# The Tribological Study On Polymer Matrix Composite Using Pin On Disc Testing Technique

By

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

A polymer is generally manufactured by polycondensation, polymerization or polyaddition, when combined with various agents to enhance or in any way alter the material properties of polymers the result is referred to as a plastic [1,2]. Composite plastics refer to those types of plastics that result from bonding two or more homogeneous materials with different material properties to derive a final product with certain desired material and mechanical properties. Advanced polymer composites are generally understood to be materials consisting of a polymer matrix reinforced with high-strength continuous fibers of a predefined orientation. The reinforcements are typically fibers, particles or flakes. The matrix in most common cases is a resin system or adhesive that binds the reinforcements together. The reinforcement material and the matrix are combined at a microscopic level where the reinforcement is immersed in the matrix [3]. The matrix is a tough but relatively weak plastic that is reinforced by stronger stiffer reinforcing filaments or fibres. The two materials bond conjointly to make one system that is commonly referred to as a composite. Depending on the orientation of the fibers, the composite can be stronger in a certain direction or equally strong in all directions. The complex interwoven nature of the fiber makes it very difficult to break. The extent that strength and elasticity are enhanced in a fibre reinforced plastic depends on the mechanical properties of the fibre and matrix, their volume relative to one another, and the fibre length and orientation within the matrix. Reinforcement of the matrix occurs by definition when the fiber reinforced plastic (FRP) material exhibits increased strength or elasticity relative to the strength and elasticity of the matrix alone [4].

Polymer composites containing different fillers and/ or reinforcements are frequently used for these purposes [1] ***(Figure 1.1)***. However, how these materials must exactly be designed depends on the requirement profile of the particular application. Polymeric composites based on continuous glass, carbon and organic fibres have found wide application in many branches of modern engineering. In this research, the focus is on studying the tribological properties of glass fiber reinforced composite using DUCOM multispecimen tester.

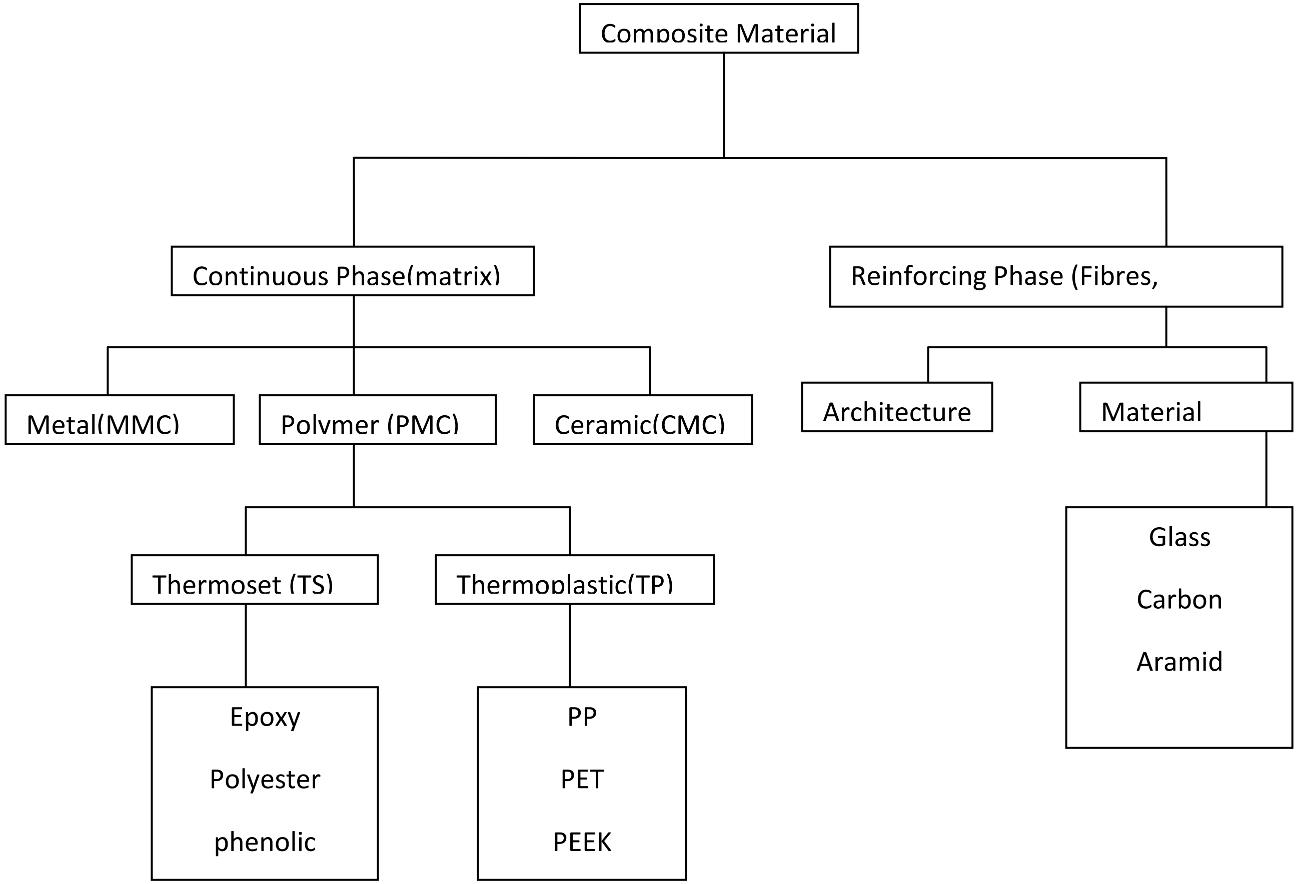



Figure 1.1: Structural component of composite materials [1].

## 1.2 Problem Statement

Although the glass fiber reinforced composite have been used in some tribological applications, the understanding of their friction and wear behaviour is very limited. There is no specific wear and friction study on fiber reinforced plastic thus very few research on tribological of this composite being published. Recently the friction and wear behaviour of this composite based on fiber type and orientation are still being studied to discover the optimum composite structure that can be designed for high performance product. This is important because every type of glass fiber will give different impact to the tribological properties of this composite.

## 1.3 Significance of Study

The study helps us to expend the usage and realize the potential of polymer matrix composite. Besides that on completing the experiment, the final data will enable the friction and wear behaviour of the composite based on their fiber types to be analyzed and understood. This information can be used as a guideline for choosing an optimum fiber type according to tribological application requirement. Other than that, durability of the composite when exposed to wear and friction can be identified.

## 1.4 Objectives

The main objective of this project is to study the behaviour of glass fiber reinforced (GFR). This study is focused on the behaviour and condition of GFR when it gets contact with other material which is steel for this project. The specific wear rate need to be calculated based on the result after wear testing. It is mean that volume loss can be calculated. So this wear testing can show which GFR will have a bigger volume loss, whether woven raving or chopped fibre glass, or is it the difference thickness of polymer matrix composite (PMC) will affect the result of volume loss or not. Besides, the objective of the project also to study the affect of the different normal loads and sliding velocities to the specific wear rate of the composites.

## 1.5 Scope of Study

In order to achieve this objective, a few tasks and research need to be carried out by collecting all technical details regarding the background test and sample. The study mainly discussed regarding the test that consist of test the GFR using pin on disc technique. The scope of study for this project is related to the tribological properties of GFR.

After completing the test, the optimum type of fiber glass for tribological application will be identified. Comparison of wear rate between each fiber glass type will be done in order to study their tribological properties. The microstructure of the samples before and after testing will be analyzed to know their surface characteristics. The coefficient of friction for the composite also will be determined. Finally complete research information will be gathered based on the findings during the tests. Data that relate the fiber fabrics with their friction and wear properties will be recorded properly for future references.

## 1.6 Relevancy and Feasibility of The Project

This study will explore how to better understand the properties of polymer composites and how industry and the United State military could use more composites with higher confidence as their reliability improves. The study also helps us to expend the usage and realize the potential of composite.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Tribology

Tribology which focuses on friction, wear and lubrication of interacting surfaces in relative motion, is a new field of science defined in 1997 by a committee of the Organization for Economic Cooperation and Development. 'Tribology' is derived from the Greek word 'tribos' meaning rubbing or sliding. After an initial period of scepticism, as is inevitable for any newly introduced word or concept, the word 'tribology' has gained gradual acceptance. As the word tribology is relatively new, its meaning is still unclear to the wider community and humorous comparisons with tribes or tribolites tend to persist as soon as the word 'tribology' is mentioned [2].

## 2.2 Polymer Matrix Composite (PMC)

PMC is the material consisting of a polymer (resin) matrix combined with a fibrous reinforcing dispersed phase. PMC are very popular due to their low cost and simple fabrication methods. The usage of non-reinforced polymers as structure materials is limited by low level of their mechanical properties. Tensile strength of one of the strongest polymers is epoxy resin which is 20000 psi (140 MPa) [1]. In addition to relatively low strength, polymer materials possess low impact resistance. Reinforcement of polymers by strong fibrous network permits fabrication of PMC characterized by the following properties which are high tensile strength, high stiffness, high fracture toughness, good abrasion resistance, good puncture resistance, good corrosion resistance and low cost [1].

## 2.3 Glass fiber

Glass fiber is a material made from extremely fine fiber of glass. There are two (2) types of glass fiber which are mat glass fiber and chopped strand mat glass fiber (refer to APPENDIX C). The search for advanced fibers led to the development of glass and graphite fiber. These fibers are currently the best known and most widely utilized in high performance resin base composite. These materials are now available on a worldwide basis at competitive prices and are now experiencing increasing levels of interest for applications such as ground transportation and infrastructures [3].

| | |
|---|---|
|  |  |
| Chopped strand mat fiber glass | Woven roving (mat) fiber glass |

Figure 2.1: The types of glass fiber used [3].

## 2.4 Polyester Resin

Polyester resin is unsaturated resin and formed by the reaction of dibasic organic and polyhydric alcohols. It is a thermosetting or thermoplastic synthetic resin and has high strength and excellent resistance to moisture and chemicals when cured. (Refer to APPENDIX C). It also most commonly used matrix in the marine and composite industry. When working with this resin with large project, it is advised to use gloves and a chemical respirator to protect you from the fumes. These resins can be used with any type of fiber glass, carbon fiber, or Kevlar, as well as used over urethane foam and other sandwich core materials. The resins tend to be fairly rigid when cured and also brittle than epoxy resins [6].

## 2.5 *Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus (ASTM G99-04 Volume 03.02)*

This method describes a laboratory procedure for determining the wear of materials during sliding using a pin-on-disc apparatus. Materials are tested in pairs under nominally non-abrasive condition. The principal areas of experimental attention in using this type of apparatus to measure wear are described. The coefficient of friction may also be determined. The values stated in SI unit are to be regarded as standard. (Refer to APPENDIX B).

### 2.5.1 Summary of Test Method

For the pin-on-disc wear test, two specimens are required. One, a pin with a rediused tip, is positioned perpendicular to the other, usually a flat circular disc. A ball, rigidly held, is often used as a pin specimen. The test machine causes either the disc specimen or the pin specimen to revolve about the disc center. In either case, the sliding path is a circle on the disc surface. The pin specimen is pressed against the disc at a specific load usually by means of an arm or lever and attached weights. Other loading methods have been used such as hydraulic or pneumatic. Wear results are reported as volume loss in cubic millimeters for the pin and the disc separately. When two different materials are tested, it is recommended that each material be tested in both the pin and the disc positions [7].

The amount of wear is determined by measuring the appropriate linear dimensions of both specimens before and after the test, or by weighing both specimens before and after the test. If linear measures of wear are used, the length change or shape change of the pin, and the depth or shape change of the disc, wear track (in millimeters), are determined by any suitable metrological technique such as electronic distance gaging or stylus profiling [7].

### 2.5.2 Test Parameters

Table 2.1 below shows the test parameters that should be considered when using this standard.

Table 2.1: Description of Test Parameters for ASTM G99 [7].

| Test Parameters | Description |
|---|---|
| Load | Values of the force in Newton (N) at the wearing contact |
| Speed | The relative sliding speed between the contact surfaces in meter per second (m/s) |
| Distance | The accumulated sliding distance in meters (m). |
| Temperature | The temperature of one or both specimens at locations close to the wearing contact |
| Atmosphere | The atmosphere (laboratory air, relative humidity, argon, lubricant, etc) surrounding the wearing contact. |

## 2.6 Panel/ Sample Fabrication

***Taken from:***

***[8] B. Suresha, Kunigal N. Shiva Kumar 2009, Materials and Design 30, " Investigations on Mechanical and two-body Abrasive Wear Behaviour of Glass/ Carbon fabric Reinforced Vinyl Ester Composites.***

The research article is about to study the mechanical wear behavior of glass and carbon fabric reinforced vinyl ester composites. The aim of the research is about to calculate specific wear rate of the composites. The writer used a combination of good mechanical and tribological properties and relatively lower cost makes the glass fiber an attractive choice for bearing applications.

The writers used woven roving (2-D-Rovloth) as a fabric for the composites. Rovloth 1854 consist of single end glass rovings with Fiber Glass Industries (FGI) Super 317 sizing for ease of handling, fast wet out, and compatibility with a number of resins including vinyl ester. The aerial weight was 610 g/m2 and the construction was unbalanced with 59% of the fibers in the warp direction and the remaining 41% of the fibers in the fill direction. The aerial weight of the carbon fibers was 634 g/m2. Both of the directional fibers were stitched with polyester knitting thread.

The 2D glass fabric reinforced vinyl ester composite panels of size 600mm x 900mm x 2.5mm were fabricated by the VARTM process. They were fabricated in the laboratories at the North Carolina State University. To achieve 2.5mm nominal thickness, six plies of FGI-1854 Rovloth fabrics or four plies of LT650-C10-R2VE fabrics were used. All the fabrics were cut and stacked in the $0^0$ (warp) direction with the warp face down. The performs were protected from dirt, grease and other contaminants that may prevent layer bonding during consolidation. The panels were cured at 25 $^0$C for 72 hours and later post cured at 71 $^0$C for about 20 hours. The post cured panels were inspected visually for surface defects and tap tested for delaminations. The volume percent of glass and carbon fibers used in the composites are 60% and 58% respectively [8].

## 2.7 Friction and Wear Measurement

***Taken from:***

***[9] S. R. Chauhan, Anoop Kumar, I. Singh, 2009, J Mater Sci, "Study on Friction and Sliding Wear Behaviour of Woven S- Glass Fiber Reinforced Vinylester Composites Manufactured With Different Coomonomers".***

The article is about the research of the effect of variation in sliding wear behavior of glass–vinylester composite (G–V) is studied by measuring the weight change and observing the surface features of worn specimens using scanning electron microscopy (SEM). The G–V composites were manufactured with Bi-directional woven S-glass fibers (60%) reinforced with vinylester resin with different comonomers. Friction and wear experiments were carried at ambient conditions on a Pin on disc machine arrangement. The wear in the experiment was determined from the weight loss measured after running against steel disc at sliding velocities of 1, 2, 3, and 4 m/s and applied normal load of 10, 20, 30, and 40 N. The experimental findings show increase in specific wear rate with increase the applied load [9].

To evaluate the friction and sliding wear performance of G–V composites A, B, and C under dry sliding condition, wear tests are carried out in a pin-on-disc test rig (DU-COM) as per ASTM G99. The counter body is a disc made of hardened ground steel. The specimen is held stationary and the disc is rotated while a normal force is applied through a lever mechanism. During the test, friction force was measured by a transducer mounted on the loading arm. The friction force readings are taken as the average of 100 readings every 40 s for the test duration. For this purpose a microprocessor controlled data acquisition system is used. The test conditions for conducting experiments for these samples composites A, B, and C are given in table below.

| Material | Composition | Color | Fiber weight fraction (%) | Density ($g/cm^3$) | Test temperature (°C) | Load (N) | Speed (m/s) | Humidity (%) |
|---|---|---|---|---|---|---|---|---|
| A | Vinylester + Styrene | Brown | 65 | 1.87 | 27.6 | 10 | 1 | 65.1 |
| | | | | | | 20 | 2 | |
| | | | | | | 30 | 3 | |
| | | | | | | 40 | 4 | |
| B | Vinylester + Methyl Acrylate | Brown | 65 | 1.77 | 26.5 | 10 | 1 | 66.2 |
| | | | | | | 20 | 2 | |
| | | | | | | 30 | 3 | |
| | | | | | | 40 | 4 | |
| C | Vinylester + Butyl Acrylate | Brown | 65 | 1.82 | 27 | 10 | 1 | 66.3 |
| | | | | | | 20 | 2 | |
| | | | | | | 30 | 2 | |
| | | | | | | 40 | 3 | |

The specific wear rate ($mm^3\ N^{-1}\ m^{-1}$) is expressed on volume loss basis. To calculate the specific wear rate of the composites, we are using this formula [10]:

$$K_S = \Delta m / L\, \rho F_N$$

Where $K_s$ is the specific wear rate ($mm^3\ N^{-1}\ m^{-1}$), Δm is the mass loss in the test duration (g), ρ is the density of the composite ($g/mm^3$ ), t is the test duration (s), V is the s sliding velocity (m/s), $F_N$ is the average normal load (N), L is sliding distance.[10]

## 2.8 Journal and Research Summary

Table 2.2: Journal summary

| No | Journal Title | Summary |
|---|---|---|
| 1 | Investigation on Mechanical and Two-Body Abrasive Wear Behaviour of Glass/ Carbon Fabric Reinforced Vinyl Ester Composites | The aim of the research is to study the mechanical and Two-Body Abrasive Wear Behaviour of Glass/ Carbon Fabric Reinforced Vinyl Ester Composites. The measured wear volume loss increases with increase in abrading distance. However, the specific wear rate decreases with increase in abrading distance. The worn surface features have been examined using scanning electron microscope (SEM). |
| 2 | Study on Friction and Sliding Wear Behaviour of Woven S-Glass Fiber Reinforced Vinylester Composites | The research was about to study the effect of variations in sliding velocities and applied normal load on the friction and sliding wear rate og Glass-vinylester composite (G-V). they can be measured by measuring the weight change and observing the surface features of worn specimens using SEM. The wear in the experiment was determined from the weight loss measured after running against steel disc at sliding velocities of 1, 2, 3, and 4 m/s and applied normal load of 10, 20, 30, and 40 N. the experimental findings show increase in specific wear rate with increase with applied load. It was also observed that increasing normal load and sliding velocities the coefficient of friction decreases. |

| | | |
|---|---|---|
| 3 | Tribological Studies of Polyester Reinforced With CSM-R-Glass Fiber Sliding Against Smooth Stainless Steel Counterface | Experimental investigations have been undertaken on Chopped strand mat (CSM) 450-R-glass fiber reinforced polyester (CGRP) composite to study its tribological performance. Friction and wear tests were carried out using pin-on-disc configuration under dry sliding contact conditions. |
| 4 | On Data Dispersion in pin-on-disc Wear Test | Ten pin-on-disc sliding wera tests for each experimental condition were carried out with a commercial tungsten carbide (WC) pin on silicon carbide (SiC) disk in order to determine wear and friction data dispersion. The tests were repeated using two sliding speeds which are 0.1 and 1.0 m/s, and two applied loads which are 5 and 50 N. the wear data showed dispersion in the range of 28-47 and 32-56%, for disc and pin, respectively. For the disc, the dispersion decreased when increasing both sliding speed and applied load. |

# CHAPTER 3

# METHODOLOGY

## 3.1 Research Methodology

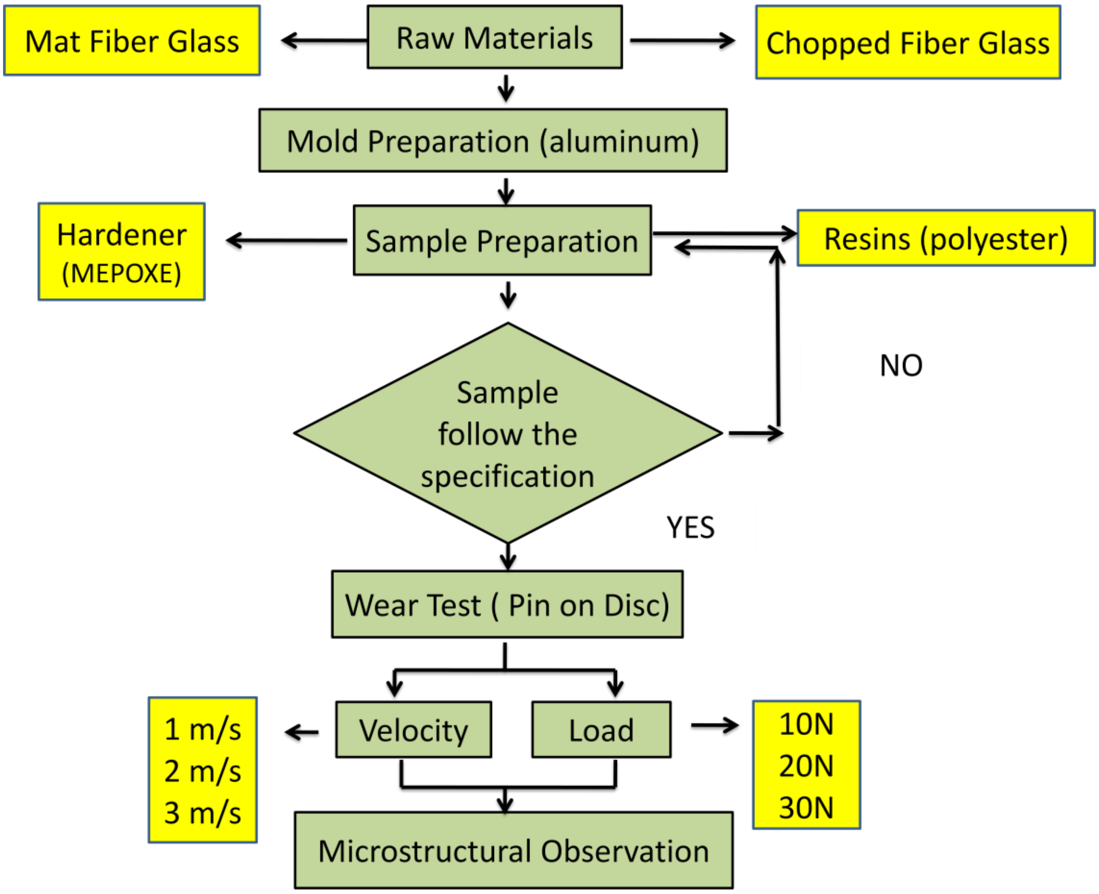



Figure 3.1: Summary of Methodology

## 3.2 Gathering and Analysis of Information

Information gathering is made from various sources such as internet, books, journals, and also related personnel who are expert in this field. Internet and online journals give the general ideas about the glass fiber reinforced composite development and the area of research done worldwide. Furthermore, the books borrowed from the Information Resource Centre help to know the basic understanding the fundamentals of this composite.

## 3.3 Wear test

The National Physical Laboratory carried out a survey of users of wear testing machines in UK in 1997, to determine the types of machines that have been used and any particular problems that have been experienced. In order to test the wear on Polymer Matrix Composite (PMC), Pin on Disc Testing is being used.

### 3.3.1 DUCOM Multi Specimen Tester

#### 3.3.1.1 Description

The wear test in conducted by using multis pecimen wear test machine manufactured by DUCOM**.** (Refer to APPENDIX B). The purpose of this multi specimen tester machine is to characterize friction and wear in sliding contact with variety of contact geometries. This equipment characterizes sliding contact between two (2) materials over a wide range of test parameters. The contact could be in term of point, line or area. For the point contact, the test will be ball-on-balls or ball-on-disc while for the line contact; the test will be cylinder-on-disc. Lastly, for the area contact, the test will be pin-on-disc or washer-on-flat [7].

#### 3.3.1.2 Specification

The user can set the parameters by key in the values. This enables the user to choose the optimal setting to test the samples. Table 3.1 below shows the parameters for the DUCOM Multi Specimen Tester.

Table 3.1: Parameters for the DUCOM Multi Specimen Tester [7].

| Parameters | Unit | Min | Max | Latest Count | Remarks |
|---|---|---|---|---|---|
| Normal Load | N | 5 | 1000 | 1 | D,R |
| Frictional Torque | Nm | 0 | 10 | 0.01 | D,R |
| Shaft Speed | RPM | 200 | 2000 | 1 | D,R |
| Wear | Micrometer | 0 | 2000 | 1 | D,R |
| Test Duration | Hours | 0 | 9999 | 0.1 | D,R |
| Stage Temperature | $^0$C | Ambient | 120 | 1 | PID controlled |

Below shows the testing procedure for DUCOM Multi Specimen Wear Test machine:

**<u>Before Operation</u>**

1. Safety first
2. Make sure the machine and pneumatic system are in good condition
3. Switch on the PC and the machine
4. Attach pin and sample properly.

**How to Operate**

Manual loading

1. Run ‘WINDUCOM 2006’ software by clicking the icon
2. Click ‘run continuously’ icon under the toolbar at the left corner of the screen.
3. Click the ‘power’ icon to switch on the machine.
4. Set desire testing time.
5. Set desire speed and speed type.
6. Set desire temperature.
7. Set desire trip value for safety.
8. Enter file name. Sample, ID. etc.
9. Click ‘acquire’ icon
10. Set all parameter to zero.
11. Apply balancing load at the leverage arm by put 5kg weighing mass to balancing mechanical load.
12. Check whether the wear sensor has touched the disc holder or not.
13. Apply the load by putting the dead weight.
14. Adjust the load icon into desired value by sliding the weighing mass slowly.
15. Click ‘run’ icon to start the test.
16. It is advisable to perform the running in test for 10 minutes.
17. Rerun the test to required setting.
18. Click the ‘power’ icon to switch off the machine.
19. Remove the sample from the holder.

Automatic load

1. Run ‘WINDUCOM 2006’ software by clicking the icon
2. Click ‘run continuously’ icon under the toolbar at the left corner of the screen.
3. Enter file name. Sample, ID. etc.
4. Click ‘acquire’ icon
5. Set desire load and then click ‘apply’ button.
6. Set desire speed
7. Set desire temperature.
8. Set desire time.
9. Set desire trip value for safety.
10. Click the’ power’ icon to switch on the icon.
11. Click ‘run’ icon to start the test when the load set and or temperature set has been reached to the desire number.
12. Click the ‘power’ icon to switch off the machine.

After operation

1. Shutdown the PC
2. Switch the power off
3. housekeeping

## 3.4 Experimental Details

### 3.4.1 Materials

A combination of good mechanical properties and relatively low cost makes glass fiber attractive choice. The woven roving and chopped glass fiber were chosen as the fabrics of the composite. Woven roving consists of single end glass roving manufactured by Changzhou Tianma Group Co. LTD from China for ease of handling, fast wet out, and compatibility with a number of resins including polyester while the chopped glass fiber was manufactured by Kumgang Korea Chemical CO. LTD from Korea. (See APPENDIX C). The areal density of the woven roving is 385g/m$^2$ and the density is 2.5 g/cm$^2$, while the aerial density of chopped glass fiber is 380 g/mm$^2$. The thicknesses of these glass fibers are not much different. The thickness of woven raving is 0.21 mm / ply than the other thickness is 0.23 mm / ply. The other materials for making composites sample are unsaturated polyester resins and hardeners, while the molds are made from aluminium. The figure 3.2 below shows the condition and size of the aluminium mold for making the composites.


Figure 3.2: The size of the aluminium mold

### 3.4.2 Panel fabrication/ preparation of composite samples

There are 2 types of the panels or aluminium molds which are types A and B. The size of mold type A is 23cm x 31cm x 1cm and type B is 17cm x 21cm x 1cm. So the panel size should follow the size of the molds. To achieve 2.5 mm nominal thickness, twelve (12) plies of woven roving and chopped strand mat glass fibre fabrics were used and at least 24 plies of both glass fibers been used in order to achieve 5.0 mm thickness (Table 3.2). First step is cut the fabrics into the size of the molds with needed quantity. The technique used was hand lay-up, so the equipment such as roller and brush need to be prepared. In order to get specimens that meet the requirements, the materials need to be prepared carefully, for example the quantity of the polyester and hardener. The ratio needed between polyester and hardener is 50:1, so some calculation must be done to get exact value based on the volume of the composites. (See APPENDIX D). The mixture (polyester and hardener) need to be stirred using spatula and apply the mixture on the fabrics by layer until completing the hand lay-up process. The hand lay-out technique was applied for both woven roving and chopped glass fibers. The mixtures (polyester +hardener+ glass fiber fabrics) were left with the room temperature until fully dry. The complete composites were cut into requirement sizes using jigsaw and were ready for the wear test**.**

Table 3.2: The variation of composites samples.

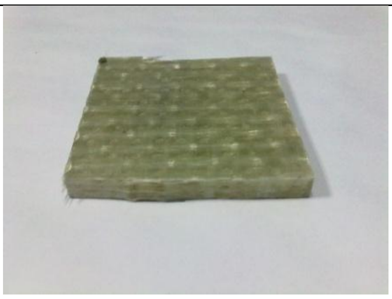
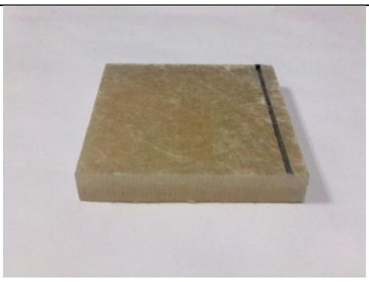
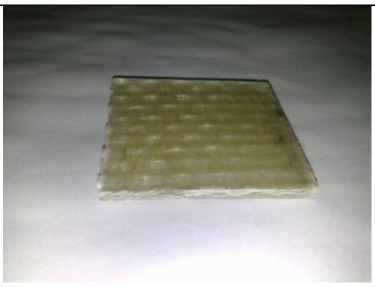
| Sample | View | Description |
|---|---|---|
| A |  | -Made from woven roving fiber glass + polyester<br>-5.0 mm thickness |
| B |  | -Made from chopped strand mat (CSM) fiber glass + polyester<br>-5.0 mm thickness |
| C |  | -Made from woven roving fiber glass + polyester<br>-2.5 mm thickness |
| D |  | -Made from chopped strand mat (CSM) fiber glass + polyester<br>-2.5 mm thickness |

Table 3.3: Properties of Woven Raving Glass Fiber [10].

| Properties | Description |
|---|---|
| Tensile strength (Mpa) | $605 \pm 2.8$ |
| Tensile modulus (GPa) | $29.2 \pm 0.8$ |
| Elongation | $2.41 \pm 0.6$ |
| 1/factor | $6.86 \times 10^{-4}$ |
| Aerial density (g/ $m^2$) | 380 |
| Density (g/$cm^2$) | 2.5 |
| Thickness/ ply (mm) | 0.21 |

Table 3.4: Composition and Ingredients of Chopped Glass Fiber [10].

| Common Name | | Wt% |
|---|---|---|
| Fiber Glass Continuous | | 98-100 |
| Filament (non respirable)<br>- non respirable filaments and particulate<br>- Respirable particulate<br>- Respirable particulate with fiber-like dimensions | | >98%<br><1 %<br><0.002 % |
| Size | Mixture | 0-2 % |

Table 3.5: Physical and Chemical Properties of Chopped Glass Fiber [10].

| | |
|---|---|
| Physical State : Solid | Specific Gravity (water=1) : 2.45- 2.65 |
| Boiling Point : N/A | Evaporative Rate : None |
| Melting Point : 1230-1270 $^{0}$C | Vapor Density : (Air=1) : N/A |
| Softening Point : 810-850 $^{0}$C | Vapor Pressure : N/A |
| Freezing Point : None | Solubility ( in water) : Insoluble |
| Color : White | pH : N/A |
| Viscosity : N/A | Freezing Point : N/A |
| Appearance : Solid | Volatile by Volume : not volatile |

Table 3.6: Properties of Unsaturated Polyester resin [6].

| Properties | Value/ description |
|---|---|
| Appearance | Liquid |
| Color | Pink |
| Density (g/ml) | 1.1-1.15 |
| Flash Point ($^{0}$C) | 31 |
| Vapor Pressure (hPa) | 6 |
| Flammability Limit-Lower (%) | 1.1 vol. % |
| Flammability Limit-Upper (%) | 6.1 vol. % |

Table 3.7: Properties of the hardener (Mepoxe) [4].

| | |
|---|---|
| Appearance | Clear, colorless liquid |
| Methyl Ethyl Ketone Peroxide | 55% |
| Phihalate Plastilizer | 45% |
| Active Oxygen | 10.0 % minimum |
| Specific Gravity | 1.13 |
| Flash Point | 72 $^0$C (minimum) |
| Solubility insoluble | Water, Glycorine |
| Soluble | Polyester resins, Ketones, Ethers |

For the other thickness, same method will be applied based on thickness of the fibre fabrics. All the fabrics were cut and stack in the $0^0$ (warp) direction with the warp face down. The performs were protected from dirt, grease and other contaminants that may prevent layer bonding during consolidation. During the sample preparation, dimension of the panels, volume and area of the composite panels, volume fraction of matrix, and volume of the fibre were calculated [11]. The volume percent of glass fiber used in the composites is 60% respectively. After getting all the parameters above, weight of matrix based on number of ply, weight of glass, weight of polyester and hardener needed also can be calculated. The technique being used was hand lay-out for making the panel composites. Test samples were prepared after proper cutting and polishing to two (2) difference thickness which are 4cm x 4 cm x 0.5cm and the other one is 4cm x 4cm x 0.25cm.

### 3.4.3 Friction and wear measurements

The friction and sliding wear performance of glass fibre composite are carried out in a pin-on-disc test rig (DUCOM) as per ASTM G99. The counter body is a disc made of hardened ground steel [12]. The specimen is held stationary and the disc is rotated while a normal force is applied through a lever mechanism. During the test, friction force was measured by a transducer mounted on the loading arm. The test conditions for conducting experiments for these samples composites A, B, C and D are given in table 3.6 and table 3.7. Each sample is tested with different loads and velocity, and sliding wear data reported here is the average of at least three (3) runs. Test duration taken was 6 minutes for each testing. The average mass loss is used to calculate the specific wear rate [13]. The sample cannot be reuse and need to use other samples if the velocity or loads are changed. The loads used are 10N, 20N, and 30N while the velocities are 1 m/s, 2 m/s and 3 m/s. The changing in weight (initial to final) must be taken carefully because the slight error might affect the value of specific wear rate of the composites tested. The results after wear testing for both mat fiber glass and chopped strand mat fiber glass are shown in the table 3.8 below. (For the example of wear calculation, refer to APPENDIX E).

Table 3.8: The condition of the composites before and after wear testing.

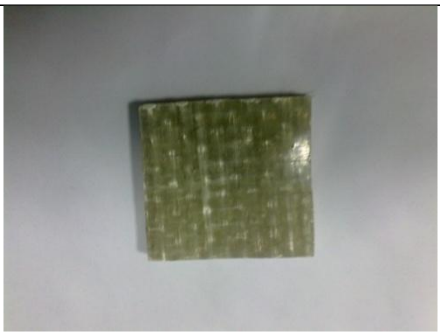
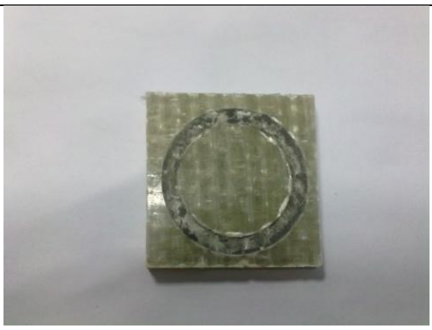
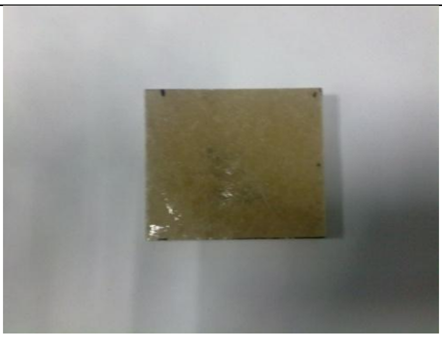
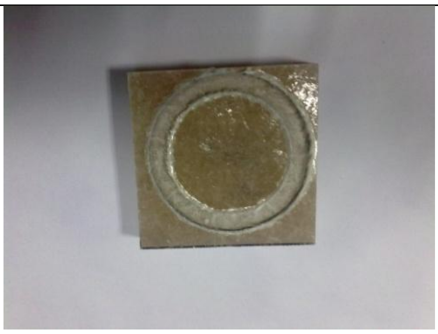
| Sample | Before | After |
|---|---|---|
| A and C |  |  |
| B and D |  |  |

Table 3.9: Details of Composite samples, testing condition, and parameters

| Materials | Composition | Thickness (mm) | Density (g/ $mm^3$) | Fiber Volume Fraction(FVF) | Load (N) | Test Duration (minutes) | Speed (m/s) |
|---|---|---|---|---|---|---|---|
| A | Mat Fiber Glass + polyester | 5.0 | | 60 % | 10<br>20<br>30 | 6 | 1<br>2<br>3 |
| B | Chopped Fiber Glass+ polyester | 5.0 | | 60 % | 10<br>20<br>30 | 6 | 1<br>2<br>3 |
| C | Mat Fiber Glass + polyester | 2.5 | | 60 % | 10<br>20<br>30 | 6 | 1<br>2<br>3 |
| D | Chopped Fiber Glass+ polyester | 2.5 | | 60 % | 10<br>20<br>30 | 6 | 1<br>2<br>3 |

Table 3.10: Specific Wear Rate of Composites with Different Testing Conditions (to be filled after testing)

| Composites Materials | Load (N) | Specific Wear Rate ( $mm^3$/ Nm) | | |
|---|---|---|---|---|
| | | Sliding Speed | | |
| | | 1 m/s | 2 m/s | 3 m/s |
| A | 10<br>20<br>30 | | | |
| B | 10<br>20<br>30 | | | |
| C | 10<br>20<br>30 | | | |
| D | 10<br>20<br>30 | | | |

## 3.5 Scanning Electron Microscope (SEM) on Worn Surface in Selected Wear Modes.

Studies on worn surface topography were done to understand wear mechanism. In this study, the mode used was Secondary Electron Imaging (SEI). Below is the procedure for the SEM studies.

1. The samples need to be coated before it is scanned under the SEM machine. The purpose of the coating is to create conductive surface on the non-metal material.
2. After coating, the samples will be patched to the holder using a carbon tape. Carbon tape was used because it is conductive.
3. Then the samples will be put inside the samples chamber. In this chamber, the air will be sucked out and leave the space inside it in vacuum atmosphere.
4. The image of the samples are digitally captured and displayed on a computer monitor and saved to a computer's hard disk.

# CHAPTER 4

# RESULT AND DISCUSSION

## 4.1 Data Gathering and Analysis

Table 4.1 presents details of composites, testing conditions and complete testing parameters used for conducting the various experiments of Glass Fiber – Polyester (G-P) composites samples A, B, C and D. All the samples are tested at room temperature with applied normal loads of 10N, 20N, and 30N. Table 4.2 shows the specific wear rate values calculated from mass loss data obtained during experimentation. The density of each sample is calculated using the formula:

$\rho = m / v \ (g/ mm^3)$

Where ρ is density, m is mass and v is the volume of the composite.

Fiber Volume Fraction (FVF) of all the samples is same which is 60%. The specific wear rate for all the samples then is calculated using the formula giving before, and then based on the result gained during experimentation, the graft can be plotted.

Table 4.1: Details of Composite samples, testing condition, and completed parameters

| Materials | Composition | Thickness (mm) | Density ($g/mm^3$) | Fiber Volume Fraction(FVF) | Load (N) | Test Duration (minutes) | Speed (m/s) |
|---|---|---|---|---|---|---|---|
| A | Woven Roving Fiber Glass + Polyester | 5.0 | 0.00167 | 60 % | 10<br>20<br>30 | 6 | 1<br>2<br>3 |
| B | Chopped Strand Mat Fiber Glass+ Polyester | 5.0 | 0.00153 | 60 % | 10<br>20<br>30 | 6 | 1<br>2<br>3 |
| C | Woven Roving Fiber Glass + Polyester | 2.5 | 0.00123 | 60 % | 10<br>20<br>30 | 6 | 1<br>2<br>3 |
| D | Chopped Strand Mat Fiber Glass+ Polyester | 2.5 | 0.00141 | 60 % | 10<br>20<br>30 | 6 | 1<br>2<br>3 |

Table 4.2: Specific Wear Rate of Composites with Different Testing Conditions

| Composites Materials | Load (N) | Specific Wear Rate ( $mm^3$/ Nm) x $10^{-3}$ | | |
|---|---|---|---|---|
| | | Sliding Speed | | |
| | | 1 m/s | 2 m/s | 3 m/s |
| A | 10 | 1.462 | 3.050 | 2.354 |
| | 20 | 2.066 | 4.711 | 3.810 |
| | 30 | 2.585 | 5.301 | 4.978 |
| B | 10 | 2.677 | 4.432 | 5.751 |
| | 20 | 2.839 | 6.693 | 6.453 |
| | 30 | 2.922 | 6.944 | 6.594 |
| C | 10 | 1.362 | 3.270 | 2.365 |
| | 20 | 1.893 | 3.834 | 3.585 |
| | 30 | 2.244 | 4.759 | 3.918 |
| D | 10 | 2.602 | 3.926 | 5.882 |
| | 20 | 2.903 | 6.349 | 6.177 |
| | 30 | 3.032 | 6.964 | 6.300 |

## 4.2 Effect of sliding velocity and load on the specific wear rate

The variation of specific wear rate of the woven roving glass fiber reinforced and chopped strand mat glass fiber reinforced with sliding velocity is presented in Table 4.2. The specific wear rate of the composites increases with increases of velocity and load. By comparing the four different G-P composites A, B, C and D, the thickness of the composites with same materials composition will not affect the specific wear rate. It means that the specific wear rate of G-P will have only small differences in values of specific wear rate whether it has the thickness of 5.0 mm or 2.5 mm. It is observed that the wear performance of G-P composite B and D decrease due to the type of the glass fiber. Chopped strand mat glass fiber is easily broken because the fabric cannot hold the load friction given compare to woven roving glass fiber which is better. The variations in the specific wear rate of the composites with increase in velocities are also shown.

Experimental results of specific wear rate are plotted in figures 4.1, 4.2, 4.3 and 4.4 for different applied normal loads (10, 20, and 30N) and sliding velocities ( 1, 2, and 3 m/s). The figures show the variation of specific wear rate with load of Glass-Polyesters (G-P) composite A, B, C and D at different sliding velocities. By comparing the composites with the same thickness but different materials compositions, figures 4.1, 4.2, 4.3, 4.4 and Table 4.2 show that the specific wear rate of composite B is higher than composite A, and same goes to other composite which is composite D will have higher specific wear rate compared to the composite C. The result shows that the composite made from woven roving fiber Glass will have less specific wear rate than the composite made from Chopped strand mat fiber Glass. For the composite A and C, the specific wear rates are increased with increased in velocities, but at the velocity of 3m/s, it is decreasing. It is because after certain condition, the specific wear rate reaches steady state condition. But different result for the composite B and D, where the specific wear rates of these composites keep increasing with increase in loads and velocities.

**Sample: A**

**Composition: Woven Roving Fiber Glass + Polyester**

**Thickness: 5 mm**

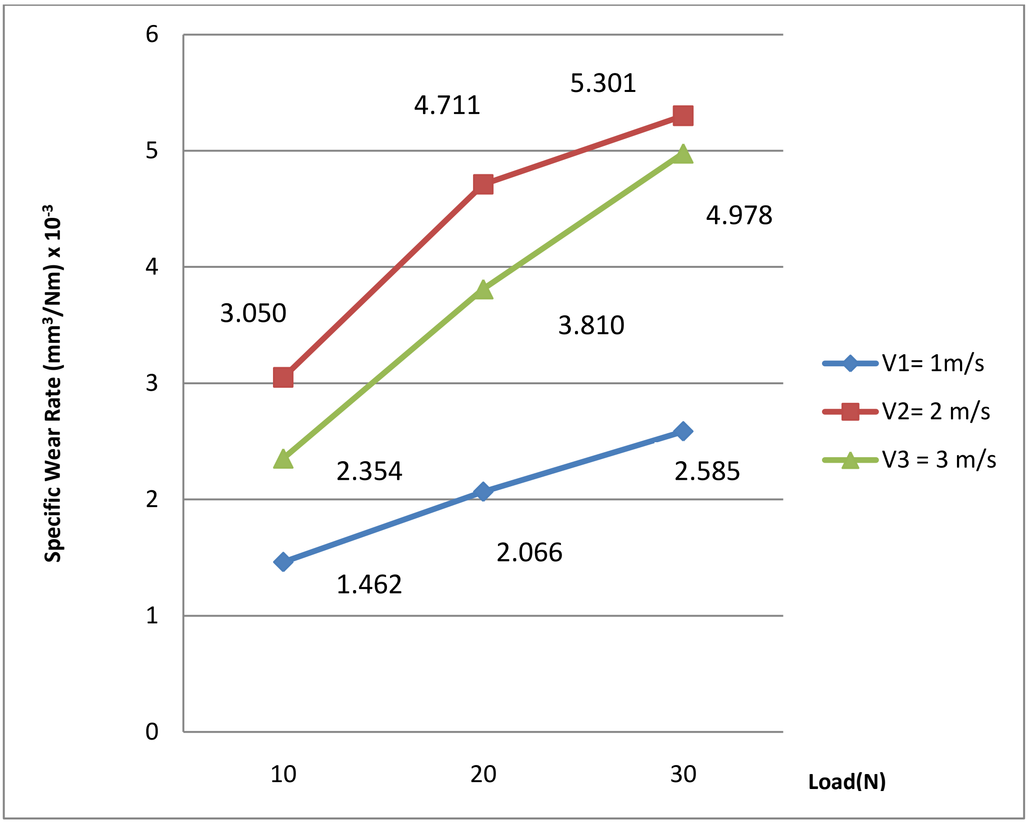



Figure 4.1: Specific wear rate versus applied load of G-P composite A

**Sample: B**

**Composition: Chopped Strand Mat + Polyester**

**Thickness: 5 mm**

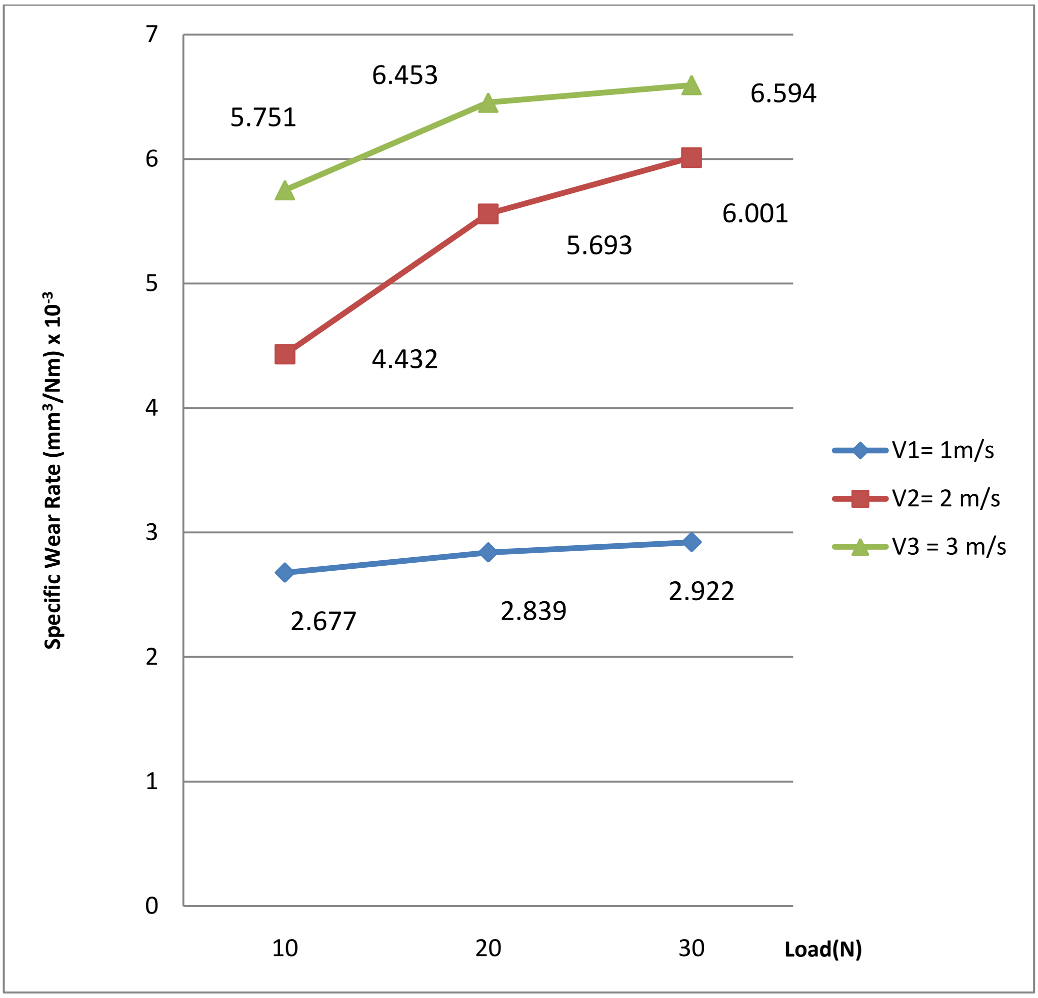



Figure 4.2: Specific wear rate versus applied load of G-P composite B

**Sample: C**

**Composition: Woven Roving Fiber Glass + Polyester**

**Thickness: 2.5 mm**

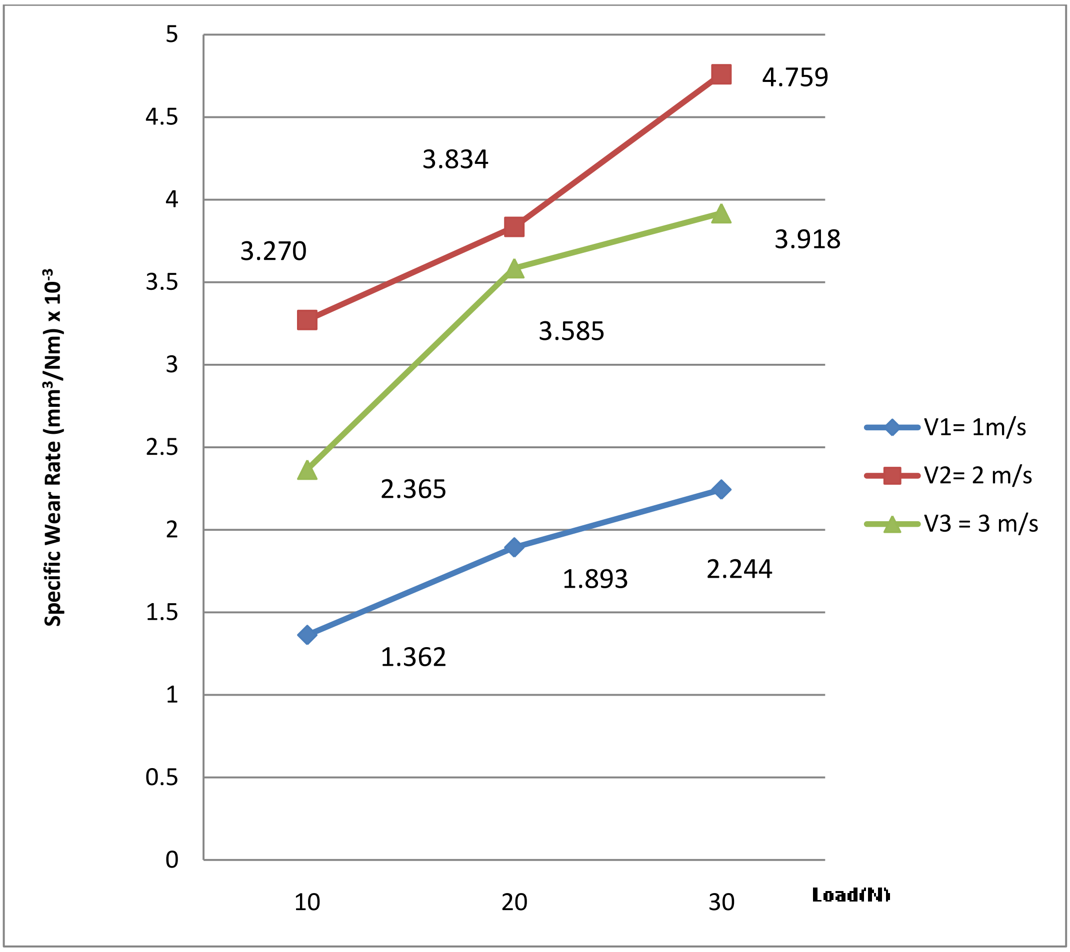



Figure 4.3: Specific wear rate versus applied load of G-P composite C

**Sample: D**

**Composition: Chopped Strand Mat + Polyester**

**Thickness: 2.5 mm**

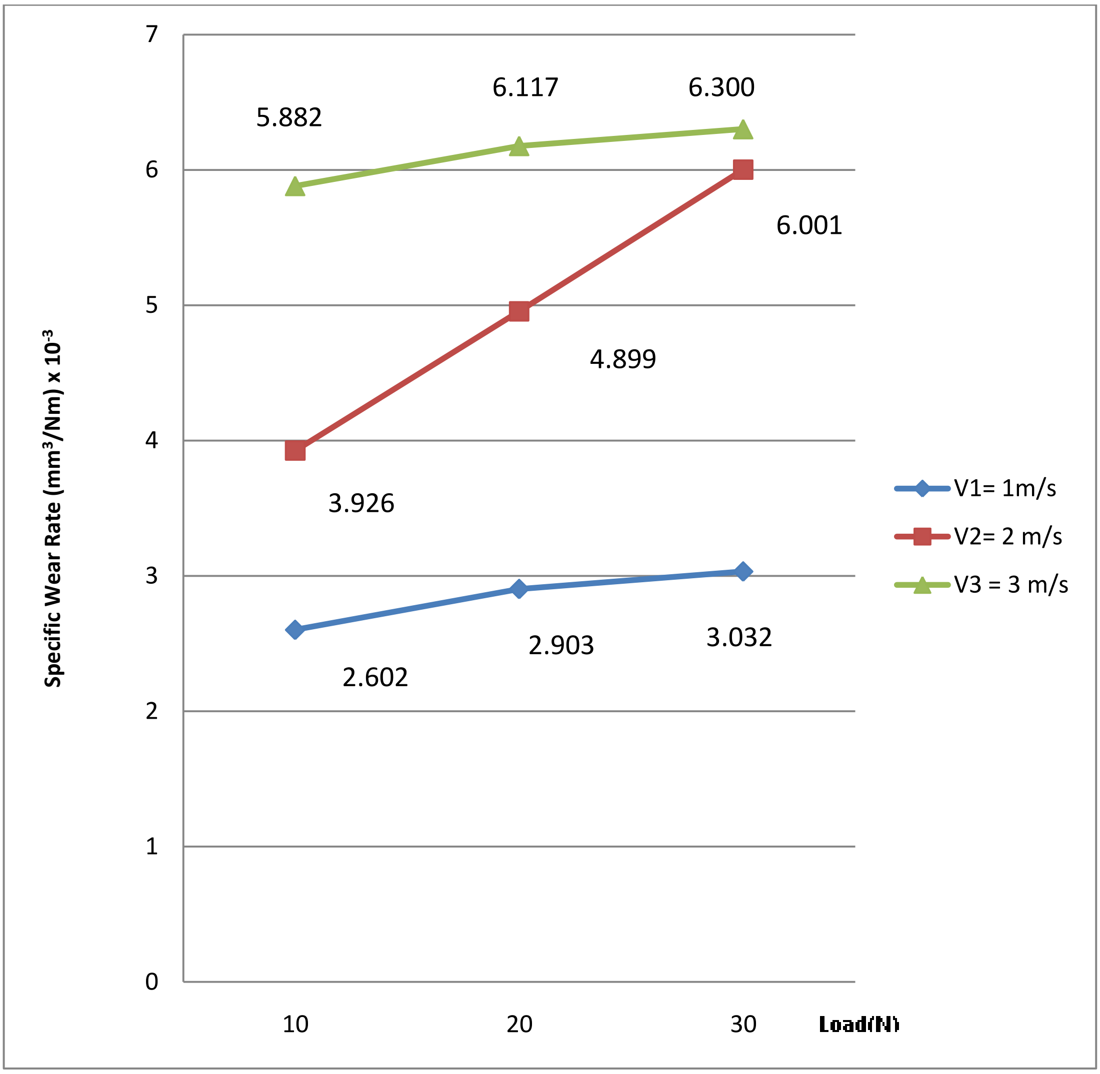



Figure 4.4: Specific wear rate versus applied load of G-P composite

### 4.3 Worn Surface Features Based on the Wear Data

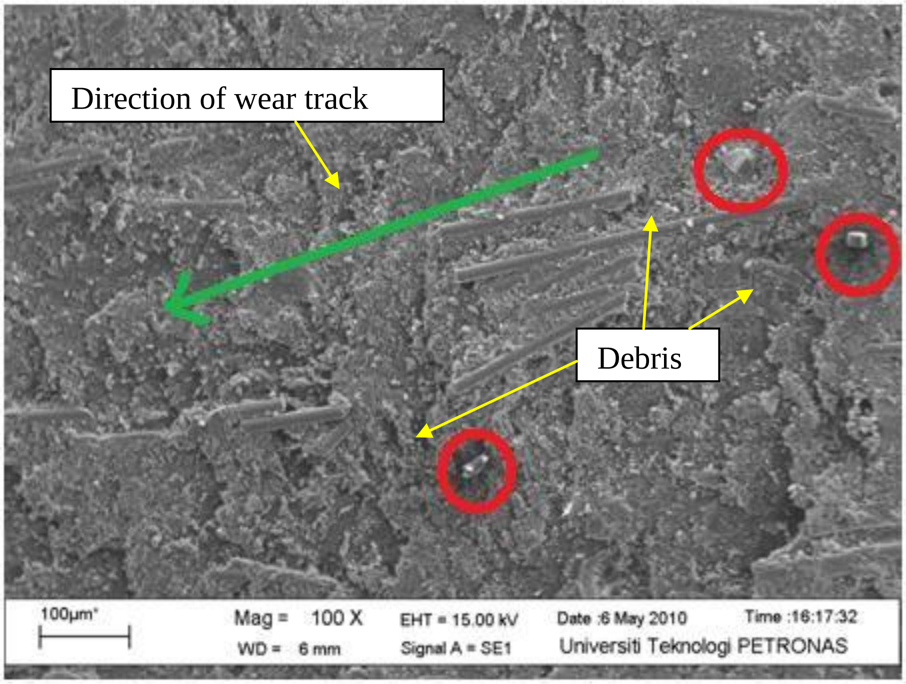



Figure 4.5: SEM picture of sample A at load 20N and sliding speed 2 m/s.

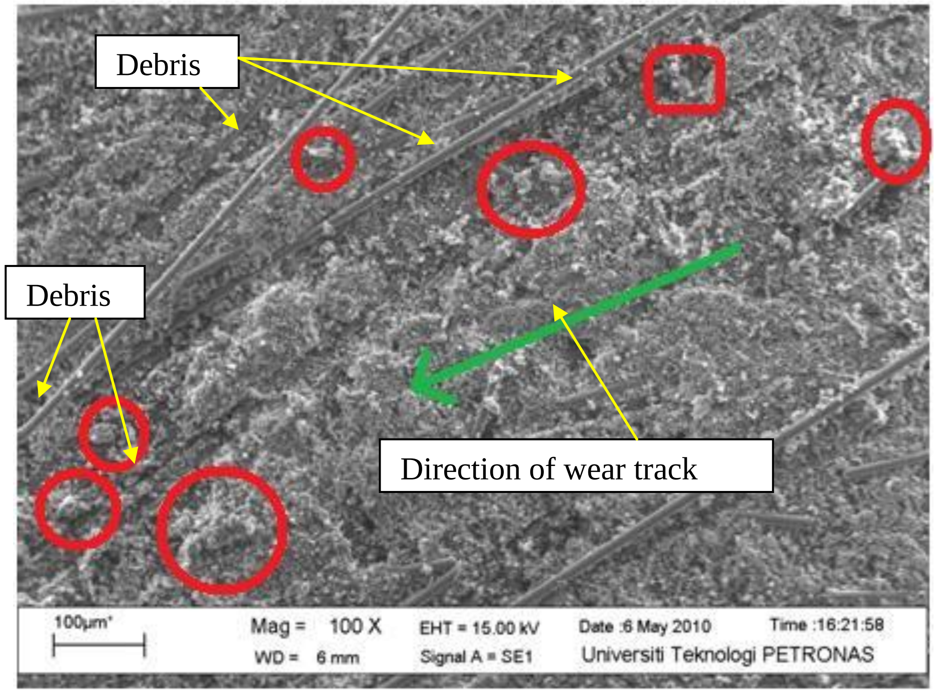



Figure 4.6: SEM picture of sample B at load 20N and sliding speed 2 m/s.

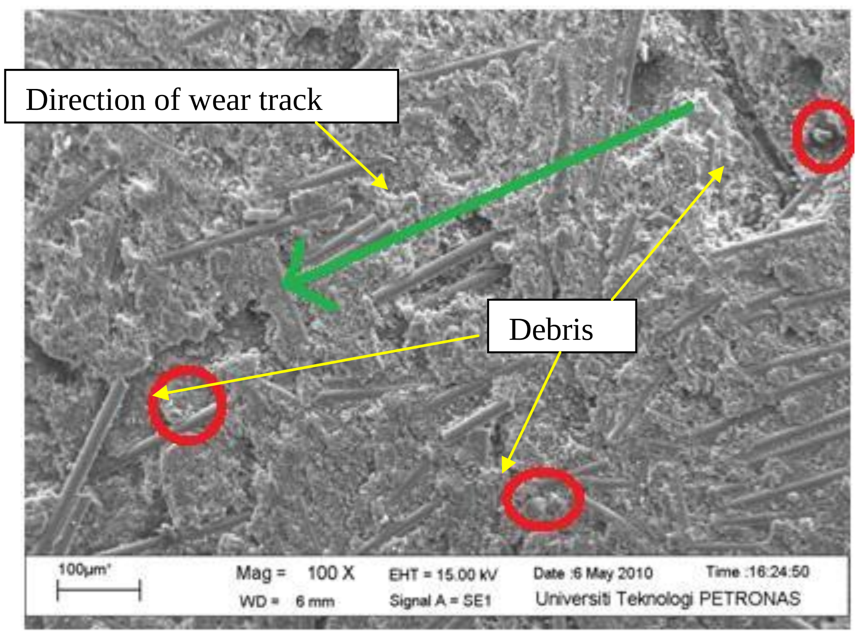



Figure 4.7: SEM picture of sample C at load 20N and sliding speed 2 m/s.

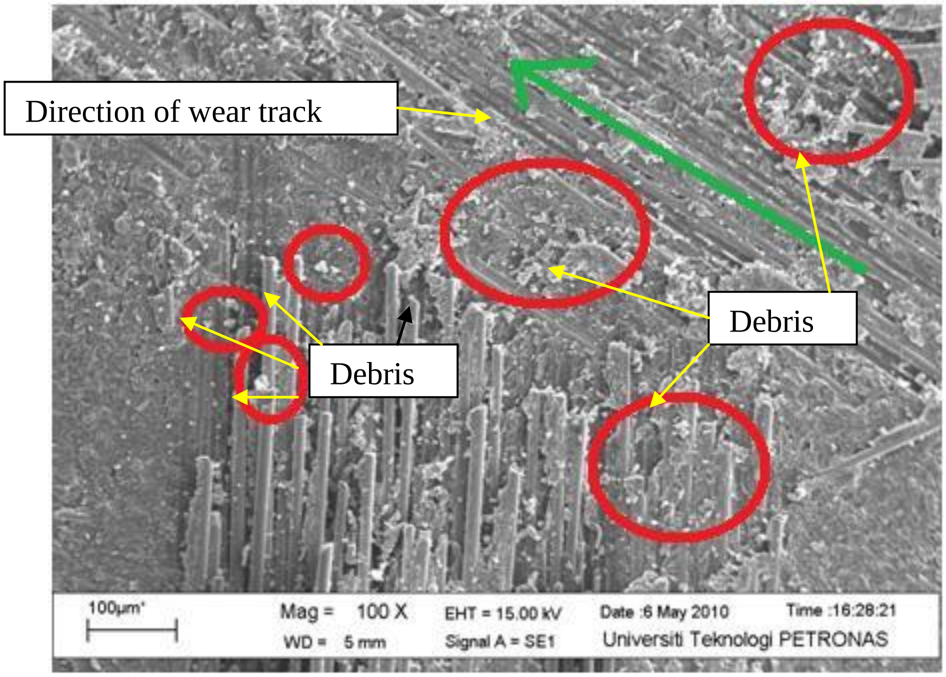



Figure 4.8: SEM picture of sample D at load 20N and sliding speed 2 m/s.

During sliding, both adhesive and abrasive wear mechanisms are operative, resulting in powdery wear debris. The frictional heat generated at the interface caused thermal softening of the matrix and some of the powdery wear debris got embedded into the matrix and formed a protective layer. The SEM picture of Glass-polyester Composite A and C (figure 4.5 figure 4.7) shown that the fractured surface are not having much different after wear testing. It is because the thickness of the composite will not affect the specific wear rate of the composite because the wear only happens on the surface. So the worn surface under similar conditions of normal load and sliding speeds for Glass-polyester Composite A, B, C and D are shown in the Figures 4.5, 4.6, 4.7 and 4.8. The micrograph of Figure 4.5 and figure 4.7 of Glass-polyester Composite A and C show small patches of debris.

However, for the Glass-polyester Composite B and D shows that more fibers are exposed and more debris formation in the form of layer is seen, which has resulted due to increased specific wear rate. The accumulation of wear debris in the form of patches is seen in some regions of the worn surface of composite specimens. This wear debris plays an important role as third body abrasive in the wear process. Such wear debris leads to high values of wear rates and friction values considerably. Due to the present of glass fibers in debris which is abrasive in nature may also abrade counterface and hence increases the roughness of the surface, and this is in turn increases the wear rate. The other two possible modes and mechanisms of wear which may occur during the experimentation are firstly the shearing stresses occurred at trailing end of the fibers and this would accelerate wear with a consequential surface failure. Second possible mechanism consists of surface degradation at the interface due to temperature rise. This gives a decrease in the friction coefficient and increase in wear rate.

It is known that glass fiber provides better wear resistance and during sliding condition, most of the removed broken, pulled out, and fractured glass fibers are from the relatively harder phase (glass fiber) which were caught and remained at the interface and embedded into the softer phase (polyester).This process may result in covering rubbing surface by glass fragments, which in turn reduces the amount of removed bulk material. Moreover, when the relatively hard phase (glass particles) covers the rubbing surface then the rubbing process would be predominated by the harder surface characteristic. This thought may be enhanced by the SEM micrograph shown in figure 4.6 and figure 4.8, in which broken fiber pieces were moved in the direction of sliding towards the soft phase (polyester). Furthermore, the fiber ends can be seen that were cut or fractured by the counterface and exposed to sliding on their length and produced smaller particles from the fractured fibers. So if the results of the SEM above (for all the samples) are being compared, it is clearly shown that the composite which has high specific wear rate will have more damage in the fractured condition.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

The tribological study of Polymer Matrix Composite (PMC) is very important because it covers the study and application of the principles of friction, lubrication and wear of the PMC. By using pin on disc testing technique, we can know the different compositions will give different strength and behavior.

Experimental results showed that the thickness of the composites will not affect the values of specific wear rate after conducting Pin on Disc Testing. It is clearly shown in the table 4.2 that for the samples A and C (samples with same composition but different thicknesses), both with the same conditions (10 N load and 1 m/s sliding velocities), the specific wear rate for both samples are not much different. At those conditions, the specific wear rate for sample A is 1.462 and specific wear rate for sample C is 1.362.

The other conclusion also can be drawn which is friction and sliding were studies against polymer counterface under various loads and sliding speeds conducted in this work shows that the specific wear rate of the composites increase with increase in loads, same goes to velocities. The results in figures 4.1, 4.2, 4.3, and 4.4 are clearly shown that the specific wear rates of the samples are increased with increased in velocities and loads.

Among two different materials composition of composites, the composites made of woven roving fiber glass showed better abrasion resistance under different loads and velocities. For example the results in table 4.2, at the 20 N loads and 2 m/s sliding velocities conditions, clearly shown that the specific wear rate for sample A (sample made of woven roving) is 4.711, which is lesser than the specific wear rate of  sample B (sample made of chopped strand mat fiber glass). At those conditions, the specific wear rate of sample B is 6.693. This is because the Mat Fiber Glass fiber has higher strength than Chopped fiber glass.

For the range of load and velocity in this study it is observed that load has stronger effect on the friction and wear than sliding velocity. Based on the investigation, it may be concluded that the friction and sliding wear performance of woven roving glass fiber reinforced composites are much superior in terms of better wear resistance as compared to chopped strand mat glass fiber reinforced composites.

## 5.2 Recommendation

For the future study, it is suggested to investigate the tribological properties of the composite in both, longitudinal and transverse direction. This can improve the understanding of wear and friction behaviour of the composite in more detail. Other than that, for better understanding of surface topography, the SEM images should be captured at different direction of the fiber. This is because each direction of the fiber will experience different effect due to the wear.

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# APPENDICES