THE DEVELOPMENT OF HYBRID BINDER USING CASSAVA STARCH-EPOXY RESIN BLENDS

by

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A report submitted in fulfillment of the requirements for the degree of Bachelor of Applied Science (Material Technology) with Honours

FACULTY OF EARTH SCIENCE
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2017

DECLARATION

I hereby declare that the work embodied in this report is the result of the original research and has not been submitted for a higher degree to any universities or institutions.

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I certify that the Report of this final year project entitled "The development of hybrid binder using cassava starch-epoxy resin blends" by Nur Adibah Binti Mohd, matric number E13A179 has been examined and all the correction recommended by examiners have been done for the degree of Bachelor of Applied Science (Material Technology) with Honours, Faculty of Earth Science, Universiti Malaysia Kelantan.

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ACKNOWLEDGEMENT

In the name of Allah SWT, the Most Gracious and the Most Merciful, I am very to the almighty Allah S.W.T for giving me the strength and opportunity to accomplish my Final Year Project (FYP).

First and foremost, I used this opportunity to express my indebtedness and appreciation goes to my supervisors Dr Mohamad Najmi Masri for his valuable guidance and constant encouragement during the entire duration of my project work, without which this work would not have been possible. His invaluable help of constructive comments and suggestions throughout the experimental and thesis works have contributed to the success of this research. Not forgotten, my appreciation to my co-supervisor, Dr Muhammad Hazim Amini for his support and knowledge regarding this topic.

I wish to express my sincere gratitude to all the lab assistants for their continuous support throughout this process. Sincere thanks to my entire friend especially Izzati, Yasmin, Amanina, Farihah, Alyaa, Sofea, Syaliani and Mas Amira for their kindness and moral support during my study. Not forgotten, my appreciation towards my teammates Nazihah, Suliana, Marinah and Shira. I wish to remember to my beloved late brother, Mohd Justilakama Mohd who was instrumental in this accomplishment and desired me to be success woman.

Last but not least, my deepest gratitude goes to my beloved parent, Mohd Yunus and Mrs. Rapisah Mat Hassan and also to all my brothers and sisters for their endless love, prayers and encouragement. To those who indirectly contributed in this research, your kindness means a lot to me. Thank you very much.

THE DEVELOPMENT OF HYBRID BINDER USING CASSAVA STARCH-EPOXY RESIN BLENDS

ABSTRACT

This research studies the development of hybrid binder by using two different types of binder which are cassava starch and epoxy resin. The cassava starch and epoxy resins were blended to produce a hybrid binder which is more environmental friendly, cassava starch was chosen because of good ductility, good adhesion, self-curing and hygroscopicity resistance while epoxy resin has high elastic modulus, low creep, low density, strong bond ability, good electrical insulation properties, chemical resistance, convenient manufacturing process and good performance at elevated temperature. The aims of this study were to prepare the hybrid binder based on epoxy resin with different concentration of cassava starch, to characterize the functional group of hybrid binder and to evaluate the effect of cassava starch concentration in hybrid binder on the tensile, impact and bending test. FTIR result shows the spectral patterns of all samples are approximately similar. Mechanical properties were tested by using tensile, impact and bending test. The hybrid binder with 20% of cassava starch exhibited better mechanical properties than others except for tensile test which is 80% cassava starch has maximum elongation.

THE DEVELOPMENT OF HYBRID BINDER USING CASSAVA STARCH-EPOXY RESIN BLENDS

ABSTRAK

Kajian ini meneliti kemajuan gam hibrid dengan menggunakan dua jenis gam iaitu kanji ubi kayu dan gam epoksi. Kanji ubi kayu dan gam epoksi dicampur untuk menghasilkan gam hibrid yang lebih mesra alam, kanji ubi kayu dipilih kerana kemuluran yang baik, ciri-ciri lekatan yang baik, ciri-ciri pengawetan dan mempunyai rintangan air manakala gam epoksi mempunyai daya elastik yang tinggi, rayapan rendah, ketumpatan yang rendah, keupayaan ikatan yang kuat, sifat penebat elektrik yang baik, rintangan kimia, proses pembuatan yang mudah dan prestasi yang baik pada suhu tinggi. Tujuan kajian ini adalah untuk menyediakan gam hibrid dengan kepekatan kanji ubi kayu yang berbeza, untuk mencirikan kumpulan berfungsi bagi gam hibrid dan untuk menilai kesan kepekatan kanji ubi kayu pada tegangan, kesan hentaman dan ujian lenturan. Hasil FTIR menunjukkan corak spektrum semua sampel adalah lebih kurang sama. Sifat-sifat mekanikal telah diuji dengan menggunakan tegangan, kesan hentaman dan ujian lenturan. Gam hibrid dengan 20 peratus kanji ubi kayu menunjukkan sifat-sifat mekanikal yang lebih baik daripada yang lain kecuali untuk ujian tegangan untuk sampel 80 peratus kanji ubi kayu mempunyai kekuatan tegangan yang maksimum pemanjangan.

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LIST OF ABBREVIATIONS

FTIR	Fourier transformation infra-red
H_2SO_4	Sulphuric acid
NaOH	Sodium hydroxide
PVP	Polyvinyl pyrrolidone
PEG	Polyethylene glycol
PVA	Polyvinyl alcohols
PTFE	Polytetrafluoroethylene
SEM	Scanning electron microscopy
UF	Urea formaldehyde
XRD	X-ray diffraction
UTM	Universal Testing Machine

LIST OF SYMBOLS

º	Degree
ºC	Degree Celcius
%	Percentage
g	Gram
M	Molarity
w/v	Weight per volume
θ	Theta
kV	KiloVolt
g/m^2	Gram per meter square
MPa	Mega Pascal
mm	Millimeter
mL	Milliliter
min/mm	Min per millimeter
g/m^2	Gram per meter square
mA	Meter Ampere

CHAPTER 1

INTRODUCTION

1.1 Background of study

Binder is well-known as adhesives, it is often specifically designed for bonded facade systems. Binder played an important role in wood processing industry as well as secondary materials in furniture industry. Besides, binder are used to improve the quality of product. There are two types of binder which are natural and synthetic binder. Natural binder are usually based on botanical sources such as starch and synthetic binder based on thermoplastic, elastomer and thermoset (Gao et al., 2015; Park et al., 2011; Lee et al., 2015; Emengo et al., 2002).

Nowadays, the concern on eco-environmental issues is increased. Improvements of eco-friendly materials have concerned on development of low-energy, low-pollution production and recycling processes. The natural materials are currently having high demands in binder application (Jeong et al., 2012). Hence, cassava starch is one of the best candidate as a natural binder compared to others.

Manihot esculenta are commonly called as cassava, manioc, tapioca or yucca. Tuber or the swollen root is the major harvested part of this plant. Cassava is a tropical root tuber commonly used as food in worldwide (Alebiowu and Osinoiki, 2010). Cassava converts the greatest amount of solar energy into soluble carbohydrates per unit of area (Tonukari, 2004). Besides, cassava also act as a main sources of starch in South East Asia including Malaysia (Ahmed et al., 2014). In Malaysia, cassava covers an area of 3,053 hectare and followed by sweet potato (Tan, 2015).

Among the other types of starchy staples, the carbohydrate production of cassava is higher than rice and maize. While cassava is the low source of calories for human nutrition and animal food. Cassava is also used to produce starch for industrial use and other industry such as pharmaceutical and cosmetic industry. Starch is a multibillion dollar business worldwide. Cassava starch can also express the same ability where maize, rice and wheat starch are currently have (Tonukari, 2004).

Cassava starch has a medium swelling power compared to others starch and cassava starch also has higher solubility (Aliasson, 2004). Cassava contain a lot of carbohydrates that make it as the third top crops for human consumption in the world. The production of cassava have been estimated around 210 million metric ton per year (Ghimirea et al., 2015).

Epoxy resin is a part of synthetic polymer which based on thermoset polymer. The advantage of synthetic polymer is it can tune the physical, chemical and biological properties to match the specific application (Maitz, 2015). Epoxy resin is widely used as adhesives in composites materials. In structural engineering application, there are many useful properties of epoxy resin such as high modulus, low creep and good performance at elevated temperature (Ahmed et al., 2015).

1.2 Problem statement

In development of binder technology, there are two types of binder which are synthetic and natural binder. The natural binder are based on organic sources such as potato (Ajayin et al., 2015), tiger nut (Builders et al., 2013; Manek et al., 2012), cassava (Sangseethong et al., 2010), sago starch (Jamaludin et al., 2015) and agar (Masri and Mohamad, 2009).

Types of synthetic binder are based on elastomers, thermoplastics, emulsion and thermosets such as polyurethane (Lee et al., 2015), polyvinyl pyrrolidone (PVP) (Aslan et al., 2015), polyethylene glycol (PEG) (Bleyan et al., 2015), polyvinyl alcohols (PVA) (Park et al., 2011) and polytetrafluoroethylene (PTFE) (Gao et al., 2015).

Starch is an alternative types of natural binder. The examples of starch are potato, sago, tigernut and cassava. According to previous research, Zavareze et al., (2011) had stated that potato starch is poorly utilized. Besides it is has lower efficiency in film making. Among the starches, cassava starch is an effective binder which can perform most of the function of other starch. However, there are still lack of research about cassava starch as a binder.

Increasing environmental concerns focused greater attention on the development of biodegradable materials. In order to improve and discover a new type of natural binder which is more environmental friendly, cassava starch was chosen because of good ductility, good adhesion properties, self-curing properties and hygroscopicity resistance. Hygroscopicity is the ability of materials to absorb water from the environment which can cause loss of its original mechanical properties (Larotonda et al., 2005).

Some synthetic polymers such thermoplastic are biodegradable and the structure can be adjusted easily. By combining the advantages of natural and synthetic binder, cassava starch with epoxy resin blends are interested to further discover. Up to now, little research has been conducted on cassava starch (Alebiowu and Osinoiki, 2010; Lawal et al., 2015; Masri et al., 2013; Oluwole and Avwerosuoghene, 2015). Cassava starch has high possibility to be a good binder while epoxy resin has high crosslink density which can lead to brittleness with low impact strength (Ahmed et al., 2015).

Based on previous study, there are many research about starches as a binder (Ahmad et al., 1998; Builders et al., 2013; Chan et al., 2012; Jamaludin et al., 2014; Jamaludin et al., 2015; Lawal et al., 2015; Osemeahon et al., 2013; Uhumwangho et al., 2006; Varzi and Passerini, 2015; Yu et al., 2009) but there are lack of research about blending the cassava starch with epoxy resin. In this work, cassava starch will be blends with epoxy resin which is to produce a hybrid binder. The different concentration of cassava starch will be used. The functional group will be characterized and the application of hybrid binder will be tested by using three testing which are tensile strength, impact and bending test.

1.3 Objectives

The objectives of this recent work are:

i. To prepare the hybrid binder based on epoxy resin with different concentration of cassava starch.
ii. To characterize the functional group of hybrid binder.
iii. To evaluate the effect of cassava starch concentration in hybrid binder on the tensile, impact and bending test.

1.4 Scope of study

This work will divided into two parts. The initial part is to prepare the hybrid binder of cassava starch-epoxy resin blends by blending the different concentration of cassava starch with the epoxy resin. The cassava starch is prepared through the process extraction of cassava starch from the cassava tuber and blending the cassava starch with epoxy resin. Then the binder will be characterized.

The evaluation will be obtained by characterize the binder by using fourier transformation infra-red (FTIR). The further investigates regarding the tensile strength, impact and bending test will be obtained based on the optimum strength of hybrid binder.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter will be cover about starch as a binder and properties and characteristic of starch as a binder. Besides, the types of natural binder and epoxy resin as synthetic binder also has been reviewed in this chapter. In addition, this chapter also emphasized about the characterization used in this research.

There are many research about binder either synthetic binder (Aslan et al., 2015; Bleyan et al., 2015; Park et al., 2011) or natural binder (Builder et al., 2013; Manek et al., 2012; Sangseethong et al., 2010; Jamaludin et al., 2015). The researches and development regarding natural binder are including cosmetic, food processing and pharmaceutical field (Aviara et al., 2014; Vanier et al., 2012; Manek et al., 2012). The natural binders that usually used are natural cellulose (Jeong et al., 2012), chitosan (Tang et al., 2015), xylan (Norstrom et al., 2015), tiger nut starch, potato starch, sweet potato starch, corn starch, agar binder, gelatin, sago starch and cassava starch (Avwerosuoghene and Oluwole, 2015; Jamaludin et al., 2015; Pejovnika et al., 2004; Builder et al., 2013; Zavareze et al., 2011; Aviara et al., 2014).

2.2 Binder

The binder contains inactive electrochemical materials. It is implemented to tether and prevent active materials from disintegrating. The increasing demand of electrochemical devices that store the energy produced by renewable sources is consist of materials that concern on environmental issues in their production and disposal activity (Varzi and Passerini, 2015). The binder also used to bind various components into a compact composite.

In addition, binder can enhance the strength of the battery electrodes, act as highly adhesive agent, act as effective dispersion agent (Pejovnika et al., 2008; Masri and Mohamad, 2009), pore forming agent for active materials, used to increase plasticity, assist the body forming aside functioning as bonds between particles and provide mechanical cohesiveness interesting (Jamaludin et al., 2015).

There are many important function of binder. For example the binder can enhance the strength of the electrodes and affect the performance of the battery in two ways which is direct binding and indirect binding. Figure 2.1 shows that the two types of principles in binding. Direct binding forms inter particle bridges while indirect binding forms a three-dimensional network in the particles. Both ways are provide electrode cohesiveness and affect the surface of properties particles (Pejovnika et al., 2008). Compared to the inert binders, the ability of direct binding are more interesting. Beside enhance the strength, the binder also act as highly adhesive agent, effective dispersion agent and pore forming agent for active materials.

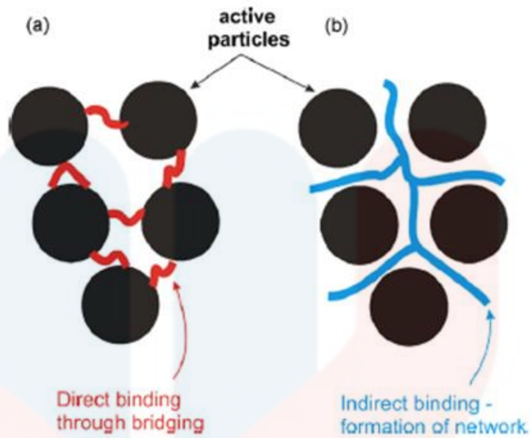

Figure 2.1: Types of principle in binding (a) Direct binding (b) Indirect binding (Pejovnika et al., 2008)

In addition, usually binders used to increase plasticity and it is also assist the body forming aside functioning as bonds between particles. On the other hand, binders in battery electrodes can affect the electrode properties by modified the surface during battery operation. It is also provide mechanical cohesiveness interesting (Jamaludin et al., 2015; Masri and Mohamad, 2009; Pejovnika et al., 2008).

2.3 Types of Natural binder

Starch is a common types of natural binder. It is common name applied to a white, granular, odorless and tasteless complex carbohydrates. It occurs in commercial quantities in such roots and tubers as cassava, yam, potato and cereal grains such as sorghum, millet and maize. Starch is normally extracted from the source material in aqueous medium (Aviara et al., 2014).

The starch that can be used as a binder are potato starch, sago starch, tiger nut starch, corn starch and cassava starch. Among the others type of starch, cassava starch was chosen because it is effective binder which is attributable to the higher gel strength of its mucilage. Besides, cassava starch binder produced the more readily deformable granules (Uhumwangho et al., 2006).

According to Lawal et al., (2015) cassava starch contain the highest values of friability for the tablet formulation compared to sweet potato starch and corn starch. Thus, with the promising properties of cassava, the potential as natural binder will be further discussed in this further chapter.

2.3.1 Potato starch

Starch which made from potato can be used as a natural water soluble organic binder with the superiorities of extensive resource and regeneration (Yu et al., 2009). According to varzi and Passerini (2015), the result achieved using polysaccharides binder such as potato starch are more appropriate for electrochemical double-layer capacitor electrodes. After cellulose, starch is one of the most abundant natural polymers and larger extent which extracted from particular potatoes. Due to wide applications, potato starch is attractive as a sustainable source for industrial process (Hong et al., 2016; Singh et al., 2004).

Compared to the other crops sweet potato are the cheaper and has many positive attribute, but this abundant resource is still poorly utilized (Julianti et al., 2015). The native potato starch film has high tensile strength. This is due to high molecular weight which causes the paste of the native potato starch to have a high viscosity. It is impossible to produce potato starch paste with high starch content because it would result in a lower efficiency in film-making. In addition, the transparency of native potato starch paste is poorer than the oxidized potato starch (Zavareze et al., 2011).

2.3.2 Sago Starch

Sago starch is isolated from sago palm or in scientific name is *Metroxylon sp*. It is better known as 'rumbia' and distributed throughout South East Asia. Sago palm is an important resource especially to the people in rural areas because it has various uses. Sago used as the production of starch such as sago flour or sago pearl (Ahmad et al., 1998). The properties of sago starch is easy to gelatinize, high viscosity, low gel syneresis, and ease of molding (Jamaludin et al., 2015).

Sago starch shows similar properties as binders but it is neglected and has less attention in Malaysia. The component that makes the sago starch suitable used in the adhesive production are abundant and cheap. The sago starch commonly shows result in cellular ceramics with high porosity but low strength (Jamaludin et al., 2014).

2.3.3 Tiger Nut starch

Tiger Nut is one of unexplored sources of starch which is extracted from perennial herb called as *Cyperus esculentus L*. On the other hand, tiger Nut starch is an odourless and brilliant white which depend on the method of extraction. There are functional and physicochemical properties of native starches which are determined by the composition of amylose and amylopectin (Builder et al., 2013). The tuber of tiger nut has high lipid content of healthy fatty acid profile (Aguilar et al., 2015).

Tiger nut oil is extracted and sold as cold pressed oil (Ezeh et al., 2015). The extraction methods of tiger nut starch will gives an odorless, white and non-hygroscopic powder with yields varying from 14% to 37% depending on the size and flesh of the tubers or nut (Kenneth et al., 2014).

2.3.4 Cassava Starch

Cassava is also known as manioc, tapioca or yucca (Daramola and Osanyinlusi, 2006). Compared to cereals and other crops which do not grow well, cassava has the ability to grow on marginal. Besides, it can tolerate drought and can grow in low-nutrient soils. Cassava roots also can be stored in the ground for up to 24 month (Apotiola and Idowu, 2012). Cassava is the third largest source of carbohydrates for human consumption in the world with an estimated annual world production of about 210 million metric ton (Ghimirea et al., 2015).

One of the most important plant products to industry is starch. It is finding application in several industries. Compared to maize, rice and wheat starch, cassava starch can perform most of the functions of others starch. The cassava production is currently increasing that will lead to higher amount of starch. It is will make it cheaper for industrial processes and opening up new markets. (Tonukari, 2014).

Figure 2.2 shows the image of cassava seed stem and roots which contain of starch. Cassava starch have many uses such as an additive in cement to improve the setting time, utilized in sizing, dyeing in the textiles industries to increase brightness and weight of the cloth. Moreover, cassava also add on as a filler material and bonding agent in confectionary and biscuit industries (Tonukari, 2004). In Malaysia, cassava starch was chosen because of very cheap and readily available among different types of starch (Abolhasani and Muhamad, 2010).

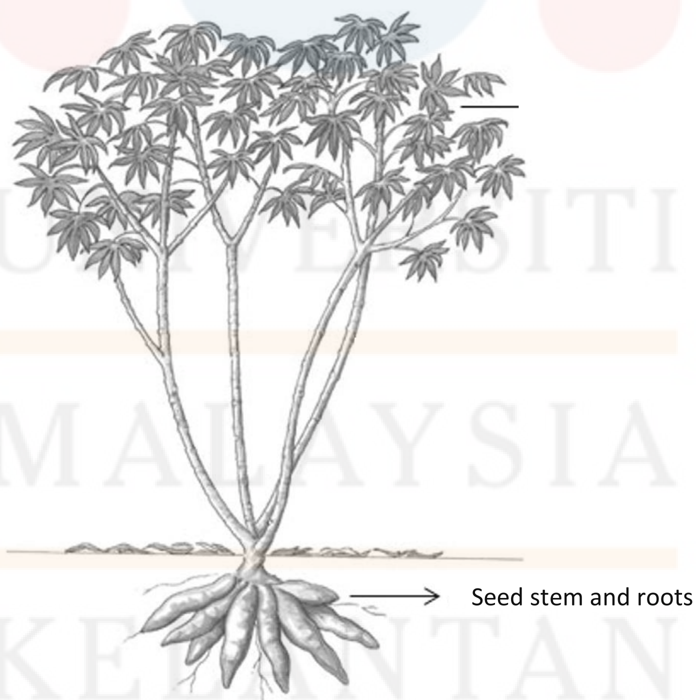

Figure 2.2: Cassava seed stem and roots (Veiga et al., 2015)

2.4 The properties of Natural Binder

Polysaccharides are an important class of biological polymers. It is joined by glycosidic bonds and universally found in almost all living organisms (Sinha and Kumria, 2001; Karaki et al., 2016). The biological function of polysaccharides is usually either structural or storage-related such as starch is a storage in plants (Klemm et al., 2005).

Figure 2.3 shows the molecular structure of starch component. Starch is composed of D-glucose in polysaccharides. It was isolated from leaves, stems, tubers, seeds, and roots of higher plants where it serves as an energy reserve. Starch is a carbohydrate polymer consisting of anhydroglucose units linked by α-D-(1, 4) glucosidic bonds (Manek et al., 2012). In addition, it consists of two inherently incompatible molecules which is amylose and amylopectin. Amylose is a linear polymer while amylopectin is a branched chain polymer (Manek et al., 2012; Masri et al., 2013).

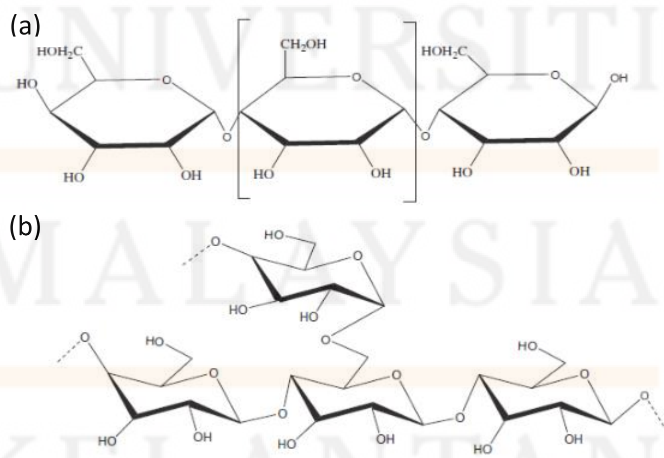

Figure 2.3: Molecular structure of the starch components (a) amylose and (b) amylopectin (Masri et al., 2013)

Starch is one of the most abundant organic compounds and applied as a binder in a pharmaceutical industry. Starch is a main raw material in glue and adhesive industries due to abundantly available and low cost (Yu et al., 2009). There are many uses of starch such as a filler material and bonding agent for making tablets. On the other hand, starch is an important raw material for powder in the cosmetics industries. In detergent soap manufacture, starch is used to get better recovery and to improve the shelf life of detergents while in the rubber and foam industries, starch is employed for getting better foaming and color (Tokunari, 2004).

In plants, starch occurs as granules that are characteristic in size, shape, and morphology. These characteristics are determined by the biological origin (Ahmad et al., 1998; Manek et al., 2012; Tokunari, 2004). The characteristic and properties of starch affect the efficiency of binder. To improve the structure and binding property of starch as a main binder, starch can be modified by physical or chemical methods (Avwerosuoghene and Oluwole, 2015).

Modification of starch by chemical methods generally involves esterification, etherification and oxidation of the available hydroxyl groups on the α-D-glucopyranosyl units that make up the starch polymers. Chemical modification will improve the stability and film forming properties to partially degraded starches that will used in paper surface sizing , textile warp sizing and adhesives (Chiu and Solarek, 2009). Starch esters with higher degree of substitution have various limitations and only can be used in non-food application (Biswas et al., 2008). Based on previous study, Waliszewski et al., (2003) had stated that chemical modification can improved starch water binding because the hydrophilic groups were incorporated.

Chemical modification have been developed to overcome the weakness of native starch such as water repellence, failure of granules to swell and develop viscosity in cold water and uncontrolled viscosity after cooking (Aggarwal and Dollimore, 1998). Physical modification process can be considered as a natural material that is safe to the environment. The most common physical modifications are heat-moisture treatment, retrogradation, pregelatinization and annealing treatment (Pinto et al., 2015).

2.4.1 Starch Binder

The characteristic and properties of starch affect the efficiency of binder. Starch binder has good ductility, good adhesion properties, self-curing properties and hygroscopicity resistance. Hygroscopicity resistance means that the binder does not have ability to absorb the water, so it can prevent the swelling. To improve the structure and binding property of starch as a main binder, starch can be modified by physical or chemical methods.

The useful materials of starch was obtained by enhance the native properties because high water sensitivity of starch. Since starch made from renewable resources, starch have a much lower undesirable impact on the environment. Starch are sources of phosphate bond polymeric materials that can generally provide a lower modulus of elasticity (Avwerosuoghene and Oluwole, 2015).

There are several variations in the properties of starch. These variations are from different botanical sources which are related to the differences in their amylose and amylopectin contents. The amylose and amylopectin content will affect the properties of starch such as gelatinization, paste viscosity, gel stability, and solubility (Builder et al., 2013).

2.5 Epoxy resin

Thermoset epoxy resins is a polymeric adhesives. Generally features of thermoset epoxy resins is a nonlinear and inelastic material behavior. The characteristics that dominates the epoxy resin is the strain rate dependent deformation behavior which leads to relaxation and creep phenomena that can affect the long-term performance of structural bonded components (Pap et al., 2013). Epoxy resin is widely used as adhesives in composites materials.

There are many useful properties of epoxy resin such as high elastic modulus, low creep, low density, strong bond ability, good electrical insulation properties, chemical resistance, convenient manufacturing process and good performance at elevated temperature (Ahmed et al., 2015; Shan et al., 2015). Thermosetting epoxy resin polymer matrix is already covers alone some of the demanded properties (Matei et al., 2016). The advantage of synthetic polymer is it can tune the physical, chemical and biological properties to match the specific application (Maitz, 2015).

Besides as adhesives, thermosetting epoxy resins have been widely employed as sealants and matrices of insulation material of superconducting magnets due to their good electrical insulation properties. Epoxy resin has large coefficient of thermal expansion (CTE) such as 40-80×10-6/K which can limits their applications. The changes of temperature will lead the volumetric shrinkage to internal stress and microcracks will occur. (Shan et al., 2015).

2.6 Characterization of cassava starch as a binder

This subchapter are covered about the characterization of cassava starch as a binder. There are four types of characterization will be covered in this subchapter which are structural properties, morphology properties, viscosity preparation of cassava and functional group of cassava.

2.6.1 Structural properties of cassava

Structural properties of starch is characterized by using X-Ray Diffraction (XRD). According to Klein et al., (2014) the XRD patterns for native cassava starch are similar with modified cassava starch. The diffraction pattern for native and modified cassava starch shows in Figure 2.4 which showed that small peak at 5.6, 11.25, 19 and 30^{o} while main peaks at 15, 17, 17.8 and 23^{o}. The relative crystallinity decreased for modified cassava starch.

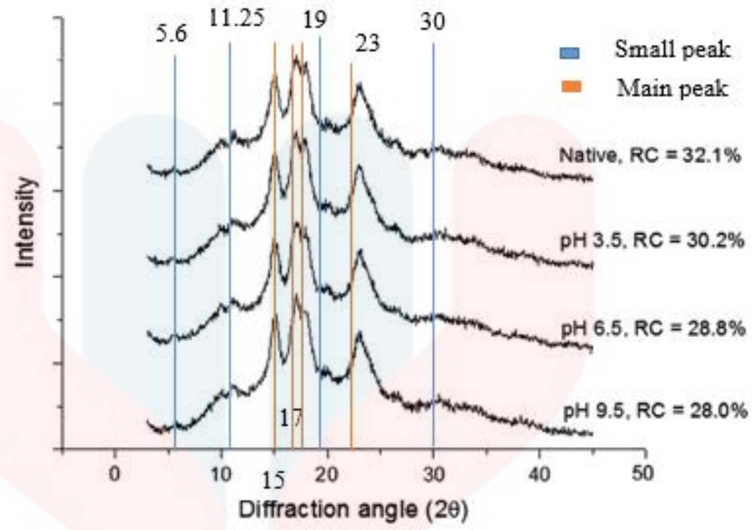

Figure 2.4: The diffraction pattern of native and modified starch (Klein et al., 2014)

The starches showed differences in the peak intensity values and relative crystallinity. The XRD and relative crystallinity of the native and modified starch verified by the intensity of the main peak. The starch modified with low concentration of active chlorine had the lowest peak intensity. The higher concentrations of active chlorine used will increase peak intensities. Higher concentrations of active chlorine will produce greater peak intensity (Vanier et al., 2012).

The differences of starch crystallinity are caused by four factors which are crystal size, the number of crystalline region affected by crystalline content and length of chain, the orientation of double helices within the crystalline area and the extent of interaction between the double helices (Miou et al., 2009). Based on Gao et al., (2012), the modified starch only had dispersive broad peak and no crystalline peaks showed. This is because the crystalline region of native starch was completely damaged during modification process. The loss of crystallinity will weakened the intermolecular and intramolecular hydrogen bonds of starch.

2.6.2 Morphology properties of cassava

The surface morphology of starch is characterized by using scanning electron microscopy (SEM). Based on previous study, SEM of native starch granules is shown in Figure 2.5(a) has round shape with truncated end on one side and the surface of native starch granules are smooth with no evidence on any fissures or pores. The modified starch slightly has rough surface is shown in Figure 2.5(b) (Sangseethong et al., 2010; Klein et al., 2014).

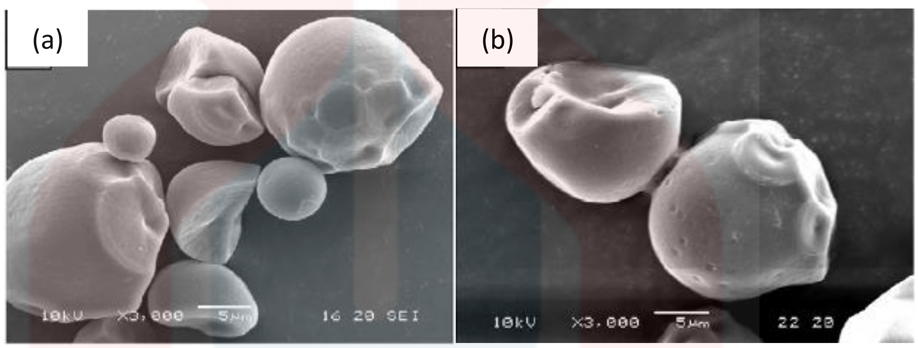

Figure 2.5: (a) Morphology of native starch and (b) modified starch (Sangseethong et al., 2010)

According to Dacanal et al., (2016), for native starch at 1500x magnification, cassava starch particles present a hemispheric shape. The shape of particles can affect the cohesiveness and fluid dynamics behavior. Aviara et al., (2014) had stated that the morphology for starch granules are mostly spherical in shape with a few having indentations similar to an egg that has been cut at various positions. The details of this explanation was approved by Figure 2.6. The surface morphology for hybrid binder are rough surface which is similar with Figure 2.5(b).

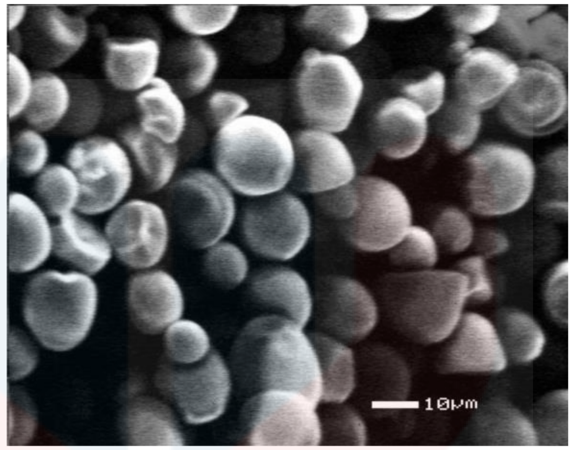

Figure 2.6: SEM of cassava starch at 2000x magnification (Aviara et al., 2014)

2.6.3 Viscosity preparation of Cassava

Studying the rheological properties of fluids or gels are important because the operation design depends on the way the product flows through a pipe, stirring in a mixer and packaging into containers. The viscosity of fluid is its resistance to flow (Hussain and Nasr, 2010). The knowledge of viscosity can help to characterize polymers and to determine indirectly molecular mass (Osemeahon and Dimas, 2014).

At low concentration of cassava starch, the viscosity of binder decreased and will increased with increasing of cassava starch concentration. The higher the concentration of starch, the higher viscosity observed (Osemeahon et al., 2013). Lower viscosity are produced because of incompletely degraded network. It would not be resistant to shear and also could not maintain the integrity of the starch granules (Chan et al., 2012). The result for the viscosity of hybrid binder are the higher concentration of cassava starch, the higher viscosity of hybrid binder.

2.6.4 Functional group of cassava

FTIR is a machine used to identify and investigate the presence of functional groups in molecule. In addition, it is also can obtain the structural and bond information (Kaniappan and Latha, 2011). For this study, FTIR will be used to determine the functional group, structural and bonding information of cassava starch

Klein et al., (2014) shows that the spectral patterns of native cassava starch sample and modified cassava starch sample were similar. Many researcher assign and match the band absorbance in starch with the vibrational modes of the chemical bonds. Moreover, cassava starch exhibited over 10 peaks in the regions of 4000–500 cm^{-1}. Crystalline phase existed in the native cassava starch was indicated by the higher value. The modification process of starch will alter the chain packing and will generate more amorphous structures in starch.

Ma et al., (2006) had stated that the low peak are resulted from the strong hydrogen bonds that drag the relative groups to a lower vibration frequency while high peak due to weak interaction of hydrogen bonding. The less hydrogen bonding in modified starch were studied in previous research.

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

The material and experimental work on this study will be explained detail on this chapter. The experimental work of prepare the hybrid binder by using cassava starch-epoxy resin blends by blending the cassava starch with epoxy resin. The chemical properties of hybrid binder were characterized and analyzed by using fourier transformation infra-red (FTIR) while mechanical properties were characterized by using tensile strength, bending and impact test.

3.2 Materials

The materials that were used in this research are natural cassava, epoxy resin (Epoxy and hardener), sodium bicarbonate, ammonium chloride and plywood panels.

3.3 Preparation of Cassava Starch

The preparation of cassava starch started by cassava tuber was pre-dried under the sunlight as shown in Figure 3.1(ii). After that, the Figure 3.1(iii) and Figure 3.1(iv) shows cassava tuber was peeled and chopped into cubes. Next, the cassava was blend and filtered using gauze as shown in Figure 3.1(v) and Figure 3.1(vi). After 24 hours, Figure 3.1(vii) shows the white starch was obtained and the top liquid was decanted and removed. In Figure 3.1(vii) the starch was mixed with water and heated at 60-70°C using thermostatically water bath. After that, the starch was cooled at room temperature (25°C). Figure 3.1 shows the process of extraction of cassava starch.

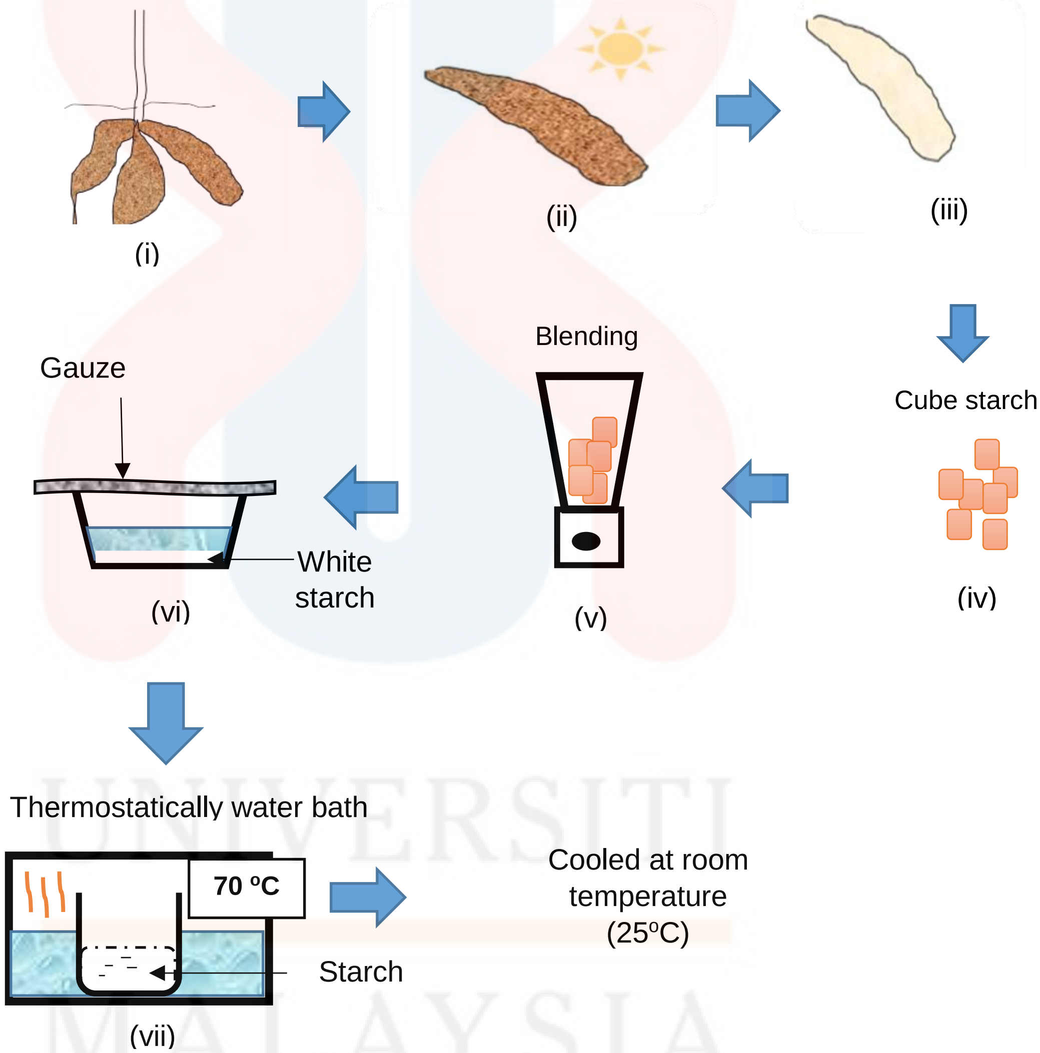

Figure 3.1: The process of extraction of cassava starch

3.4 Preparation of Cassava starch-epoxy resin blends

Figure 3.2 shows the blending process of cassava starch-epoxy resin blends. The preparation of hybrid binder was prepared by mixing the part A and part B of epoxy resin as shown at Figure 3.2(i). Figure 3.2(ii) shows the blending of the cassava starch with epoxy resin was carried out by preparing 20% of cassava starch in epoxy resin at room temperature (25 ^{o}C). Then, the solution was mixed thoroughly using stirrer as shown at Figure 3.2(iii).

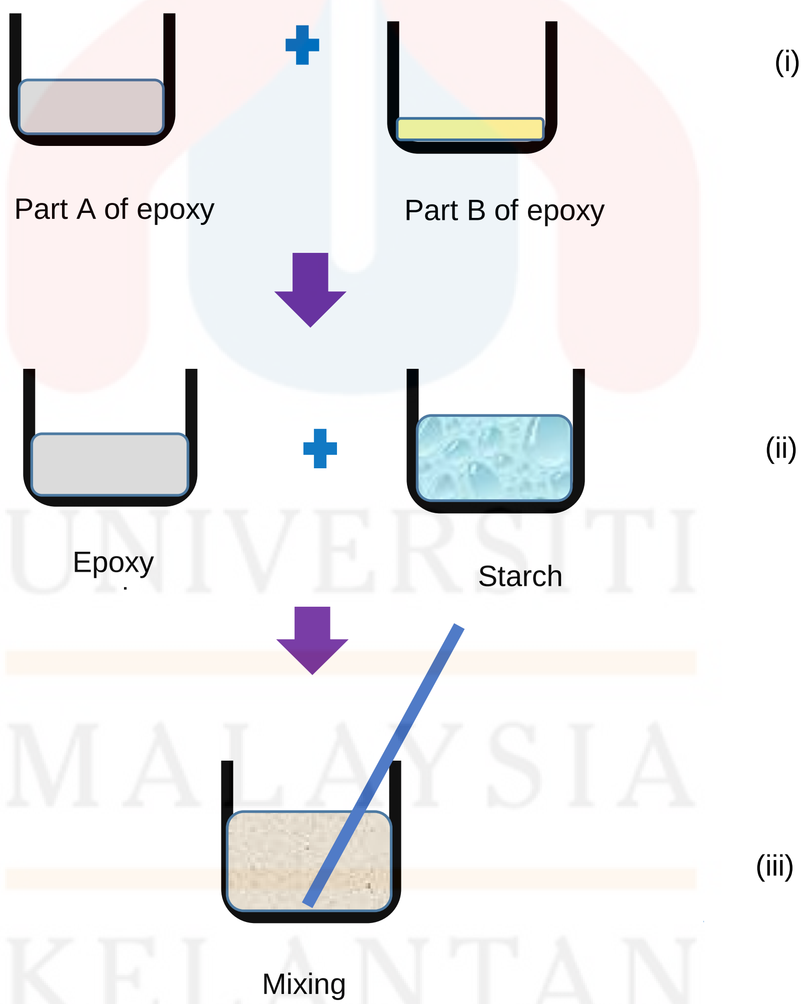

Figure 3.2: Blending process of cassava starch-epoxy resin blends

The above procedure were repeated at different concentration of cassava starch (20, 40, 60, 80 and 100%). Table 3.1 shows the composition of cassava starch with epoxy resin.

Table 3.1: The composition of cassava starch- epoxy resin blends

Cassava starch (%)	Epoxy resin (%)
20	80
40	60
60	40
80	20
100	-

3.5 Characterization of cassava starch as binder

This subchapter was covered about the characterization of cassava starch as a binder. There are one type of characterization was covered in this subchapter which is functional group of cassava.

3.5.1 Functional group of cassava

Infrared Spectroscopy (FTIR) was utilized to identify and investigate the presence of functional group of binder. Besides, it is provide information about chemical bonding in binder. Each specific chemical bond has a unique energy absorption band and information on a complex compound can be obtained thus, its strength and the fraction of hydrogen bonding and miscibility can be studied

(Kaniappan and Latha, 2011). The FTIR analysis was conducted by using infra-red spectrophotometer (Spectrum 1000, Perkin-Elmer, USA) within 400 to 4000 cm^{-1} with a resolution of 4 cm^{-1} and 32 scan.

3.6 Characterization of Binder Application

The mechanical properties of binder were tested by using plywood as a medium. The plywood panels of dimension 200 mm x 200 mm x 5 mm were be prepared as shown in Figure 3.3. The plywood was dried to a moisture content of approximately 3%. Then, the cassava starch-epoxy resin blends was applied to both sides of plywood at spreading rate of 350 g/m2.

Figure 3.3: Plywood panel with dimension 200 mm x 200 mm x 5 mm

In order the plywood to be penetrated by the binder, it must be dried for 15 minutes. The veneers were cold pressed at 5 MPa for 24 hours. After cold pressing, the panels were heated under condition 75 ºC for 2 hours. The panels were cut based on their standard size as shown in Figure 3.4(i) for bending test, Figure 3.4(ii) for impact test and Figure 3.4(iii) for tensile test.

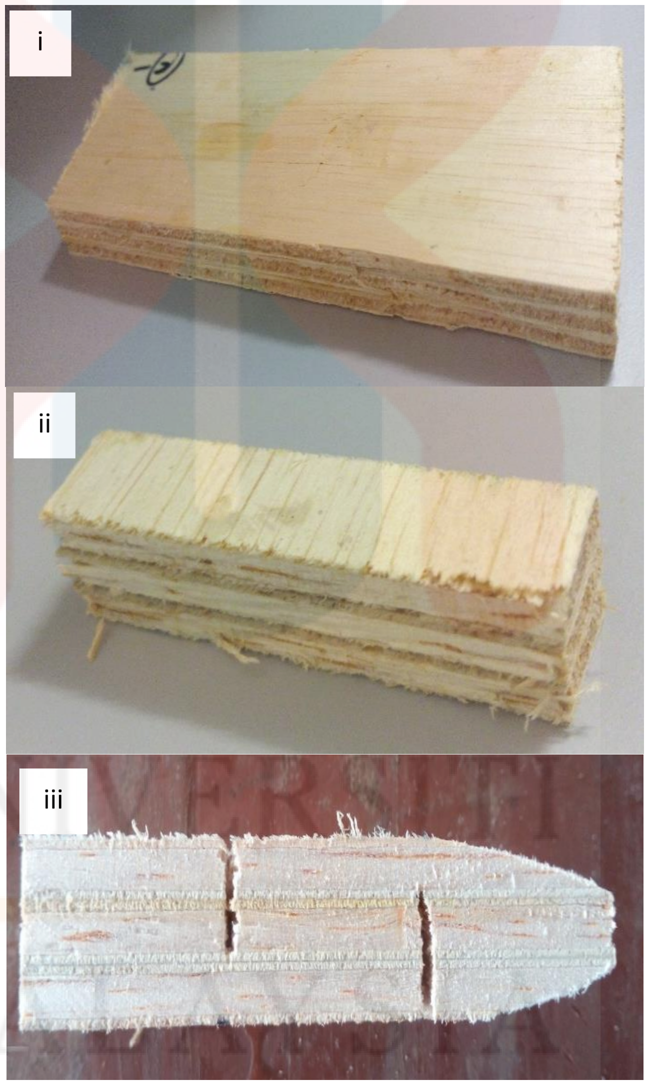

Figure 3.4: Three-layer plywood panels based on their standard size.

The mechanical properties of binder were tested by using three testing method which are tensile, impact and bending test. Figure 3.5 (i)(ii) shows universal testing machine (UTM) while Figure 3.5 (iii) shows the Charpy machine.

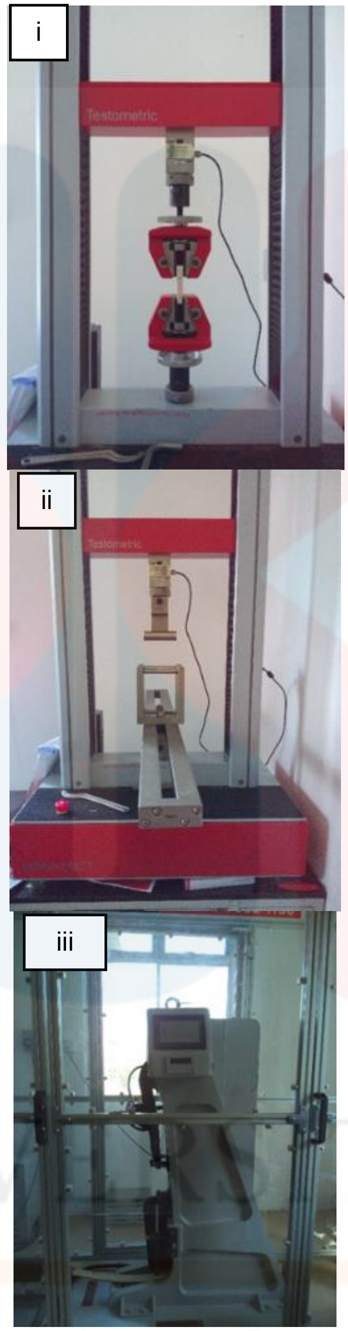

Figure 3.5: Universal testing machine (UTM) and Charpy machine

3.7 Flow chart of overall project

Figure 3.6 shows the overall experimental work in this research. There are three stages in this project. First stage is preparation of materials, second stage is characterize the sample and last stage is characterize the application of binder.

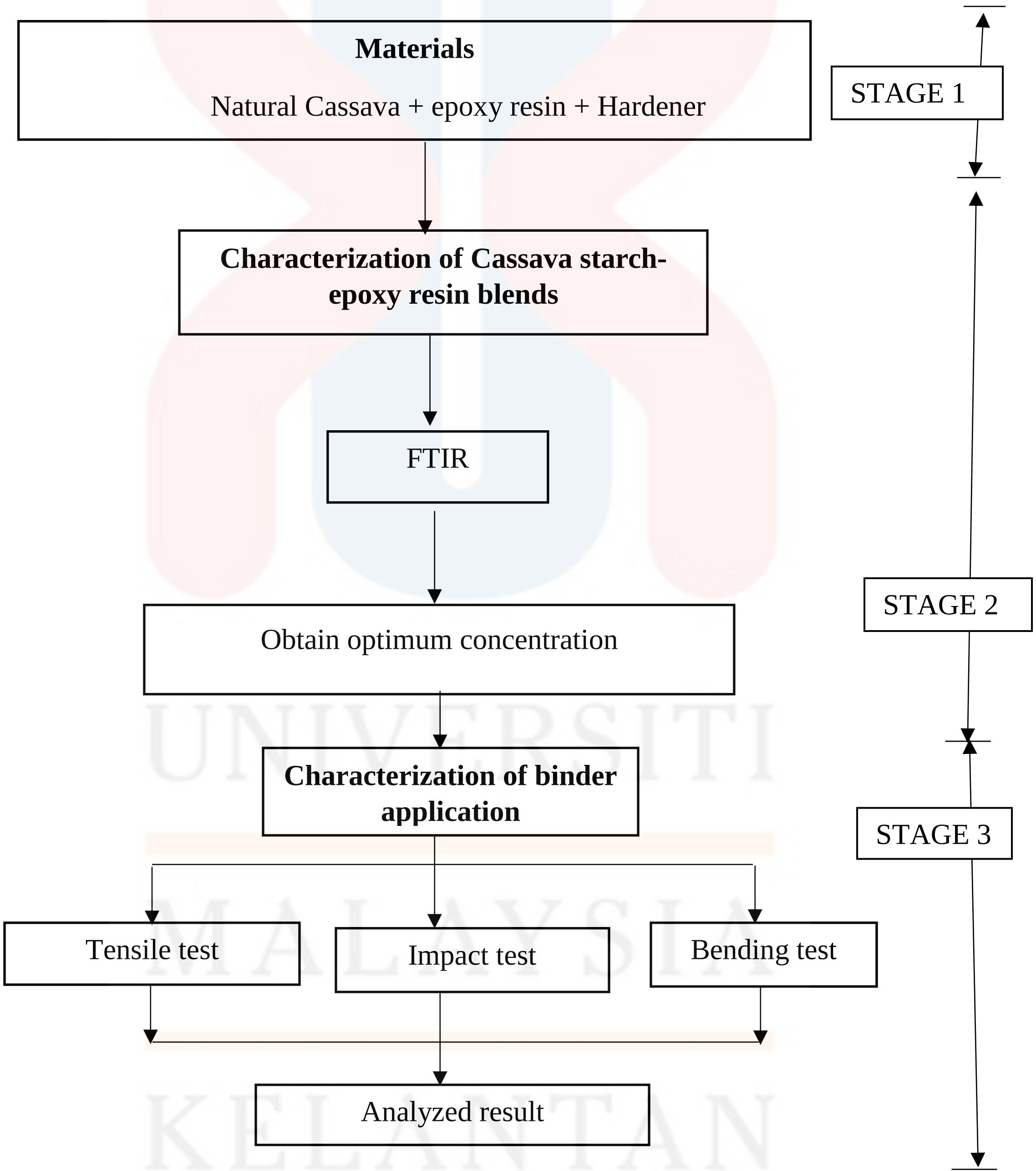

Figure 3.6: Flowchart of overall experimental work

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter focused on the discussion of the development of hybrid binder using cassava starch-epoxy resin blends. There are five samples which were contain different percentages of starch including 20, 40, 60, 80 and 100% of starch. The properties of starch were analyzed and characterized by using Fourier transformation infra-red (FTIR). The three-layer plywood panels were subjected to mechanical characterization. Its mechanical properties studied were analyzed and compared by using universal testing machine (UTM) and impact testing.

4.2 Fourier Transformation Infra-Red

The presence or absence of functional groups information in a molecule were identified and obtained by using FTIR spectroscopy. Specific chemical bond often has a unique energy absorption band, structural, bond information on a complex study the strength and the fraction of hydrogen bonding and miscibility were obtained. The band absorbance in starch has been assigned and matched with the vibrational modes of the chemical bonds by many researcher (Klein et al., 2014).

Infrared band shapes come in various forms. Two of the most common are narrow and broad. Narrow bands are thin and pointed, like a dagger. Broad bands are wide and smoother. Table 4.1 shows the wavelength of peaks used for FTIR analysis and corresponding functional groups.

Table 4.1: Wavelength of peaks used for FTIR analysis and corresponding functional groups.

Wavenumbers (cm^{-1})	**Phenomenon**	**Functional groups**
~1050 ~1100	C-O	Primary alcohol Secondary alcohol
2935–2915 2865-2845	CH_2	Methylene
2975-2950	NH stretch	Primary amines
1270-1230	C-O-C stretch	Aromatic ether
1490-1410/880-860	-	Inorganic carbonate
2140-2100	C-C (triple bond) stretch	Alkynes monosubstituted

Figure 4.1 represents the FTIR spectra of different percentages of cassava starch and epoxy resin in hybrid binder. The spectral patterns of all samples are approximately similar. Some of important changes in FTIR spectra of hybrid binder were observed based on the percentages of cassava starch and epoxy resin in hybrid binder. The modification of absorbance in hybrid binder can be seen in figure 4.1. In FTIR spectra for 20% of cassava starch present a characteristics band at 1490-1410 cm^{-1} or 880-860 cm^{-1}, which corresponds to the inorganic carbonate.

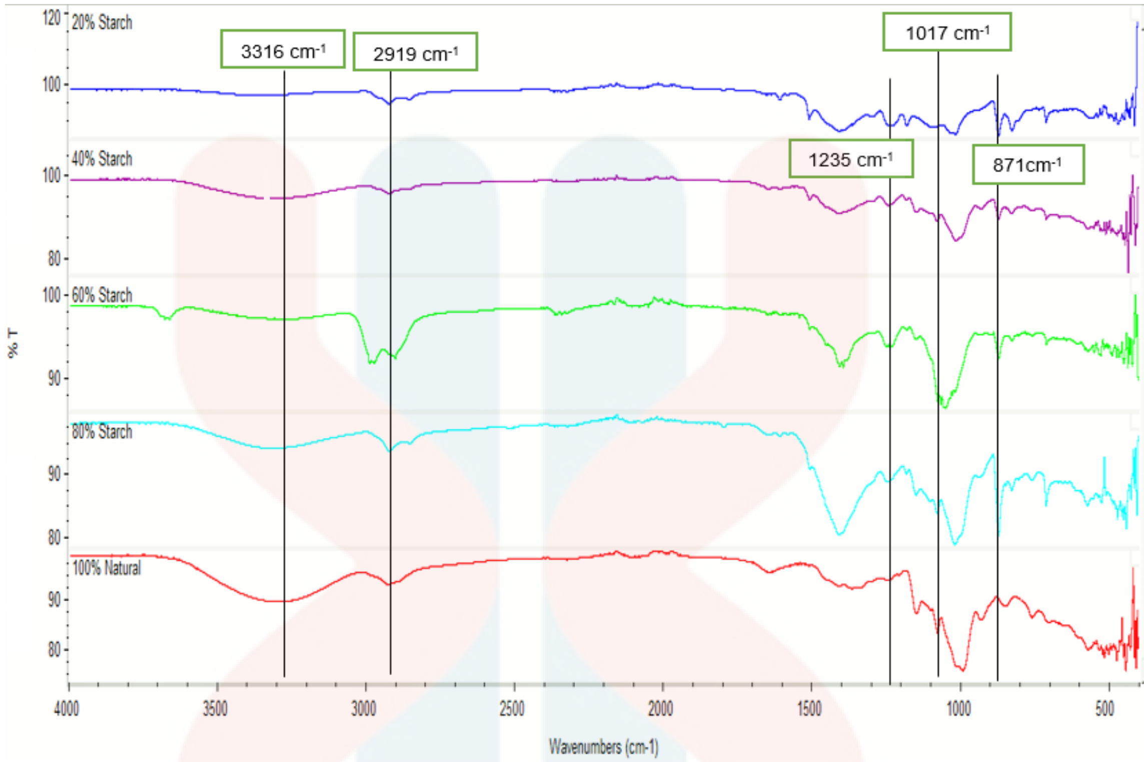

Figure 4.1: FTIR spectra of hybrid binder with different percentages of cassava starch and epoxy resin in hybrid binder.

For inorganic carbonate compounds, the IR absorption spectra are very distinctive. The strong characteristic absorption peak are found around 871 cm^{-1}. The absorption peak are same with FTIR spectra for 80%. This peaks appears strong and narrow band shape for 80% of cassava starch while for 20% of cassava starch, the peak appear medium and narrow band shape. The peaks for 40 and 60% of cassava starch shows weak and narrow band. Compared with others percentages of hybrid binder, peak for 100% of cassava starch appears broad with weak band. This is because there are no composition of epoxy resin.

For aromatic ether groups, the C-O-C stretching absorption is found in the 1270-1230 cm^{-1} range for aryl ethers which is at peak 1235 cm^{-1}. This region have the broad and weak band shape. The graph pattern for this region are affected by increased the percentages of cassava starch. The addition of cassava starch in hybrid binder caused the band shape becomes wide and smoother. Aromatic ether only existed in hybrid binder with 20% of cassava starch. Aromatic ether group are disappear in others composition of hybrid binder.

The IR absorption for aliphatic hydrocarbon characteristics band are around 2935–2915 cm^{-1}. The strong CH_2 absorption are found at 2919 cm^{-1}. This region shows that the asymmetry CH_2 peak have smooth band. The atoms directly attached to the aliphatic groups may result in significant shifts from the standard frequencies. In particular adjacent atoms with high electronegativity will shift the band locations to higher frequencies. The aliphatic hydrocarbon existed in hybrid binder contains 40, 60 and 100% of cassava starch. The graph shows that hybrid binder contain 60% of cassava starch have strong band compared the others peaks which shows weak band.

Spectral interpretation NH stretching for aliphatic primary amides are near 3350-3180 cm^{-1} while CO and NH_2 are near 1650 cm^{-1} and 1650-1620 cm^{-1}.Aliphatic primary amides only existed in 100% of cassava starch. The infrared spectroscopy detection for the alkyne triple bond depends on the substitution. Klein et al., (2014) stated that peak at 1647 cm^{-1} was found in native cassava which is shows that the presence of O-H bending of adsorbed water. The monosubstituted acetylenes can easily be identified by the strong -C:::C-H which is carbon hydrogen stretching absorption 3290 cm^{-1}.

Alcohol are compounds which contain hydroxyl group. The hydroxyl function is probably one of the most dominant and characteristic of all of the infrared group frequencies. These compounds are classified as primary, secondary or tertiary according to the number of other carbon atoms attached to the oxygen bound carbon. Alcohols contain the very polar -OH group. This allows hydrogen bonding between molecules in the condensed phase. Due to this hydrogen bonding the boiling points of alcohols are much higher than the corresponding alkane with the same number of carbon atoms. Primary aliphatic alcohol has IR absorption at peak 1019 cm^{-1} while secondary aliphatic alcohol has IR absorption at peak 1017 cm^{-1}.

Secondary aliphatic alcohol have two carbon atoms attached to the oxygen bound carbon. C-O stretching and OH deformation vibrations are at 1100 cm^{-1}. Secondary aliphatic alcohol have two carbon atoms attached to the oxygen bound carbon. C-O stretching and OH deformation vibrations are at 1100 cm^{-1}. Secondary aliphatic alcohol have two carbon atoms attached to the oxygen bound carbon. C-O stretching and OH deformation vibrations are at 1100 cm^{-1}. Based on previous research Lin et al., (2016) the peak at 1016 cm-1 are found in native cassava starch. The intensity band peaks for aliphatic alcohol increasing as the increasing of percentages of starch and the band shift to the right.

Based on previous studies, bands in the 1369-1420cm^{-1} are contributed by C-H bending vibrations. The peaks at 1156 and 1080 cm^{-1} were mainly attributed to C-O stretch of C-O-H in starch (Sukhija et al., 2016). The higher value indicated that a crystalline phase existed in the cassava starch (Klein et al., 2014).

According to Ma et al., (2006), the peak at the low wave number results from the strong hydrogen bonds which drag the relative groups to a lower vibration frequency. On the other hand, the peaks at higher wave number are due to the weak interaction of hydrogen bonding. Thus the above changes in wave number indicated less hydrogen bonding in hybrid binder.

Based on the FTIR spectra analysis, increasing percentages of cassava starch will increase the presence of OH groups in hybrid binder. The functional group for OH groups are alcohol and water. The result shows that hybrid binder with 20% of cassava starch contain less OH group compared to 100% of cassava starch. The decrease OH group in binder will increased the advantages of binder. This is shows that the hybrid binder with 20% of cassava starch has a possibility to be a good binder.

4.3 Mechanical properties

The mechanical properties were evaluated such as bending strength, tensile strength, impact strength, and tensile modulus, elongation at break and flexural modulus of the materials. The significant reduction in flexural strength is due to the impact induced damage and that the residual flexural strength is more susceptible to damage than residual flexural modulus.

4.3.1 Bending test

The three point bending or flexural test was carried out on UTM for the samples prepared as the dimension is 162 x 50 x 15mm. Maximum span length that were used are 100 mm and load are 1 N. Bending strength is the maximum stress in the stress-strain curve while bending modulus is the slope of the linear region. The results are taken from the average of three samples tested.

The bending behavior showing three main phases which are a first corresponding to a linear increase of the load applied with the arrow, second phase of non-linear behavior in which the maximum load was reached and final decrease of the load until specimen failure. The result for each ratios were recorded in Table 4.2. Modulus of rupture also known as flexural strength, bend strength or fracture strength is a mechanical parameter for brittle materials. It is defined as the ability of materials to resist deformation under load. It is also represents the highest stress experienced within the material at its moment of rupture (Buddi et al., 2015).

Table 4.2: Result of bending test for different concentration of cassava starch

cassava starch (%)	**Epoxy Resin (%)**	**Bending Strength (N/mm²)**	**Young's Modulus (N/mm²)**	**Standard deviation**
20	80	78.51	3798.76	4.29
40	60	108.72	7420.41	8.88
60	40	120.44	7362.54	10.14
80	20	126.58	7671.11	18.74
100	-	226.50	15161.52	22.6

Figure 4.2 shows the bending strength of three-layer plywood panel for different concentration of cassava starch. The bending strength for three-layer plwood panels which contains hybrid binder with ratio 20% cassava starch and 80% epoxy resin is 78.51 N/mm^2. For hybrid binder with ratio 40% cassava starch and 60% epoxy resin, the bending strength was increased from 78.51 N/mm^2 to 108.72 N/mm.

The three-layer plywood panel which contain 60 and 80% cassava starch in hybrid binder shows the value of bending strength is 120.44 and 126.58 N/mm^2. The three-layer plywood panel with 100% cassava starch has 226.50 N/mm^2 bending strength.

The values of standard deviation for three-layer plywood panels which contains 20 and 40% cassava starch of hybrid binder are 4.29 and 8.88. The three-layer plywood panels with 60% cassava starch and 40% epoxy resin shows the values of standard deviation is 10.14. The standard deviation for 80 and 100% cassava starch of hybrid binder are 18.74 and 22.6.

For bending testing, three-layer plywood panel with 100% cassava starch showed the maximum bending strength compared with three-layer plywood panel with others composition which indicates higher brittleness. Three-layer plywood panel with 20% cassava starch shows the lowest value of bending strength which indicates highest ductility. The value of bending strength were increased due to the increase of percentages of cassava starch. The ductile materials have a lower young modulus as it undergoes a considerable deformation before failure happens.

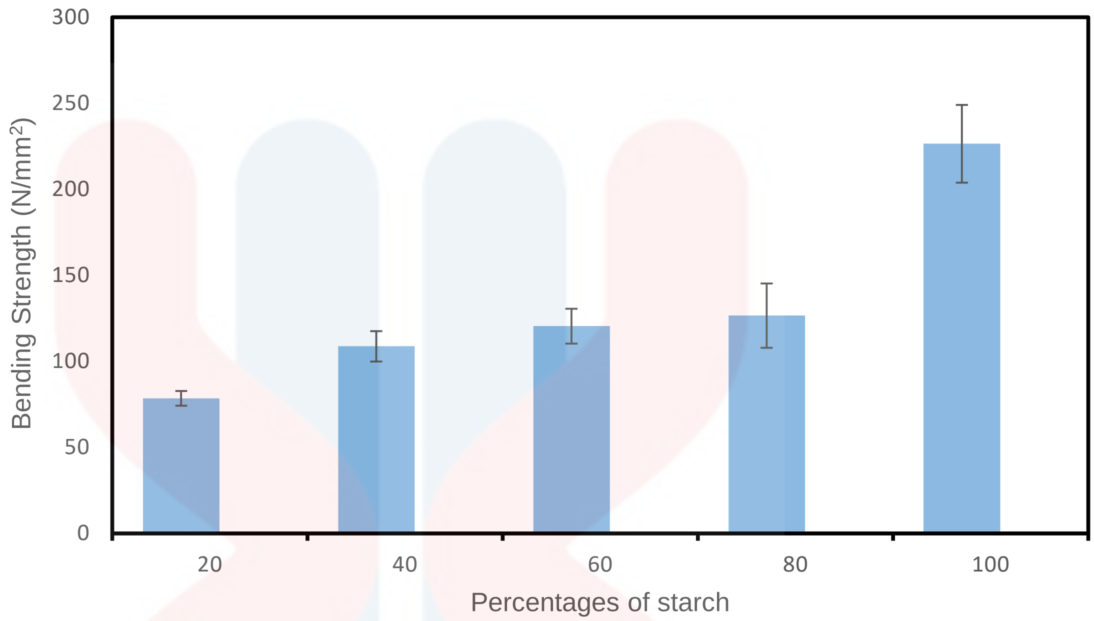

Figure 4.2: Bending strength of three-layer plywood panel for different percentages of cassava starch

Young's modulus indicates stiffness as well as the extent of deformation of a material when it is subjected to the bending stress and gives a measure of the ductility of the material. The brittle materials have a high value of young's modulus as it fails before undergoing deformation.

Figure 4.3 shows the Young's modulus of three-layer plywood panel for different percentages of cassava starch. The Young's modulus for three-layer plywood panel with 20% cassava starch and 80% epoxy resin is 3798.76 N/mm^2. For three-layer plywood panel with ratio 40% cassava starch of hybrid binder shows 7420.41 N/mm^2 of young's modulus. On the other hand, the values of young's modulus for 60 and 80% cassava starch are 7362.54 and 7671.11 N/mm^2. The three-layer plywood panel which contain 100% cassava starch shows 15161.52 N/mm^2 value of young's modulus.

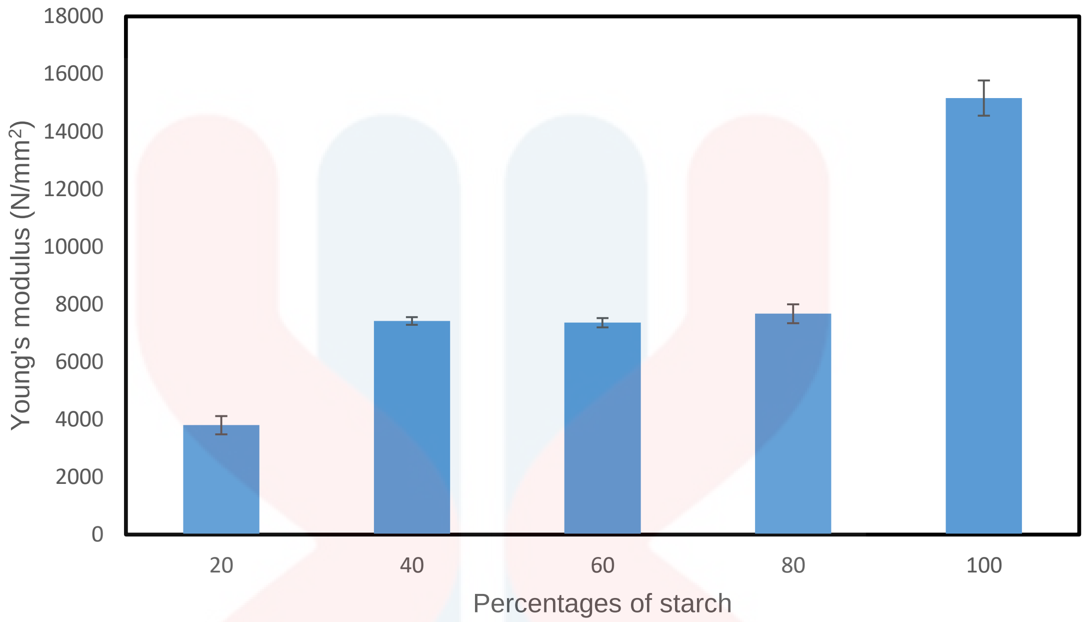

Figure 4.3: Young modulus of three-layer plywood panel for different percentages of cassava starch

Compared with previous research by Liu et al., (2012) bending strength and young's modulus increased and then decreased with increasing of starch. Prompunjai and Sridach (2010), also stated that flexural strength of materials increased and the decreased with increasing percentages of starch.

100% of cassava starch have a much higher value of young modulus of 15161.52 N/mm^2 compared to 3798.76 N/mm^2 of 20% cassava starch which indicates higher value of stiffness. The typical characteristic of the brittle material is to fail while the deformation is elastic and does not show any plastic deformation. On observation, the three-layer plywood panel with 20% cassava starch of hybrid binder shows better results than others in term of its ductility.

4.3.2 Impact test

The Charpy test specimens were made according to the dimension 55 x 10 x 15 mm. The 5.20 m/sec speed was used. The main reasons of concern for three-layer plywood panels generally is the low values of impact energy. The impact test was carried out by charpy test and the results were recorded are shown in Table 4.3.

Table 4.3: Impact testing on three-layer plywood panel which contain different percentages of cassava starch

Samples (%)		**Energy used (J)**	**Standard deviation**
Cassava starch	**Epoxy resin**		
20	80	48.62	12.11
40	60	38.51	2.57
60	80	38.27	1.29
80	20	36.01	2.34
100	-	29.90	0.34

The average energy used for three-layer plywood panels with hybrid binder contain 20% cassava starch and 80% epoxy resin are 48.62 J. For 40 and 60% cassava starch, the energy were used slightly decrease which is 38.51 and 38.27 J. The energy used continuously decreased for 80 and 100% cassava starch which is from 36.01 and 29.90 J. The values of standard deviation for hybrid binder with 20% cassava starch is 12.11 followed by hybrid binder with 40% cassava starch is 2.57. The standard deviation for hybrid binder with 60 and 80% cassava starch are 1.29 and 2.34.

The hybrid binder with 100% of cassava starch with no composition of epoxy resin shows standard deviation values is 0.34. The tests showed that the three-layer plywood panels made with 100% starch were not very good with the impact stress as it showed very low values from the tests performed. The percentages of epoxy resin provides strength for the plywood panels as the sample with high percentages of epoxy resin in three-layer plywood panels which is 20% starch and 80% epoxy resin seems to have low impact strength when compared to the others ratios. Figure 4.4 shows the impact strength of three-layer plywood panel for five different percentages of starch.

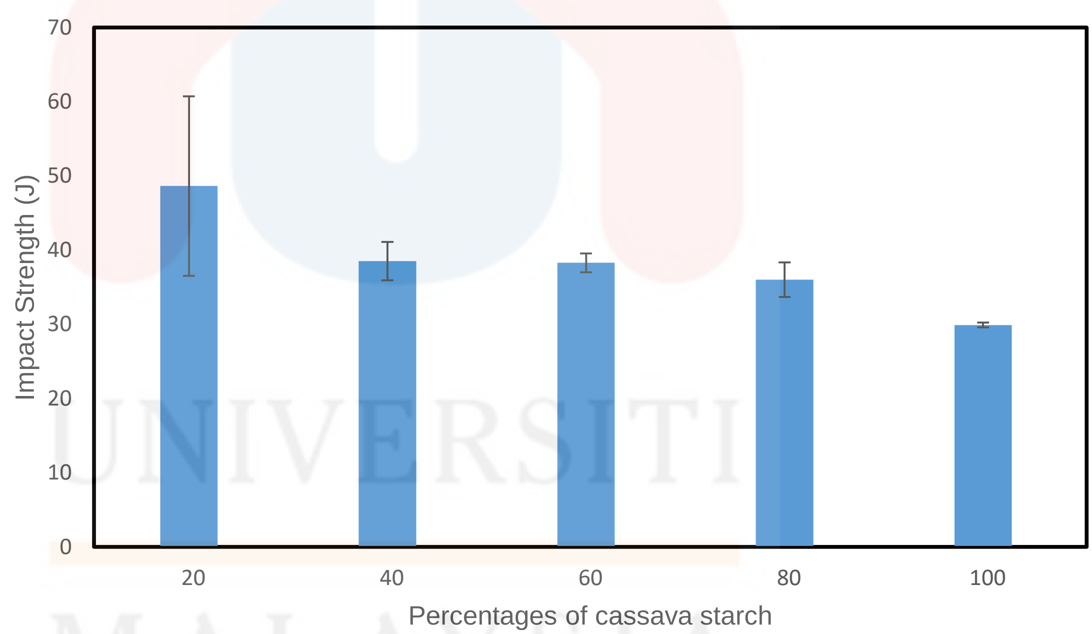

Figure 4.4: Impact strength of three-layer plywood panel for different percentages of cassava starch

The 20% starch seems to have a better impact strength than the 100% starch. The increase in the impact strength with the increased percentages of epoxy resin may be due to the fact that more energy will have to be used up to break the bonding between the binders. There are lack research about blending the cassava starch with epoxy resin using impact testing. But previous research had compared about the epoxy resin with polyester and they had stated that polyester has high impact values compared to epoxy resin (Gopinath et al., 2014).

The results from impact test shows that hybrid binder with 100% of cassava starch have low values of energy. It is proves that the three-layer plywood panels with 100% of cassava starch are the weakest samples for impact test and 20% of cassava starch have high strength because high energy are needed to break the samples. The tests also showed that the three-layer plywood panels made with 100% starch were not very good with the impact stress as it showed very low values from the tests performed.

4.3.3 Tensile test

Tensile test was carried out using UTM to estimate the tensile strength at different percentages of cassava starch applied at three-layer plywood panels. The three-layer plywood were prepared as dimension 80 mm x 25 mm x 15 mm.

Table 4.4 shows all the data that were recorded in tensile test. In the table contain the values of elongation and young's modulus.

Table 4.4: Tensile testing of different concentration of hybrid binder

Samples (%)		Elongation (mm)	Young's Modulus (N/mm^2)
Cassava starch	Epoxy Resin		
20	80	0.58	4073.59
40	60	0.66	758.31
60	40	1.10	943.63
80	20	1.61	910.37
100	-	1.24	2454.30

Figure 4.5 shows the values of young modulus which is depend on the percentages of cassava starch in hybrid binder. From the figure 4.5, the three-layer plywood panels which contain 20% cassava starch and 80% epoxy resin have 4073.59 N/mm^2 of young's modulus. On the other hand, the value of young's modulus for composition 40% cassava starch and 60% epoxy resin was decreased which is 758.31 N/mm^2 and increased at 943.63 N/mm^2 for composition 60% cassava starch and 40% epoxy resin.

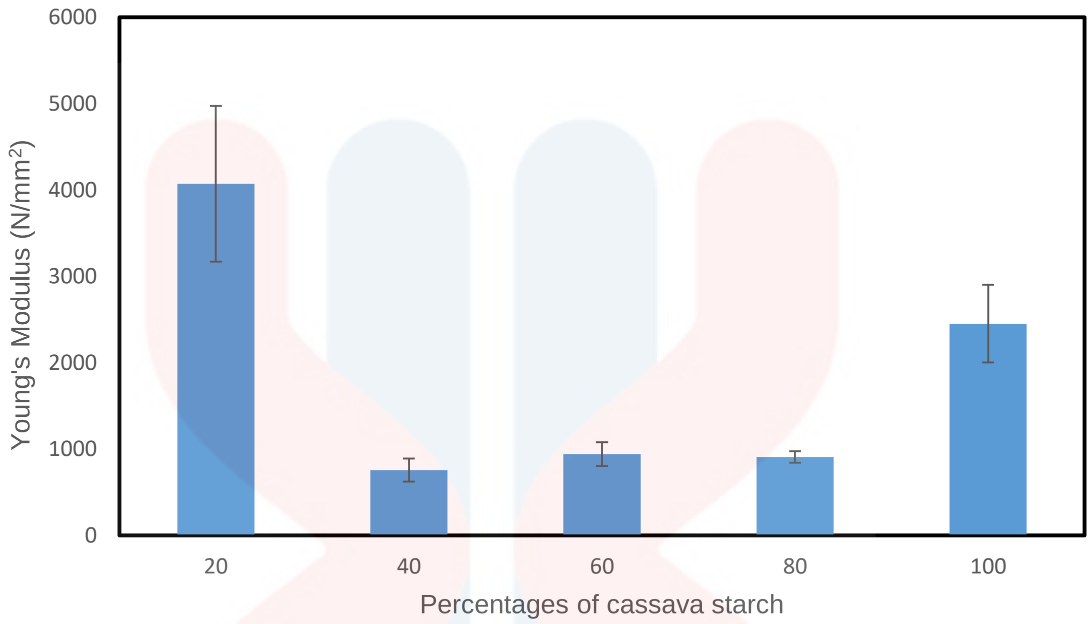

Figure 4.5: Young modulus of three-layer plywood panel with different percentages of cassava starch in hybrid binder

For 80% cassava starch and 20% epoxy resin, the value for young's modulus was decreased to 910.37 N/mm^2 and increased again at 2454.30 N/mm^2 for 100% cassava starch. These result are quite similar with the previous research by Belibi et al., (2014) which state that increased percentages of cassava starch will increase the values of young's modulus.

Rachtanapun et al., (2012) also stated addition percentages of cassava starch leads to increased the values of young's modulus. The tensile test results showed that the maximum value of young modulus of tensile test is 4073.59N/mm^2 which contain 20% cassava starch. While the minimum value is 758.31 N/mm^2 which the hybrid binder contain 40% of cassava starch.

Figure 4.6 shows the elongation of three-layer plywood panels depending on different ratios of hybrid binder. The elongation result shows that hybrid binder with ratio 20% cassava and 80% epoxy resin has elongation 0.58 mm and the elongation graph was continuously increased for hybrid binder with have composition of 40, 60 and 80% cassava starch which are 0.66, 1.10, 1.61 mm.

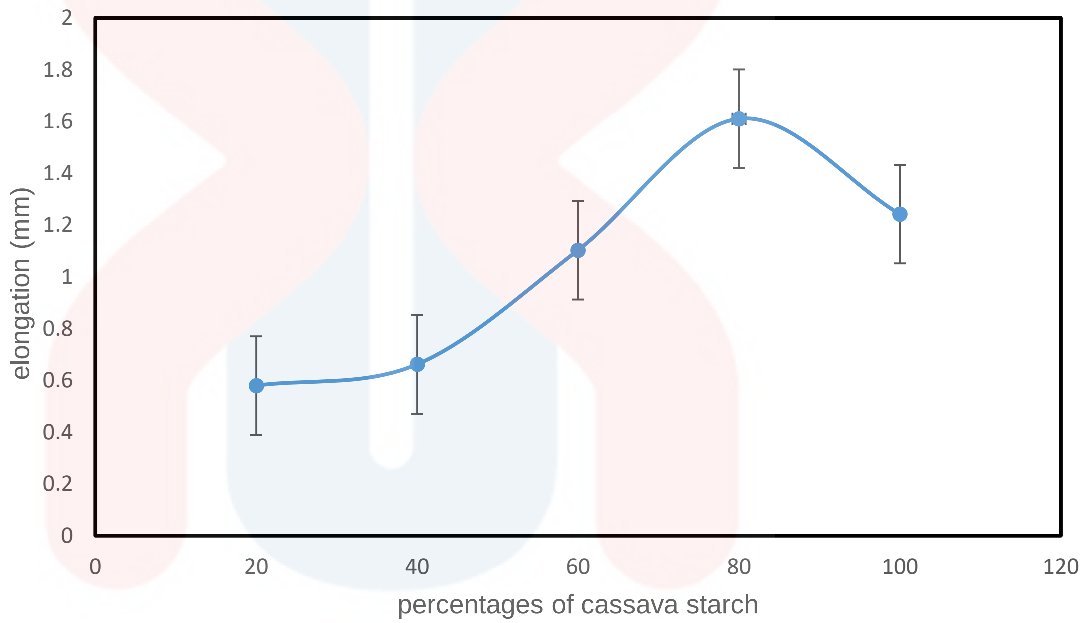

Figure 4.6: Elongation of three-layer plywood panels depending on different ratios of hybrid binder

For 100% cassava starch, graph pattern shows slightly decrease which is from 1.61 to 1.24 mm. The percentage of elongation increased when cassava starch is increased to the hybrid binder. According to previous research which is using cassava starch as their matrix in composites, the percent elongation at break naturally decreases when starch is decreased to the materials (Carvalho et al., 2011).

Based on research by Belibi et al., (2014) the elongation was decreased with decreased the percentages of cassava starch. For the materials to perform well under the shear loads the binder element must not only exhibit good mechanical properties but must also have high adhesion to the materials. The results in this work confirm that the three-layer plywood panel with 80% of cassava starch exhibited better tensile strength than others.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this paper, hybrid binder by using cassava starch-epoxy resin blends were prepared and characterized. The preparation of hybrid binder were prepared by different concentration of cassava starch act as parameter in this research. Chemical properties were analyzed by using FTIR spectroscopy. The mechanical properties were tested by using UTM and charpy test.

Based on the analysis, FTIR result shows that the graph pattern from different samples are similar. FTIR spectral shows that functional group such as aliphatic alcohol were existed in every samples except hybrid binder with 60% and 80% of cassava starch. In the spectra of 60% and 80% of cassava starch, only one functional group are existed which are aliphatic hydrocarbon and inorganic carbonate compund. Spectral interpretation for 100% starch, the functional group existed are aliphatic primary amides, alkynes mono-substituted, aliphatic hydrocarbons and primary aliphatic alcohols.

The results from impact test shows that hybrid binder with 100% of cassava starch have low values of energy. It is proves that 100% of cassava starch are the weakest samples for impact test and 20% of cassava starch have high strength because high energy are needed to break the samples.

Besides, for bending testing, three-layer plywood panel with 100% cassava starch showed the maximum bending strength of 226.55 N/mm^2 compared 78.51 N/mm^2 showed by three-layer plywood panel with 20% cassava starch. The three-layer plywood panel with 20% cassava starch shows better results than others in term of its ductility. On the other hand, tensile test shows that 80% of cassava starch has high values for elongation. The results in this work shows that the three-layer plywood panel with 80% of cassava starch exhibited better tensile strength than others. The results shows that hybrid binder with 20% cassava starch exhibited better mechanical properties.

5.2 Recommendation

Future works must evaluate the hybrid binder by using others natural such as corn, sago, potato, wheat starch, agar and synthetic binder such as urea formaldehyde resin, polyester, polyethylene glycol (PEG), polyvinyl alcohols (PVA) and polytetrafluoroethylene. Moreover, future studies must increase the types of characterization such as x-ray diffraction, scanning electron microscopy, viscosity and others suitable physical testing such as water absorption, moisture content and density test. Besides, the mechanical testing such as shear test must be added in future research.

On the other hand, the parameter also must be added to strengthen the research. The examples of parameter that must be added are temperature and volume of water in extraction starch process. Besides, In future research must make a comparison between different types of hybrid binder, not focus only one types of hybrid binder with different composition. In further research, the hybrid binder should prepared in film form.

REFERENCES

Abolhasani, H., & Muhamad, N. (2010). A new starch-based binder for metal injection molding. *Journal of Materials Processing Technology*, 210, 961-968.

Aggarwal, P., & Dollimore, D. (1998). The effect of chemical modification on starch studied using thermal analysis. *Thermochimica Acta*, 324, 1-8.

Aguilar, N., Albanell, E., Minarro, B., & Capellas, M. (2015). Chickpea and tiger nut flours as alternatives to emulsifier and shortening in gluten-free bread. *LWT- Food Science and Technology*, 62, 225-232.

Ahmad, F., Williams, P. A., Doublier, J., Durand, S., & Buleon, A. (1998). Physico-chemical characterization of sago starch. *Carbohydrate Polymers*, 38, 361-370.

Ahmed, M. A., Kandil, U. F., Shaker, N. O., & Hashem, A. I. (2015). The overall effect of reactive rubber nanoparticles and nano clay on the mechanical properties of epoxy resin. *Journal of Radiation Research and Applied Sciences*, 8, 549-561.

Ahmed, O. H., Abdullahi, N., Siddik, J. B., & Zakariah, M. H. (2014). Effect of planting methods on growth and yield of cassava (manihot esculenta crantz) grown with polythene-covering. *Journal of Experimental Biology and Agricultural Sciences*, 1, 2320 – 8694.

Airey, G. D., Mohammed, M. H., & Fichter, C. (2008). Rheological characteristics of synthetic road binders. *Fuel*, 87, 1763–1775.

Ajayin, O. A., Akinrinde, I. M., & Akinwunmi, O. O. (2015). Towards the development of shelf stable 'iru' (Parkia biglobosa) condiment bouillon cubes using corn, cassava and potato starch extracts as binders. *Nigerian Food Journal*, 33, 67-72.

Alebiowu, G., & Osinoiki, K. A. (2010). Assessment of tapioca starches obtained after different steeping periods as binder in paracetamol tablet formation. *Farmacia* 58, 12.

Ann-Charlotte Aliasson. (2004). *Starch in Food: Structure, Function and Applications*. Cambridge, England: Woodhead Publishing Limited.

Apotiola, Z.O., & Idowu, M.A. (2012). Effect of addition of Ficus exasperata and Spoudias mombin leaves on functional and sensory properties of cassava roots in "Lafun" Production. *Nigerian Food Journal*, 3, 28-32.

Aslan, M., Weingarth, D., Herbeck-Engel, P., Grobelsek, I., & Presser, V. (2015). Polyvinylpyrrolidone/polyvinyl butyral composite as a stable binder for castable supercapacitor electrodes in aqueous electrolytes. *Journal of Power Sources*, 279, 323-333.

Aviara, N. A., Onuoha, L. N., Falola, O. E., & Igbeka, J. C. (2014). Energy and exergy analyses of native cassava starch drying in a tray dryer. *Energy*, 73, 809-817.

Belibe, P. C., Daou, T. J., Ndjaka, J. M. B., Nsom, B., Michelin, L., & Durand, B. (2014). A comparative study of some properties of cassava and tree cassava starch films. *Physics Procedia*, 5, 220-226.

Biswas, A., Shogren, R. L., Selling, G., Salch, J., willet, J. L., & Buchanan, C. M. (2008). Rapid and environmentally friendly preparation of starch esters. *Carbohydrate polymers*, 74, 137-141.

Bleyan, D., Svoboda, P., & Hausnerova, B. (2015). Specific interactions of low molecular weight analogues of carnauba wax and polyethylene glycol binders of ceramic injection moulding feedstocks. *Ceramics international*, 41, 3975–3982.

Buddi, T., Muttil, N., Rao, B. N., & Singh, S. K. (2015). Development of a soya based adhesives in plywood manufacturing. *Materials Today: Proceedings*, 2, 3027-3031.

Builders, P. F., Mbah, C. C., Adama, K. K., & Audu, M. M. (2013). Effect of pH on the physicochemical and binder properties of tigernut starch. *Starch Journal* 281-293.

Carvalho, O. T., Averous, L., & Tadini, C. C. (2011). Mechanical properties of cassava starch-based nano-biocomposites. *Trends in Food Science & Technology*, 14, 71-78.

Chan, H. T., Fazilah, A., Bhat, R., Leh, C. P., & Karim, A. A. (2012). Effect of deproteinization on degree of oxidation of ozonated starch. *Food Hydrocolloids*, 26, 339-343.

Chen, S., Lu, X., Wang, T., & Zhang, Z. (2016). Preparation and characterization of urea-formaldehyde resin/reactive kaolinite composites. *Particuology*, 24, 203-209.

Chiu, C. W., & Solarek, D. (2009). Modification of starches. *Food Sciences and technology*, 3, 629-655.

Dacanal, G. C., Feltre, G., Thomazi, M. G., & Menegalli, F. C. (2016). Effects of pulsating air flow in fluid bed agglomeration of starch particles. *Journal of Food Engineering*, 181, 67-83.

Daramola, B., & Osanyinlusi, S. A. (2006). Investigation on modification of cassava starch using active components of ginger roots (Zingiber officinale Roscoe). *African Journal of Biotechnology*, 5, 917-920.

Emengo, F. N., Chukwu, S. E. R., & Mozie, J. (2002). Tack and bonding strength of carbohydrates based adhesives from different botanical sources. *International Journal of Adhesion and adhesives*, 22, 93-100.

Ezeh, O., Gordon, M. H., & Niranjan, K. (2016). Enhancing the recovery of tiger nut (Cyperus esculentes) oil by mechanical pressing: Moisture content, particle size, high pressure and enzymatic pre-treatment effects. *Food Chemistry*, 194, 354-361.

Gao, J., Luo, Z. G., & Luo, F. X. (2012). Ionic liquids as solvents for dissolution of corn starch and homogeneous synthesis of fatty-acid starch esters without catalysts. *Carbohydrate Polymers*, 89, 1215-1221.

Gao, S., Su, Y., Bao, L., Li, N., Chen, L., Zheng, Y., Tian, J., Li, J., Chen, S., & Wu, F. (2015). High-performance LiFePO4/C electrode with polytetrafluoroethylene as an aqueous-based binder. *Journal of Power sources*, 298, 292–298.

Ghimirea, A., Sena, R., & Annachhatrea, A. P. (2015). Biosolid management options in cassava starch industries of Thailand: Present practice and future possibilities. *Procedia Chemistry*, 14, 66-75.

Giertl, G., Schdmidtova, J., & Daxnoreva, M. (2015). Economic Aspects of Foamed Adhesives Using in Wood Processing Industry. *Procedia Economics and Finance*, 34, 284-289.

Gopinath, A., Kumar, M. S., & Elayaperumal, A. (2014). Experimental investigations on mechanical properties of jute fiber reinforced composites with polyester and epoxy resin matrices. *Procedia Engineering*, 97, 2052 – 2063.

Hong, J., Chen, R., Zeng, X. A., & Han, Z. (2016). Effect of pulsed electric fields assisted acetylation on morphological, structural and functional characteristics of potato starch. *Food Chemistry*, 192, 15-24.

Hussain, A. L., & Nasr, H. E. (2010). The role of carboxylic acid on the characterization and evaluation seed emulsion of styrene/butyl acrylate copolymer lattices as paint. *Nature science*, 8(8), 94-103.

Jamaludin, A. R., Kasim, S. R., Abdullah, M. Z., & Ahmad, Z. A. (2014). Sago starch as binder and pore-forming agent for the fabrication of porcelain foam. *Ceramics International*, 40, 4777-4784.

Jamaludin, A. R., Kasim, S. R., Ismail, A. K., Abdullah, M. Z., & Ahmad, Z. A. (2015). The effect of sago as binder in the fabrication of alumina foam through the polymeric sponge replication technique. *Journal of the European Ceramic Society*, 35, 1905–1914.

Jeong, S. S., Bockenfeld, N., Balducci, A., Winter, M., & Passerini, S. (2012). Natural cellulose as binder for lithium battery electrodes. *Journal of Power Sources*, 199, 331-335.

Julianti, E., Rusmarilin, H., Ridwansyah, & Yusraini, E. (2015). Functional and rheological properties of composite flour from sweet potato, maize, soybean and xanthan gum. *Journal of the Saudi Society of Agricultural Sciences*.

Kaniappan, K., & Latha, S. (2011). Certain investigations on the formulation and characterization of polystyrene/ poly (methylmethacrylate) blends. *Int J. Chem. Res.*, 3(2), 708-717.

Karaki, N., Aljawish, A., Humeau, C., Muniglia, L., and Jasniewski, J. (2016). Enzymatic modification of polysaccharides mechanisms, properties, and potential applications: A review. *Enzyme and Microbial Technology,* 90, 1-18.

Kenneth, K. A., Michael, O. A., Anthony, A. O., & Sunday, T. (2014). Isolation and physicochemical characterization of tigernut (Cyperus esculentus) starch as potential industrial biomaterial. *International Journal of materials Science and Applications*, 3, 37-41.

Klein, B., Vanier, N. L., Moomand, K., Pinto, V. Z., Colussi, R., Zavareze, E. D. R., & Dias, A. R. G. (2014). Ozone oxidation of cassava starch in aqueous solution at different pH. *Food Chemistry*, 155, 167-173.

Klemm, D., Heublein, B., Fink, H. P., Bohn, A. (2005). Cellulose: Fascinating biopolymer and sustainable raw material. *Angewandte Chemie International Edition*, 44, 3358-3393.

Laratonda, F. D. S., Matsui, K. N., Sobral, P. J. A., & Laurindo, J. B. (2005). Hygroscopicity and water vapor permeability of Kraft paper impregnated with starch acetate. *Journal of Food Engineering*, 71, 394-402.

Lawal, M. V., Odeniyi, M. A., & Itiola, O. A. (2015). Effect of thermal and chemical modifications on the mechanical and release properties of paracetamol tablet formulations containing corn, cassava and sweet potato starches as filler-binders. *Asian Pacific Journal of Tropical Biomedicine*, 5(7), 585-590.

Lee, S., choi, J. H., & Lee, J. W. (2015). Curing behavior of polyurethane as a binder for polymer-bonded explosives. *Journal of Industrial and Engineering Chemistry*, 21, 980–985.

Lin, M., Shang, X., Liu, P., Xie, F., Chen, X., & Sun, Y. (2016). Zinc chloride aqueous solution as a solvent for starch. *Carbohydrate Polymer*, 136, 266-273.

Liu, J., Jia, C., & He, C. (2012). Rice straw and cornstarch biodegradable composites. *AASRI Procedia*, 3, 83-88.

Ma, X., Yu, J., & Zhao, A. (2006). Properties of biodegradable poly (propylene carbonate)/starch composites with succinic anhydride. *Composites Science and Technology*, 66, 2360-2366.

Maitz, M. F. (2015). Applications of synthetic polymers in clinical medicine. *Biosurface and Biotribology*, 1, 161-176.

Manek, R. V., Builder, P. F., Kolling, W. M., Emeje, M., & Kunle, O. O. (2012). Physicochemical and binder properties of starch obtained from Cyperus esculentus. *PharmSciTech*, 13, 379-388.

Masri, M. N., & Mohamad, A. A. (2009). Effect of adding potassium hydroxide to an agar binder for use as the anode in Zn–air batteries. *Corrosion Science*, 51, 3025–3029.

Masri, M. N., Nazeri, M. F. M., Chai Y. N., & Mohamad, A. A. (2013). Tapioca binder for porous zinc anodes electrode in zinc–air batteries. *Journal of King Saud University – Engineering Sciences*, 27, 217-224.

Matei, S., Stoicanescu, M., & Crisan, A. (2016). Composites with Short Fibers Reinforced Epoxy resin Matrix. *Procedia Technology*, 22, 174-181.

Necasova, B., Kovarova, B., Liska, P., & Slanhof, J. (2015). Determination of adhesion of silyl modified polymer adhesives to wooden facade cladding – case study. *Procedia Engineering*, 108, 410-418.

Norstrom, E., Fogelstrom, L., Nordqvist, P., Khabbaz, F., & Malmstrom, E. (2015). Xylan- A green binder for wood adhesives. *European Polymer Journal*, 67, 483-493.

Oluwole, O. I., & Avwerosuoghene, O. M. (2015). Effects of cassava starch and natural rubber as binders on the flexural and water absorption properties of recycled paper pulp based composites. *International Journal of Engineering and Technology Innovation*, 5. 255-263.

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.

Osemeahon, S. A., Maitera, O. N., Hotton, A. J., & Dimas, B. J. (2013). Influence of starch addition on properties of urea formaldehyde/starch copolymer blends for application as a binder in the coating industry. *Journal of environmental chemistry and ecotoxilogy*, 5(7), 181-189.

Park, H. K., Kong, B. S., & Oh, E. S. (2011). Effect of high adhesive polyvinyl alcohol binder on the anodes of lithium ion batteries. *Electrochemistry Communications*, 13, 1051–1053.

Pap, J. S., Kastner, M., Muller, S., & Jansen, I. (2013). Experimental characterization and simulation of the mechanical behavior of an epoxy adhesive. *Procedia Materials Science*, 2, 234 – 242.

Pejovnika, S., Dominkoa, R., Belea, M., Gabersceka, M., & Jamnika, J. (2008). Electrochemical binding and wiring in battery materials. *Journal of Power Sources*, 184, 593–597.

Pinto, V. Z., Vanier, N. L., Deon, V. G., Moomand, K., Halal, S. L. M. E., Zavareze, E. D. R., Lim, L. T., & Dias, A. R. G. (2015). Effect of single and dual physical modifications on pinhoa starch. *Food Chemistry*, 187, 98-105.

Prompunjai, A., & Sridach, W. (2010). Preparation and some mechanical properties of composite materials made from sawdust, cassava starch and natural rubber latex. *World Academy of Science, Engineering and Technology*, 48, 928-932.

Rachtanapun, P., Pankan, D., & Srisawat, D. (2012). Edible films of blended cassava starch and rice flour with sorbital and their mechanical properties. *Journal of Agricultural Science and Technology*, 2, 252-258.

Sangseethong, K., Termvejsayanon, N., & Sriroth, K. (2010). Characterization of physicochemical properties of hypochlorite- and peroxide-oxidized cassava starches. *Carbohydrate Polymers*, 82, 446–453.

Shan, X., Huang, C., Yang, H., Wu, Z., Li, J., Huang, R., & Li, L. (2015). The thermal expansion and tensile properties of nanofiber-ZrW2O8 reinforced epoxy resin nanocomposite. *Physics Procedia*, 67, 1056 – 1061.

Singh, N., Chawla, D., & Singh, J. (2004). Influence of acetic anhydride on physicochemical, morphological and thermal properties of corn and potato starch. *Food Chemistry*, 86,601-608.

Sinha, V. R., & Kumria, R. (2001). Polysaccharides in colon-specific drug delivery. *Int. J. Pharm*, 224, 19-38.

Tan, S. L. (2015). Cassava – silently, the tuber fills. *UTAR agriculture science journal*, 1, 12-24.

Tang, H., Weng, Q., & Tang, Z. (2015). Chitosan oligosaccharides: a novel and efficient water soluble binder for lithium zinc titanade anode in lithium-ion batteries. *Electrochimica Acta*, 151, 27-34.

Tonukari, N. J. (2004). Cassava and the future of starch. *Electronic Journal of Biotechnology*, 7. 5-8.

Uhumwangho, M. U., Okor, R. S., Eichie, F. E. and Abbah, C. M. (2006). Influence of some starch binders on the brittle fracture tendency of paracetamol tablets. *African Journal of Biotechnology*, 5, 1950-1953.

Vanier, N. L., Zavareze, E. D. R., Pinto, V. Z., Klein, B., Botelho, F. T., Dias, A. R. G., & Elias, M. C. (2012). Physicochemical, crystallinity, pasting and morphological properties of bean starch oxidised by different concentrations of sodium hypochlorite. *Food Chemistry*, 131, 1255–1262.

Varzi, A., & Passerini, S. (2015). Enabling high areal capacitance in electrochemical double layer capacitors by means of the environmentally friendly starch binder. *Journal of Power Sources*, 300, 216-222.

Veiga, J. P. S., Valle, T. L., Feltran, J. C., & Bizzo, W. A. (2015). Characterization and productivity of cassava waste and its use as an energy source. *Renewable Energy*, 93, 691-699.

Waliszewski, K. N., Aparicio, M. A., Bello, L.A., & Monray, J. A. (2003). Changes of banana starch by chemical and physical modification. *Carbohydrate Polymers*, 52, 237-242.

Yu, W., He, H., Cheng, N., Gan, B., & Li, X. (2009). Preparation and experiments for a novel kind of foundry core binder made from modified potato starch. *Materials and Design*, 30, 210-213.

Zavareze, E. D. R., Pinto, V. Z., Klein, B., Halal, S. L. M. E., Elias, M. C., Hernández, C. P., & Dias, A. R. G. (2011). Development of oxidised and heat–moisture treated potato starch fil. *Food Chemistry*, 132, 344–350.