The Performance of Glass Fiber Reinforced Polymer (GFRP) Under Abrasive Condition

By

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

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A project dissertation submitted to the Civil Engineering Programme

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CIVIL ENGINEERING

Approved by,

……………………

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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.

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MOHAMAD FAKHRUDDIN MOHD NURUDDIN

ABSTRACT

In many fields of industry, abrasion wear is one of dominant wear mechanism that reduces service life of a material. In searching for sustainability material, usage of glass fiber reinforced polymer (GFRP) has become popular not only in building material, automobile and also in replacing the usage of steel on offshore deck. Therefore, this paper intended to discuss in depth the performance of glass fiber reinforced polymer (GFRP) under abrasive condition. The first objective of this project is to perform abrasive resistance test on GFRP materials which is polyester, vinyl ester and phenolic by using abrasion testing machine according to American Society for Testing and Materials (ASTM) G65 standard. ASTM G65 is a standard test method for measuring abrasion using the dry sand and rubber wheel apparatus which is most suitable standard to be used. The second objective is to identify the performance of GFRP materials under abrasive condition and finally to find out which resins has most abrasive resistance. These samples will be classified into three different conditions which are the molded normal condition (control samples) ,molded 2 months aging condition (immerse into salt water and temperature of 60ºC) and pultruded normal condition. The methodology of the study is described in a flow chart which shows steps of data collection, data analysis, ranking of the resins and the conclusion. As the testing has been done, it can be seen the result of abrasive resistivity, surface profile each type of resins as each resins has different hardness. The project outcome may actually facilitate the study on GFRP materials and help in publishing standard code for the usage of GFRP.

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INTRODUCTION

3.7 BACKGROUND STUDY

Steels are essentially alloy of iron and carbon but they always contain other elements, either as impurities or alloying elements. Steel is man-made metal containing 95% or more iron and 1 – 2% carbon, and smaller amount of manganese and nickel to improve their certain properties. Carbon in steel improved its strength and hardness but it will reduce its ductility and toughness. Steel has been used widely in various types of structures such as multi-story building skeleton, industrial building, railway bridges and offshore structures. Because of its design strength that high strength to weight ratio, high stiffness to weight ratio, ductile material, cheap and easy to recycle makes steels as one of the top choices as construction materials. Although it has very strong properties, steels also have its weaknesses which are it has high density, heavy and corroded if exposed to air.

In oil and gas industries, the offshore and onshore structures are mainly exposed to extreme corrosive and hostile marine environments. Offshore and onshore structures are mainly built with steels, exposing these structures to this conditions make steels on disadvantages side. The environment that exposes to direct sun light, high temperature, oxygen, moisture and salt contained in the water will accelerate the corrosion of the steels [1]. The steels will rapidly corrode the hundreds millions of dollar structures in overtime by the combination of salt water and sour sulfur crude, no matter how well the operating companies maintain and treat the structures such as regular pigging, cathodic protection, injection corrosion inhibitor and many other more the steels structures will keep on corroded[2].

Besides the loss of strength and durability, corroded steels also can cause serious accidents. According to U.S. Minerals management Services, more than 900 fires and explosions, 1,548 injuries and 60 fatalities were related to offshore energy exploration and production in the Gulf of Mexico from 2001 and 2009 [3]. Those accidents were majorly cause by equipment failure, poor equipment maintenance, saltwater corrosion, operator error, harsh weather conditions, rig collapse, loss of well control and human errors.

Besides corrosion, using steels as material on offshore structures also give significant effect on the load that will be carried by the structures especially on the topside of the platform. The higher weight carried by the structures, there will be higher cost need to be spent on the structures. Therefore, reducing topsides weight as much as possible will provide more options and opportunity to reduce the cost [4]. Plus, during the design basics, selection of material and equipment that has less weight is also one of important criteria. This is because; the bulk weight of offshore will affect the overall economics of operation.

Glass fiber is a material made from extremely fine fibers of glass. Glass fibers have become one of the popular materials used as construction as it poses a light weight, extremely strong and robust properties. Even though the glass fiber strength properties are lower than carbon fiber, glass fiber is less brittle and less expensive compare to the carbon fiber. Plus, its bulk strength and weight properties are also favorable when compared to steels. Glass fiber reinforced can be divided into many categories based on the mixture of the fiber glass with other materials. The materials that can be mix with the fiber glass are polymer, stone, concrete, and gypsum. Glass fiber reinforce polymer have become one of material that being used in many applications. This material can be found in rocket engine casing, small boats hulls, automobile bodies, fishing poles, archery bows, and many other diverse products [1].

Replacing steels to composite material such as glass fiber reinforced polymer (GFRP) as a material used for offshore structures gives a lot of positive impacts toward the offshore business. One of the application of GFRP in offshore structures are replacing steels grating to GFRP grating used as drain cover on the offshore platform. But, before the GFRP grating is installed on the offshore deck, running proper test and investigation are very important to check the strength, durability, and efficiency of the GFRP grating as the GFRP grating will be installed on the extreme condition on the offshore deck. One of the tests is the performance of the GFRP under abrasive condition which to investigate the efficiency and impact of the GFRP grating under abrasion.

1.2 PROBLEM STATEMENT

Steel has been used widely in various types of structures such as multi-story building skeleton, industrial building, railway bridges and offshore structures. Using of steels in offshore has exposed the steels into very extreme condition that can damage the steel strength and durability. The conditions that will be facing by steel in the offshore environment are the extreme corrosive and hostile marine environment. The first problem is corrosion. Corrosion of steel structure on the offshore platform can caused serious damage to overall structure and may lead to fatal accidents to the operator. There have been recorded that lot of the accidents in oil and gas exploration happened because of the equipment failure, salt water corrosion, rig collapse and many other more. Besides the steel will exposed to the corrosion, the second problem when using a lot of steel as material on offshore is increasing the bulk weight on the topside of the offshore platform. Due to extremely heavy of the structure, the operating cost will increase as it become more difficult to transport and also will limited the topside design as the topside cannot be too heavy as the jacket need to support it.

Throughout the years, glass fiber reinforced polymer has become more option in replacing the usage of steels. With the advantages of GFRP that has lighter weight, corrosion resistance, lower cost of construction and maintenance compare to the steels make GFRP are more preferable to be used as a material for offshore structure. Although GFRP has been establish more than a decade ago, but in oil and gas industries and offshore structure, GFRP is a new material. The usage of GFRP can be seen in automotive and aircraft industry that mainly being used as car body and airplane body. Today, many researches have been conducted to study the characteristic and behavior of this new material. Yet, there is still no a standard or code has being publish regarding to usage of GFRP under abrasive condition. Therefore, this report presents a systematic study to identify the performance of glass fiber reinforced polymer which the polymers are polyester, vinyl ester and phenolic under abrasive condition.

1.3 OBJECTIVE AND SCOPE OF STUDY

The objectives of this project are:

- To perform abrasive resistance test on GFRP materials which is polyester vinyl ester and phenolic by using abrasion testing machine according to ASTM G65 standard.
- To identify the performance of the GFRP materials under abrasive condition
- To find out which resins has the most abrasive resistance

The scope of study is to identify the performance of the GFRP materials under abrasive condition. To identify the best GFRP materials under abrasive condition, three different resins have been used which are polyester, vinyl ester and phenolic. These three materials will conducted under control condition according to ASTM G65 standards. Furthermore, these materials also being submerge in saltwater in control temperature and time according to Arrhenius equation to accelerate the aging of the materials. Then the same test will be test and the abrasion and time relation will be identify in this project.

1.4 RELEVANCY OF THE PROJECT

Since most industries consists or rely on steel such as manufacturing, construction and many others, a renewable material or alternative material should be taking in consideration. As GFRP only be used recent years, many researches need to carry out due to its ability, workability and sustainability to the environment. As for a start, GFRP product mostly focusing on replacing traditional steel covering like drainage grating, manhole covering and steel staircase. According to the author's research which is the abrasiveness of GFRP material are more likely relevant to real life situation of grating that exposed to the pedestrian walking which imposed to rough surface and weight.

1.5 FEASIBILITY OF THE PROJECT

With all the required equipment for experimental lab such as the machine for abrasion test, sieving and the tank for aging samples available in UTP, it is believed that this project is feasible in terms of resources. In cases where the equipment is unavailable due to some constraints, the option is to outsource the facility from other universities or independent laboratories. In terms of time, the research should be completed within 28 weeks where the first 14 weeks will be focusing on the developing the abrasion machine while the last 14 weeks will be focusing on experimental of GFRP samples.

CHAPTER 2

LITERATURE REVIEW

Issues and topics regarding abrasion concept, type of glass fiber reinforce polymer and its performance under abrasive condition will be discussed accordingly in each section. Findings from several related journals, proceedings, book, and reports reviewed by the author are presented in this chapter.

2.1 ABRASION

Abrasion is a process of wearing down or rubbing away by means of friction. In a simple concept, when there are two surfaces of one material on the other material, there will create a friction between those surfaces and eventually by a certain time both of the surfaces material will be torn off. In material science, wear is erosion or sideways displacement of material from its derivative and original position onto a solid surface performed by the action of another surface. The interactions between surface and the removal and deformation of material on a surface are result of mechanical action of the opposite surface [16]. Some commonly referred to wear mechanisms are:

- Adhesive wear,
- Abrasive wear,
- Surface fatigue,
- Fretting wear and
- Erosive wear.

Abrasive wear happens when a hard rough surface slides across a softer surface [14]. American Society for Testing and Materials (ASTM) define abrasive wear as the loss of material due to hard particle or hard protuberances that are forced against and move along a solid surface [15]. Abrasive wear is product of sliding of softer surface material with harder and sharp material. The abrasive agent may be one of the surfaces or it may cause by the third component (abrader). There are a few uses of the wear phenomenon like in Figure 2.1.1 and Figure 2.1.2, but in the great majority of the cases wear is a nuisance, and a tremendous expenditure of human and material resources is required to overcome the effects [19].

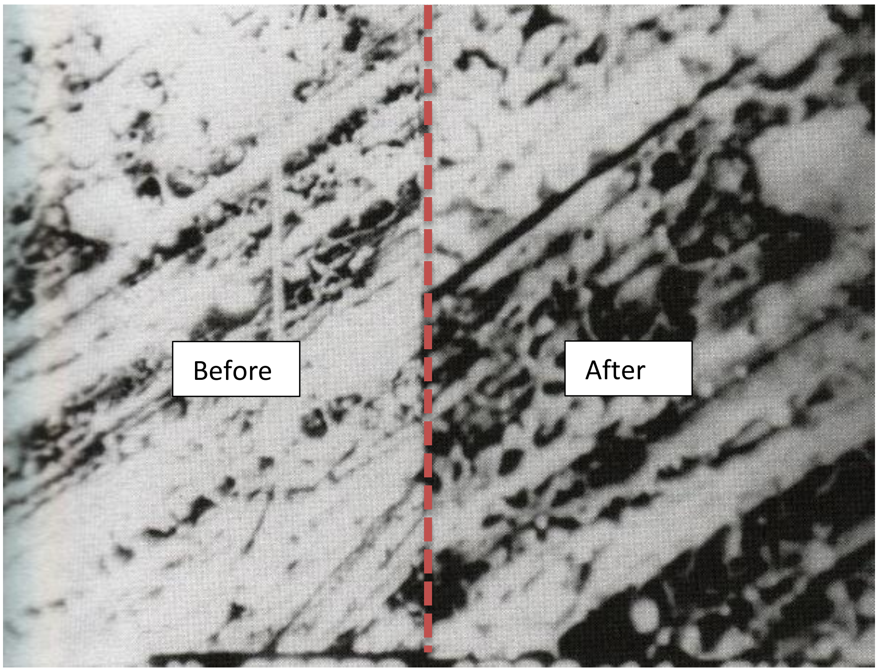


Figure 2.1.1: Abrasive Wear Scar Before and After

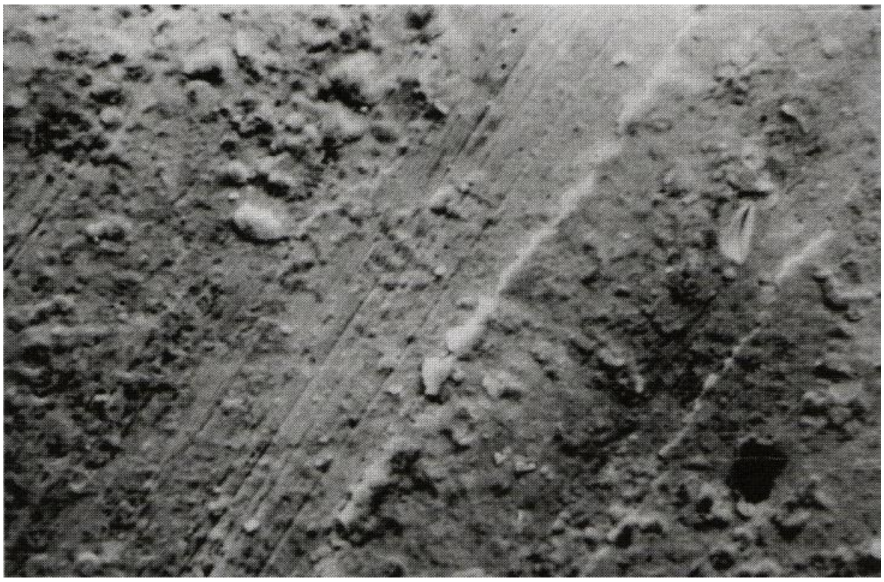


Figure 2.1.2: Wear Debris on an abraded surface

2.2 ABRASIVE WEAR MECHANISM

Abrasive wear was originally thought was caused by grits or hard asperities closely resembled cutting by a series of machine tools or a file. However, through microscopic examination revealed that the cutting process is only approximated by the sharpest grits and many other indirect mechanisms are involved. The particles or grit may remove material by microcutting, microfracture, and pull out of individual grains or accelerated fatigue by repeated deformations [20].

In Figure 2.2.1, the first mechanism illustrated (a) cutting represents the classic model where a sharp grit or hard asperity cuts the softer surface. The material which is cut is removed as wear debris. When the abraded material is brittle, (b) may occur. In this instance wear debris is the result of crack convergence. When a ductile material is abraded by a blunt grit then cutting is unlikely and the worn surface is repeatedly deformed (c). In this case wear debris is the result of metal fatigue. The last mechanism illustrated (d) represents grain detachment or grain pulls out. In this mechanism the entire grain is lost as wear debris [20].

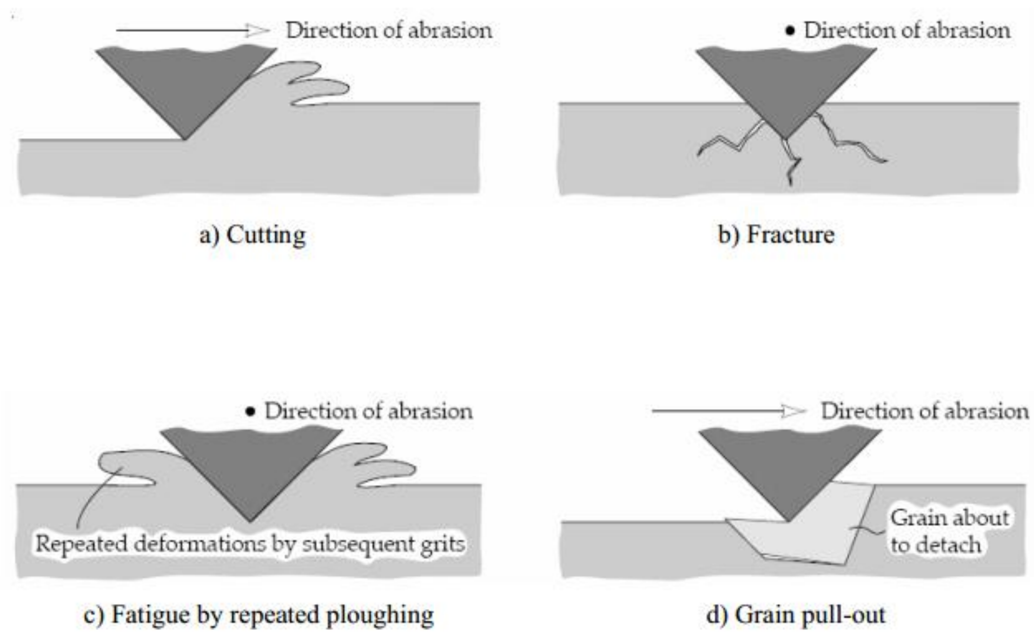


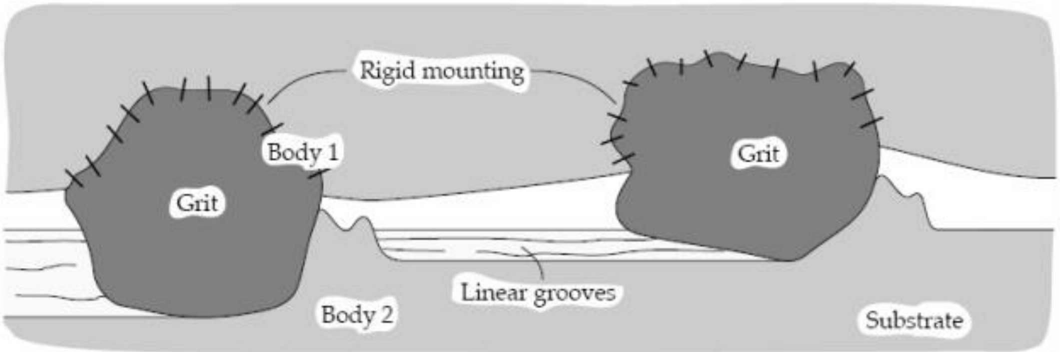
Figure 2.2.1: Mechanism of Abrasive Wear

2.3 MODES OF ABRASIVE WEAR

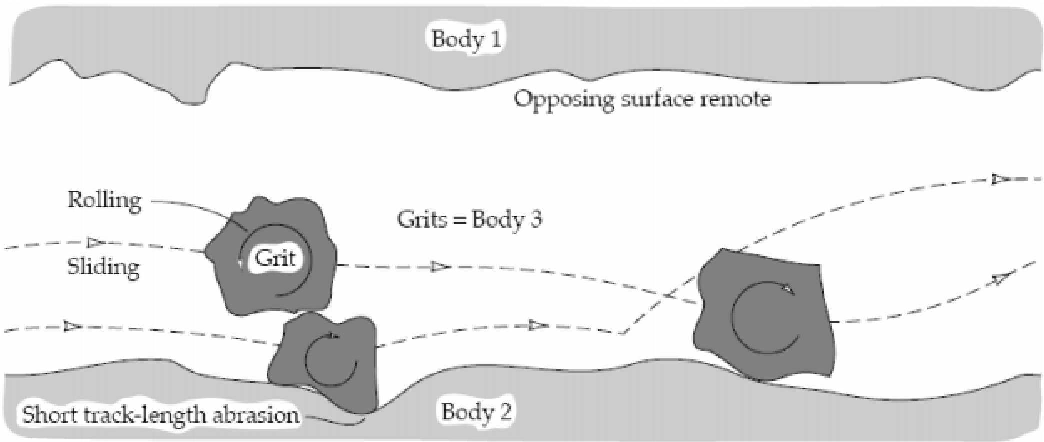
The nature of abrasive wear can be determined by the way the grits pass over the worn surface. Two basic modes of abrasive wear can be literarily denotes as:

- Two-body and
- Three-body abrasive wear

Two-body abrasive wear is exemplified by the action of sand paper on a surface. Hard asperities or rigidly held grits pass over the surface like a cutting tool. In three-body abrasive wear the grits are free to roll as well as slide over the surface, since they are not held rigidly. This mode of abrasive wear was illustrated schematically in Figure 2.3.1.



Two-body mode



Three-body mode

Figure 2.3.1: Modes of abrasive wear

2.4 FIBER REINFORCED POLYMER

Fiber reinforced polymer (FRP) is a polymer matrix resin reinforced with fibers and has a lower modulus of elasticity compared to steels. Fiber reinforced polymer (FRP) can be composites that consist of glass, carbon, and aramid continues fiber bond together in a matrix of epoxy, polyester, vinyl ester and many other resins[1]. Most common fiber reinforced polymer material can be referred as fiberglass. Fiberglass is a composite with a polymer resin matrix that surrounds, coats, and is reinforced by glass fibers [7].

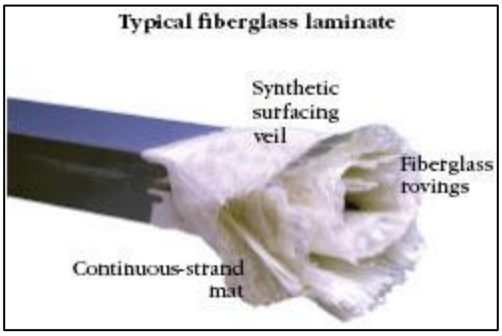


Figure 2.4.1: The composite of FRP materials.

Today, there are many applications that have using fiber reinforced polymer as one of their essential material in their products. Any design that need to have light weight, precision engineering, finite tolerances and cheaper than aluminums and steels like aerospace material, automotive, marine and also construction industries are best using fiber reinforced polymer. Fiber reinforced polymers are non-corrosive, nonconductive, nonmagnetic, low-density, and high modulus and when added to polymer matrix, the fiber reinforced polymer is made suitable for many more applications [2]. Plus, with high strength, rapid setting and corrosive resistance qualities make fiber reinforced polymer very convenient material in construction material that exposed to strong acid and alkaline environments [3]. The properties of the fiber reinforced polymer are largely dependent on the amount and type of polymer used in the composite. Epoxy and polyester resins are some of the most popular polymer binders used. Basic principle differences in mechanical properties and brittle linear-elastic behavior of fiber reinforced polymer reinforcements are the mostly influencing factors when trying to adapt steel based existing design regulations. As shown in figure 2.4.2, there is comparison of carbon fiber reinforced polymer (CFRP), aramid fiber reinforced polymer (AFRP), glass fiber reinforced polymer (GFRP), high strength steel and mild steel on stress-strain curves [7].

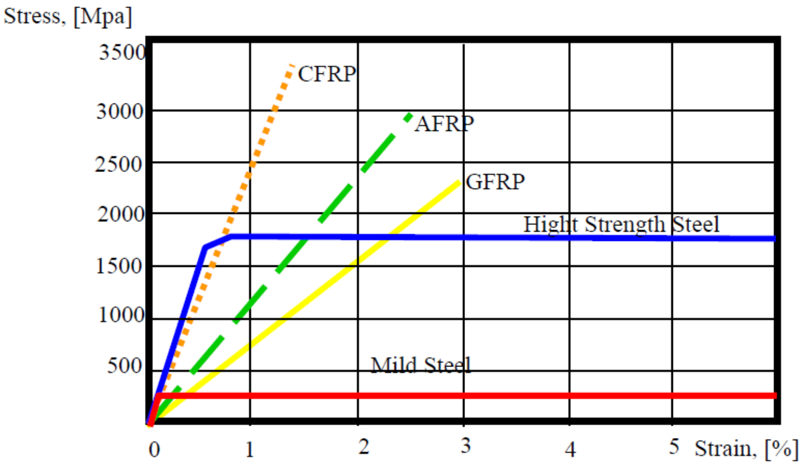


Figure 2.4.2: Stress-strain curves of some FRP composite and steel

Although fiber reinforced polymer has many advantages, there are drawbacks of using fiber reinforced polymer especially when using it in structures reinforcement [5, 6]. One of the examples is polyester fiber reinforced polymer exhibits brittle failure under normal working condition [4]. The drawbacks of the fiber reinforced polymers are:

1. Fiber reinforced polymer are typically brittle materials.
2. At high temperatures the material's strength decrease and deflection increases.
3. Limited experience with fiber reinforced polymer materials in the construction design industry.
4. Limited of design standards and codes.
5. Lack of performance history.

2.5 GLASS FIBER REINFORCED POLYMER (GRFP)

2.5.1 GLASS FIBER

Fiber reinforced polymer can be divided by many categories based on the mixture of the fiber glass with other materials like resins, stone, concrete and gypsum. Commonly used reinforced fibers are carbon fiber reinforced polymer, aramid fiber reinforced polymer and glass fiber reinforced polymer. Glass fiber reinforced polymer has been said as alternative to steels because it is a material that has low weight and resistance to corrosion. The glass fiber reinforced polymer is made up from silica (SiO_2) with the addition of oxides of Calcium (Ca), Baron (B), Sodium (Na), Iron (Fe) and Aluminum (Al). Glass fiber reinforced polymer can be divided into several classes which are E-glass (high electrical resistance), S-glass (very high tensile strength) and C-glass (high corrosion resistance) [8]. The class of glass fiber reinforced polymer can used based on the specific condition, for example for building structures like reinforcement in concrete and bridges S-glass is more suitable, for electrical conductor E-glass is more suitable and for extreme condition that exposed to acid and alkaline like offshore structures, C-glass is the best. Usually, the polymers used in glass fiber reinforced polymer are epoxy, vinyl ester or polyester thermosetting plastic. Most of the glass reinforced polymers have been thermosetting and the polymers employed being principally epoxy or polyester-styrene type resins [9].To compared with other fiber reinforced polymers, glass fiber reinforced polymers is less expensive and also lower in strength and stiffness. [10]. Even though the glass fiber reinforced polymer has lower strength and stiffness compared to other fiber reinforced polymers, but the strength and mechanical properties are still adequate and acceptable to be used as reinforcement, load carrying and retrofitting purposes. Plus, to compare with steels, glass fiber reinforced polymer has much lower weight with acceptable strength. The advantages of glass fiber reinforced polymers are:

1. High strength : Glass fiber reinforced polymer has very high strength to weight ratio
2. Lightweight : Low weights, faster installation and lower shipping costs
3. Resistance : Resists salt water, chemicals and environment
4. Low maintenance : Research shows no loss of laminate properties after 30 years
5. Durability : Can withstand extreme condition

2.5.2 MANUFACTURING PROCESS

There are several methods in production of glass fiber reinforced polymer. The methods are pultrusion process, contact molding process and RTM process. Pultrusion methods is continuous moulding process fabricating products of uniform cross section such as I Beams, Channels, Flat Bars, Rods, Hollow Section, utilizing glass fiber, resin, filler, peroxide and release agent. The glass reinforcement is drawn into a resin impregnation zone where the glass substrate is thoroughly impregnated with the resin mixture. The wet fibrous material will be pulled through a performer into a heated die. Then, the shape of the end product is determined by the configuration of the die and the resin is then polymerized. This continuous and uniform method ensures consistency throughout the entire product length, therefore eliminating the possibility of weak spots. Figure 3 shown the process of making glass fiber reinforced polymer through pultrusion method.

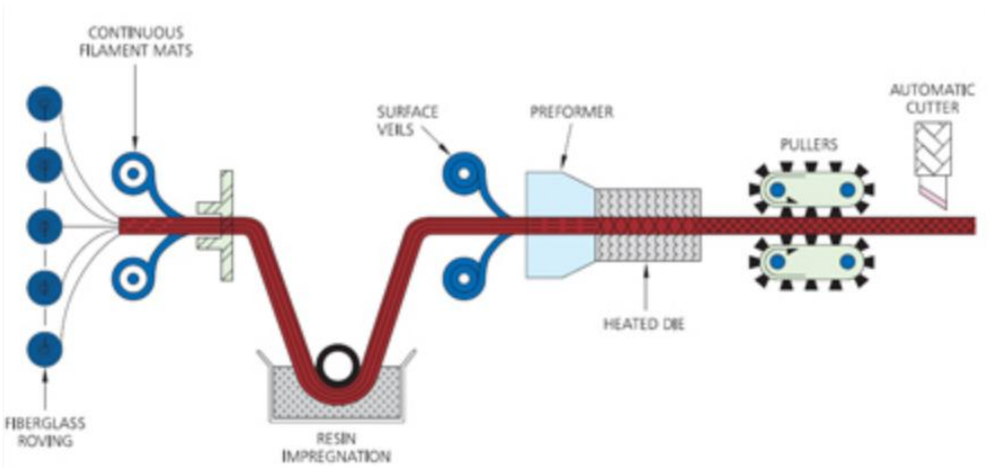


Figure 2.5.2.1: Pultrusion process

Second method in producing glass fiber reinforced polymer is by contact molding process. The contact moulded process is basically a handlay-up method whereby glass reinforcements are layed and resin mixture the applied layer by layer on a special design mould until the desired thickness and shape is formed. A special designed roller is used by the production operator to roll and apply pressure to make manually mold the product. The last method is resin transfer moulding (RTM) process which is using RTM machine. This process is most suitable used for mass production of fiber reinforced polymer product [11].

2.5.3 POLYESTER

Polyester is a category of polymers which contain the ester functional group in their chain. Depending on the chemical structure, polyester can be a thermoplastic or thermoset, there are also polyester resins cured by hardness, however most common polyester are thermoplastics. Polyester is a term often defined as "long-chain polymers chemically composed of at least 85% by weight of an ester and a dihydric alcohol and a terephthalic acid" [12].

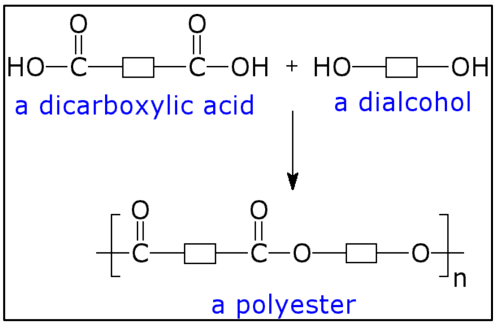


Figure 2.5.3.1: Polyester chain

In other words, to produce polyester it comes from the linking of several esters within the fibers [13]. Reaction of alcohol with carboxylic acid results in the formation of esters. As such we hear it sometimes referred to as fiberglass resin. Polyester is probably the most consistent in terms of the process by which it is polymerized. Generally by the simple addition of a peroxide catalyst, the base resin cures into a hard solid within a matter of minutes or hours depending on the type. Most polyester resins will accept a variety of fillers to achieve varying physical and visual effects as well [12]. Some characteristic of polymer are:

- Polyester fabrics and fibers are extremely strong.
- Polyester is very durable: resistant to most chemicals, stretching and shrinking, wrinkle resistant, mildew and abrasion resistant.
- Polyester is hydrophobic in nature and quick drying. It can be used for insulation by manufacturing hollow fibers.
- Polyester retains its shape and hence is good for making outdoor clothing for harsh climates.
- It is easily washed and dried

2.5.4 VINYL ESTER

Vinyl ester resins are addition products of various epoxide resins and unsaturated Monocarboxylic acids, most commonly methacrylic acid [15]. They have terminal reactive double bonds derived from the carboxylic acid used. These reactive groups can form a cross linked network with or without the addition of a commoner. In many industrial products, vinyl esters resins are comprised of 40-50 wt. % styrenes. Vinyl ester resins combine the best properties of epoxies and unsaturated polyesters. They can be easily handled at room temperature and have mechanical properties similar to epoxy resins. They have better chemical resistance than cheaper polyester resins, especially hydrolytic stability, and at the same time offer greater control over cure rate and reaction conditions than epoxy resins Vinyl ester resins were first introduced commercially in the early 1960s. Today, they are one of the most important thermosetting materials. Vinyl ester resins have been widely recognized as materials with excellent resistance to a wide variety of commonly encountered chemical environments. Vinyl ester resins are used to fabricate a variety of reinforced structures, including pipes, tanks, scrubbers and ducts.

2.5.5 PHENOLIC

The first synthetic resins and plastics were produced by polycondensation of phenol with aldehydes. The resins formed were, however, not of industrial and certainly not of scientific interest. Besides the production of plastics, phenolic resins were sought as a replacement for natural resins, which were then used on a large scale for oil varnishes. In 1910 oil-soluble modified phenolic resins were produced by Behrends by polycondensation of phenols, formaldehyde and rosin. Phenolic resin consists of:

- Phenols
- Formaldehyde
- Catalyst

The use of phenolic resins as thermosets and electrical insulating materials were the main application areas. Phenolic FRP resins are used in a wide range of applications including ballistics, mine ventilation, offshore water pipe systems, aerospace, rail and mass transit [17]. Phenolic resin is the predominate polymer for the abrasive industry and is used widely in resinoid bonds. If a thermoplastic polymer is used for bond, the abrasive product will soften and melt during use. Other thermoset resins, like epoxies or urethanes, can be more flexible than phenolic resin, but these are only used in limited finishing applications. Their heat resistance is too low for use in dry grinding or high-efficiency applications. Phenolic resin has excellent properties and is used widely as the abrasive binder. Phenolic resin has high heat-resistance and provides strong adhesion to grain. When compared to the other heat-resistant resins, like polyimide, phenolic resin is less expensive in cost and easier to mold than other resins [18]. Abrasive products consist of grain and binder. The grain removes the work material and the binder, using phenolic resin, holds the grain. The grain is an inorganic material with exceptional hardness. Typical kinds of grain are alumina and silicon carbide.

2.6 COMPARISON OF GFRP PRODUCTS VS. OTHER PRODUCTS

Table 2.6.1: Comparison of GFRP products against other products

PROPERTY	GFRP PRODUCTS	MILD STEEL	STAINLESS STEEL	ALUMINIUM PRODUCTS
COST EFFECTIVE	Extremely long life compare to other materials. Maintenance free.	Maintenance required.	Depend on application and grade.	Depend on application.
FLATNESS & THICKNESS CONSISTENCY	Pultusion is pultruded from heated die, therefore flatness is consistence even cut into smaller sizes. Thickness is even and consistent.	Flatness and thickness is even and consistent.	Flatness and thickness is even consistent.	Flatness and thickness is even and consistent.
IMPACT RESISTANCE	Continuous strand glass mat in FRP Products distributes the impact load to prevent surface damage even under sub-zero temperature and will not permanently deform and stay flat for the life of the product under closed mold pultrusion processing. High in mechanical strength.	Will permanently deform under impact and take a permanent set (dishing in trench application due to overloading). High in mechanical strength.	Will permanently deform under impact and take a permanent set (dishing in trench application due to overloading). High in mechanical strength.	Will permanently deform under impact and take a permanent set (dishing in trench application due to overloading). Low in mechanical strength.

CORROSION RESISTANT	Corrosion resistant under the most aggressive conditions.	Non-corrosion resistant	Depends on grade. SS304 not recommended in off-shore. SS316 better corrosive resistant.	Corrosion Resistant.
SAFETY	Electrically non-conductive and non-magnetic. Low in thermal conductivity. No sharp edges after cutting.	Conductive. Grounding potential around electrical equipment. High in thermal conductivity. Sharp edges after cutting.	Conductive. Grounding potential around electrical equipment. High in thermal conductivity. Sharp edges after cutting.	Conductive. Grounding potential around electrical equipment. High in thermal conductivity. Sharp edges after cutting.
FABRICATION	Produced in light weight and it can be shipped to the site or fabricated and installed on site with simple carpenter tools.	Require special blade, torch, and harder to cut it. Sometimes requires more manpower to move and place.	Require special blade, torch, and harder to cut it. Sometimes requires more manpower to move and place.	Require special blade, torch, and harder to cut it. Sometimes requires more manpower to move and place.
VANDALISM	Totally no recycle value and this will not encourage any theft or vandalism.	Mild steel products carry good recycle value.	Stainless steel products carry good recycle value.	Aluminium Products carry good recycle value.

2.7 TEST METHOD

In testing abrasiveness of specimens, there are many international standards that can be used as a guideline like American Society for Testing and Materials (ASTM), International Organization for Standardization (ISO), Japanese Standards Association (JSA), German Institute for Standardization (DIN) and many other more. For this research, author has select American Society for Testing and Materials (ASTM) as the guideline. The standard that will be used is ASTM G65 which is standard test method for measuring abrasion using the dry san/rubber wheel apparatus. This test method can be done in laboratory to determine the wear abrasive resistance of the specimens by using dry sand and rubber wheel. The abrasion test results are calculated based on the percentage of volume loss which means materials of higher abrasion resistance will have a lower volume loss [17]. Referring to the ASTM standard G65 (low stress abrasion), which means force applied to abrading particles is not sufficient to crush or fracture the particles [18]. And it is chosen since it is a well standardized test method (first published in 1980) that uses dry quartz sand of tightly limited particle size, 95% minimum in the U.S. sieve size range -50 to +70 (-300 to +212 microns), flowing in a thin layer at 300 to 400 g/min between the test piece and a hard rubber wheel 229 mm (9 inch) in diameter. The force applied pressing the test piece against the wheel is 130 N and the test is carried out for 6000 revolutions of the wheel at 200 rpm. The test piece is weighed before and after the test, and the weight loss can be used directly or converted to volume loss [18].

The dry sand and rubber wheel abrasion test as shown in Figure 2.7.1 and Figure 2.7.2 involve the abrading of a standard test specimen with a grit of controlled size and composition. The abrasive is introduced between the test specimen and a rotating wheel with a rubber tier or rim of a specified hardness. This test specimen is pressed against the rotating wheel at a specified force by means of a lever arm while a controlled flow of grit abrades the test surface. The rotating of the wheel is such that its contact face moves in the direction of the sand flow. Note that the pivot axis of the lever arm lies within a plane which is approximately tangent to the rubber wheel surface, and normal to the horizontal diameter along which the load is applied. The test duration and force applied by the lever arm is varied as according to the specimen category. Specimens are weighed before and after the test and the loss in mass recorded. It is necessary to convert the mass loss to volume loss in cubic millimeters, due to wide differences in the density of materials. Abrasion is reported as volume loss per specified procedure.

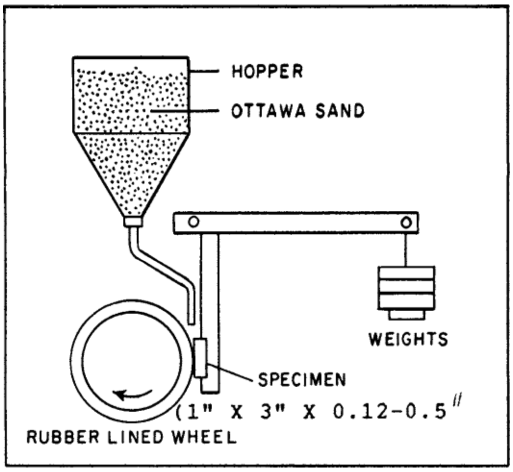


Figure 2.7.1: Schematic Diagram of Test Apparatus

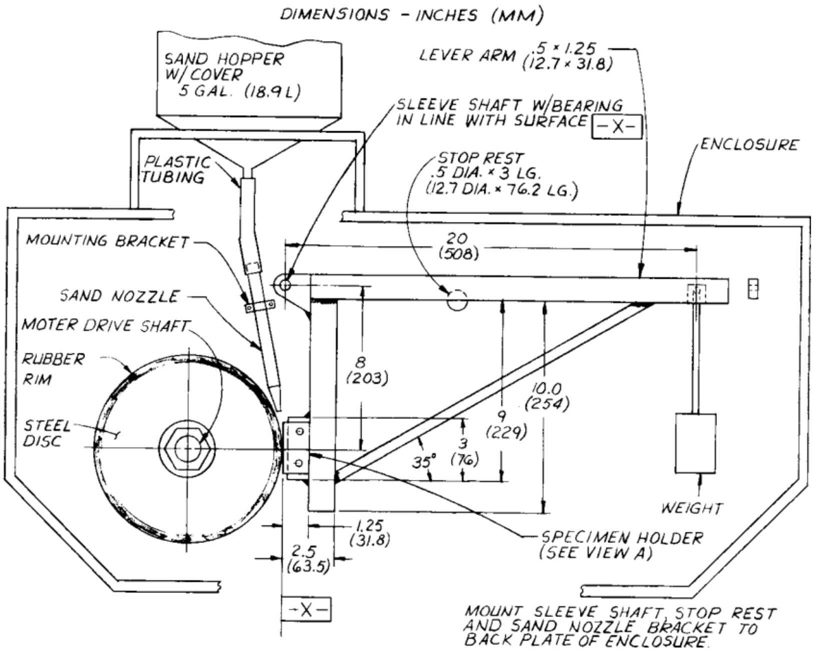


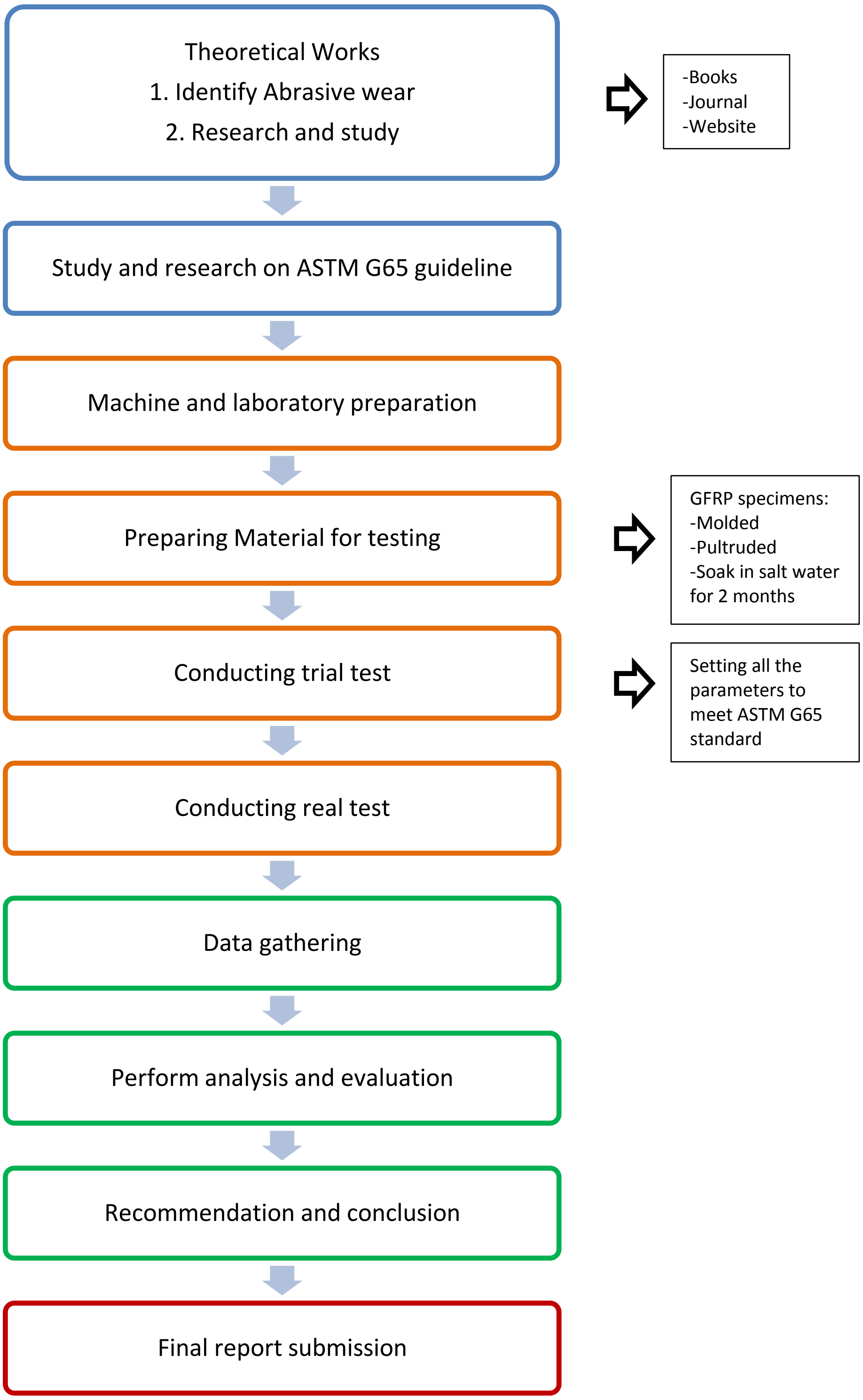
Figure 2.7.2: Dry/Rubber Wheel Abrasion Test Apparatus

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

The systematic method of study that can be applied for this project as followed:



3.2 RESEARCH GUIDELINE

The test is conducted based on ASTM G65; hence all parameters should follow what has written in the standard. Therefore, rubber wheel used should be the optimum hardness of the cured rubber like Durometer A-60, a range from A58 to 62 is acceptable. The type of abrasive shall be rounded quartz grain sand as typified by AFS 50/70 Test Sand. The moisture content shall not exceed 0.5 weight %. Sand that has been subjected to dampness or to continued high relative humidity may take on moisture, which will affect test results. If test sand contains moisture in excess of 0.5% it shall be dried by heating to 100ºC (212ºF) for 1h minimum. As for the nozzle, it must produce a sand flow rate of 300 to 400 g/min and motor drive should have the constant rate of revolution and it must remain constant under load.

1) Sand had tightly limited particle size in U.S. sieve size -50 to +70 (-300 to +212 microns) and moisture content under 0.5% weight.
2) The rate of sand flow through the special nozzle, in the shape of thin layer between the test piece and a hard rubber wheel 229mm (diameter), was adjusted at the rate 300-400g/min.
3) The force applied pressing the test coupon against the wheel rubber was TL=130 ± 4N (TL=Test Load) and 2000 revolutions of the rubber wheel at 200rpm for 10 minutes.
4) The 34mm (wide), 180mm (length) and 5mm (thick) abrasive wear resistance test specimens were cut from wear of the deposit were surface ground were smooth.
5) Then the tested specimens were weighed with accuracy 0.01g as required in ASTM G65 between and after the test.

Table 3.2.1 show test parameters according to ASTM G65 guideline, for this research the procedure B is selected as reference as the GFRP materials is a medium and low abrasive resistant type materials. Procedure A parameters is used for metallic materials that have extreme abrasion resistance. Procedure B is used for ranking of medium and low abrasive resistance materials. Procedure C is used for variation of Procedure A for use on thin coatings. Procedure D is used for lighter load variation of Procedure A and Procedure E is used for short term variation Procedure B that is useful in the making of Procedure B that is useful in the ranking of materials with medium or low abrasion resistance.

Table 3.2.1: Test parameters according to ASTM G65

Specified procedure	Force against specimen, N	Wheel revolutions	Duration, min	Lineal abrasion, m
A	130	200	30	4309
B	130	200	10	1436
C	130	200	30sec	71.8
D	45	200	30	4309
E	130	200	5	718

In the experiment preparation, all of the parameter measures must be completely defined and tested. As this experiment conducted with different standard of the machine, all the parameters set in the ASTM G65 guideline are very hard be fulfilled. Therefore, few adjustments have to be done but the procedures and the objectives of the experiment will be the same to the standard ASTM G65. In the guideline, it needs the experiment to be conduct with 130 Newton force against the specimen, 2000 wheel revolutions, and 1436 meter linear abrasion with a constant 200 revolution per minute of the wheel rotation. Even though those stated parameters are very hard to achieve, the main point of the test is to get the mass loss of the specimen under a standard linear abrasion is achievable. Therefore, for this experiment, the load used is 120 Newton with 700 revolutions per minute of the wheel revolution will be used because that is the limit of the AC Motor Drives capability. Because of the increased of the revolution per minute, the duration of the experiment will be shorter. The duration is calculated based on the linear abrasion of the wheel, this mean when the 1436 meter linear abrasion is achieve then the experiment will be stop. For the revolution of the motor, the initial speed before the motor being put under the load is different with the speed of the motor when load is acting on it. The initial speed of the motor can be control by the AC Motor Drives that can be set the frequency from 0.0 to 600 Hertz. But, through this experiment, the speed and revolution per minute of the motor under the load acting on it is more important. To measure the revolution per minute of the motor, Tachometer has been used. This Tachometer is placed perpendicular to the motor to measure the revolution per minute of the wheel. After conducted few trial test with constant load and AC Motor Drives speed, minimum of 600 revolution per minute only can be achieve. When all of the parameters are defined, the preparation of the experiment is complete and can continue with testing real specimens which are molded GFRP of polyester, vinyl ester and phenolic, 8 weeks molded GFRP of polyester, vinyl ester and phenolic that being submerge in salt water and pultruded GFRP of polyester, vinyl ester and phenolic. Table 3.2.2 shows the test parameters that are being used in this research.

Table 3.2.2: Test parameter used in this research

Specified procedure	Force Against Specimen, N	Wheel Revolutions	Duration, min	Lineal Abrasion, m
Modified B	130	700	3	1436

The calculation to find actual load that is being used as force against the specimen is shown below:

Taking moment at point B (clockwise is positive);

If 130N weigh is used,

130N (427.80mm) – Cx (318.20mm + 200mm) = 0

Therefore, Cx = [130N (427.80) / (318.20 + 200)]

Cx = 107.325 N

Therefore, higher weight is needed to get pressure 130N on the sample.

If Cx = 130N

Ay (427.80mm) – 130N (318.20mm + 200mm) = 0

Therefore, Ay = [130N (318.20mm + 200mm) / 427.80mm]

Ay = 157.4708N ≈ 160N

Based on the calculation result, to achieved pressure 130N as required by ASTM G65 standard, 160N weight must be used. This weight reduction may cause by the force orientation of the abrasion machine.

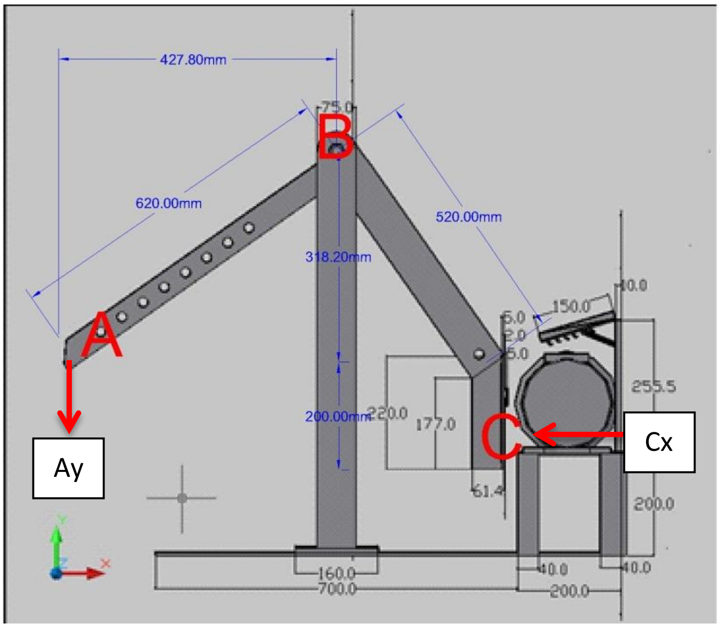


Figure 3.2.1: Direction of force Ay and Cx

3.3 Abrasion Testing Machine Dimension and Components

Figure below shows the schematic picture of abrasion testing machine Author needs to design the machine that follow all the parameters set by the ASTM G65 guideline.

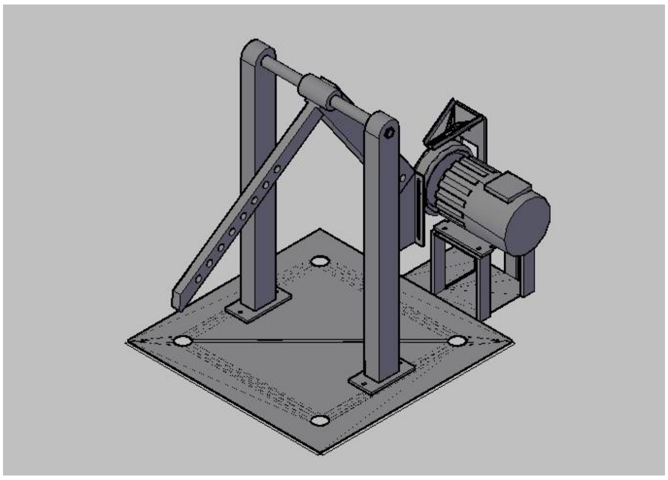


Figure 3.3.1: SE Isometric View

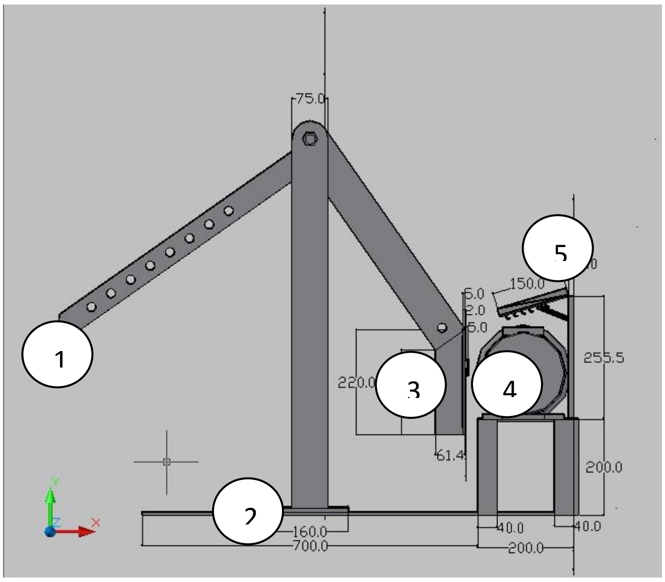


Figure 3.3.2: Right View

1= Load to be applied

2= Base plate

3= Sample's holder

4= Rubber wheel

5= Sand slider

3.4 TOOLS AND EQUIPMENT

In order to know the abrasive condition of GFRP material the equipment needed are:

- Abrasion Testing Machine
- GFRP Sample
- Sand (212 microns as an abrader)
- Weight (130N)
- Calliper
- Stopwatch
- Tachometer

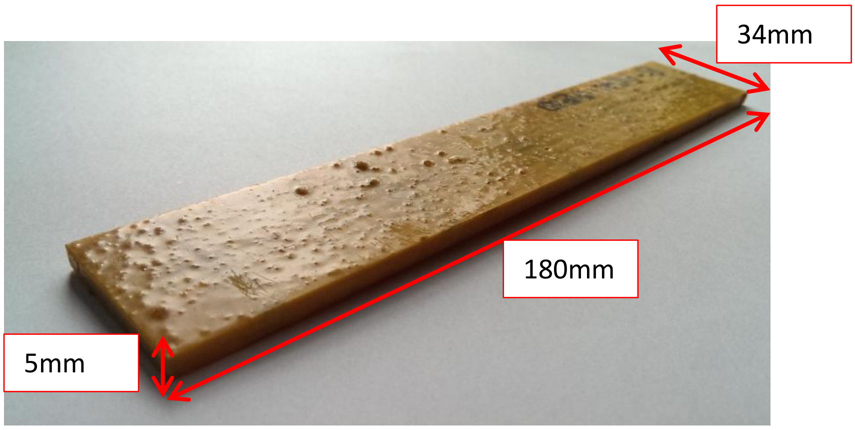


Figure 3.4.1: Typical size of GFRP specimen

Nameplate information:

Nameplate Information	Description
B	Product identification from factory
AB	Plate identification to be used for abrasion testing
P	Plate type (M=Molded, P=Pultruded)
PE	Plate resin type (PE=Polyester, VE=Polyester, PH=Phenolic)
2	Plate identification number

3.1 TEST PROCEDURE

Chart below shows the test procedure for abrasion test on GFRP material:

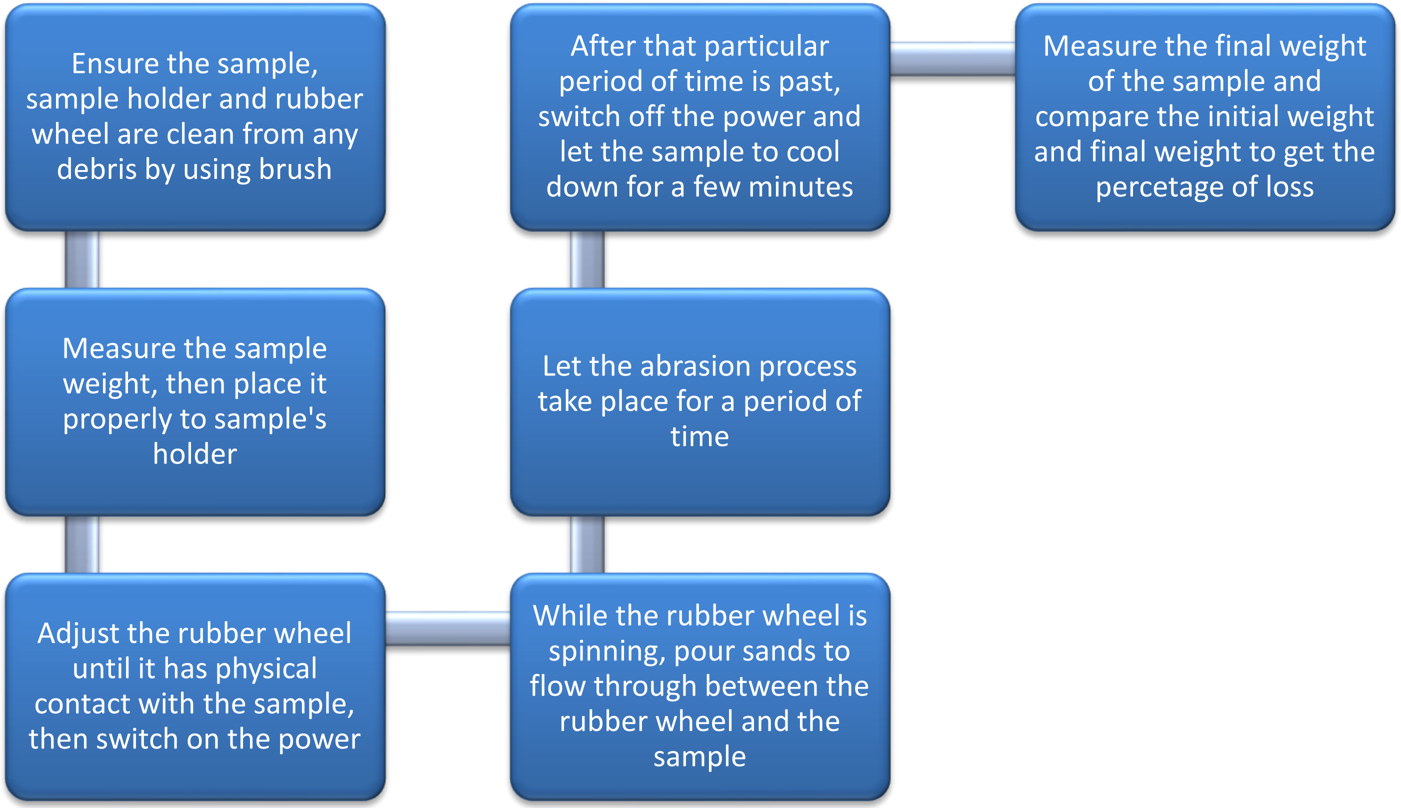


Figure 3.5.1: Test Procedure for GRP

3.6 PROJECT ACTIVITIES

Figure 3.6.1: Abrader preparation

In preparing the abrader to be used in the experiment, the abrader must be sieve for pass 250 microns and dried in the oven at temperature of 120 degree Celsius for at least 24 hours to make sure the abrader moisture content is removed. This is because the abrader with moisture content will affect the test results.

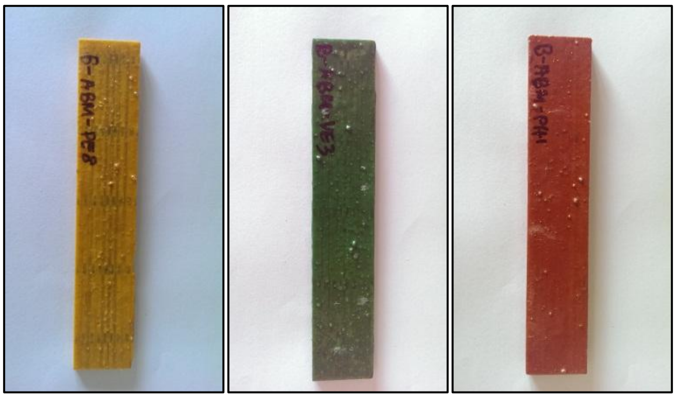


Figure 3.6.2: GFRP specimens

The GFRP specimen that being used in the experiment as shown in figure above. The specimens come with a bar shape and differentiate with color which is yellow for polyester, green for vinyl ester and red for phenolic.

Figure 3.6.3: GFRP specimens is weight before test is conducted

The specimen's weight must be recorded before and after the test is conducted. Weigh the specimen to the nearest 0.01g as per specified by the guideline.

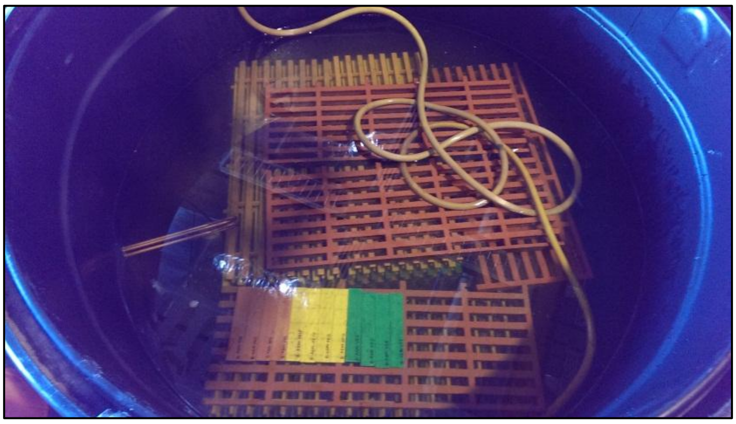


Figure 3.6.4: GFRP specimens aging

For the GFRP specimen's preparation, the specimens have been soaked with salt water at 60 degree Celsius for its specific duration.

Figure 3.6.5: Experiment set-up

The figure illustrates the set up for abrasion testing. The specimen holder is attached to the lever arm to which weights are added, so that a force applied along the horizontal diametral line of the wheel.

Figure 3.6.6: Streamlined sand flow produced

The figure illustrates the nozzle produce a sand flow rate of 300-400 g/min. The sand flow produces a streamlined flow and pass between the specimen and rubber wheel.

Figure 3.6.7: Tachometer used in determine wheel revolution

The figure illustrates the tachometer is used to determine the revolution of the rubber wheel. According to the ASTM G65 guideline, a constant revolution must be maintained though out the experiment.

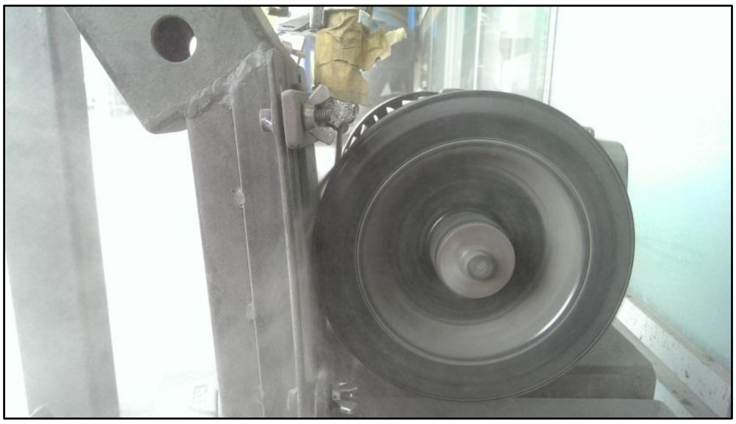


Figure 3.6.8: Wheel rubber contact with GFRP specimen

The figure illustrates the contact between the rubber wheel and the GFRP specimen. The contact time between rubber wheel and the specimen is control according to the ASTM standard. The rubber wheel must reach 1436 m linear abrasion for each test as required by the ASTM G65 standard.

Figure 3.6.9: GFRP specimen wear scar and weigh recorded after test is conducted

The GFRP specimens weight and wear scars is recorded after the test is conducted. The data then being analyses by comparing the weight loss, percentage loss and volume loss for each specimens.

3.7 KEY MILESTONE AND GANTT CHART

Table 3.7.1: Gantt chart of the research project

	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
FYP 1	Selection of Project Topic								Mid-Semester Break							
	Preliminary Research Work															
	Submission of Extended Proposal Defense															
	Proposal Defense															
	Project work continues															
	Submission of Interim Draft Report															
	Submission of Interim Report															
FYP 2	Project Work Continues								Mid-Semester Break							
	Submission of Progress Report															
	Project Work Continues															
	Pre SEDEX															
	Submission of Draft Report															
	Submission of Dissertation (Soft Bound)															
	Submission of Technical Paper															
	Oral Presentation															
	Submission of Project Dissertation (Hard Bound)															

Process
Suggested milestone

CHAPTER 4

RESULT AND DISCUSSION

In this chapter, results from the experimental program on GFRP specimens on their abrasive performance are presented with relevant tables and graphs. Discussions on the analyzed results are further elaborated in depth with comparisons to relevant findings by other researches.

4.1 WEIGHT OF MOLDED GFRP SPECIMENS BEFORE AND AFTER AGING

Table 4.1.1: Weight of Molded GFRP specimens before and after aging

Weight of GFRP before and after soak in Salt Water for 2 months						
Type of GFRP	Poly Ester	Poly Ester	Vinyl Ester	Vinyl Ester	Phenolic	Phenolic
Specimen Id	B-ABM-PE 12	B-ABM-PE 13	B-ABM-VE 4	B-ABM-VE 5	B-ABM-PH 3	B-ABM-PH 4
Initial Weight	43.87	45.34	44.78	44.97	65.54	66.07
Final Weight	43.78	45.28	45.06	45.2	69.03	69.07
Weight Degraded	-0.09	-0.06	0.28	0.23	3.49	3
Percentage Weight Degraded	-0.21	-0.13	0.63	0.51	5.32	4.54
Average Weight Degraded	-0.075		0.255		3.245	
Average Percentage Weight Degraded	-0.17		0.57		4.93	

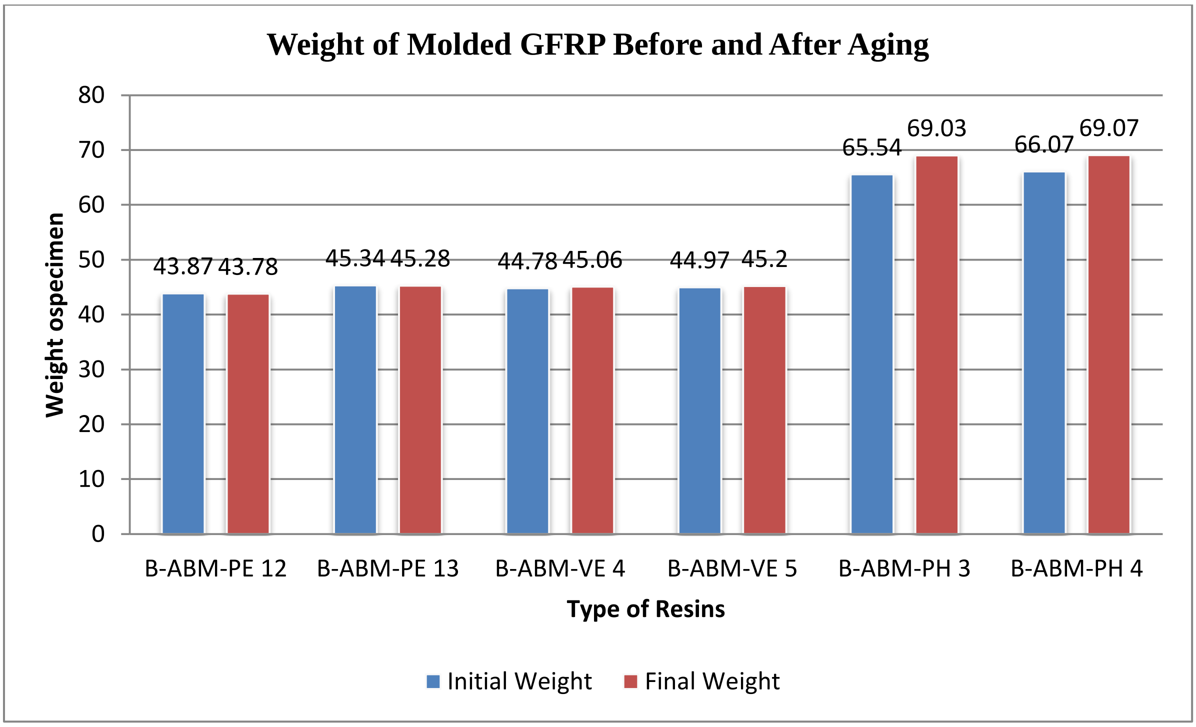


Figure 4.1.1: Graph of GFRP specimens before and after aging process

From the graph 4.1.1, we can see the differential weight of GFRP specimens before and after the specimens go through aging process which are the specimens is being soaked in salt water at temperature 60 degree Celsius for 2 months. From the data recorded, polyester specimens had shown slightly decreasing weight after going through aging process. The weight decrease very small which is 0.075 g. The vinyl ester and phenolic had shown increasing in weight after going through the aging process. For vinyl ester, here are slightly increase in weight about 0.25g whereas for the phenolic specimens, the specimens had increase about 5.245g. Furthermore, through the observation, the aging process of the specimens has caused the surface of the specimens to degrade and change in color. This might be because of the salt water and the temperature used during the aging has caused the surface of the specimens to change.

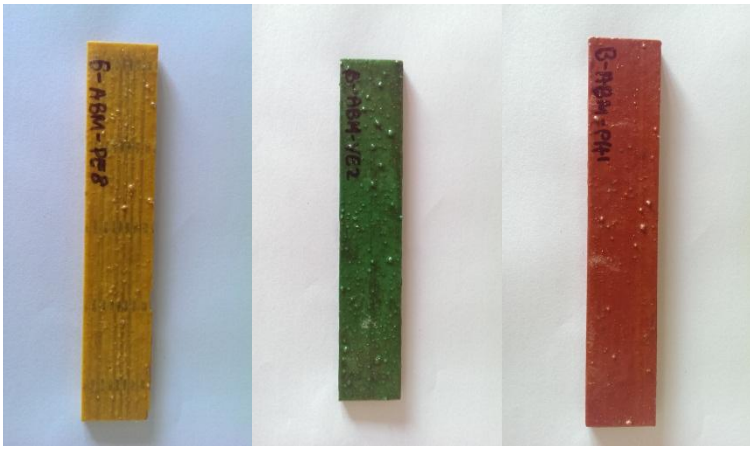


Figure 4.1.2: GFRP specimens before aging process

Figure 4.1.3: GFRP specimens after aging process

4.2 CALCULATING AND REPORTING RESULTS

According to the ASTM G65 guideline, the abrasion test results should be reported as volume loss in cubic millimeters. The formula used in calculating the volume loss is:

$$\boldsymbol{Volume\ loss, mm}^3 = \frac{mass\ loss\ (g)}{density\ (\frac{g}{cm^2})}\ X\ 1000$$

As the rubber wheel decrease in diameter the amount of scratching abrasion developed in a given practice will be reduced accordingly. The actual volume loss produced by these slightly smaller wheels will be inaccurate. The adjusted volume loss value takes this into account and indicates the actual abrasion rate that would be produced by the rubber wheel. The formula used in determines the adjusted volume loss is:

$$\boldsymbol{Adjusted\ Volume\ loss, mm}^3 = \frac{wheel\ diameter\ before\ use}{wheel\ diameter\ after\ use}\ X\ measured\ volume\ loss$$

4.3 RESULTS FOR MOLDED GFRP

Table 4.3.1: Control Molded GFRP results

Control Molded GFRP						
Type of GFRP	Poly Ester	Poly Ester	Vinyl Ester	Vinyl Ester	Phenolic	Phenolic
Specimen Id	B-ABM-PE 8	B-ABM-PE 9	B-ABM-VE 2	B-ABM-VE 3	B-ABM-PH 1	B-ABM-PH 2
Load Applied, N	130	130	130	130	130	130
Initial Weight, g	46.21	46.18	47.27	45.36	62.95	65.67
Final Weight, g	41.63	43.09	43.55	41.28	58.15	58.88
Mass Loss, g	4.58	3.09	3.72	4.08	4.8	6.79
Density, g/cm^3	1.945	1.944	1.989	1.909	1.514	1.579
Volume Loss, mm^3	2354.76	1589.51	1870.29	2137.24	3170.41	4300.19
Adjusted Volume Loss, mm^3	2367.71	1598.25	1880.57	2149.00	3187.85	4323.84
Percentage Mass Loss, %	9.91	6.69	7.87	8.99	7.63	10.34
Average Mass Loss, g	3.84		3.90		5.80	
Average Volume Loss, mm^3	1972.13		2003.77		3735.30	
Average Adjusted Volume Loss, mm^3	1982.98		2014.79		3755.84	
Average Percentage Mass Loss, %	8.30		8.43		8.98	
Ranking	1		2		3	

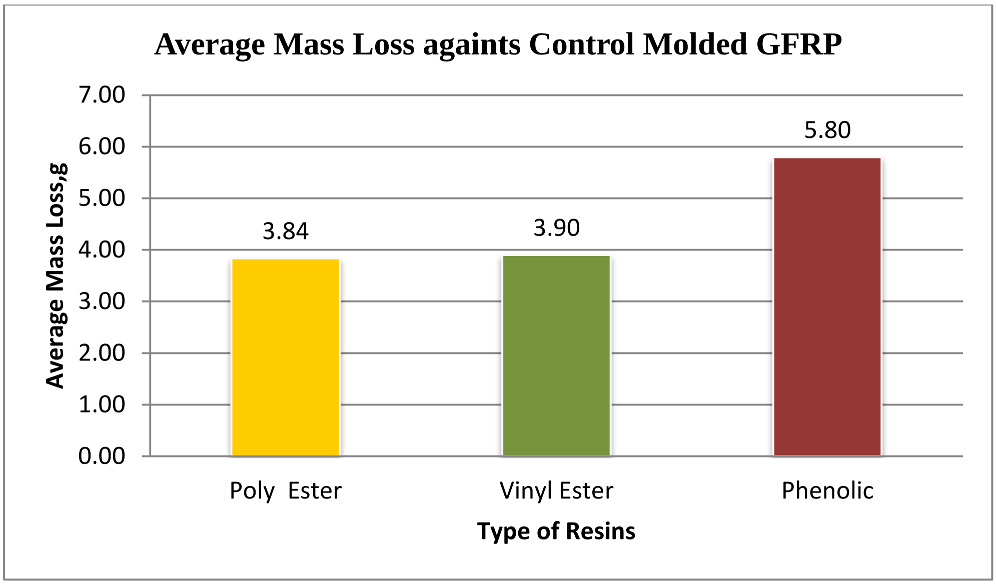


Figure 4.3.1: Graph of comparison average mass loss of control molded GFRP

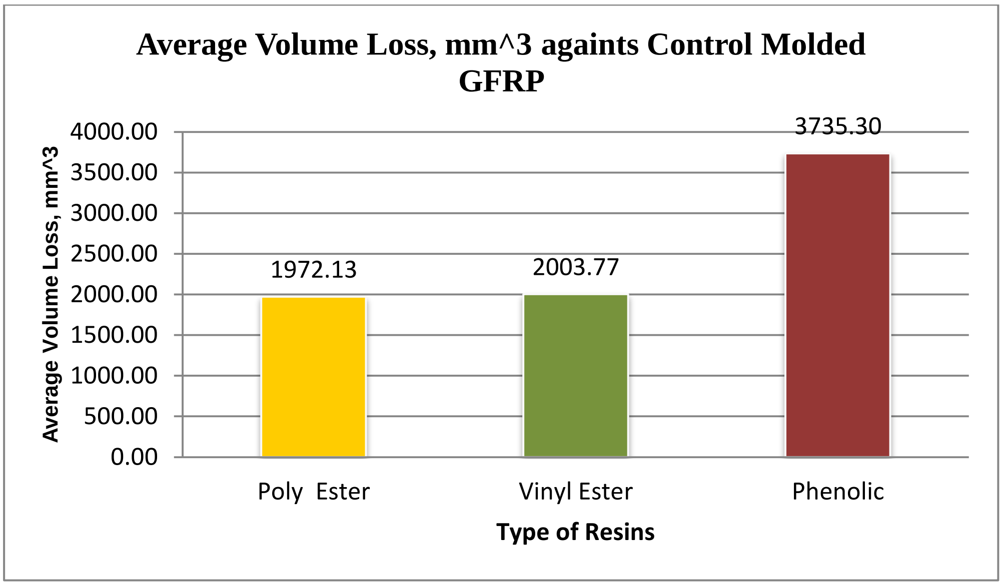


Figure 4.3.2: Graph of comparison average volume loss of control molded GFRP

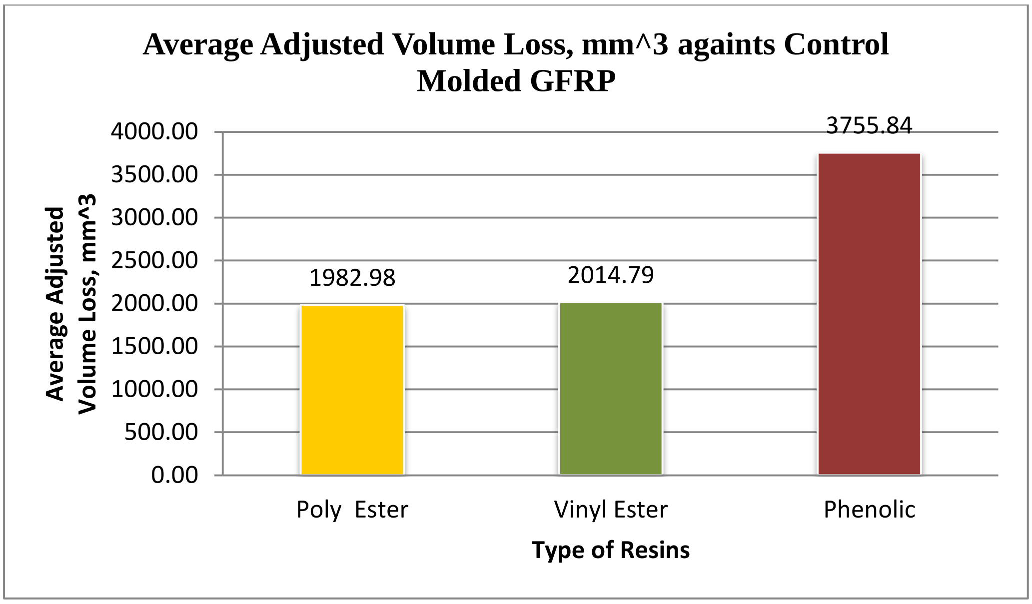


Figure 4.3.3: Graph of comparison average adjusted volume loss of control molded GFRP

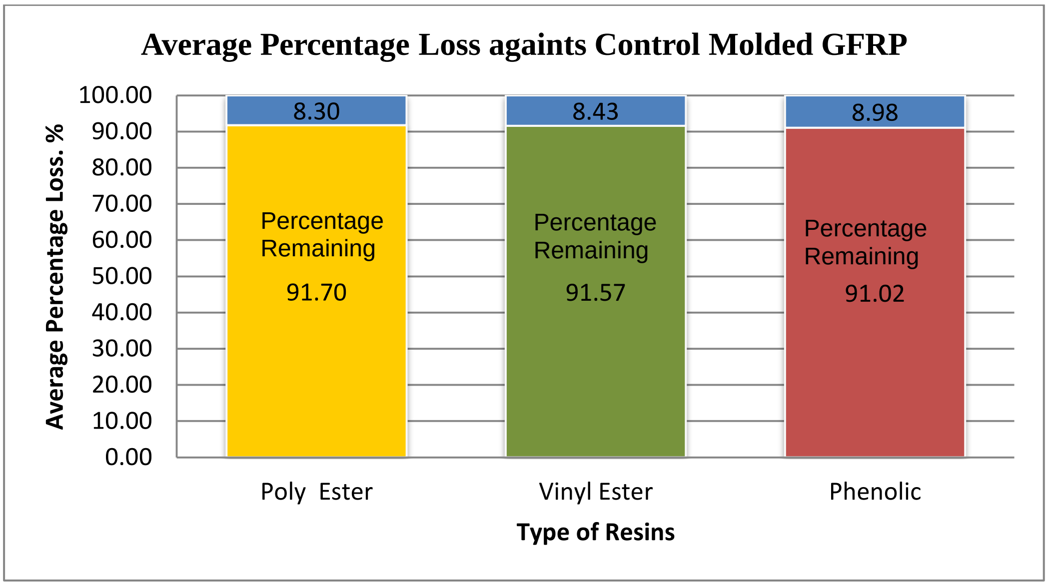


Figure 4.3.4: Graph of comparison average percentage loss of control molded GFRP

Table 4.3.1 shows the result of control molded GFRP specimens after being test under abrasive performance according to ASTM G65 guideline. From the Figure 4.3.1 shows that polyester has the least average mass loss which is 3.84g compared to other resins. The vinyl ester has slightly higher average mass loss compared to polyester which is 0.06g more means the average mass loss for vinyl ester is 3.90g. For the phenolic, its experience large effect on the abrasive test which is its loss 5.80 g which make it has highest average mass loss compared to the other resins. Figure 4.3.3 and Figure 4.3.4 show the comparison of average volume loss and adjusted volume loss of the GFRP specimens. From the figure, the average adjusted volume loss for polyester, vinyl ester and phenolic is 1982.98mm^3, 2014.79 mm^3 and 3755.84 mm^3 respectively. The polyester has the least volume loss compared to the other resins show that the molded polyester has the highest abrasive resistance compare to molded vinyl ester and molded phenolic. Figure 4.3.4 shows the percentage loss of the GFRP specimens after being test under abrasive performance. All of the GFRP specimens' loss about 8% of its mass after being after going through the test. The polyester loss about 8.30%, vinyl ester loss 8.43% and phenolic loss about 8.98%. The polyester has the least loss means that the molded polyester specimen has the strongest abrasiveness performance compared to other resins.

4.4 RESEULTS FOR CONTROL PULTRUDED GFRP

Table 4.4.1: Control Pultruded GFRP results

Control Pultruded GFRP

Type of GFRP	Poly Ester	Poly Ester	Vinyl Ester	Vinyl Ester	Phenolic	Phenolic
Specimen Id	B-ABP-PE 1	B-ABP-PE 2	B-ABP-VE 1	B-ABP-VE 2	B-ABP-PH 1	B-ABP-PH 2
Load Applied, N	130	130	130	130	130	130
Initial Weight, g	70.58	71.06	51.71	53.29	35.64	36.54
Final Weight, g	66.67	66.75	47.12	48.48	31.12	31.62
Mass Loss, g	3.91	4.31	4.59	4.81	4.52	4.92
Density, g/cm^3	2.178	2.193	1.915	1.974	1.65	1.695
Volume Loss, mm^3	1795.22	1965.34	2396.87	2436.68	2739.39	2902.65
Adjusted Volume Loss, mm^3	1805.10	1976.15	2410.05	2450.08	2754.46	2918.62
Percentage Mass Loss, %	5.54	6.07	8.88	9.03	12.68	13.46
Average Mass Loss, g	4.11		4.70		4.72	
Average Volume Loss, mm^3	1880.28		2416.77		2821.02	
Average Adjusted Volume Loss, mm^3	1890.63		2430.06		2836.54	
Average Percentage Mass Loss, %	5.80		8.95		13.07	
Ranking	1		2		3	

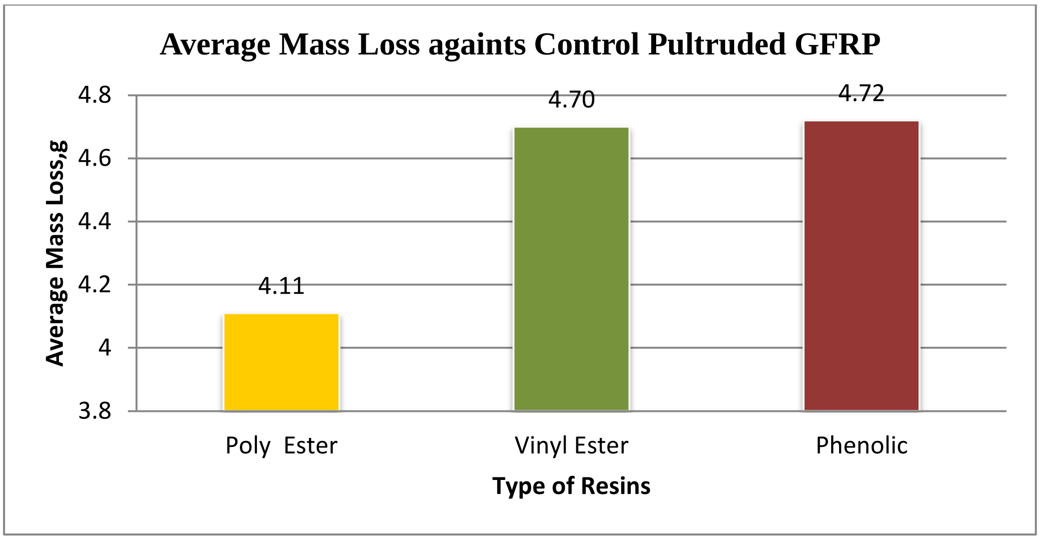


Figure 4.4.1: Graph of comparison average mass loss of control pultruded GFRP

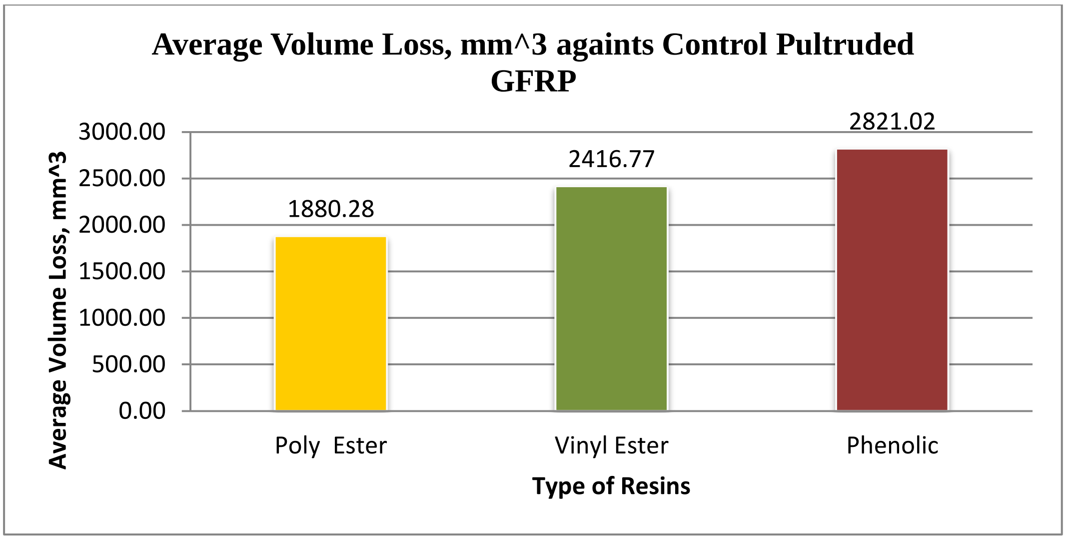


Figure 4.4.2: Graph of comparison average volume loss of control pultruded GFRP

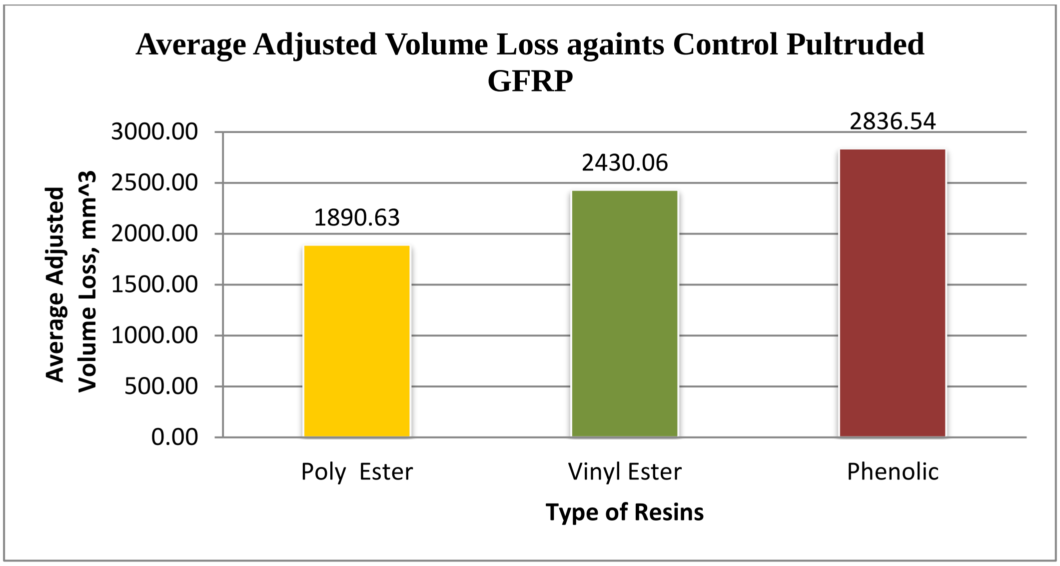


Figure 4.4.3: Graph of comparison average adjusted volume loss of control pultruded GFRP

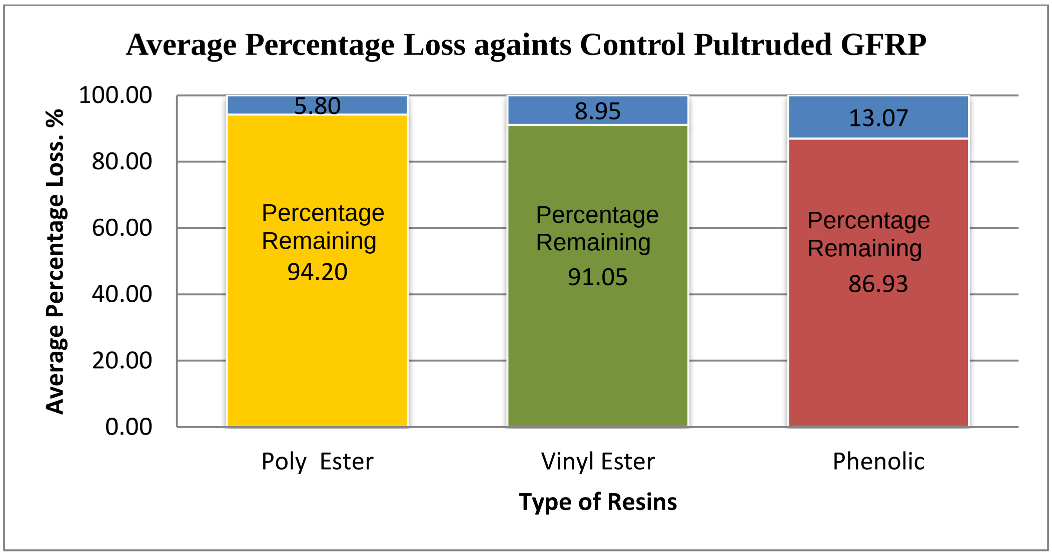


Figure 4.4.4: Graph of comparison average percentage loss of control pultruded GFRP

Table 4.4.1 shows the result of control pultruded GFRP specimens after being test under abrasive performance according to ASTM G65 guideline. From the Figure 4.4.1 shows that polyester has the least average mass loss which is 4.11g compared to other resins. The vinyl ester and phenolic loss 4.70g and 4.72g respectively which is much higher to the polyester. Figure 4.4.3 and Figure 4.4.4 show the comparison of average volume loss and adjusted volume loss of the pultruded GFRP specimens. From the figure, the average adjusted volume loss for polyester, vinyl ester and phenolic is 1890.63mm^3, 2430.06 mm^3 and 2836.54 mm^3 respectively. The polyester has the least volume loss compared to the other resins show that the pultruded polyester has the highest abrasive resistance compare to pultruded vinyl ester and pultruded phenolic. Figure 4.4.4 shows the percentage loss of the GFRP specimens after being test under abrasive performance. The pultruded polyester has the lowest mass loss compared to other resins which is about5.80%. The vinyl ester and the phenolic loss about 8.95% and 13.07% respectively. Based on the result, the polyester has the least mass loss means that the pultruded polyester specimen has the strongest abrasiveness performance compared to vinyl ester and phenolic.

4.5 RESULTS FOR 2 MONTHS AGING MOLDED GFRP

Table 4.5.1: 2 Months aging Molded GFRP results

2 Months Aging Specimens of Molded GFRP

Type of GFRP	Poly Ester	Poly Ester	Vinyl Ester	Vinyl Ester	Phenolic	Phenolic
Specimen Id	B-ABM-PE 12	B-ABM-PE 13	B-ABM-VE 4	B-ABM-VE 5	B-ABM-PH 3	B-ABM-PH 4
Load Applied, N	130	130	130	130	130	130
Initial Weight, g	43.78	45.28	45.06	45.2	69.03	69.07
Final Weight, g	40.8	42.04	41.66	42.23	61.36	64.01
Mass Loss, g	2.98	3.24	3.4	2.97	7.67	5.06
Density, g/cm^3	1.843	1.906	1.896	1.902	1.66	1.661
Volume Loss, mm^3	1616.93	1699.90	1793.25	1561.51	4620.48	3046.36
Adjusted Volume Loss, mm^3	1625.82	1709.24	1803.11	1570.10	4645.89	3063.11
Percentage Mass Loss, %	6.81	7.16	7.55	6.57	11.11	7.33
Average Mass Loss, g	3.11		3.185		6.365	
Average Volume Loss, mm^3	1658.412		1677.382		3833.420	
Average Adjusted Volume Loss, mm^3	1667.533		1686.607		3854.504	
Average Percentage Mass Loss, %	6.981		7.058		9.219	
Ranking	1		2		3	

2 Months Aging Specimens of Molded GFRP

Type of GFRP	Poly Ester	Poly Ester	Vinyl Ester	Vinyl Ester	Phenolic	Phenolic
Specimen Id	B-ABM-PE 12	B-ABM-PE 13	B-ABM-VE 4	B-ABM-VE 5	B-ABM-PH 3	B-ABM-PH 4
Load Applied, N	130	130	130	130	130	130
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Mass Loss, g	2.98	3.24	3.4	2.97	7.67	5.06
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Average Mass Loss, g	3.11		3.185		6.365	
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Average Percentage Mass Loss, %	6.981		7.058		9.219	
Ranking	1		2		3	

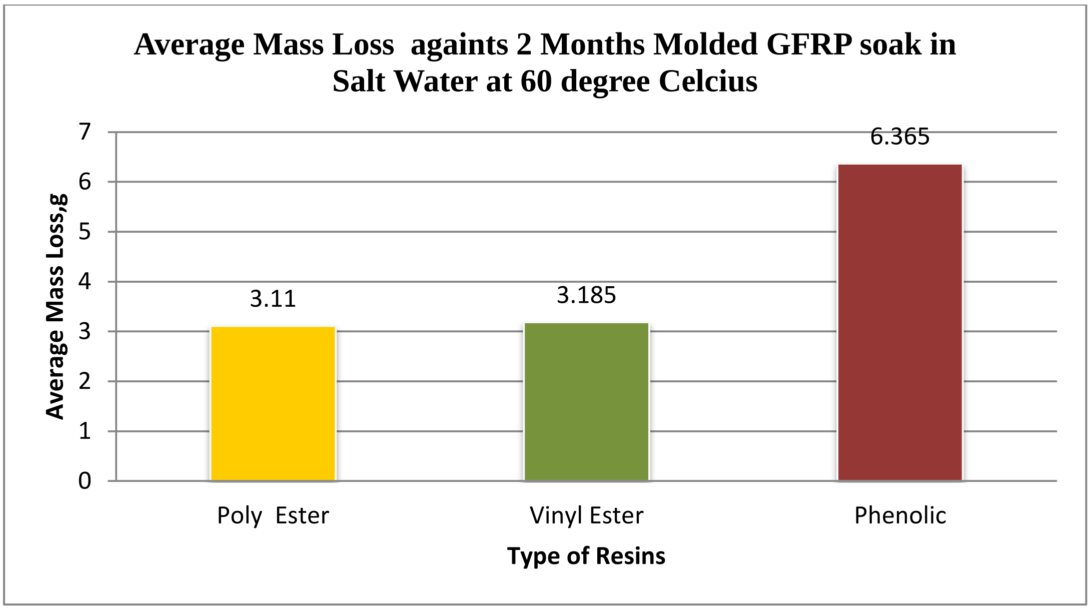


Figure 4.5.1: Graph of comparison average mass loss of 2 months aging molded GFRP

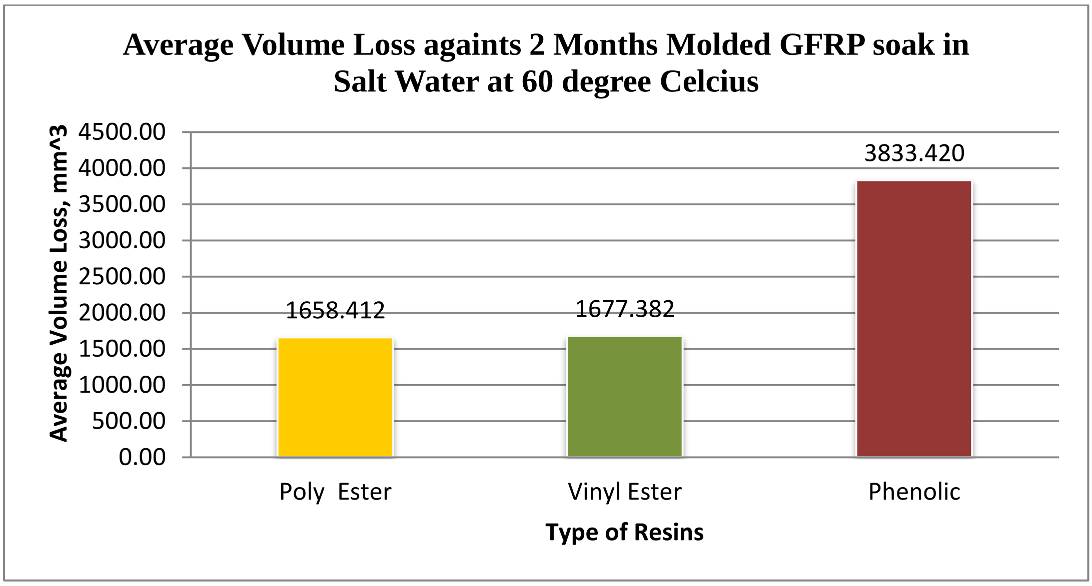


Figure 4.5.2: Graph of comparison average volume loss of 2 months aging molded GFRP

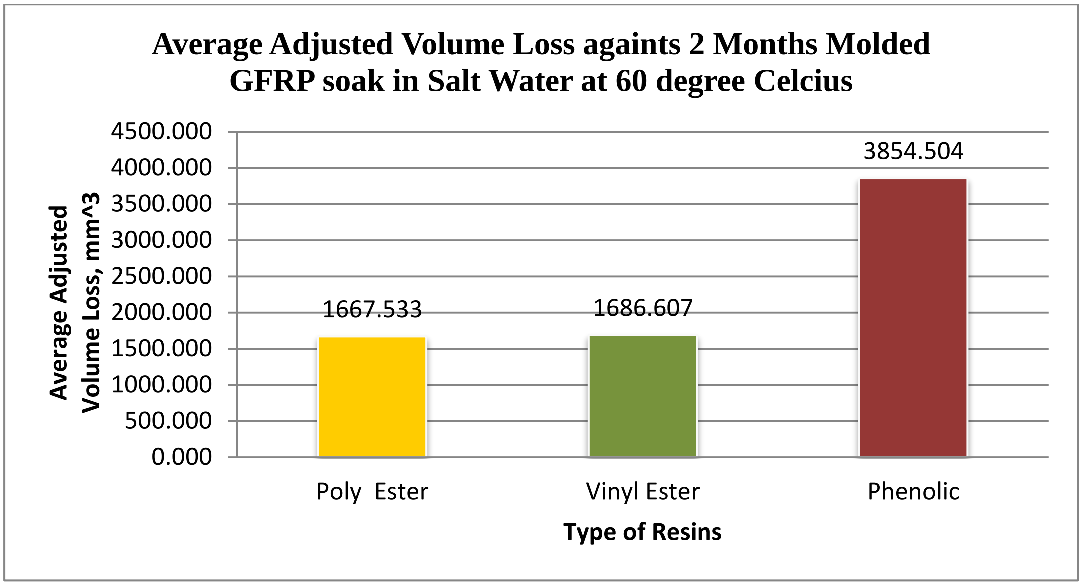


Figure 4.5.3: Graph of comparison average adjusted volume loss of 2 months aging molded GFRP

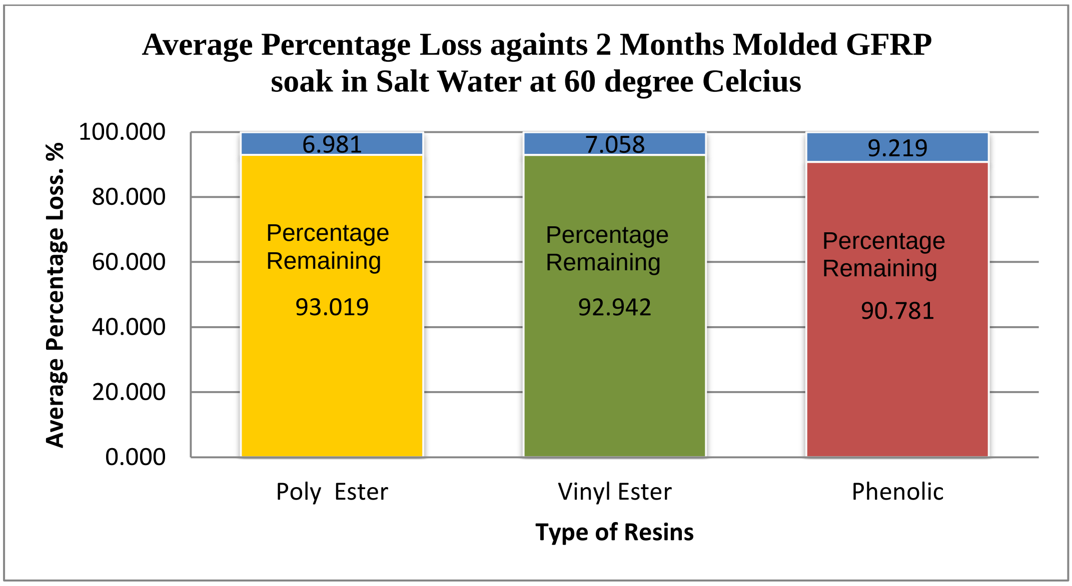
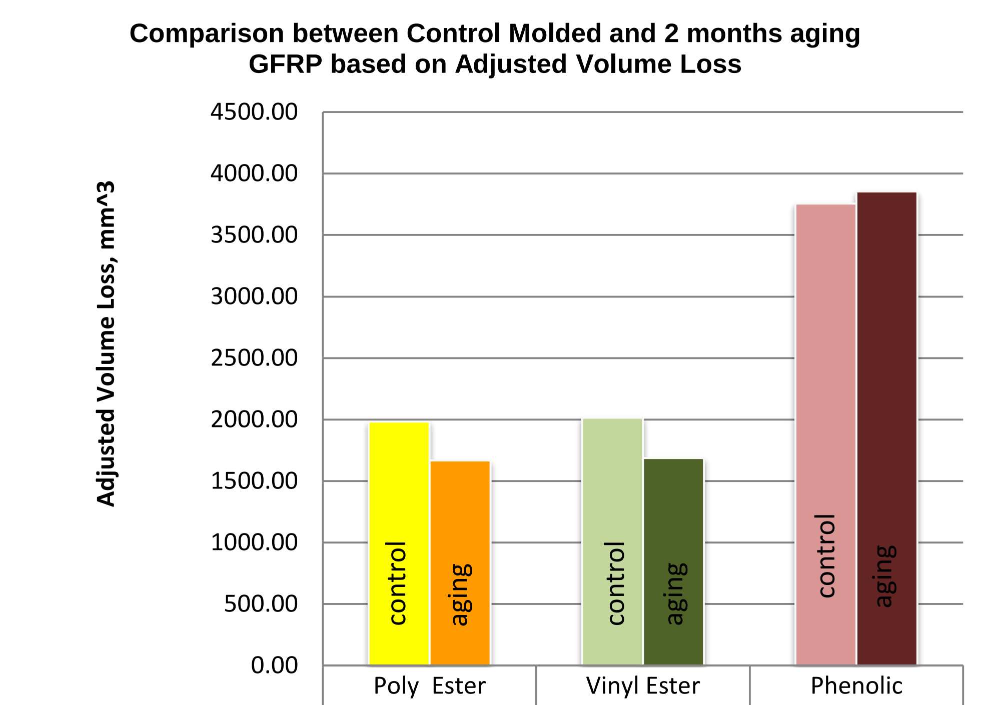


Figure 4.5.4: Graph of comparison average percentage loss of 2 months aging molded GFRP

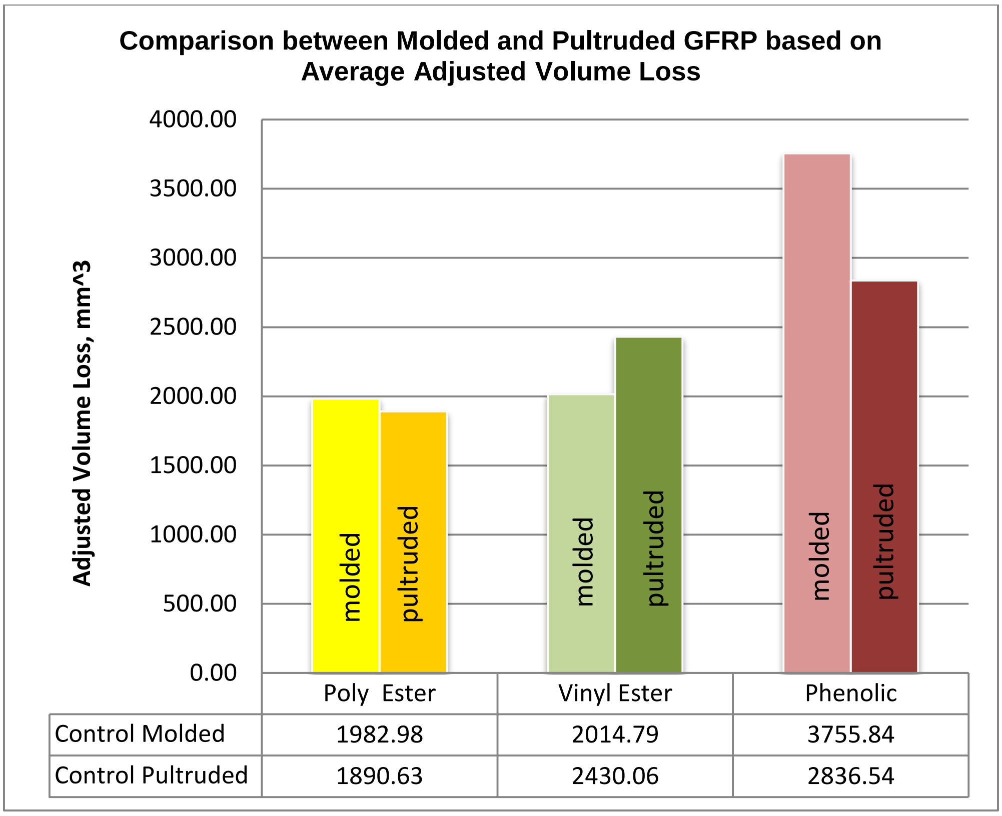
Table 4.5.1 shows the result of 2 months aging GFRP specimens after being test under abrasive performance according to ASTM G65 guideline. From the Figure 4.5.1 shows that polyester has the least average mass loss which is 3.11g compared to other resins. The vinyl ester shows slightly more mass loss compared to the polyester with difference of 0.075g which is 3.185g. The phenolic shows the highest mass loss compared to the polyester and vinyl ester which is 6.365g. Figure 4.5.3 and Figure 4.5.4 show the comparison of average volume loss and adjusted volume loss of the 2 months aging GFRP specimens. From the figure, the average adjusted volume loss for polyester, vinyl ester and phenolic is 1667.533mm^3, 1686.607mm^3 and 3854.504mm^3 respectively. The polyester and the vinyl ester have only small difference that show that both resins have the same resistance against the abrasion. Figure 4.5.4 shows the percentage loss of the 2 months aging GFRP specimens after being test under abrasive performance. The pultruded polyester has the lowest mass loss percentage compared to other resins which is about 6.981%%. The vinyl ester have almost the same amount of mass loss with the polyester which is 7.058% with only difference of 0.077% The phenolic has the highest mass loss percentage compared to the polyester and vinyl ester which is 9.219%. Based on the result, the polyester and the vinyl ester have almost the same volume loss means that the both of the specimens have the same strength in resisting abrasion.



	Poly Ester	Vinyl Ester	Phenolic
Control Molded	1982.98	2014.79	3755.84
2 Months Aging Molded	1667.533	1686.607	3854.504

Figure 4.5.5: Graph of comparison between control molded GFRP and 2 months aging GFRP based on adjusted volume loss

Based on the figure 4.5.5, the comparison between adjusted volume loss of control molded GFRP and 2 month aging molded GFRP has been made. For the polyester type specimens, the control molded adjusted volume loss is 1982.98mm^3 and the aging adjusted volume loss is 1667.53mm^3. The difference between the control and aging specimens is 315.45mm^3 which is show that the control molded polyester GFRP specimen has higher adjusted volume loss compared to the 2 months aging polyester GFRP specimen. For the vinyl ester type specimens, the control vinyl ester specimen has 2014.79mm^3 adjusted volume loss and the aging vinyl ester specimen has 1686.607mm^3 adjusted volume loss. Same with the polyester, the aging vinyl ester show least loss in adjusted volume loss which is 328.183mm^3 less than the control vinyl ester specimen. For the phenolic type specimens, the control molded phenolic the adjusted volume loss is 3755.84mm^3 and the aging molded specimen adjusted volume loss has 98.664mm^3 higher which is 3854.504mm^3. For the polyester and vinyl ester, the aging specimens show higher abrasive resistance. This might be because of the how the specimens were made which is by the molding process. In the molding process, the specimens were layer by layer without proper pressure, and when these specimens were put in salt water at 60 degree Celsius for 2 months, this process act as curing for the specimens and make the specimens become stronger.



	Poly Ester	Vinyl Ester	Phenolic
Control Molded	1982.98	2014.79	3755.84
Control Pultruded	1890.63	2430.06	2836.54

Figure 4.5.6: Graph of comparison between molded and pultruded GFRP based on average adjusted volume loss

Based on the figure 4.5.5, the control molded GFRP specimens which is polyester, vinyl ester and phenolic average adjusted volume loss is 1982.983755.84mm^3, 2014.793755.84mm^3 and 3755.84mm^3 respectively. For the pultruded GFRP specimens which is polyester, vinyl ester and phenolic the adjusted volume loss is 1890.63 mm^3 , 2430.05 mm^3 and 2836.54 mm^3 respectively.For the polyester, the difference between molded and pultruded specimen is 92.35 mm^3 which is the pultruded specimen has least volume loss compare to control specimen. For the viny ester, the pultruded has higher adjusted volume loss compare to the molded specimen by 415.27 mm^3 . For the phenolic, the control show higher adjusted volume loss compare to pultruded by 919.3 mm^3. The difference between the might be because of how the specimens were made where for the molded it made by using special mold whereas for the pultruded it made the pultrusion process.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The performance of Glass Fiber Reinforced Polymer (GFRP) under abrasive condition is an integration of theoretical and laboratory works about the abrasive resistance and performance of GFRP specimens that come from different resins with different conditions. Through this experiment, the type of resins that were investigated are polyester, vinyl ester and phenolic and the conditions for the testing is control molded GFRP specimens, 2 months aging molded GFRP specimens and control pultruded GFRP specimens. Based on the methodology and Gantt chart, all the project activities have been planned and done properly. Relating to the objective of this research, all the objectives of this research has been achieved successfully. The GFRP specimens have been test according to the ASTM G65 standard and the performance of the specimens has been determined. Through this research, it also proven that the different type of resins and specimens condition affects the abrasive performance of the specimens. Based on the results of performance of molded GFRP specimens, pultruded GFRP specimens and 2 months GFRP specimens, the polyester type GFRP has the least volume loss compared to other resins shows that polyester type resin has the best performance in resisting abrasion. Further study need to be done to find out more on performance of the specimens when the aging process in increased. The performance between aging molded and aging pultruded also need to be done to find which type GFRP is better after aging process. Through this experiment, using GFRP as an alternative in replacing the usage of steel in offshore platform is viable. The GFRP specimen not only show very good performance in abrasive resistance but also has other advantages which is lightweight, maintenance free, corrosion resistance etc. that is really suitable to be used in very harsh environment. Author also hope that this sustainable material can be commercialize in the construction industry for a better and greener environment since fibers are indeed renewable resources which the supply can be unlimited compared with traditional steel and other reinforcement materials. It is hoped that this research can help to further explore the potential of GFRP in their performance especially under abrasive condition. Also, from this research, the performance of GFRP under abrasive condition could be used for development of design standards for the usage of GFRP.

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APPENDIX

Type of GFRP material	No. of sample	Duration soak with salt water at 60 degree Celsius	Date Start	Date Finish
Polyester	2	2 month	19th May 2014	14th July 2014
Polyester	2	Specimens still remain in the tank for aging process	19th May 2014	-
Vinyl Ester	2	2 month	19th May 2014	14th July 2014
Vinyl Ester	2	Specimens still remain in the tank for aging process	19th May 2014	-
Phenolic	2	2 month	19th May 2014	14th July 2014
Phenolic	2	Specimens still remain in the tank for aging process	19th May 2014	-

Detail	Description
Type of GFRP	There are three types of specimens that are being tested which is polyester. Vinyl ester and Phenolic
Specimen ID	Each specimen is labeled with their specimen ID for example B-ABM-PE 1
Load Applied, N	The load apply at the abrasion testing machine with is 130N for every experiment
Specimen Volume,V (cm^3)	$V_{L =}$ h x l x w
Initial Weight, W_i (g)	Weight of GFRP before used in the experiment
Final Weight,W_f (g)	Weight of GFRP after being used in the experiment
Mass Loss, M_L (g)	$M_L = W_f - W_i$
Density, ρ (g/cm^3)	$\rho = W_i / V_S$
Volume Loss, V_L (mm^3)	$V_L = M_L / \rho$
Initial Wheel Diameter, D_i (mm)	Diameter of the abrasion wheel before test
Final Wheel Diameter, D_f (mm)	Diameter of the abrasion wheel after test
Adjusted Volume Loss, V_{AL} (mm^3)	$V_{AL} = V_L \times D_i / D_f$
Percentage Mass Loss, $M_{\%}$ (%)	$M_{\%} = M_L / W_i \times 100$
Average Mass Loss, g	Total of mass loss divided by number of GFRP specimen
Average Volume Loss, mm^3	Total of volume loss divided by number of GFRP specimen
Average Adjusted Volume Loss, mm^3	Total of adjusted volume loss divided by number of GFRP specimen
Average Percentage Mass Loss, %	Total percentage divided by number of GFRP specimen
Ranking	Based on average volume loss, the three specimens is compared and the least adjusted volume loss is rate by 1 to 3