# INVESTIGATION ON MECHANICAL PROPERTIES OF GLASS FIBER REINFORCED POLYAMIDE 6-POLYPROPYLENE COMPOSITES UNDER DIFFERENT OPERATING CONDITIONS

NURIZZATHANIS MOHAMAD KUSASEH

Master

UNIVERSITI MALAYSIA PAHANG

**UNIVERSITI MALAYSIA PAHANG**

**DECLARATION OF THESIS AND COPYRIGHT**

| | | |
|---|---|---|
| Author's Full Name | : | NURIZZATHANIS BINTI MOHAMAD KUSASEH |
| Date of Birth | : | 30th SEPTEMBER 1992 |
| Title | : | INVESTIGATION ON MECHANICAL PROPERTIES OF GLASS FIBER REINFORCED POLYAMIDE 6-POLYPROPYLENE COMPOSITES UNDER DIFFERENT OPERATING CONDITIONS |
| Academic Session | : | SEMESTER 2 (2019/2020) |

I declare that this thesis is classified as:

| | | |
|---|---|---|
| ☐ | CONFIDENTIAL | (Contains confidential information under the Official Secret Act 1997)* |
| ☐ | RESTRICTED | (Contains restricted information as specified by the organization where research was done)* |
| ☒ | OPEN ACCESS | I agree that my thesis to be published as online open access (Full Text) |

I acknowledge that Universiti Malaysia Pahang reserves the following rights:

1. The Thesis is the Property of Universiti Malaysia Pahang
2. The Library of Universiti Malaysia Pahang has the right to make copies of the thesis for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:



| | |
|---|---|
| (Student's Signature) | (Supervisor's Signature) |
| 920930-01-7178 | Assoc. Prof. Dr. Dewan Muhammad Nuruzzaman |
| New IC/Passport Number<br>Date: 17 August 2020 | Name of Supervisor<br>Date: 17 August 2020 |

NOTE : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach a thesis declaration letter.

## SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

_______________________________

(Supervisor's Signature)

Full Name : Dr. DEWAN MUHAMMAD NURUZZAMAN

Position : ASSOCIATE PROFESSOR

Date : 17 AUGUST 2020

_______________________________

(Co-supervisor's Signature)

Full Name : Ir. Ts. Dr. NOOR MAZNI ISMAIL

Position : SENIOR LECTURER

Date : 17 AUGUST 2020

## STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

_______________________________

(Student's Signature)

Full Name : NURIZZATHANIS BINTI MOHAMAD KUSASEH

ID Number : MMF15012

Date : 17 AUGUST 2020

# INVESTIGATION ON MECHANICAL PROPERTIES OF GLASS FIBER REINFORCED POLYAMIDE 6-POLYPROPYLENE COMPOSITES UNDER DIFFERENT OPERATING CONDITIONS

NURIZZATHANIS MOHAMAD KUSASEH

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Manufacturing and Mechatronic Engineering Technology

UNIVERSITI MALAYSIA PAHANG

AUGUST 2020

# ACKNOWLEDGEMENTS

Firstly, I want to thanks Allah for the time that HE gives me to finish this research study and also the strength for me to face challenges during this research study. Thank you Allah for grant health to my body, hearing, and sight to keep my pace in finishing this research. Secondly, I want to thank to myself for never give up through the tough times and be able to push through those times. Alhamdulillah.

Thirdly, I wish to express my sincere appreciation to my supervisor, Assoc. Prof. Dr. Dewan Muhammad Nuruzzaman, who provided me with his germinal ideas, invaluable guidance, continuous encouragement, and the research opportunity that was both challenging and rewarding. Thanks also to his positive words that always give strength to me during completing this research study.

Next, I also wish to extend my special thanks towards my co-supervisor, Ir. Ts. Dr. Noor Mazni Ismail and the technical staffs in the Machining and Material Laboratory, Allahyarham Mr. Yahaya Saleh and Mr. Aidil Shafiza Safiee for their co-operation, knowledge sharing, and helpful advice that made an invaluable contribution to this research. My sincere thanks also go to my bestfriend Nik Ruqiyah and Mohd Syafiq, other fellow friends, and lab mates who always keep my spirit on to finish my research for all these times.

Finally, I wish to express my sincere indebtedness and gratitude to my parents Mohamad Kusaseh Samat and Maslina Mastuji for their love, prayers, and sacrifice throughout my life, and great encouragement throughout my study. Special thanks to them.

*The strength which makes us stand firm against all odds, having trust in Allah and accepting His plan.*

*"Be patient, for indeed Allah is with the patient"*
*[Al-Baqarah: 153]*

# ABSTRAK

Polimer tetulang gentian telah menghasilkan sifat-sifat yang baik seperti ringan, tahap kekakuan yang tinggi, nisbah kekuatan-berat yang tinggi, dan mempunyai ketahanan yang sangat impresif berbanding dengan logam/aloi yang lain. Penyelidikan ini mengkaji sifat-sifat mekanik komposit poliamida 6-polipropilena bertelulang gentian kaca di bawah kadar beban yang berbeza. Biasanya hanya satu jenis matrik dan satu jenis gentian yang digunakan untuk menghasilkan komposit tetapi gabungan ini tidak dapat memenuhi keperluan semasa dalam pengeluaran produk berasaskan komposit polimer yang memerlukan produk yang lebih baik dari segi sifat dan kemampuannya. Oleh itu, dua matriks poliamida 6 dan polipropilena digabungkan dengan gentian kaca untuk menghasilkan sifat-sifat baru komposit yang mempunyai kekuatan komposit dan bahan mulur yang tinggi. Lima spesimen komposit poliamida 6-polipropilena bertetulang gentian kaca berbentuk tulang anjing yang berbeza telah dihasilkan; 70%PA6+30%PP polimer paduan, 65%PA6+30%PP+5%GF komposit, 60%PA6+30%PP+10%GF komposit, 55%PA6+30%PP+15%GF komposit, dan 50%PA6+30%PP+20%GF komposit. Penyelidikan komposit poliamida 6-polipropilena bertetulang gentian kaca akan berbeza dengan penyelidik lain kerana terdapat 3 kategori ujian mekanikal yang berbeza dengan keadaan operasi mekanikal yang berbeza yang dilakukan untuk penyelidikan ini. Komposit PA6-PP-GF yang mempunyai peratusan yang berbeza telah dikaji oleh ujian tegangan, lenturan, dan hentaman di bawah kadar beban yang berbeza iaitu daripada kadar yang rendah hingga kadar yang tinggi. Kadar beban yang berbeza digunakan untuk ujian tegangan dengan kadar tegangan rendah iaitu 2 mm/min, kadar tegangan sederhana iaitu 6 mm/min, dan kadar tegangan tinggi iaitu 10 mm/min. Bagi ujian lenturan, dua kadar beban digunakan iaitu kadar tegangan rendah; 2 mm/min dan kadar tegangan tinggi; 4 mm/min dan dua daya kilas yang berbeza digunakan dalam ujian hentaman iaitu 4 N.m dan 5 N.m. Sifat tegangan 70%PA6+30%PP polimer paduan menunjukkan modulus tegangan dan kekuatan tegangan yang rendah tetapi 50%PA6+30%PP+20%GF komposit menghasilkan keputusan yang tinggi walaupun pada kadar tegangan yang berbeza. Polimer paduan PA6-PP menunjukkan tingkah laku mulur jika dibandingkan dengan komposit PA6-PP-GF dengan 20%GF yang memperlihat komposit tingkah laku rapuh. Graf lengkung tegasan-terikan 50%PA6+30%PP+20%GF komposit di bawah kadar tegangan 10 mm/min juga menunjukkan keupayaan pemanjangan yang sedikit sebelum patah berbanding komposit PA6-PP-GF yang lain kerana kadar tegangan tinggi yang digunakan dan juga kerana kekakuan rapuh komposit itu sendiri. Sifat lenturan komposit PA6-PP bertetulang gentian kaca menunjukkan peningkatan secara berterusan apabila kandungan gentian kaca meningkat. Ciri-ciri tegangan dan lenturan menunjukkan peningkatan hasil dengan peningkatan kadar gentian kaca apabila kadar tegangan meningkat. Keputusan kekuatan lenturan komposit PA6-PP bertetulang gentian kaca pada kadar tegangan 4 mm/min adalah lebih tinggi berbanding kadar tegangan 2 mm/min. Kekuatan lenturan komposit PA6-PP bertetulang gentian kaca pada kadar tegangan 2 mm/min juga menunjukkan kekuatan yang lebih tinggi berbanding keputusan kekuatan tegangan pada kadar tegangan 2 mm/min. Keputusan ujian tegangan dan lenturan menunjukkan peningkatan hasil secara berterusan dengan peningkatan kandungan gentian kaca. Selain itu, kekuatan hentaman menunjukkan keputusan yang lebih tinggi pada 70%PA6+30%PP polimer paduan tetapi menurun secara drastik pada 65%PA6+30%PP+5%GF komposit. Kemudian, kekuatan hentaman meningkat sedikit apabila kandungan gentian kaca bertambah pada 10% dan 15% tetapi

apabila kandungan gentian kaca bertambah pada 20%, kekuatan hentaman menurun semula kerana kandungan gentian kaca yang tinggi menyebabkan penyerapan tenaga yang kurang berbanding dengan polimer paduan. Sifat mekanik komposit PA6-PP-GF dipengaruhi oleh komposisi gentian kaca yang berbeza. Analisis mikrostruktur komposit PA6-PP-GF menunjukkan tarikan gentian kaca dari panjang ke pendek apabila kadar tegangan yang digunakan makin tinggi dan juga kekuatan ikatan antara muka gentian kaca dan matrik PA6-PP yang kukuh. Sifat mekanik komposit PA6-PP-GF dapat menyumbang kepada aplikasi industri seperti saluran masuk atau manifold pengambilan di bahagian automotif, bumper automotif untuk menyerap tenaga hentaman sekiranya berlaku perlanggaran, injap automotif, dan penyelidikan akademik lain di masa depan.

# ABSTRACT

Fiber reinforced polymers possess good properties such as light-weight, high levels of stiffness, high strength-to-weight ratio, and outstanding endurance strength as compared to other most common metallic alloys. This research study is investigating on mechanical properties of glass fiber reinforced polyamide 6-polypropylene composites under different operating conditions. Commonly only one type of matrix and one type of fiber are used to produce composites but this combination cannot meet the current needs in the production of polymer composite-based products that require better products in terms of their properties and capabilities. Thus, two matrices of polyamide 6 and polypropylene are combined and reinforced with glass fiber to produce new properties of a composite that have high strength of ductile materials. Five different dog-bone-shaped specimens of glass fiber reinforced polyamide 6-polypropylene composites were prepared; 70%PA6+30%PP polymer blend, 65%PA6+30%PP+5%GF composite, 60%PA6+30%PP+10%GF composite, 55%PA6+30%PP+15%GF composite, and 50%PA6+30%PP+20%GF composite. The research of glass fiber reinforced polyamide 6-polypropylene composites would differ from other researchers as there are 3 different categories of mechanical tests with different mechanical operating conditions performed for this research. The influence of different compositions of glass fiber reinforced PA6-PP composites was investigated with tensile, flexural, and impact tests under different loading conditions which is from a low rate to a high rate. Different strain rates are used for tensile tests with a low strain rate of 2 mm/min, medium strain rate of 6 mm/min, and high strain rate of 10 mm/min. For flexural tests, two different tension rates are used which are a low strain rate of 2 mm/min and a high strain rate of 4 mm/min and two different torques were used in impact tests which are 4 N.m and 5 N.m. Tensile properties of 70%PA6+30%PP polymer blend show low tensile modulus and tensile strength but at 50%PA6+30%PP+20%GF composite show an increased result even at different strain rates. The PA6-PP polymer blend show a ductile behavior if compare to PA6-PP-GF composite with 20%GF that show brittle behavior composites. A stress-strain graph of 50%PA6+30%PP+20%GF composite under strain rate of 10 mm/min tensile test shows a little elongation ability before fracturing compared to other PA6-PP-GF composites due to the high strain rate applied and also because of the brittle behavior of composites itself. Flexural properties of glass fiber reinforced PA6-PP composites show continuously increased properties as the glass fiber content is increased. Tensile and flexural properties show continuously increased results with the increase of glass fiber content as the strain rates increased. The flexural strength result of glass fiber reinforced PA6-PP composites at a strain rate of 4 mm/min is higher than a strain rate of 2 mm/min. The flexural strength of glass fiber reinforced PA6-PP composites at a strain rate of 2 mm/min also shows a higher strength than tensile strength results at 2 mm/min strain rate. Tensile and flexural test results show continuously improved results with glass fiber content increases. Moreover, the impact strength shows the higher result at 70%PA6+30%PP polymer blend but drastically decreased at 65%PA6+30%PP+5%GF composites. Then, the impact strength slightly increased when the glass fiber content up to 10% and 15% but when the glass fiber content is up to 20%, the impact strength is decreased again because of high glass fiber content absorbs less energy compared to a neat polymer blend. The mechanical properties of PA6-PP-GF composites are influenced by the different composition of glass fiber. The microstructure analysis of PA6-PP-GF composites revealed a long to short fiber pull-out as the strain rates applied

for tensile properties is high and also showed a good interfacial bonding between glass fibers and PA6-PP matrices. The mechanical properties of the PA6-PP-GF composites can contribute to industrial applications such as inlets or intake manifolds in automotive parts, automotive bumpers to absorb impact energy if happens any collision, automotive valves, and other academic research in the future.

## TABLE OF CONTENT

# LIST OF TABLES

## LIST OF FIGURES

# LIST OF SYMBOLS

| | |
|---|---|
| RT | Room Temperature |
| S0 | Sample 0 |
| S1 | Sample 1 |
| S2 | Sample 2 |
| S3 | Sample 3 |
| T | Temperature |
| wt% | Weight percent |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| ABS | Acrylonitrile-butadine-styrene resin |
| ASTM | American Society for Testing Materials |
| CFRP | Carbon fiber reinforced polymer |
| CNT | Carbon nanotube |
| CRP | Carbon fiber-reinforced polypropylene |
| DFFIM | Direct Fiber Feeding Injection Molding |
| EDX | Energy Dispersive X-Ray |
| FKP | Fakulti Kejuruteraan Pembuatan |
| FRPs | Fiber reinforced polymers |
| GF | Glass fiber |
| GFRP | Glass fiber reinforced polymer |
| MAPP | Maleic anhydride-grafted polypropylene |
| PA | Polyamide |
| PA 6 | Polyamide 6 |
| PA 66 | Polyamide 6,6 |
| PA 610 | Polyamide 6,10 |
| PA 11 | Polyamide 11 |
| PA 612 | Polyamide 6,12 |
| PA 12 | Polyamide 12 |
| PA 69 | Polyamide 69 |
| PA 46 | Polyamide 46 |
| PDF | Portable Document Format |
| PMCs | Polymer matrix composites |
| PMMA | Polymethyl methacrylate |
| PP | Polypropylene |
| PP-g-MAH | Maleic Anhydride grafted Polypropylene |
| RT | Room temperature |
| SEM | Scanning Electron Microscope |
| SFRP | Short fiber reinforced polymer |
| SFRPCs | Short fiber reinforced polymer composites |
| SGFR-PA6 | Short glass fiber reinforced polyamide 6 |

| | |
|---|---|
| SiC | Silicon carbide |
| SRPP | Self-reinforced polypropylene |
| UTM | Universal Testing Machine |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

A polymer is commonly known as a plastic material. Scientifically, polymers consist of many monomers (assembly of long chain organic molecules from smaller molecules) units in a long-chain. Polymers have low mechanical properties, low density, and low coefficient of friction and can be produced transparent. Polymers also have good corrosion resistance and good moldability. Polymers have strength and flexible physical properties that generally stronger in long-chains.

Nowadays, fiber reinforced polymer composites are becoming increasingly popular, and they are increasingly being used in bearings, cams, rollers, gear, wheels, piston rings, mechanical seals, grips, and other industrial applications where the properties of their lubricants are exploited to avoid any lubrication requirements (Kusaseh et al., 2018 and Sen et al., 2015). A composite material consists of two or more different materials that generate a combined, better than the individual material. Composite materials can, therefore, be very important because of their strong and high levels of stiffness, high strength-to-mass ratio and etc (Zhou et al., 2013). In addition, the advantages of composites are lightweight, good corrosion resistance, fatigue resistance, design flexibility and easy manufacture (Liu et al., 2013).

Fiber reinforced polymers or FRPs are composite materials consisting of plastic resins and fillers such as aramid, carbon, and glass fiber. For FRP composites, reinforcing fibers form the spine of the material and determine the strength and stiffness in the fiber direction (Ku et al., 2011 and Taranu et al., 2015). Glass fibers are usually used as reinforcements because of their low cost, lightweight, less brittle, and robust material compared to carbon (Ashik and Sharma, 2015). A matrix of thermoplastic or thermosetting plastic is usually used as a bonding agent and load transfer between matrix and fiber (Frigione and Lettieri, 2018 and Ramesh et al., 2013). By reinforcing the plastic matrix, various physical strengths and properties can be developed as FRP composites. The type and configuration of reinforcements can also be selected with the addition of plastic types and matrices. This variation allows a variety of extraordinary strengths and physical properties. FRP composites can be specially designed for the performance required for traditional materials such as wood, metal, and ceramics.

As been reported in previous research, glass fiber reinforced polyamide (GFRP) composites are rising materials in the automotive industry because of their superior mechanical properties, light in weight, and lower mass production costs than pure polyamide (Chaichanawong et al., 2016). In addition, a reinforced polymer has its own mechanical properties and physical properties. Fiber-reinforced composite (FRP) applications in the civil sector were popularly used because of excellent bending strength and load-carrying capacity to strengthen the concrete beam (Rajak et al., 2019). Type, shape, length, and orientation of the reinforcing material can affect the mechanical and physical properties of a reinforced polymer. The percentage parameters of the reinforcing material also give effect on the mechanical and physical properties of the reinforced polymer.

## 1.2 Problem Statement

In spite of many advantages of polymer, better physical and mechanical properties of a polymer are needed for industrial applications. As the industry now needs a lightweight and high strength to weight ratio of glass fiber materials that can be used as a replacement for traditional reinforcing materials in composites. So that, reinforced polymers (composites plastics) have produced good materials with light-weight properties, high levels of stiffness, high strength/weight ratio, incredible fatigue resistance, and superb corrosion resistance to compare to most common metallic alloys, such as steel and aluminum alloys. The strength and stiffness of polymers are good by adding fibers of glass, carbon, nylon and etc. Generally, only one type of matrix and one type of fiber are used to produce composites but this combination cannot meet the current needs in the production of polymer composite-based products that require better products in terms of their properties and capabilities (Ou and Zhu, 2015 and Khan et al., 2010). To produce a composite that contributes to the high strength of ductile materials, two matrices were used to reinforce with glass fiber that are polyamide 6 and polypropylene. Besides, the combination of these materials can improve their mechanical properties for new properties in GFRP composite field. The mechanical properties of the PA6-PP-GF composites can contribute to industrial applications such as inlets or intake manifolds in automotive parts, automotive bumpers to absorb impact energy if happens any collision, automotive valves, and etc.

This study aims to investigate the mechanical properties by using two polymers with different strengths as polyamide 6 has high strength while polypropylene has good ductility and light-in-weight material and reinforced with glass fiber that possesses high modulus of elasticity and high strength (Karsli and Aytac, 2013; Rudresh et al., 2016 and Zhang et al., 2014). As a result, by combining these two polymers with reinforced of glass fiber, a high strength of ductile materials can be achieved as popularly known that polyamide 6 and polypropylene matrices bonds well to the fiber surface and which can transfer stress effectively to the fiber. The investigation of glass fiber reinforced polyamide 6-polypropylene composites would be different from other researchers because there are 3 different categories of mechanical testing with different mechanical operating conditions was carried out for this research. Previous studied mostly focused on only one applied condition that had only one strain rate for example; 5 mm/min strain rate for tensile and flexural tests. Then, the percentage difference of the polymer composite used is studied to find out how the percentage difference can affect the mechanical result based only on one strain rate (Rathnakar and Shivanand, 2012 and Rudresh et al., 2016). Tensile testing is carried out with 3 different strain rates at low, medium, and high rates. Whiles, for flexural testing, it is carried out with 2 different strain rates and impact testing also is carried out with 2 different torques. The mechanical behavior for each testing is observed and the effects from different types of glass fiber content with different operating conditions are discussed.

## 1.3 Objectives

i. To determine the suitable process parameters of injection molding machine, in fabricating the various composition of composites.

ii. To investigate the influence of glass fiber content on the tensile, flexural, and impact properties of glass fiber reinforced polyamide 6-polypropylene composites under different loading conditions.

iii. To examine the failure behavior of the fractured specimens of glass fiber reinforced polyamide 6-polypropylene composites under different loading conditions.

## 1.4 Research Scope

This research study focuses on mechanical properties of glass fiber reinforced polyamide 6-polypropylene composites under different operating conditions. The research scopes as follows:

i. Dog-bone-shaped specimens with different compositions of glass fiber reinforced PA6-PP composites were fabricated by using an injection molding machine.

ii. Five different types of glass fiber reinforced PA6-PP composites are: 70%PA6+30%PP polymer blend, 65%PA6+30%PP+5%GF composite, 60%PA6+30%PP+10%GF composite, 55%PA6+30%PP+15%GF composite, and 50%PA6+30%PP+20%GF composite.

iii. The influence of fiber reinforcement on the mechanical properties of these PA6-PP-GF composites under different loading conditions was investigated with 3 different tests; tensile, flexural, and impact test.

iv. There are 3 different strain rates used for a tensile test which is 2 mm/min of low strain rate, 6 mm/min of medium strain rate, and 10 mm/min of high strain rate with following ASTM D638. For the flexural test, two different strain rates were used which are 2 mm/min and 4 mm/min with following ASTM D790.

v. Impact test was carried out using two different torques to tighten the specimens at the specimen support with a designated torque of impact test machine which is 4 N.m torque and 5 N.m torque with following ASTM D4812.

vi. Analysis of the test results were carried out under different loading conditions for different types of composites.

vii. The failure behavior of fractured specimens after testing were examined by using Scanning Electron Microscopy (SEM).

## 1.5 Significance of Study

Polymer composites of one polymer with one fiber are common and many researchers only focus on one condition of mechanical testing (Elanchezhian et al., 2014 and Tian et al., 2017). To understand a better mechanical behavior of polymer composites, two polymers are used to reinforce with glass fiber. Five different dog-bone-shaped specimens of glass fiber reinforced polyamide 6-polypropylene composites were prepared; 70%PA6+30%PP polymer blend, 65%PA6+30%PP+5%GF composite, 60%PA6+30%PP+10%GF composite, 55%PA6+30%PP+15%GF composite, and 50%PA6+30%PP+20%GF composite. The polyamide 6 composition was gradually reduced when the glass fiber composition was increased by 20%, while the polypropylene composition was constant at 30% to maintain the high ductility of polypropylene in the PA6-PP-GF composites. The minimum PA6 composition used was 50% because if the composition of PA6 is less than 50%, the high ductility of PP will result in low impact strength for PA6-PP-GF composites. The higher GF composition used in PA6-PP-GF composites was 20% because if more composition of glass fiber is used, the composites are impending to brittle which will result in low ductility composites. A lot of improvement is made with different glass fiber content in one composite within this research and different mechanical operating conditions for tensile, flexural, and impact testing were used which is from a low rate to a high rate. Different strain rates were used for tensile tests with a low strain rate of 2 mm/min, medium strain rate of 6 mm/min, and high strain rate of 10 mm/min. Three different strain rates for tensile testing were used because to investigate how the tensile properties of PA6-PP-GF composites behave at low, medium, and high strain rates. For flexural tests, two different tension rates were used which are a low strain rate of 2 mm/min and a high strain rate of 4 mm/min and two different torques were used in impact tests which are 4 N.m and 5 N.m. Therefore, the polymer composites properties and findings from this study would contribute to industrial applications such as in automotive components, roller, bearing, etc. for a better future in this polymer composites field.

## 1.6 Thesis Outline

The layout of this thesis begins with the introduction and general knowledge about this research study in Chapter 1 which includes the problem statement, objectives, research scope, significance of study, and thesis outline. For a further explanation from previous researchers, the literature review about other research works are presented in Chapter 2. Chapter 3 focuses on research flowchart and experimental procedures. Whiles, Chapter 4 is the main character in this thesis which discusses all the results for all mechanical testing that were carried out. Finally, the conclusions of this research objective and some recommendations for further improvement are stated in Chapter 5.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

Polymer matrix composites (PMCs) consist of a polymer resin as a matrix. It is being used in the largest quantities like glass fiber reinforced polymer, carbon fiber reinforced polymer, and aramid fiber reinforced polymer. Thermoset and thermoplastic (crystalline and amorphous) are the classifications of PMCs. The polymer composites made from polymers and fiber reinforced composites are made of one's material that attached with another material. The combination of polymer with another material such as glass will result in a unique property. The mechanical properties of composite are improved with additional fibers which have high resistance to failure especially at high tensile strengths such as glass fiber, carbon, and Kevlar (Massaq et al., 2019). The objectives of this combination are to improve strength, stiffness, and toughness of polymer composites.

## 2.2 Composite

Composite is a combination of any materials that made of two or more components with different properties that, when combined, produce a material that is better than the sum of the individual components. Composite materials also were high strength-to-weight ratio compared to steel. Glass fiber reinforced polymer (GFRP), is a composite material made of plastic reinforced by fine fibers from glass, that are low cost, high chemical resistance, and the last important thing is high strength (Wambua et al., 2003 and Deshmukh and Jaju, 2011). Fibers have two categories, natural and synthetic. Natural fibers are like wood fiber, flax, hemp, silk, cotton, and more. Synthetic fibers are like glass, carbon, and aramid.

There are studies in natural and synthetic fiber when combining with composites and the result is especially focused on their mechanical properties. The mechanical properties of synthetic fiber reinforced thermoplastic are better than natural fiber (Maddah, 2016). But every material has pros and cons. Natural fiber reinforced thermoplastic is environmentally compared to the synthetic fiber reinforced thermoplastics (Shubhra et al., 2013). The environmental friendliness of natural fiber advantage mostly refers to the meaning of sustainability that cause less or no damage to the environment and therefore able to continue for a long time. Sustainability is a new criterion that engineers want nowadays when trying to produce a new product. But then, a synthetic fiber reinforced plastic composite gives better durability, high strength, and good mechanical properties (Khan et al., 2009a, b, and Shubhra et al., 2013). The most compatible fiber composite is glass fiber because it is cheaper than aramid and carbon, and also better in physical and mechanical properties (Khan and Sultana, 2010).

Polypropylene (PP) is one of a thermoplastic polymer that is used in many applications such as stationery, laboratory equipment, automotive components and containers, electric industry, etc. (Arencón and Velasco, 2009; Gamze Karsli et al., 2014 and Varga, 2002). PP is normally used in engineering with good resistance to fatigue failure, flexible, good mechanical properties, inexpensive, excellent resistance to humidity, and process (Kalpakjian and Schmid, 2010; Lingesh et al., 2014 and Rudresh et al., 2016). Glass fiber (GF) is the most widely used reinforcement among polypropylene composite materials, because of their good balance between properties and cost. However, their final properties are largely ascertained by the strength and stability of the polymer fiber interlayer (Etcheverry and Barbosa, 2012). Good mechanical properties of composites come out from a good quality of polymer-fiber interface and PP have an outstanding character for composite because of its suitability in reinforcement, filling, and blending (Khan et al., 2010).

Nylon is known as polyamides (a group of plastic) and nylons are characterized by amide groups (CONH). Due to its fascinating combination of mechanical properties and processes, the polyamide is frequently used in various technical applications (Tjong et al., 2002). Polyamide (PA) is a tough and semi-crystalline polymer with low glass transition and is often used in the automotive parts and textile fibers because of its mechanical strength and high impact strength and excellent performance (Kuram et al., 2013). There are many types of polyamides such as PA 66, PA 6, PA 610, PA 11, PA

612, PA 12, PA 69, and PA 46. In nylon fabrication, it is stated that nylon is excellent material especially for machining, tough, and abrasion resistant (Coronado, 2012). Strong mechanical properties such as good thermal stability, low cost, and high tensile strength, PA become strong candidates of good matrices among others (Botelho et al., 2003 and Karsli and Aytac, 2013). Polyamide 6 (PA6) is a high strength engineering thermoplastic with good mechanical properties. PA6 have a tendency to absorb water (moisture surface) until it reaches equilibrium and can reduce mechanical properties but increases the nylon number, impact resistance and flexibility. In order to provide good resistance to moisture and ensure good processability of polymer composite, PA6 is mixed with polypropylene (PP) and it reduced the effects of water humid conditions on mechanical properties (Roeder et al., 2002 and Miri et al., 2009).

Glass fiber is a material made from very fine glass fibers which are non-crystalline materials with a short-range network structure (Park and Seo, 2011). Glass fiber has a range of excellent properties such as high strength, high modulus of elasticity, and high heat resistance (Zhang et al., 2014). Glass fiber is used to enhance mechanical strength, resist external damage, and maintain a permanent appearance. The results of combined both polymer and glass fiber, the high tensile strength are supported. Besides, the properties of lightweight, strong, and good thermal insulation are one of the factor glass composition and modern composite material (Ashik and Sharma, 2015 and Russo et al., 2013). E-glass fibers provide stiffness and strength composites and the polyamide-6 matrix provides a way to achieve resistance and chemical resistance while holding the fiber together (Zhen et al., 2002). The reinforcement of short glass fiber with polypropylene polymer could also enhance the stiffness and impact resistance of composites, therefore allows use in higher performance in automotive applications (Hartl et al., 2015).

The fiber reinforced polymers (FRPs) consist of high strength fibers and modulus embedded in or bonded to the matrix with different interfaces between them (Braga and Magalhaes, 2015). In general, fibers are the main load bearing elements, while the matrix holds them in the desired position and orientation, and to transfer the load to the fierce fiber through the shear stress at the interface (Boopalan et al., 2013; Hachemane et al., 2013; Mir et al., 2010 and Wambua et al., 2003). There are many conventional properties of glass fiber reinforced plastic, for example, long fibers are more effective than short fibers. Their resistance to fatigue, creep, and wear also depends on the type and amount of reinforcement. FRP composites of carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) are widely used in the industries such as aerospace, automotive, oil and gas industries, and etc. These two types of FRP have their own advantages and disadvantages based on previous research which showed that GFRP composites are low-cost materials and have excellent mechanical properties compared to CFRP composites (Kumarasamy et al., 2018). GFRP is a polymer composite category in which glass fibers are used specifically to mechanically enhance plastic strength and stiffness (Landesmann et al., 2015 and Callister, 2007). GFRP composites have the ability properties to meet wide-ranging performance specifications and the ability to markedly reduce part assembly. GFRP composites also have high strength at low weight, good impact, and compression. The molding part is in close dimensional tolerances. Moreover, these composites show excellent chemical and corrosion resistance, good thermal insulation, and respectable abrasion resistance with ready to bond with dissimilar materials (Valliappan, 2015).

## 2.3 Processing Methods and Mechanical Properties

In preparing the composite GFRP, there are many processing techniques that researchers have previously used such as hand lay-up technique, compression molding, hot press technique, extrusion, injection molding, and etc. (Sathishkumar et al., 2014). Mostly the hand lay-up technique is widely used in processing natural fiber with epoxy resin or woven glass fiber reinforced epoxy composite. But nowadays, most of the efficient manufacturing technique used to produce a plastic product is an injection molding process. Most studies have a focus on injection molding process because of its high efficiency of production, low cost, and high production speeds (Herrington, 2015 and Mortazavian and Fatemi, 2015). The injection molding process is also suitable to process thermoplastic part in large quantities and it is a more precise manufacturing method with highly automated and economical (Karandikar et al., 2014). There are many processing methods that can be used to process fiber reinforced thermoplastics. For this short fiber reinforced polymer, it is suitable to use the injection molding process because of high melt viscosity of the reinforced polymer. Before run of the injection molding process, flow analysis of the plastic will be modeled and analysed by using Autodesk Moldflow programmed. The model geometry is divided into a mesh to form the element properties and continue until the analysis of the mesh product finish (Misirli et al., 2011). Figure 2.1 shows an example of previous research about the modeling of plastics flow or filling time (2.634 [s]) of the mold cavity for dog-bone-shaped specimens with edge gate location. The moldflow analysis also can determine the flow parameters of plastic material such as pressure, temperature, flow rate, etc. (Nuruzzaman et al., 2016).

In the case of PP, crystallization and the improvement of heat contact between polymer and the mold would be possibly integrated with a form of the heat exchange process. A comparison of temperature experiments with theoretical results can determine the characteristics of the process at the beginning of this heating event. Basic knowledge of thermal properties is important to produce good thermoplastic specimens. The melt-temperature and decomposition-temperature condition of some thermoplastic is shown in Figure 2.2 (Klein, 2011). There is a method to measure the temperature of the polymer such as rigid design which is equipped with a thermocouple during the injection molding machine (Nicolazo et al., 2010). In general, for the purpose of achieving high performance of short fiber reinforced polymer (SFRP), higher fiber content is necessary (Ahmad et al., 2006). It is often noted that the presence of fiber or other reinforcing agents in the polymer matrix increases the strength of the composite and the elastic modulus (Li et al., 2006). Hence, the enhancement of tensile properties of fiber content affects the particular interests of many researchers (Ku et al., 2011).

The orientation of fibers and dispersions are important factors in controlling the final characteristic of the injection product. A good understanding of these parameters has been developed for glass fiber reinforced composites. A typical orientation of the core-shell structure is observed, characterized, and modeled. The spread of fiber across the thickness is related to the orientation of fiber, length, and concentration. In the case of injected molded composites, the effect of glass fiber content in terms of tensile, compression and a flexural load is improved differently. The fiber reinforced composite behavior is highly dependent on the orientation and distribution of the fibers in the injection molded specimens (Bajracharya et al., 2016).

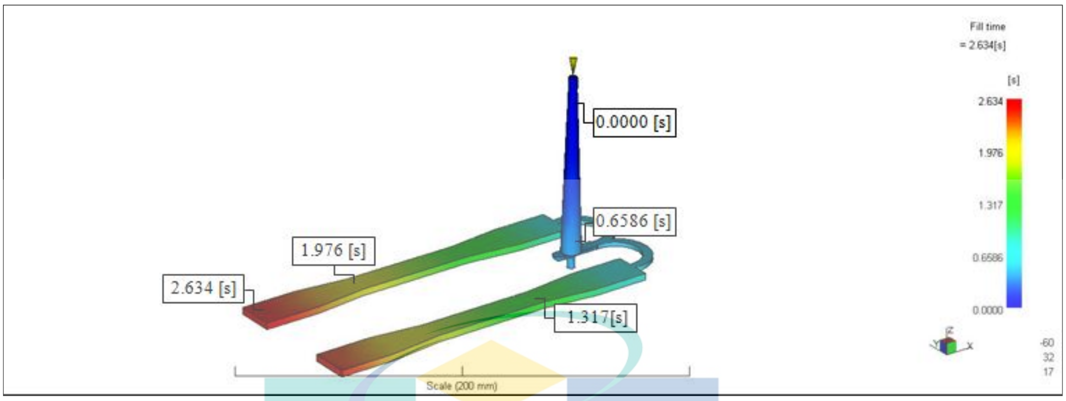



Figure 2.1 Fill time of dog-bone-shaped specimen in moldflow analysis

Source: Nuruzzaman et al. (2016)

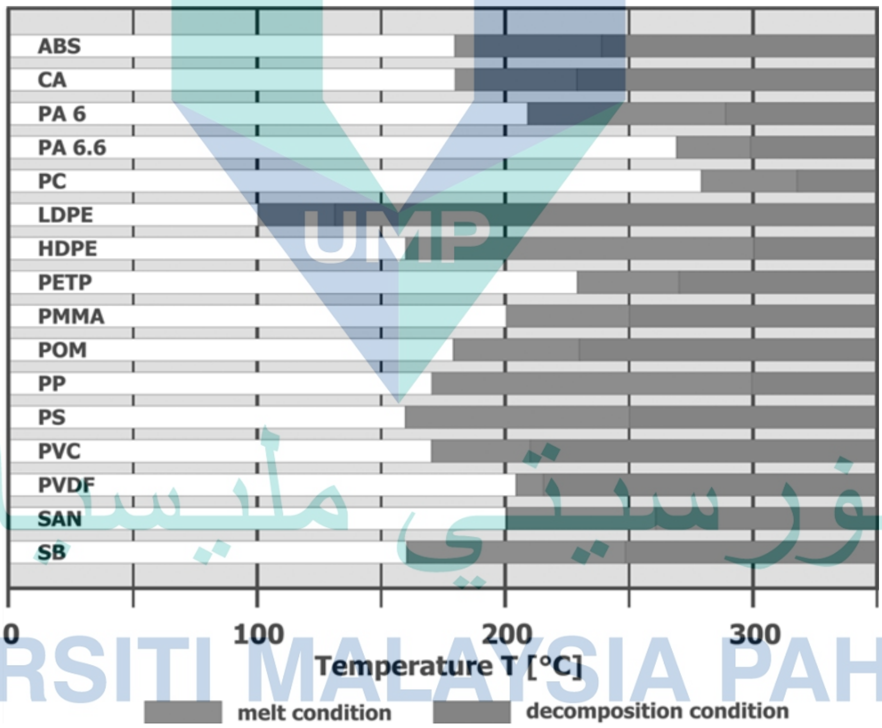



Figure 2.2 Melt condition and decomposition condition of some thermoplastic

Source: Klein (2011)

Furthermore, most of the factors that may affect the orientation and dispersion of glass fibers in the thermoplastic polymer have been examined in detail as injection conditions, geometric molds, and melt reactions (Abdennadher, 2016). An improvement to an injection molding machine to produce high-efficiency production process of carbon fiber composite material has been made and it called as DFFIM (Direct Fiber Feeding Injection Molding) (Figure 2.3). The dumbbell specimen of carbon fiber and commingle yarn of carbon fiber and PA66 were fabricated by using DFFIM with 3 different matrix resin feeding rate of 20 rpm, 40 rpm, and 60 rpm. The effect of different feeding rate used is investigated through the tensile test. The average tensile strength results of carbon fiber and commingle yarn were decreased as the feeding rate of DFFIM is increased (Nakao et al., 2016).

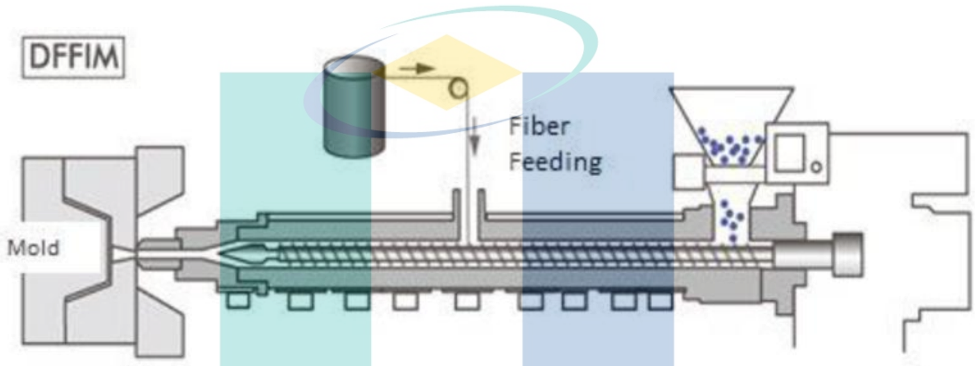



Figure 2.3 Schematic of DFIM (Direct Fiber Feeding Injection Molding)
Source: Nakao et al. (2016)

Recent studies showed that the tensile strength and modulus of short fiber reinforced polymer composites (SFRPCs) is increased when the fiber volume fraction is increased. The composite plates of different fiber volume fraction of short carbon fiber reinforced epoxy resin; (0%, 5%, 10%, 15%, 17.5%, and 20%) were fabricated using compression molding process. The tensile properties of short carbon fiber reinforced epoxy composites is investigated by using the Instron Universal Testing machine (High Wycombe, UK, model 4206), with a crosshead speed of 1 mm/min. The stress-strain graph obtained from the tensile test shows (Figure 2.4) the increase in tensile strength and stiffness of short carbon fiber reinforced epoxy composites when the fiber volume fraction is increased (Capela et al., 2019). The tensile modulus also shows an increased result as the fiber volume fraction is increased but vice-versa, the strain at failure is decreased as the fiber volume fraction is increased. The fiber reinforced composite mechanical behavior basically depends on the strength of the fiber and the modulus, the chemical stability, the strength of the matrix, and the bond between the fiber/matrix allowing stress transfer (Erden et al., 2010). The effect of reinforcement arising from fiber content is largely dependent on the retention of the length of the fiber and its orientation. Regrettably, the shear force during the compounding and injection molding process often leads to fiber damage. It is expected to optimize the length of the fiber and to promote good mixing during the compounding process. In extrusion and injection molding, the resulting flow field always encourages several degrees of fiber orientation. The fiber orientation stage depends on the intensity of the flow field and the characteristic of the fiber reaction (Pisharath and Wong, 2003).

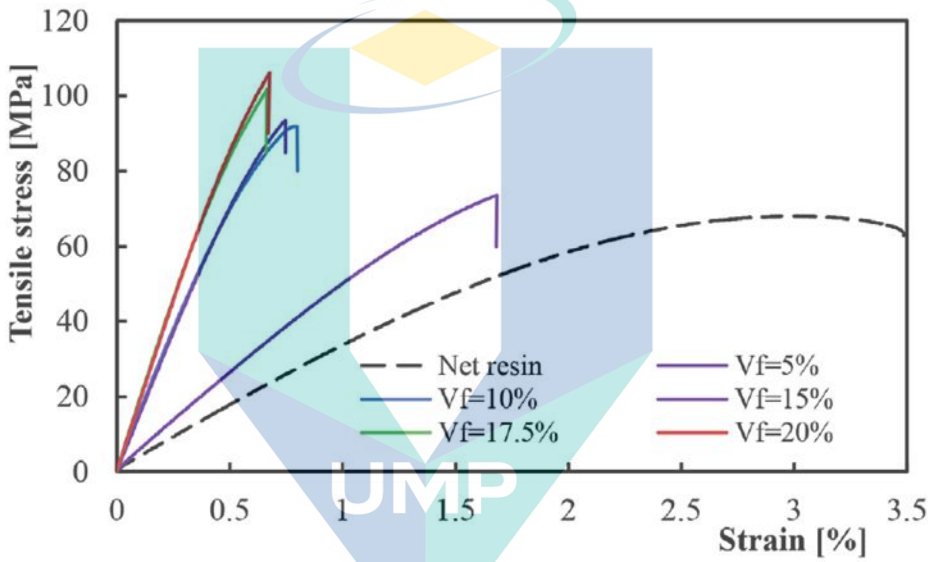



Figure 2.4 Stress-strain curves of short carbon fiber reinforced epoxy composites

Source: Capela et al. (2019)

The adhesion between the filler and the polymer matrix is known to be one of the main factors that determine the structure and properties of the obtained polymer composite (Franco-Marquès et al., 2011; Li et al., 2014 and Tang et al., 2013). The filler acts as additional reinforcement components and enhances its mechanical properties. These composite properties depend on the type and size of fillers used (Devendra and Rangaswamy, 2013; Raja et al., 2013; Reddy, S. P. and Reddy, A. C., 2014). The effect of different fibers on the properties of short fiber reinforced polypropylene composites was studied. Most types of fibers used to show the effect of the gain, according to the characteristics of the respective fibers. Comparison of the use of different sizes and coupling agents were the interaction fiber/matrix to have a significant effect on the properties of the composite material is shown. By using a longer fiber, it may help in increasing the final fiber length. However, the results of this study indicate that as fiber lengths increase, a certain amount of adhesion is required to improve composite performance (Unterweger et al., 2014).

A glass fiber reinforced unsaturated polyester (GFRP) based polymer composite had been influenced by the various temperature levels under heat treated process for one hour of 60˚C, 90˚C, 120˚C, and 150˚C before mechanical testing (Elahi et al., 2014). The tensile testing was performed by using Universal Testing Machine (Hounsfield series, model: INSTRON 1011, UK) under the cross-head speed of 10 mm/min. The obtained tensile strength results of GFRP shows a gradually increased from untreated to 90˚C but started to decrease with the increase in temperature at 120˚C until 150˚C. The tensile modulus of GFRP also increased from untreated until 90˚C and decreased as the temperature is increased. The heat treatment methods show increased tensile properties of GFRP from untreated to 60˚C and 90˚C but show decreased properties when the temperature applied is above the boiling temperature (100˚C).

Glass fiber reinforced polymer (GFRP) composite is one of the FRP composites that extensively used in engineering applications but GFRP composites show limitation at high-temperature applications (Kumarasamy et al., 2018). The tensile strength of GFRP epoxy and polyester laminates was investigated under hot and cold environment. The GFRP epoxy and polyester laminates specimens were fabricated using wet hand lay-up with assisted by vacuum bag. The GFRP laminates are placed to a close chamber box that attached to the Testometric machine for hot/cold temperature environment test. There are hot and cold temperatures setup for this tensile test which are room temperature (RT), 40˚C, 50˚C, 60˚C, and 80˚C for hot temperature and for cold temperature are RT, -5˚C, -10˚C, -15˚C, and -20˚C with a crosshead speed of 2 mm/min. The tensile strength and modulus of GFRP laminates at hot temperatures resulting in decrease results when the temperature applied is increased. Both tensile strength and modulus were decreased because of the resin softening of the GFRP laminates. At cold temperatures, the tensile strength and modulus of GFRP laminates attained an increased result as the temperature applied. The tensile modulus of GFRP laminates observed a slightly increased from RT to -5˚C and slightly decreased from -5˚C to -20˚C. GFRP laminates also show a brittle behavior at low temperatures.

The tensile behavior of glass fiber reinforced composite at different strain rates and temperatures was studied. Dog-bone-shaped specimens of glass fiber reinforced composite were used in completing the tensile test under different strain rates of $1/600s^{-1}$, $40s^{-1}$, $80s^{-1}$, $120s^{-1}$, and $160s^{-1}$. The result shows a linear elastic deformation before reaching the fracture stress and drops to zero after the brittle failure. From the investigation, it was found that the tensile strength and toughness of GFRP increases as the strain rates increased (Ou and Zhu, 2015). Other than that, the mechanical behavior of glass and carbon fiber reinforced composites was studied under varying strain rates and temperatures. Due to the eco-friendly properties of fiber reinforced composites, they have gained a lot of interest from many researchers. Particularly for industries, which require light and high strength materials, glass fiber and carbon can be used as a substitute for conventional reinforcement materials in composites. Tensile test of GFRP and CFRP composites was done by using a universal testing machine. The composites specimens were cut followed ASTM D638. The strain rates used for tensile testing are 2.5mm/min and 1.5mm/min, whiles the temperature is 35˚C and 70˚C. A Load vs. Displacement graph of tensile test for both composites is observed. It shows that CFRP composite has high tensile strength than GFRP for both tensile test parameters.

The flexural tests of GFRP and CFRP composites were carried out by 3-point flexure test and the composites specimens were cut followed ASTM D790 with a crosshead speed of 2 mm/min. The results show that the maximum flexural strength and a flexural modulus of CFRP composites are higher than GFRP composites. This is because the adhesion of CFRP and the epoxy matrix is better than the GFRP and epoxy matrix composites. The impact test of GFRP and CFRP composites was done by using Charpy impact testing machine and followed ASTM D256. The impact strength of carbon fiber is higher than glass fiber with 11J of energy absorbed. Lastly, the internal structures of composites have been investigated by using SEM (Scanning Electron Microscope). Morphological analysis showed that the angular orientation of the fibers plays an important role in the mechanical behavior of CFRP and GFRP composite in a composite. As conclusion for this study, the CFRP composites are stronger than the GFRP composites (Elanchezhian et al., 2014).

Other than that, some researchers added compatibilizer of maleic anhydride-grafted polypropylene (MAPP) into carbon fiber reinforced composites to improve the interfacial bonding strength between carbon fiber and polypropylene matrix. A single-screw injection molding machine is used to fabricate dumbbell-shaped tensile bars of carbon fiber-reinforced polypropylene (CRP) composites. A different carbon fiber content of CRP composites with 0%CF, 5%CF, 10%CF, 15%CF, and 20%CF undergo tensile and flexural testing under the universal testing machine (MTS systems China Co, Ltd) with a crosshead speed of 50 mm/min for tensile and 2 mm/min for flexural with a span length of 64 mm. The obtained results showed an increase in tensile and flexural strength of CRP composites with increasing of carbon fiber content (Tian et al., 2017).

The flexural strength of heat-polymethyl methacrylate (PMMA) denture resin reinforced with glass, aramid, or nylon fibers was investigated by a previous researcher. Flexural strength was tested with a 3-point bending test at a crosshead speed of 2 mm/min. The experimental data (Figure 2.5) of PMMA resin reinforced with glass, aramid, and nylon showed higher flexural strength than the pure PMMA resin. Moreover, PMMA resin reinforced with glass fibers exhibited the highest flexural strength, followed by PMMA resin reinforced with aramid and nylon showed the lowest flexural strength (John et al., 2001). The mechanical behavior of short glass fiber reinforced polyamide 6,6 was investigated under three different conditions of glass fiber content, temperature, and a crosshead speed. The mechanical test results showed an increased strength as the crosshead speed and glass fiber content increased. Besides, temperature plays a major role in material behavior, rising temperatures cause more ductility and less stiffness. Glass fiber reinforced PA6,6 also exhibits improvement in its tensile strength and modulus with the decrease in ductility but increase in stiffness when the glass fiber content is increased (Mouhmid et al., 2006).

The effect of silane coated glass fibers on the mechanical properties of polypropylene (PP) and polyamide 6 (PA6) plastics resulted in an exhibited improvement in tensile and impact strength. The mechanical properties of the composites that made of plastic and fibers can differ depending on the fibers distribution in structure, fiber size, fiber content, and plastic fiber sticks. To strengthen high adhesion between plastic and fibers, fibers are coated with materials that have less surface energy, such as silane. Thus, increases the humidity of the matrix. The tensile strength of 15wt% and 30wt% silane coated glass fiber reinforced PA6 and PP plastics increased as the fiber content increased. While the impact test results showed a decreased value at 15wt% fiber reinforced composites but the increased value at 30wt%. Fiber fractures also increase with increased fiber content (Güllü et al., 2006). The effect of hybrid glass fiber (GF)/carbon nanotube (CNT) reinforcement on the mechanical properties of polypropylene composites was investigated and the obtained results showed that GF and CNT reinforced hybrid composites can provide improved tensile strength and tensile modulus than only GF or CNT reinforced composites (Gamze Karsli et al., 2014).

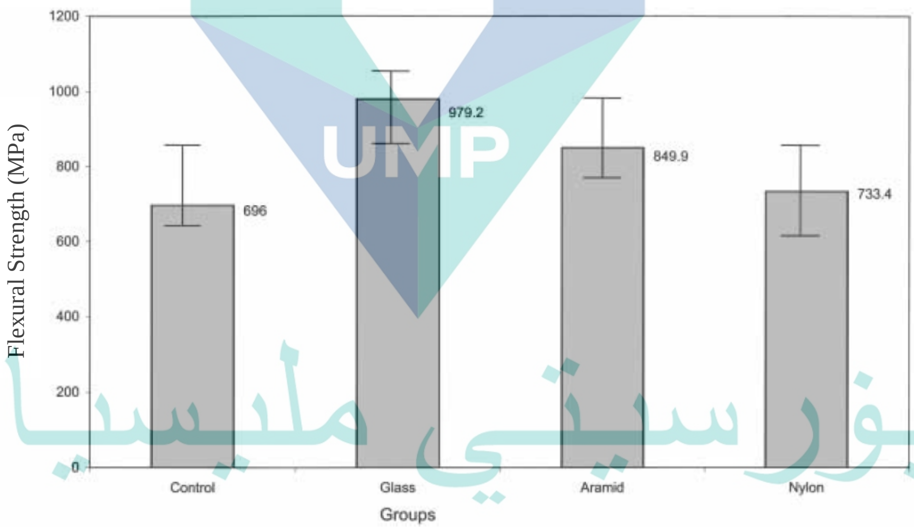



Figure 2.5 Flexural strength of pure PMMA resin and PMMA resin with reinforced materials

Source: John et al. (2001)

The polyester resin was reinforced with glass fiber and carbon fiber, and their mechanical properties were investigated (Durairaj et al., 2016). The results revealed that the bending properties and impact properties are strongly affected depending on the type of composite and the strength of the reinforcement. Different glass fiber compositions have greatly influenced the mechanical properties of nylon reinforced glass fibers (Nuruzzaman et al., 2016). The different types of resins used such as thermoplastic or thermoset had different effects on the impact behavior of composites (Arikan and Sayman, 2015). Tensile properties such as tensile modulus, tensile strength, and elongation at break of calcite particle, glass fiber and glass fiber/calcite hybrid reinforced ABS/PA6 composites were investigated (Gamze Karsli et al., 2013). The obtained results revealed that tensile properties of the composites were different depending on the filler type and filler loading level. It was reported that tensile properties of fiber reinforced polymer composites are influenced by strain rate conditions (Ou et al., 2016; Reis et al., 2012 and Shokrieh and Omidi, 2009).

Other than that, the tensile and bending properties of E-glass fiber reinforced PP composite shows outstanding results compared to Jute fiber reinforced PP composite and pure PP. The tensile strength of pure PP is 21 MPa while Jute fiber/PP composite is 48 MPa and E-glass fiber/PP composite shows the highest tensile strength of 85 MPa. The full tensile and bending properties results are shown in Table 2.1. It is clear in this investigation that the composite jute proves the adhesion of a good fiber matrix by obtaining greater mechanical properties relative to the matrix material. However, E-glass fiber/PP composite had a significant increase in mechanical properties compared to the pure PP and Jute fiber/PP composite (Khan et al., 2010). It concludes that E-glass fiber/PP composite mechanical properties almost doubled the value of jute composite.

Table 2.1 Tensile and bending properties of PP sheet and the composites

| | Tensile and bending properties | | | | |
|---|---|---|---|---|---|
| | Tensile properties | | | Bending properties | |
| Material | Strength (MPa) | Modulus (GPa) | Elongation at Break (%) | Strength (MPa) | Modulus (GPa) |
| PP | 21 ± 2 | 0.53 ± 0.14 | 378 ± 35 | 27 ± 1.4 | 1.98 ± 0.11 |
| Jute fiber/PP composite | 48 ± 2.4 | 2.50 ± 0.20 | 12 ± 3 | 56 ± 2.6 | 4.50 ± 0.14 |
| E-glass fiber/PP composite | 85 ± 3.5 | 7.00 ± 0.10 | 14 ± 4 | 85 ± 4 | 12.00 ± 0.12 |

Source: Khan et al. (2010)

The mechanical behavior of glass fiber reinforced polypropylene composites under three different forming pressures (MPa) was investigated. The composites were fabricated with film stacking technique by using a hot compression molding machine.

The levels factors of forming pressure were 4 MPa, 7 MPa, and 9 MPa. The mechanical testing was carried by following ASTM D638 for tensile test and ASTM D790 for flexural test. The results obtained from this studied is that the tensile and flexural strength shows an increased result as the forming pressure are increased. Tensile strength with forming pressure 4 MPa shows 102.33 MPa and increase steadily to 125.67 MPa under forming pressure 7 MPa while under forming pressure of 10 MPa, the tensile strength is 106.00 MPa respectively. Flexural strength also reveals an increased result of 49.67 MPa under 4 MPa and under forming pressure of 7 MPa and 10 MPa is 78.67 MPa and 55.33 MPa respectively. The researchers conclude that the optimum parameter of forming pressure is 7 MPa because of the highest tensile and flexural strength of glass fiber reinforced polypropylene composite was optimized under forming pressure of 7 MPa (Suresh and Senthil Kumar, 2014).

An injection-molded of short glass fiber reinforced polypropylene composites has been studied by flexural test and the effect different of loading rates and temperatures dependence of these materials has been investigated. Dumbbell-shaped bars specimens of pure polypropylene and pre-compounded short glass fiber reinforced polypropylene (25 wt%) with a thickness of 3 mm and width of 10 mm were fabricated by using injection machine (TOYO MACHINERY & METAL CO., Ltd., YI-30F6, Japan) and with 200-240˚C temperature applied. The flexural tests were carried out by using Instron universal testing machine (INSTRON 55R4206) with different loading rates of 0.1 mm/min, 1 mm/min, and 10 mm/min and different temperatures of 25˚C, 40˚C, 60˚C, 80˚C, and 100˚C. The obtained flexural modulus and flexural strength results of pure PP and GFPP composite were increased upon the increase of loading rate from 0.1 mm/min to 10 mm/min. But, the flexural modulus and strength results were decreased upon the increase of temperature from 25˚C to 100˚C. Both flexural modulus and flexural strength are depending on the loading rate and temperature used (Lichao and Yan, 2019). A three-point bending test of self-reinforced polypropylene (SRPP) composites is investigated with a span length of 20 mm and a different displacement rate of 200, 20, 2, 0.2, and 0.02 mm/min which are corresponded to strain rates of $4.25\text{x}10^{-2}$, $4.25\text{x}10^{-3}$, $4.25\text{x}10^{-4}$, $4.25\text{x}10^{-5}$, and $4.25\text{x}10^{-6}$ $s^{-1}$. The flexural modulus and flexural strength of SRPP composites is increased with the increase of the strain rates (Reis et al., 2018).

A flexural properties of pultruded continuous glass fiber reinforced PA6 composites with different fiber contents of 50wt%, 60wt%, and 70wt% were investigated by using a universal testing machine (KXWW-20C, Taiding test, Chengde, China) with followed ASTM D790 (80 mm x 10 mm x 4 mm) and span size of 64 mm. The obtained results showed that flexural strength and flexural modulus increased as the fiber content is increased. This is because glass fiber as a reinforcement plays a major role in the mechanical properties of composites. The fiber dispersion of pultruded composites were observed under scanning electron microscopy and as the fiber content is increased, the fibers dispersed more evenly and denser from 50 wt% to 70 wt%. The microstructure of pultruded continuous glass fiber reinforced PA6 composites also showed almost no void as the fibers content up to 60 wt% and 70 wt% (Figure 2.6) (Chen et al., 2019). Electron microscopy is used to analyse the fracture surface of the specimen after the test and the crack path of the fracture specimen is subjected to interrupted fatigue test (Belmonte et al., 2017). There are two recommendations in observation of fracture specimens that are fracture surface and side surface of the specimen with their own advantages and disadvantages. The mechanism of damage reported in fatigue testing can be the effect of fracture surface specimens.

In addition, the third component, maleic anhydride grafted polypropylene (PP-g-MAH) is investigated and the relationship between compounding sequence and the properties of aminosilane-treated glass fiber-reinforced PA66 composite is studied and shows different mechanical properties. There are four different types of sample preparation of glass fiber-reinforced PA66 composite which are PA66/GF composite which was prepared by using twin screw extruder (S0), PA66, PP-g-MAH, and GF were also prepared by using twin screw extruder (S1), for (S2), PA66 and GF are mixed together first in twin screw extruder and then are mixed again with PP-g-MAH for the second time, and lastly for (S3), PP-g-MAH/GF mixture were mixed PA66 by using twin screw extruder. After that, all composites were fabricated using an injection molding machine. The mechanical tests were investigated by using universal tensile tester (AGX, Shimadzu) and followed ASTM D638 for tensile test and ASTM D790 for a flexural test with a crosshead speed of 5 mm/min. Figure 2.7 shows all mechanical test results obtained from the investigation.

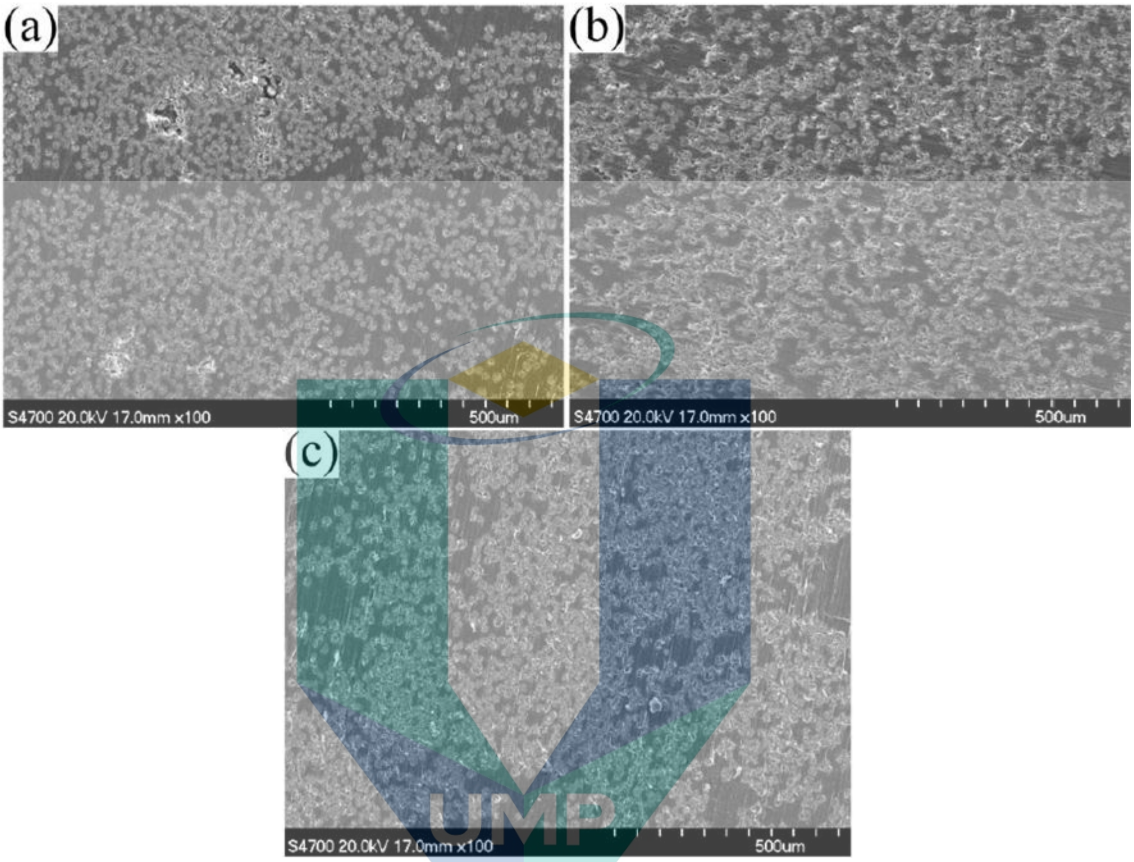



Figure 2.6 SEM micrograph of the pultruded continuous glass fiber reinforced PA6 composites: (a) 50wt% glass fibers, (b) 60 wt% glass fibers, and (c) 70 wt% glass fibers

Source: Chen et al. (2019)

The tensile strength of S1 and S2 shows a decrease result if compared to S0 and an increased result at S3. For the tensile elongation of various compounded composites shows a similar elongation at S1 and S0 but increase tensile elongation at S2 and S3. For flexural strength obtained a result is a decrease value at S1 and S2 but increase at S3 more than at S0. Both tensile and flexural strength at S3 shows a higher result than at S1 and S2. The impact strength of S1 is lower than S0, but then gradually increased results at S2 and S3. As a conclusion, the compounding sequence of GF/nylon-6,6 composite improved the mechanical properties as shown at the results that S3 showed good mechanical properties compare to S0, S1, and S3 (Mun et al., 2019).

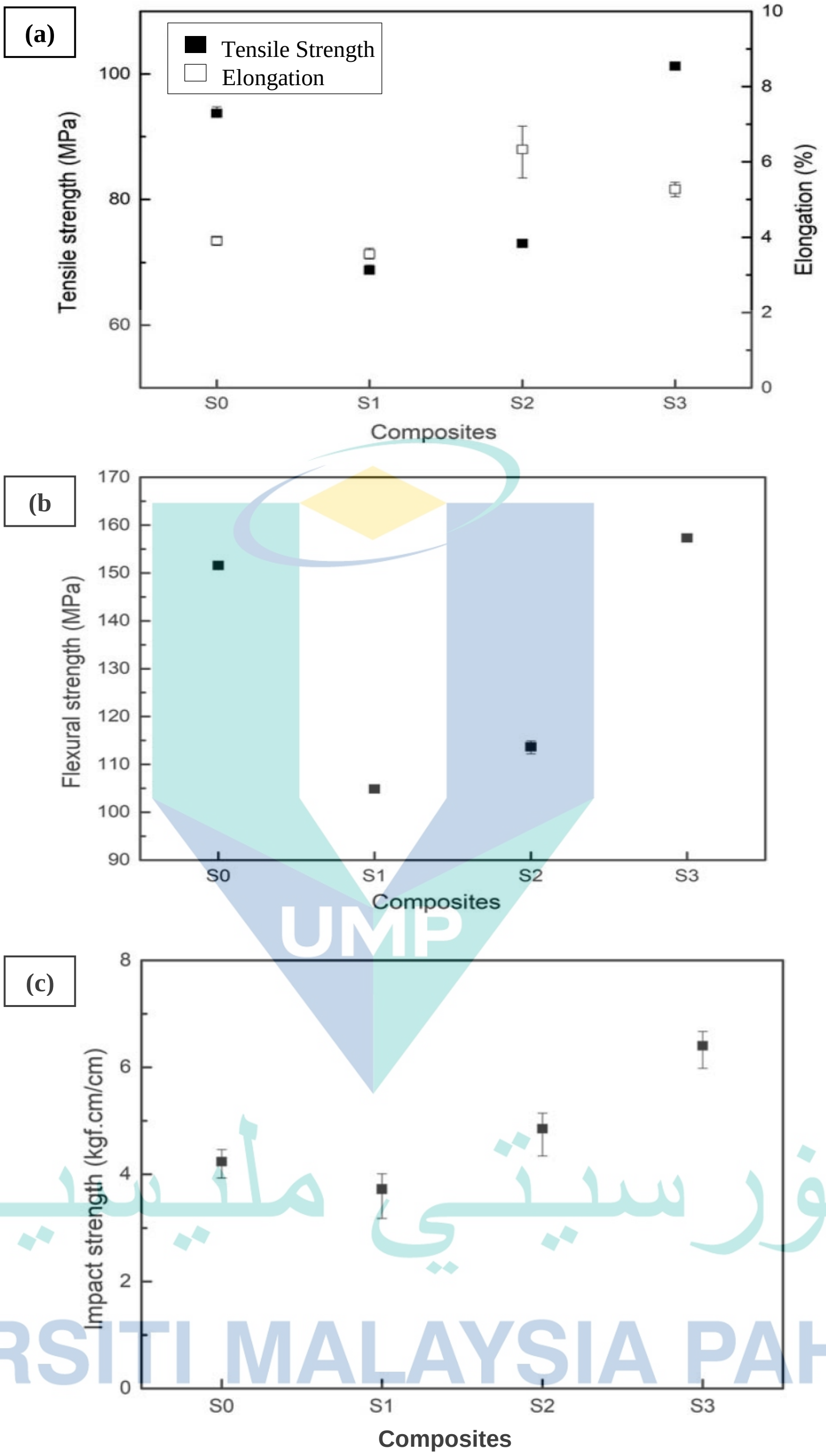



Figure 2.7 (a) Tensile strength (MPa) and tensile elongation (%) of composite, (b) Flexural strength (MPa) of composite, and (c) Impact strength (kgf.cm/cm) of composite

Source: Mun et al. (2019)

The mechanical properties of glass fiber/silicon carbide (SiC) reinforced epoxy composite was investigated and two different compositions of SiC used in the research study; 2% and 4%. The tensile strength result of glass fiber/SiC reinforced polymer composite shows a decreased strength as the composition of SiC is increased. The decreased in tensile strength because of the hardness and brittleness of SiC filler material that makes the composites become brittle fracture behavior. But the other mechanical test results of bending strength, compressive strength, and hardness strength of GFRP composite obtained an increased result as the SiC filler is increased (Sharma et al., 2018). Other than that, the influence of different moisture content of dry, 2%, and 4-5% on the tensile properties of short glass fiber reinforced polyamide 6 (SGFR-PA6) with different fiber contents of 10wt% and 50wt% were studied. Dog-bone-shaped specimens of SGFR-PA6 with dimensions of (170 mm x 20 mm x 4 mm) were fabricated by using injection molding. Instron 8501 universal test machine was used for tensile testing with followed ASTM D638 for each combination of different glass fiber contents and moisture contents.

The stress-strain graph of SGFR-PA6 with a different glass fiber content of 10wt% and 50wt% and moisture content of 0% until 5% is shown in Figure 2.8. The tensile modulus, yield strength, and tensile strength obtained a decrease in results as the moisture contents are increased for both 10wt% and 50wt% glass fiber contents. The highest tensile strength is 192.77 MPa at the dry condition with 50wt% glass fiber content while the lowest tensile strength is 47.69 MPa at 5% moisture content with 10wt % glass fiber content. The tensile behavior is observed to be related to the plasticization of water molecules in polyamide 6 material because of hydrogen bond from polyamide may bind with water molecules and decreased the tensile properties of SGFR-PA6 (Ibáñez-Gutiérrez et al., 2019).

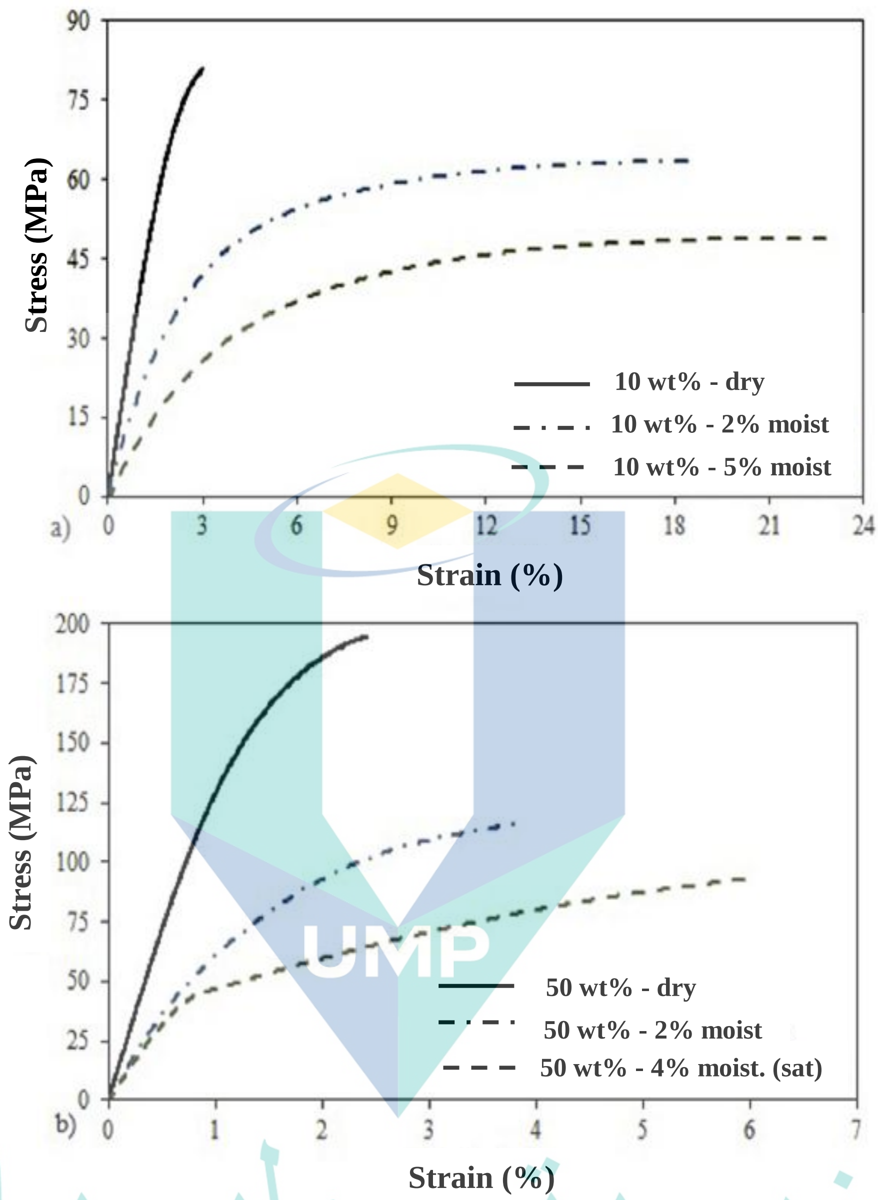



Figure 2.8 Stress-strain graph of SGFR-PA6 with glass fiber content of 10wt% and 50wt%

Source: Ibáñez-Gutiérrez et al. (2019)



## 2.4 Summary

The combination of polymer and fiber could improve the mechanical properties of the polymer composite such as high resistance to failure, high strength, high strength-to-weight ratio, high modulus of elasticity, etc. Glass fiber reinforced polymer (GFRP) composites have the ability properties to meet wide-ranging performance specifications because of the good properties of glass fiber that specifically to enhance the strength and stiffness of polymer. In preparing the GFRP composites, there are many processing techniques to fabricate the composites into a specimen such as compression molding, hot press, extrusion, injection molding, etc. Nowadays, the injection molding machine is used to be the most efficient manufacturing technique because of its high efficiency of production, low cost, and high production speeds. The important factors of choosing the right manufacturing technique in producing good polymer composites products are because to get good dispersions and orientation of fibers in the polymer composites. The fiber reinforced composite mechanical behavior depends on the strength of the fiber and the modulus, the chemical stability, the strength of the matrix, and the bond between the fiber/matrix allowing stress transfer. The mechanical properties of GFRP composites can be determined under tensile, flexural, and impact tests. The mechanical properties of GFRP composites showed either an increase or decrease in mechanical properties when the strain rates applied are increased. The GFRP composites also showed either ductile or brittle behavior when the glass fiber contents are increased. The fracture surface of GFRP composites after tests is analyzed under electron microscopy. The pultruded of fiber or fiber pull-out and interfacial bonding between glass fiber and polymer matrices can be seen under the electron microscopy. Lastly, the polymer composites properties would contribute to the industrial applications for example; use in higher performance in automotive applications such as inlets, intake manifolds, automotive bumpers, valves, etc.

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

This methodology represents an essential role in completing this research study correspondingly. The material preparation is needed before fabricating a dog-bone-shaped specimen of glass fiber reinforced polyamide 6-polypropylene composites. Pellets of polyamide 6, polypropylene, and glass fiber are measured in weight for a different composition (Appendix A). Five composition was used in this study; 70%PA6+30%PP polymer blend, 65%PA6+30%PP+5%GF composite, 60%PA6+30%PP+10%GF composite, 55%PA6+30%PP+15%GF composite, and 50%PA6+30%PP+20%GF composite. The percentage composition was determined so that the total percentage of PA6-PP-GF composite used was one hundred percent. The composition of polyamide 6 was gradually reduced from 70% to 50% when the composition of glass fiber was increased by 20%, while the composition of polypropylene is constant at 30% in order to maintain the high density of polypropylene in the PA6-PP-GF composites. The minimum composition of PA6 used in the PA6-PP-GF composites was 50% because if the PA6 composition used was less than 50%, the high ductility of PP will result in low impact strength for the PA6-PP-GF composites. The highest composition of GF used in PA6-PP-GF composites was 20% because if more composition of GF were used, the composites are impending to brittle which will result in low ductility composites. The different glass fiber content in PA6-PP-GF composites made many improvements in this research. There are different mechanical operating conditions for tensile, flexural, and impact testing were used which is from a low rate to high rate in this research. The materials then were mixed and injected into the injection molding machine to produce the specimens. The influence of fiber reinforcement on the mechanical properties of PA6-PP-GF composites under different operating conditions was investigated. The mechanical properties of glass fiber reinforced PA6-PP composites results reported were averages of at least three measurements to ensure the reliability of the results and the average values of these results were taken into consideration (Durairaj et al., 2016).

For experimental, tensile testing of the PA6-PP-GF composites specimen was carried out using an Instron Universal Testing Machine (Model 3369)-ASTM D638 and different strain rates used were 2 mm/min, 6 mm/min, and 10 mm/min. Tensile properties such as tensile modulus, yield strength, tensile strength, fracture strength, and elongation at break were investigated for different types of PA6-PP-GF composites. Flexural test also was carried out by using Instron Universal Testing Machine (Model 3369)-ASTM D790 with different strain rates; 2 mm/min and 4 mm/min. The impact test was carried out by using Instron CEAST 9050 Impact Pendulum and followed Izod Impact (Unnotched) ASTM D4812 for different types of PA6-PP-GF composites. 11J of hammer energies was used for impact testing and different torques were applied for tightening the PA6-PP-GF composites specimen; 4N.m and 5N.m. Then, the microstructure observation of the fractured specimens was performed by Scanning Electron Microscopy (SEM) to study the fracture behavior of fractures on different types of PA6-PP-GF composites under tensile and impact tests. It is expected that different compositions of glass fiber reinforcements in the polymer composites will produce a significant impact on the properties of the composites which in turn will affect the behavior of the mechanical components in industrial applications.

## 3.2 Research Methodology

The flowchart for the preparation and characterization of PA6-PP-GF composites (Figure 3.1) of this research study showed the flow of investigating the mechanical of glass fiber reinforced polymer composites under different operating operations. The sequence of this research study is start from collecting material of polyamide 6, polypropylene, and glass fiber pellets for the fabrication of dog-bone-shaped specimens by using injection molding process. Then, the investigations of PA6-PP-GF composites were carried out with tensile, flexure, and impact tests. Lastly, the fractured specimens of PA6-PP-GF composites were observed by using SEM micrograph.

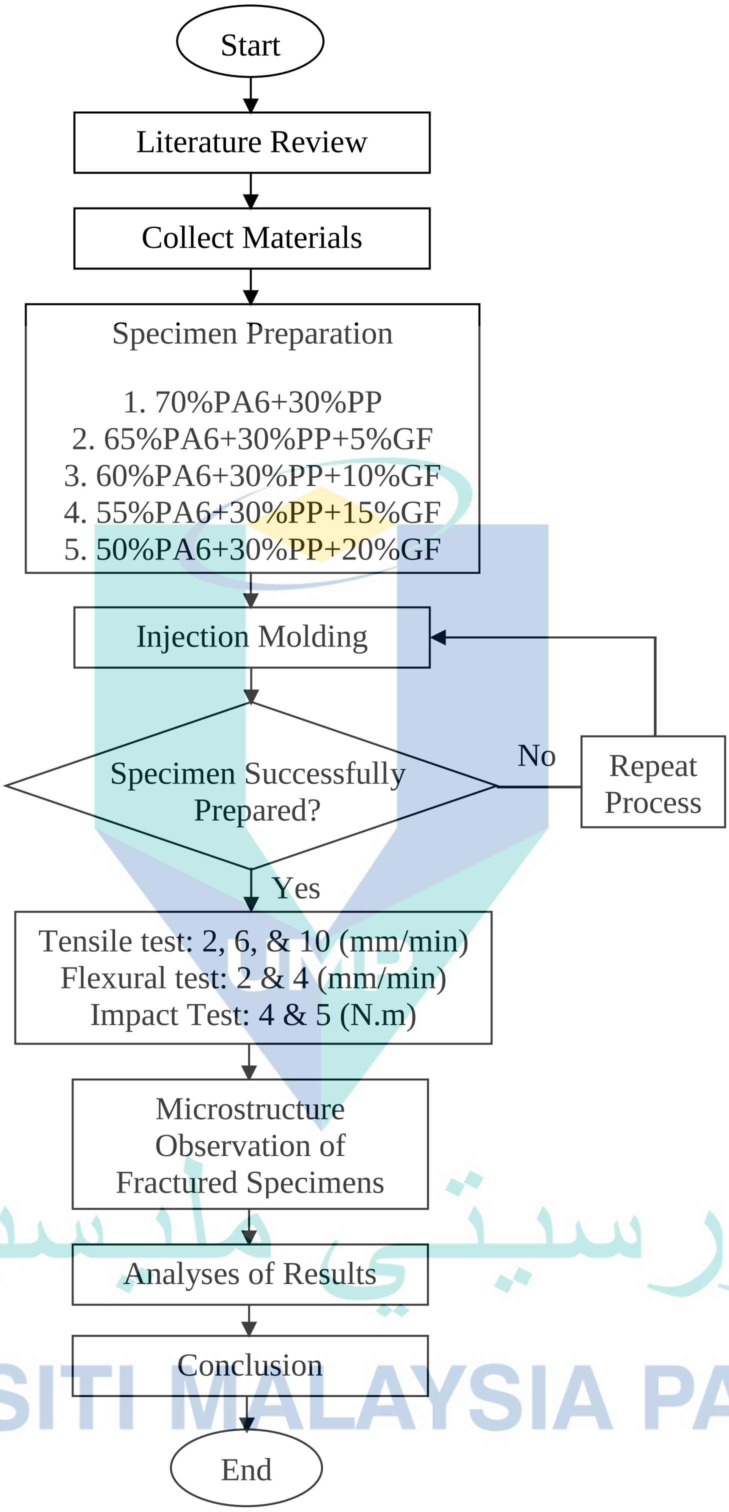



Figure 3.1 Flowchart for the preparation and characterization of PA6-PP-GF composites

## 3.3 Injection Molding Process

Injection molding machine is a type of machine in which convert a pellets/granules of plastic into the desired shape by applying heat and pressure. In this machine, a material is fed into the hopper and goes through the heated barrel, mixed and forced into the mold cavity where it cools and hardens to the configuration of the cavity. Figure 3.2 shows the injection molding machine that was used in carried out this study.

### 3.3.1 Procedure

1. The pellets of plastic material were inserted into the hopper.
2. The barrel starts to be heated and the screw thread began to rotate.
3. A screw thread starts to push the pellets along the heater and the pellets were melted into a liquid.
4. The screw thread was moved forward to inject melted pellets into the mold cavity.
5. The specimen was cooled and solidified in the mold cavity.
6. The mold cavity was then opened and the specimen removed.

Table 3.1 shows detail on the temperature used for different compositions of glass fiber reinforced PA6-PP composites. The full parameter of the injection molding machine is stated in Appendix B. The differences of temperature used followed a melt-temperature range that suitable for each material properties of plastics as shown in Figure 2.2 in Chapter 2 (Klein, 2011). The melt-temperature range for polyamide 6 (PA6) shown is from 210˚C until 290˚C and melt-temperature for polypropylene (PP) are from 175˚C until 300˚C.The melt-temperature range for PA6-PP-GF composite was determined as shown in Table 3.1 were based on Figure 2.2 and the melt-temperature range used in the previous study for PA6-GF composites were 210˚C to 255˚C (Nuruzzaman et al., 2016). Figure 3.3 shows dog-bone-shaped specimens of glass fiber reinforced PA6-PP composites after the injection molding process.

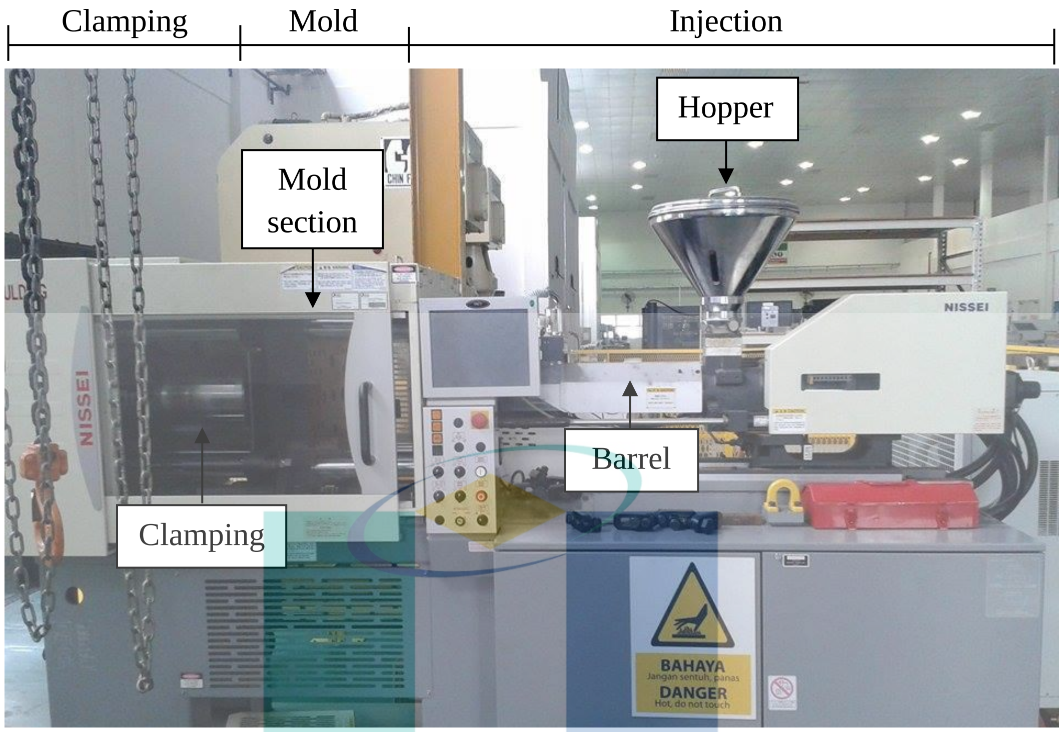



Figure 3.2 FKP Injection Molding Machine

Table 3.1 Temperature used for material composition of polymer composites

| **Material Composition** | **Temperature (˚C)** | | | | |
|---|---|---|---|---|---|
| | **Nozzle** | **Head** | **Front** | **Middle** | **Rear** |
| 70%PA6+30%PP | 238 | 233 | 228 | 223 | 219 |
| 65%PA6+30%PP+5%GF | 241 | 236 | 231 | 226 | 221 |
| 60%PA6+30%PP+10%GF | 247 | 242 | 237 | 232 | 227 |
| 55%PA6+30%PP+15%GF | 253 | 248 | 243 | 238 | 233 |
| 50%PA6+30%PP+20%GF | 259 | 254 | 249 | 244 | 239 |

## 3.4 Mechanical Testing

The mechanical properties of glass fiber reinforced PA6-PP composites were determined by several mechanical testing such as tensile test, flexural or bending test, and impact test. The results reported were averages of at least three measurements to ensure the reliability of the results and the average values of these results were taken into consideration (Durairaj et al., 2016).

### 3.4.1 Tensile Test

The tensile properties of glass fiber reinforced PA6-PP composites were determined using Universal Testing Machine (UTM) 3369 at three different strain rates of 2 mm/min, 6 mm/min, and 10 mm/min. The tensile test followed a standard test method to determine tensile properties of unreinforced and reinforced plastic in dog-bone-shaped specimens that was known as ASTM D638 and an extensometer was used in this tensile test (ASTM D638-02a, 2002). The extensometer automatically records changes in length during the test (Pisharath and Wong, 2003). Figure 3.4 (a) shows Universal Testing Machine (UTM) 3369 and (b) shows Bluehill 2 software for generating the results.

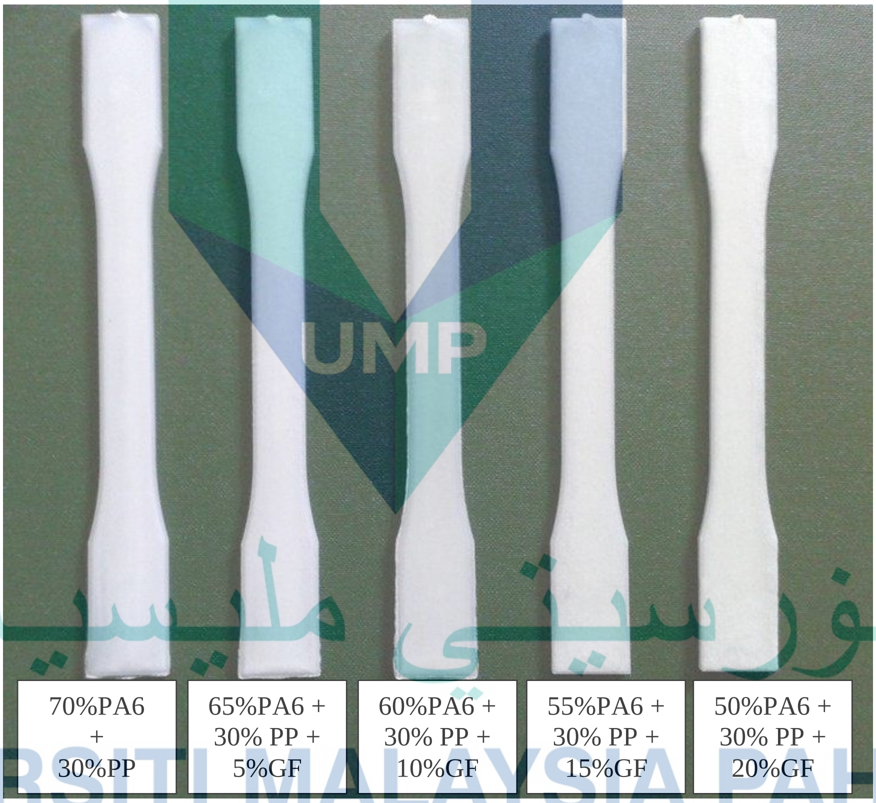



Figure 3.3 Dog-bone-shaped specimens of glass fiber reinforced polyamide 6-polypropylene composites

#### 3.4.1.1 Procedure

1. The Universal Test Machine was powered on and the Bluehill 2 software was opened from the desktop icon.

2. Test methods such as specimen parameters, strain rate, and type of graphs were formed before performing mechanical tests.

3. The specimen was placed vertically between the grips of the test machine and the calibrated extensometer was clamped on the test specimen as it is used to measure changes in test specimen length.

4. The test then was started by the upper grips moving according to the specified pulling rate and stress-strain graph was generated from the Bluehill software during the experiment.

5. The machine was automatically stopped once it detects the specimen was broken.

6. The broken specimen was removed and the steps were repeated for any additional tests.

7. The programme was exited and the machine was switched off after the test has been completed.

### 3.4.2 Flexural/Bending Test

The flexural properties of glass fiber reinforced PA6-PP composites were determined using Universal Testing Machine (UTM) 3369 with three-point bending fixture (Figure 3.5) at two different strain rates of 2 mm/min and 4 mm/min. The flexural test followed a standard test method for unreinforced polymer and reinforced polymer bending properties; ASTM D790 (ASTM D790-03, 2003).

#### 3.4.2.1 Procedure

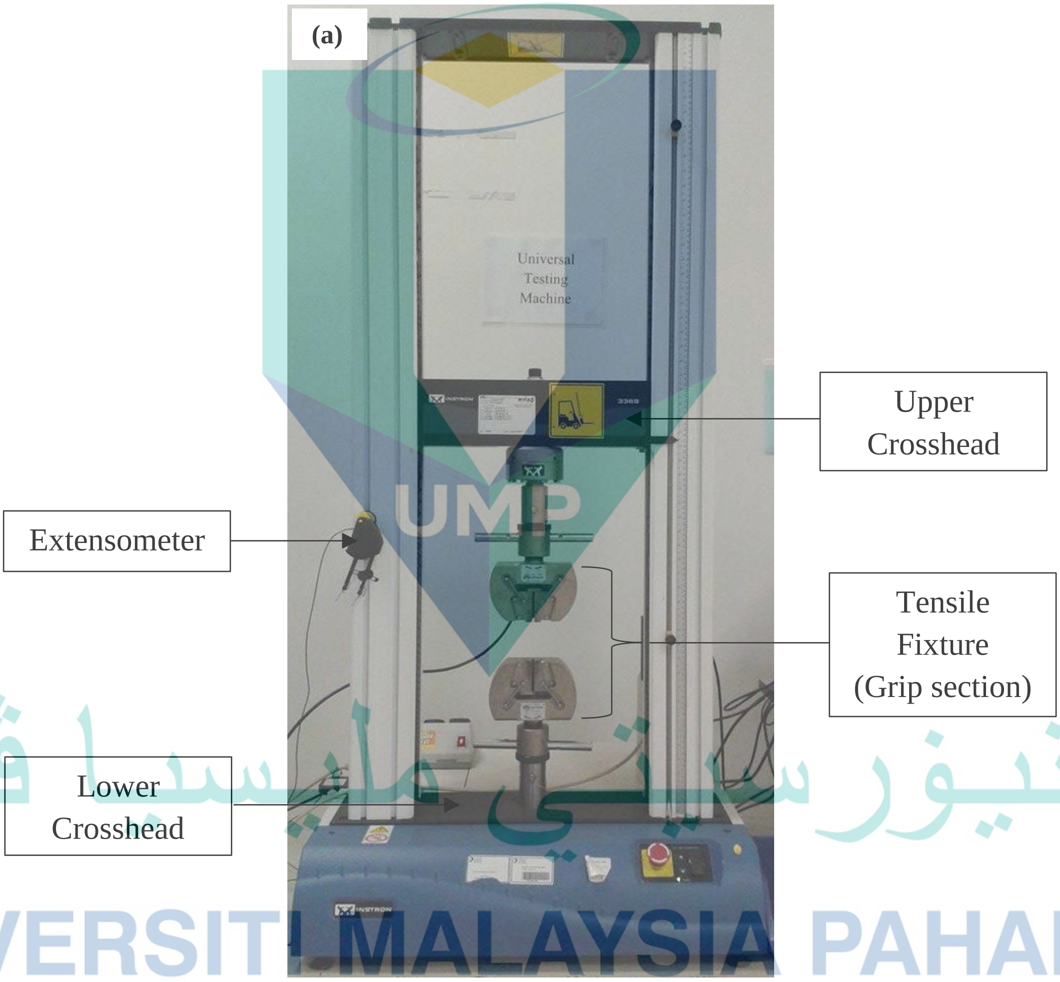
1. The Universal Test Machine was turned on and the Bluehill 2 software was opened from the desktop icon.

2. Three-point bending fixtures were set on the test machine and the specimen was placed on two supporting pins at a specified distance.

3. The flexural test began and the loading pin moves towards the specimen until the specimen was deflected until a breaking point occurs on the outer surface of the test specimen.

4. Stress-strain graph was generated from Bluehill software during the experiment and the previous steps were repeated for any additional tests.

5. The machine was switched off after the test was completed.



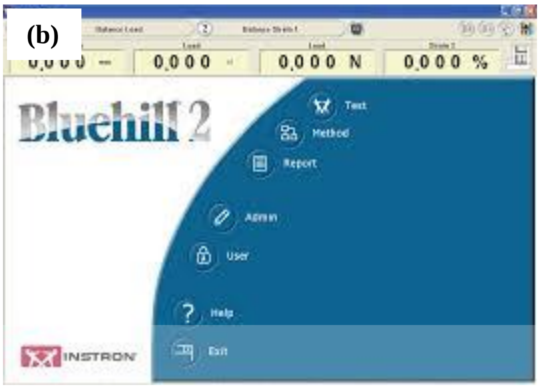



Figure 3.4 (a) Universal Testing Machine (UTM) 3369 and (b) Bluehill 2 Software


Figure 3.5 Three-point Bending Fixture

### 3.4.3 Izod Impact Test (Unnotched)

The impact properties of glass fiber reinforced PA6-PP composites were determined using a CEAST 9050 Impact Pendulum testing machine (Figure 3.6) at two different torque of 4 N.m and 5 N.m. The impact test followed a standard test method for unnotched cantilever beam impact resistance of plastic as it shows the energy extracted from a standard pendulum hammer that works in breaking down a specimen with one pendulum swing; ASTM D4812 ( ASTM D4812-99, 1999). The torque meter shown in Figure 3.7 is used to tighten the specimens at the specimen support with a designated torque.

#### 3.4.3.1 Procedure

1. The impact test machine was powered on and the specimen was clamped to the pendulum impact test fixtures with the thin edge facing the striking edge of the pendulum.
2. Torque meter was used to tighten specimens with specific torque values.
3. The pendulum was released and allowed to strike through the specimen.
4. The machine was switched off after the test was completed.

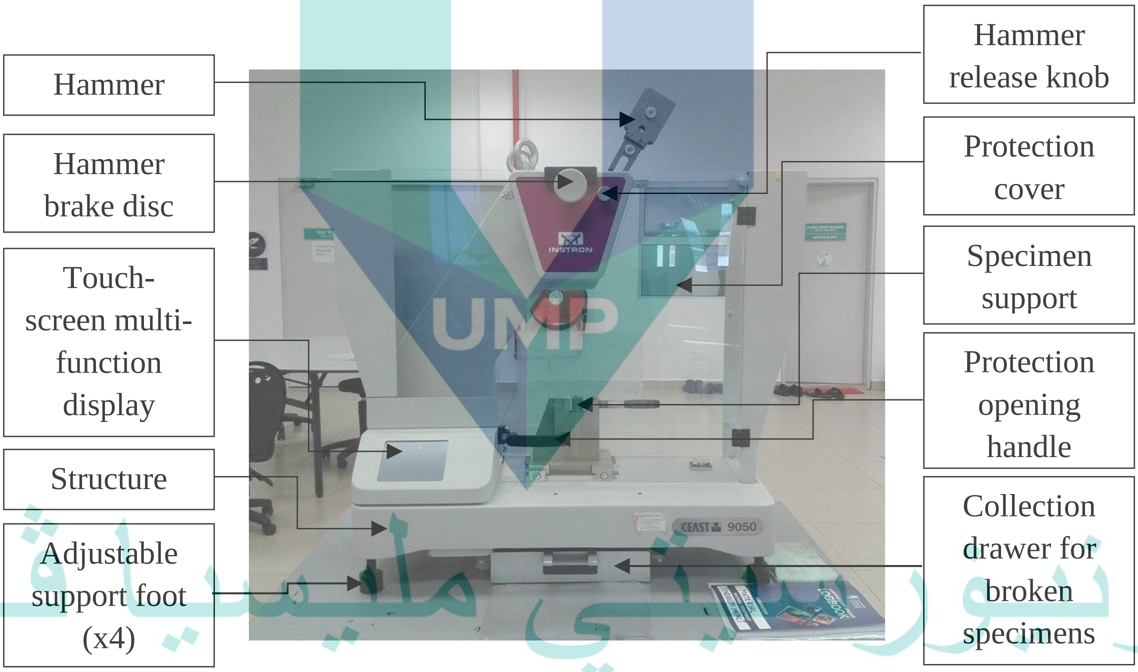



Figure 3.6 CEAST 9050 Impact Pendulum



Figure 3.7 Torque Meter

## 3.5 Characterization of Fractured Specimen

Scanning Electron Microscopy (SEM) with Energy Dispersive X-Ray Analysis (EDX) was used in this research studies. SEM provides detailed high-resolution images by launching an electron beam that was focused on the entire surface and detects secondary or backscattered electronic signals. An Energy Dispersive X-Ray Analyzer (EDX) was also used to identify elemental compositional information. Due to its high density and simple image interpretation and easy sampling, SEM is the preferred technique for viewing sample details at a resolution far beyond the optical microscope. The SEM image clearly displays the three-dimensional properties of the object's surface under examination. Fracture specimens of PA6-PP-GF composites from tensile and impact test with different crosshead speeds were examined to differentiate changes in failure mode. The fracture specimens were cut to about 10 mm from the fracture region to fit the height size of SEM's specimen chamber. The samples then were put on a sample holder and being coated with a platinum-coated to prevent charge build-up by the electron absorbed by the samples. The purpose of sample coating is because a nonconductive specimen collects the charge when it is scanned in an electron beam, particularly in secondary electronics imaging mode, which can cause a not good scanned image (Suzuki, 2002). In the SEM observation, the surface of the specimen is scanned with an electron beam and the defeated electron beams are collected and displayed at the same scanning rate. The screen images are photographed.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Introduction

Mechanical tests play an important role in assessing the basic properties of engineering materials, in the development of new materials, and in quality control of materials for use in the industrial application. Materials used as part of the engineering design structure need to know their ability or strength to withstand loads before being manufactured and marketed. The most common types of tests used to measure the mechanical properties of a material are the tensile test, flexural test, and impact test. The mechanical properties of glass fiber reinforced PA6-PP composites results reported were averages of at least three measurements.

The order of this chapter begins with a tensile test result analysis for different strain rates of 2 mm/min, 6 mm/min, and 10 mm/min. The comparisons among the tensile properties of these 3 different strain rates are discussed. Then, followed by flexural test results analysis for 2 mm/min and 4 mm/min strain rates. The impact test results under 4 N.m torque and 5 N.m torque are shown in the next section of this chapter and the SEM micrographic of fractured specimens for tensile and impact tests are analysed and discussed. Lastly, observations EDX analyses are included to prove the element identification of PA6-PP-GF composites.



## 4.2 Tensile Test Results Analyses

Tensile testing is widely used to provide information about the basic design and material strength that constitutes acceptance test specifications. Several material properties can be determined by simply measuring the force required to pull the specimen to the point of breaking. As mentioned in Chapter 3, Universal Testing Machine (UTM) was used to determine the tensile properties and an Instron's Bluehill software was used to control, monitor test, collect data, analyse, calculate results, produce graphs, and generate details data. The tensile test was followed ASTM D638. Three different strain rates were used in this tensile testing: 2 mm/min of low strain rate, 6 mm/min of medium strain rate, and 10 mm/min of high strain rate. Five different compositions of polymer composite were investigated and the stress-strain graphs were plotted (Figure 4.1, 4.2, and 4.3). The fracture specimens for different strain rates used for the tensile test are shown in Figure 4.4, 4.5, and 4.6. The PA6-PP polymer blend specimen showed incomplete fracture compared to the PA6-PP-GF composites but the PA6-PP polymer blend specimen had a fracture inside the specimen.

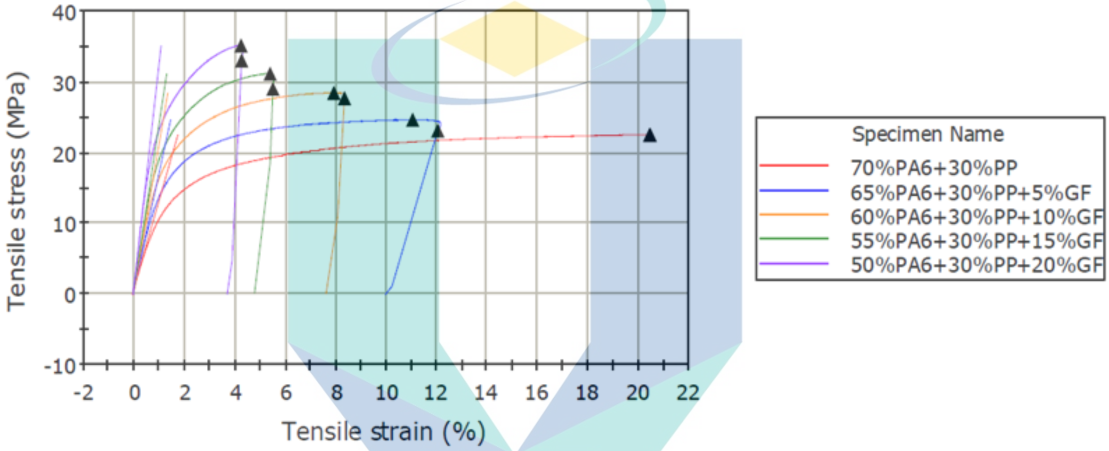



Figure 4.1 Stress-strain curve of glass fiber reinforced PA6-PP composites under strain rate of 2 mm/min

Figures 4.1, 4.2, and 4.3 show the stress-strain curve of PA6-PP-GF composites with strain rates of 2, 6, and 10 mm/min respectively. From the graphs, 70%PA6+30%PP polymer blend experiences a uniform extension curve from start until failure for all different strain rates because of their high ductility. The stress-strain curve for 65%PA6+30%PP+5%GF composite, 60%PA6+30%PP+10%GF composite, 55%PA6+30%PP+15%GF composite, and 50%PA6+30%PP+20%GF composite were experienced less elongation until failure as the glass fiber content is increased and the PA6-PP-GF composites become less elasticity. 50%PA6+30%PP+20%GF composite has the highest tensile properties but the lowest elongation as it becomes less ductility as compared to the other composites. As a conclusion, the tensile properties of glass fiber reinforced PA6-PP composites increased as the percentage of fibers increased at 3 different strain rates. The tensile properties of glass fiber reinforced PA6-PP composites such as tensile modulus, yield strength, tensile strength, fracture strength, and elongation at break are tabulated in Table 4.1, 4.2, and 4.3 for strain rates of 2, 6, and 10 mm/min respectively. The results reported are averages of at least three measurements as mentioned in Chapter 3. Tensile properties of each specimen are discussed in these following graphs.

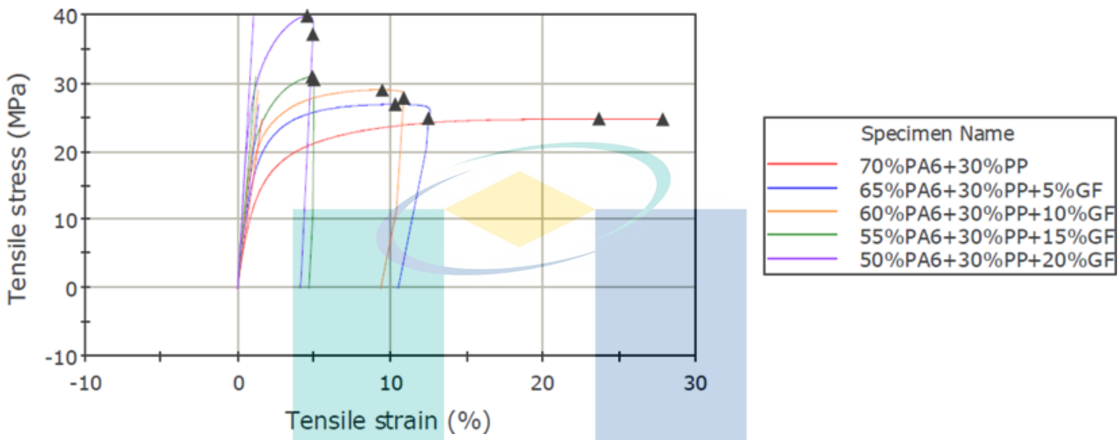



Figure 4.2 Stress-strain curve of glass fiber reinforced PA6-PP composites under strain rate of 6 mm/min

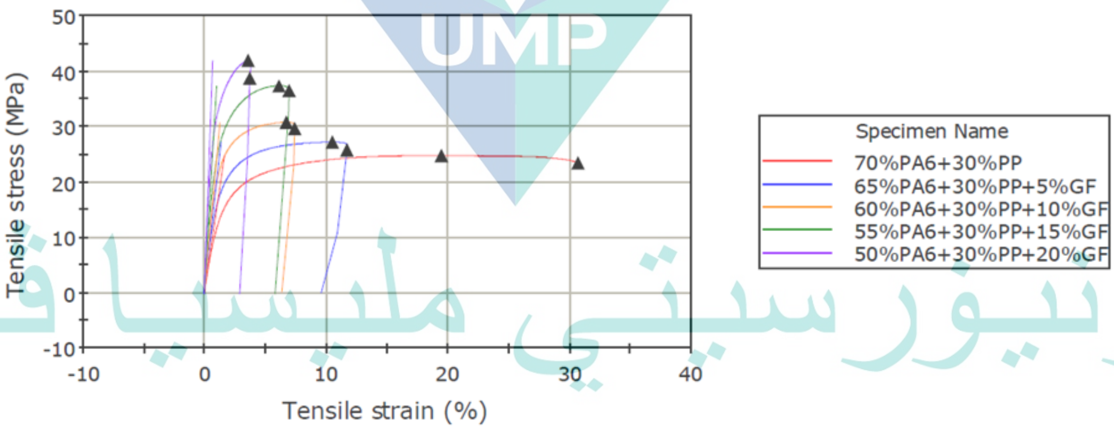



Figure 4.3 Stress-strain curve of glass fiber reinforced PA6-PP composites under strain rate of 10 mm/min

The average tensile modulus of glass fiber reinforced polyamide 6-polypropylene composites under strain rates of 2, 6, and 10 mm/min is shown in Figure 4.7. The tensile modulus value of the material defines how it holds elastic deformation, which occurs when the force is applied to the substance that causes its shape to change. The tensile modulus trend for all strain rates shows an increasing result from

70%PA6+30%PP polymer blend until 50%PA6+30%PP+20%GF composite. The result of the neat polymer blend shows a low tensile modulus of 1.32 GPa at 2 mm/min, 1.61 GPa at 6 mm/min, and 1.52 GPa at a 10 mm/min strain rate. The trend for tensile modulus at 6 mm/min strain rate shows the highest compared to others. The same goes for the 65%PA6+30%PP+5%GF composite that shows the highest tensile modulus of 2.04 GPa at 6 mm/min while at 2 mm/min and 10 mm/min strain rates were 1.88 GPa and 2.02 GPa respectively.

Table 4.1 Average Results of Tensile Test (Strain rate of 2 mm/min)

| **Strain Rate of 2 mm/min** | | | | | |
|---|---|---|---|---|---|
| **Specimen Composition** | **Tensile Modulus (GPa)** | **Yield Strength (MPa)** | **Tensile Strength (MPa)** | **Fracture Strength (MPa)** | **Elongation at Break (%)** |
| 70%PA6 + 30%PP | 1.32 | 13.08 | 25.86 | 25.85 | 24.24 |
| 65%PA6 + 30%PP + 5%GF | 1.88 | 14.74 | 28.11 | 26.48 | 15.37 |
| 60%PA6 + 30%PP + 10%GF | 2.39 | 17.16 | 30.79 | 29.43 | 7.90 |
| 55%PA6 + 30%PP + 15%GF | 2.72 | 19.67 | 34.91 | 33.13 | 6.41 |
| 50%PA6 + 30%PP + 20%GF | 3.34 | 22.13 | 39.26 | 37.29 | 4.77 |

Table 4.2 Average Results of Tensile Test (Strain rate of 6 mm/min)

| **Strain Rate of 6 mm/min** | | | | | |
|---|---|---|---|---|---|
| **Specimen Composition** | **Tensile Modulus (GPa)** | **Yield Strength (MPa)** | **Tensile Strength (MPa)** | **Fracture Strength (MPa)** | **Elongation at Break (%)** |
| 70%PA6 + 30%PP | 1.61 | 16.82 | 29.06 | 28.01 | 37.64 |
| 65%PA6 + 30%PP + 5%GF | 2.04 | 19.42 | 31.59 | 29.92 | 13.72 |
| 60%PA6 + 30%PP + 10%GF | 2.51 | 19.55 | 34.04 | 32.58 | 9.76 |
| 55%PA6 + 30%PP + 15%GF | 2.90 | 20.59 | 36.33 | 35.47 | 5.10 |
| 50%PA6 + 30%PP + 20%GF | 3.78 | 26.18 | 42.67 | 40.50 | 4.80 |

Table 4.3 Average Results of Tensile Test (Strain rate of 10 mm/min)

| **Strain Rate of 10 mm/min** | | | | | |
|---|---|---|---|---|---|
| **Specimen Composition** | **Tensile Modulus (GPa)** | **Yield Strength (MPa)** | **Tensile Strength (MPa)** | **Fracture Strength (MPa)** | **Elongation at Break (%)** |
| 70%PA6 + 30%PP | 1.52 | 13.38 | 26.62 | 23.81 | 32.57 |
| 65%PA6 + 30%PP + 5%GF | 2.02 | 16.08 | 29.56 | 28.04 | 15.49 |
| 60%PA6 + 30%PP + 10%GF | 2.38 | 18.76 | 32.20 | 30.92 | 8.53 |
| 55%PA6 + 30%PP + 15%GF | 3.65 | 19.19 | 38.57 | 37.59 | 6.12 |
| 50%PA6 + 30%PP + 20%GF | 4.43 | 24.15 | 42.48 | 41.03 | 4.47 |

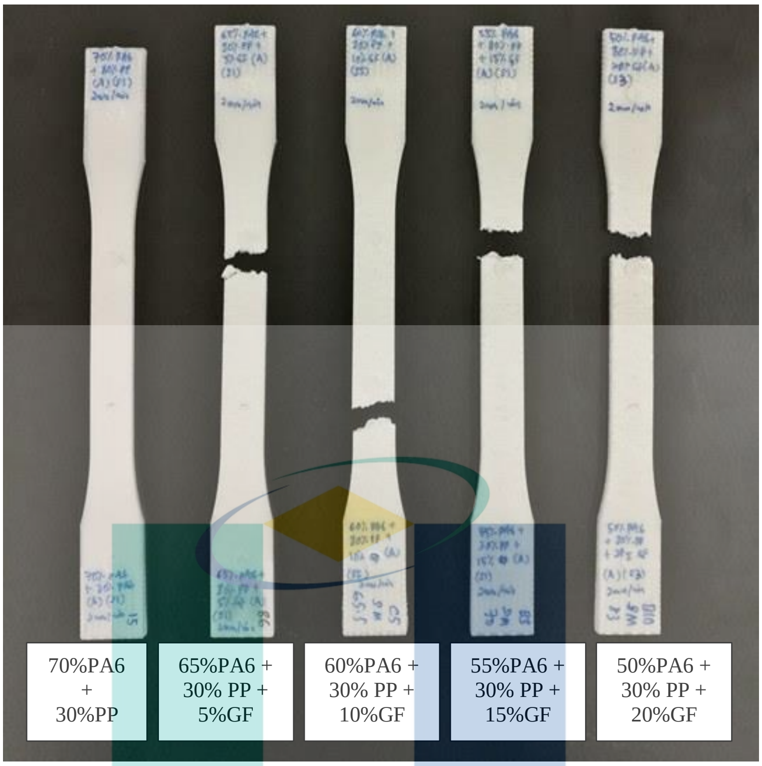



Figure 4.4 Fracture dog-bone-shaped specimens of tensile test under 2 mm/min strain rate

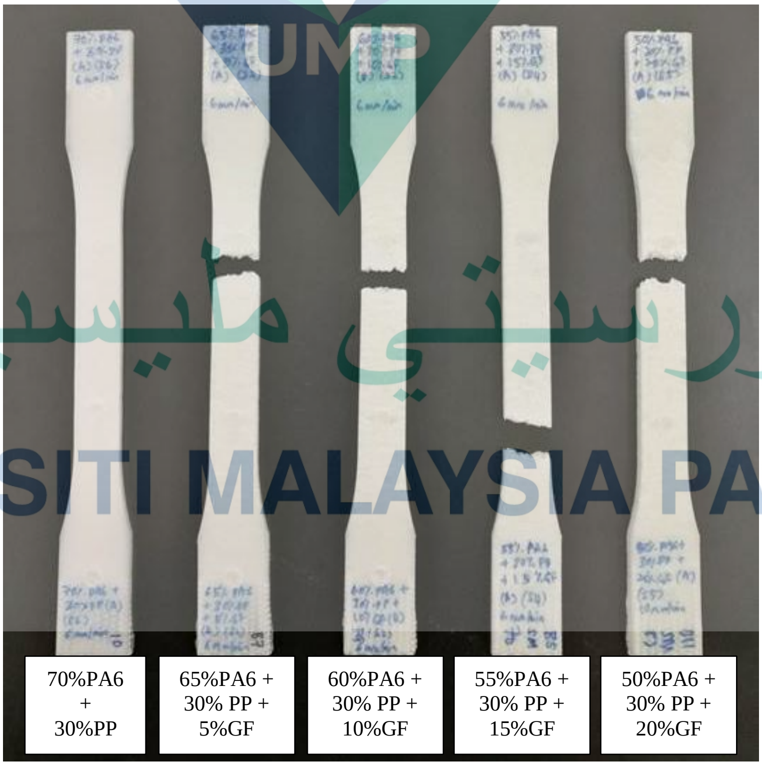



Figure 4.5 Fracture dog-bone-shaped specimens of tensile test under 6 mm/min strain rate

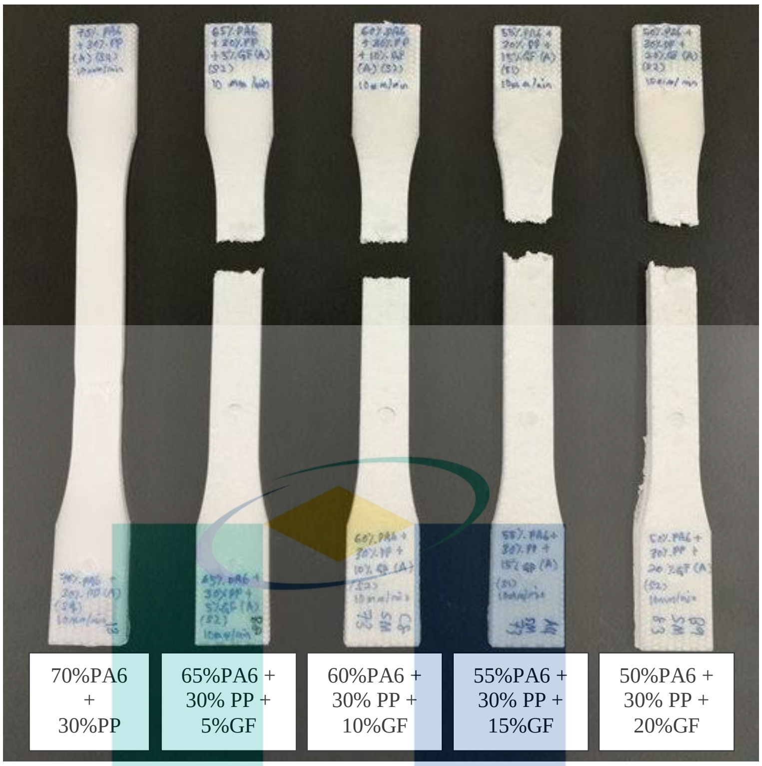



Figure 4.6 Fracture dog-bone-shaped specimens of tensile test under 10 mm/min strain rate

The 60%PA6+30%PP+10%GF composite shows an increased tensile modulus of 2.39 GPa under 2 mm/min strain rate. PA6-PP-GF composite under 6 mm/min strain rate shows an improved tensile modulus of 2.51 GPa and the PA6-PP-GF composite under 10 mm/min strain rate shows an increased modulus of 2.38 GPa. The tensile modulus of PA6-PP-GF composite with 10%GF under strain rate of 10 mm/min shows the lowest tensile modulus compared at 2 and 6 mm/min strain rates because of the reinforcement material cannot support the stress transmitted from the polymer matrix and maybe of micro-spaces between the bonding of glass fiber and polymer matrix, which is hindering the propagation of stresses when the tensile stress is applied and leads to increased brittleness (Yang et al., 2004). The tensile modulus of PA6-PP polymer blend and composites of PA6-PP-GF with 5%GF and 10%GF under strain rate of 10 mm/min showed a lower modulus compared at 6 mm/min strain rate because of 10 mm/min strain rate is the highest strain rate applied which make the PA6-PP-GF composites have been broken faster than at 2 and 6 mm/min strain rates and tensile modulus tends to increase with fiber loading at low load ratios, but decrease when the optimum value is reached (Goh et al., 2019). It concluded that the strain rate of 6 mm/min is the optimum loading rate that PA6-PP-GF composites can endure. For 55%PA6+30%PP+15%GF composite shows a further improved modulus of 2.72 GPa, 2.90 GPa, and 3.65 GPa at 2, 6, and 10 mm/min strain rates respectively. Finally, the tensile modulus for 50%PA6+30%PP+20%GF composite shows higher modulus of 3.34 GPa at 2 mm/min, 3.78 GPa at 6 mm/min, and 4.43 GPa at 10 mm/min. This reveals that as the glass fiber content increased, the tensile modulus of the polymer composites also improved (Yang et al., 2004).

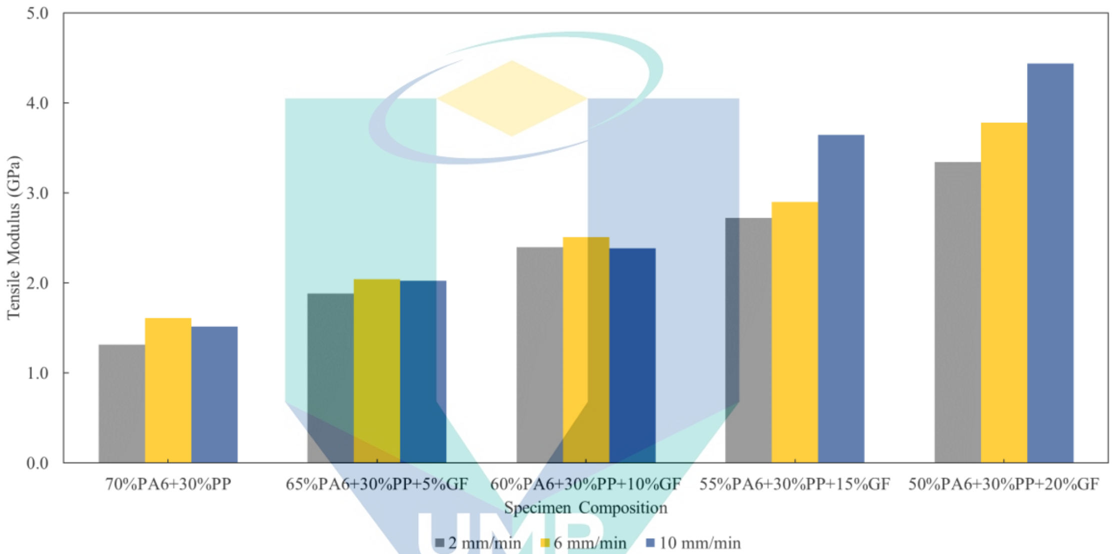



Figure 4.7 Tensile modulus (GPa) of glass fiber reinforced PA6-PP composites under 3 different strain rates

The average yield strength of glass fiber reinforced polyamide 6-polypropylene composites under 3 different strain rates of 2, 6, and 10 mm/min is shown in Figure 4.8. Yield strength is stress in which the material exhibits a certain permanent deformation and practical approximation of the elastic limit which means that the material begins to change plastically. The yield strength trend shows an incremented result from 70%PA6+30%PP polymer blend to 50%PA6+30%PP+20%GF composite for all strain rates. The strain rate of 2 mm/min shows the lowest yield strength of 13.08 MPa for 70%PA6+30%PP polymer blend but increased gradually up until 50%PA6+30%PP+20%GF composite with a yield strength of 22.12 MPa which is 69.11% higher than the neat polymer blend. The 70%PA6+30%PP polymer blend at a strain rate of 6 mm/min shows the highest yield strength of 16.82 MPa compared to other strain rates of 2 mm/min and 10 mm/min. The 50%PA6+30%PP+20%GF composite at a strain rate of 6 mm/min also shows the highest increment yield strength of 26.18 MPa which is 55.65% higher than the neat polymer blend. A 70%PA6+30%PP polymer blend at 10 mm/min strain rate shows a low yield strength of 13.38 MPa but reveals a further increase of 24.14 MPa for 50%PA6+30%PP+20%GF composite which is 80.42% higher than the neat polymer blend. The inconsistent yield strength of glass fiber reinforced polyamide 6-polypropylene composite that caused by a high strain rate of 10 mm/min caused the plastic deformation of PA6-PP-GF composites to occur faster than at 6 mm/min strain rate. Also, a higher glass fiber content at a higher strain rate leads to loss of the ductility of the PA6-PP-GF composites (Reynaud et al., 2001).

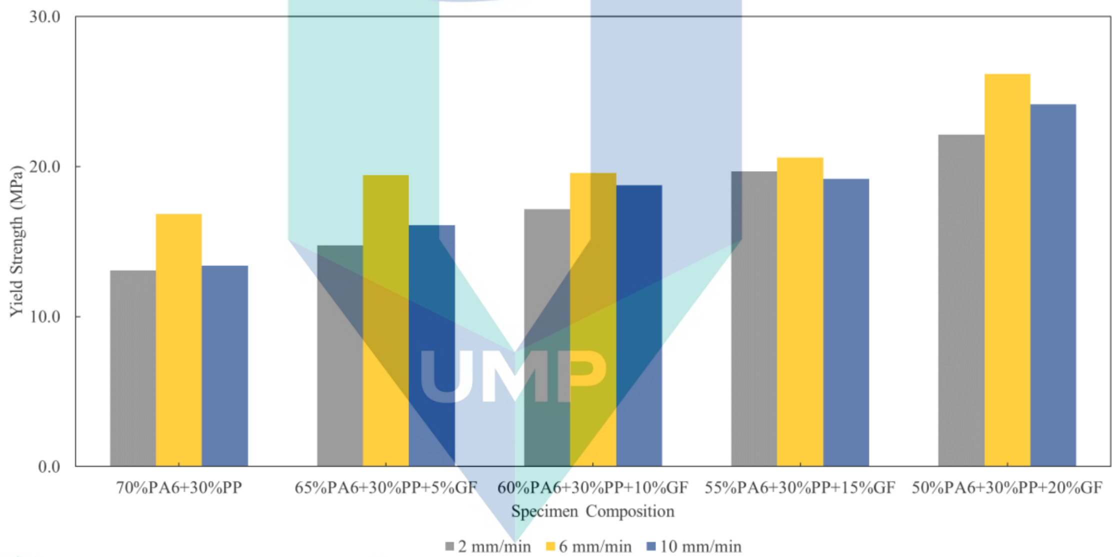



Figure 4.8 Yield strength (MPa) of glass fiber reinforced PA6-PP composites under 3 different strain rates

Figure 4.9 shows average tensile strength of glass fiber reinforced PA6-PP composites under 3 different strain rates. The tensile strength of the material is the maximum amount of stress that it can take before the failure, such as rupture or permanent deformation. The tensile strength trend shows an incremented result from 70%PA6+30%PP polymer blend to 50%PA6+30%PP+20%GF composite for all strain rates. The tensile strength of 70%PA6+30%PP polymer blend at 2 mm/min strain rate is 25.85 MPa and when the glass fiber content increased to 20%, the PA6-PP-GF composite strength increased to 39.26 MPa which is 51.88% higher than that of a neat polymer blend. The tensile strength of PA6-PP-GF composite under a strain rate of 6 mm/min also shows a further increase results. The obtained result of 70%PA6+30%PP polymer blend strength is 29.06 MPa. For PA6-PP-GF composite with 20% glass fiber content reveals further increased strength of 42.67 MPa which is 46.83% higher than the neat polymer blend.

Furthermore, the tensile strength of glass fiber reinforced PA6-PP composites at a 10 mm/min strain rate showed gradual increase results from 70%PA6+30%PP polymer blend until the PA6-PP-GF composite with a glass fiber content of 20%. The tensile strength of neat polymer blend shows at low strength of 26.62 MPa. Finally, 50%PA6+30%PP+20%GF composite attained 42.48 MPa which is 59.58% higher than the neat polymer blend. Despite the tensile strength of PA6-PP-GF composite with 20%GF under 10 mm/min strain rate is lower than the 6 mm/min strain rate due to the brittleness of 50%PA6+30%PP+20%GF composite, but it has higher tensile modulus compared at 2 mm/min and 6 mm/min (Figure 4.7).

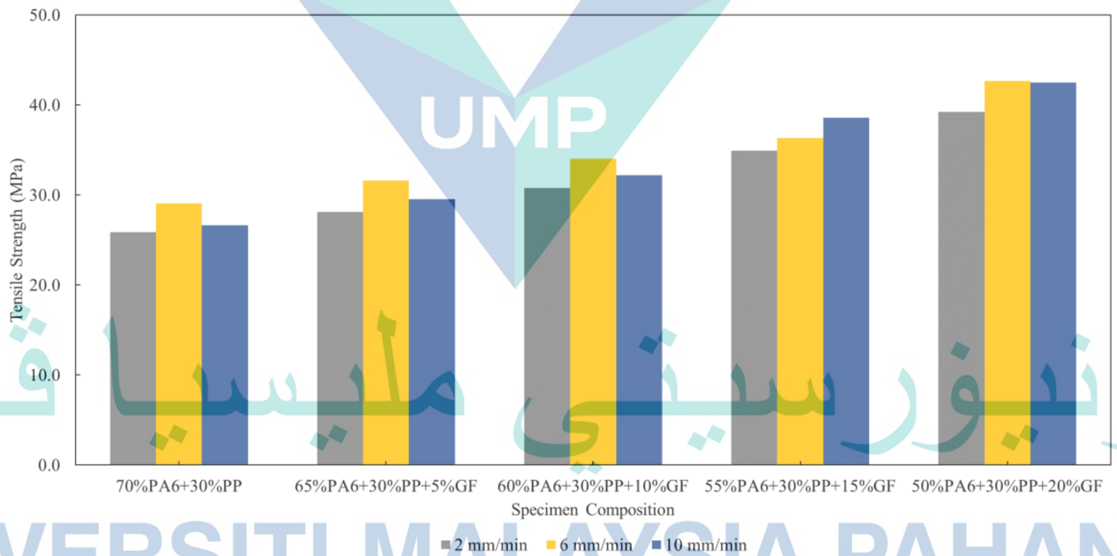



Figure 4.9 Tensile strength (MPa) of glass fiber reinforced PA6-PP composites under 3 different strain rates

PA6-PP-GF composite with 20%GF also shows a little ability to deform plastically before fracturing at a strain rate of 10 mm/min because of the high strain rate applied and the high stiffness of composite. As per the overall observation, the tensile strength of PA6-PP-GF composites increases and elongation at break (Figure 4.11) decreases as the glass fiber content increases according to expected trends (Yoo et al., 2011). This is because the addition of glass fibers into the polymer blend is in a good bond between the aggregate of the composite polymer mixture of PA6-PP-GF composite with 20%GF in Figure 4.15 (e).

Figure 4.10 reveals the average fracture strength of glass fiber reinforced PA6-PP composites under strain rates of 2, 6, and 10 mm/min. The trend of the result obtained was steadily increased from 70%PA6+30%PP polymer blend until 50%PA6+30%PP+20%GF composite for all three different strain rates. The fracture strength of neat polymer blend under a strain rate of 2 mm/min is 25.85 MPa. The obtained results of glass fiber reinforced PA6-PP composites under a strain rate of 2 mm/min shows the fracture strength of 26.48 MPa, 29.43 MPa, 33.13 MPa, and 37.29 MPa for the glass fiber content 5%, 10%, 15%, and 20%. For glass fiber reinforced PA6-PP composites under a strain rate of 6 mm/min shows fracture strength of 28.01 MPa, 29.92 MPa, 32.58 MPa, 35.47 MPa, and 40.50 MPa for the glass fiber content 0%, 5%, 10%, 15%, and 20% respectively. From the obtained result, 70%PA6+30%PP polymer blend at 10 mm/min strain rate shows the lowest fracture strength of 23.81 MPa but the 50%PA6+30%PP+20%GF composite reveals the highest fracture strength for of 41.03 MPa which is 72.32% higher than the neat polymer blend.

The fracture strength of PA6-PP-GF composites with 5%GF, 10%GF, and 15%GF under strain rate of 10 mm/min are 28.04 MPa, 30.92 MPa, and 37.59 MPa respectively. The fracture strength of neat polymer blend under 10 mm/min strain rate was lower than 2 mm/min and 6 mm/min as the high strain rate applied resulted in a fast fracture and reduced the fracture strength result. The fracture strength of the PA6-PP-GF composites with 5%GF and 10%GF under a strain rate of 10 mm/min also showed lower results than the 6 mm/min strain rate due to the change of PA6-PP-GF composites from ductile to brittle at high strain rates and results in less elongation of PA6-PP-GF composite before fracture. This brittle fracture behavior can be seen in Figure 4.15 (b) and (c). These fracture strength results when compared to the results of tensile strength, it is clear that breaking or fracture strength of the composite is somewhat lower than the tensile strength.

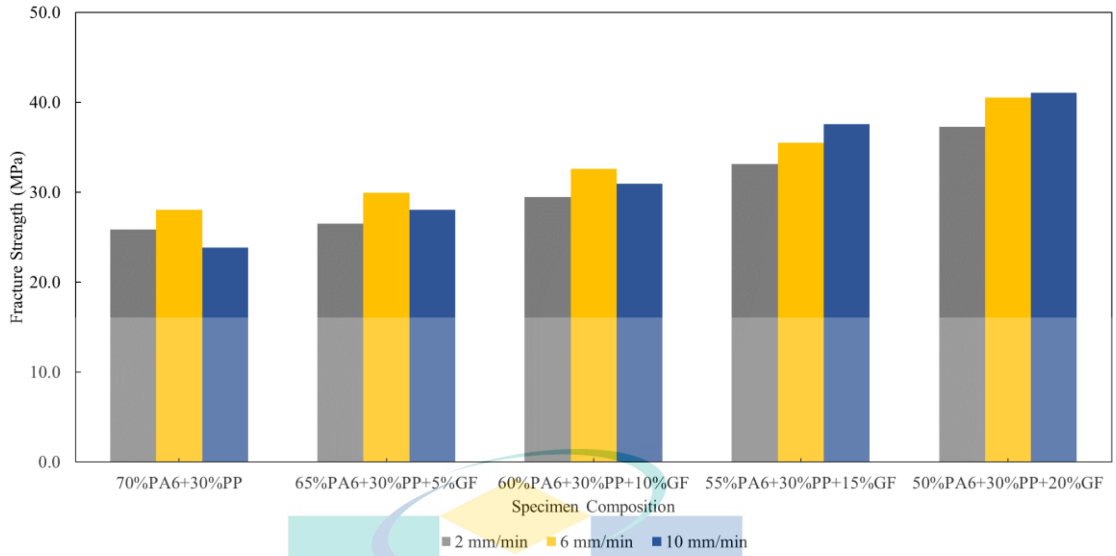



Figure 4.10 Fracture strength (MPa) of glass fiber reinforced PA6-PP composites under 3 different strain rates

Figure 4.11 shows the average elongation at break of glass fiber reinforced PA6-PP composites under 3 different strain rates of 2, 6, and 10 mm/min. The obtained results for 70%PA6+30%PP polymer blend shows the highest elongation at break for all three different strain rates and drastically decreased as the glass fiber content of PA6-PP-GF composites increased. The obtained result for PA6-PP polymer blend under a strain rate of 2 mm/min experiences a elongation at break of 24.24%. The other glass fiber reinforced PA6-PP composites also experiences the elongation of 15.37%, 7.90%, 6.41%, and 4.77% before failure for the glass fiber content of 5%, 10%, 15%, and 20% respectively. The elongation at break for 70%PA6+30%PP polymer blend at 6 mm/min strain rate are 37.64% and as the glass fiber content increased to 5%, 10%, 15%, and 20%, the elongation at break is decreased to 13.72%, 9.76%, 5.10%, and 4.80% respectively. For a strain rate of 10 mm/min, the elongation at break shows higher elongation of 32.57% at 70%PA6+30%PP polymer blend and shows further decreased to 15.49% at 65%PA6+30%PP+5%GF composite. For the 60%PA6+30%PP+10%GF composite, elongation at break continues decreased to 8.53% and 55%PA6+30%PP+15%GF composite attained result of 6.12%. Finally, as the glass fiber content increased to 20%, the elongation at break results decreased to 4.47% because as the plastic strain of the composite decreases gradually as the glass fiber content increases. This is due to increasing glass fiber content, which will act as a local stress concentration area, then the percentage of elongation at fracture will be reduced (Hanna et al., 2011).

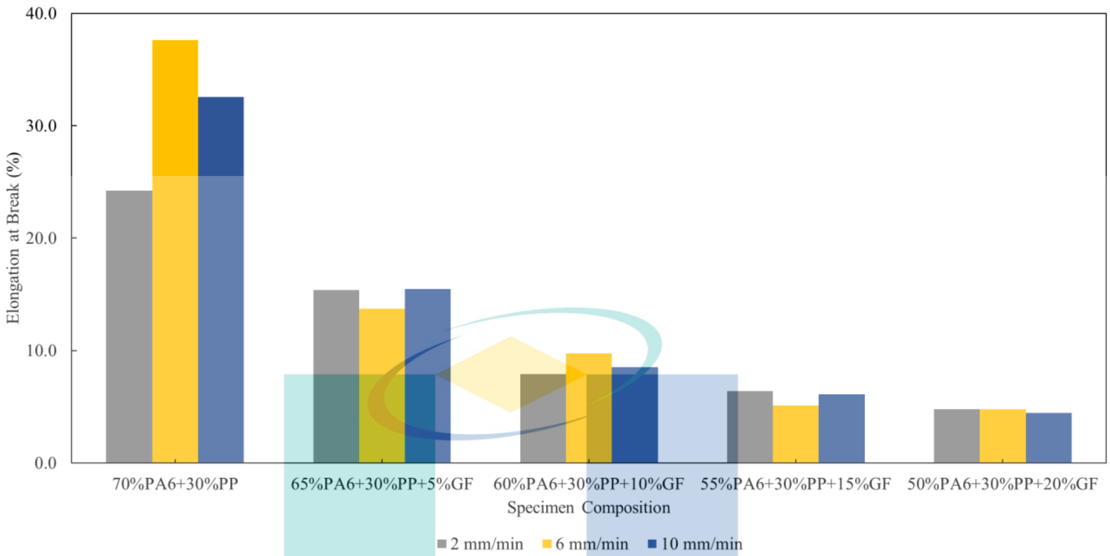



Figure 4.11 Elongation at break (%) of glass fiber reinforced PA6-PP composites under 3 different strain rates

As a conclusion, tensile modulus (GPa), yield strength (MPa), tensile strength (MPa), and fracture strength (MPa) of glass fiber reinforced PA6-PP composites under different strain rates gave a significantly increased results from PA6-PP polymer blend until PA6-PP-GF composites because of their stronger fiber-matrix adhesion (Feldmann, 2016). Besides, the material behavior can be influenced by the strain rates of glass fiber content itself (Elanchezhian et al., 2014). The reported results also show increasing results of tensile modulus and strength as the strain rates increased. While, the elongation at break show decreasing results as the strain rates increased (Brown et al., 2010). The glass fiber content also has a significant effect on the elongation at break. It is generally seen that the elongation at break of composite decreases with the increase in glass fiber content (Fu et al., 2000).

### 4.2.1 Characterization of Tensile Fracture Specimens

The microstructural observation or microstructure of glass fiber reinforced polyamide 6-polypropylene composites is defined as a structure of fracture specimen of material revealed by optical microscope and Scanning Electron Microscope (SEM).

Figure 4.12 shows an optical microstructure of glass fiber reinforced PA6-PP composites under 10x magnification for different glass fiber content; (a) 5%GF; (b) 10%GF; (c) 15%GF; and (d) 20%GF.

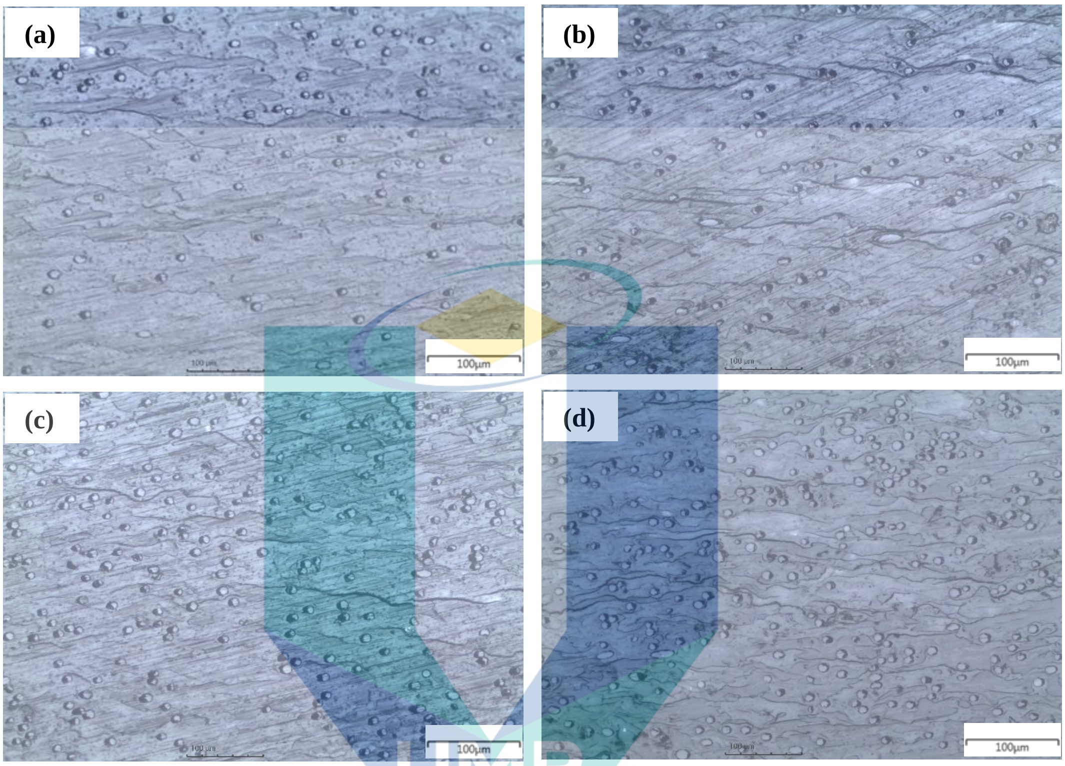



Figure 4.12 Optical microstructure of glass fiber reinforced PA6-PP composites with different glass fiber content: (a) 5%GF; (b) 10%GF; (c) 15%GF; and (d) 20%GF

The differences in glass fiber content in each PA6-PP-GF composites are shown under optical microscope observation and prove that the glass fibers dispersion is increased as the glass fiber content is increased. The overall aspect of the microstructure of glass fiber reinforced PA6-PP composites shows a regular fiber spacing which looks like the glass fiber content is almost uniformly distributed or randomly oriented throughout polyamide 6-polypropylene matrix in the respective compositions. This is happened because of some influencing factors such as the flow of melt materials and pressure inside the barrel zone was not flow uniformly throughout the length of the barrel during the injection molding process. The micrographs in Figure 4.13 shows a tensile fracture surface of a PA6-PP-GF composites with different glass fiber content under a strain rate of 2 mm/min; (a) 0%GF; (b) 5%GF; (c) 10%GF; (d) 15%GF and (e) 20%GF that were observed under Scanning Electron Microscope (SEM). The SEM micrographs of 70%PA6+30%PP polymer blend in Figure 4.13 (a) shows a ductile fracture behavior as polymer matrices of polyamide 6 and polypropylene undergoes matrix tearing under slow strain rate of 2 mm/min. Throughout the range of glass fiber content in PA6-PP-GF composites, glass fibers are almost uniformly distributed in a polyamide 6-polypropylene matrix, and all microscopic images of PA6-PP-GF composites show the existence of fiber pull-out on the fracture surfaces. The SEM micrograph of the fracture surface of glass fiber reinforced PA6-PP composite also shows that glass fibers were dispersed in many directions and embedded well with the polymeric matrix because of good interfacial adhesion between the fiber and polyamide 6 and polypropylene blend.

The PA6-PP-GF composites with 5%GF and 10%GF in Figure 4.13 (b) and (c) respectively shows a ductile fracture behavior with the existence of some matrix tearing on the fracture surface and consistent with the ductile nature of the tensile stress-strain curves in Figure 4.1 and the fracture dog-bone-shaped specimen shown in Figure 4.4. PA6-PP-GF composites with 5%GF, 10%GF, and 15%GF also shows long protruding fiber on the fracture surface. 50%PA6+30%PP+20%GF composite shows a rough fracture surface with short fiber pull-out and the glass fiber is still embedded with the PA6-PP matrix which shows a good bonding between glass fiber and matrices. The decrease in elongation at break is explained due to the increase in glass fiber content. The tensile fracture specimen of PA6-PP-GF composites with 5%GF, 10%GF, and 15%GF under strain rate of 2 mm/min shows that some of the matrices is tearing and leads to the formation of polymer filaments on the fracture surface (Belmonte et al., 2017). Moreover, long fiber pull-out in all different percentage of composites can be seen clearly from the micrograph because of ductile fracture behavior under slow strain rate of 2 mm/min. The fiber pull-out observed depends on the bond strength and the load transfer mechanism from matrix and fiber (Okoli, 2001). It was observed also that are more fiber pull-out than broken fiber on the fracture surface of PA6-PP-GF composites tensile fracture specimens (Bajracharya et al., 2016).

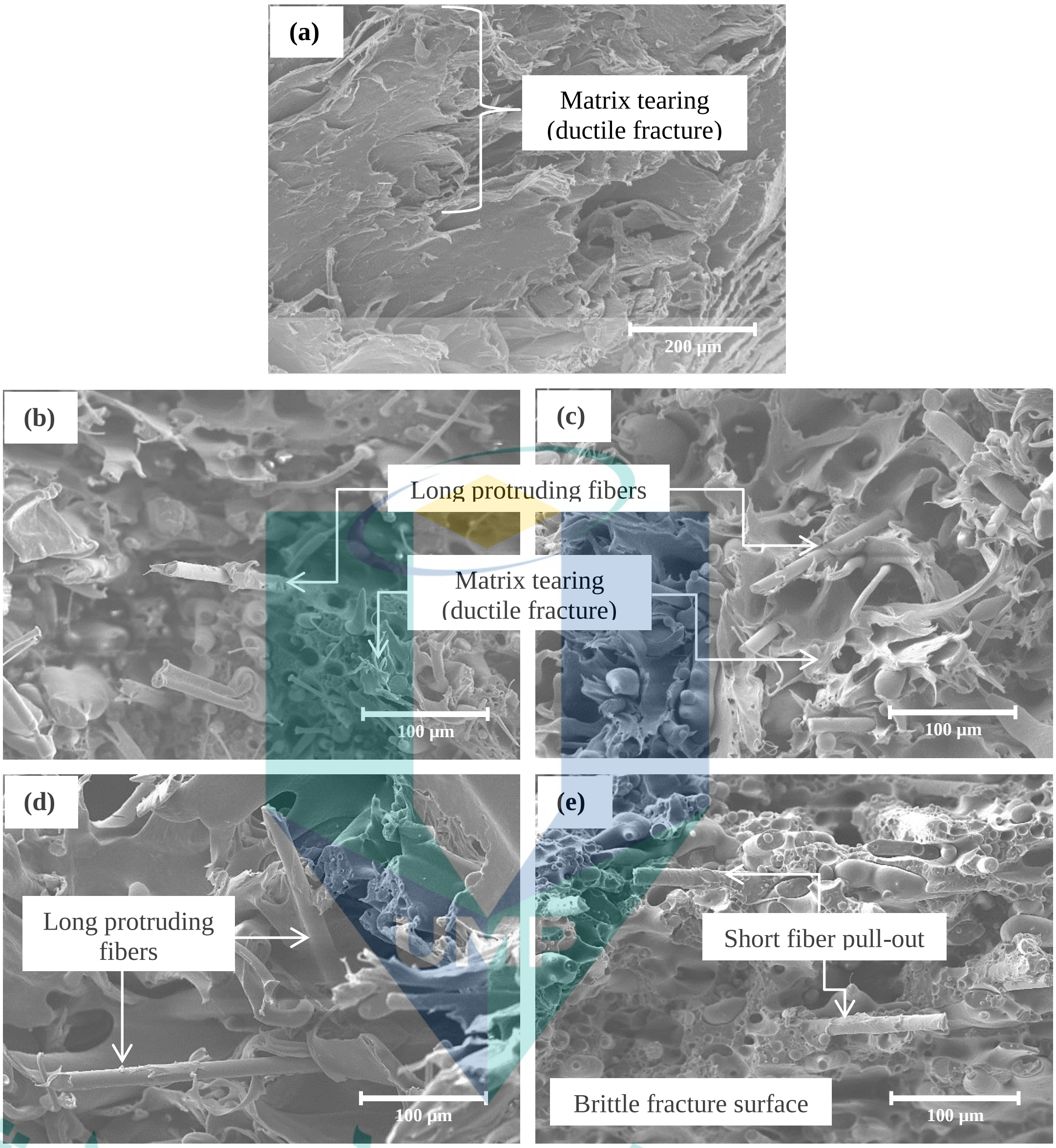



Figure 4.13 SEM micrograph of tensile fracture surface of an PA6-PP composites with different glass fiber contained under strain rate of 2 mm/min: (a) 0%GF; (b) 5%GF; (c) 10%GF; (d) 15%GF and (e) 20%GF

The SEM micrograph of tensile fracture surface of PA6-PP-GF composites with different glass fiber content under a strain rate of 6 mm/min: (a) 0%GF; (b) 5%GF; (c) 10%GF; (d) 15%GF and (e) 20%GF are shown in Figure 4.14. 70%PA6+30%PP polymer blend with 0%GF in Figure 4.14 (a) which shows a matrix tearing of PA6-PP matrices when a medium strain rate of 6 mm/min is applied to the specimen. The differences of matrix formation in the specimen are affected by the strain rate applied as the matrix formation that shown in Figure 4.13 (a) under strain rate of 2 mm/min is different if compared to the matrix formation that showed in Figure 4.14 (a). The microstructure of neat polymer blend under a strain rate of 6 mm/min indicates that the matrix tearing is shorter than at a strain rate of 2 mm/min. For the fracture surface microstructure PA6-PP-GF composite with 5%GF (Figure 4.14 (b)) shows a ductile fracture behavior surface with a fiber pull-out as the 6 mm/min strain rate is applied and the long fiber pull-out is shown but it is slightly shorter than at a strain rate of 2 mm/min. PA6-PP-GF composite with 10%GF shows a ductile fracture behavior with some fiber pull-out in between the matrix under a medium strain rate of 6 mm/min. The 55%PA6+30%PP+15%GF composite shows a ductile to brittle fracture behavior because some of the matrices are followed the protruding fiber and some of the matrices have brittle fracture behavior where the glass fiber is still embedded with the matrix. SEM micrograph of PA6-PP-GF composite with 20%GF shows a brittle fracture behavior and good bonding between the glass fiber and polymer matrix. There is no matrix tearing at both specimens' fracture surface of 55%PA6+30%PP+15%GF composite and 50%PA6+30%PP+20%GF composite because the PA6-PP-GF composites were brittle fracture specimens.

Figure 4.15 shows SEM micrograph of tensile fracture surface of PA6-PP-GF composites with different glass fiber content under strain rate of 10 mm/min: (a) 0%GF; (b) 5%GF; (c) 10%GF; (d) 15%GF and (e) 20%GF. The neat polymer blend microstructure (Figure 4.15 (a)) shows more matrix tearing towards each other which is shows good interaction between polyamide 6 and polypropylene. Next, the PA6-PP-GF composites microscopic images showed the presence of protruding fibers on the fractured surface. SEM micrograph of PA6-PP-GF composites with 5%GF, 10%GF, and 15%GF shows several voids that is due to the fiber pull-out from the matrix during the testing that happened because of the high stress carried by the glass fiber itself and this voids occurs because of fiber-matrix interaction between the fiber and the polymer matrix (Braga and Magalhaes, 2015). The PA6-PP polymer blend structure showed the waviness of polyamide 6 and polypropylene matrix under all strain rates and demonstrated good mixing of both PA6-PP matrix (Lingesh et al., 2014). The fiber pull-out showed at all PA6-PP-GF composites under strain rate of 10 mm/min is shorter if compared to strain rates of 2 and 6 mm/min.

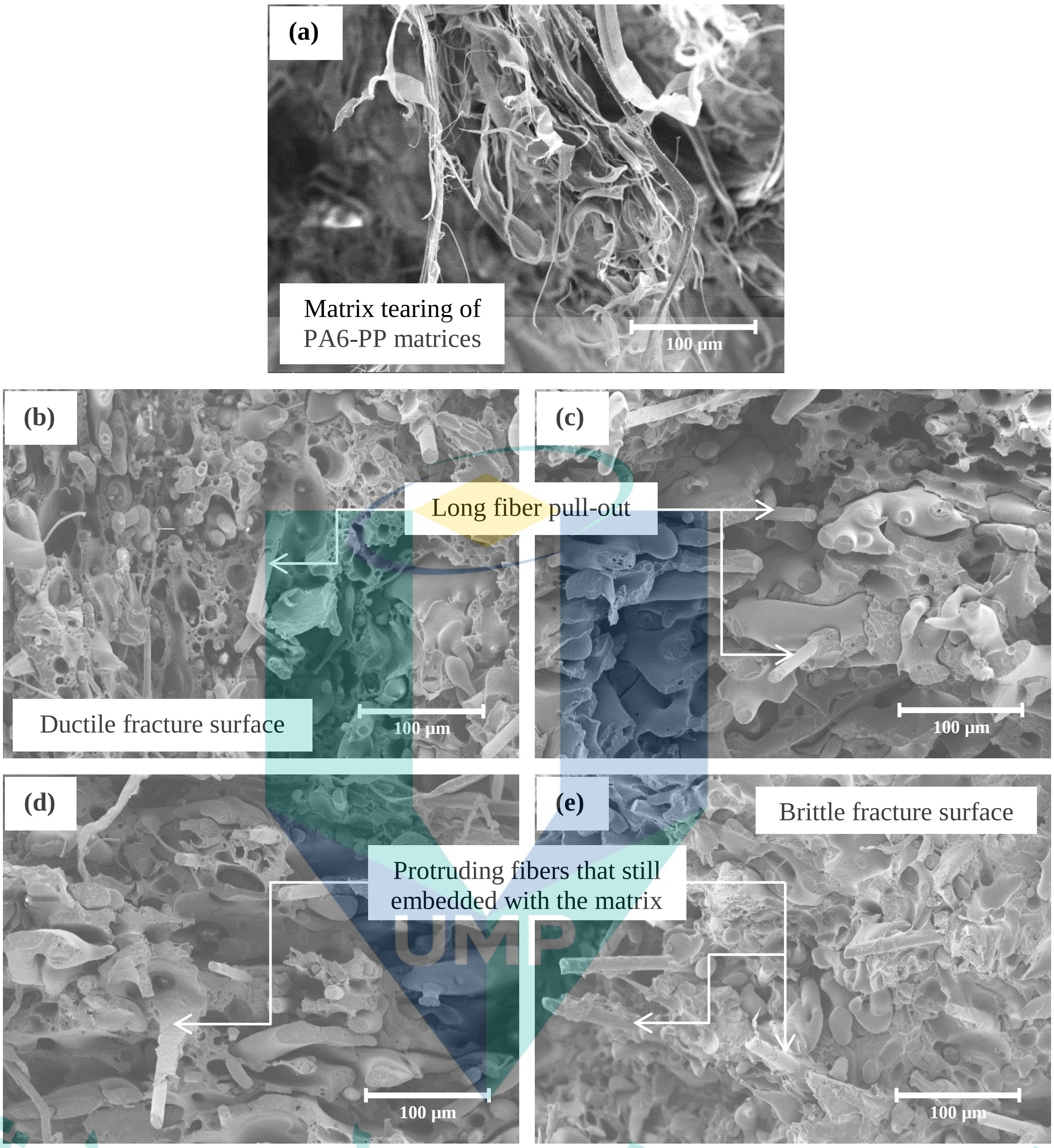



Figure 4.14 SEM micrograph of tensile fracture surface of an PA6-PP composites with different glass fiber contained under strain rate of 6 mm/min: (a) 0%GF; (b) 5%GF; (c) 10%GF; (d) 15%GF and (e) 20%GF

The fracture surface of PA6-PP-GF composite with 5%GF observed is ductile fracture behavior while the fracture surface of PA6-PP-GF composite with 10%GF showed a ductile to brittle fracture behavior and the PA6-PP-GF composites with 15%GF and 20%GF were observed as brittle fracture behavior. As the glass fiber content is increased and crosshead speed increased, the composite became more brittle behavior (Premalal et al., 2002). The fracture surface of PA6-PP-GF composites with 15%GF and 20%GF also indicates an unstable crack propagation (Figure 4.6) that prove a brittle fracture behavior has occurred (Belmonte et al., 2017). Moreover, the tensile properties of PA6-PP-GF composites under a strain rate of 10 mm/min showed were higher than under a strain rate of 2 mm/min in Figure 4.9. This proved that the applied stresses can be transferred to the micro particles of glass fiber from the matrix effectively and the strength properties are clearly improved with the well-bonded between fiber and matrix (Fu et al., 2008).

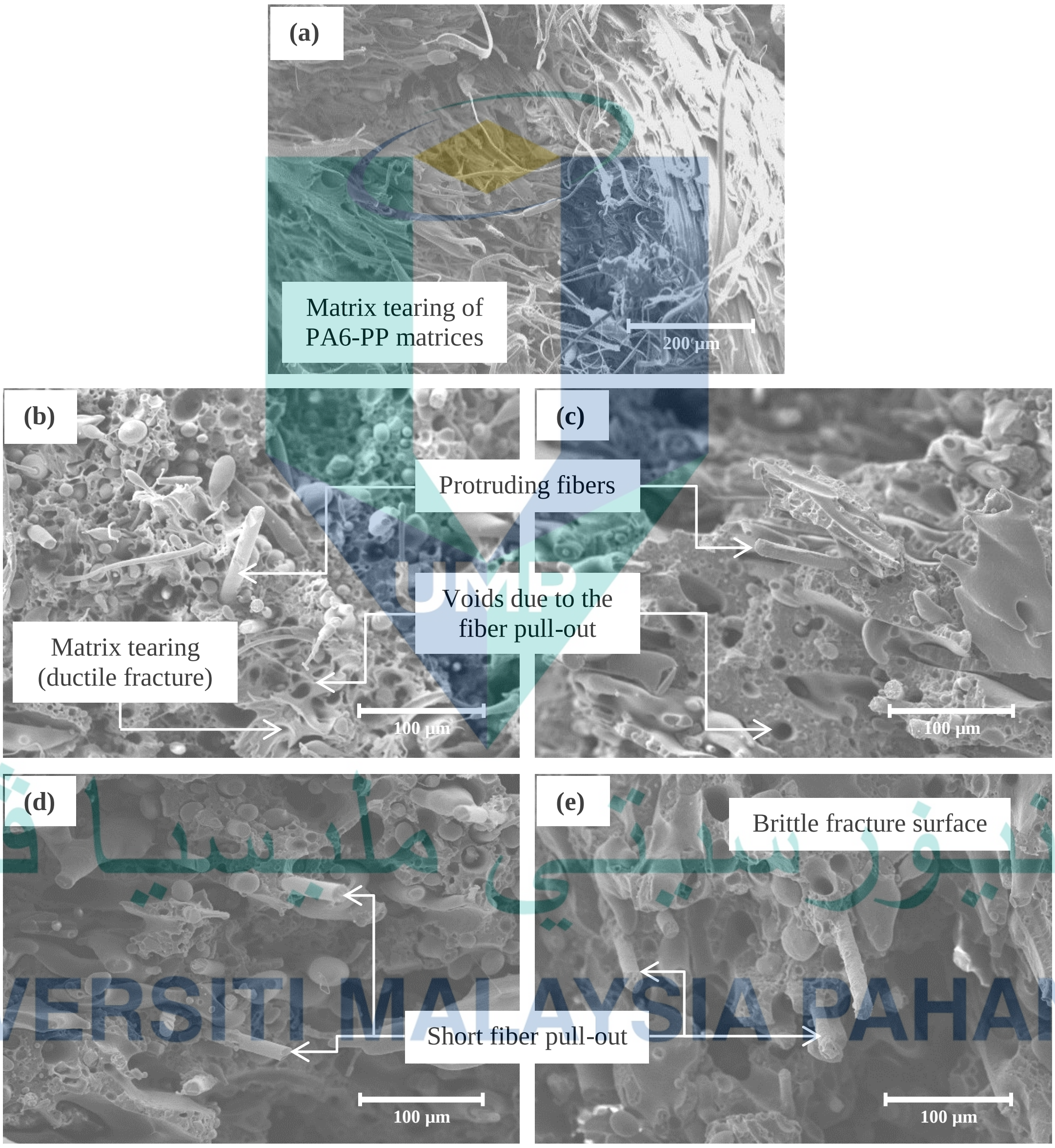



Figure 4.15 SEM micrograph of tensile fracture surface of an PA6-PP composite with different glass fiber contained under strain rate of 10 mm/min: (a) 0%GF; (b) 5%GF; (c) 10%GF; (d) 15%GF and (e) 20%GF

### 4.3 Flexural Test (3-point Bend) Results Analyses

Flexural test is used to determine the flexural modulus or flexural strength of a material. Flexural test was followed ASTM D790. Flexural modulus is calculated from the slope of the stress vs. strain deflection curve. The maximum stress of the fiber that is exposed to the tension part of the specimen is defined as the flexural strength. These two values can be used to evaluate the ability of specimens to withstand flexural or bending forces. The flexural test results for each composition of glass fiber reinforced PA6-PP composites under strain rate of 2 mm/min are shown in Figure 4.16 and the flexural specimens after the test are shown in Figure 4.18. Whiles, the flexural test results for each composition of glass fiber reinforced PA6-PP composites under strain rate of 4 mm/min are shown in Figure 4.17 and the flexural specimens after the test are shown in Figure 4.19. The flexural specimens after test showed a partial fracture on the tension side of the outermost area of specimens. This is because the bending load used in the bending test causes compression or maximum stress at the outermost side (i.e., upper or bottom) within the specimen cross-section (Tanimoto et al., 2002). The flexural properties of glass fiber reinforced polyamide 6-polypropylene composites such as flexural modulus, flexural yield strength, flexural strength and flexural strain were tabulated in Table 4.4 and 4.5 for strain rates 2 and 4 mm/min respectively.

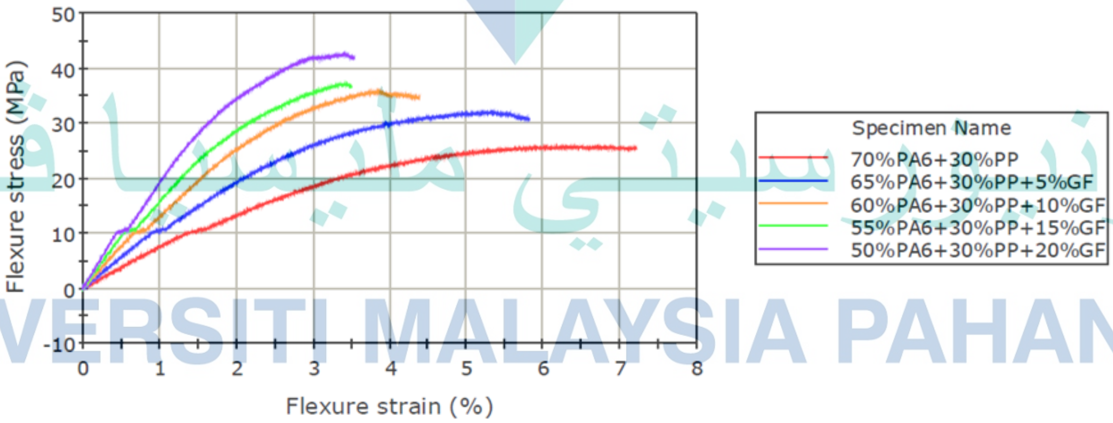



Figure 4.16 Flexural stress-strain curve of glass fiber reinforced PA6-PP composites under strain rate of 2 mm/min

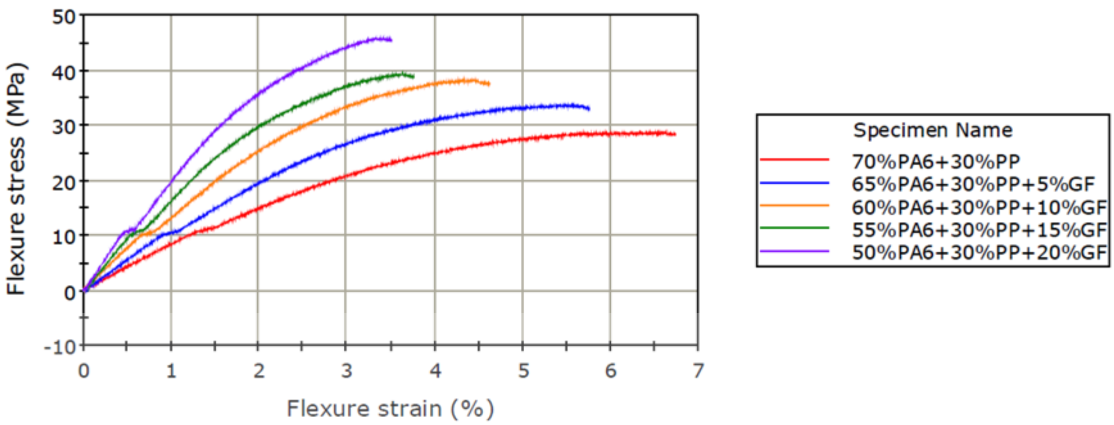



Figure 4.17 Flexural stress-strain curve of glass fiber reinforced PA6-PP composites under strain rate of 4 mm/min

Table 4.4 Average Results of Flexural Test (Strain rate of 2 mm/min)

| **Strain Rate of 2 mm/min** | | | | |
|---|---|---|---|---|
| **Specimen Composition** | **Flexural Modulus (GPa)** | **Flexural Yield Strength (MPa)** | **Flexural Strength (MPa)** | **Flexural Strain (%)** |
| 70%PA6 + 30%PP | 0.75 | 25.49 | 25.97 | 6.16 |
| 65%PA6 + 30%PP + 5%GF | 1.13 | 31.73 | 31.98 | 5.18 |
| 60%PA6 + 30%PP + 10%GF | 1.49 | 35.72 | 36.14 | 4.11 |
| 55%PA6 + 30%PP + 15%GF | 1.74 | 35.94 | 36.26 | 3.57 |
| 50%PA6 + 30%PP + 20%GF | 2.01 | 40.11 | 40.60 | 3.11 |

Table 4.5 Average Results of Flexural Test (Strain rate of 4 mm/min)

| **Strain Rate of 4 mm/min** | | | | |
|---|---|---|---|---|
| **Specimen Composition** | **Flexural Modulus (GPa)** | **Flexural Yield Strength (MPa)** | **Flexural Strength (MPa)** | **Flexural Strain (%)** |
| 70%PA6 + 30%PP | 0.81 | 27.61 | 28.19 | 5.81 |
| 65%PA6 + 30%PP + 5%GF | 1.12 | 33.14 | 33.66 | 5.39 |
| 60%PA6 + 30%PP + 10%GF | 1.48 | 37.97 | 38.52 | 4.11 |
| 55%PA6 + 30%PP + 15%GF | 1.80 | 38.57 | 38.87 | 3.64 |
| 50%PA6 + 30%PP + 20%GF | 2.02 | 42.54 | 42.82 | 3.44 |

As mentioned in Chapter 3, the results reported were averages of at least three measurements. The flexural modulus or of different composition of glass fiber reinforced PA6-PP composites under 2 different strain rates of 2 and 4 mm/min is shown in Figure 4.20.

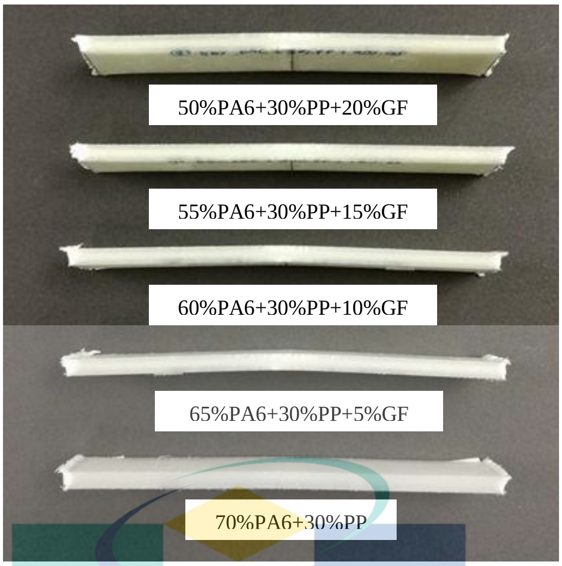



Figure 4.18 Flexural specimens after test under strain rate of 2 mm/min


Figure 4.19 Flexural specimens after test under strain rate of 4 mm/min

Flexural modulus result of 70%PA6+30%PP polymer blend shows a low flexural modulus of 0.75 GPa at 2 mm/min strain rate and 0.81 GPa flexural modulus at 4 mm/min strain rate. The trend of the graph shown gradually increased results from PA6-PP polymer blend until 50%PA6+30%PP+20%GF composite for both different strain rates. The flexural modulus of 65%PA6+30%PP+5%GF composite is increased at 1.13 GPa under 2 mm/min strain rate and also increased the modulus of 1.12 GPa under 4 mm/min strain rate. When the glass fiber content increase to 10%, 60%PA6+30%PP+10%GF composite reveals an increased modulus of 1.49 GPa under strain rates of 2 mm/min while at 4 mm/min also reveals increased modulus of 1.48 GPa. The flexural modulus of PA6-PP-GF composite with 15% glass fiber content gained 1.74 GPa under a 2 mm/min strain rate and at a strain rate of 4 mm/min revealed an increase of 1.80 GPa modulus. Finally, 50%PA6+30%PP+20%GF composite shows a further increased modulus of 2.01 GPa under strain rates of 2 and 4 mm/min is 2.02 GPa. Therefore, the strength of the composite material under bending load increases as the content of the glass fiber reinforced PA6-PP composite increases and causes more resistance to deformation (Nuruzzaman et al., 2018).

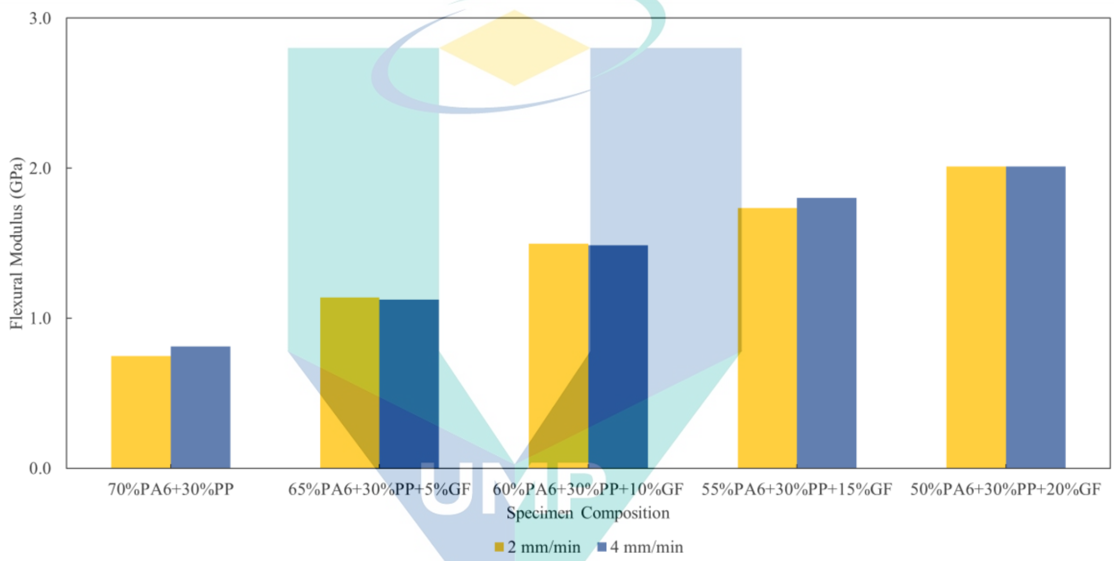



Figure 4.20 Flexural modulus (GPa) of glass fiber reinforced PA6-PP composites under 2 different strain rates



The flexural yield strength of each composition of glass fiber reinforced polyamide 6-polypropylene composites under strain rates of 2 and 4 mm/min is shown in Figure 4.21. PA6-PP polymer blend plastic deformation under a strain rate of 2 mm/min initiated at a low-stress level of 25.49 MPa. The obtained result of 65%PA6+30%PP+5%GF composite is 31.73 MPa and for 60%PA6+30%PP+10%GF composite increased to 35.72 MPa. For the further increase of glass fiber content to 15%, the flexural yield strength of 55%PA6+30%PP+15%GF composite slightly increases of 35.94 MPa. For 50%PA6+30%PP+20%GF composites, the flexural yield strength value increased to 40.11 MPa. The obtained flexural yield strength of 70%PA6+30%PP polymer blend under a strain rate of 4 mm/min is 27.61 MPa while as the glass fiber content is increased, the flexural yield strength results are increased. For 65%PA6+30%PP+5%GF composite show increased flexural yield strength of 33.14 MPa. The 60%PA6+30%PP+10%GF composite reveals a further increase of 37.97 MPa. As the glass fiber content up to 15%, the flexural yield strength shows slightly an increased result of 38.57 MPa. Finally, when the glass fiber content up to 20%, 50%PA6+30%PP+20%GF composite shows an increased result of 42.54 MPa.

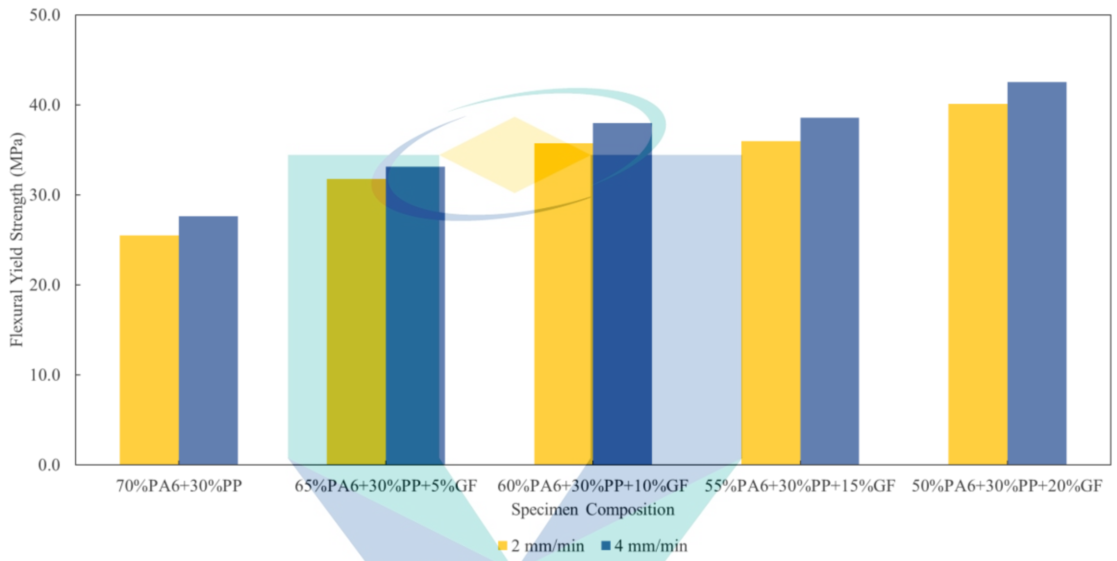



Figure 4.21 Flexural yield strength (MPa) of glass fiber reinforced PA6-PP composites under 2 different strain rates

The flexure strength of glass fiber reinforced PA6-PP composites under 2 different strain rates is shown in Figure 4.22. The flexure strength of 70%PA6+30%PP polymer blend under strain rate of 2 mm/min is 25.97 MPa and 65%PA6+30%PP+5%GF composite is 31.98 MPa. The PA6-PP-GF composite with 10%GF obtained 36.14 MPa flexural strength and for 55%PA6+30%PP+15%GF composite, the flexure strength is slightly increased to 36.26 MPa from 60%PA6+30%PP+10%GF composite but it is higher than PA6-PP polymer blend. Lastly, the 50%PA6+30%PP+20%GF composite show a further increased strength of 40.60 MPa. The flexural strength of 70%PA6+30%PP polymer blend under 4 mm/min shows a low strength of 28.19 MPa. The flexural strength of 65%PA6+30%PP+5%GF composite shows an increased result of 33.66 MPa. As the glass fiber content increased to 10%, the flexural strength of PA6-PP-GF composite increased to 38.52 MPa. For

PA6-PP-GF composite with 15% glass fiber content also shows an increased flexural strength of 38.87 MPa. For 50%PA6+30%PP+20%GF composite reveals an increased flexural strength of 42.82 MPa. From the obtained results, the flexure strength of the composite gradually increases as the glass fiber content is increased (Kusaseh et al., 2018). Uniform distribution of glass fiber and strong adhesion of polyamide 6 and polypropylene matrix affect improvement or increasing of flexural strength (Hemanth et al., 2014).

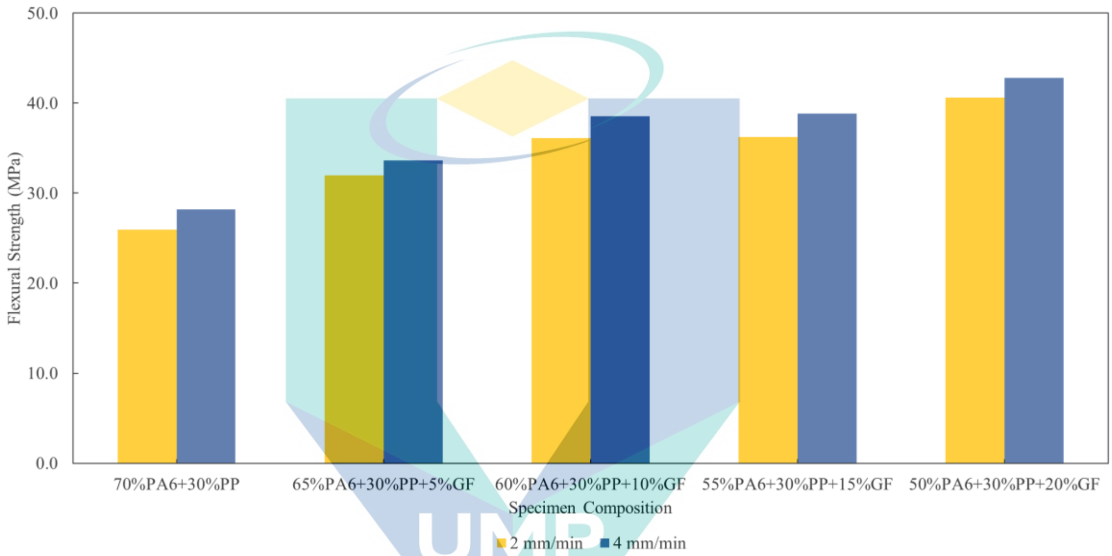



Figure 4.22 Flexural strength (MPa) of glass fiber reinforced PA6-PP composites under 2 different strain rates

Figure 4.23 shows the result of flexural strain for different compositions of glass fiber reinforced polyamide 6-polypropylene composites under 2 different strain rates. The flexural strain is the point at which the material gives up, the force does not continue to increase and begins to decrease or break under strain rates of 2 and 4 mm/min. The obtained result under a strain rate of 2 mm/min shows that the elongation of a neat polymer blend, 70%PA6+30%PP is 6.16%. Whiles, the elongation of PA6-PP-GF composites with 5%GF is 5.18%, 10%GF is 4.11%, 15%GF is 3.57% and 20%GF is 3.11%. This shows that the strain at break is continually decreased as the glass fiber content of the composite is increased and causes a decrease in ductility of the composite.

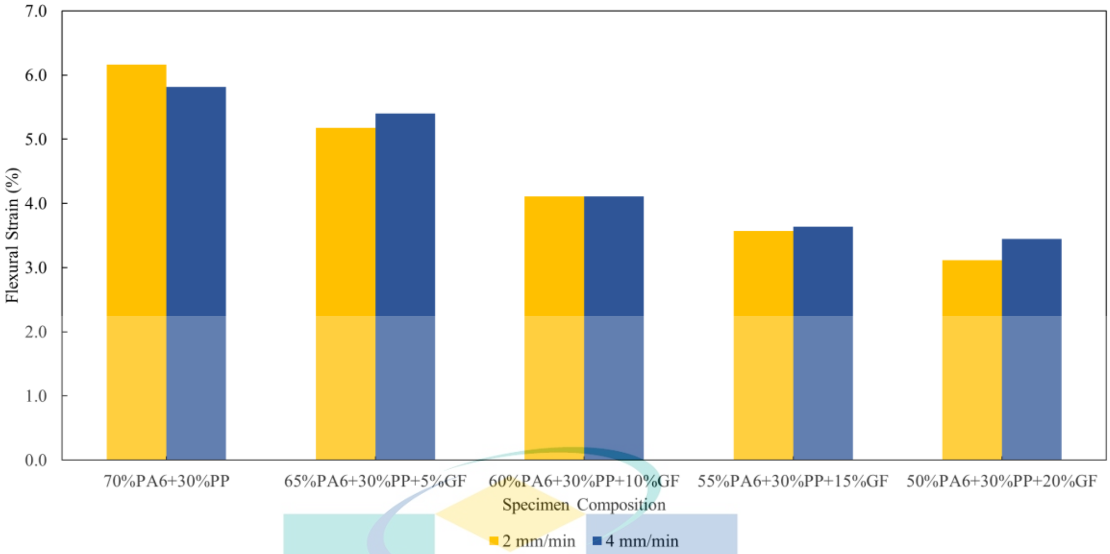



Figure 4.23 Flexural strain (%) of glass fiber reinforced PA6-PP composites under 2 different strain rates

The flexural strain result under a strain rate of 4 mm/min of 70%PA6+30%PP polymer blend shows elongation of 5.81%. While the elongation of PA6-PP-GF composites with 5%GF is 5.39%, 10%GF is 4.11%, 15%GF is 3.64% and 20%GF is 3.44%. The obtained result shows a decreased trend as the glass fiber content of composites is increased due to the decrease in ductility of the PA6-PP-GF composites. For overall discussions on flexural properties result of glass fiber reinforced PA6-PP composites under strain rates of 2 mm/min and 4 mm/min has been shown that the flexural properties were increased when the force applied on the specimens were increased. Other factors associated with the strength of fiber composites are the quantity of fiber in the polymer matrix, fiber orientation, and fiber adhesion on the polymer matrix (Bino et al., 2017). When the glass fiber content is increased, the fiber and the matrix interaction could be unlimited and the load can be transferred from the matrix to the fiber, resulted in only micro-fracture of the specimen and led to high flexural strength value (Mathew et al., 2017). From these mechanical testing shows that the flexural strength of PA6-PP-GF composites gave higher results than tensile strength at a strain rate of 2 mm/min. Besides, increasing flexural strength may also be due to the high elastic modulus of the glass fiber compared to the matrix materials (Hanna et al., 2011).

## 4.4 Impact Test (Unnotched) Results Analyses

ASTM D4812 is a standard test method for unnotched cantilever beam impact resistance of plastic as it shows the energy extracted from a standard pendulum hammer that works in breaking down a specimen with one pendulum swing. The results of this test method are reported as absorbed energy per unit width of the specimen. Impact strength is described as the ability of a substance to continuously absorb energy or impact. Impact energy is computed as the ratio of absorbed energy to the cross-sectional area of the specimen and Izod impact test is used to calculate the impact energy of the PA6-PP-GF composites. The fracture specimens of 70%PA6+30%PP polymer blend and glass fiber reinforced PA6-PP composites with 5%GF, 10%GF, 15%GF, and 20%GF are shown in Figure 4.24 (4 N.m) and 4.25 (5 N.m).

The neat polymer blend shows a stress-whitening line around the impact zone after being hit by the 11 J of hammer and found as ductile fracture behavior. While, the PA6-PP-GF composites with reinforced by glass fiber of 5%, 10%, 15%, and 20% shows a jagged edge around the impact zone or completely fracture specimens. Table 4.6 shows the impact strength result with a torque of 4 N.m and table 4.7 shows impact test result with a torque of 5 N.m. The tabulated results were the average of at least three sets of PA6-PP-GF composites specimens. The impact strength of glass fiber reinforced PA6-PP composites with torque 4 N.m and 5 N.m is shown in Figure 4.26. The result obtained with the torque of 4 N.m indicates that 70%PA6+30%PP polymer blend has high impact strength of 79.83 kJ/m$^2$. In contrast, all PA6-PP-GF composites showed a decrease in impact strength. The impact strength of 65%PA6+30%PP+5%GF composite is 43.93 kJ/m$^2$ which is much lower than that of a neat polymer blend. The impact strength of PA6-PP-GF composite is improved to 44.70 kJ/m$^2$ when the glass fiber content is increased to 10%, and the PA6-PP-GF composites with 15% glass fiber content are improved to 45.21 kJ/m$^2$. The increase in impact strength due to the good distribution of glass fiber in the matrix helps to enhance the interaction or adhesion of the interface between the matrix and glass fiber (Alomayri et al., 2014). The PA6-PP-GF composite with 20% glass fiber content shows a decreased result of impact strength to 43.56 kJ/m$^2$.

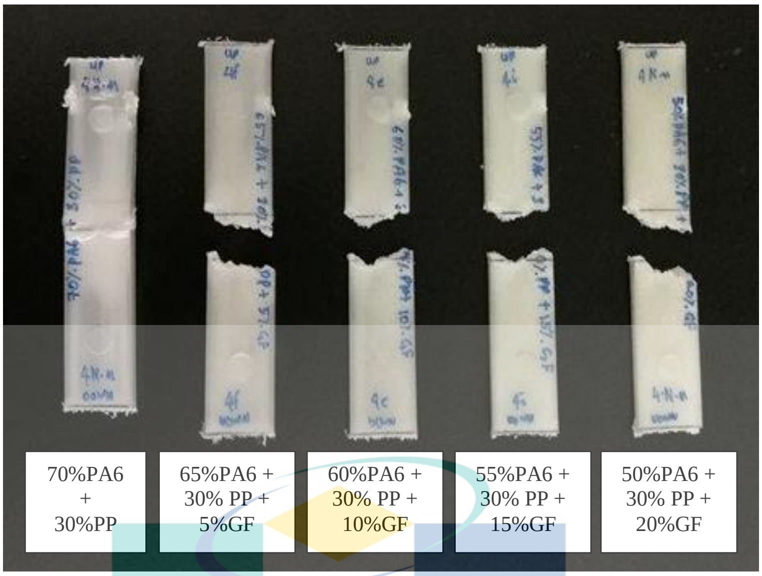



Figure 4.24 Fracture impact test specimen with torque 4 N.m

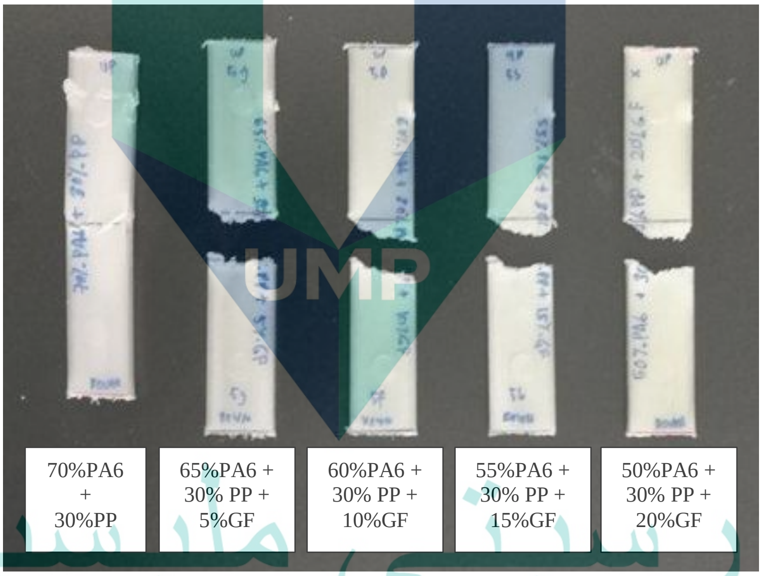



Figure 4.25 Fracture impact test specimen with torque 5 N.m



Table 4.6 Average Results of Impact Test (Torque of 4 N.m)

| Specimen Composition | Impact Strength, Re ($kJ/m^2$) |
|---|---|
| 70%PA6 + 30%PP | 79.83 |
| 65%PA6 + 30%PP + 5%GF | 43.93 |
| 60%PA6 + 30%PP + 10%GF | 44.70 |
| 55%PA6 + 30%PP + 15%GF | 45.21 |
| 50%PA6 + 30%PP + 20%GF | 43.56 |

Table 4.7 Average Results of Impact Test (Torque of 5 N.m)

| Specimen Composition | Impact Strength, Re (kJ/m$^2$) |
|---|---|
| 70%PA6 + 30%PP | 79.64 |
| 65%PA6 + 30%PP + 5%GF | 41.51 |
| 60%PA6 + 30%PP + 10%GF | 42.90 |
| 55%PA6 + 30%PP + 15%GF | 44.47 |
| 50%PA6 + 30%PP + 20%GF | 41.94 |

The PA6-PP-GF composites are behaved as ductile to brittle transition and reducing the impact strength as the glass fiber content increases from 15% to 20% (Nuruzzaman et al., 2016). The impact result for a torque of 5 N.m also shows that 70%PA6+30%PP polymer blend have significantly high impact strength of 79.64 kJ/m$^2$. In contrast, PA6-PP-GF composites show a decrease in impact strength. The results have revealed that impact strength decreases by increasing the glass fiber contents in PA6-PP-GF composites. This is happened because of the reinforced material, which may represent the point for the local stress concentration where the failure will commence (Hanna et al., 2011).

The impact strength of 65%PA6+30%PP+5%GF composite is 41.51 kJ/m$^2$ which is much lower than that of a neat polymer blend. The impact strength of the 60%PA6+30%PP+10%GF composite is increased to 42.90 kJ/m$^2$, and when the glass fiber content increased to 15%, the impact strength also is increased to 44.47 kJ/m$^2$. Meanwhile, the impact strength of the 50%PA6+30%PP+20%GF composite has decreased by 41.94 kJ/m$^2$ due to an increase in glass fiber content of 15% to 20%, and the transition from ductile to brittle behavior leading to reduced impact strength composite. The decreases of impact strength of 50%PA6+30%PP+20%GF composite is because the inability to absorb deformation energy that affected by the reduction of elasticity of material due to the increase of glass fiber content (Hemanth et al., 2014).

The impact strength of PA6-PP-GF composites for both 4 N.m and 5 N.m applied torque shows that 70%PA6+30%PP polymer blend resulted in higher impact strength but decreased at 65%PA6+30%PP+5%GF composite. While at PA6-PP-GF composites with 10%GF and 15%GF shows slightly increased impact strength. But as the glass fiber content up to 20%, the impact strength of 50%PA6+30%PP+20%GF composite is decreased. When glass fiber content increases, the impact strength tends to decrease gradually. On the contrary, if the fiber-matrix adhesion is very strong, fibers limit the movement of matrix molecules and also resulted in reduced impact strength (Premalal et al., 2002). As a comparison from the torque of 4 and 5 N.m, the impact strength of glass fiber reinforced polyamide 6-polypropylene composites with a torque of 4 N.m generate higher strength than the torque of 5 N.m. This happens because the PA6-PP-GF composites specimens at 5 N.m absorb less energy compared to PA6-PP-GF composites specimens at 4 N.m and the when more clamping pressure is applied on the specimen it gives an effect of impact strength results.

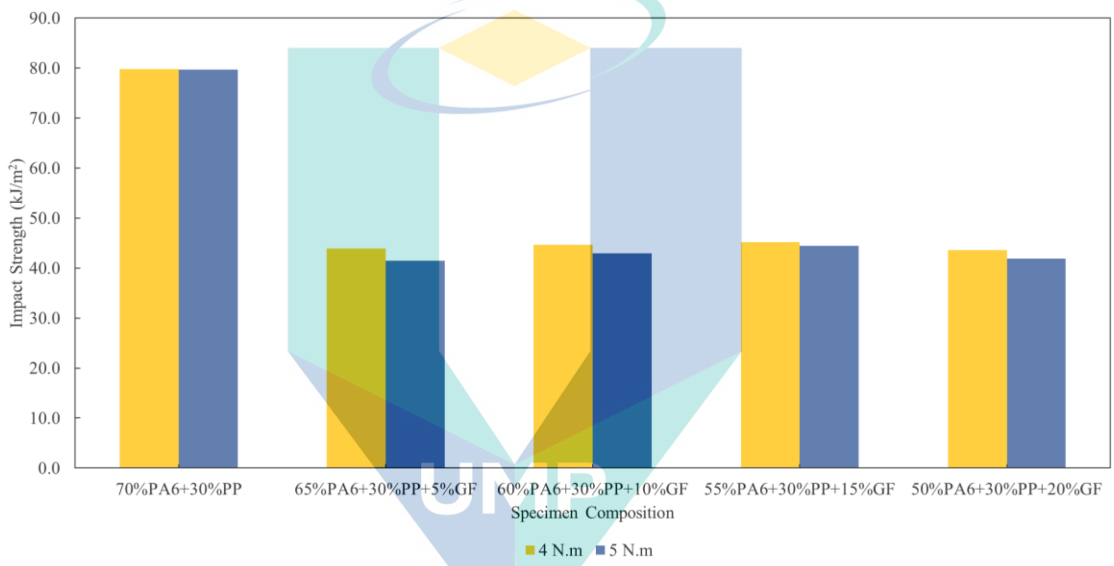



Figure 4.26 Impact strength (kJ/m$^2$) of glass fiber reinforced PA6-PP composites with torque of 4 N.m and 5 N.m



### 4.4.1 Characterization of Impact Fracture Specimens

The micrographs of an impact fracture surface of PA6-PP-GF composites with different glass fiber content under 11J of hammer with a torque of 4 N.m are shown in Figure 4.27; (a) 5%GF; (b) 10%GF; (c) 15%GF; and (d) 20%GF. When the composite is subjected to sudden force, impact energy is dissipated by a combination of fiber pull-out, fiber break, and matrix deformation (Wambua et al., 2003). It was observed that the fracture impact surface of 65%PA6+30%PP+5%GF composite shows a matrix ends and fiber ends with indicates a ductile failure mode because the matrix and fiber observed were slightly pulled on the fracture surface. The fibers are still embedded in the matrix after failure which means that the adhesion between fiber and matrix are good. A similar impact fracture microstructure shown for PA6-PP-GF composites with 10%GF, 15%GF, and 20%GF. The glass fiber was dispersed in many directions and embedded well with the polymeric matrix because of good interfacial adhesion between the fiber and polyamide 6-polypropylene blend (Kuram et al., 2013). Figure 4.28 shows SEM micrograph of impact fracture surface of PA6-PP-GF composites with different glass fiber content under torque of 5 N.m; (a) 5%GF; (b) 10%GF; (c) 15%GF; and (d) 20%GF.

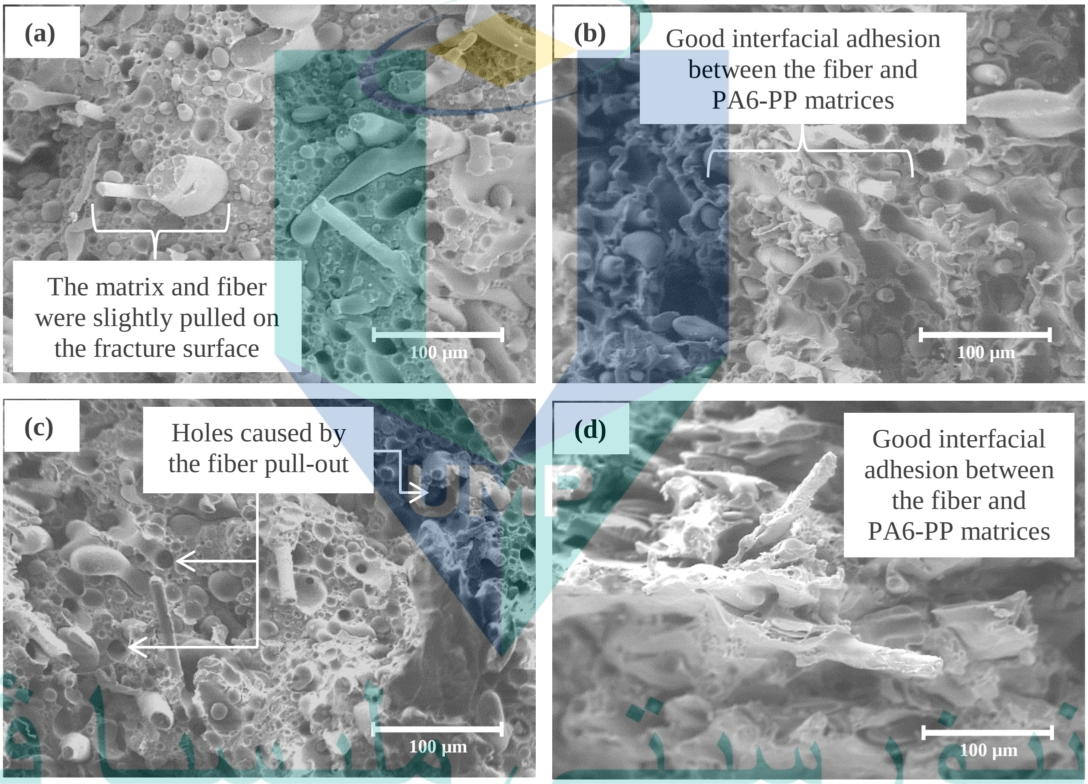



Figure 4.27 SEM micrograph of impact fracture surface of an PA6-PP composite with different glass fiber contained with torque 4 N.m: (a) 5%GF; (b) 10%GF; (c) 15%GF; and (d) 20%GF



The 65%PA6+30%PP+5%GF composite shows many holes caused by the fiber pull-out from the other side of the fracture specimen and left some of the fiber that still embedded to the matrix. For PA6-PP-GF composite with 10%GF shows, a small range of brittle fracture behavior of matrix ends caused by the impact of the pendulum. The sudden cut of matrix and glass fiber also can be seen in PA6-PP-GF composites with 15%GF and 20%GF that does prove a brittle fracture behavior. Besides, the fiber is still embedded well with the matrix of the composite that proved a good interfacial adhesion between fiber and matrix (Kuram et al., 2013).

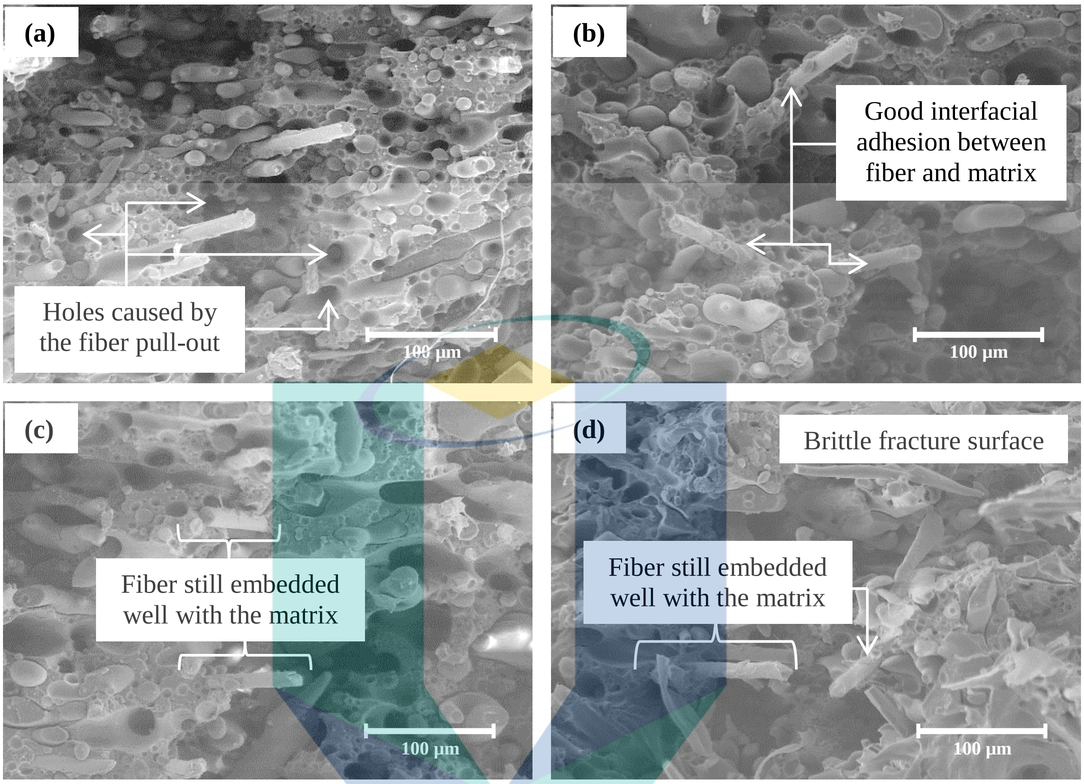



Figure 4.28 SEM micrograph of impact fracture surface of an PA6-PP composite with different glass fiber contained with torque 5 N.m: (a) 5%GF; (b) 10%GF; (c) 15%GF; and (d) 20%GF

## 4.5 EDX Analyses

Energy-dispersive X-ray spectroscopy (EDX) is an analytical technique used to identify the elemental composition or chemical characterization of materials. The data produced by the EDX analysis comprises a spectrum with a peak equal to all elements contained in the sample. In addition, the EDX system can identify automatically the percentage for each element detected to show a qualitative analysis (elemental type) and quantitative analysis (percentages of individual elemental concentrations).There are three broad categories of elements concentration that are major components which are more than 10 wt%, minor components which are 1-10 wt%, and trace elements which are 1 wt% (Hafner, 2006). The chemical composition for polypropylene (PP), polyamide 6 (PA6), and glass fiber (GF) are shown in Figure 4.29, 4.30, and 4.31 respectively.

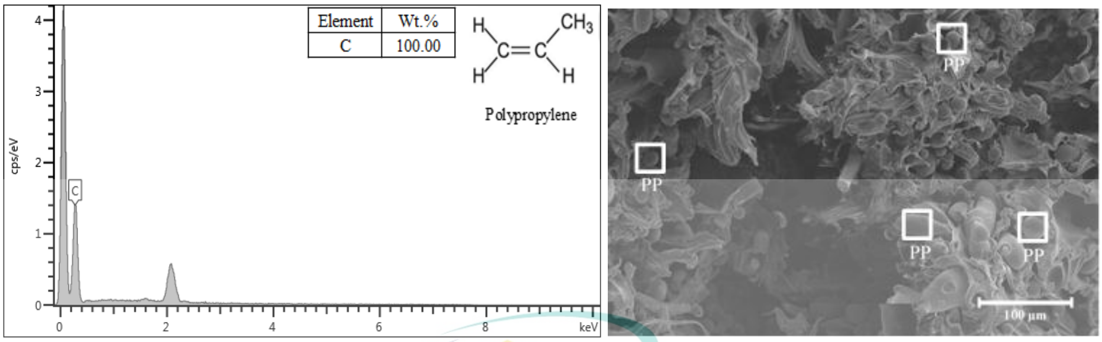



Figure 4.29 Polypropylene (PP) EDX result

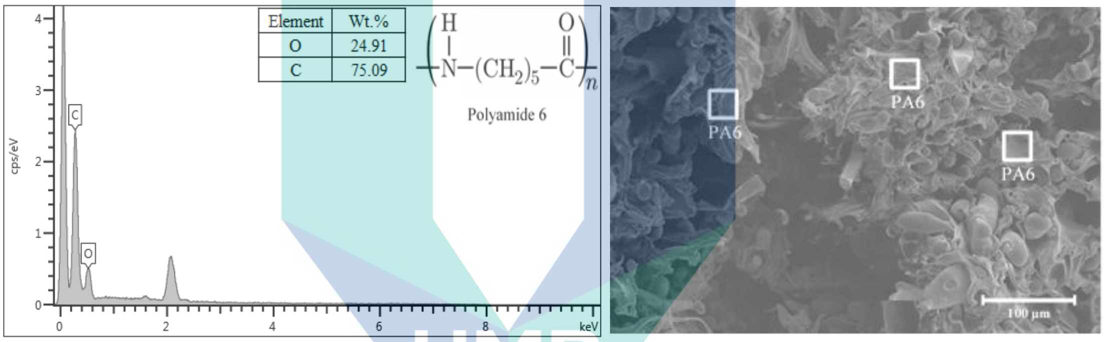



Figure 4.30 Polyamide 6 (PA6) EDX result

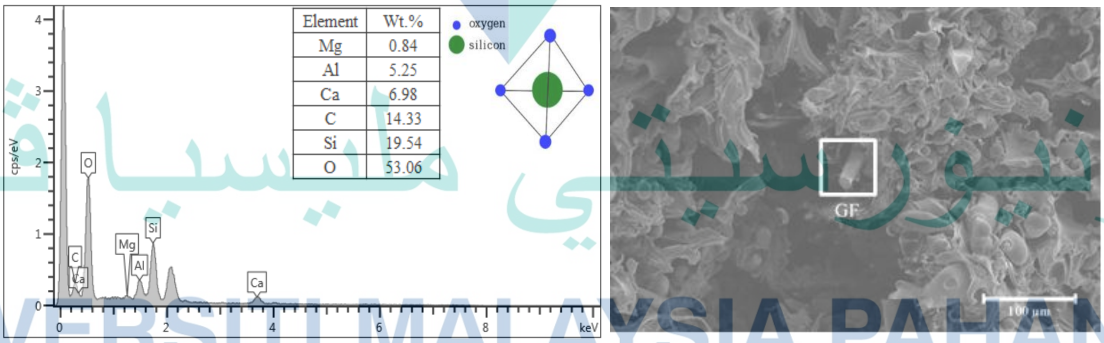



Figure 4.31 Glass fiber (GF) EDX result



The peak position at the graph leads to the identification of the element and the peak height serves to quantify the concentration of each element in the sample. The chemical formula for polypropylene is (C3H6)n and the element shown in the EDX spectra (Figure 4.29) is carbon (C) 100.00 wt.%. The EDX spectra for Figure 4.29 proved that it was polypropylene. The chemical formula of polyamide 6 is

(C6H11NO)n and the EDX spectra for PA6 (Figure 4.30) shown two chemical elements; oxygen (O) 24.91 wt.% and carbon (C) 75.09 wt.%. The basic chemical formula of glass fiber is SiO2 and with addition others oxide of Ca, Al, Mg, etc. The main composition of glass fiber in EDX analysis as shown in Figure 4.31 consisted of magnesium (Mg) 0.84 wt.%, aluminum (Al) 5.25wt.%, calcium (Ca) 6.98 wt.%, carbon (C) 14.33 wt.%, silica (Si) 19.54 wt.%, and oxygen (O) 53.06 wt.%. The EDX analysis proved that test specimen contains polypropylene (PP), polyamide 6 (PA6), and glass fiber (GF).

# CHAPTER 5

# CONCLUSION

## 5.1 Conclusion

The objective of this research is to study the influence of different glass fiber content with reinforced polyamide 6-polypropylene composites and resulted in improvement strength as the glass fiber content is increased. The dog-bone-shaped specimens of glass fiber reinforced polymer composites were successfully prepared with the injection molding process. Then, the mechanical tests were performed on five different polymer composites; 70%PA6+30%PP polymer blend, 65%PA6+30%PP+5%GF composite, 60%PA6+30%PP+10%GF composite, 55%PA6+30%PP+15%GF composite, and 50%PA6+30%PP+20%GF composite under different loading conditions. The mechanical properties of glass fiber reinforced PA6-PP composite under different operating conditions such as tensile, flexural, and impact properties are concluded as follows. For the first time, three variables were considered which are a composition of glass fiber reinforced polyamide 6-polypropylene composites, strain rates of tensile and flexural test, and torque value for the impact test.

i. Tensile properties of the PA6-PP-GF composites were investigated under strain rates of 2 mm/min, 6 mm/min, and 10mm/min. The tensile properties were found to increase with strain rate. However, in this research study, the tensile properties did not increase continuously as the strain rate applied was increased. This behavior had been shown at yield strength and tensile strength of PA6-PP-GF composites under 6 mm/min strain rate which results in a higher than 10 mm/min strain rate. The tensile strength of the PA6-PP-GF composites is slightly decreased while the tensile modulus improved as the glass fiber content is increased to 20% where the strain rate is also increased to 10 mm/min. The acceptable tensile properties of PA6-PP-GF composites are up to 15%GF because of the improvements in strength while PA6-PP-GF composites with

20%GF is impending to brittle nature. Consistent with the overall observation, glass fiber content also has a major impact on elongation at break where it is understood that generally, the elongation at break of the composite decreases with increasing glass fiber content.

ii. The flexural properties of glass fiber reinforced PA6-PP composite under strain rates of 2 mm/min and 4 mm/min showed gradually increased results as the glass fiber content is increased. The flexural properties of composite showed better flexural properties under strain rates of 4 mm/min as compared to that of 2 mm/min. 70%PA6+30%PP polymer blend had the lowest flexural properties and tensile properties. Whiles 50%PA6+30%PP+20%GF composite had the highest flexural and tensile properties. The amount of fiber content has a significant and direct effect on mechanical properties especially the composite strength; the higher the fiber content, the higher the flexural and tensile strength. The influence of the different loading conditions and the fiber content on the mechanical properties resulted significant effects on the corresponding final strength of the composite itself. The results demonstrated that both tensile and flexural strength improved with the percentage of reinforcement fibers and showed improvements compared to the 70%PA6+30%PP polymer blend. Furthermore, the flexural strength of PA6-PP-GF composites resulted in higher strength than tensile strength at a strain rate of 2 mm/min.

iii. The impact strength of glass fiber reinforced polyamide 6-polypropylene composites under torque of 4 N.m shows a higher result than torque of 5 N.m. 70%PA6+30%PP polymer blend resulted higher impact strength but decreased at 65%PA6+30%PP+5%GF composite for both torque applied, while at 60%PA6+30%PP+10%GF composite and 55%PA6+30%PP+15%GF composite shows slightly increased impact strength. But as the glass fiber content up to 20%, the impact strength of 50%PA6+30%PP+20%GF composite is decreased because of when the glass fiber content increases, the impact strength tends to decrease gradually (Premalal et al., 2002).

iv. All of the microstructure analysis have been analysed using SEM and it's revealing a fracture specimens' behavior either ductile or brittle fracture behavior which correspond to the mechanical properties of PA6-PP-GF composites. Tensile fracture surface of 65%PA6+30%PP+5%GF composite shows a ductile fracture behavior and 60%PA6+30%PP+10%GF composite shows a ductile to brittle fracture behavior. While tensile fracture surface of PA6-PP composites with 15%GF and 20%GF shows a brittle fracture behavior. Moreover, the microstructure analysis of PA6-PP-GF composites showed different fiber pull-out and matrix tearing depends on their different mechanical operating conditions in different mechanical testing. A PA6-PP-GF composites microstructure of fracture specimen from tensile test at 2 mm/min strain rates shows longer fiber pull-out than at 6 and 10 mm/min strain rates. The fiber pull-out shows shorter as the strain rates applied is increased.

v. The impact fracture surface of PA6-PP-GF composites under the torque of 4 N.m and 5 N.m shows quite a similar fracture behavior which are most of the glass fiber is still embedded in the matrix and shows a good interfacial adhesion between fibers and matrices.



## 5.2 Recommendations

For further studies of glass fiber reinforced polyamide 6-polypropylene composites, several recommendations are as follows:

i. Further research studies should be carried out considering different compositions of polymer composites, containing 25% and 30% glass fibers. The addition of a percentage of glass fibers to the polymer composites may give different results either increase or decrease in its mechanical properties as well as changes in brittleness on the polymer composites.

ii. Further research studies should be carried out at a higher strain rate of 20 mm/min and 30 mm/min for tensile tests. Flexural tests should also be carried out at higher strain rate of 5 mm/min and 6 mm/min in order to verify the flexural strengths under higher strain rates.

iii. Further recommendation is, experiments should be carried out for higher impact energy using 50J hammer and also for notched specimens in order to verify the energy absorbing performance under higher impact load.

iv. Further research can be carried out using ABS-PA6-GF or PC-ABS-GF composites under the same operating conditions. The different of polymer composites use may give a different operating condition for injection molding process and give different results in mechanical properties even the percentages of suggested polymer composites and the mechanical testing use are same with PA6-PP-GF composites.

## REFERENCES


Abdennadher, A. (2015). Injection Moulding of Natural Fibre Reinforced Polypropylene: Process, Microstructure and Properties. Ph.D. Thesis. Paris Institute of Technology, Paris

Ahmad, I., Baharum, A. and Abdullah, I. (2006). Effect of extrusion rate and fiber loading on mechanical properties of twaron Fiber-Thermoplastic Natural Rubber (TPNR) composites. Journal of Reinforced Plastics and Composites, 25(9), 957-965.

Alomayri, T., Shaikh, F. U. A. and Low, I. M. (2014). Synthesis and mechanical properties of cotton fabric reinforced geopolymer composites. Composites Part B: Engineering, 60, 36–42.

Arencón, D. and Velasco, J. I. (2009). Fracture toughness of polypropylene-based particulate composites. Materials, 2, 2046-2094.

Arikan, V. and Sayman, O. (2015). Comparative study on repeated impact response of E-glass fiber reinforced polypropylene & epoxy matrix composites. Composites Part B: Engineering, 83, 1–6.

Ashik, K. P. and Sharma, R. S. (2015). A Review on Mechanical Properties of Natural Fiber Reinforced Hybrid Polymer Composites. Journal of Minerals and Materials Characterization and Engineering, 03(05), 420–426.

ASTM D4812-99 (Standard Test Method for Unnotched Cantilever Beam Impact Resistance of Plastics). 1999. ASTM International, West Conshohocken, PA.

ASTM D638-02a (Standard Test Method for Tensile Properties of Plastics). 2002. ASTM International, West Conshohocken, PA.

ASTM D790-03 (Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials). 2003. ASTM International, West Conshohocken, PA.

Bajracharya, R. M., Manalo, A. C., Karunasena, W. and Lau, K. (2016). Experimental and theoretical studies on the properties of injection moulded glass fibre reinforced mixed plastics composites. Composites Part A: Applied Science and Manufacturing, 84, 393–405.

Belmonte, E., Monte, M. D., Hoffmann, C. J. and Quaresimin, M. (2017). Damage mechanisms in a short glass fiber reinforced polyamide under fatigue loading. International Journal of Fatigue, 94, 145–157.

Bino, P. R. D, Stanly, J. R., Mohini, S. and Likitha, T. G. (2017). Tensile, Flexural and Impact Properties of Glass Fibre Reinforced Polymer Matrix Composites. International Journal of Mechanical Engineering and Technology, 8(11), 467–

475.

Boopalan, M., Niranjanaa, M. and Umapathy, M. J. (2013). Study on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites. Composites Part B: Engineering, 51, 54–57.

Botelho, E. C., Figiel, L., Rezende, M. C. and Lauke, B. (2003). Mechanical behavior of carbon fiber reinforced polyamide composites. Composites Science and Technology, 63(13), 1843–1855.

Braga, R. A. and Magalhaes, P. A. A. (2015). Analysis of the mechanical and thermal properties of jute and glass fiber as reinforcement epoxy hybrid composites. Materials Science and Engineering C, 56, 269–273.

Brown, K. A., Brooks, R. and Warrior, N. A. (2010). The static and high strain rate behaviour of a commingled E-glass/polypropylene woven fabric composite. Composites Science and Technology, 70(2), 272–283.

Callister, W. D. (2007). Materials science and engineering: An introduction. New York: John Wiley & Sons.

Capela, C., Oliveira, S. E. and Ferreira, J. A. M. (2019). Fatigue behavior of short carbon fiber reinforced epoxy composites. Composites Part B: Engineering, 164, 191–197.

Chaichanawong, J., Thongchuea, C. and Areerat, S. (2016). Effect of moisture on the mechanical properties of glass fiber reinforced polyamide composites. Advanced Powder Technology, 27(3), 898–902.

Chen, K., Jia, M., Sun, H. and Xue, P. (2019). Thermoplastic Reaction Injection Pultrusion for Continuous Glass Fiber-Reinforced Polyamide-6 Composites. Materials, 12, 463.

Coronado, J. J. (2012). Effect of Abrasive Size on Wear. Abrasion Resistance of Materials, Marcin Adamiak, IntechOpen. (online). https://www.intechopen.com/books/abrasion-resistance-of-materials/effect-of-abrasive-size-on-wear (16 March 2012).

Deshmukh, B. B. and Jaju, S. B. (2011). Design and analysis of glass fiber reinforced polymer (GFRP) leaf spring. International Conference on Emerging Trends in Engineering and Technology, ICETET, 82–87.

Devendra, K. and Rangaswamy, T. (2013). Strength Characterization of E-glass Fiber Reinforced Epoxy Composites with Filler Materials. Journal of Minerals and Materials Characterization and Engineering, 1, 353–357.

Durairaj, R. B., Mageshwaran, G. and Sriram, V. (2016). Investigation on Mechanical Properties of Glass and Carbon Fiber Reinforced With Polyester Resin Composite. International Journal of ChemTech Research, 9(06), 417–423.

Elahi, A. H. M. F., Hossain, M., Afrin, S. and Khan, M. A. (2014). Study on the Mechanical Properties of Glass Fiber Reinforced Polyester Composites. International Conference on Mechanical Industrial and Energy Engineering, 3, 1-6.

Elanchezhian, C., Ramnath, B. V. and Hemalatha, J. (2014). Mechanical Behaviour of Glass and Carbon Fibre Reinforced Composites at Varying Strain Rates and Temperatures. Procedia Materials Science, 6, 1405–1418.

Erden, S., Sever, K., Seki, Y. and Sarikanat, M. (2010). Enhancement of the mechanical properties of glass/polyester composites via matrix modification glass/polyester composite siloxane matrix modification. Fibers and Polymers, 11(5), 732–737.

Etcheverry, M. and Barbosa, S. E. (2012). Glass fiber reinforced polypropylene mechanical properties enhancement by adhesion improvement. Materials, 5(6), 1084–1113.

Feldmann, M. (2016). The effects of the injection moulding temperature on the mechanical properties and morphology of polypropylene man-made cellulose fibre composites. Composites Part A: Applied Science and Manufacturing, 87, 146–152.

Franco-Marquès, E., Méndez, J. A., Pèlach, M. A., Vilaseca, F., Bayer, J. and Mutjé, P. (2011). Influence of coupling agents in the preparation of polypropylene composites reinforced with recycled fibers. Chemical Engineering Journal, 166(3), 1170–1178.

Frigione, M. and Lettieri, M. (2018). Durability Issues and Challenges for Material Advancements in FRP Employed in the Construction Industry. Polymers, 10(247), 1–15.

Fu, S. Y., Lauke, B., Mäder, E., Yue, C. Y. and Hu, X. (2000). Tensile properties of short-glass-fiber-and short-carbon-fiber-reinforced polypropylene composites. Composites Part A: Applied Science and Manufacturing, 31(10), 1117–1125.

Fu, S. Y., Feng, X. Q., Lauke, B. and Mai, Y. W. (2008). Effects of particle size, particle/matrix interface adhesion and particle loading on mechanical properties of particulate-polymer composites. Composites Part B: Engineering, 39(6), 933–961.

Gamze Karsli, N., Yesil, S. and Aytac, A. (2014). Effect of hybrid carbon nanotube/short glass fiber reinforcement on the properties of polypropylene composites. Composites Part B: Engineering, 63, 154–160.

Gamze Karsli, N., Yilmaz, T., Aytac, A. and Ozkoc, G. (2013). Investigation of erosive wear behavior and physical properties of SGF and/or calcite reinforced ABS/PA6 composites. Composites Part B: Engineering, 44(1), 385–393.

Goh, G. D., Yap, Y. L., Agarwala, S. and Yeong, W. Y. (2019). Recent Progress in

Additive Manufacturing of Fiber Reinforced Polymer Composite. Adv. Mater. Technol, (4), 1-22.

Güllü, A., Özdemir, A. and Özdemir, E. (2006). Experimental investigation of the effect of glass fibres on the mechanical properties of polypropylene (PP) and polyamide 6 (PA6) plastics. Materials and Design, 27(4), 316–323.

Hachemane, B., Zitoune, R., Bezzazi, B. and Bouvet, C. (2013). Sandwich composites impact and indentation behaviour study. Composites Part B: Engineering, 51, 1–10.

Hafner, B. (2006). Energy Dispersive Spectroscopy on the SEM: A Primer. Characterization Facility, University of Minnesota, Twin Cities.

Hanna, W. A., Gharib, F. E. and Marhoon, I. I. (2011). Ceramic Filled Polymer Matrix Composite Used For Bio-Medical Application. Journal of Minerals & Materials Characterization & Engineering, 10(12), 1167–1178.

Hartl, A. M., Jerabek, M. and Lang, R. W. (2015). Effect of fiber orientation, stress state and notch radius on the impact properties of short glass fiber reinforced polypropylene. Polymer Testing, 43, 1–9.

Hemanth, R., Sekar, M. and Suresha, B. (2014). Effects of Fibers and Fillers on Mechanical Properties of Thermoplastic Composites. Indian Journal of Advances in Chemical Science, 2, 28–35.

Herrington, K. D. (2015). Factors Affecting Fiber Orientation and Properties in Semi-Flexible Fiber Composites : Including the Addition of Carbon Nanotubes. Ph.D. Thesis. Blacksburg, VA.

Ibáñez-Gutiérrez, F. T., Cicero, S. and Carrascal, I. A. (2019). On the influence of moisture content on the fracture behaviour of notched short glass fibre reinforced polyamide 6. Composites Part B: Engineering, 159, 62–71.

John, J., Gangadhar, S. A. and Shah, I. (2001). Flexural strength of heat-polymerized polymethyl methacrylate denture resin reinforced with glass, aramid, or nylon fibers. Journal of Prosthetic Dentistry, 86(4), 424–427.

Kalpakjian, S. and Schmid, S. R. (2010). Manufacturing Engineering and Technology SI (6th Edition). Pearson Education Canada.

Karandikar, P. M., Kharde, R. R., Bhoyar, S. B. and Kadu, R. L. (2014). Study the Tribological Properties of PEEK / PTFE Reinforced with Glass Fibers and Solid Lubricants at Room Temperature. International Journal of Current Engineering and Technology, 4(4), 2401–2404.

Karsli, N. G. and Aytac, A. (2013). Tensile and thermomechanical properties of short carbon fiber reinforced polyamide 6 composites. Composites Part B: Engineering, 51, 270–275.

Khan, M. N. and Sultana, S. (2010). Comparative Studies of Mechanical and Interfacial Properties Between Jute and E-Glass Fiber-reinfroced Polypropylene Composites. Journal of Reinforced Plastics and Composites, 29(7), 1078-1088.

Khan, R. A., Khan, M. A., Khan, A. H. and Hossain, M. A. (2009a). Effect of gamma radiation on the performance of jute fabrics-reinforced polypropylene composites. Radiations Physics and Chemistry, 78, 986–993.

Khan, R. A., Khan, M. A., Sultana, S., Khan, M. N., Shubhra Q. T. H. and Noor, F. G. (2009b). Mechanical, Degradation, and Interfacial Properties of Synthetic Degradable Fiber Reinforced Polypropylene Composites. Journal of Reinforced Plastics and Composites, 29(3), 466–476.

Khan, R. A., Khan, M. A., Zaman, H. U., Pervin S., Khan, N., Sultana, S., Saha, M. and Mustafa A. I. (2010). Comparative Studies of Mechanical and Interfacial Properties Between Jute and E-glass Fiber-reinforced Polypropylene composites. Journal of Reinforced Plastics and Composite, 29(7), 1078–1088.

Klein, R. (2011). Laser Welding of Plastics First Edition. Wiley-VCH Verlag GmbH & Co. KGaA.

Ku, H., Wang, H., Pattarachaiyakoop, N. and Trada, M. (2011). A review on the tensile properties of natural fiber reinforced polymer composites. Composites Part B: Engineering, 42(4), 856–873.

Kumarasamy, S., Abidin, M. S. Z., Bakar, M. N. A., Nazida, M. S., Mustafa, Z. and Anjang. A. (2018). Effects of High and Low Temperature on the Tensile Strength of Glass Fiber Reinforced Polymer Composites. IOP Conference Series: Materials Science and Engineering, 370(1), 1-7.

Kuram, E., Tasci, E., Altan, A. I., Medar, M. M., Yilmaz, F. and Ozcelik, B. (2013). Investigating the effects of recycling number and injection parameters on the mechanical properties of glass-fibre reinforced nylon 6 using Taguchi method. Materials and Design, 49, 139–150.

Kusaseh, N. M., Nuruzzaman, D. M., Ismail, N. M., Hamedon, Z., Azhari, A. and Iqbal, A. K. M. A. (2018). Flexure and impact properties of glass fiber reinforced nylon 6-polypropylene composites. IOP Conference Series: Materials Science and Engineering, 319(1), 1-14.

Landesmann, A., Seruti, C. A. and De Miranda Batista, E. (2015). Mechanical Properties of Glass Fiber Reinforced Polymers Members for Structural Aplications. Materials Research, 18(6), 1372–1383.

Li, M., Wen, X., Liu, J. and Tang, T. (2014). Synergetic effect of epoxy resin and maleic anhydride grafted polypropylene on improving mechanical properties of polypropylene/short carbon fiber composites. Composites Part A: Applied Science and Manufacturing, 67, 212–220.

Li, X., Tabil, L. G., Panigrahi, S. and Crerar, W. J. (2006). The Influence of Fiber Content on Properties of Injection Molded Flax Fiber-HDPE Biocomposites. CSBE/SCGAB 2006 Annual Conference, 1-10.

Lichao, Y. and Yan, M. (2019). Loading rate and temperature dependence of flexural behavior in injection-molded glass fiber reinfroced polypropylene composites. Composites Part B, 161, 285-299.

Lingesh, B. V., Rudresh, B. M. and Ravikumar, B. N. (2014). Effect of Short Glass Fibers on Mechanical Properties of Polyamide66 and Polypropylene (PA66/PP) Thermoplastic Blend Composites. Procedia Materials Science, 5, 1231–1240.

Liu, Q., Lin, Y., Zong, Z., Sun, G. and Li, Q. (2013). Lightweight design of carbon twill weave fabric composite body structure for electric vehicle. Composite Structures, 97, 231–238.

Maddah, H. A. (2016). Polypropylene as a Promising Plastic: A Review. American Journal of Polymer Science, 6(1), 1–11.

Massaq, A., Rusinek, A., Klosak, M., Bahi, S. and Arias, A. (2019). Strain rate effect on the mechanical behavior of polyamide composites under compression loading. Composite Structures, 214, 114–122.

Mathew, M., Shenoy, K. and Ravinshankar K. S. (2017). Impact strength of poly propylene fiber reinforced PMMA. International Journal of Scientific & Engineering Research, 6(2), 21–25.

Mir, A., Zitoune, R., Collombet, F. and Bezzazi, B. (2010). Study of mechanical and thermomechanical properties of jute/epoxy composite laminate. Journal of Reinforced Plastics and Composites, 29(11), 1669–1680.

Miri, V., Persyn, O., Lefebvre, J. M. and Seguela, R. (2009). Effect of water absorption on the plastic deformation behavior of nylon 6. European Polymer Journal, 45(3), 757–762.

Misirli, C., Erdogan, S. E. and Hüner, U. (2011). Prediction in CAE Programme with/without Reinforced Plastic Production in Injection Molding Process. International Journal of Modern Manufacturing Technologies ISSN 2067-3604, III(1), 45–50.

Mortazavian, S. and Fatemi, A. (2015). Effects of fiber orientation and anisotropy on tensile strength and elastic modulus of short fiber reinforced polymer composites. Composites Part B, 72, 116–129.

Mouhmid, B., Imad, A., Benseddiq, N., Benmedakhène, S. and Maazouz, A. (2006). A study of the mechanical behaviour of a glass fibre reinforced polyamide 6,6: Experimental investigation. Polymer Testing, 25(4), 544–552.

Mun, H. J., Cha, S. H., Choi, P. S., Kim, J. I. and Ryu, S. H. (2019). Correlation between compounding sequence and the properties of glass fiber-Reinforced nylon-6,6 composite. Polymer Engineering and Science, 59(1), 155–161.

Nakao, R., Inoya, H. and Hamada, H. (2016). Mechanical properties of injection molded products fabricated by Direct Fiber Feeding Injection Molding. Energy Procedia, 89, 307–312.

Nicolazo, C., Sarda, A., Vachot, P., Mousseau, P. and Deterre, R. (2010). Change on temperature at the surface of injection moulded parts. Journal of Materials Processing Technology, 210(2), 233–237.

Nuruzzaman, D. M., Iqbal, A. K. M. A., Oumer, A. N., Ismail, N. M. and Basri, S. (2016). Experimental investigation on the mechanical properties of glass fiber reinforced nylon. IOP Conference Series: Materials Science and Engineering, 114, 1-7.

Nuruzzaman, D. M., Kusaseh, N., Basri, S., Oumer, A. N. and Hamedon, Z. (2016). Modeling and flow analysis of pure nylon polymer for injection molding process. IOP Conference Series: Materials Science and Engineering, 114(1), 1-7.

Nuruzzaman, D. M., Kusaseh, N. M., Chowdhury, M. A., Rahman, N. A. N. A., Oumer, A. N., Fatchurrohman, N. and Ismail, N. M. (2018). Experimental investigation on flexure and impact properties of injection molded polypropylene-nylon 6-glass fiber polymer composites. IOP Conference Series: Materials Science and Engineering, 342(1), 1-7.

Okoli, O. (2001). The effects of strain rate and failure modes on the failure energy of fibre reinforced composites. Composite Structures, 54, 299–303.

Ou, Y. and Zhu, D. (2015). Tensile behavior of glass fiber reinforced composite at different strain rates and temperatures. Construction and Building Materials, 96, 648–656.

Ou, Y., Zhu, D., Zhang, H., Huang, L., Yao, Y., Li, G. and Mobasher, B. (2016). Mechanical characterization of the tensile properties of glass fiber and its reinforced polymer (GFRP) composite under varying strain rates and temperatures. Polymers, 8(5).

Park, S. J. and Seo, M. K. (2011). Element and Processing. Interface Science and Technology. Science Direct. (online). https://www.sciencedirect.com/bookseries/interface-science-and-technology/vol/18/suppl/C (14 July 2014).

Pisharath, S. and Wong, S. C. (2003). Processability of LCP-Nylon-Glass Hybrid Composites. Polymer Composites, 24(1), 109–118.

Premalal, H. G. B., Ismail, H. and Baharin, A. (2002). Comparison of the mechanical properties of rice husk powder filled polypropylene composites with talc filled polypropylene composites. Polymer Testing, 21(7), 833–839.

Raja, R. S., Manisekar, K. and Manikandan, V. (2013). Effect of fly ash filler size on mechanical properties of polymer matrix composites. International Journal of Mining, Metallurgy & Mechanical Engineering, 1(1), 34–38.

Rajak, D. K., Pagar, D. D., Menezes, P. L. and Linul, E. (2019). Fiber-Reinforced Polymer Composites : Manufacturing, Properties, and Applications. Polymers, 11(10), 1667.

Ramesh, M., Palanikumar, K. and Reddy, K. H. (2013). Mechanical property evaluation of sisal-jute-glass fiber reinforced polyester composites. Composites Part B: Engineering, 48, 1–9.

Rathnakar, G. and Shivanand, H. K. (2012). Effect of Thickness on Flexural Properties of Epoxy based Glass Fiber Reinforced Laminate. International Journal of Science and Technology, 2(6), 409–412.

Reddy, S. P. and Reddy, A. C. (2014). Tensile and Flexural Strength of Glass Fiber Epoxy Composites. International Conference on Advanced Materials and Manufacturing Technologies (AMMT), 98–102.

Reis, J. M. L., Coelho, J. L. V., Monteiro, A. H. and Da Costa Mattos, H. S. (2012). Tensile behavior of glass/epoxy laminates at varying strain rates and temperatures. Composites Part B: Engineering, 43(4), 2041–2046.

Reis, P. N. B., Gorbatikh, L., Ivens, J. and Lomov, S. V. (2018). Viscoelastic Behaviour of Self-reinforced Polypropylene Composites under Bending Loads. Procedia Structural Integrity, 13, 1999–2004.

Reynaud, E., Jouen, T., Gauthier, C., Vigier, G. and Varlet, J. (2001). Nanofillers in polymeric matrix: A study on silica reinforced PA6. Polymer, 42(21), 8759–8768.

Roeder, J., Oliveira, R. V. B., Gonçalves, M. C., Soldi, V. and Pires, A. T. N. (2002). Polypropylene/polyamide-6 blends: Influence of compatibilizing agent on interface domains. Polymer Testing, 21(7), 815–821.

Rudresh, B. M., Ravikumar, B. N. and Madhu, D. (2016). Influence of Fine Particles on the Mechanical Behavior of Short Glass Fiber Reinforced Thermoplastics Blends. Indian Journal of Advances in Chemical Science, 4(1), 68–76.

Russo, P., Acierno, D., Simeoli, G., Iannace, S. and Sorrentino, L. (2013). Flexural and impact response of woven glass fiber fabric/polypropylene composites. Composites Part B: Engineering, 54(1), 415–421.

Sathishkumar, T. P., Satheeshkumar, S. and Naveen, J. (2014). Glass fiber-reinforced polymer composites - A review. Journal of Reinforced Plastics and Composites, 33(13), 1258–1275.

Sen, M., Sarkar, P., Modak, N. and Sahoo, P. (2015). Woven E-glass Fiber Reinforced Epoxy Composite – Preparation and Tribological Characterization. International Journal of Materials Chemistry and Physics, 1(2), 189-197.

Sharma, D., Yadav, S., Chand, S., Kumar, U., Kandpal, B. C., Kumar, A., and Gupta, D. K. (2018). Fabrication and characterization of Glass Fiber/SiC Reinforced Polymer composite. International Journal of Applied Engineering Research ISSN 0973-4562, 13(6), 171–176.

Shokrieh, M. M. and Omidi, M. J. (2009). Tension behavior of unidirectional glass/epoxy composites under different strain rates. Composite Structures, 88(4), 595–601.

Shubhra, Q. T., Alam, A. and Quaiyyum, M. (2013). Mechanical properties of polypropylene composites. Journal of Thermoplastic Composite Materials, 26(3), 362–391.

Suresh, S. and Senthil Kumar, V. S. (2014). Experimental determination of the mechanical behavior of glass fiber reinforced polypropylene composites. Procedia Engineering, 97, 632–641.

Suzuki, E. (2002). High-resolution scanning electron microscopy of immunogold-labelled cells by the use of thin plasma coating of osmium. Journal of Microscopy, 208(3), 153–157.

Tang, J. J., Li, S. Y., Wang, Y. H. and Tang, T. (2013). In situ ethylene copolymerization with an olefin-type monomer for one-pot synthesis of polyethylene tethered on multi-walled carbon nanotubes. Chinese Journal of Polymer Science (English Edition), 31(10), 1329–1333.

Tanimoto, Y., Nishiwaki, T., Nishiyama, N., Nemoto, K. and Maekawa, Z. (2002). A Simplified Numerical Simulation Method of Bending Properties for Glass Fiber Cloth Reinforced Denture Base Resin. Dental Materials Journal, 21(2), 105–117.

Taranu, N., Oprisan, G., Budesco, M., Secu, A. and Gosav, I. (2015). The use of Glass Fibre Reinforced Polymer Composites as Reinforcement for Tubular Concrete Poles. International Conference on Sustainability in Science Engineering, 508–513.

Tian, H., Zhang, S., Ge, X. and Xiang, A. (2017). Crystallization behaviors and mechanical properties of carbon fiber-reinforced polypropylene composites. J Therm Anal Calorim, 128, 1495–1504.

Tjong, S. C., Xu, S. A., Kwok-Yiu Li, R. and Mai, Y. W. (2002). Short glass fiber-reinforced polyamide 6,6 composites toughened with maleated SEBS. Composites Science and Technology, 62(15), 2017–2027.

Unterweger, C., Brüggemann, O. and Fürst, C. (2014). Effects of different fibers on the properties of short-fiber-reinforced polypropylene composites. Composites Science and Technology, 103, 49–55.

Varga, J. (2002). β-Modification of Isotactic Polypropylene: Preparation, Structure, Processing, Properties, and Application. Journal of Macromolecular Science, Part B, 41(4-6), 1121-1171.

Valliappan, M. (2015). An Experimental Investigation on Mechanical Properties and Tribological Behaviour of FRP Composite. International Journal of Applied Engineering Research, 10(85).

Wambua, P., Ivens, J. and Verpoest, I. (2003). Natural fibres: can they replace glass in fibre reinforced plastics?. Composites Scienceand Technology, 63, 1259–1264.

Yang, H. S., Kim, H. J., Son, J., Park, H. J., Lee, B. J. and Hwang, T. S. (2004). Rice-husk flour filled polypropylene composites; mechanical and morphological study. Composite Structures, 63, 305–312.

Yoo, Y., Spencer, M. W. and Paul, D. R. (2011). Morphology and mechanical properties of glass fiber reinforced Nylon 6 nanocomposites. Polymer, 52(1), 180–190.

Yu, L. and Ma, Y. (2019). Loading rate and temperature dependence of flexural behavior in injection-molded glass fiber reinforced polypropylene composites. Composites Part B, 161, 285–299.

Zhang, X., Li, K. Z., Li, H. J., Fu, Y. W. and Fei, J. (2014). Tribological and mechanical properties of glass fiber reinforced paper-based composite friction material. Tribology International, 69, 156–167.

Zhen, W., Zhou, Y. and Mallick, P. K. (2002). Effects of Temperature and Strain Rate on the Tensile Behavior of Short Fiber Reinforced Polyamide-6. Polymer Composites, 23(5), 858-871.

Zhou, S., Zhang, Q., Wu, C. and Huang, J. (2013). Effect of carbon fiber reinforcement on the mechanical and tribological properties of polyamide6/polyphenylene sulfide composites. Materials and Design, 44, 493–499.

# APPENDICES

Appendix A: Sample Calculations

**a) 70%PA6+30%PP**

70%PA6+30%PP = 400gm

$$Pure\ PA6: \frac{70}{100} \times 400\text{gm} = 280\text{gm}$$

$$Pure\ PP: \frac{30}{100} \times 400\text{gm} = 120\text{gm}$$

**b) 65%PA6+30%PP+5%GF**

65%PA6+30%PP+5%GF = 400gm

$$Pure\ PP: \frac{30}{100} \times 400\text{gm} = 120\text{gm}$$

∴ 65%PA6+30%PP+5%GF (×4)

↓ 260gm ↓ 120gm ↓ 20gm

Premix materials (70%PA6+30%GF)

30→100

$$1 \rightarrow \frac{100}{30}$$

$$GF \rightarrow \frac{100 \times 20}{30} = 66.67\text{gm}$$

66.67gm – 20gm = 46.67gm (PA6 in premix)

260gm – 46.67gm = 213.33gm (Pure

Total Weight = 213.33gm (PA6) + 120gm (PP) + 66.67gm (GF) = <u>400gm</u>

**c) 60%PA6+30%PP+10%GF**

60%PA6+30%PP+10%GF = 520gm

$$Pure\ PP: \frac{30}{100} \times 520\text{gm} = 156\text{gm}$$

∴ 60%PA6+30%PP+10%GF (×5.2)

↓ 312gm ↓ 156gm ↓ 52gm

Premix materials (70%PA6+30%GF)

30→100

$$1 \rightarrow \frac{100}{30}$$

$$GF \rightarrow \frac{100 \times 52}{30} = 173.33\text{gm}$$

173.33gm – 52gm = 121.33gm (PA6 in Premix)

312gm – 121.33gm = 190.67gm (Pure

Total Weight = 190.67gm (PA6) + 156gm (PP) + 173.33gm (GF) = 520gm

**d) 55%PA6+30%PP+15%GF**

55%PA6+30%PP+15%GF = 540gm

$$Pure\ PP: \frac{30}{100} \times 540\text{gm} = 162\text{gm}$$

∴ 55%PA6+30%PP+15%GF (×5.4)

297gm 162gm 81gm

Premix materials (70%PA6+30%GF)

30→100

$$1 \rightarrow \frac{100}{30}$$

$$GF \rightarrow \frac{100 \times 81}{30} = 270\text{gm}$$

270gm – 81gm = 189gm (PA6 in Premix)

297gm – 189gm = 108gm (Pure

Total Weight = 108gm (PA6) + 162gm (PP) + 270gm (GF) = 540gm

**e) 50%PA6+30%PP+20%GF**

50%PA6+30%PP+20%GF = 580gm

$$Pure\ PP: \frac{30}{100} \times 580\text{gm} = 174\text{gm}$$

∴ 50%PA6+30%PP+20%GF (×5.8)

290gm 174gm 116gm

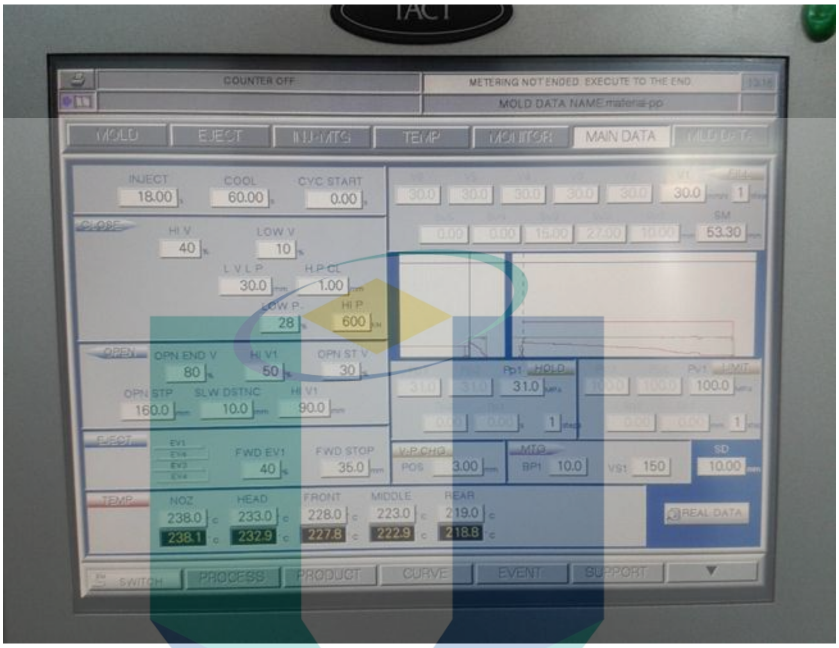
Premix materials (70%PA6+30%GF)

| | |
|---|---|
| 30→100 | 386.67gm – 116gm = 270.67gm (PA6 in Premix) |
| $1 \rightarrow \frac{100}{30}$ | 290gm – 270.67gm = 19.33gm (Pure |
| $GF \rightarrow \frac{100 \times 116}{30} = 386.67\text{gm}$ | |

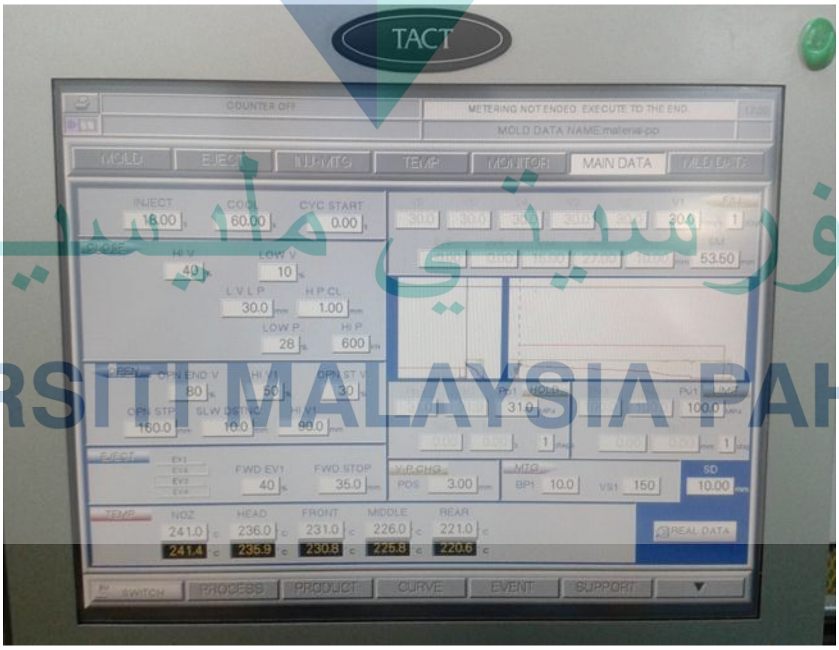
Total Weight = 19.33gm (PA6) + 174gm (PP) + 386.67gm (GF) = 580gm

Appendix B: Injection Molding Process

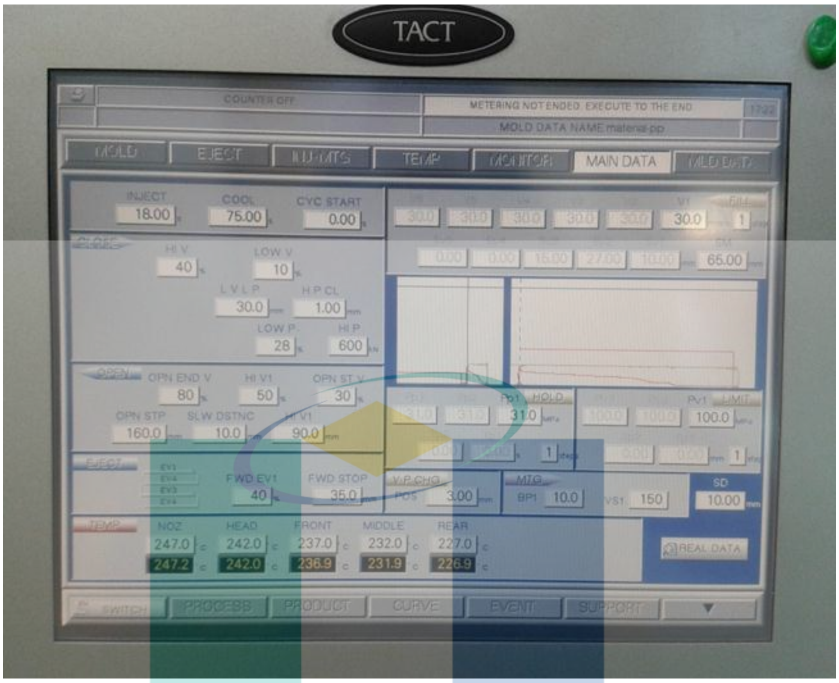
1. Injection molding parameter of 70%PA6+30%PP pure polymer blend.



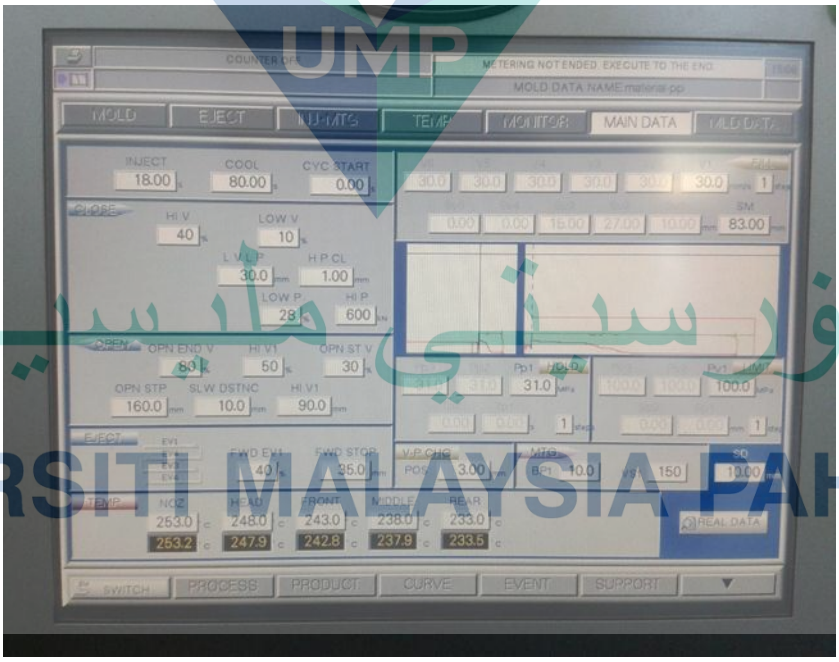
2. Injection molding parameter of 65%PA6+30%PP+5%GF composite.



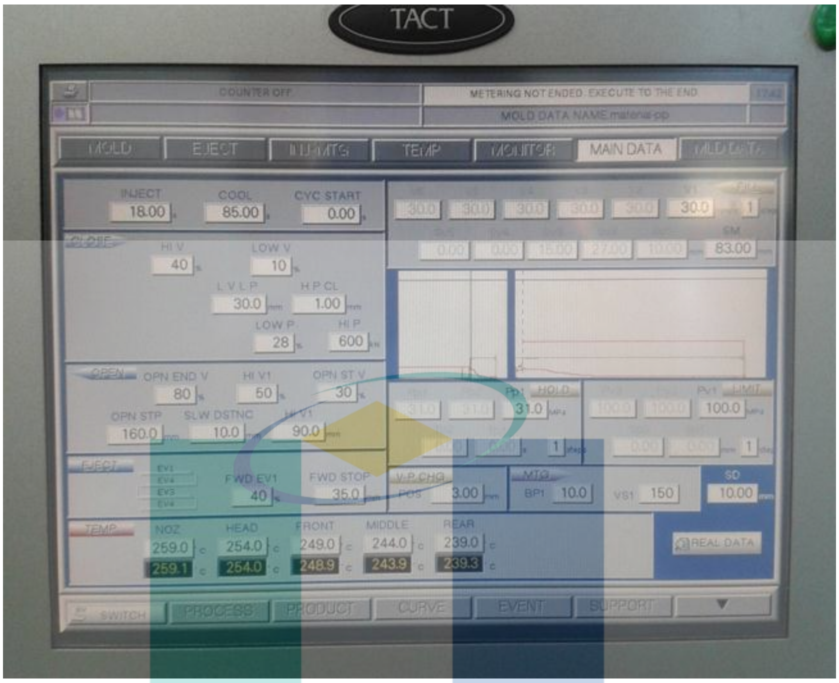
3. Injection molding parameter of 60%PA6+30%PP+10%GF composite.




4. Injection molding parameter of 55%PA6+30%PP+15%GF composite.



5. Injection molding parameter of 50%PA6+30%PP+20%GF composite.



Appendix C : List of Publications

1. **N M Kusaseh**, D M Nuruzzaman, N M Ismail, Z Hamedon, A Azhari and A K M A Iqbal, "Flexure and impact properties of glass fiber reinforced nylon 6-polypropylene composites". *IOP Conf. Series: Materials Science and Engineering 319*, 1-14. (2018) (SCOPUS).

2. D M Nuruzzaman, **N M Kusaseh**, M A Chowdhury, N A N A Rahman, A N Oumer, N Fatchurrohman, A K M A Iqbal and N M Ismail, "Experimental investigation on flexure and impact properties of injection molded polypropylene-nylon 6-glass fiber polymer composites". *IOP Conf. Series: Materials Science and Engineering 342,* 1-7. (2018) (SCOPUS).

3. D M Nuruzzaman, **N Kusaseh**, S Basri, A N Oumer and Z Hamedon, "Modeling and flow analysis of pure nylon polymer for injection molding process". *IOP Conf. Series: Materials Science and Engineering 114*, 1-7. (2016) (SCOPUS).

4. **N M Kusaseh**, D M Nuruzzaman, M A Chowdhury, A K M A Iqbal, N M Ismail, N Fatchurrohman and C S Yi, "Infuence of Glass Fiber Content on the Flexural Properties of Polyamide 6-Polypropylene Blend Composites". *Lecture Notes in Mechanical Engineering (LNME),* (In Press) (2020).

5. Nuruzzaman, D.M., **Kusaseh, N.M.**, Ismail, N.M., Iqbal, A.K.M.A., Rahman, M.M., Azhari, A., Hamedon, Z. and Yi, C.S. "Influence of glass fiber content on tensile properties of polyamide-polypropylene based polymer blend composites" *Materials Today*: Proceedings (In Press) (SCOPUS).

**1.** **N M Kusaseh**, D M Nuruzzaman, N M Ismail, Z Hamedon, A Azhari and A K M A Iqbal, "Flexure and impact properties of glass fiber reinforced nylon 6-polypropylene composites". *IOP Conf. Series: Materials Science and Engineering 319*, 1-14. (2018) (SCOPUS).


IOP Conf. Series: Materials Science and Engineering **319** (2018) 012045 doi:10.1088/1757-899X/319/1/012045

# Flexure and impact properties of glass fiber reinforced nylon 6-polypropylene composites

**N M Kusaseh[1], D M Nuruzzaman[2], N M Ismail[2], Z Hamedon[2], A Azhari[2] and A K M A Iqbal[2]**

[1,2]Faculty of Manufacturing Engineering, University Malaysia Pahang, 26600 Pekan, Pahang Darul Makmur, Malaysia

[1]E-mail: izzathanis92@gmail.com

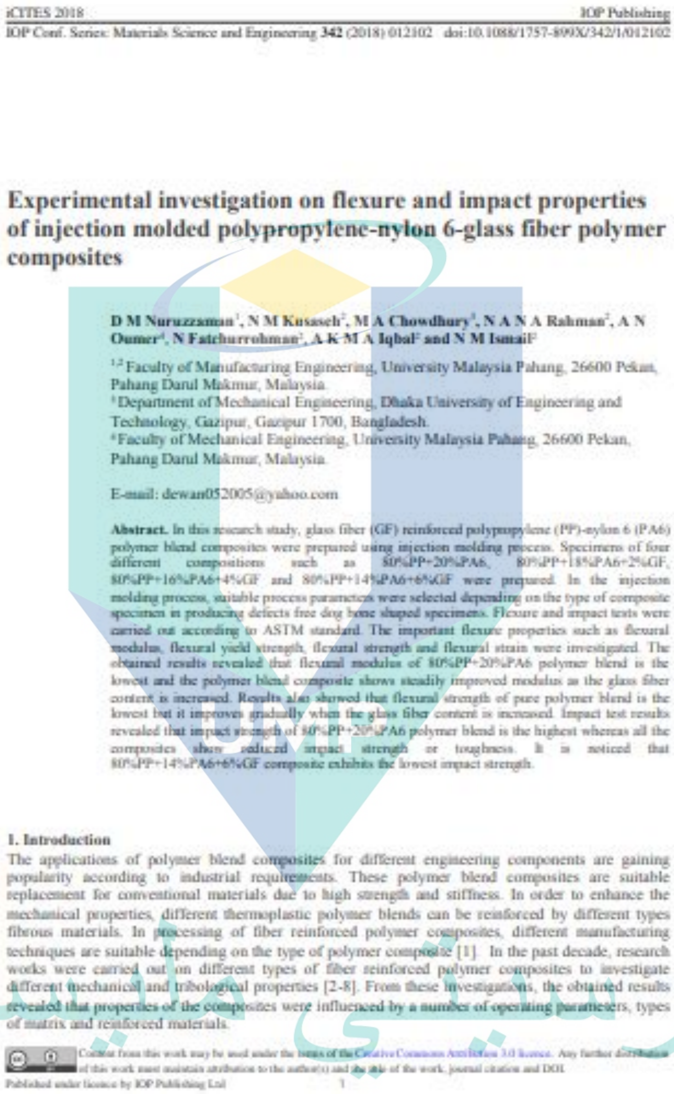
**Abstract.** In recent years, polymer composites are rapidly developing and replacing the metals or alloys in numerous engineering applications. These polymer composites are the topic of interests in industrial applications such as automotive and aerospace industries. In the present research study, glass fiber (GF) reinforced nylon 6 (PA6)-polypropylene (PP) composite specimens were prepared successfully using injection molding process. Test specimens of five different compositions such as, 70%PA6+30%PP, 65%PA6+30%PP+5%GF, 60%PA6+30%PP+10%GF, 55%PA6+30%PP+15%GF and 50%PA6+30%PP+20%GF were prepared. In the experiments, flexure and impact tests were carried out. The obtained results revealed that flexure and impact properties of the polymer composites were significantly influenced by the glass fiber content. Results showed that flexural strength is low for pure polymer blend and flexural strength of GF reinforced composite increases gradually with the increase in glass fiber content. Test results also revealed that the impact strength of 70%PA6+30%PP is the highest and 55%PA6+30%PP+15%GF composite shows moderate impact strength. On the other hand, 50%PA6+30%PP+20%GF composite shows low toughness or reduced impact strength.

## 1. Introduction

Polymers and their composites are gaining popularity in numerous engineering applications such as bearing material, gears, cams, wheels, rollers etc. for improved mechanical properties in relation to industrial requirements. The application of high performance polymer blend composites is a suitable alternative to conventional materials due to their high specific strength and stiffness. Polymer blends of different thermoplastics can be prepared and these polymer blends can be reinforced by different fibrous materials to enhance the mechanical properties. During the past decade, a number of research works were carried out to investigate the mechanical and tribological properties of different types of polymer composites [1-8]. The obtained results showed that the properties were significantly influenced by several operating conditions and the type of reinforced material.

Impact behaviour of E-glass fiber reinforced epoxy and polypropylene matrix composites was investigated and the obtained results show that the type of resin is an important parameter for the impact behaviour of the composites [9]. Flexural strength of polymethyl methacrylate (PMMA) resin reinforced with glass, aramid and nylon fibers were evaluated using 3-point bending test with universal testing machine [10]. The experimental data were compared with the flexural strength of pure PMMA resin and the comparison revealed that reinforced specimens showed better flexural strength than the conventional acrylic resin. Moreover, the specimens reinforced with glass fibers exhibited highest flexural strength, followed by the specimens reinforced with aramid and specimens reinforced with nylon showed the lowest flexural strength. Flexural properties of glass fiber reinforced polyamide 6-6 composites were investigated [11]. The obtained results showed that

2. D M Nuruzzaman, **N M Kusaseh**, M A Chowdhury, N A N A Rahman, A N Oumer, N Fatchurrohman, A K M A Iqbal and N M Ismail, “Experimental investigation on flexure and impact properties of injection molded polypropylene-nylon 6-glass fiber polymer composites”. *IOP Conf. Series: Materials Science and Engineering 342*, 1-7. (2018) (SCOPUS).


iCITES 2018 IOP Publishing
IOP Conf. Series: Materials Science and Engineering **342** (2018) 012102 doi:10.1088/1757-899X/342/1/012102

**Experimental investigation on flexure and impact properties of injection molded polypropylene-nylon 6-glass fiber polymer composites**

**D M Nuruzzaman[1], N M Kusaseh[2], M A Chowdhury[3], N A N A Rahman[2], A N Oumer[4], N Fatchurrohman[2], A K M A Iqbal[2] and N M Ismail[2]**

[1,2] Faculty of Manufacturing Engineering, University Malaysia Pahang, 26600 Pekan, Pahang Darul Makmur, Malaysia
[3] Department of Mechanical Engineering, Dhaka University of Engineering and Technology, Gazipur, Gazipur 1700, Bangladesh.
[4] Faculty of Mechanical Engineering, University Malaysia Pahang, 26600 Pekan, Pahang Darul Makmur, Malaysia

E-mail: dewan052005@yahoo.com

**Abstract.** In this research study, glass fiber (GF) reinforced polypropylene (PP)-nylon 6 (PA6) polymer blend composites were prepared using injection molding process. Specimens of four different compositions such as 80%PP+20%PA6, 80%PP+18%PA6+2%GF, 80%PP+16%PA6+4%GF and 80%PP+14%PA6+6%GF were prepared. In the injection molding process, suitable process parameters were selected depending on the type of composite specimen in producing defects free dog bone shaped specimens. Flexure and impact tests were carried out according to ASTM standard. The important flexure properties such as flexural modulus, flexural yield strength, flexural strength and flexural strain were investigated. The obtained results revealed that flexural modulus of 80%PP+20%PA6 polymer blend is the lowest and the polymer blend composite shows steadily improved modulus as the glass fiber content is increased. Results also showed that flexural strength of pure polymer blend is the lowest but it improves gradually when the glass fiber content is increased. Impact test results revealed that impact strength of 80%PP+20%PA6 polymer blend is the highest whereas all the composites show reduced impact strength or toughness. It is noticed that 80%PP+14%PA6+6%GF composite exhibits the lowest impact strength.

**1. Introduction**

The applications of polymer blend composites for different engineering components are gaining popularity according to industrial requirements. These polymer blend composites are suitable replacement for conventional materials due to high strength and stiffness. In order to enhance the mechanical properties, different thermoplastic polymer blends can be reinforced by different types fibrous materials. In processing of fiber reinforced polymer composites, different manufacturing techniques are suitable depending on the type of polymer composite [1]. In the past decade, research works were carried out on different types of fiber reinforced polymer composites to investigate different mechanical and tribological properties [2-8]. From these investigations, the obtained results revealed that properties of the composites were influenced by a number of operating parameters, types of matrix and reinforced materials.

3. D M Nuruzzaman, **N Kusaseh**, S Basri, A N Oumer and Z Hamedon, "Modeling and flow analysis of pure nylon polymer for injection molding process". *IOP Conf. Series: Materials Science and Engineering 114*, 1-7. (2016) (SCOPUS).


IOP Conf. Series: Materials Science and Engineering **114** (2016) 012043 doi:10.1088/1757-899X/114/1/012043

# Modeling and flow analysis of pure nylon polymer for injection molding process

**D M Nuruzzaman[1], N Kusaseh[2], S Basri[2], A N Oumer[3] and Z Hamedon[2]**

[1,2] Faculty of Manufacturing Engineering, University Malaysia Pahang, Malaysia
[3] Faculty of Mechanical Engineering, University Malaysia Pahang, Malaysia

E-mail: dewan052005@yahoo.com

**Abstract.** In the production of complex plastic parts, injection molding is one of the most popular industrial processes. This paper addresses the modeling and analysis of the flow process of the nylon (polyamide) polymer for injection molding process. To determine the best molding conditions, a series of simulations are carried out using Autodesk Moldflow Insight software and the processing parameters are adjusted. This mold filling commercial software simulates the cavity filling pattern along with temperature and pressure distributions in the mold cavity. In the modeling, during the plastics flow inside the mold cavity, different flow parameters such as fill time, pressure, temperature, shear rate and warp at different locations in the cavity are analyzed. Overall, this Moldflow is able to perform a relatively sophisticated analysis of the flow process of pure nylon. Thus the prediction of the filling of a mold cavity is very important and it becomes useful before a nylon plastic part to be manufactured.

## 1. Introduction

In recent years, using the high speed digital computer and commercial simulation software. the mathematical analysis of the flow processes of the polymer is gaining popularity. Computational polymer processing is very important for the information of different flow parameters. The detailed and important up-to-date information about the rheology and polymer processing computations have been discussed by several authors [1-5]. Polymers can be processed by different methods such as blow molding, film blowing, fiber spinning, extrusion, thermoforming, compression molding, injection molding etc. Among these methods, extrusion and injection molding are the most important polymer processing operations [6]. Injection molding involves the steps: heating and melting of polymer, inject the melted polymer to mold cavity, forming the melted polymer into the required dimensions/shape, packing, cooling and solidification and finally, the ejection of the molded product [1]. Under the same processing conditions, the effects of velocity and pressure on the melt front advancements of HDPE and PP were investigated by both experimentally and using an injection molding analysis program [7]. In the analyses, six different injection velocities and five different injection pressures were used. It was found that experimentally obtained melt front profiles are almost similar to the theoretical results, but the filling times are different.

[1] Corresponding author

**4.** **N M Kusaseh**, D M Nuruzzaman, M A Chowdhury, A K M A Iqbal, N M Ismail, N Fatchurrohman and C S Yi, "Infuence of Glass Fiber Content on the Flexural Properties of Polyamide 6-Polypropylene Blend Composites". *Lecture Notes in Mechanical Engineering (LNME)*, (In Press) (2020).

Author Proof

# Influence of Glass Fiber Content on the Flexural Properties of Polyamide 6-Polypropylene Blend Composites

Nurizzathanis Mohamad Kusaseh[1], Dewan Muhammad Nuruzzaman[1](✉), Mohammad Asaduzzaman Chowdhury[2], A. K. M. Asif Iqbal[1], Noor Mazni Ismail[1], Nanang Fatchurrohman[1], and Chan Shin Yi[1]

[1] Faculty of Mechanical and Manufacturing Engineering, University Malaysia Pahang, 26600 Pekan, Pahang Darul Makmur, Malaysia
dmnuruzzaman@ump.edu.my

[2] Department of Mechanical Engineering, Dhaka University of Engineering and Technology, Gazipur, Gazipur 1700, Bangladesh

**Abstract.** Recently, polymer blend composites are receiving significant attention to fulfill the growing demand from automotive industries because of their improved properties as compared to that of pure polymer blends. In this research work, considering 0%, 3%, 6% and 9% glass fiber content, four different compositions of polyamide 6 (PA6)-polypropylene (PP)-glass fiber composites such as, 80%PA6+20%PP, 77%PA6+20%PP+3%GF, 74%PA6+20%PP+6%GF and 71%PA6+20%PP+9%GF were prepared using an injection molding machine. Different process parameters were taken into consideration in order to produce dog bone shaped specimens free of defects. All flexural tests were performed according to ASTM standard. Results showed that flexural yield strength steadily improves as fiber content increases. Test data showed that flexural stiffness or modulus is lowest for pure blend and it gradually improves with addition in glass fiber. Flexural strength is lowest for pure blend and it gradually develops with increase in fiber content. On the other hand, it was observed that flexural strain is hardly impacted by fiber content.

AQ1

**Keywords:** Flexural properties · Polyamide · Polypropylene · Glass fiber

## 1 Introduction

Thermoplastic polymer materials are reinforced by different types materials in order to strengthen mechanical properties and these polymer composites can be prepared by different manufacturing techniques. During past decade, research efforts were applied on dissimilar composite materials to examine mechanical or tribological properties [1–10]. Different types of reinforcing and matrix materials, different processing methods as well as different operating parameters are responsible for properties of these composites. Fiber reinforced polyamide-6 composite was prepared by application of injection process and flexural properties were examined in detail [11]. Experimental data revealed


M. N. Osman Zahid et al. (Eds.): iMEC-APCOMS 2019, LNME, pp. 1–6, 2020.
https://doi.org/10.1007/978-981-15-0950-6_71

5. Nuruzzaman, D.M., **Kusaseh, N.M.**, Ismail, N.M., Iqbal, A.K.M.A., Rahman, M.M., Azhari, A., Hamedon, Z. and Yi, C.S. “Influence of glass fiber content on tensile properties of polyamide-polypropylene based polymer blend composites” *Materials Today*: Proceedings (In Press) (SCOPUS).

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Materials Today: Proceedings 00 (2019) 0000–0000

materialstoday: PROCEEDINGS

www.materialstoday.com/proceedings

AMC 2018

## Influence of glass fiber content on tensile properties of polyamide-polypropylene based polymer blend composites

D M Nuruzzaman[a,*], N M Kusaseh[a], N M Ismail[a], AKM Asif Iqbal[a], M M Rahman[b], A Azhari[a], Z Hamedon[a], C Shin Yi[a]

[a]Faculty of Manufacturing Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
[b]Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

**Abstract**

In recent years, the rapid development of polymer composites is replacing the use of metals and alloys in high performance engineering applications, particularly in automotive and aerospace industries. In this research study, influence of glass fiber (GF) content on tensile properties of polyamide-polypropylene (PA-PP) based blend composites was investigated. Considering, 0%, 3%, 6%, 9% and 12% GF content, PA6-PP-GF composites of five compositions were prepared through injection molding method. In the experiments, tensile tests were performed under strain rate of 5 mm/min for all types of composite specimens. Test results show that tensile properties of composites of five different compositions are influenced by glass fiber content. In general, tensile strength of composite increases gradually with the increase in glass fiber content. On the other hand, tensile modulus increases significantly with increase in fiber content. The experimental data also revealed that yield strength, strength at fracture and strain at break of the composites are influenced by the content of glass fiber. Test data also show that tensile strain at maximum load almost corresponds to the tensile strain at break for all composite specimens.

Selection and peer-review under responsibility of 4th Advanced Materials Conference 2018, 4th AMC 2018, 27th & 28th November 2018, Hilton Kuching Hotel, Kuching, Sarawak, Malaysia.

*Keywords:* Tensile properties; polyamide-polypropylene; glass fiber; composites

* Corresponding author. Tel.: +609-4245842; fax: +609-4245888
*E-mail address:* dmnuruzzaman@ump.edu.my ; dewan052005@yahoo.com

2214-7853 © 2019 Elsevier Ltd. All rights reserved.
Selection and peer-review under responsibility of 4th Advanced Materials Conference 2018, 4th AMC 2018, 27th & 28th November 2018, Hilton Kuching Hotel, Kuching, Sarawak, Malaysia.