PHYSICAL AND MECHANICAL PROPERTIES OF WOOD PLASTIC COMPOSITE (WPC) MADE FROM THREE DIFFERENT PLASTIC WASTE CODES AND ACACIA WOOD FLOUR

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I hereby declare that the material in this thesis is my own expect for the citation, equations and references which have been fully acknowledgement.

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ABSTRACT

Over the past years, wood plastic composite (WPC) has been a favourite topic among the researchers. The main reason for the use of plastic wastes in producing WPC was because of the environmental concern and the availability of wood flour. In this study, three types of WPC were produced by using three different plastic waste codes combine with Acacia wood flour namely polypropylene-wood flour (PP-WF), high density polyethylene-wood flour (HDPE-WF) and low density polyethylene-wood flour (LDPE-WF) with different plastic content at 100%, 90%, 80%, 70%, 60% and 50%. Plastic waste particles and wood flour were mixed and melted together by using Hot-press machine. Later the mixture which were in mat-form were cut into small sheet before placed in a mould where the dimension of test piece followed American Society for Testing and Materials (ASTM) D638-02 and D790-02 standard specifications. The effect of plastic contents on physical, mechanical and morphological properties of all type of WPC were investigated in this study. The moisture content of the WPC increased along with the increase of wood flour content from 10% to 50%. Among the three different types of plastic waste codes, PP with 100% plastic content had the highest density (1.033 g/cm³) followed by 100% plastic content of LDPE (0.87 g/cm³) and HDPE (0.863 g/cm³) at 100% plastic content. Water absorption and thickness swelling increased more than 50% and 4% respectively as the plastic content decreased at 50%. Results showed that as the plastic content decreased, the tensile strength, Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) also decreased. Plastic waste codes of PP, HDPE and LDPE at 100% plastic content showed 25.02 N/mm², 16.41 N/mm² and 12.45 N/mm² of tensile strength respectively and showed significant difference at $p \leq 0.05$. Similar findings for MOE and MOR, the trend result also decreased as the plastic content decreased. Range value of MOE for PP-WF composite was 1020.07 N/mm² to 520.81 N/mm², while HDPE-WF and LDPE-WF composite achieved 423.27 N/mm² to 176.19 N/mm² and 372.42 N/mm² to 162.66 N/mm² respectively. Based on the results obtained in this study, the mechanical and physical properties of WPCs influenced by the plastic contents. The mechanical properties of PP-WF composite were higher than HDPE-WF and LDPE-WF composites.

ABSTRAK

CIRI-CIRI FIZIKAL DAN MEKANIKAL KOMPOSIT PLASTIK KAYU YANG DIPERBUAT DARIPADA TIGA JENIS KOD BAHAN BUANGAN PLASTIK DAN TEPUNG KAYU AKASIA

Sejak beberapa tahun yang lalu, komposit plastik kayu (WPC) telah menjadi topik kegemaran dalam kalangan penyelidik. Sebab utama penggunaan bahan buangan plastik dalam penghasilan WPC adalah kerana kesedaran alam sekitar dan gentian kayu yang mudah didapati. Dalam kajian ini, tiga jenis WPC dihasilkan dengan menggunakan tiga jenis bahan buangan plastik yang dicampurkan dengan tepung kayu Akasia iaitu polipropilena-tepung kayu (PP-WF), polietilena berketumpatan tinggi-tepung kayu (HDPE-WF) dan polietilena berketumpatan rendah-tepung kayu (LDPE-WF) dengan kandungan plastik yang berbeza pada 100%, 90%, 80%, 70%, 60% dan 50%. Bahan buangan plastik dan tepung kayu telah dicampur dan dicairkan bersama dengan menggunakan mesin tekanan panas. Kemudian campuran yang dalam bentuk hamparan telah dipotong menjadi partikel kecil sebelum diletakkan dalam acuan di mana dimensi bahan uji mengikut spesifikasi standard ASTM D638-02 dan ASTM D790-02. Kesan kandungan plastik pada sifat fizikal, morfologi dan mekanikal untuk semua jenis WPC telah disiasat dalam kajian ini. Kandungan lembapan komposit kayu plastik semakin meningkat dengan pertambahan kandungan tepung kayu dari 10% ke 50%. Antara tiga jenis kod bahan buangan plastik, PP dengan kandungan plastik 100% mempunyai ketumpatan tertinggi (1.03 g/cm^3) diikuti dengan kandungan plastik 100% LDPE (0.87 g/cm^3) dan HDPE (0.86 g/cm^3) pada kandungan plastik 100%. Keputusan menunjukkan bahawa apabila kandungan plastik menurun, penyerapan air dan pembengkakan ketebalan meningkat masing-masing dengan nilai lebih daripada 50% dan 4%. Manakala kekuatan tegangan, MOE (Modulus kekenyalan) dan MOR (Modulus pecahan) menurun apabila kandungan plastik menurun. Kod bahan buangan plastik iaitu PP, HDPE dan LDPE pada kandungan plastik 100% masing-masing menunjukkan 25.02 N/mm^2, 16.41 N/mm^2 dan 12.45 N/mm^2 untuk kekuatan tegangan dan menunjukkan perbezaan ketara pada $p \leq 0.05$. Keputusan yang sama untuk MOE dan MOR, tren graf juga menurun apabila kandungan plastik berkurangan. Nilai MOE untuk komposit PP-WF adalah 1020.07 N/mm^2 sehingga 520.81 N/mm^2, manakala komposit HDPE-WF dan LDPE-WF mencapai 423.27 N/mm^2 sehingga 176.19 N/mm^2 dan 372.42 N/mm^2 sehingga 162.66 N/mm^2 . Berdasarkan hasil yang diperolehi dalam kajian ini, sifat fizikal dan mekanikal WPC dipengaruhi oleh kandungan plastik. Sifat mekanik komposit PP-WF lebih tinggi daripada komposit HDPE-WF dan LDPE-WF.

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LIST OF SYMBOLS

%	Percentage
° C	Degree Celsius
g	Gram
mm	Milimeter
cm	Centimeter
N	Newton

LIST OF ABBRERIATIONS

ASTM	America Society for Testing and Materials
WPC	Wood Plastic Composite
PP	Polypropylene
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
PET	Polyethylene terephthalate
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
WA	Water Absorption

CHAPTER 1

INTRODUCTION

1.1 Study Background

It is undeniable that the financial developments and progress of the community in the metropolitan area resulted in the excessive number of municipal solid waste (MSW) output (Rahman, 2013). MSW are types of garbage which is available from daily things that are eliminated by the community. Some of the MSW are food waste, recyclable items such as plastic, aluminium, paper, bottle, manufacturing waste and many more. There is a quote saying 'the future will either be green or not at all'. Without our concern, as the increasing of growth population, the fact about the increasing amount of waste is undeniable too. Plastic wastes are one of the waste that is not easy to decompose which eventually end up in landfills and throw into the river.

Wood plastic composite (WPC) can be manufactured from wood-based materials such as wood flour and plastics. WPC have many superlative properties in term of durability, strength, stiffness and wear resistance. It also can be processed by various method such as compounding, extrusion and injection moulding with a specific heat and pressure conditions (Murayama *et al.,* 2019). Plastics have been with human over more than a century. Since 1990, the requirement of plastics had arising the landfill problem. Therefore, the idea of producing green plastic material made from natural resources is the solution for these problem (Kunwar *et al.,* 2016). With this requirement, a large amount of fossil fuel must be consumed in order to accomplish the worldwide demand. Relying on fossil fuel resource definitely affect ecological damage through their processing and utilization inclusive of wildlife's shelter loss, water pollution, soil eroding and other harmful effects.

The production of plastic waste from municipal and industry had impacted on the environment. It cannot be denied that when some irresponsible organisation take an easy way to dispose these plastic material such as through combustion. When burning these material, exceed of carbon dioxide release in the air which is then causes greenhouse effect and global warming.

1.2 Justification

Since the 20th century, plastics have been used increasingly in a large range of products because of their favourable properties, including low density, high strength-to-weight ratio, high durability, ease of manufacture and low cost. Recently, plastic products are widely used in almost every field, particularly in packaging, building and construction, automotive, electrical and electronics, agriculture and other industries (Gu and Ozbakkaloglu, 2016). However, due to the increasing in plastic use, the amount of plastic wastes produced also increased. Plastic waste considered for 8-12% of total municipal solid waste (MSW) produced in different countries throughout the world where the actual percentage different based on the population of the country. It was also approximated in 2025, the global plastic waste generation will increase to 9-13% of total municipal solid waste (MSW) (Hoornweg and Bhada-Tata, 2014).

To overcome this problem, therefore using plastic waste for the production of wood plastic composites (WPCs) has recently attracted considerable attention among researchers (Moreno and Saron, 2017). This is because using the plastic waste materials can reduce the environmental impact and the dependent of virgin plastics. Nowadays, wood plastic composites (WPC) have become popular due to recyclability, low density, low cost, low maintenance and eco-friendliness with good mechanical properties (Najafi, 2013). WPCs are produced by mixing wood flour into molten plastic matrices and then composite materials were formed through various processing methods such as compression, extrusion or injection moulding (Ratanawilai *et al.*, 2014).

Several studies have been made on WPC based on plastic waste and wood flour (Sommerhuber *et al.,* 2015; Haq and Srivastava, 2016; Petchwattana, 2018). However, there has been limited use on three different plastic waste codes which are PP code number 5, HDPE code number 2 and LDPE code number 4. When plastics were blended with wood flour, it showed higher strength and stiffness. Besides, blending plastics with wood flour can create value-added products that could enhance the value of plastic waste. Therefore, using plastics waste to produce WPC would not only provide an effective method of disposing plastic waste, but also reduce the consumption of natural and energy resources (Najafi, 2013).

1.3 Objectives

The aim of this study were:

1. To determine the physical properties of wood plastic composite (WPC) made from three different type of plastic waste at different ratio of 100%, 90%, 80%, 70%, 60%, 50% and Acacia wood flour.
2. To determine the mechanical properties of wood plastic composite (WPC) made from three different type of plastic waste at different ratio of 100%, 90%, 80%, 70%, 60%, 50% and Acacia wood flour.
3. To determine the effect of plastic content on physical and mechanical properties of wood plastic composite (WPC).

CHAPTER 2

LITERATURE REVIEW

2.1 History of Wood Plastic Composite (WPC)

Wood plastic composite (WPC) also can be named as wood-polymer composite and green composite. The existent of the term WPC came from plastic and wood flour combine together to form a composite materials. In the recent decades, WPC has been one of the major interesting research topics due to several advantages such as cheap, great stiffness and attainability of natural resources (Kaseem *et al.,* 2015). The involvement of WPC in the manufacturing sector has grown by leaps and bounds over the last few years. Among the key driver for this market growth are decking, fencing, moulding and siding. The market of WPC globally is estimated to grow about 13.2% over the next ten years to achieve roughly 9.7 billion dollar by 2025 (Cole, 2017).

There are two classes of plastics can be used in WPC. One of the classes of the thermoplastics that can be heated and melted, cooled and froze, and then re-melted without changing their properties. Example of thermoplastics are polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC) and polyethylene terephthalate (PET). While thermosets such as phenolic and epoxy are plastic that once it become solid, it cannot be re-melted. Wood is one of the good functional filler but only limited to degradation temperature of 200° C during the combination with plastic when heated (Najafi *et al.,* 2006).

In 1990, Selke and his team members investigated the combination of wood flour and recycled High density polyethylene (HDPE). They discovered that there was a relationship between the processing condition and the mechanical properties of the wood-plastic composite. To further investigate the role of plastic waste in wood-plastic composite, Simpson *et al.* (1990) carried out a series of experiment. They investigated the workability of recycled multi-layer of polypropylene in combination with wood flour.

2.2 Content of Wood Plastic Composite (WPC)

2.2.1 Wood flour

The nature of wood has proven since it consists of cellulose, hemicellulose, lignin and extractives. The content of cellulose ranges from 40% to 47%, while hemicellulose range from 20% to 35% in softwood and hardwood. Lignin content ranges from 18% to 35%. The amount of each portion in softwood and hardwood are shown in Table 2.1. The formation of cellulose began with the process of photosynthesis in the leaves of a tree. It was began when water and carbon dioxide were mixed together with the aid of sunlight to form glucose, simple sugars and oxygen.

Table 2.1 : Chemical composition of wood

Component	Softwood	Hardwood
Cellulose (% dry weight)	40 - 44	40 - 44
Hemicellulose (% dry weight)	20 - 32	15 - 35
Lignin (% dry weight)	25 - 35	18 - 25

Source : Shmulsky and Jones (2011)

After that, glucose was transformed to starch or to other sugars known as glucose 6-phosphate, fructose 6-phosphate and sucrose. Next, sucrose and other sugars which were in the form of sap moved to the branch, bark and root of a tree. From there, sucrose combined with water to form glucose and fructose. Glucose molecules were bonded together just like a repeating unit to form a cellulose (Figure 2.1). The chemical formula of cellulose consists degree of polymerization (DP). The DP different depending on the cellulose source and the treatment it had undergone (Shmulsky and Jones, 2011).

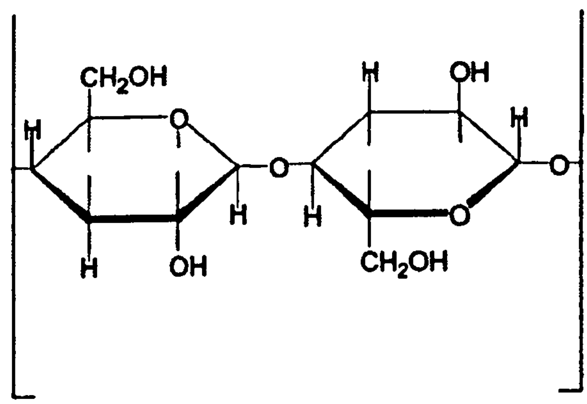

Figure 2.1 : Chemical structure of cellulose

Source : Thakur *et al.* (2014)

Cellulose is a polysaccharide with linear chain of 1,4-β-bonded anhydro-glucose units (Figure 2.2). Mostly, the setup of molecular cellulose is due to the outer hydroxyl groups. A great amount of cellulose is crystalline which joined together by the connection of intermolecular hydrogen. The hydroxyl groups located in the middle of glucose units in the same molecule (intra-molecular) or between two adjacent molecules (intermolecular linkages). The structure of cellulose such as have line up fibril arrangement and superior hydrogen bond result in high stiffness. In such a way, when wood flour was combine with a plastic, it can increase the stiffness of the wood plastic composite.

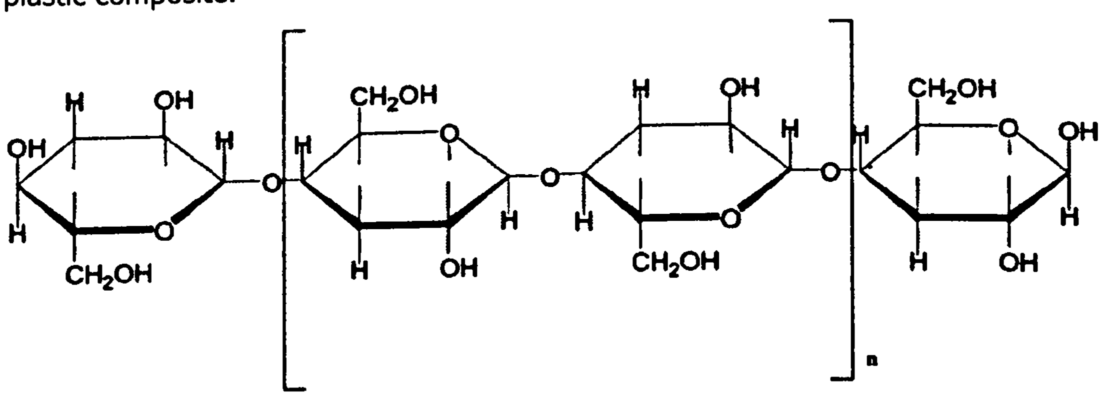

Figure 2.2 : The linear structure of cellulose molecule

Source : Thakur *et al.* (2014)

Hemicellulose can be found as a group of polysaccharide with lower degree of polymerization than cellulose and also a branched heterogenous polysaccharide consist of five types of sugars namely glucose, mannose, galactose, xylose and arabinose. Its structure is same with the cellulose which is the same method to the hemicelluloses are organized in 5 or 6 carbon sugars in chains. However, chains are relatively not long and irregular compared to the cellulose, therefore, the hemicelluloses are soluble or easily degraded. Hemicellulose have lower molecular weight and lower degree of polymerization (DP).

Lignin is an insoluble resin and have a phenolic character. Lignin is a very complex structure and was called an amorphous polymer. The main function of lignin is to form the middle lamella and bind the fibres together. It bind the cellulose fibrils so that stress from matrix can transfer efficiently to the cellulose molecules. Lignin is a binding agent that holds cellulose fibres together. This is a brittle and relatively inert material acting as both bonding and stiffening agent. Diffusion of lignin into the fibre wall increases the stiffness of the wood cell and allows for stress transfer between matrix and fillers in the wood plastic composite. It is comprised of carbon, hydrogen and oxygen. The chemical structure of lignin is shown in Figure 2.3. Lignin is not as active as cellulose due to lack of hydroxyl group.

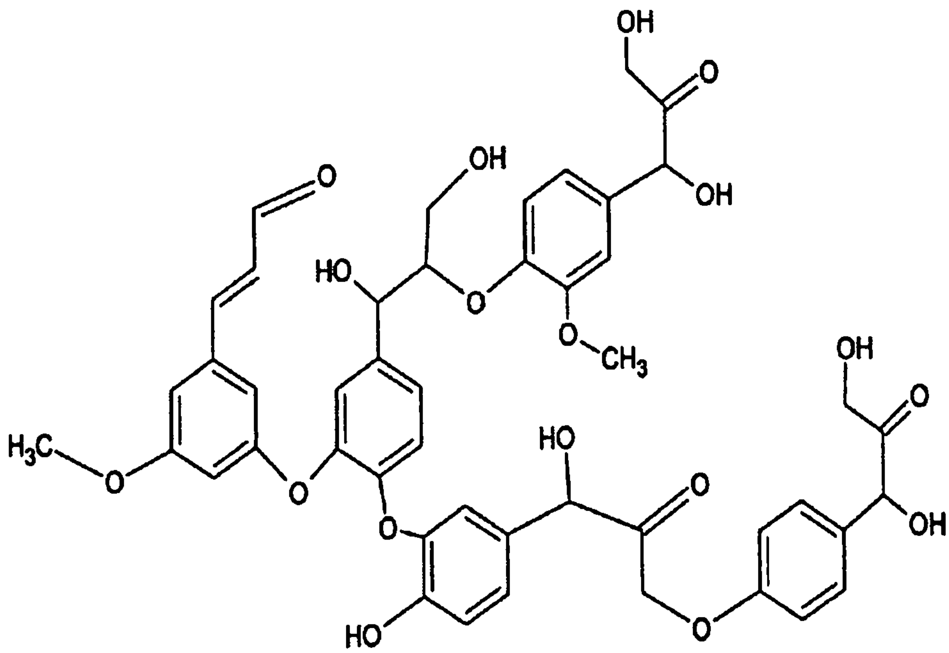

Figure 2.3 : Chemical structure of lignin

Source : Mahmood *et al.* (2018)

2.2.2 Types of Plastics

Thermoplastics are plastic category which has features such as can be a liquid when heated and becomes hard when cooled. In other words, they can be reformed and recycled. These kind of plastics are not undergo crosslinking and suitable to be used in wood plastic composite (Schwarzkopf and Burnard, 2016). Thermoplastics are used in many applications like bottles, packaging, suitcases, rugs, market bags and many more. The most frequent thermoplastic materials are PP (Polypropylene), HDPE (High density polyethylene) and LDPE (Low density polyethylene).

The meaning of plastic recycling is the process of regain waste plastic and reprocessing the material into beneficial products. There are several reasons why plastic should be recycled. During the process of recycling, materials are transformed into new products. Therefore, this practice can reduce the consumption of natural resources which will help to protect the habitats of flora and fauna in the future. Besides, in the production process during recycling, less energy is required compared to manufacturing new products from raw materials. Other than that, recycling can

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