Faculty of Manufacturing Engineering

INFLUENCE OF WATER AGEING ON THE FATIGUE BEHAVIOUR OF RUBBERWOOD REINFORCED RECYCLED POLYPROPYLENE

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DECLARATION

I declare that this thesis entitled “Influence of Water Ageing on the Fatigue Behaviour of Rubberwood reinforced Recycled Polypropylene” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

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Name : TUAN MUHAMMAD IDZUDDIN BIN TUAN NAWI

Date : 1 FEBRUARY 2021

APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality as a partial fulfilment of Master of Manufacturing Engineering (Advanced Materials and Processing).

Signature : ____________________________________

Supervisor Name : ASSOC. PROF. DR. ZALEHA BINTI MUSTAFA

Date : 1 FEBRUARY 2021

DEDICATION

Dedicated to

my beloved father, Tuan Nawi Bin Tuan Ismail

my appreciated mother, Zainab Binti Daud

my adored sister & brothers,

Nazilah, Rahim, Nazrin, Izzuwan, Natasha, Aina, Saffiya

my helpful friends and housemates,

Alif, Naim, Fikri, Arif, Hilmi and others

for giving me moral support, money, cooperation, encouragement and also understandings

Thank You So Much & Love You All Forever

ABSTRACT

Wood polymer composite (WPC) is considered as one of the emerging materials that have been frequently used because of its outstanding properties. WPC provides an alternative to preserve the timber. In general, composite materials will degrade in performance over time, particularly for structural under cyclic conditions, however not much attention was given to the analysis of the fatigue characteristic in determining WPCs performances for long-term usage. Wood flour, being a natural fibre is also sensitive to moisture. Therefore, the aim of this study to evaluate the fatigue properties of wood flour reinforced recycle polypropylene as well as the influence of water aging on their fatigue strength. The composite granule was compressed moulded at 190°C, 1000 psi for 20 minutes. The quasi-static tensile was carried out for dry specimens and aging specimens subjected to 30 days of water immersion. Tension–tension fatigue test was carried out at various stress levels (40 - 80% UTS), stress ratio of 0.1, and frequency of 4Hz. The initial tensile strength and modulus of the dry specimens is 26.33 MPa and 1.69 GPa, and subsequently reduced to 12.19 MPa and to 0.74 GPa respectively after water immersion. The fatigue life for dry WPC is in the range of 100 cycles to 600,000 cycles when tested at 60 to 80% UTS. At a lower stress level (40% UTS), the number of cycles to failure is more than 1.5 million cycles. A similar observation is seen in water aging WPC. The secant modulus was reduced while energy dissipation was increased with the increasing fatigue life cycle. The morphology study shows water aging induces composite degradation due to fibre swelling and plasticising. The statistical analysis was used to estimate the safety designed life of the material under different reliability levels. The reliability shows that 50% of the specimen are predicted to survive in the range of 200 to 700 cycles at 80% UTS while 50% of the specimen are predicted to survive in the range of 2.0×10^5 to 6.0×10^5 cycles at 60% UTS for both specimens.

ABSTRAK

Komposit polimer kayu (WPC) dianggap sebagai salah satu bahan baru yang sering digunakan kerana sifatnya yang luar biasa. WPC menyediakan alternatif untuk memelihara kayu. Secara umum, bahan komposit akan merosot dalam prestasi dari masa ke masa, terutama untuk struktur dalam keadaan dinamik, sesungguhpun begitu tidak banyak perhatian diberikan pada analisis ciri keletihan dalam menentukan prestasi WPC untuk penggunaan jangka panjang. Tepung kayu, menjadi serat semula jadi juga sensitif terhadap kelembapan. Oleh itu, tujuan kajian ini untuk menilai sifat keletihan polipropilena kitar semula tepung kayu sebagai penguat serta pengaruh penuaan air terhadap kekuatan keletihan mereka. Butiran komposit itu dimampatkan dengan acuan pada suhu 190 °C, 1000 psi selama 30 minit. Tegangan kuasi-statik dilakukan untuk spesimen kering dan spesimen penuaan dikenakan rendaman air selama 30 hari. Uji keletihan ketegangan - ketegangan dilakukan pada pelbagai tahap tegasan iaitu 40-80 % daripada kekuatan tegangan sebenar (UTS),ratio tegasan = 0.1 dan pada   frekuensi 4Hz Kekuatan tegangan dan modulus bagi spesimen kering adalah 26.33 MPa dan1.69 GPa, telah mengalami degradasi menjadi 12.19 MPa dan 0.74 GPa setelah melalui rendaman air. Kehidupan keletihan untuk WPC kering adalah dalam lingkungan 100 hingga 600.000 kitaran ketika diuji pada tahap 60 hingga 80% (UTS). Pada tahap tekanan yang lebih rendah (40% UTS), jumlah kitaran hingga kegagalan lebih daripada 1.5 juta kitaran. Pemerhatian sama juga dilihat pada penuaan air WPC. Modulus pemisah dikurangkan sementara pelesapan tenaga ditingkatkan dengan kitar hidup keletihan yang semakin meningkat. Kajian morfologi menunjukkan penuaan air menyebabkan degradasi komposit kerana pembengkakan dan pemplastikan serat. Analisis statistik yang digunakan untuk menganggarkan keselamatan bahan yang dirancang di bawah tahap kebolehpercayaan yang berbeza. Kebolehpercayaan menunjukkan bahawa 50% spesimen diramalkan akan bertahan dalam lingkungan 200 hingga 700 kitaran pada 80% UTS sementara 50% spesimen diramalkan akan bertahan dalam julat 2.0 x10^{5} hingga 6.0 x10^{5} kitaran untuk kedua-dua spesimen.

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In the name of ALLAH, the most gracious, the most merciful, with the highest praise to Allah that I manage to complete this final year project successfully without difficulty.

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LIST OF ABBREVIATIONS

ASTM	-	American Standard for Testing and Materials
GMA	-	Glycidyl Methacrylate
MMA	-	Methyl methacrylate
RI	-	Reliability Index
rPP	-	Recycle polypropylene
St	-	Styrene
UTS	-	Ultimate Tensile Strength
WPC	-	Wood Polymer Composite
Wt%	-	Weight Percent

CHAPTER 1

INTRODUCTION

1.1 Background of Study

As one of the dynamic growth materials in the structural application, wood-plastic composites (WPCs) are being extensively developed. By spreading fibres into molten plastic with additives and coupling agents, WPC is manufactured through a variety of processing techniques such as injection moulding, compression moulding, or extrusion to form the desired composite material. Presently, WPCs are primarily used for construction products such as fencing, garden furniture, decking doors, siding, and exterior windows, although other applications can also be implemented in marine structures, automotive components, railway crossings, and road transportation structures.

WPCs possess lots of advantages over the raw materials of polymers with the presence of wood filler. Compared to wood, WPCs have better durability against bio-degradation. Furthermore, when waste streams such as sawdust are used, WPC also helps minimize machine wear and tear in equipment processing and also reduces the cost of the product compared to inorganic fillers. The WPC had relatively high mechanical properties compared to the polymers and better deterioration resistance. In this study, the durability of WPC will be investigated the fatigue properties based on the stress level condition of rubber wood flour into the recycled polypropylene.

1.2 Problem Statement

Despite numerous benefits of using wood fillers instead of inorganic fillers in a polymer composite, the use of wood fillers in structural applications confronts a great challenge because of their fatigue reliability under different stress loading conditions. Comprehending the behaviour of these materials under dynamic loading is also limited in engineering design.

The major issue for the performance of WPCs is probably because of the wood is having high susceptibility to moisture. Wood, due to its hydrophilic nature, tends to absorb moisture from the air or to have direct contact with water or other liquids. Moisture exposure on the composites reduces fatigue properties and tends to lead to bio-degradation.

Composites are largely engaged in industrial sectors, and because of their recycling is often not economically viable, this gives rise in an escalating rate of waste accumulation. For these reasons, the advancement of easily recyclable composites or compostable would be a great significance to plastics sustainability.

1.3 Objective

The aim of this research is to develop and investigate the performance of WPCs product made of recycled polypropylene (rPP) plastics and rubber wood flour that focus on the fatigue properties of the composite. Thus, the objectives of this research are as follows:

i. Analyse the effect of different stress level conditions on fatigue strength of rubber wood/recycle polypropylene (rPP) composite.

ii. Investigate the influence of moisture exposure on the fatigue strength of rubber wood/recycle polypropylene (rPP) composite.

1.4 Scope

The scopes for this research are:

The WPC granules are extruded and supplied by Prince Songkla University, Thailand. The fatigue test will be carried in tensile–tensile and bending conditions using different cyclic parameters: frequency (4 Hz), ratio, R of 0.1 and stress amplitude (40%, 60% and 80% of their ultimate tensile test) in air. In order to evaluate the influence of the wet environment onto the composite behaviour, the specimen will also be immersed in distilled water for up to 30 days and tested in static and cyclic conditions.

1.5 Significant of Study

The importance of this scientific finding can be summarized as follows:

i. To reduce the potential impact of wood dust accumulation (wood flour into organic polypropylene reinforcement as the matrix that is a beneficial polymer composite material) from waste accumulation. This green approach has a good economic impact.

ii. Can substitute the inconvenience of existing composite polymer and wood with low durability and mechanical properties.

iii. Finally, to improve the significance of the fatigue characteristic and understanding of wood polymer composite in order to maintain its long-term loading application use.

1.6 Thesis overview

This report is divisible into five (5) chapters. Each chapter was reviewed as follows:

CHAPTER 1 describes the introduction for this study which contains the background study, problem statement, objective, scope, the significance of the study and the overview of every chapter.

CHAPTER 2 describes the theoretical understanding and literature review that related to the study. In this chapter, the underlying theory of the wood polymer composite (WPC), the composition of wood, and their own properties which reviewed in detail. In this chapter also briefly explain the manufacturing of WPCs. Next, the manufacturing option to fabricate the WPCs and their application that utilizing the use of WPCs were assessed. This chapter also briefly explains the marketability and also has a little bit of clarification on the sustainability and recycling of WPCs. Besides, the related journal on durability and natural fibres-based composite is reviewed in this chapter. Lastly, the hydrothermal aging effect is also further discussed.

CHAPTER 3 is covered on the methodology of this study. It elaborates on the material and method to be used to conduct the experiment on fatigue properties. The testing on the tensile and fatigue is also described in further detail. The water absorption consideration has also been stated to study the effect of moisture exposure.

CHAPTER 4 is covered data analysis from the experimental data. The findings were discussed referring to the theories and previous results from other researchers.

CHAPTER 5 is the closure of all works and findings from previous chapters in this study. For further improvisation that could be made for the next research attempt, recommendations were also highlighted for future work. Details were highlighted on the sustainability and complexity element.

1.7 Summary

In summary, the research of preparing the rubberwood/recycled polypropylene (rPP) composite as a material that is the appropriate candidate that can replace the existing inorganic composite and wood. This composite is expected to lower production costs and reduce environmental impact on the surroundings. In order to evaluate the durability performance of polypropylene/wood flour composite, tensile and fatigue testing need to be conducted. Lastly, the durability that is influenced by the water exposure is also assessed by studying the effect of water absorption.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Both thermoplastics and thermoset plastics can be used in the manufacture of WPCs. Thermoplastics are built with linear or moderately branched polymers in which the composition of the molecular chains is repeated over each other. At ambient temperature, this type of plastic is in solid form while it can be melted and formed at elevated temperatures. Due to the reversible process of their polymer chains, they can soften at high temperatures and harden at low temperatures. Without substantial chemical changes, it can undergo a lot of melting-freezing cycles, which is why the WPCs are suitable for recycling. Thermosets, on the other hand, are network structured polymers generated by cross-linked responses, and the process is irreversible and makes it impossible to re-melt, due to their structures. Applications that need to good stability at high temperatures or demanding high mechanical properties, thermoset resins like epoxy and phenolics are commonly used.

In the case of wood or certain natural fibres composites, thermoplastics are normally utilized as a material for the matrix. The processing temperature of thermoplastic WPCs should lower than the wood's thermal degradation temperature which is around

200^{o}C. Given the limited thermal stability of wood, thermoplastic like LDPE, HDPE, PP, PS and PVC comply with this requirement and are reasonable to be used and utilized as specified by Optimat (2003). Even though PVC may be the first thermoplastic that was used commercially in the production of WPC, PE is now the most commonly used material, followed by PP amongst other thermoplastics for WPCs (Optimat, 2003). For exterior building components such as decking, fencing, and infrastructure, WPCs made from PE are popularly exploited.

Polypropylene (PP) is one of the thermoplastics produced through propylene gas polymerization with a semi-crystalline polymer structure similar to PE. PP has outstanding stress resistance, low specific gravity as well as remarkable tensile, flexural and impact strength. It has a melting point of around 160-165^{o}C, and compared to HDPE, it has a low density (0.85 g/cm3 with amorphous, 0.95 g/cm3 with crystalline) and greater rigidity and strength. It is used in a diverse range of products, including plastic parts, different kinds of reusable containers and food packaging.

2.2 Wood polymer composite

For decades, wood has been used as a polymer reinforcement filler, but its application with thermoplastics is comparatively new that triggered by the advancement of coupling agents as well as enhancement in processing technology. Compared to inorganic fillers, the use of wood as the filler in WPCs does have benefits such as slightly higher biodegradability, renewable, low specific gravity and less erosion to machinery (e.g., glass fibres and clay). Pine, maple, and oak are frequently used wood types for the production of WPCs, whereas some species could still be implemented. Depending on the type of species, the properties in chemical, physical, and micro-structural of wood species are different from one another.

Selecting wood species to be utilized in WPCs could have a significant impact on the performance and properties of WPCs, according to Selke (2004). The choice of wood species for use in WPCs could have a significant impact on the micro-structure and properties of WPCs, according to Selke (2004).

The wood can be available in the forms of sawdust, sawmill chips, wood flour, wood powder, wood fibres, or pulp for the WPCs manufacturing. For polymer-based composites, however, the wood must be refined into fibres or grounded into fine flour. Tajvidi et al. (2008) investigated extruded Reed flour-PP composites that made from 100 mesh sizes and smaller particle sizes are reported that the smallest particle size was found that having the lowest water absorption and thickness. Stark NM et al. (2003) had carried an experiment on the composites made from wood flour-PP with different sizes of wood particles (35, 70, 120, and 235 mesh) and the result presented that aspect ratio had a significant effect on stiffness and strength. On the other hand, in composites with the aspect ratio of wood fibre calculated to be between 16 and 26, the tensile strength and Young's modulus of the wood fibre were reported to decrease and failure strain extended with a decrease in average fibres length.

The wood fibre usage had a slight effect on impact properties. Wood flours used as fillers in thermoplastics are largely commercially manufactured and have an aspect ratio of 3.4 particle size of less than 0.425 mm (Xanthos, 2010). Compared to coarser wood flour, extremely fine wood flours, somehow will increase the cost and melt viscosity. On the contrary, composites made with fine flour also usually have a better appearance that has a smooth and uniform surface finish.

2.2.1 Chemical composition of wood

According to Jiang (2004), wood is categorized as a lignocellulosic material and consist of three main chemical constituents which is (45-50% cellulose: 20-25% hemicellulose: and 20-30% lignin) and else insignificant component (0-0.5% ash and 1-10% extractives). Different wood species having their own chemical composition. The main components of wood are briefly explained below.

Cellulose

Cellulose is the extremely plentiful and major structural component of wood. The cellulose building blocks having a straight, long linear chain of homo-polymer made up from three elements namely carbon, oxygen, and hydrogen which are structured into anhydro d-glucopyranose linked via β1, 4 glycosidic bonds as shown in Figure 2.1. The linear polymer of anhydroglucose element with a polymerization value of around 10,000 makes it highly crystalline. It is the major constituent that bestowing structural stability and wood strength.

By weight, cellulose is usually 60-90 percent crystalline. The shape of the cellulose building block is largely due to the groups of surface hydroxyls. Crystalline, bound collectively by inter-molecular hydrogen bonding, seems to be a great quantity in cellulose. The hydroxyl groups in the same molecule may be between two adjacent molecules (inter-molecular bonds) or between glucose units (intra-molecular). The cellulose hydroxyl groups are essentially accountable for their reactive nature. In cellulose, hygroscopic behaviour is because it contains polar molecules and bonds with hydrogen easily (Jiang, 2004). The number of free hydroxyl groups, not the ones connected with each other, will influence water absorption by cellulose. The molecules of water shall not enter the crystalline region, but they must be capable to inhabit the amorphous regions.

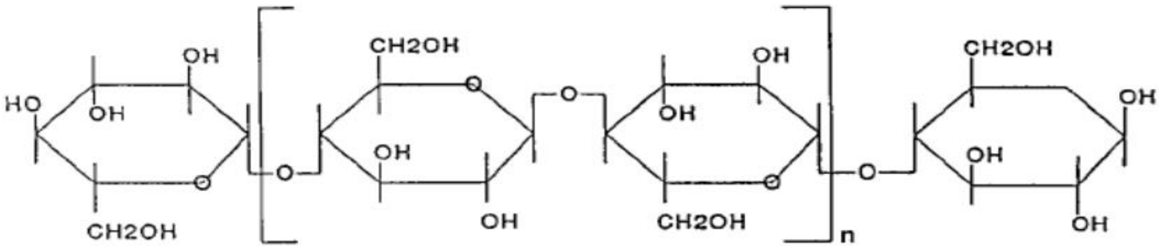

Figure 2.1 Fragment of a cellulose molecule presenting linear and unbranched structure.

Hemicelluloses

Hemicelluloses be made up of a group polysaccharide with a polymerization level lower than that of cellulose. Its structure is similar to that of cellulose in the way that 5 or 6 carbon sugars in chains organize in hemicelluloses. In spite of this, compared to cellulose, the chains are considerably shorter and less frequent. Hemicelluloses are therefore easily and quickly degraded or soluble.

Lignin

Lignin is a binding agent that holds together the fibres of cellulose. It is a fragile and fairly inert material that acts both as a stiffening agent and as a bond entity. Dispersion of lignin into the fibres wall enhances the rigidity of the cell of the wood and permits for load transfer between fillers and matrix in the WPCs. It is also consisting of carbon, oxygen and hydrogen.