UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Fabrication of Polymer Composites for Use as Jigs and Racks

Report submitted in accordance with partial requirements of the Universiti Teknikal Malaysia Melaka for the Bachelor of Manufacturing Engineering (Engineering Materials)

By

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Signature	:	…………………………………………
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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirement for the degree of Bachelor of Manufacturing Engineering (Engineering Materials). The members of the supervisory committee are as follow:

ZURINA BINTI SHAMSUDIN

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(Main Supervisor)

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ABSTRACT

This study concerns the fabrication of polymer composites for use as jigs and racks. The objectives were achieved by conducting mechanical testing on polymer composites, with and without filler materials in order to evaluate their mechanical properties. Charcoal and wood flour was used as filler material, which were mixed with polypropylene at various percentages and then tested for tensile and flexural properties. The specimens were then examined to relate their performance with their content. A raw material cost reduction was estimated as to justify mass production of jigs and racks using polymer composites. From the testing, it was discovered that the addition of filler material reduced the strength while increasing the rigidity. The content of 30% charcoal and 30% wood flour is found to be optimal for filled polymer composites in this study as higher content of filler material renders the composite unsuitable for practical use. Also, it is estimated that using this ratio the resin cost can be reduced by up to 30%. For low load applications such as inspection jigs and shoe racks, the composite studied would prove to be suitable.

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ABSTRAK

Kajian ini meliputi fabrikasi komposit polimer untuk kegunaan sebagai jig dan rak. Objektif kajian ini tercapai dengan melakukan ujian-ujian mekanikal ke atas komposit polimer, dengan dan tanpa bahan pengisi, demi penilaian sifat mekanikal bahan tersebut. Arang dan tepung kayu digunakan sebagai bahan pengisi akan dicampur dengan polipropelina dalam peratusan yang berbeza dan diuji dengan ujian tegangan dan lenturan. Spesimen-spesimen ujian diteliti untuk mengaitkan prestasi dengan kandungan. Dugaan penjimatan kos bahan mentah juga telah dibuat untuk memastikan kebolehan pengeluaran besar-besaran jig dan rak dengan menggunakan bahan polimer. Daripada ujian yang dijalankan, didapati bahawa kekuatan bahan komposit berkurang tetapi ketegaran bertambah. Hasil ujian mendapati kandungan tepung kayu sebanyak 30% dan arang sebanyak 30% adalah paling sesuai antara komposit polimer berisi dalam kajian ini di mana kandungan bahan pengisi yang lebih tinggi menyebabkan komposit ini kurang sesuai untuk kegunaan praktikal. Untuk aplikasi beban rendah seperti jig pemeriksaan dan rak kasut, komposit dalam kajian ini didapati sesuai untuk aplikasi tersebut.

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DEDICATION

This report is dedicated to the pioneer batch of students for Bachelor of Manufacturing Engineering (Engineering Materials) of Universiti Teknikal Malaysia Melaka.

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LIST OF ABBREVIATIONS, SYMBOLS AND SPECIALIZED NOMENCLATURE

USD	US Dollar, currency for United States of America
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
MPa	Mega Pascal, a unit to measure forces
GPa	Giga Pascal, a unit to measure forces
g	gram, measurement unit for weight
cc	cubic centimeter, a unit for volume
OPEC	Organization of the Petroleum Exporting Countries
AISI	American Iron and Steel Institute
ºC	degree Celsius, measurement unit for temperature
PP	Polypropylene
S	Siemens, a unit for electrical conductivity
h	hour, measurement unit of time
min	minute, measurement unit of time
wt%	weight percentage
mm	millimeter

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CHAPTER 1

INTRODUCTION

1.1 Background

Jigs and racks are a common sight in the manufacturing industry as they play a role in precision work for the former and in storage for the latter. While jigs can be of various sizes and are found in different forms, racks have a common shape and are normally used for bulk storage or holding multiple objects in place.

Jigs are described as a class of tools that possess various reference surfaces and points for accurate alignment of parts and tools (Kalpakjian and Schmid, 2001). In this study, the type of jigs mentioned functions as a holder and template for examination and minor precision work for use in the electronic industry.

Racks serve as storage systems which are both easily accessible and have high storage density (Freitas *et. al.,* 2005). While most rack design assumes that there will be pallets of which to place the objects on, or the object will fit into grooves in the rack frame, the racks in this study is about removable plates which functions as both partition and shelf of which to place objects on. The rack design for this study concerns light loads and are intended to be mass produced for commercial use.

1.2 Problem Statement

Metal has been used as a common material for various tools and applications, including jigs and racks. While metal such as steel has excellent mechanical properties, its high density and increasing manufacturing costs have urged manufacturers to look for alternative material for use as jigs and racks.

While polymers have a significant lower density, even when reinforced with denser materials, their mechanical properties and durability remain inferior compared

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to metals. However, polymers may prove to be more cost effective for disposable inserts and small storage structures.

For normal applications, fillers are added to polymer materials in order to reduce cost of the raw materials required, and may also be used to increase rigidity as well as impart other properties, such as infrared radiation absorption (Bartczak *et. al.*, 1997).

1.3 Scope

This study will investigate the effects of charcoal and wood flour as filler material for polypropylene (PP). The testing will be conducted using tensile and flexural test for both types of filler with PP being the matrix material.

The filler content will be from 10 to 40% for charcoal and 20 to 40% for wood flour by weight. As this study deals with the effects of the amount of filler material, the particle size of the filler materials is not related. However, the overall cost of the filled composite will be considered based on the cost of the raw materials.

1.4 Aims

The aim of this project is to determine the maximum amount of filler material that can be used in commodity plastics for minor load bearing applications. Besides determining the properties of the materials with the said amount of filler material, the cost of the raw materials will also be determined.

1.5 Objective

The objectives of this study are:

1. Determine mechanical properties of polymer / composite parts to be used as jigs and racks.
2. Analyze the properties of commodity plastics filled using low-cost filler material.
3. Estimate cost reduction based on cost of raw materials.

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CHAPTER 2

LITERATURE REVIEW

2.1 Material Comparison

Normal materials used to construct jigs are metals, especially steel. This is shown by Kim, *et. al.* (2002), Wise, *et. al* (2003), and Caimmi, *et. al* (2005), in which their jigs were fabricated using metals. However, jigs will undoubtedly sustain wear and tear if used repeatedly. Therefore, it would be more economical if frequently used jigs, such as the type mentioned in this study, are made from low cost materials, such as polymers. The relatively low cost of polymers compared to metals justifies mass production and disposability of the damaged jigs.

As for racks, the frames are made from cold formed steel, with the objects placed on pallets which are supported by the steel frames (Bernuzzi and Castiglioni, 2001). Normal pallets used in most warehouses are made from wood, which are susceptible to moisture and rot over time. Being made from wood, they are considered expendable as wooden pallets are easily fabricated and the cost of wood is relatively low compared to engineering polymers or metal. However, these pallet designs are meant for mass storage, unlike the design meant for light loads as mentioned in Chapter 1. The racks for this study are meant to be a balance between functionality and mass production cost, of which polymers, especially commodity plastics, are suited for this purpose.

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Table 2.1: Raw material prices as of July 2007

Material	Price (USD / tonne)*
Grade 304 Stainless Steel (Cold Rolled Coil)	4278
Carbon Steel (Cold Rolled Coil)	568
HDPE	1499.4
LDPE	2072.7
Polypropylene Homopolymer	1323

Source: IDES (2007), MEPS (2007)

*Price for steel is based on the Asian market as provided by MEPS. Price quoted for polymer resin is based on average vendor price below 10000 lbs.

Table 2.2: Properties of steel (stainless and carbon) compared to commodity thermoplastics

Material	Ultimate Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Density (g/cc)
AISI Type 304 Stainless Steel	505	193 - 200	8.00
AISI 1021 Steel, Cold Rolled	484	200	7.858
HDPE (Injection Molded)	20.3	0.911	0.956
LDPE (Molded)	11.0	0.21	0.923
Polypropylene (Molded)	36.8	1.9	0.937

Source: http://www.matweb.com

2.2 Polymer materials

Polymer materials are a category of materials which are made up from macromolecules which contain a chain of repeating units known as ‘mer’. The types of polymers are identified by their ‘mer’ units and is named using the prefix ‘poly‘,

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followed by the ‘mer’. Most of the polymers used for engineering applications are of synthetic origin, in which they are produced using chemical reactions.

The types of polymers to be used for this project are categorized under thermoplastics, in which they can be reformed by applying heat. Once a certain amount of heat energy is absorbed, the bonds between molecules will weaken, enabling the material to be formed easily.

The formability of polymers makes it easy to add in additional material in order to modify its mechanical, chemical and thermal properties or to reduce cost. When the additional material can be easily distinguished from the polymer base, it becomes known as a polymer matrix composite (PMC).

2.3 Polymer Matrix Composite (PMC)

Polymer matrix composites refer to a category of polymer materials that are strengthened by the addition of a reinforcing material, normally in the form of fibers, especially E-glass or carbon fibers. Also, the reinforcement may be in the form of particulates as well, which generally act as a toughening mechanism. The strength of polymer matrix composites usually relies on the alignment of the reinforcing material.

For most applications, thermosetting polymers are normally used in making polymer matrix composites, as shown by Gürü, *et. al*. (2006) and Naik *et. al.* (2006), in which urea-formaldehyde and epoxy resin is used as the matrix material. The strength of the resulting composite is dependant on the ratio and type of reinforcement used. For example, large amounts of particulate reinforcement will actually weaken the composite.

In this study, the mixing proportion is based on weight percentage in which the contents of the composite are mixed by weight. For example, a 20% charcoal content would mean that 20% of the sample’s mass consist of charcoal.

$$\textbf{Specimen mass} = [(100-x) * \textbf{Matrix mass}] + [x * \textbf{Reinforcement mass}] \qquad \textbf{(2.1)}$$

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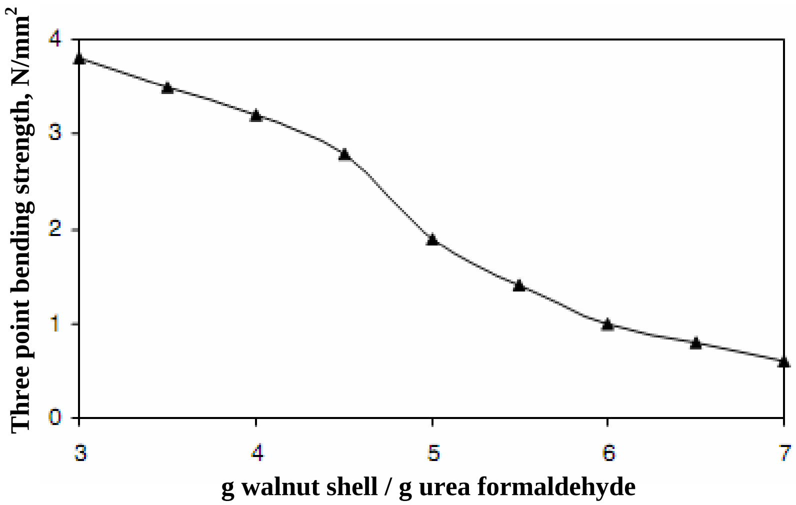

Figure 2.1: Effect of reinforcement/matrix ratio on flexural strength of particleboard (wood particles in thermosetting matrix) (Gürü, *et. al*., 2006).

2.3.1 Matrix

The matrix is the main constituent of the composite, of which can be used as it is without any form of reinforcement, but is reinforced to increase its properties, especially mechanical properties. In the case of filled polymers, the reinforcement may increase the properties of the composite material depending on the type of fillers used, but the purpose of the filler is to reduce production cost by decreasing the amount of actual resin to be used for a particular product, since fillers are available at low cost (Kalpakjian & Schmid, 2001).

Primarily, the matrix serves as the medium which binds the reinforcements and transfers the externally applied load onto the reinforcements. The matrix also protects the reinforcement from the environment, which may damage or weaken the reinforcement if it is exposed (Callister, 2003).

The load transfer to the reinforcement is affected by the adhesion of the matrix and reinforcement. If the adhesion is weak, the matrix will bear the whole load without effectively transferring the load to the reinforcement. This can be improved by improving the adhesion, such as using compatibilizers (Guan, G., *et. al*., 2007).

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2.3.1.1 Thermosetting Polymers

Generally, thermosetting polymers refer to a group of polymers that cure into a stronger form through the addition of energy in the form of heat, irradiation or chemical reaction. The curing process forms cross-links between polymer chains that are permanent, creating a 3-D structure. This structure, having a high molecular weight, will have an increased melting point. However, these materials undergo degradation at temperatures below their melting point and therefore cannot be shaped plastically after the curing process has been completed. In the case of thermosetting polymer matrices, polyesters and epoxies are examples widely used thermosetting polymer matrix materials.

Polyesters resins are one of the most widely used thermosetting polymer, as it dominates the market due to low cost and viscosity, which enables widespread use. Generally, polyesters consist of unsaturated linear polyesters dissolved in styrene which the curing process is initiated using organic peroxide. However, one of the drawbacks for polyesters is its relatively high shrinkage (approximately 4-8%). (Matthews & Rawlings, 1999)

Epoxies, on the other hand, have excellent mechanical and electrical properties, good dimensional stability and good resistance to heat and chemicals. Fiber-reinforced epoxies are highly favored in demanding applications such as pressure vessels, rocket motor casings and similar structures due to its excellent mechanical properties. (Kalpakjian & Schmid, 2001)

2.3.1.2 Thermoplastics

Thermoplastics refer to polymers that can be deformed, turns into liquid state when heated sufficiently and solidifies to a brittle, glassy state when cooled. This process can be repeated so long as the polymer does not sustain degradation through excessive heat or chemical reaction which will decrease its properties. For thermoplastics, the polymer molecules are held together by van der Waals force, dipole-dipole interaction or hydrogen bonding. This type of bonding does not consist of permanent bonding between

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polymer chains; therefore the material can be reshaped by heating it to a liquid state before cooling it back down to a solid state.

(a) Polypropylene

Polypropylene (PP) is used as the main matrix material as it has a good cost / performance ratio and is easily obtainable. Compared to other commercial polymers, such as low and high density polyethylene and polyvinyl chloride, PP has intermediate properties in between most of the others, making it versatile and usable for a wide variety of applications. Furthermore, it is highly resistant to chemicals and possesses a fairly high operating temperature range. Based on a study conducted by Costa, *et. al.* (2007), the strain properties (yield stress and modulus) and impact strength of PP are only slightly affected by multiple extrusions as a result of degradation.

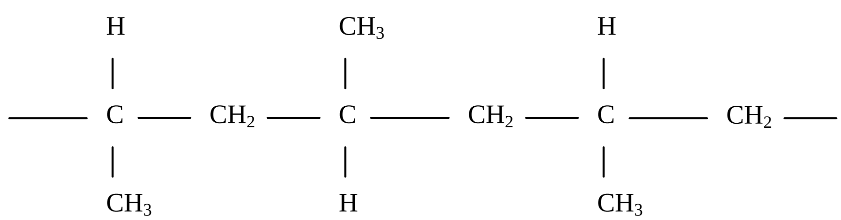

Figure 2.2: Section of a Polypropylene chain (figure reproduced from http://en.wikipedia.org/wiki/Image:Polypropylene.jpg)

Table 2.3: Properties of PP, molded

Density (g/cc)	0.937
Ultimate Tensile Strength (MPa)	36.8
Tensile Modulus (GPa)	1.9
Flexural Modulus (GPa)	1.4
Melting Point (ºC)	160 (average)

Source: http://www.matweb.com

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