Faculty of Manufacturing Engineering

AN EXPERIMENTAL DETERMINATION OF CARBON DUST WASTE PERFORMANCE IN MATERIALS PRODUCED VIA POLYMER PROCESSING

Ismail bin Adam

Master of Industrial Engineering

2024

AN EXPERIMENTAL DETERMINATION OF CARBON DUST WASTE PERFORMANCE IN MATERIALS PRODUCED VIA POLYMER PROCESSING

ISMAIL BIN ADAM

A thesis submitted
in fulfillment of the requirements for the degree of Master of Manufacturing Engineering (Industrial Engineering)

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEDICATION

All the praises and thanks to Allah S.W.T for His Guideness and Enlightment.

This thesis is dedicated to my beloved parents, my wife and my siblings,

Thank you very much for your understanding and encouragement.

ABSTRACT

Carbon dust (CD) is an industrial waste generated during machining process of carbon fibre reinforced polymer composite industries. The common practice disposing carbon dust was into landfill and recycling process. The recycling or reused carbon dust as filler still at the earlier stages due to the uncertainity in reclaimation process and to control the distribution of the carbon dust loading in thermoset under different parameters polymer processing. It has been reported that this carbon dust has demonstrated the possibility to use as filler to replace raw material especially virgin carbon fibre. This research demonstrate the fabrication of polymer composite using reclaimed carbon dust and resin as the matrices. The number of sample using different ratio of carbon dust varied from 0% to 30% and fabricated using vacuum bagging and autoclave curing method. Different approach of curing method performed on test sample to study the impact of process toward quality of sample that impact mechanical properties of the sample. The mechanical properties was determined using Universal Testing Machine (UTM) according to ASTM D3039 and ASTM D6641. Non Distruction Test (NDT) were also performed on fabricate samples according to E494-95 to validate the strength properties under destructive testing. The correlation between the distribution of the CD and the mircostructure from fractography images of tensile strength was observed through scanning electron microscope (SEM) to understand the relevant failure factors with the strength properties and processing parameters. The final result shows that the increase of rCD content as a filler loading inside thermoset decrease the value of tensile strength but increase the value of compression strength. The observation using SEM shows that the increase of rCD cause more weak ashesion between resin and the matrix hence impact the mechanical properties of thermoset. During curing parameter control using Autoclave, the increase of pressure cause better inner quality of thermoset with less void content and porosity hence increase the tensile strength value. However, the compression strength does not shows significant impact upon increasing of curing pressure.

ABSTRAK

Habuk karbon ialah sisa industri yang dijana semasa proses pemesinan industri komposit polimer karbon. Amalan kebiasaan dalam membuang habuk karbon ialah membuangnya ke dalam tapak pelupusan saMPah dan proses kitar semula. Kebiasaan mengitar semula habuk karbon yang telah digunakan sebagai bahan pengisi tambahan masih berada pada peringkat awal disebabkan ketidakpastian dalam proses penebusan dan untuk mengawal taburan pemuatan habuk karbon dalam termoset di bawah parameter pemprosesan polimer yang berbeza. Terdapat laporan berkenaan habuk karbon yang menunjukkan kemungkinan untuk digunakan sebagai pengisi tambahan untuk menggantikan bahan mentah terutamanya gentian karbon dara. Penyelidikan ini telah menunjukkan proses pembuatan komposit polimer menggunakan habuk karbon sebagai pengisi tambahan dan resin sebagai matriks. Bilangan sampel yang menggunakan nisbah habuk karbon yang berbeza telah dimanipulasi dan diubahsuai daripada 0% hingga 30% dan akan difabrikasi menggunakan kaedah beg vakum dan dibakar di dalam mesin autoclave. Pendekatan kaedah pembakaran yang berbeza telah dilakukan ke atas sampel ujian untuk mengkaji kesan proses terhadap kualiti sampel yang akan memberi kesan kepada sifat mekanikal sampel. Sifat mekanikal kemudian telah ditentukan menggunakan Universal Testing Machine (UTM) mengikut ASTM D3039 dan ASTM D6641. Ujian Tanpa Musnah (NDT) juga telah dilakukan pada sampel fabrikasi untuk mengesahkan sifat kekuatan di bawah ujian yang merosakkan. Hubungkait antara taburan habuk karbon dan struktur mikro daripada imej fraktografi kekuatan tegangan telah diperhatikan melalui mikroskop elektron pengimbasan (SEM) untuk memahami faktor kegagalan yang berkaitan dengan sifat kekuatan dan parameter pemprosesan. Hasil kajian akhir menunjukkan bahawa peningkatan kandungan rCD sebagai pengisi tambahan di dalam thermoset melemahkan kekuatan regangan tetapi meningkatkan kekuatan maMPatan. Pemerhatian menggunakan SEM menunjukkan menunjukkan bahawa peningkatan kandungan rCD menyebabkan ikatan yang lemah di antara resin dan matriks seterusnya memberi kesan kepada sifat mekanikal termoset. Berkenaan kawalan tekanan semasa proses pengawetan menggunakan autoclave, peningkatan tekanan akan menyebabkan kualiti

termoset menjadi lebih baik dengan kandungan gelembung udara terperangkap yang kurang di dalamnya seterusnya meningkatkan nilai kekuatan tegangan. Walau bagaimanapun, kekuatan maMPatan tidak menunjukkan kesan yang ketara terhadap kawalan tekanan semasa proses pengawetan.

ACKNOWLEDGEMENTS

First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor Dr. Zurina binti Shamsudin from the Faculty of Manufacturing Engineering Universiti Teknikal Malaysia Melaka (UTeM) for her essential supervision, support and encouragement towards the completion of this thesis.

I would also like to express my greatest gratitude to Mr Zulhairi bin Zulkifli from Material Engineering Department for his help, arrangement and advice during the fabrication of thermoset sample using CD as filler material. In addition, I also like to thank all related technician in all related area from mould preparation, autoclave, and non destructive test department for their cooperation during my reaserach. And not to forget to Mr Mazlan from CTRM TL that help me arrange and perform mechanical testing for my research and the advice of what are the most suitable method to perform for destructive test selection.

Particularly, I would also like to express my deepest gratitude to my family especially my wife, for his understanding and mental support during finishing my research and report writing. Special thanks to all my peers, beloved mother, father and siblings for their moral support in completing this degree. Lastly, thank you to everyone who had been to the crucial parts of realization of this project.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

UTM	-	Universal Test Machine
NDT	-	Non Destructive Test
CD	-	Carbon Dust
rCD	-	reclaim Carbon Dust
SEM	-	Scanning Electron Microscopy
CFRP	-	Carbon Fibre Reinforced Polymer
CFRC	-	Carbon Fibre-Reinforced Composites
RTM	-	Resin Transfer Mould
CF	-	Carbon Fibre
UD	-	Unidirectional Dimension
FOD	-	Foreign Object Defect
CNC	-	Computer numerical control
CLC	-	Combined Loading Compression
CTRM	-	Composite Technology Research Malaysia
AC	-	Aero Composite
TL	-	Testing Laboratory
UNSW	-	The University of New South Wales
PPE	-	Personal Protective Equipment
OSHA	-	Occupational Safety and Health
PSA	-	Particle Size Analyzer

FESEM	-	Field Emission Scanning Electron Microscopy
EDX	-	Energy Dispersive X-Ray
EoL	-	End of Life
EU	-	European Member

LIST OF SYMBOLS

D, d	-	Diameter
μm	-	micrometer
MPa	-	Mega Pascal
kPa	-	Kilo Pascal
°C	-	degree celcius
min	-	minute
%	-	percentage
mm	-	milimeter
m^3	-	square meter
ml	-	mililitre
sqm	-	square meter
pcs	-	pieces
kN	-	kilo newton
N	-	newton
grm	-	Gram

CHAPTER 1

INTRODUCTION

1.0. Introduction

Carbon fibres is a composite material that are widely used in modern industrial applications. As shown in **Figure 1.1**, many industries have widely used carbon fibre as their raw material such as aerospace, medical, sporting goods, automotive, musical instrument, etc. especially due to its advance properties that are superior to the steel and plastic. According to Pooja Bhatt and Alka Goe (2017), the character of carbon fibre that are commonly known to be superior is that they are high-strength, light in weight and more reliable. The unique properties of a carbon fibre part are that its strength is close to the steel meanwhile the weight is close to the plastic. Thus, the overall strength to weight ratio (as well as stiffness to weight ratio) of a carbon fibre part is much higher than either steel or plastic.

Pooja Bhatt and Alka Goe (2017) also mention that in addition to its physical properties, carbon fibre is chemically inert, resistant to heat, high electrical conductivity and possess high tensile strength. Based on this character, carbon fibre became more favorable to be used in many industries that required strong but light product and also durable. Carbon fibre consists of thin, strong crystalline filaments of carbon, essentially carbon atoms bonded together in long chains. In term of form, carbon fiber material comes in a variety of shape,

including yarns, uni-directional, weaves, braids, and several others, which are in turn used to create composite parts.

Figure 1.1: Variety of Composite Product (Nicolas Grizzle, 2019)

The increasing demand of carbon fibre are very simulating especially in aerospace and automotive industries. According to Esfandiar et.al (2021), the needed of durable but light product has made carbon fibre demand increase and their market value rose high. Manufacturing of carbon fibre product required complex process flow compare to manufacturing of steel and plastic product which one of the reason why carbon fibre product does not very popular despite its ability have been discover far more earlier. Nowadays many technologies have been invented to manufacture carbon fibre in more easy and simple process. However, the increase of its demand and usage also lead to potential of the increasing of carbon fibre waste.

Carbon fibre creates hazardous dust during machining known as carbon dust. In fact, it produces more dust compare to metal during machining process. Based on research

conducted by Anirudh (2015), carbon dust release during performing machining process such as milling, trimming, drill or chamfering of the carbon fibre part. Carbon fibre dust generally has a diameter of 6 – 10 μm and length of 37.5 μm as shown in **Figure 1.2**. If they spilt length-ways during machining, they could produce fibres below 5μm in size. These carbon dust may irritate the skin or mucous members, such as eyes and lungs. In addition, since it conducts electricity, it can also cause shorts in electrical equipment.

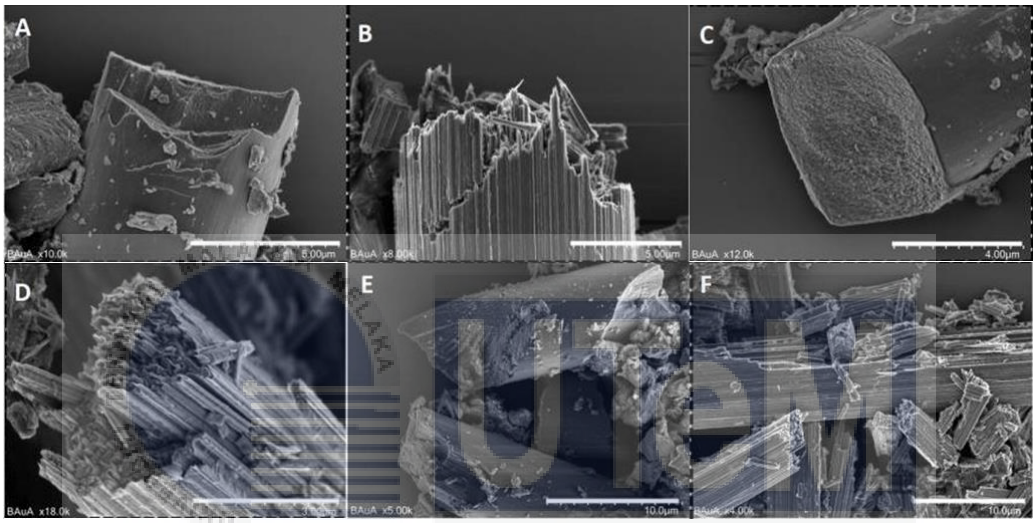

Figure 1.2: Composite carbon dust size (D = 6 - 10 μm) (Dominic, 2019)

Based on fact from OSHA (2021), carbon dust is commonly dispose using either release it to the sewage or by dump it into the landfill. Many companies decide to use landfill as their disposal method for carbon dust ways which the action can cause damage to the environment and human. Nowadays, the disposal of carbon dust from carbon fibre manufacturing industries are still not in the dangerous level since it is not monopolizing the global industries such as metal and plastic industries. However, the increasing use of carbon fibre have potential to have carbon dust waste as one of dangerous disposal waste in the future.

According to Jin Zhang et.al (2020), the future plan of recycling carbon waste was very challenging due to the rising of carbon fibre application around the world. In addition, the use of high-performance thermoset polymers as the matrix makes the recovery of the fibres and the resins extremely difficult. Thermoset are known to be component that is non-recyclable where its matrix is very hard to be separate after cured. However, despite having difficulties in recovery matrix from thermoset many technology research approach in order to recycle carbon fibre component without need to recover the matrix from the thermoset. One of the strategies are using the carbon waste as a filler loading for second generation of carbon fibre raw material.

1.1. Problem Statements

The increasing of demand for carbon fibre throughout the year are very astonishing. According to Amiruddin et.al (2022), it is estimated around 65,000 to 85,000 metric tonnes of carbon fibre demand required annually. The value will be increased nearly double in 2030 forcing the production of carbon fibre to be increased as well. Referring to **Figure 1.3**, this trend is recorded based on previous demand from 2008 and the growth of composite carbon fibre product especially on aerospace and wind turbine industries that monopolize demand of carbon fibre raw material.

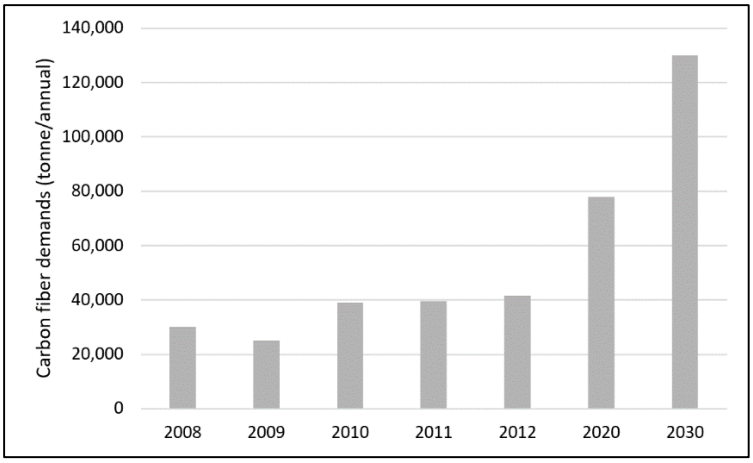

Figure 1.3: Increase in carbon fibre global demand (Amiruddin et.al, 2022)

Despite this great news for carbon fibre industries, the excessive reduction of carbon fibres into waste has become the one of the impact that become main issue and has triggered environmental concerns all around the world. As preferred by many carbon fibre material industries, the combination of carbon fibre with polymer resin will result a strong and light composite. However, Amiruddin et.al (2022) mention that according to one of the carbon fibre company, during the manufacturing processes of composite carbon fibre product, the material is often laid up by hand and almost one-third of the actual size of carbon fibre sheets is left unused after being machining. As a result, a huge amount of the carbon fibre does not end up becoming a composite product, even worse it become a waste which usually sent to landfill for disposal.

Carbon dust is a waste accumulate from machining carbon fibre product. Carbon fibre does not bring harm when in dry or fabric form but in the form of dust it can cause damage to human health. It can cause skin irritation upon contact and effect human lung during breath especially if the carbon dust is released into air. Amiruddin et.al (2022) stated that approximately 62,000 tonnes of carbon waste are accumulated each year, mostly with the aircraft and wind energy industries contributing the most to this amount. It is estimated if there is countermeasure regarding this problem, by 2035, a predicted cumulative amount of 23,600 tonnes of carbon fibre waste will be produced by the aircraft sector, with an additional 483,000 tonnes from the wind turbine industry.

The goals of recycling carbon waste, especially from carbon dust have been research since the increase of carbon dust waste produced by composite manufacturing company. Theoretically, carbon fibre dust can be reused for polymer processing. It is estimated due to the properties of carbon, the carbon fibre dust can be used as a filler material during polymer processing hence enhance mechanical properties of polymer. Since carbon fibre have properties of high tensile strength, carbon fibre dust might increase the mechanical properties