



Faculty of Manufacturing Engineering

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

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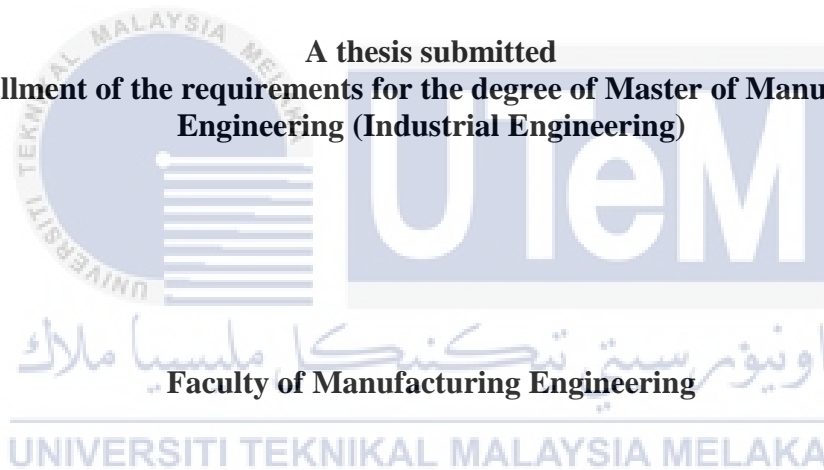
Master of Industrial Engineering

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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)**



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DEDICATION

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

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 uncertainty in reclamation 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 Distraction 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 pemesanan 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 termoset 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.



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TABLE OF CONTENT

DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iv
TABLE OF CONTENT	v
LIST OF TABLES	viii
LIST OF FIGURES	x
LIST OF APPENDICES	xiii
LIST OF ABBREVIATIONS	xiv
LIST OF SYMBOLS	xvi
1.0 Introduction	1
1.1 Problem Statements.....	4
1.2 Research Objectives.....	8
1.3 Research Scope	8
1.4 Research Outcome	9
1.5 Conclusion	9
2.0 Literature Review	10
2.1 Recycling Carbon Fibre Waste	10
2.1.1 Carbon Fibre Dust.....	14
2.1.2 Recycling Carbon Fibre Dust	15
2.2 Fabrication of Composite.....	18
2.2.2 Vacuum Bag	18
2.2.2 Autoclave Curing Process	20
2.3 Non-Destructive Test	23
2.4 Mechanical Properties of Thermoset	25
2.4.1 Filler Loading Mechanical Properties	26
2.5 Scanning Electron Microscopy (SEM).....	27

2.6 Summary	28
3.0 Research Methodology	29
3.1 Research Flow Chart	29
3.2 Carbon Dust (CD)	31
3.3 Reclaim of CD Process	32
3.3.1 Filtering CD	32
3.3.2 Fesem EDX.....	34
3.3.3 Particle Size Analyzer (PSA).....	35
3.4 Fabrication Process.....	36
3.4.1 Sample Preparation	37
3.4.2 Laid Up Process	39
3.4.3 Curing Process	41
3.4.4 Machining Process.....	43
3.5 Non-Destructive Test	45
3.6 Mechanical Testing	47
3.6.1 Tensile Strength	48
3.6.2 Compression Strength.....	49
3.7 Microstructure Analysis	50
3.8 Summary	50
4.0 Result and Discussion.....	51
4.1 Characterisation of reclaimed carbon dust (rCD)	51
4.1.1 Particle Size Analyzer (PSA).....	51
4.1.2 FESEM-EDX.....	53
4.2 Mechanical Properties	54
4.2.1 Tensile Strength	55
4.2.1.1 Zero Pressure Curing Parameter	55
4.2.1.2 Medium Pressure Curing Parameter.....	57
4.2.1.3 High Pressure Curing Parameter	58
4.2.1.4 Tensile Strength Overall Result Sample.....	59
4.2.2 Compression Strength.....	63
4.2.2.1 Zero Pressure Curing Parameter	63
4.2.2.2 Medium Pressure Curing Parameter.....	65
4.2.2.3 High Pressure Curing Parameter	66
4.2.2.4 Compression Strength Overall Result Sample	67

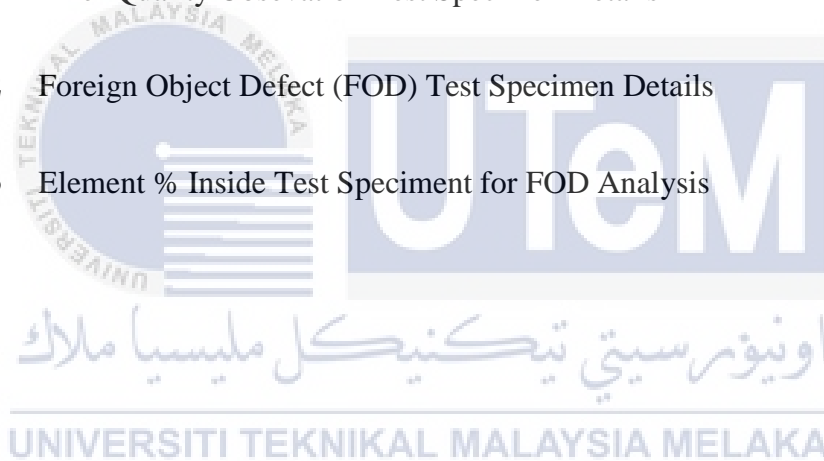
4.2.3 Tensile Modulus	69
4.3 Non Destructive Test Indicator Image	72
4.4 Microstructure Analysis	73
4.4.1 Analysis on Inner Structure Test Specimen.....	73
4.4.2 Foreign Object Defect (FOD).....	75
4.5 Summary	76
5.0 Conclusion	77
5.1 Recommendation.....	78
REFERENCES	79
APPENDICES	85



LIST OF TABLES

TABLE	TITLE	PAGE
Table 2.1	Standard Mechanical Properties for Carbon Fibre	26
Table 3.1	Waste Collected Date Record	31
Table 3.2	Resin-hardener mixed Preparation Data	37
Table 3.3	Volume Fraction for Each Composites Plate	39
Table 3.4	Vacuum Bag Sequence Description	40
Table 3.5	Autoclave Working Range	41
Table 3.6	Curing Parameter Setting	42
Table 3.7	Test Specimen Size	43
Table 3.8	Key Parameters and Quantity of testing sample	44
Table 3.9	Mechanical Testing Objective	47
Table 3.10	Testing Specification	47
Table 4.1	Particle Size Analysis (PSA) Result	52
Table 4.2	Carbon Element inside Filtered rCD	54
Table 4.3	Tensile Strength Test Result for Zero Pressure	55

Table 4.4	Tensile Strength Test Result for Medium Pressure	57
Table 4.5	Tensile Strength Test Result for High Pressure	58
Table 4.6	Compression Strength Test Result for Zero Pressure	63
Table 4.7	Compression Strength Test Result for Medium Pressure	65
Table 4.8	Compression Strength Test Result for High Pressure	66
Table 4.9	Young Modulus Result	69
Table 4.10	Test Sample NDT C-Scan Image	72
Table 4.11	Inner Quality Observation Test Specimen Details	73
Table 4.12	Foreign Object Defect (FOD) Test Specimen Details	75
Table 4.13	Element % Inside Test Speciment for FOD Analysis	75



LIST OF FIGURES

FIGURE	TITLE	PAGE
Figure 1.1	Variety of Composite Product	2
Figure 1.2	Composite carbon dust size ($D = 6 - 10 \mu\text{m}$)	3
Figure 1.3	Increase in carbon fibre global demand	4
Figure 2.1	Carbon Fibre Waste Recycling Method	12
Figure 2.2	Carbon Fibre Machining Process	14
Figure 2.3	Epoxy residue at recycled carbon fibre	17
Figure 2.4	Vacuum Bag for Hand Layup Process	19
Figure 2.5	Autoclave Curing Cycle	21
Figure 2.6	Relationship between mechanical properties, void content and pressure applied	22
Figure 2.7	The ultrasonic C-Scan mapping of the void distribution inside thermoset	24
Figure 2.8	Mechanical Strength Properties	25
Figure 3.1	Research Methodology Flowchart	30
Figure 3.2	Manual Trimming Waste Tray	31
Figure 3.3	CD collected from waste tray	32

Figure 3.4	Octagon D200 Digital Test Sieve Shaker	33
Figure 3.5	FOD/Impurities from CD Waste	33
Figure 3.6	rCD Claimed after Sieve Process	34
Figure 3.7	FESEM EDX SU5000 Machine	34
Figure 3.8	Example of FESEM-EDX Analysis	35
Figure 3.9	Malvern Mastersizer 2000 PSA Machine	36
Figure 3.10	Fabrication Sample Process	36
Figure 3.11	Mixing Process Step	37
Figure 3.12	Mixture with 40% rCD filler Loading	38
Figure 3.13	Mould for sample preparation	38
Figure 3.14	(a) Clean mould surface; (b) Pour mixed epoxy with filler loading into mold	40
Figure 3.15	Vacuum Bag Sequence	40
Figure 3.16	Vacuum bag process	41
Figure 3.17	Autoclave Curing Equipment	42
Figure 3.18	Test Piece for each % filler loading	43
Figure 3.19	Test Panel trimming machine	44
Figure 3.20	Flat Bed NDT C-Scan Equipment	45
Figure 3.21	Olympus Epoch 600 NDT A-Scan Equipment	46
Figure 3.22	Universal Testing Machine INSTRON 5582	48

Figure 3.23	Universal Testing Machine INSTRON 5969	49
Figure 4.1	PSA for Sample 1	52
Figure 4.2	Microscopic image of rCD after sieve with a) 1,000X magnification; b)	53
Figure 4.3	Tensile Strength for Zero Pressure	56
Figure 4.4	Tensile Strength for Medium Pressure	57
Figure 4.5	Tensile Strength for High Pressure	59
Figure 4.6	Overall comparison between each pressure parameter for tensile strength	60
Figure 4.7	Fractography surface at 10k magnification for a) rCD 10 wt.%; b) rCD 20 wt.%; c) rCD 30 wt.%	61
Figure 4.8	Fractography images for a) rCD wt.10% medium pressure and b) rCD wt.30% high pressure	62
Figure 4.9	Compression Strength for Zero Pressure	64
Figure 4.10	Compression Strength for Medium Pressure	65
Figure 4.11	Compression Strength for High Pressure	67
Figure 4.12	Mixture with 40% rCD filler Loading	68
Figure 4.13	NDT S-Scan Wavelength Image Capture	69
Figure 4.14	Mean Value for Young Modulus	71
Figure 4.15	a) Sample for zero pressure ; b) Sample for medium pressure ; c) Sample for high pressure	74
Figure 4.16	Images of test sample fracture a)ST3.6-1; b)ST3.6-3	76

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Master Project Schedule (Gantt Chart)	86
B	Autoclave Curing Report	87
C	Particle Size Analyzer (PSA) Result	88
D	FESEM EDX Result	89
E	Non Destructive Test (NDT) C-Scan Report	90
F	Mechanical Testing Result	91
G	FESEM EDX Result (Fractography Analysis)	93

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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
$^{\circ}\text{C}$	-	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 5 μm 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.

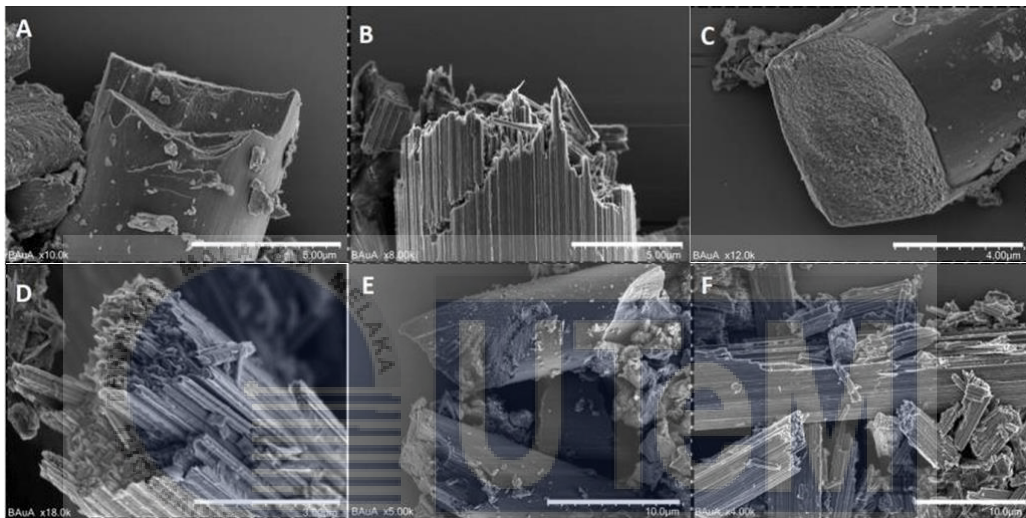


Figure 1.2: Composite carbon dust size ($D = 6 - 10 \mu\text{m}$) (Dominic, 2019)

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.

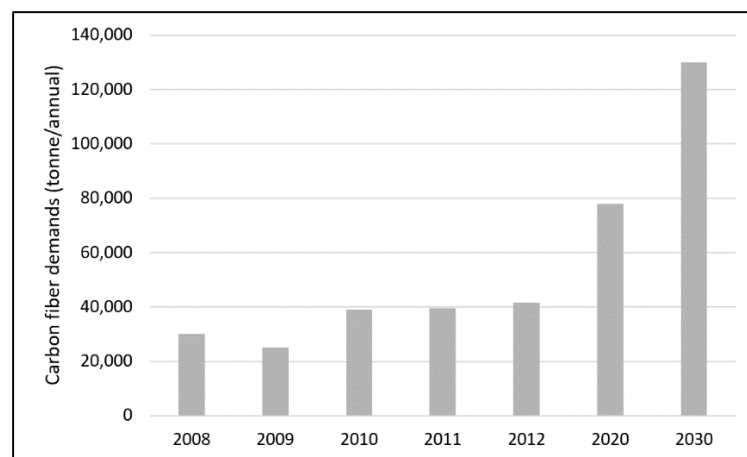


Figure 1.3: Increase in carbon fibre global demand (Amiruddin et.al, 2022)

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