# INVESTIGATION THE TRIBOLOGICAL PROPERTIES OF FIBER COMPOSITE MATERIAL REINFORCED WITH CARBON NANO TUBE (CNT)

By

Zul Hilmi bin Awang

Dissertation submitted in partial fulfillment of
the requirements for the
for the Degree
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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## CERTIFICATION OF APPROVAL

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Approved:

______________________________

Assoc. Prof. Dr Mustafar Sudin
Project Supervisor

Universiti Teknologi PETRONAS

Tronoh, Perak

January 2008

## CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

( ZUL HILMI BIN AWANG)

# ABSTRACT

The objective of this study is to investigate the Tribological Properties of Composite Material with the addition of Carbon Nano Tube (CNT). Industries today use a lot of composite in much area such as marine industry, automobiles, and aircraft. However, this composite material must be improved whereby the future application need a better composite material with excellent mechanical properties and better wear resistance.

This project was focused on wear analysis for composite material reinforce with Carbon Nano Tube (CNT), after it had experience a wear testing process. There are two types of experiments done on this project which is wear test using pin on disk and linear abraser machine.

For pin on disc experiment, two variable were used which are: Specimen type and load. For the specimen type, it has 6 types which are : Neat epoxy, epoxy + CNT, epoxy +matte fibre glass, epoxy + matte fibre glass + CNT, epoxy + woven roving fibre glass, and epoxy + woven roving fibre glass + CNT. Each type of specimens used had different hardness, coefficient of friction and wear rate. For the load variable, the load applied to the specimen varies from 100 N, 200 N, and 300 N.

For the experiment using linear abraser machine, the load varies from 2.5 N, 5 N and 7.5 N. The speed was preset to 60 cycle/min and the total cycle is 300 cycle.

# ACKNOWLEDGEMENTS

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Last but not least, for those who are contributed directly and indirectly to the success of this project, thank you and may god bless all of you.

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# LIST OF ABBREVIATIONS

1. CNT : Carbon Nano tube
2. PF : Phenolic resins
3. EP : Epoxy
4. Si : Silicone
5. PI : Polyimide
6. UP : Unsaturated polysters
7. N : Newton

# CHAPTER 1
# INTRODUCTION

## 1.1 Background of study

Today, fiber composite are routinely used in such diverse applications such as automobiles, aircraft, space vehicle, offshore structures, container, piping electronic and appliance. Polymeric materials posses the widest variety and range of mechanical properties. However, polymeric materials are seldom used unmodified. The bulk properties of a polymer can be significantly altered and widened to enhance the scope of its application by use of new additive, Carbon Nano Tube (CNT). A selected reinforcement ( glass fiber ), compatible epoxy, and Carbon Nano Tube are mixed together to get a desired specimen. The composite produced would has different properties than the original materials and the tribological properties of this material will be investigate.

## 1.2 Problem statement

The future applications that used composite material will massively increase since it has good properties, lightweight but strong compare to steel. Therefore, composite material needs to be improved in term of mechanical properties, resistance to the wear and friction that is the most common problems that encountered. In this research, it focuses on the glass fibre reinforcement with Carbon Nano Tube (CNT). The weakest areas in a traditional carbon-fibre component are the tiny spaces between the fibers that contain only resin.The purpose of research in tribology in understandably the minimization and elimination of losses resulting from friction and wear at all levels of technology where the rubbing of surface is involved. Research in tribology leads to greater plant efficiency, better performance, fewer breakdowns, and significant savings.

## 1.3 The relevancy of the project

When materials such as ceramics and polymers are manipulated into increasingly smaller and smaller particle sizes, the resulting increase in available surface area leads to a direct improvement in a variety of material properties, including thermal and electrical conductivity, and surface chemistry (which affects particle dispersibility and reactivity).

In general, using much smaller loadings of nanoscaled additives, today's nanocomposites demonstrate the following improved properties, compared with both the neat resin and conventional composites that are made using micron-sized additive particles

- Better mechanical properties, such as higher tensile and flexural strength and moduli, improved toughness, improved scratch resistance and surface appearance even at low additive loading levels.
- Better barrier properties in terms of decreased liquid and gas permeability, and improved resistance to organic solvents
- Improved fire retardancy

## 1.4 Objective and scope of study

- To study and analyze the wear and friction ( tribological properties) behaviour of the composite material with the addition of Carbon Nano Tube (CNT) using pin-on-disc and linear abraser testing techniques.

- To select the optimum property regarding the wear and friction of the composite material reinforced with Carbon Nano Tube (CNT).

# CHAPTER 2
# LITERATURE REVIEW & THEORY

## 2.1 Carbon Nano Tube ( CNT )

Carbon nanotubes are unique nanostructures with remarkable electronic and mechanical properties. Interest from the research community first focused on their exotic electronic properties, since nanotubes can be considered as prototypes for a one-dimensional quantum wire. As other useful properties have been discovered, particularly strength, interest has grown in potential applications. Carbon nanotubes could be used, for example, in nanometre-sized electronics or to strengthen polymer materials. [ 1 ]

It is configurationally equivalent to two dimensional graphene sheet rolled into a tube. It is grown now by several techniques in the laboratory and is just a few nanometers in diameter and several microns long. CNT exhibits extraordinary mechanical properties: the Young's modulus is over 1 Tera Pascal. It is stiff as diamond. The estimated tensile strength is 200 Giga Pascal. These properties are ideal for reinforced composites, nanoelectromechanical systems (NEMS). [2]

Graphite, the stuff in a pencil, is formed from carbon atoms arranged in a honeycomb pattern. These honeycomb layers are stacked one above the other. A single sheet of graphite is very stable, strong, and flexible. Since a single sheet is so stable by itself, it binds only weakly to the neighboring sheets.

Although the individual flakes are very strong and flexible, the graphite used in a pencil is weak, since the flakes can easily slide relative to each other. In carbon fibers, the individual layers of graphite are much larger and form a long, thin winding spiral pattern. These fibers can be stuck together in an epoxy, forming an extremely strong, light (and expensive) composite used in aircraft, tennis rackets, racing bicycles, racecar suspensions, etc. Carbon Nano Tube is a tube of graphite. These nanotubes are the strongest fibers known. A single perfect nanotube is about 10 to 100 times stronger than steel per unit weight. [ 3]

Carbon nanotubes (CNTs) are carbon allotropes. A single-walled carbon nanotube (SWNT) is a one-atom thick sheet of graphite (called graphene) rolled up into a seamless cylinder with diameter on the order of a nanometer. This results in a nanostructure where the length-to-diameter ratio exceeds 10,000. Such cylindrical carbon molecules have novel properties that make them potentially useful in many applications in nanotechnology, electronics, optics and other fields of materials science. They exhibit extraordinary strength and unique electrical properties, and are efficient conductors of heat. Inorganic nanotubes have also been synthesized.[4]

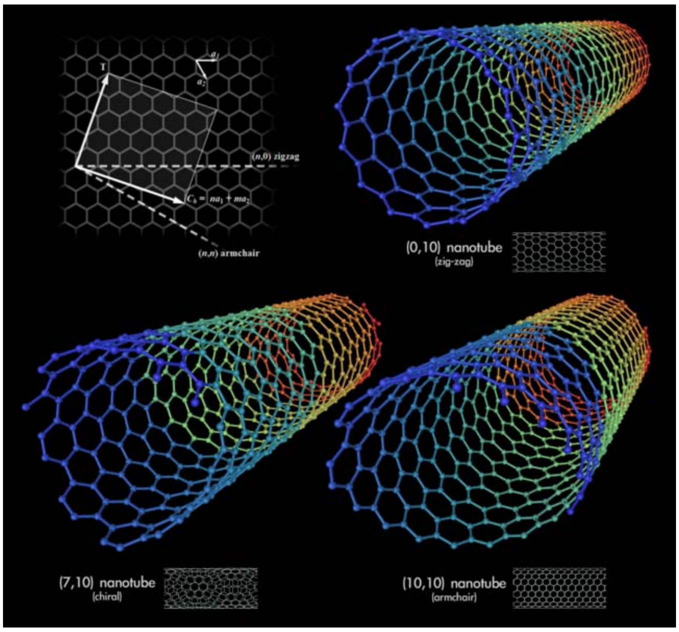


Figure 2.1 : 3D model of single-walled carbon nanotubes.

Nanotubes are members of the fullerene structural family, which also includes buckyballs. Whereas buckyballs are spherical in shape, a nanotube is cylindrical, with at least one end typically capped with a hemisphere of the buckyball structure. Their name is derived from their size, since the diameter of a nanotube is in the order of a few nanometers (approximately 50,000 times smaller than the width of a human hair), while they can be up to several millimeters in length. There are two main types of nanotubes: single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs).

Conceptually, single-wall carbon nanotubes (SWCNTs) can be considered to be formed by the rolling of a single layer of graphite (called a graphene layer) into a seamless cylinder. A multiwall carbon nanotube (MWCNT) can similarly be considered to be a coaxial assembly of cylinders of SWCNTs, like a Russian doll, one within another; the separation between tubes is about equal to that between the layers in natural graphite. Hence, nanotubes are one-dimensional objects with a well-defined direction along the nanotube axis that is analogous to the in-plane directions of graphite." [5]

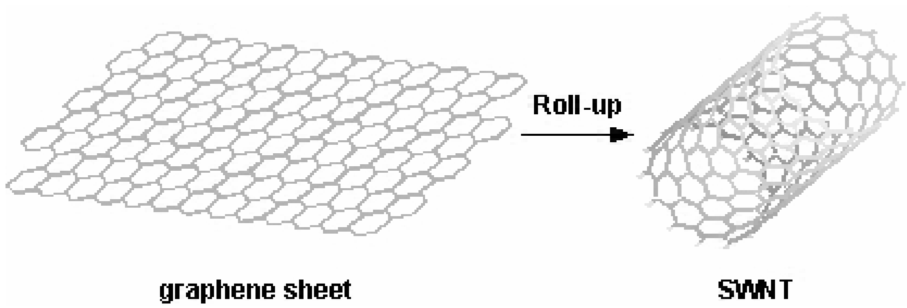


Figure 2.2 : Rolling of a single layer of graphite into a seamless cylinder

## 2.2 Polymer composites [6]

Polymer composites are made from:
•A polymer matrix, thermoset or thermoplastic.

A non-miscible reinforcement closely linked with the matrix: fibres of significant length compared to the diameter, yarn, mats, fabrics, foams, honeycombs, etc.The consumption of composites with organic matrices is a few percent of the total plastic consumption. The main advantages of the composites are:

• Mechanical properties higher than those of the matrix,

• The possibility of laying out the reinforcements to obtain the best properties in the direction of the highest stresses.

The development of the composites is held back by the recycling difficulties, attenuated in the case of the thermoplastic matrices. The "pyramid of excellence" (see Figure 2.2) classifies, as arbitrarily as for the thermosets, the composites according to their performances. consumption level and degree of specificity:

• Unsaturated polyesters (UP) reinforced with glass fibres: the most used for their performances and low cost.

• Phenolic resins (PF) reinforced with glass fibres: fire resistance, good performances and low cost.

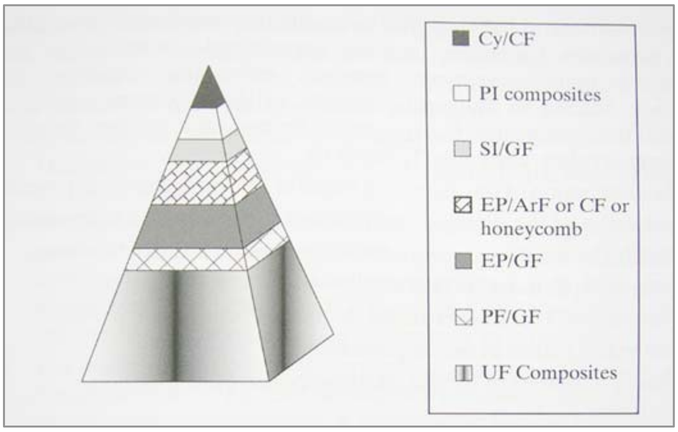


Figure 2.3 : Pyramid of excellence
for some composite families

• Epoxy (EP) reinforced with glass fibres perform better than the UP GF.

• Epoxy (EP) reinforced with aramid or carbon fibres or with honeycombs: high-tech and high cost composites performing better than the EP/GF.

• Silicone (Si) reinforced with glass fibres: flexibility, heat resistance, chemical resistance and physiological harmlessness.

• Polyimide (PI) reinforced with aramid or carbon fibres or with honeycombs: very high-tech and high cost composites performing better than the EP composites. The consumption is limited.

• Polycyanate matrices: very specific uses, high-tech and high cost composites, very restricted distribution.

## 2.3 Epoxy resin

Epoxy or polyepoxide is a thermosetting epoxide polymer that cures (polymerizes and crosslinks) when mixed with a catalyzing agent or "hardener". Most common epoxy resins are produced from a reaction between epichlorohydrin and bisphenol-A. The applications for epoxy based materials are extensive and include coatings, adhesives and composite materials such as those using carbon fiber and fiberglass reinforcements.

The chemistry of epoxies and the range of commercially available variations allows cure polymers to be produced with a very broad range of properties. In general, epoxies are known for their excellent adhesion, chemical and heat resistance, and good to excellent mechanical properties. Epoxy adhesives are a major part of the class of adhesives called "structural adhesives" or "engineering adhesives" (which also includes polyurethane, acrylic, cyanoacrylate, and other chemistries.) These high performance adhesives are used in the construction of aircraft, automobiles, bicycles, golf clubs, skis, snow boards, and other applications where high strength bonds are required. Epoxy adhesives can be developed that meet almost any application. They are exceptional adhesives for wood, metal, glass, stone, and some plastics. They can be made flexible or rigid, transparent or opaque/colored, fast setting or extremely slow. Epoxy adhesives are almost unmatched in heat and chemical resistance among common adhesives. In general, epoxy adhesives cured with heat will be more heat- and chemical-resistant than when cured at room temperature. [7]

Other materials can become part of the reaction yielding Bis F resins, Novolac resins, and multifunctional resins.The reaction product is high in viscosity and can either undergo further reaction processes to yield a lower viscosity resin. Epoxy resins are often modified using other products to improve some measured property of the final product such as toughness or tensileness. Epoxy resins and their additives contribute to the viscosity of the system and to the shrinking characteristics.  The amount of the fillers and diluents will impact both the physical and handling properties of the resin system. Epoxy resins are part of a two-component thermo-set plastic that requires an epoxy hardener to determine the majority of the handling and physical properties of the base. The use of several variations of unmodified and modified epoxy resins with the same epoxy hardener will produce some variations in their properties; however, the epoxy hardener is the primary factor in the base property. [8]

## 2.4 Epoxy Hardeners

Epoxy hardeners are not catalysts and they react with the epoxy resins, greatly contributing to the ultimate properties of the cured epoxy resin system. Epoxy hardeners provide: gel time; mixed viscosity; demold time of the epoxy resin system. Physical properties of the epoxy resin system such as tensility, compression, flexural properties, etc., are also influenced by epoxy hardeners.

The performance of epoxy hardeners in the epoxy resins system depend on the chemical characteristics of the epoxy resins and the physical characteristics while applying the epoxy resins system. The chemical characteristics of the epoxy resins that influence epoxy hardeners are: viscosity; amount and kind of diluents and filers in epoxy resins. The physical characteristics of the epoxy resins system influencing the behaviour of epoxy hardeners in the epoxy resins system are: temperature of the work area, temperature of the resins system (i.e. the heated resins), and moisture (dampness).

## 2.5 Friction of coefficient

### *2.5.1 Measurements of friction coefficient*

In almost all tribology test (with the exception of tests based on a block sliding down an inclined slope) the friction coefficient is deduced from measurement of the friction force. There are two uncertainties involved in the determination of friction coefficient from friction force.

- The friction force varies continuously so that the notion of a precise coefficient of friction is an approximation to reality.
- The calculation of friction coefficient is based on the nominal contact load, ie:

| Friction coefficient = Friction force / Nominal contact Load |
|---|

In most cases the nominal contact load is usually applied by the hanging weight to impose a contact stress on the sliding surfaces. It is an essential to provide the weight with soft suspension because with rough surfaces the contact load can vary significantly, i.e. the rougher the surface the higher the load variation. Friction force is also affected the surface roughness [9]. When the relationship between variation in contact load and friction force is not known, it has to be assumed that peaks in friction force coincide with peak in contact load to provide an averaging affect. If there is an averaging effect, then the equation for friction coefficient given above is approximately correct.

The definition of friction of coefficient as friction force / nominal contact load enables the energy dissipation rate to be found directly from the friction coefficient. This feature is very useful for predicting average temperature rises. The definition of friction of coefficient as instantaneous friction force/ instantaneous contact load provides a measure of the intensity of asperity interaction or film shearing forces at a particular point in time. This definition of friction of coefficient alone allows the effect of microscopic processes such as mechanical vibration of the sliding system. It is also possible to measure the true friction coefficient by simultaneous measurement of instantaneous contact load frictional force [10]

## 2.6 Wear

### *2.6.1 Introduction*

Wear is a surface damage or removal of material from one or both of two solid surface in a sliding, rolling or impact motion relative to one other. In most cases, wear occur through surface interaction at asperities. During relative motion, first material on the contacting surface may be displaced so that properties of the solid body, at least at or near the surface are altered but little or no material is actually lost. Later, material may be removed from a surface and may result in the transfer to mating surface or may break loose as a wear particle. In the case of transfer from one surface to another, net volume or mass of the interaction is zero, although one of the surfaces is worn (with a net volume or mass loss) [11]. The mechanism of wear is very complex and the theoretical treatment without the use of rather sweeping simplifications is not possible. It should be understood that the real area of contact between two solid surfaces compared with the apparent area of contact is invariably very small, being limited to points of contact between surface asperities. The load applied to the surfaces will be transferred through these points of contact and the localised forces can be very large. The material intrinsic surface properties such as hardness, strength, ductility, work hardening etc. are very important factors for wear resistance, but other factors like surface finish, lubrication, load, speed, corrosion, temperature and properties of the opposing surface etc. are equally important.

### *2.6.2 Abrasive Wear*

The abrasive wear mechanism is basically the same as machining, grinding, polishing or lapping that we use for shaping materials. Two body abrasive wear occurs when one surface (usually harder than the second) cuts material away from the second, although this mechanism very often changes to three body abrasion as the wear debris then acts as an abrasive between the two surfaces. Abrasives can act as in grinding where the abrasive is fixed relative to one surface or as in lapping where the abrasive tumbles producing a series of indentations as opposed to a scratch.

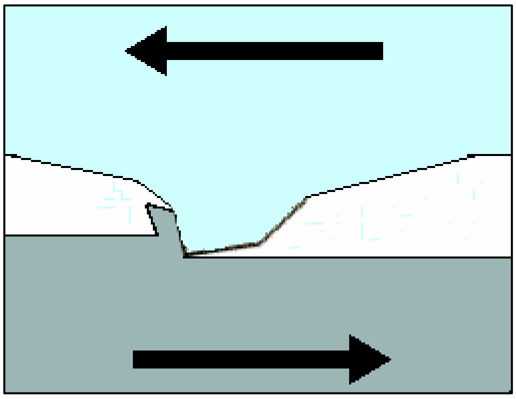

Figure 2.4: abrasive wear

Abrasive Wear Effects:

- Dimensional changes
- Leakage
- Lower efficiency
- Generated particles contribute more wear

Abrasive wear is a primary wear mechanism. Particles enter the clearance space between two moving surfaces, and act like cutting tools to remove material from the surfaces. The particle sizes causing the most damage are those equal to and slightly larger than the clearance space. To protect opposing surfaces from abrasive wear, particles of approximately the operating clearance size range must be removed.[12]

### *2.6.3 Adhesive Wear*

Adhesive wear is produced by the formation and subsequent shearing of welded junctions between two sliding surfaces. For adhesive wear to occur it is necessary for the surfaces to be in intimate contact with each other. Surfaces which are held apart by lubricating films, oxide films etc. reduce the tendency for adhesion to occur.

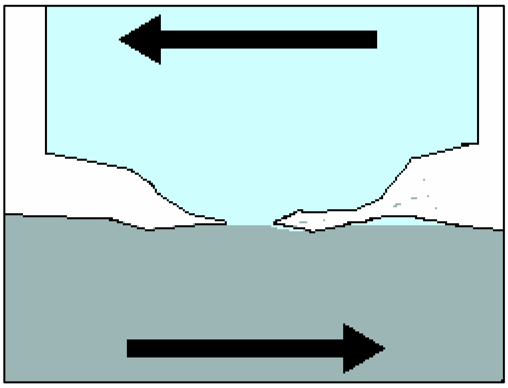

Figure 2.5 : adhesive wear

### *2.6.4 Erosion*

Erosion is caused by a gas or a liquid which may or may not carry entrained solid particles, impinging on a surface. When the angle of impingement is small, the wear produced is closely analogous to abrasion. When the angle of impingement is normal to the surface, material is displaced by plastic flow or is dislodged by brittle failure.

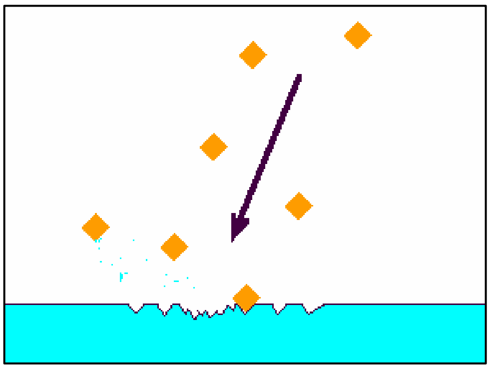

Figure 2.6: Erosion

### *2.6.5 Cavitation Erosion*

Cavitation is the formation and collapse, within a liquid, of cavities or bubbles that contain vapour or gas. Normally, cavitation originates from changes in pressure in the liquid brought about by turbulent flow or by vibration, but can also occur from changes in temperature (boiling). Cavitation erosion occurs when bubbles or cavities collapse on or very near the eroded surface. The mechanical shock induced by cavitation is similar to that of liquid impingement erosion causing direct localised damage of the surface or by inducing fatigue.

### *2.6.6 Fretting Wear*

Fretting is a small amplitude oscillatory motion, usually tangential, between two solid surfaces in contact. Fretting wear occurs when repeated loading and unloading causes cyclic stresses which induce surface or subsurface break-up and loss of material. Vibration is a common cause of fretting wear.[13]

Fretting wear is the repeated cyclical rubbing between two surfaces, which is known as fretting, over a period of time which will remove material from one or both surfaces in contact. It occurs typically in a bearings, although most bearings have their surfaces hardened to resist the problem. Another problem occurs when cracks in either surface are created, known as fretting fatigue. It is the more serious of the two phenomena because it can lead to catastrophic failure of the bearing. An associated problem occurs when the small particles removed by wear are oxidised in air. The oxides are usually harder than the underlying metal, so wear accelerates as the harder particles abrade the metal surfaces further. Fretting corrosion acts in the same way, especially when water is present. Unprotected bearings on large structures like bridges can suffer serious degradation in behaviour, especially when salt is used during winter to deice the highways carried by the bridges[14]

### *2.6.7 Determination of wear from weight loss*

Measurement of mass change is usually performed using an analytical balance. Quite accurate data can be obtained if the specimens are cleaned before measurements and are only handed remotely using tongs or tweezers for small specimens. Mass change in wear is usually small, e.g of a few mg, and a sensitive analytical balance is required. Changes in mass of the specimen may not only be the result of wear. Other factors such as corrosion of the specimen and absorption of fluid need to be considered particularly when tests on materials in corrosive and wet environments are performed. Simples examples of this type of tests are corrosive-abrasive wear experiments and studies of polymers wear in organic fluids.[15]

### *2.6.8 Pin-on-Disc Apparatus*

This apparatus is perhaps the most widely used. A pin is pressed against a rotating disc either on its flat surface, as shown in Figure 2.7, or on the circumference of the disc. The latter configuration is sometimes referred to as pin-on-drum. The dimensions of the pin and disc depend on the type of tests conducted. The pin-on-disc apparatus offers far better control of experimental conditions and for this reason is becoming increasingly used in preference to other tribometers.

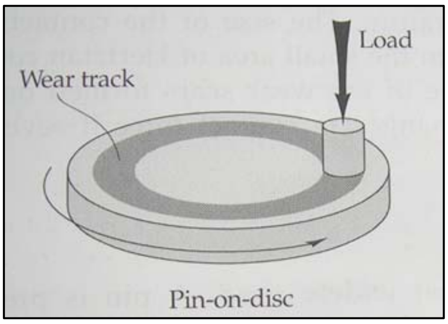


Figure 2.7 : Pin on disc concept

The apparatus allows experiments to be conducted under relatively steady conditions without systematic variations, e.g. in contact area or sliding speed, as they often occur in other tribometers. One of the problems encountered in these tribometers is the control of normal load on the pin. Initially, at the beginning of the test, the surface of the disc is smooth but later the transfer films may accumulate on the surface or wear roughening and wear anisotropy may take place causing the pin to vibrate or bounce over the surface of the disc. Wear anisotropy is often found in ceramics where one part of a ceramic disc wears more than other parts because of the change in direction of sliding relative to grain orientation. For consistent experimental data hanging weights should not be used as a load system and instead a spring or hydraulic system (with a pressure stabilizer) should rather be applied [16].

Pin-on-disc testing is a commonly used technique for investigating sliding wear. As the name implies, such apparatus consists essentially of a "pin" in contact with a rotating disc. Either the pin or the disc can be the test piece of interest. The contact surface of the pin may be flat, spherical, or, indeed, of any convenient geometry, including that of actual wear components.

In a typical pin-on-disc experiment, the coefficient of friction is continuously monitored as wear occurs, and the material removed is determined by weighing and/or measuring the profile of the resulting wear track. Changes in coefficient of friction are frequently indicative of a change in wear mechanism, although marked changes are often seen during the early stages of wear tests as equilibrium conditions become established.

The main variables which affect friction and wear are velocity and normal load. In addition, specimen orientation can be important if retained wear debris affects the wear rate. Most commercial pin-on-disk testers use high loads (e.g., 100 - 1000N) obtained with a dead weight and large areas of contact. In the NanoTest, a lower, continuously variable load (from the mN range to 20N with the high load head) and a smaller pin are employed to achieve equivalent pressures. This reflects the current movement towards lower load, smaller scale tribology testing.[17]

### *2.6.9 Linear abrasion testing*

Pin-on-disk and reciprocating sliding tests are two of the most used tribological test instruments for testing at normal forces. Friction and wear mechanisms occurring at high normal forces are well established for different materials and coatings, and such highly loaded sliding tests are relevant for instance for cutting tools. The dissipated frictional energy in such tests is very high and gives rise to considerable wear rates in the order of micrometer per hour. As a result, an abundance of third body particles is created, influencing the contacts and thereby affecting friction and wear processes considerably [18].

There are many tribo-systems operating in various environments, where such high wear rates or high contact pressures are not relevant. Mechanical components even in conventional engines and machines, are wearing at rates in the order of nanometer per hour, which is a thousand times slower than in many lab tests. Also, more and more applications emerge where sliding occurs over small displacements in the range of micrometers under low normal forces of a few micro/milli-Newtons and low contact pressures of a few MPa or less. Such sliding conditions can be found in micro-motors and bio-implants [19].

# CHAPTER 3
# METHODOLOGY

## 3.1 Research Methodology

Figure 3.1.1 show the methodology that will be carried out during this project. It started with problem identification, study the literature review, and preparing the sample. After carry out all of the steps, the samples were produced according to the design.

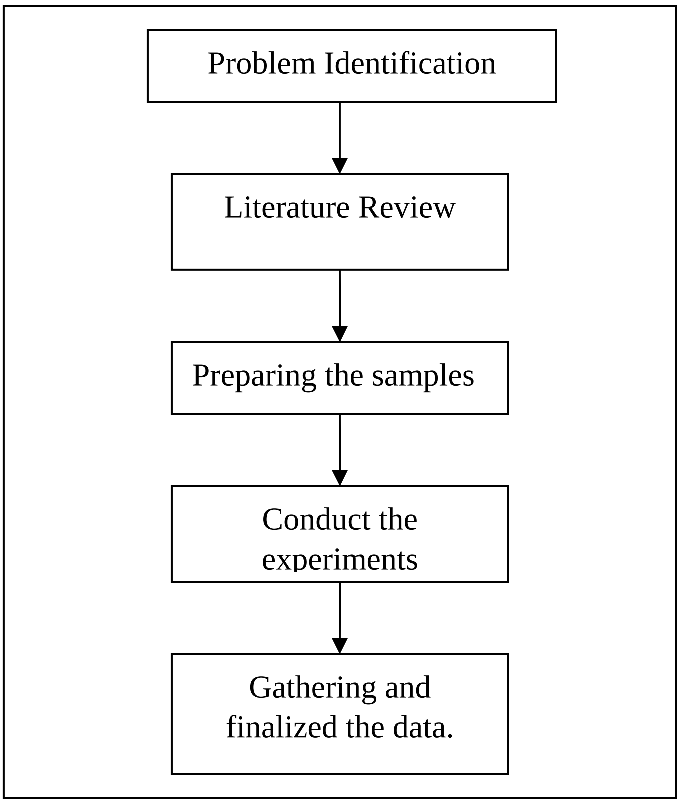


Figure 3.1 **:** The research methodology that was carry out during this project

## 3.2 Experiment Procedure

### *3.2.1 Designing the mould*

In order to design the mould, the aluminium plate is cut into the chosen size with dimensions of 46 mm x 46mm. Then, the aluminium is shaped to form a tiny box as shown in ***figure 3.2***. ***Figure 3.3*** show the 3D mould model that was done using Catia Software.

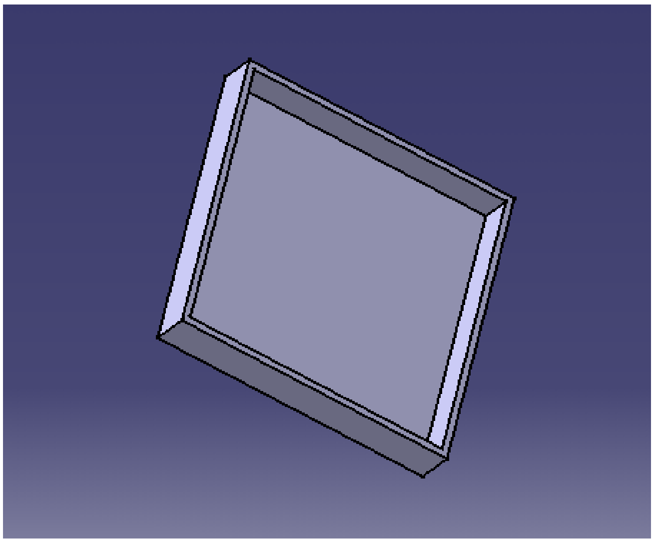

Figure 3.2 : The 3D mould model for the specimen

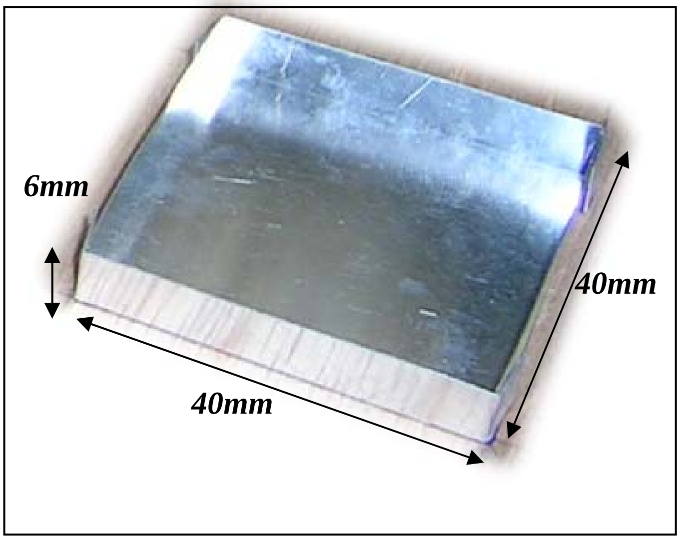


Figure 3.3 : The real mould made by aluminium

### *3.2.2 Specimen preparation*

There are six types of specimens that was tested ;

- Neat epoxy.
- Epoxy + carbon Nanotube (CNT).
- Epoxy + woven roving fibre glass + carbon Nanotube (CNT).
- Epoxy + woven roving fibre glass .
- Epoxy + mat fibre glass .
- Epoxy + mat fibre glass + carbon Nanotube (CNT).

Figure 3.4 and figure 3.5 show the 2 types of fibre glass used in this study.

Figure 3.4 : Woven roving fibre glass

Figure 3.5 : Matte fibre glass
fibre glass

#### *3.2.2.1 Neat Epoxy Specimen*

In preparing the neat Epoxy Resin specimen, a mould is first treated with liquid wax. Meanwhile, the resin is prepared with the addition of hardener and is properly mixed. The ratio mixture of epoxy resin and hardener is 5:3. The mixture was stirred thoroughly for approximately 2 minutes using multimixer machine.The mixture is then poured onto the mold and left to cure at room temperature for one day.

Figure 3.6 : Multimixer machine

### *3.2.2.2 Composite Specimen*

In a hand lay-up technique, a mould is first treated with a release agent such as liquid wax so that it would be easier to remove tile composite from the mould after the curing process. In this study, alumnium plates are used as the mould. For the first specimen, a layer of woven roving fiberglass is placed over the steel plate and tile epoxy resin is poured on top of the fiber. The epoxy resin is distributed over tile entire fiber surface and into the fibers by using hand rollers. Two layers of Fiberglass are used in preparing the samples. The same principle goes to the other specimen, but the difference is, the addition of Carbon Nano Tube to the composite material : epoxy + CNT + fiber glass,

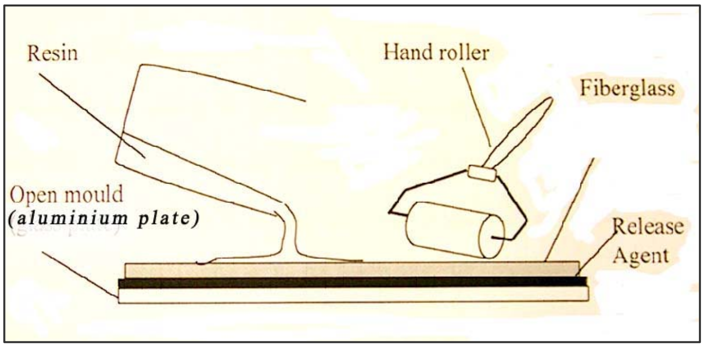


Figure 3.7 : Hand lay up method

These rollers also compress the fibers to remove any air that might be trapped. Additional layers of fiberglass cloth/mat are added to build up the desired thickness and more resins is added and distributed. At the end of the process, another plate of glass is placed over tile final layer to give a smooth surface and also to provide pressure to ensure even thickness and good compaction of the specimen. The composite is left to cure at room temperature for one day.

### *3.2.3 Pin on disc machine*

This test method describes a laboratory procedure for determining the wear of materials during sliding using a pin-on-disk apparatus. Materials tested in pair under nominally non-abrasive conditions. 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.

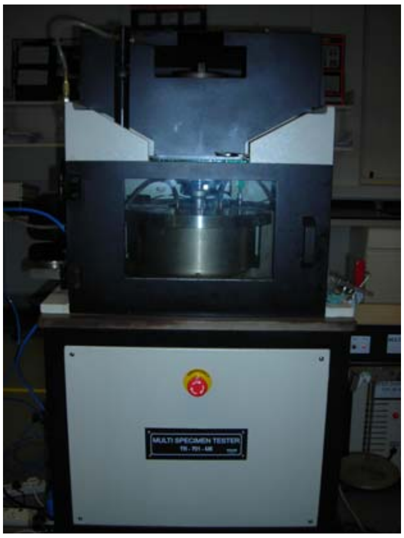

Figure 3.8 : Pin on disk machine

#### *3.2.3.1 Procedure*

Immediately prior to testing, and prior to measuring or weighing, the specimens must be clean and dry . All dirt and foreign matter was removed from the specimens. Use non chlorinated, non-film-forming cleaning agents and solvents.

Then, the material was dry with open grains to remove all traces of the cleaning fluids that may be entrapped in the material.

The first sample is neat epoxy, with dimensions of 40 mm x 40 mm x 6 mm was used in this experiment. The procedure of experiment as stated below:

1. The sample ( Epoxy + Carbon Nanotube) was weighted using weight measurement (Balance Mettler Toledo). Weight the specimen to the nearest 0.0001 gram.

Figure 3.9 : Balance Merrier Toledo

2. The specimens was inserted securely in the holding device so that the specimen is fixed perpendicular to the axis of the resolution.

Figure 3.10 : Disc Holder

3. The pin (brass) was inserted securely in its holder and, the specimen is perpendicular to the disc surface when in contact, in order to maintain the necessary contact condition.

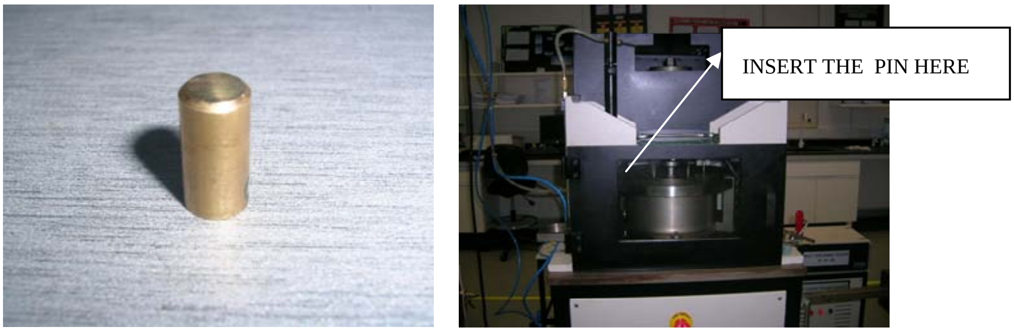


Figure 3.11 : Pin brass

4. Open the windcom software.

5. Set the parameter value for the machine, with speed 30 rev/min, and time 0.2 hours for each experiment.

6. Add the proper mass to the system lever or bale to develop the selected force pressing the pin agains the disc. For the first case, load of100 Newton was installed.

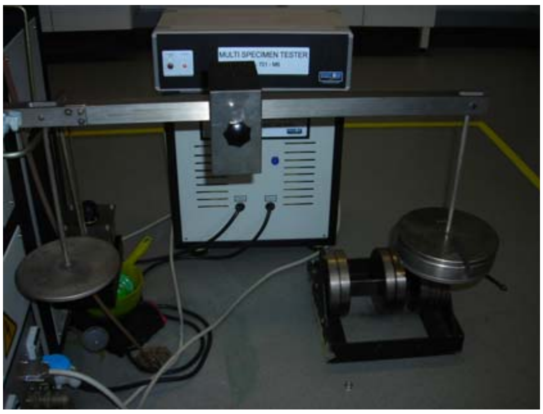


Figure 3.12 : Installing the disk to get the desired load

7. Run the software and the data will record into the computer.

8. The specimen was removed and clean off any loose wear debris. Remeasure the weight specimen to the nearest 0.0001 g, as appropriate.

9. The experiment was repeated but with different load, 200N and 300 N.

10. Then, the procedure 1 to 8 was repeated using other different specimens.

### *3.2.4 Linear abraser machine*

Figure 3.13 : Linear abraser machine

#### *3.2.4.1 Procedure*

First ,to install the Wearaser into the collet, the following procedure was followed :

1. Using the lock mechanism, lock the collet assembly in the "up" position.

2. With the wearaser collet mounted to the spline shaft, loosen (but DO NOT remove) the collet nut by turning it clockwise.

3. Insert the Wearaser so that it extends approximately 0.100" from the bottom of the collet. The Wearaser depth gage can be used to check the measurement

4. Tighten the collet nut by turning it counterclockwise.

Figure 3.14 : Wearaser

5. Set the parameter value for the machine, with speed 60 cycle/min, and total cycle 60 for each experiment.

6. The specimen was placed to the holder of linear abraser machine


Figure 3.15 : Installing the specimen and wearaser to the machine

7. Add the proper mass to the system. For the first case, load of 2.5 Newton was installed.

8. The specimen was removed and clean off any loose wear debris. Remeasure the weight specimen to the nearest 0.0001 g, as appropriate.

9. The experiment was repeated but with different load, 5 N and 7.5 N.

(note :

10. Then, the procedure 5 to 9 was repeated using other different specimens.

# CHAPTER 4
# RESULT AND DISCUSSION

## 4.1 Pin On Disc Test

### *4.1.1 Load Vs Weight Loss*

The Wear Test (Pin On Disc Test) of 3 samples has been executed to find out the wear characteristic of the samples. For each load, the experiment takes about 12 minutes to completed and the weight loss was determined using weight apparatus (Mettler Toledo Balance). Table 4.1.1.1 to 4.1.1.6 show the result obtained.

**Neat epoxy**

| No | Load (Newton) | Weight Loss (g) | Weight Loss II (g) | Weight Loss III (g) | mean |
|---|---|---|---|---|---|
| 1 | 100 | 0.0161 | 0.0159 | 0.0164 | 0.0161 |
| 2 | 200 | 0.0417 | 0.0419 | 0.0415 | 0.0417 |
| 3 | 300 | 0.0880 | 0.0883 | 0.0879 | 0.0881 |

Table 4.1 : Weight loss of specimen 1 (SI) under different load

**Epoxy + CNT**

| No | Load (Newton) | Weight Loss (g) | Weight Loss II (g) | Weight Loss III (g) | mean |
|---|---|---|---|---|---|
| 1 | 100 | 0.0011 | 0.0013 | 0.0010 | 0.0013 |
| 2 | 200 | 0.0127 | 0.0125 | 0.0120 | 0.0124 |
| 3 | 300 | 0.0241 | 0.0245 | 0.0239 | 0.0242 |

Table 4.2 : Weight loss of specimen 2 (S2) under different load

**Epoxy +matte fibre glass**

| No | Load (Newton) | Weight Loss (g) | Weight Loss II (g) | Weight Loss III (g) | mean |
|---|---|---|---|---|---|
| 1 | 100 | 0.0046 | 0.0044 | 0.0050 | 0.0047 |
| 2 | 200 | 0.0147 | 0.0146 | 0.0145 | 0.0146 |
| 3 | 300 | 0.0329 | 0.0327 | 0.0330 | 0.0329 |

Table 4.3: Weight loss of specimen 3 (S 3) under different load

**Epoxy + matte fibre glass + CNT**

| No | Load (Newton) | Weight Loss (g) | Weight Loss II (g) | Weight Loss III (g) | mean |
|---|---|---|---|---|---|
| 1 | 100 | 0.0011 | 0.0010 | 0.0012 | 0.0011 |
| 2 | 200 | 0.0097 | 0.0097 | 0.0094 | 0.0096 |
| 3 | 300 | 0.0154 | 0.0155 | 0.0153 | 0.0154 |

Table 4.4: Weight loss of specimen 42 (S4) under different load

**Epoxy + woven roving fibre glass**

| No | Load (Newton) | Weight Loss (g) | Weight Loss II (g) | Weight Loss III (g) | mean |
|---|---|---|---|---|---|
| 1 | 100 | 0.0050 | 0.0055 | 0.0054 | 0.0053 |
| 2 | 200 | 0.0156 | 0.0155 | 0.0157 | 0.0156 |
| 3 | 300 | 0.0340 | 0.0345 | 0.0344 | 0.0343 |

Table 4.5: Weight loss of specimen 5 (S5) under different load

**Epoxy + woven roving fibre glass + CNT**

| No | Load (Newton) | Weight Loss (g) | Weight Loss II (g) | Weight Loss III (g) | mean |
|---|---|---|---|---|---|
| 1 | 100 | 0.0016 | 0.0015 | 0.0017 | 0.0016 |
| 2 | 200 | 0.0109 | 0.0108 | 0.0110 | 0.0109 |
| 3 | 300 | 0.0189 | 0.0184 | 0.0185 | 0.0186 |

Table 4.6: Weight loss of specimen 6 (S6) under different load

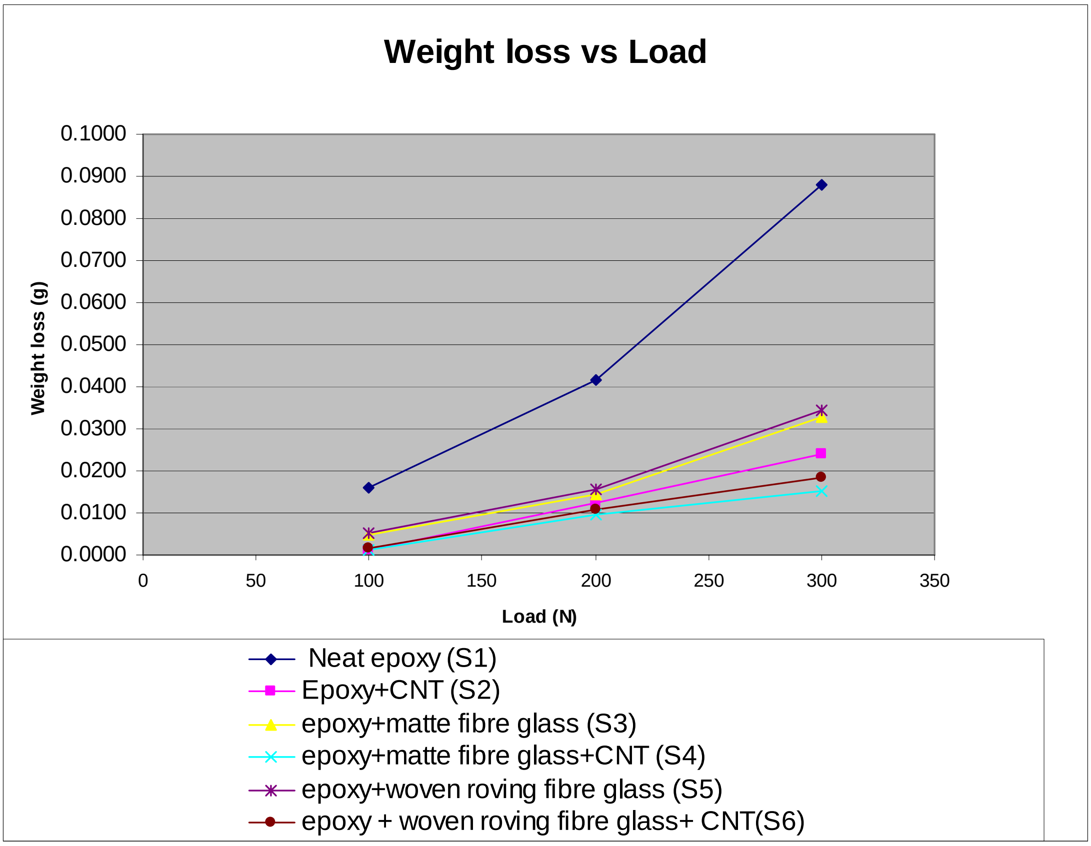


Figure 4.1: Weight loss vs load graph

Table 4.1 to table 4.6 show the effect of different loads to the rate of weight loss after it had experienced a wear test on 6 different types of material. From figure 4.1, Specimen S4 experience lowest value of weight loss compare to the other 5 specimens. The specimen that had the highest wear resistance will experience less weight loss. So in this case, specimen S4 had the highest value of wear resistant compare to the other. The different composition of the epoxy highly affects the result of the experiment. Specimen S5 have Carbon Nano Tube (CNT) as a additive that give more wear resistance compared the other 5 samples. For Specimen S3, the matte Fibre Glass provide better bonding to the material and experienced less weight loss during the friction process.

### *4.1.2 Load Vs Coefficient of Friction (COF)*

For each load, the experiment takes about 12 minutes to complete and the coefficient of friction value was obtained using the Windcom software. Table 4.1.1 to 4.1.3 show the result obtained.

**Epoxy**

| No | Load (Newton) | COF 1 | COF II | COF III | mean |
|---|---|---|---|---|---|
| 1 | 100 | 0.46348 | 0.42351 | 0.43856 | 0.44185 |
| 2 | 200 | 0.43436 | 0.42677 | 0.41963 | 0.42692 |
| 3 | 300 | 0.38783 | 0.39542 | 0.43919 | 0.40748 |

Table 4.7 : COF of the specimen 1(S1) under different load

**Epoxy + CNT**

| No | Load (Newton) | COF 1 | COF II | COF III | mean |
|---|---|---|---|---|---|
| 1 | 100 | 0.39421 | 0.43254 | 0.39569 | 0.40748 |
| 2 | 200 | 0.36211 | 0.33255 | 0.46415 | 0.38627 |
| 3 | 300 | 0.35299 | 0.37233 | 0.38852 | 0.37128 |

Table 4.8 : COF of the specimen 2(S2) under different load

**Epoxy +matte fibre glass**

| No | Load (Newton) | COF 1 | COF II | COF III | mean |
|---|---|---|---|---|---|
| 1 | 100 | 0.36588 | 0.31698 | 0.32145 | 0.33477 |
| 2 | 200 | 0.31581 | 0.27998 | 0.31084 | 0.30221 |
| 3 | 300 | 0.29552 | 0.27156 | 0.26875 | 0.27861 |

Table 4.9 : COF of the specimen 3(S3) under different load

**Epoxy + matte fibre glass + CNT**

| No | Load (Newton) | COF 1 | COF II | COF III | mean |
|---|---|---|---|---|---|
| 1 | 100 | 0.15826 | 0.17325 | 0.15542 | 0.16231 |
| 2 | 200 | 0.10688 | 0.08532 | 0.09688 | 0.09636 |
| 3 | 300 | 0.06500 | 0.08241 | 0.07324 | 0.07355 |

Table 4.10: COF of the specimen 4(S4) under different load

**Epoxy + woven roving fibre glass**

| No | Load (Newton) | COF 1 | COF II | COF III | mean |
|---|---|---|---|---|---|
| 1 | 100 | 0.21813 | 0.23158 | 0.21542 | 0.22171 |
| 2 | 200 | 0.12047 | 0.13698 | 0.14362 | 0.13369 |
| 3 | 300 | 0.08039 | 0.11785 | 0.10314 | 0.10046 |

Table 4.11: COF of the specimen 5(S5) under different load

**Epoxy + woven roving fibre glass + CNT**

| No | Load (Newton) | COF 1 | COF II | COF III | mean |
|---|---|---|---|---|---|
| 1 | 100 | 0.01930 | 0.19934 | 0.17652 | 0.18962 |
| 2 | 200 | 0.08635 | 0.10682 | 0.11931 | 0.10416 |
| 3 | 300 | 0.08511 | 0.09422 | 0.08125 | 0.08686 |

Table 4.12 : COF of the specimen 6(S6) under different load

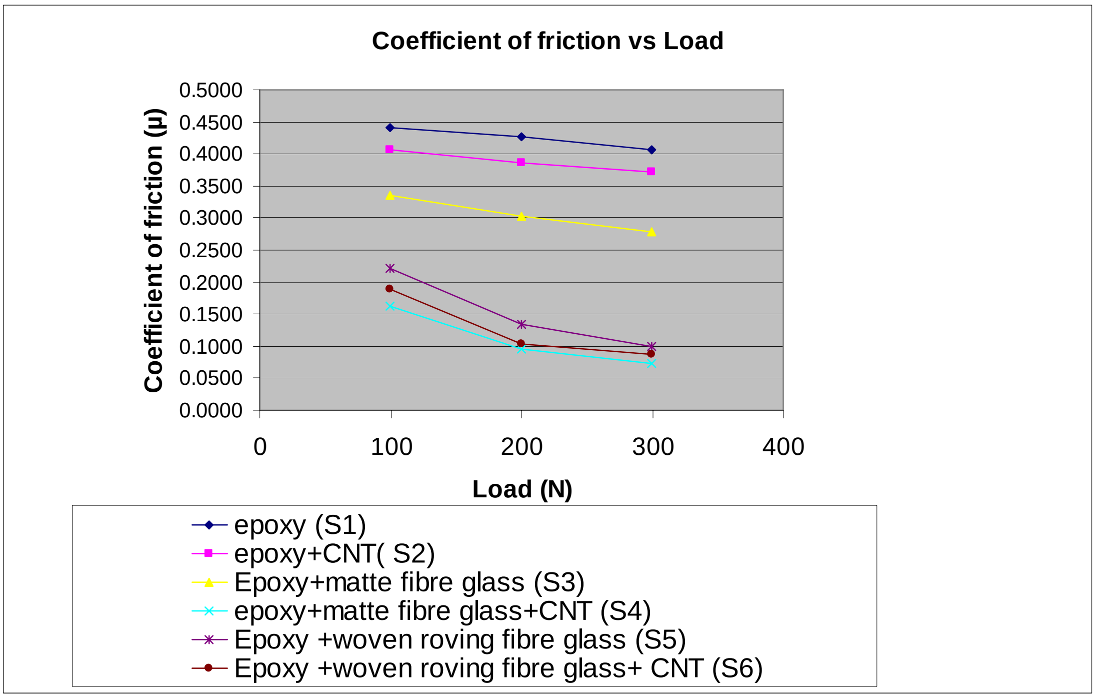


Figure 4.2 : Coefficient of friction vs Load graph

The coefficient of friction is the quotient obtained by dividing the value of the force necessary to move one body over another at a constant speed by the weight of the body. It is a number which represents the friction between two surfaces. For example, if a force of 20 newtons is needed to move a body weighing 100 newtons over another horizontal body at a constant speed, the coefficient of friction between these two materials is 20/100 or 0.2 Based on the figure 4.1.4 above, all the specimen had negative slope, mean that the value of coefficient of friction is decreasing with increasing in load.

Specimen S4 had the lowest value of coefficient of friction, that mean it is a good material to resist the friction. Then it was followed by S6, S2, S3, S5 and S1.

## 4.2 Linear Abrader Test

**Neat epoxy**

| No | Load (Newton) | Weight (before) (g) | Weight (after) (g) | Weight Loss (g) |
|---|---|---|---|---|
| 1 | 6 | 9.8783 | 9.8723 | 0.0060 |
| 2 | 8.5 | 9.8723 | 9.8657 | 0.0066 |
| 3 | 11 | 9.8657 | 9.8584 | 0.0073 |

Table 4.13 : Weight loss of specimen 1 (SI) under different load

**Epoxy + CNT**

| No | Load (Newton) | Weight (before) (g) | Weight (after) (g) | Weight Loss (g) |
|---|---|---|---|---|
| 1 | 6 | 11.2930 | 11.2893 | 0.0037 |
| 2 | 8.5 | 11.2893 | 11.2846 | 0.0047 |
| 3 | 11 | 11.2846 | 11.2791 | 0.0055 |

Table 4.14 : Weight loss of specimen 2 (S2) under different load

**Epoxy +matte fibre glass**

| No | Load (Newton) | Weight (before) (g) | Weight (after) (g) | Weight Loss (g) |
|---|---|---|---|---|
| 1 | 6 | 11.5218 | 11.5178 | 0.0040 |
| 2 | 8.5 | 11.5178 | 11.5127 | 0.0051 |
| 3 | 11 | 11.5127 | 11.5068 | 0.0059 |

Table 4.15: Weight loss of specimen 3 (S 3) under different load

**Epoxy + matte fibre glass + CNT**

| No | Load (Newton) | Weight (before) (g) | Weight (after) (g) | Weight Loss (g) |
|---|---|---|---|---|
| 1 | 6 | 11.3713 | 11.3683 | 0.0030 |
| 2 | 8.5 | 11.3683 | 11.3647 | 0.0036 |
| 3 | 11 | 11.3647 | 11.3600 | 0.0047 |

Table 4.16: Weight loss of specimen 4 (S4) under different load

**Epoxy + woven roving fibre glass**

| No | Load (Newton) | Weight (before) (g) | Weight (after) (g) | Weight Loss (g) |
|---|---|---|---|---|
| 1 | 6 | 11.9266 | 11.9219 | 0.0047 |
| 2 | 8.5 | 11.9219 | 11.9164 | 0.0055 |
| 3 | 11 | 11.9164 | 11.9099 | 0.0065 |

Table 4.17: Weight loss of specimen 5 (S5) under different load

**Epoxy + woven roving fibre glass + CNT**

| No | Load (Newton) | Weight (before) (g) | Weight (after) (g) | Weight Loss III (g) |
|---|---|---|---|---|
| 1 | 6 | 10.9632 | 10.9597 | 0.0035 |
| 2 | 8.5 | 10.9597 | 10.9554 | 0.0043 |
| 3 | 11 | 10.9554 | 10.9503 | 0.0051 |

Table 4.18: Weight loss of specimen 6 (S6) under different load

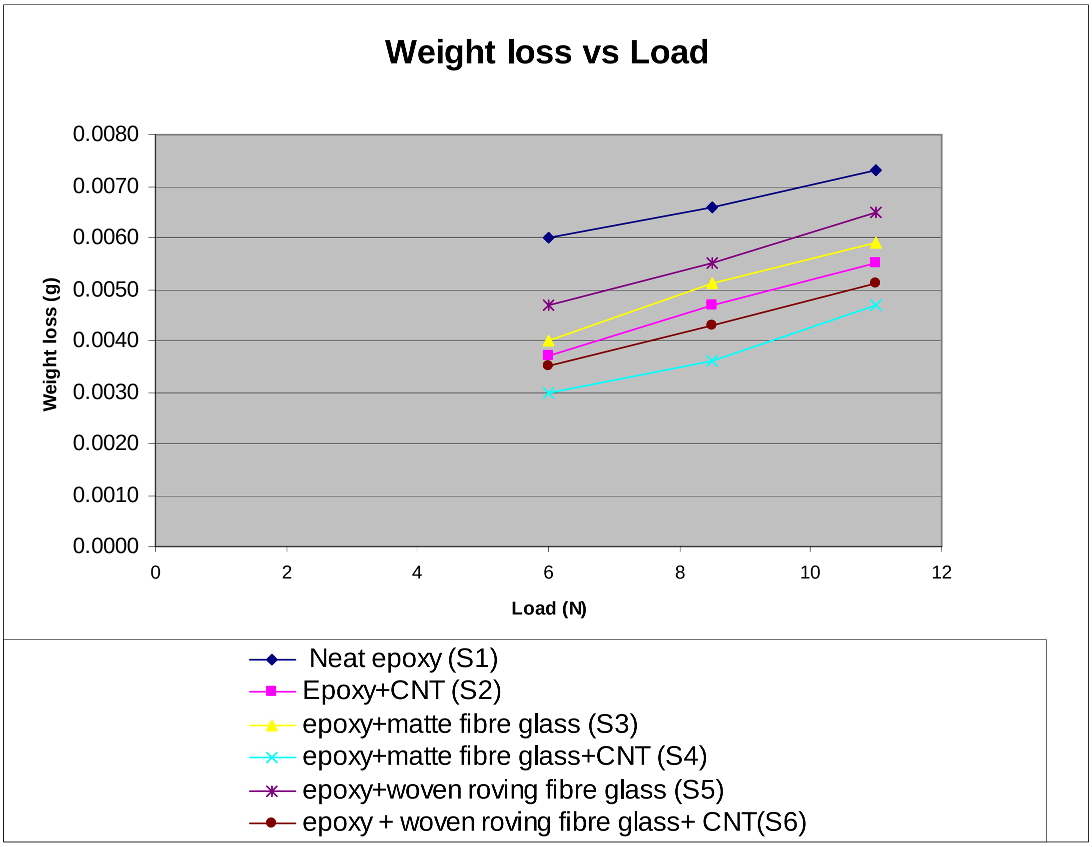


Figure 4.3: Weight loss vs Load graph

The amount of wear is determined by measuring appropriate linear dimensions of both specimens before and after the test, or by weighing both specimens before and after the test. In this experiment, the method weight loss is used. Using linear abrasion method, the material having the less weight loss is S4, followed by S6, S2, S3, S5 and S1.

# CHAPTER 5
# CONCLUSION AND RECOMMENDATION

Based on the experiment result, there were some conclusions that can be made: Firstly, increasing the load will increase the weight loss of the specimen. From the experiment, when 100 N load applied to the specimen SI, the weight loss was 0.0161 gram. After the load was increased to 200 N and 300N , the weight loss increase to 0.0417g and 0.088l g respectively.

Secondly, when the load is increased, the coefficient of friction will decrease. For the example, when 100 N load was applied to the specimen I, the coefficient of friction was 0.44185. After applying load of 200N and 300N, the coefficient of friction of Sl decreases to 0.42692 and 0.40748 respectively.

As a conclusion, the first objective of this project that is to study and analyze the wear and friction ( tribological properties) behaviour of the composite material with the addition of Carbon Nano Tube (CNT) using pin-on-disc and linear abraser testing techniques was accomplished.

The second objective is to select the optimum property regarding the wear and friction of the composite material reinforced with Carbon Nano Tube (CNT). From the result the best property of material that can sustained the scratch resistance is specimen 4 which is combination of epoxy + matte fibre glass + CNT. Then it was followed by specimen S1, S6, S2, S3, S5, and S1.

There are several recommendations that can be made to improve the quality of the result. The specimen prepared must be surface evenly flat and meet the dimension. The machine must be properly calibrate and the specimen holder must be in balance condition.

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# APPENDICES

## APPENDIX A : LINEAR ABRASER MACHINE SPECIFICATION

# LINEAR ABRASER

The Taber® linear abraser offers the greatest versatility of any Taber instrument available.

Designed to test virtually any size or shape specimen, this unit is ideal for material properties of contoured surfaces and finished products. Initially developed to evaluate wear resistance, this instrument can also be used to evaluate scratch resistance (single or multiple pass) and color transfer. Plus, with the universal or a custom attachment, 'real world' testing and other forms of material durability can be performed.
The linear abraser can be used for both wet and dry testing.

**Operation**

A precision bearing on the spline shaft creates a "free-floating head". As the arm strokes in a linear motion, this "free-floating head" follows the contours of the specimen - curved or flat.

To enable you to simulate real world conditions, test parameters can be altered so optimal settings for each material can be established. The linear abraser allows you to select stroke length, speed and load.

The collet assembly comes standard with each unit, and is used for wear testing. Optional attachments can be used to perform scratch, coin scrape, crockmeter, rub and custom testing.


*Model 5750*

## Features

- Versatile wear and scratch testing with a single rugged, durable machine
- The new linear abraser uses a free-floating head with laser alignment guide to follow the contours of every sample, permitting testing of finished products
- With virtually no limit on sample size or shape, the linear abraser is ideal for testing plastics, automotive components, painted parts, printed graphics, optical products, rubber, leather, textiles and for use in laboratories
- Programmable test duration
  - program counter up to 999999 cycles (note : abradant may wear prior to end of test)
  - backlit display adds in viewing
- Abradants
  - CS-10 Calibrase® and H-18 Calibrade® Wearasers™ are included
- Interface port for remote start/stop

*Packaging, Plastics, Printing Inks, Textile, ...*

7.05

## Physical specifications

Dimensions
51 x 23 x 28 cm

Net Weight
9 kg

## Options

The linear abraser can be modified from a wear tester to other testers by changing the attachment.

- Attachments
  - Scratch kit : perform single or multiple pass scratch testing
  - Crock kit : for evaluating color transfer
  - Universal kit : perform 'real world' testing by attaching virtually anything to this attachment and abrade against your specimen (or visa-versa)
  - Coin scrape attachment (available as 45°, 60°, 75°)
  - Custom attachments

A critical aspect in testing is holding the specimen in place during the test.

- Specimen tables
  - Flat specimen table
  - Vacuum vise
  - 45° vacuum vise
- Adjustable load
  - additional weight discs (50, 75, 100, 150, 250 g) increase load to 2100 g
  - optional light weight spline kit expands testing flexibility
- Abradants
  - wide selection of abradants, made from the world famous abrasive materials found in Taber wheels (CS-10F, CS-10, CS-17, H-18, H-22)
  - custom abradents available
- Goose neck work light

## Standards

**ASTM D6279, F1319, ISO 105-X12**
**The linear abraser is CE marked.**

## Performance data

Adjustable load
Standard range from 350 to 1100 g.
Using supplemental weight discs, the maximum load of the linear abraser is 2100 g.

Operating speed
Standard preset speeds 2, 15, 25, 30, 40 and 60 cycles per minute.
Variable stroke speed from 2-75 cycles per minute.

Five operating stroke lengths
The five operating stroke lengths are adjusted manually. By changing the location of the crank pin, a connecting rod can be set to stroke standard lengths of 12.7, 25.4, 50.8, 76.2, or 101.6 mm.
A reference label under the cover indicates proper set-up for changing stroke lengths.
Custom stroke lengths are available upon request.

Power supply
230 V, 50/60 Hz

Agent

Cardboard Non-wovens Packaging Paper Plastics Printing Inks Pulp EUROPE Textile

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