): 2960-2980
- Cezary, G., Stanislaw, Z., Marek, K., Arnold, W. & Jacek, M. (2011). Effect of wood particle size on mechanical properties of industrial wood particle-polyethylene composites. *Polymer*, 56(5):1-10.
- Cezary, G., Stanislaw, Z., Marek, K., Arnold, W. & Jacek, M. (2011). Effect of wood particle size on mechanical properties of industrial wood particle-polyethylene composites. *Polymer*, 56(5):375-380.
- Chaharmahali., Mirbagheri, J., Tajvidi, M., Najafi, S. K. & Mirbagheri, Y. (2010). Mechanical and physical properties of wood- plastic composite panels. *Journal of Reinforced Plastics and Composites*, 29(2):310-319.
- Chai, L. L., Sarani, Z., Chia, C. H., Sharifah, N. & Rozaidi, R. (2009). Physico-mechanical Properties of PFComposite Board from EFB Fibres Using Liquefaction Technique. *Iranian Polymer Journal* 18 (11):917-923.
- Chanakan, C. W. & Supachai, P. (2010). Effect of adhesives and particle sizes on properties of composite materials from sawdust. *Proceeding of the 7<sup>th</sup> IMT-GT UNINET and the 3<sup>rd</sup> International PSU-UNS conferences on Bioscience*, PP: 108-121.
- Chandra, V. S., Pandurangadu, V. & Subba, R. (2014). TGA, DSC, DTG properties of epoxy composites reinforced with feather fibers of ‘Emu’ Bird. *International Journal of Innovative Research in Science, Engineering and Technology*, 3(5):13017-13023.
- Chang, L., Zhang, Z. & Breidt, C. (2004). Impact resistance of short fibre/particle reinforced. *Applied Composite Materials*, 11(1):1-15.
- Charles, T. W., Skog, K. E., Ince, P. J. & Michler, P. J. (2007). Critical literature review of relationships between processing parameters and physical properties of particleboard. *USDA*

- Forest Service, Forest Products Laboratory, General Technical Report FPL-10, U.S. Department of Agriculture Forest Service Forest Products Laboratory, Madison, Wis, USA, 1977
- Chung, Y. H., Robert, L. G., Ernest, W. H. & Tang, R. C. (2000). Effect of resin type on properties of steam-press-cured flakeboards. *Forest Products Journal*, 45(1): 57-62
- Conner, A. H. (1996). Urea formaldehyde adhesive resin. *Polymeric Materials Encyclopaedia*, 2:8497-8581.
- Corcione, M. F. (2012). Characterization of nanocomposites by thermal analysis. *Materials*, 5(12):2960-2980.
- Dahmardeh, G., Madhoushi, M., Tabarsa, T. & Nazerian, M. (2011). The manufacture of particleboards using mixture of reed (surface layer) and commercial species (middle layer). *European Journal Wood Products*, 69(3): 341-344.
- Dhakal, Z. Y., Zhang, M. & Richardson, O. W. (2007). Effect of water absorption on the mechanical properties of hemp fibre reinforced unsaturated polyester composites. *Composites Science and Technology*, 67(7-8):1674-1683.
- Dhanalakshmi, S., Ramadevi, P. & Basavaraju, B. (2015). Areca fiber reinforced epoxy composites: effect of chemical treatments on impact strength. *Oriental Journal of Chemistry*, 31(2): 763-769.
- Dungani, R. Islam, M. N., Abdul Khalil, H.P.S., Davoudpour, Y. & Alfi, R. (2014). Modification of the inner part of the oil palm trunk (OPT) with oil palm shell (OPS) nanoparticles and phenol formaldehyde (PF) resin: physical, mechanical and thermal properties. *Bioresources*, 9(1): 455-471.
- Dunky, M. (2015). Urea formaldehyde (UF) adhesive resins for wood. *International Journal of Adhesion & Adhesives*, 18:95-107.
- Ebewele, O. R., Bryan, H. R. & Geogre, E. M. (2004). Behavior of amine-modified urea-formaldehyde-bonded wood joints low formaldehyde urea molar ratios. *Journal of Applied Polymer Science*, 52:689-700.

- Eike, M., Stefan, P., Clemens, S. & Wolfgang, G. A. (2016). Effect of addition of microfibrillated cellulose to urea -formaldehyde on selected adhesive characteristics and distribution in particle board. *Cellulose*, 23(1):571-580.
- Elbadawi, I., Osman, Z., Paridah, T., Nasroun. T. & Kantiner, W. (2015). Mechanical and physical properties of particleboards made from ailanthus wood and UF resin fortified by Acacias tannins blend. *Journal of Materials and Environmental Science*, 6(4): 1016-1021.
- Emmanuel, K. S., Semple, K. E. & Gregory D. S. (2008). Improving core bond strength of particleboard through particle size redistribution. *Wood and Fiber Science*, 40(2):214-224.
- Emmanuel, K. S., Semple, K. E., Seung, W. O., Gregory D. S. (2012). Effect of microcrystalline cellulose, species and particle size on mechanical and physical properties of particleboard. *Wood and Fiber Science*, 44(2):1-9.
- Emmanuel, A. O. (2011). Characterization of phenol formaldehyde adhesive and adhesive-wood particle composites reinforced with microcrystalline cellulose. Master of Science Thesis, Auburn University.
- Enayati, A. A., Eslah, F. & Farhid, E. (2013). Evaluation of particleboard using multivariate regression equations based on structural factors. *Journal Agriculture Science Technology*, 15: 1405-1413.
- Eslah, F., Enayati, A. A., Tajvidi, M. & Faezipour, M. M. (2012). Regression Models for the Prediction of Poplar Particleboard Properties based on Urea Formaldehyde Resin Content and Board Density. *Journal Agriculture Science Technology*, 14(6): 1321-1329.
- Esposito, C. & Mariaenrice, F. (2012). Characterization of Nanocomposites. *Thermal Analysis Materials*, 5(12): 2960-2980.
- Evi, G., Takemi, M. & Masao., Y. (2008). A Simple Model to Simulate Sago Palm Growth. *World Conference on Agricultural Information and IT, IAALD AFITA WCCA*, pp 55-59.
- Fabrice, R., Christophe, B. & Gregory, G. D. B. (2012). Compressive and tensile behaviour of PLLA Matrix composites reinforced with randomly dispersed flax fibres. *Applied Composite Material*, 19: 171-188.

- Fatih, M. & Kadir, K. (2008). Some properties of Eucalyptus wood flour filled recycled high density polyethylene polymer-composites. *Turkish Journal Agriculture and Forestry*, 32:537-546.
- Fauzi, F., See, P. H, Ching, K. M. & Wahyu, H. (2012). Properties enhancement of rubber wood particleboard laminated with lowdensity polyethylene (LDPE) Resin. *Journal Ilmu dan Teknologi Kayu Tropis*, 10(2):186-194.
- Fleck, N. A. & Smith, R. A. (1981). Effect of Density on Tensile Strength, Fracture Toughness and Fatigue Crack Propagation Behaviour of Sintered Steel. *Power Metallurgy*, 3: 121-125.
- Fu, S. Y., Feng, X. Q., Bernd, L. & Yiu, W. M. (2008). Effects of particle size, particle/matrix interface adhesion and particle loading on mechanical properties of particulate-polymer composites. *Composites Part B: Engineering*, 39(6):933–961.
- Gagan, B., Singh, V. K., Patil, P. P. & Shweta, R. (2016). Water absorption and thickness swelling characterization of chicken feather fiberand extracted fish residue powder filled epoxy based hybrid biocomposite. *International Journal of Waste Resources*, 6(3):1-6
- Gassan, J. & Bledzki, A.K. (2000). Possibilities to improve the properties of natural fiber reinforced plastics by fiber modification- Jute polypropylene composites. *Applied Composite Materials*, 7:373-385.
- Geetanjali, D. & Sandhayarani, B. (2016). Physical, mechanicaland water absorption behaviour of coir fiber reinforced epoxy composites filled with  $Al_2O_3$  particulates, *Materials Science and Engineering*, 115 (1): 1-10.
- Gilles, S., Nihat, S.C., Callum, A. S. H. & Mark, H. (2000). RTM hemp fibre-reinforced polyester composites. *Applied Composite Materials*, 7:341-349.
- Grigorious, A. H. (2000). Straw-wood composites bonded with various adhesive system. *Wood Science and Technology*, 34(4):355-365.
- Gurses, K. S., Mindivan, K. G., Dogar, C. & Akturk, C. (2013). Preparation and characterization of urea/formaldehyde/ rosa Canina sp. seeds composites. *Advances in Applied Physics and Materials Science Congress*, 125(2):368-373.

- Habibi, Y., El-Zawawy, W., Ibrahim, M. M. & Dufresne, A. (2008). Processing and characterization of reinforced polyethylene composites made with lignocellulosic fibres from Egyptian agro-industrial residues. *Journal of Composites Science and Technology*, 68: 1877-1885.
- Hairul, A., Eko, K. & Mastariyanto, P. (2016). Metroxylon sago fiber reinforced composite processed by vacuum. Research Gate, <https://www.researchgate.net/publication/267226186>.
- Hamid, N. H., Mohd, F. Y., Noraishah, H. & Micheal, D. H. (2015). Selected properties of hybrid particleboard composite made from oil palm empty fruit bunch (EFB) and merpauh (Irvingia Malayan Olive) particles bonded with Melamine Urea Formaldehyde resin. *International Journal of Development Research*, 5(3):3913-3920.
- Hasan, M. A.W., Tania, I., Khandkar, S. R., Sourav, B. R., Islam, M. A., Arifa, S. & Islam, M. N. (2015). Hybrid particleboard from wood and non-wood species: physical and mechanical properties as a function of particle mixing ratio. *Advances in Research*, 3(5): 502-511.
- Hassine Bouafif., Ahmed, K., Patrick, P. & Alain, C. (2009). Effects of fiber characteristics on the physical and mechanical properties of wood plastic composites. *Composites : Part A*, 40 :1975-1981.
- Hassine Bouafif., Ahmed, K., Patric, P., Alain, C. & Bernard, R. (2009). Wood particle/ high-density polyethylene composite : thermal sensitivity and nucleating ability of wood particles. *Journal of Applied Polymer Science*, 113:593-600.
- Hatakeyama, T. & Quinn, F. X. (1999). *Thermal Analysis- Fundamentals and Applications to Polymer Science*. John Wiley & Sons.
- Hazwani, L., Jamaludin, K., Nur Atiqah, N. J. & Izyan, L. M. M. (2014). Influence of board density and particle sizes on the homogenous particleboard properties from kelempayan (*Neolamarckia cadamba*). *International Journal of Latest Research in Science and Technology*, 3(6): 173-176.
- Hazwani, L., Jamaludin, K., Nur, A. N. J. & Izyan, L. M. M. (2014). influence of board density and particle sizes on the homogenous particleboard properties from kelempayan (*Neolamarckia cadamba*). *International Journal of Latest Research in Science and Technology*, 3(6):173-176.

- Hornsby, P.R., Hinrichsen, E. & Tarverdi, K. (2007). Preparation and properties of polypropylene composites reinforced with wheat and flax straw fibres. *Journal of Materials Science*, 32:1009-1015.
- Hussain, A. A. S., Esmaeel, S. N., Alazi, S. A. & Daear, H. F. (2013). Particle weight fraction effect on bending of epoxy particle composite. *International Journal of Application or Innovation in Engineering of Management*, 2(11):1-10.
- Ibrahim, M. N.A., Md. Ghani. & N. Nen (2007). Formulation of lignin phenol formaldehyde resins as a wood adhesive. *The Malaysian Journal of Analytical Sciences*, 11( 1): 213-218.
- Idris, U. D., Aigbodion, V. S., Atuanya, C. U. & Abdullahi, J. (2011). Eco-Friendly (Water melon peels): alternatives to wood-based particleboard composites. *Tribology in Industry*, 33(4):173-181.
- Ihak, S. & Suzuki, S. (2014). Dimensional Stability and Mechanical Properties of Strandboard made from Bamboo. *Bio Resources*, 9(1): 1159-1167.
- Inamdar, S. S. & Rathod, K. K. (2013). Study of characteristics of partial replacement of phenol by coconut shell flour in a phenol formaldehyde resin. *International Journal of Research in Engineering and Technology*, 2(9): 314-32.
- Indira, K.N., Jyotishkumar, P. & Sabu, T. (2013). Mechanical properties and failure topography of banana fiber PF macrocomposites fabricated by RTM and CM techniques. *ISRN Polymer Science*, 2013: 1-6.
- Ishak, M. R., Leman, Z., Sapuan, S. M., Edeerozey, A. M. M. & Othman, I. S. (2010). Mechanical properties of kenaf bast and core fibre reinforced unsaturated polyester composites. *IOP Conference Series: Materials Science and Engineering*, 11(1):1-6.
- Islam, M., Sinin, H., Sobuz, H.R., Rahman, R. & Ahmed, A.S. (2012). Thermal and Decay-resistance Properties of Tropical Wood-plastic Composites. *Journal of Composite Materials*, 47(12): 1493-1500.
- Islam, M. S., Sinin, H., Jusoh, I., Rezaur, R. M. & Abu, S. A. (2012). The effect of alkali pretreatment on mechanical and morphological properties of tropical wood polymer composites. *Materials and Design*, 33:419-424.

- Iswanto, I. A. & Supriyanto, A. S. (2014). Effect of resin type, pressing temperature and time on particleboard properties made from sorghum bagasse. *Agriculture, Forestry and Fisheries*, 3(2):62-66.
- Jani Saad, M. & Izran, K., (2012). Mechanical and physical properties of low density kenaf core particleboards bonded with different resins. *Journal of Science and Technology*, 4(1):17-32.
- Javad, H., Aziz, H. & Nor, M. M. A. R. (2015) Improving the thermal properties of fluoroelastomer (Viton GF-600S) using acidic surface modified carbon nanotube. *Polímeros*, 25(4): 392-401.
- Jawaid, M., Khalil, H. P. S. A. & Bakar, A. A. (2011). Hybrid composites of oil palm empty fruit bunches/woven jute fiber: chemical resistance, physical, and impact properties. *Journal of Composite Materials*, 45(24):2515-2522.
- Jia, G. B., Rokiah, H., Othman, S., Wan, N. A . W . N., Lee, C .Y., Salim, H., Tomoko, S., Masatoshi, S. & Mahamad, H .I. (2014). The influence of starch in oil palm trunk particleboard without synthetic adhesive. *Peer-review article Lignocellulose*, 3(2): 119-130
- Jin, H. Kwon., Nadir, A. & Tae, H. H. (2014). Combined effect of thermoplastic and thermosetting adhesives on properties of particleboard with rice husk core, *Material Research*, 17(5):1309-1315.
- Jirapat, P., Sureurg, K. & Pannipa, C. (2015). Curing behavior and bonding performance of urea formaldehyde resin admixed with formaldehyde scavenger. *Wood Research*, 60(4):645-654.
- JIS A 5908. (1994). Japanese Industrial Standard Particle Boards, Japanese Standards Association.
- Jonathan, C. G. (2009). Screw withdrawal strength in Wood's assemblies. *Oregon Wood Innovation Center*, pp 1-31.
- Jovan, M., Madan, P., Milanka. & Ivana, D. M. (2007). Edge screw withdrawal resistance in conventional particleboard and osb-influence of the particles type. *Glasnik Sumarskog Fakulteta*, 95:109-117.
- Juliana, A. H., Paridah, M. T., Rahim, S. & Awan. N. (2012). Properties of Particleboard made from Kenaf as a Function of Particle Geometry. *Materials and Design*, 34: 406-4119.
- Karastergiou, P. S. & Philippou, J. L. (2000). Thermogravimetric analysis of fire retardant treated particleboard. *Wood and Fire Safety*, pp 385-394.

- Kasim, J., Abd Jalil, Hj.A., Jalaludin, H., Zaidon, A. A., Latid, M. & Mohd Nor, M.Y. (2001). Properties of particleboard manufactured from commonly utilized malaysian bamboo (*Gigantochloa scortechinii*). *Pertanika Journal of Tropical Agricultural Science*, 24(2) : 151-157.
- Khalil, A., Shaikh, S. N., Nudrat, Z. R. & Farzana, H. (2013). The effect of silica on the properties of marble sludge filled hybrid natural rubber compisites. *Journal of King Saud University Science*, 2013(25):331-339.
- Khazaei, J. (2008). Water absorption characteristics of three wood varieties. *Cercetari Agronomice in Moldova*, 41(2):134-145.
- Kimoto, K., Ishimori, E., Sasaki, H. & Maku, T. (2015). Effect of resin content and particle dimension on the physical and mechanical properties of low density particle boards. *Wood research*, 32:1-14.
- Kumar, A. & Flynn, P. C. (2006). Uptake of fluids by boreal wood chips: implications for bioenergy. *Fuel Processing Technology*, 87: 605-608.
- Leng, W., John, F. H. & Mehdi, T. (2017). Effects of density, cellulose nanofibrils addition ratio, pressing method and particle size on the bending properties of wet-formed particleboard. *BioResources*, 12(3):4986-5000.
- Li, X., Cai, Z., Jerrold, E. W. & Altaf, H. B. (2010). Selected properties of particleboard panels manufactured from rice straws of different geometries. *Bioresource Technology* 101: 4662-4666.
- Li, X., Tabil, L. G., Panigrahi, S. & Crerar, W. J. (2009). The influence of fiber content on properties of injection molded flax fiber-HDPE. *Canadian Biosystems Engineering*, 8(148):1-10.
- Liliana, B., Nicolae, T. & Adriana, S. (2013). Effect of Hybridization on Stiffness Properties of Woven Textile Composites. *Applied Composite Materials*, 20(2):185–194.
- Lopez, J. P., Pere, M., Angles, M. P., Mansouri, N. E. E. I., Sam, B. & Fabiola, V. (2012). Analysis of the tensile modulus of polypropylene composites reinforced with stone ground wood fibers. *BioResources*, 7(1):1310-1323.
- Luo, J., Zhang, J. Z., Luo, J., Li, J. Z. & Gao, Q. (2015). Effect of melamine allocation proportion on chemical structures and properties of melamine-urea-formaldehyde resins. *BioResources*, 10(2):3265-3276.

- Malhotra, N., Sheikh, K. & Rani, S. (2012). A review on mechanical characterization of natural fiber reinforced polymer composites. *Journal of Engineering Research and Studies*, 3(1):75-80.
- Mamza, P. A. P., Ezech, E. C., Gimba, E. C. & Arthur, D. E. (2014). Comparative study of phenol formaldehyde and urea formaldehyde particleboards from wood waste for sustainable environment. *International Journal of Scientific & Technology Research*, 3(9):53-61.
- Maneesh, T., Singh, V. K., Gope, P. C. & Arun, K. C. (2012). Evaluation of mechanical properties of bagasse-glass fiber reinforced composite. *Journal Mater Environment Science*, 3 (1):171-184.
- Marek Kociszewski., Cezary, G., Arnold, W., Stanislaw, Z. & Jacek, M. (2012). Effect of industrial wood particle size on mechanical properties of wood-polyvinyl chloride composites. *European Journal of Wood Products*, 70:113-118.
- Mariko, A., Shin, S., Zar, Z. H., Momoko, N. & Hideki, N. (2009). Influence of contained adhesives on the pyrolysis characteristics of wood biomass, *The 5th ISFR*, PP 29-34.
- Mário, V. S., Danillo, W. S., Rafael, F. M. & Lourival, M. M. (2013). Use of maize cob for production of particleboard. *Ciênc. agrotec.*, Lavras, 37(4):330 – 337.
- Md Saiful, Islam., Reza, M., & Hossein, R. (2012). The effect of nanoparticles percentage on mechanical behaviour of silica-epoxy nanocomposites. *Journal of Nanoscience*, Article ID 275037, 10 pages.
- Md. Rezaur, R., Sinin, H., Abu, S. A., Islam, M. S., Talib, Z. A., Wan Abdullah, W. F. & Che, M. M. S. (2011). Thermogravimetric analysis and dynamic young's modulus measurement of N,N-Dimethylacetamid-impregnated wood polymer composites. *Journal of Vinyl & Additive Technology*, 17(3):1-7.
- Mehanička, S. (2016). Resin Content and Board Density Dependent Mechanical Properties of One-Layer Particleboard Made from Willow (*Salix viminalis*). *Drvna Industrija*, 67 (2):127-131.
- Mettler. (2002). UserCom 1/2000, Chapter 11: Information for users of Mettler Toledo thermal analysis systems, [http://www.masontechnology.ie/x/Usercom 11.pdf](http://www.masontechnology.ie/x/Usercom%2011.pdf). PP 1-28.

- Migneault, S., Koubaa, A., Erchiqui, F., Chaala, A., Englund, K. & Krause, C. (2008). Effect of fiber length on processing and properties of extruded wood-fiber/HDPE composites. *Journal of Applied Polymer Science*, 110(2):1085-1092.
- Miyamoto, K., Suzuki, S., Inagaki, T. & Iwata, R. (2002). Effects of Press Closing Time on the Mat Consolidation Behavior during Hot Pressing and Linear Expansion of Particleboard. *Journal of Wood Science*. 48: 309–314.
- Morteza, N., Mohammad, D. G., Mehdii, S., Heman, S. & Mohammad, H. T.(2011). Properties of three-layer particleboard made from wood of athel (*Tamarix Aphylla*) and pruning particles of almond (*Amygdalus Communis*) and pistachio (*Pistacia Vera*), *Journal of Basic and Applied Scientific Research* , 1(8)837-843.
- Moubarik, A., Allal, A., Pizzi, F. C. & Charrier, B. (2010). Preparation and mechanical characterization of particleboard made from maritime pine and glued with bio-adhesives based on cornstarch and tannins. *Maderas: Ciencia Tecnologia*, 12(3):189-197.
- Nadir Ayrilms. (2008). Effect of compression wood on dimensional stability of medium density fibreboard. *Silva Fennica*, 42(2): 285–293.
- Natasa, C., Matjaz, K. & Sergej, M. (2011). Properties of particleboards made by using an adhesive with added liquefied wood. *Original Scientific Article, MTAEC* 9, 45(3):241-245.
- Navdeep Malhotra, Khalid, S. & Sona, R. ( 2012 ). A review on mechanical characterization of natural fiber reinforced polymer composites. *Journal of Engineering Research and Studies*, 3(1): 75-80.
- Nirdosha, G. & Setunge, S. (2006). Formulation and process modelling of particleboard production using hardwood saw mill waste using experimental design. *Thirteen International Conference on Composites Structures*. 75: 1-4
- Njokua, R. E., Okona,A.E. & Ikpakia, T.C. (2011). Effects of variation of particle size and weight fraction on the tensile strength and modulus of periwinkle shell reinforced polyester composite. *Nigerian Journal of Technology*, 30(2): 87-93.
- Nourbakhsh, Amir. & Alireza, A. (2010). Wood plastic composites from agro-waste materials: analysis of mechanical properties. *Bioresource Technology* 101: 2525-2528.

- Nur Izreen, F. A., Zaidon, A., Rabiatal, A. M. A., Bakar, E. S. & Paridah, M. T. (2011). Enhancing the properties of low density hardwood *Dyera costulata* through impregnation with Phenolic resin admixed with formaldehyde scavenger. *Journal of Applied Sciences*, 11(20): 3474-3481.
- Nurhazwani. O., Jawaidd. M., Tahir, P. M., Juliana, A. H. & Abdul, H. S. (2016). Hybrid Particleboard Made from Bamboo (*Dendrocalamus asper*) Veneer Waste and Rubberwood (*Hevea brasilienses*). *BioResources*, 11(1): 306-323.
- Nurul, S. S., Rokiah, H., Salim, H., Mohd Hazim, M. A., Othman, S. & Mohd Ezwanselamat. (2013). Rubberwood particleboard manufactured using epichlorohydrin-modified rice starch as a binder. *Cellulose Chemical Technology*, 50(2):329-338.
- Nwanonenyi, S. C., Obidiegwu, M. U. & Onuegbu, G. C. (2013). Effects of Particle Sizes, Filler Contents and Compatibilization on the Properties of Linear Low Density Polyethylene Filled Periwinkle Shell Powder. *The International Journal of Engineering and Science*, 2(2): 1-8.
- Oksman, K. (2000). Mechanical Properties of Natural Fibre Mat Reinforced Thermoplastic. *Applied Composite Materials*. 7(5):403-414.
- Olufemi, A. S., Abiodun, O. O., Omaorogedoh, P. & Adeogun, F. (2012). Evaluation of cement-bonded particle board produced from *afzelia Africana* wood residues. *Journal of Engineering Science and Technology*, 7(6):732-743.
- Omar, N. N., Iskandar, S. M., & Rokiah, H. (2017). Fabrication of *Rhizophora* particleboard bonded with *Rhizophora*-based Phenol Formaldehyde resin as a potential phantom material. *Journal of Physical Science*, 28(1):111-128.
- Onuorah, E. O. (2011). The effects of some manufacturing variables on the properties of particleboard. *Nigerian Journal of Technology*, 20(1): 19-41.
- Onuorah, E.O. (2011). The effects of some manufacturing variables on the properties of particleboard. *Nigerian Journal of Technology*, 20(1):19-41.
- Osemeahon, S. A. & Dimas, B. J. (2014). Development of urea formaldehyde and polystyrene waste as copolymer binder for emulsion paint formulation. *Journal of Toxicology and Environmental Health Sciences*, 6(3):75-88.

- Othman, N., Mohammad, J., Paridah, M. T., Abdul, H. J. & Abdul, H. S. (2016). Hybrid particleboard made from bamboo (*Dendrocalamus asper*) veneer waste and rubberwood (*Hevea brasilienses*). *Bioresources.com*, 11(1):306-323.
- Ozturk. (2010). Effect of fiber loading on the mechanical properties of kenaf and fiberfrax fiber-reinforced phenol-formaldehyde composites. *Journal of Composite Materials*, 44(19):2265-2288.
- Papadopoulos, N. (2006). Property comparison and bonding efficiency of UF and PMDI bonded particleboards as affected by kety process variables. *BioResources*, 1(2): 201-208.
- Paul, A. P. M., Emmanuel, C. E., Gimba, E. C. & David, E. A. (2014). Comparative study of phenol formaldehyde and urea formaldehyde particleboards from wood waste for sustainable environment. *International Journal of Scientific & Technology Research*, 3(9): 53-61.
- Paul, W., Ohlmeyer, M., Leithoff, H., Boonstram, J. & Pizzi, A. (2006). Optimising the Properties of OSB by a One Step Heat Pre-treatment Process. *Holz-rohwerkst*, 64(3): 227-234.
- Rafael, F. M., Lourival, M. M., José, B. G. J., Rosimeire, C. D. S. & Lina, B. (2009). The adhesive effect on the properties of particleboards made from sugar cane bagasse generated in the distiller. *Revista De Ciências Agrárias* 210, 32(2):209-218.
- Rafael, R. D. M., Diego, M. S., Ricardo, R. C. S. & Talita, D. P. (2014). Physical and mechanical properties of particleboard manufactured from wood, bamboo and rice husk. *Materials Research*, 17(3): 682-686.
- Raghavendra, N. & Ramamurthy, V. S. (2014). Effect of particle size and weight fraction of alumina reinforcement on wear behavior of aluminum metal matrix composites. *International Journal of Innovative Research in Science, Engineering and Technology*, 3(4):11191-11198.
- Ramadan, A. N., Mefarrej, H. A. A., Abde, M. A. & Alshahrani, T. S. (2014). Effect of tree species and wood particle size on the properties of cement-bonded particleboard manufacturing from tree prunings. *Journal of Environmental Biology*, 35: 961-971.
- Randa, K. H., Asrar, A. S., Suror, N. E., Sahar, A. A. & Halah, F. D. (2013). Particle weight fraction effect on bending of Epoxy particle composite. *International Journal of Application or Innovation in Engineering of Management*, 2(11)-1-10.

- Reza, A., Azman, H., Khaliq, M. & Zainoha, Z. (2015). Rice Husk Filled Polymer Composites. International Journal of Polymer Science, Volume 2015, Article ID 501471, 32 pages
- Ricardo, G. A. M., José, M. M., Anand, R. S., Antônia, A. S. C., Gustavo, H. D. T., Thomas, M. V. & Lourival, M. M. (2016). Coir and Sisal Fibers as Fillers in the Production of Eucalyptus Medium Density Particleboards – MDP. Materials Research. 19(6): 1429-1436.
- Rowell. (2012). Handbook of Wood Chemistry and Wood Composites, 2nd edition, CRC Taylor & Francis Group.
- Rusli, R. & Hashim, W. S. (2013). Properties of small diameter acacia hybrid logs for biocomposites production. Borneo Science, 33:9-15.
- Salem, E. Z., Adam, A. A., Entesar, A. H. & Elkady, M. A. (2014). Properties of particleboard based on date palm fronds as renewable Egyptian lignocellulosic materials. International Journal of Innovation and Scientific Research, 9(2):326-334.
- Salem, E. Z., Adam, A. A., Entesar, A. H. & Elkady, M. A. (2015). Renewable egyptian lignocellulosic materials as alternative raw material for particleboard manufacturing. International Journal of Innovation and Scientific Research, 18(2):262-272.
- Samariha, A., Amir, H. H., Ismail, G. & Behzad, B. (2011). Short-term water absorption and thickness behavior of recycled polyethylene reinforced with bagasse flour. Middle-East Journal of Scientific Research, 8(5): 971-974.
- Samie, S., Atefeh, N., Mohammad, R. A. & Samaneh, A. (2015). Preparation and characterization of the modified PEEK/CNTs- nanocomposites. Journal of Applied Physics, 115: 1-5.
- Sari, B., Nadir, A., Gökyay, N., Mehmet, B., Esat, G. & Selahattin, B. (2012). Effects of chemical composition of wood and resin Type on properties of particleboard. Peer-reviewed article, Lignocellulose, 1(3):174-184.
- Sarifuddin, N., Ismail, H. & Ahmad, Z. (2013). The effect of kenaf core fibre loading on properties of low density polyethylene/ thermoplastic sago starch/kenaf core fiber composites. Journal of Physical Science, 24(2):97–115.

- Scatolino, M. V., Danillo, W. S., Rafael, F. M. & Lourival, M. M. (2013). Use of maize cob for production of particleboard. *Ciênc. agrotec.*, Lavras, 37(4):330 – 337.
- Sculpture Sawmillers, (2016) <http://www.sculptureatsawmillers.com>
- Sebe, N. S., Cetin, C., Hill, A. S. & Hughes, M. (2000). RTM hemp fibre-reinforced polyester composites. *Applied Composite Materials*, 7(5-6):341-349.
- Sim, S. F., Nurul, A. L. M. I., Noor, S. P. S. & Samsudin, S.N. S. (2012). Computer-assisted analysis of fourier transform infrared (FTIR) spectra for characterization of various treated and untreated agriculture biomass. *Bioresources*, 7(4): 5367–5380.
- Singha, A. S. & Vijay, K. T. (2008). Effect of fibre loading on urea-formaldehyde matrix based green composites. *Iranian Polymer Journal*, 17(11):861-873.
- Singha, A. S. & Vijay, K. T. (2009). Study of mechanical properties of urea-formaldehyde thermosets reinforced by pine needle powder. *Bioresources*, 4(1): 292-308.
- Siva, I., Winowlin, J. J. T., Sankar, I., Amico, S. C. & Ravindran, D. (2013). Effect of fiber volume fraction on the mechanical properties of coconut sheath/usp composite. *Journal of Manufacturing Engineering*, 8(1):060-063.
- Sotannde, A. O., Oluwadare, O., Ogedoh. & Adeo- gun, P. F. (2012). Evaluation of cement-bonded particle board produced from *Afzelia africana* wood residues. *Journal of Engineering Science and Technology*, 7(6):732-743.
- Sreekala, M. S., Kumaran, M. G., Seena, J., Maya, J. & Sabu, T. (2000). Oil palm fibre reinforced phenol formaldehyde composites: influence of fibre surface modifications on the mechanical performance. *Applied Composite Materials*, 7:295-329.
- Stark, A., Pouya, K. & Mnolis, K. (2007). Systematic discovery and characterization of fly micro RMAS using 12 drosophila genomes. *Genome Research*, 17(12):1865-1879.
- Suffian, M., Ormondroyd, G. A. & Hale, M. D. (2009). Comparisons of particleboard produced from ACACIA hybrid and a UK commercial particleboard furnish from recycled wood. *Journal of Tropical Forest Science*, 22(3):227-236.

- Sulaiman, N. S., Hashim, R., Amini, M. H. M., Sulaiman, O. & Hiziroglu, S. (2013). Evaluation of the properties of particleboard made using oil palm starch modified with epichlorohydrin. *BioResources*, 8(1):283–301.
- Suvarna, A. S., Akash, K., Jackson, P., Sunil, K., Basavaraju, B., Pramod, V.B. & Suresh , K.V. (2015). Mechanical properties of abaca fiber reinforced urea formaldehyde composites. *Material Science Research India*, 12(1):54-59.
- Takian, F. & Islam, M. A. (2013). Degradation behaviour of natural fiber reinforced polymer matrix composites. *SciVerse Science Direct, Procedia Engineering*, 56:795-800.
- Thomas William Goodrich. ( 2009 ).The physical properties and microstructural changes of composite materials at elevated temperature. Master of science in Mechanical Engineering, Blacksburg,VA
- Toh, W. Y., Lai, J. C. & Wan, A.W. A. R. (2011). Influence of Compounding Methods on Poly(vinyl) Alcohol/Sago Pith Waste Biocomposites: Mechanical and Water Absorption Properties. *Sains Malaysiana*, 40(7): 719-724.
- Toh, W. Y., Wan, A.W. A. R. & Lee, T. S. (2011). Properties and morphology of poly (vinyl alcohol) blends with sago pith bio-filler as biodegradable composites. *Journal of Vinyl and Additive Technology*, 17(3): 184-189.
- Vanchai, L. (2010). Physical and mechanical properties of particleboard from Bamboo Waste. *International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering*, 4(4):276-280.
- Vanreppelen, K., Schreurs, S., Kuppens, T., Thewys, T., Carleer, R. & Yperman, J. (2013). Activated carbon by co-pyrolysis and steam activation from particle board and melamine formaldehyde resin: production, adsorption properties and techno economic evaluation. *Journal of Sustainable Development of Energy, Water and Environment Systems*, 1(1): 41-57.
- Vassilion, V. & Ioannis, B. (2005). Screw withdrawal capacity used in the eccentric joints of cabinet furniture connectors in particleboard and MDF. *Journal Wood Sciences*, 51: 572-576.

- Vilay, V., Mariatti, M., Mat Taib, R. & Todo, M. (2008). Effect of fiber surface treatment and fiber loading on the properties of bagasse fiber-reinforced unsaturated polyester composites. *Composites Science and Technology*, 68(3-4): 631–638.
- Wanchai, P., Buhnnum, K., Sureurg, K. & Maruay, M. (2009). Effect of pre-treatment and heat treatment on tensile and thermal behaviour pf parawood strands. *Songklanakarin Journal of Science and Technology*, 31(3):323-330.
- Wang, W., Sain, M. & Cooper, P. A. (2005). Hygrothermal weathering of Rice Hull/HDPE composites under extreme climatic conditions. *Polymer Degradation and Stability*, 90(3):540-545.
- Wong, E. D., Zhang, M., Wang, Q. & Kawai, S. (1999). Formation of the density profile and its effects on the properties of particleboard. *Wood Science and Technology*, 33: 327-340.
- Wong, K. J., Zahi, S., Low, K. O., & Lim, C.C. (2010). Fracture characterisation of short bamboo fibre reinforced polymer composites. *Materials and Design*, 31(9): 4147-4154.
- Woraphot, P., Abideng, H. & Thaniya, K. (2011). Feasibility study of cement composites with para wood particle wastes: strength and durability. *Global NEST Journal*, 13(2):182-191.
- Wu, Q. (2001). Comparative properties of bagasse particleboard. *International Symposium on Utilization of Agricultural and Forest Residue Nanjing , China*. PP: 1-10.
- Wu, Z., Lee, Q. J. N. & Hiziroglu, S. (2004). Influence of Board Density, Mat Construction, and Chip Type on Performance of Particleboard made from Eastern Red Cedar. *Forest Product Journal*, 54(12): 226-232.
- Xu, J., Widyorini, R. & Yamauchi, H. ( 2006). Development of binderless fibreboard from kenaf core. *Journal Wood Science*, 53: 236-243.
- Yaacob, M. C., Amin., I. M., Hashim, K. & Bakar, B. A. (2011). Optimization of reaction conditions for carboxymethylated sago starch. *Iranian Polymer Journal*, 20(3):195–204.
- Yang, F., Benhua, F., Zhengxin, W., Liang, P . & Yunshui, Y. (2014). Selected properties of corrugated particleboard made from bamboo waste laminated with medium-density fiberboard panels. *Peer-Reviewed Article, BioResources*, 9(1):1085-1096.

- Yee, T. W., Lai, J.C. & Wan, A. W. A. R. (2011). Mechanical and water absorption properties of poly(vinyl alcohol)/sago pith waste biocomposites. *Journal of Composite Materials*, 45(11):1201-1207.
- Yong, S. O. & Sung, S. L.(2012). Use of buckwheat stalk in particleboard bonded with urea-formaldehyde resin adhesive. *Cellulose Chemical Technology*, 46 (9-10): 643-647.
- Yue, K., Liu, W., Chen, Z., Lu, X. & Lu,W. (2016). Investigation of the creep property of fast-growing poplar wood modified with low molecular weight resins. *Bioresources.com*, 11(1):1620-1633.
- Zeki, C. & Turgay, A. (2015). Physical and mechanical properties of nanoreinforced particleboard composites. *Maderas. Ciencia Tecnologia*, 17(2):319-334.
- Zhang, Y., Gu, J., Tan, H., Mingwei, D., Zhu, L. & Weng, X. (2011). Straw based particleboard bonded with composite adhesives. *BioResources*, 6(1):464-476.
- Zhongli, P., Xheng, Y., Zhang, R. & Bryan, M. J. (2007). Physical properties of thin particleboard made from saline eucalyptus. *Industrial Crops and Products*, 26(2):185-194.

## APPENDICES

### Appendix A – Board Application

Sago composite particleboard that fulfill the American and Japanese standard.

| Type of particleboard                                  | M-O | M-1<br>Commercial | M-S<br>Commercial | M-2<br>Commercial | M-3<br>Interior stair tread |
|--------------------------------------------------------|-----|-------------------|-------------------|-------------------|-----------------------------|
| Sago composite particleboard with 1.18mm               | X   | X                 |                   | X                 | X                           |
| Sago composite particleboard with 0.6mm + 80wt%        | X   |                   |                   |                   |                             |
| Sago composite particleboard with 0.6mm + 85wt%        | X   |                   |                   |                   |                             |
| Sago composite particleboard with 2mm + 80wt%          | X   |                   |                   |                   |                             |
| Sago composite particleboard with 1.18mm + 90wt%       |     |                   |                   | X                 |                             |
| Sago composite particleboard with 1.18mm + 85wt%       |     |                   |                   | X                 |                             |
| Sago composite particleboard with 1.18mm + 80wt%       | X   | X                 | X                 |                   |                             |
| Sago composite particleboard with 2mm + 90wt%          | X   | X                 | X                 |                   |                             |
| Sago composite particleboard with 2mm + 85wt%          | X   | X                 | X                 |                   |                             |
| Sago composite particleboard with 2mm + 80wt%          | X   | X                 | X                 |                   |                             |
| Sago composite particleboard with PF (15wt%)           |     | X                 |                   |                   |                             |
| Sago composite particleboard with PF (20wt%)           |     |                   | X                 |                   |                             |
| Sago composite particleboard with UF (10wt%)           |     |                   |                   | X                 |                             |
| Sago composite particleboard with UF (15wt%)           |     |                   |                   | X                 |                             |
| Sago composite particleboard with 700kg/m <sup>3</sup> | X   | X                 | X                 | X                 |                             |
| Sago composite particleboard with 800kg/m <sup>3</sup> | X   | X                 | X                 | X                 |                             |
| HY(75S : 25W)                                          | X   | X                 |                   |                   |                             |
| HY(25S : 75W)                                          | X   | X                 |                   |                   |                             |

## **Appendix B - Publication**

1. Tay, C. C., Sinin, H. & Mohd Shahril, B. O. (2015). The effect of weight fraction and size on the properties of sago particles Urea Formaldehyde particleboard. *Jurnal Teknologi*, 73(1) : 61-67.
2. Tay, C. C., Sinin, H. & Mohd Shahril, B. O. (2014). Water absorption and thickness swelling behavior of sago particles Urea Formaldehyde particleboard. *International Journal of Science and Research*, 3(12): 1375-1379.
3. Tay, C. C., Sinin, H. & Mohd Shahril, B. O. (2016). Urea Formaldehyde composites reinforced with sago fibers analysis by FTIR, TGA and DSC. *Advances in Materials Science and Engineering*, 2016 :1-10. ID : 5954636.
4. Tay, C. C., Sinin, H. & Mohd Shahril, B. O. (2015). Mechanical properties of sago/Urea Formaldehyde particleboard affected by the weight fraction of sago, *EDP Sciences, MATEC Web of Conferences* 27.01001
5. Tay, C. C., Sinin, H. & Mohd Shahril, B.O. (2016). Properties of sago particleboard resonated with UF and PF Resin. *Advances in Materials Science and Engineering*, 2016: 1-12. ID : 5323890.
6. Tay, C. C., Sinin, H. & Mohd Shahril, B. O. (2015). Effects of density of sago/ urea formaldehyde particleboard towards its thermal stability, mechanical and physical properties. *Jurnal Teknologi*, 78(11) : 1-11.
7. Tay, C. C., Sinin, H. & Mohd Shahril, B. O. (2015). Mechanical strength of sago/urea formaldehyde particleboard affected by the particle size. *Applied Mechanics and Materials*, 833 : 3-10.