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

By

Muhammad Zulhusni Bin Zaini

A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)
DECEMBER 2013

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan
MALAYSIA

CERTIFICATE OF APPROVAL

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

By

Muhammad Zulhusni Bin Zaini

A project dissertation submitted to the
Civil Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

____
Dr. Ibrisam Akbar

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK, MALAYSIA
December 2013

CERTIFICATE 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.

MUHAMMAD ZULHUSNI BIN ZAINI

Abstract

Steel as we can see today is widely used in construction especially for drain covering. As we all know steel is a very strong material in addition with its flexural ability compared to concrete or reinforced concrete. Hence, we can see the application of steel is everywhere. Unfortunately, steel will tend to rust when it is not covered or layered with protective material, thus it is cannot be exposed to air nor water. In order to maintain the strength and properties of steel itself such cost is needed like repainting cost. Thus, this report is mainly about replacing the steel to Glass Fiber Reinforced Polymer (GFRP). First of all, before entering the broader scope of GFRP usage, the author proposed the GFRP grating initially would be likely placed on joint covering or drainage covering. Major resistance that these grating would face is the wear and tear resistance caused from pedestrian force. Test will be conducted based on ASTM G65 standard. As for this paperwork we will be specified on abrasion test. This research examines the wear and tear ability of the sample. This test will involve three (3) surfaces which are the sample surface (GFRP), sand (as abrader) and rubber wheel. Samples that will be used are the polyester, vinyl ester and phenolic. The outcome of the results will tell us which resins have the highest resistance in terms of abrasion and these samples will be classified into two different conditions which are the normal condition (control samples) and the 1 month aging condition (immerse into salt water and temperature of 60ºC). The methodology of this test will be consisting of 3 phases which are research methodology, data collection and data analysis. At the end of the research we will able to justify whether is it reliable to advancing the usage of GFRP material in replacing steel for grating

Acknowledgements

In the name of Allah, the Most Gracious, the Most Merciful. Praise to Him the Almighty that in His will and given strength, I managed to complete the dissertation for this semester.

The special thanks goes to my supervisor, Dr Ibrisam Akbar for the enlightening supervision and countless hours spent in sharing his insightful understanding, profound knowledge and valuable support throughout completing this project. Besides, his kind assistance and guidance from beginning to the end of the project really help me in completing the project successfully. During the period of time, it is very tough and challenging for me to complete the project without people behind me to give endless support.

Here, I would like to express my full appreciations towards concrete lab technician especially Mr Johan Aarif, Mr Hafiz, Mr Rozaimi and Mr. Amir Izzuddin (Master Student) for their assistance and knowledge sharing and several industry persons who involved indirectly for their information regarding my project. Their cooperation and guidance are highly appreciated.

Not forget, great appreciations go to Final Year Project coordinators for their reminder and warm supports that had made this project a memorable and an informative one. Last but not least, to all author's fellow friends who have directly or indirectly lent a helping hand here and there. The support and encouragements from the people above always be a pleasant memory throughout my life.

Thank you.

Contents

List of Figures

List of Tables

1 INTRODUCTION

An FRP is a composite with a polymer matrix and a glass, carbon or aramid fiber reinforcement. Common uses for FRPs generally occur in the aerospace, automotive and marine industries as low weight, high strength materials [1]. The durability is a function of both the matrix and the fiber making them much more durable than the fibers on their own. The strength, however, is more influenced by the fibers making them very strong in tension. The bi-linear stress strain model, as we can see in below describes the stress-strain relationship of the FRP and shows the dual Young's moduli for the composite. The figure refers to E_m and E_{mp} as the Young's modulus for the concrete and reinforcement material, respectively, combining to form a composite modulus, $(E_s)_m$. Some typical FRP properties are shown in *Figure 1-1* as compared to steel. Note that depending on the amount of reinforcement material, the strength properties can vary dramatically [2].

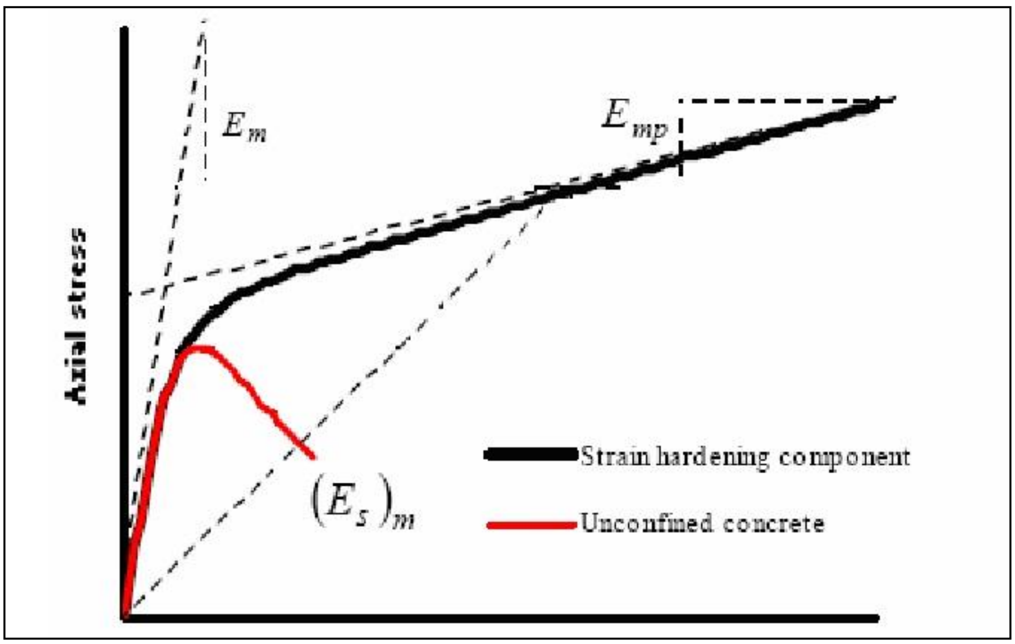


Figure 1.1-1: Bi-Linear Compressive Stress/Strain Curve for Typical FRP Composite [3].

Glass fiber reinforced polymer bars have become popular in recent years as reinforcement for concrete structures. One advantage of these bars over steel is their resistance to corrosion. Although the bars do not corrode in contact with deicing chemicals, they can deteriorate rapidly in an alkaline environment [4]. One type of glass fiber reinforced polymer bar subjected to a saturated solution of calcium hydroxide exhibited loss of strength due to high level of water gain [5]. Inadequate material selection under adverse environmental conditions may cause severe inside or outside deterioration of glass fiber reinforced polymer reinforced concrete structures.

Hence in this study, the author will carry out a test which resulting in findings the abrasiveness of the GFRP materials. As for now the samples are moulded with three different resins which are polyester, vinyl ester and phenolic. Resins used in each sample will have different properties and outcome. The test will be carried out based on ASTM G65 standard or also known as The Dry Sand/Rubber and Wheel Abrasion Test and have been used by several research and industrial laboratories in the United States in evaluating hard surfacing alloys, castings, and wrought products for their resistance to abrasive wear. The samples are categorized in 3 different parameters which were the control samples, the 1 month aging samples and 2 months aging samples.

1.1 Background of Study

As stated previously, the study of this research paper is to find out the weight loss/reduction caused by abrader (sand) and how does weight/load derive the life-cycle of the GFRP samples. Sand that will be used is based on ASTM G65 standard which according to U.S. sieve size 70 or 212mikrons. The loads that will be used are 20, 130 and 250N but apparently only 20N has been tested. As for the samples, there were three (3) of them which are polyester, vinyl ester and phenolic, and samples are tested in three (3) different conditions which were normal condition (control samples), 1 month aging samples (under heat & saltwater) and 2 months aging samples (under heat & saltwater).

1.2 Problem Statement

Corrosion of internal reinforcing steel is one of the major causes of failure of concrete structures. Inevitably concrete will crack, creating a direct avenue for chlorides to begin oxidizing the steel rebar. Some problems related to steel are the cost of steel is expensive and this will increase the cost of structure directly. Occasionally, some concrete aggregates can react aggressively with steel and caused spalling e.g in bridges, tunnels etc. and combating this aggression can be costly.

In order to maintain the strength of steel, periodically maintenance should be carried out such as paintings and coatings to avoid the rusty situation that will directly reduce the strength and bearing capacity of the material. Hence from this maintenance of course it will involve in costing which apparently would be a consistent or fixed cost for consumers. In business matter, such costs are not likely favor to consumers which involve dollars and cents.

Meanwhile, in automotive and aircraft industry mainly uses steel in their production as car body and aircraft body. Hence steel itself will influence the fuel usage as it needs to carry heavier weight. Thus an alternative material such as fiber will reduce the weight of vehicle itself therefore reduces the fuel consumption and CO2 emissions to the environment. Recent prominent examples shows that many aircraft and automotive companies uses fiber such as Boeing 787 Dreamliner is constructed largely of carbon-fiber-reinforced plastic instead of traditionally aluminium body structure, and the BMW Project I is a new electric vehicle, whose support structure contains a significant amount of carbon fiber to reduce weight and to enhance driving dynamics. Besides these prominent examples, many other clever solutions have recently been introduced, e.g., the use of a one-piece carbon fiber car fender instead of a four-piece metal part, allowing for a 30 percent weight reduction and a 60 percent reduction in its tooling cost, and the use of carbon fiber bearings for an Airbus A340 horizontal tail, reducing its weight by 50 percent and cost by 30 percent.

1.3 Objective of Study

The main objectives of this study are:

- To identify the abrasiveness of GFRP materials
- To find out which resins has the most abrasive resistance
- To identify how does load can influence the abrasion testing

1.4 Scope of Study

This research will be focusing on the case study of a Glass Fiber Reinforced Polymer (GFRP) material under abrasive condition. Abraders that will be use in the experiment were the 50 & 70 according to the US sieve size. The main objective of this study is to replace the conventional of using steel grating to GFRP grating for drainage covering. Hence, some recordings need to be carried out throughout material testing period. The results will show us the effectiveness of the material comparing to steel.

1.5 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.

1.6 Feasibility of the project

With all the required equipments 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 equipments are 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.

2 LITERATURE REVIEW

2.1 Introduction to Abrasion Testing

According to a “classic” definition by SAE abrasive wear concerns the removal of material from a surface by mechanical action of abrasive (hard) particles in contact with the surface. Arbitrary classifications of abrasive wear are based on observed conditions [6]:

- **Gouging Abrasion**: The result of this type of abrasive wear is the removal of large particles from a metal surface. Worn surfaces show heavy gouges.
- **High Stress Grinding Abrasion**: This type of abrasive wear occurs during the progressive fragmentation or grinding of the abrasive which was initially of small size and takes place on the surfaces employed to grind the abrasive. The wear is believed to be caused by concentrated compressive stress at the point of abrasive contact and to result from plastic flowing and fatiguing of ductile constituents and cracking of hard constituents of the metal surface. The use of the words “high stress” in this classification is intended to imply that the crushing strength of the abrasive is exceeded.
- **Low Stress Scratching Abrasion** or **Erosion**: The result of this type of abrasive wear is scratching of the metal surface, and the scratches are usually minute. The stress imposed on the abrasive particle does not exceed the crushing strength of the abrasive

Based on our experiment, 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 [7]. 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 [8].

The type and intensity of abrasive wear depends on abrasive mass (particle size, form, composition, hardness, dampness) and the wearing surface properties (composition, hardness), and also the abrasive particle and surface harness ratio [9]. Abrasive mass abrasivity is ranked by particle hardness, size and sharpness. The harder, higher and sharper particles, then the wear is intensive [10].

2.2 Glass Fiber Reinforced Polymer

With the rapid development nowadays, consuming of structural material such as wood and steel can be demanding. Many researches were carried out to overcome the demanding of material supplies, and recyclable material is highly recommended by the societies. Combinations of materials were mixed so that contribution of reinforcement will increase. As per discussion on this paperwork, we will be reviewed on Glass Fiber Reinforced Polymer (GFRP).

The earliest FRP materials used glass fibers embedded in polymeric resins that were made available by the burgeoning petrochemical industry following World War II. The combination of high-strength, high-stiffness structural fibers with low-cost, lightweight, environmentally resistant polymers resulted in composite materials with mechanical properties and durability better than either of the constituents alone. Fiber materials with higher strength, higher stiffness, and lower density, such as boron, carbon, and aramid, were commercialized to meet the higher performance challenges of space exploration and air travel in the 1960s and 1970s.

Since the early 1990s, the use of small pultruded FRP structural shapes [cross sections less than 1003100 mm (434 in.)] to build industrial platforms and walkways and to build relatively short singlespan [9–18 m ~30–60 ft] pedestrian bridges has also increased significantly [6]. For small highway bridge superstructure and building structural elements, Strongwell has recently developed a new standard pultruded FRP double web beam (DWB) in a 200x150 mm (836 in.) size. A design guide for the beam is available from Strongwell (1999). The beam has been used in a demonstration bridge [11].

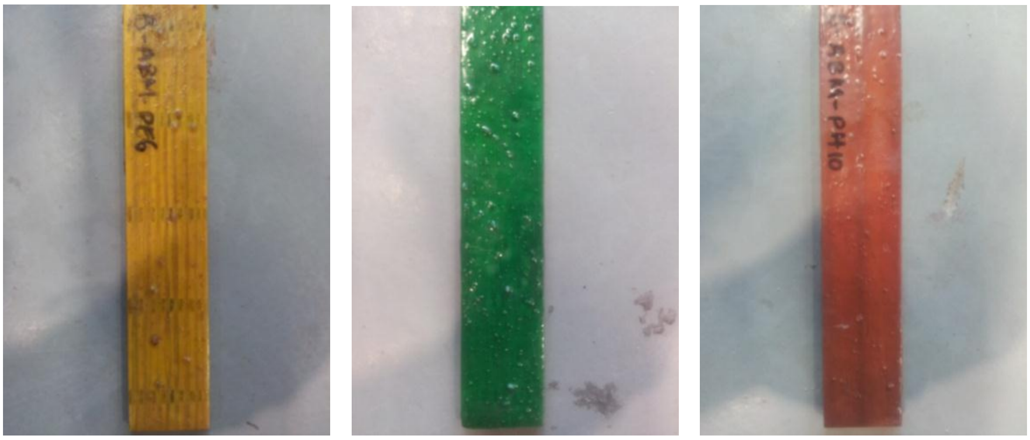


Figure 2.2-1: GFRP Samples Used in Research (Polyester, Vinyl ester and Phenolic)

2.3 Fiber Reinforced Composites and Properties

There are many factors that can influence the performance of natural fiber reinforced composites. Apart from the hydrophilic nature of fibre, the properties of the natural fibre reinforced composites can also be influenced by fibre content / amount of filler. In general, high fibre content is required to achieve high performance of the composites. Therefore, the effect of fibre content on the properties of natural fibre reinforced composites is particularly significance. It is often observed that the increase in fibre loading leads to an increase in tensile properties [12]. Another important factor that significantly influences the properties and interfacial characteristics of the composites is the processing parameters used.

Therefore, suitable processing techniques and parameters must be carefully selected in order to yield the optimum composite products. This article aims to review the reported works on the effects of fiber loading, chemical treatments, manufacturing techniques and process parameters on tensile properties of natural fiber reinforced composites.

The increased acceptance of pultruded structural shapes for mainstream building and bridge superstructure applications will depend on three key developments:

- The development of an internationally accepted material specification for pultruded materials.
- The development of a design code for pultruded structures that is consensus based and incorporated into building and bridge codes.

- The third development will be the reduction of cost of the pultruded shapes which are currently not competitive with shapes made from traditional materials for mainstream structural applications.

2.3-1: Resins Used in Samples

Polyester	**Vinyl Ester**	**Phenolic**
- Unsaturated polyester resins are the simplest, most economical resin system easiest to prepare & good performance. - It is made from condensation polymerization of various alcohols & dibasic acids.	- Improved polyester & also called bisphenol chlorinated. - It is made from combination of polyester & epoxy.	- Made from reaction of phenol & formaldehyde. - It can be cured via heat & pressure w/out use of catalyst or curing agents. - The oldest thermosetting resins. - It is also at reasonable cost.

One of composite main advantages is how their components for example glass fiber and resin matrix complements each other. While thin glass fibers are quite strong, they are also susceptible to damage. Certain plastics are relatively weak, yet extremely versatile and tough. Combining these two components together, however, results in a material that is more useful than either is separately. With the right fiber, resin and manufacturing process, designers can tailor composites to meet final product requirements that could not be met by using other materials. The purpose of reinforcement in the polymeric material is aimed to improve the toughness of the composites, and achieving the desired balance between stiffness and toughness, also to reduce the brittleness of matrix and inhibits notch sensitivity.

The goals of the polymer composite also are to improve the heat distortion temperature and reduced some environmental effects such as water susceptibility and reduce the cost of materials and processing. The mechanical performance of the related composites also can be tailored by adding a coupling agent, compatibiliser and impact modifier. As a result, these added materials improve the interfacial adhesion between the reinforcement and matrix.

2.4 Tribological Properties of Resins/Fibers

In order to select the optimum tribological parameters, i.e., load and sliding distance the result of stage 1 were used. It depicts the variation of wear volume of biaxial non-woven (BANW) reinforced vinylester composite tested under various loads: 10, 30, 50, 100, 150N for two sliding distances, 21.6m and 43.2m. Hence the medium load of 100N was selected for the further tribological tests in the next two stages [13].

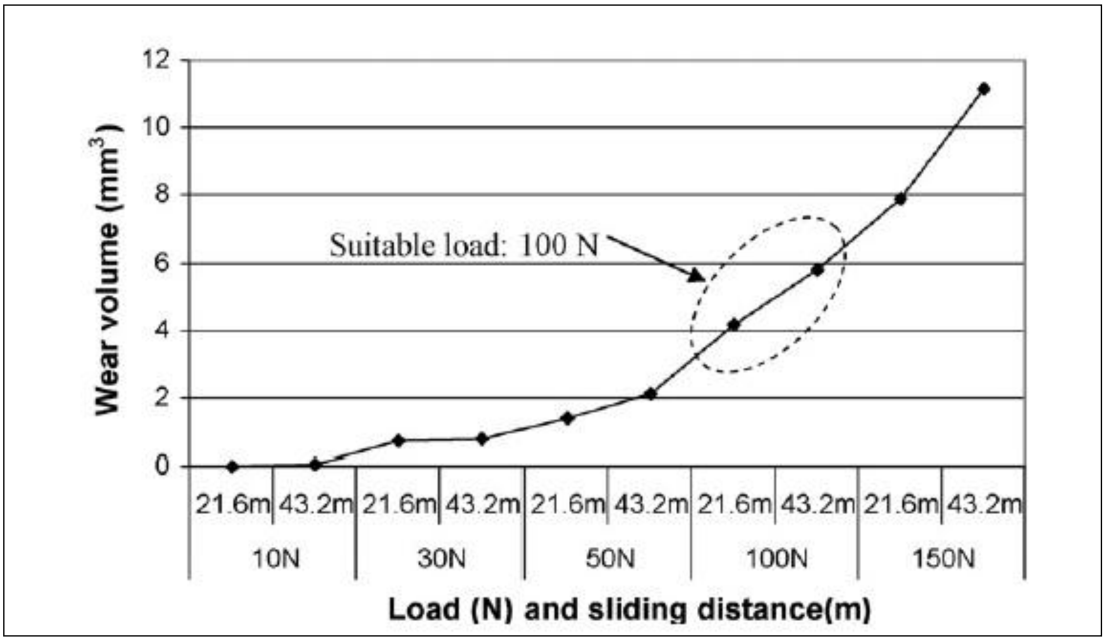


Figure 2.4-1: Variation of wear volume as a function of normal load (10, 30, 50, 100, 150N) and sliding distances (21.6, 43.2m) for vinyl ester composites with BANW preform

Based on their study, they compared the variation of wear volume under four types of multi-axial warp knit performs, i.e., biaxial (BAWK), biaxial non-woven (BANW), Triaxial (TAWK) and Quadraxial (QAWK)oriented warp knit as shown in the *Figure 2.4-1*. There were three (3) types of direction of oriented warp knit structures which were horizontal (weft - 90°), vertical (wale - 0°) and diagonal (±45°).

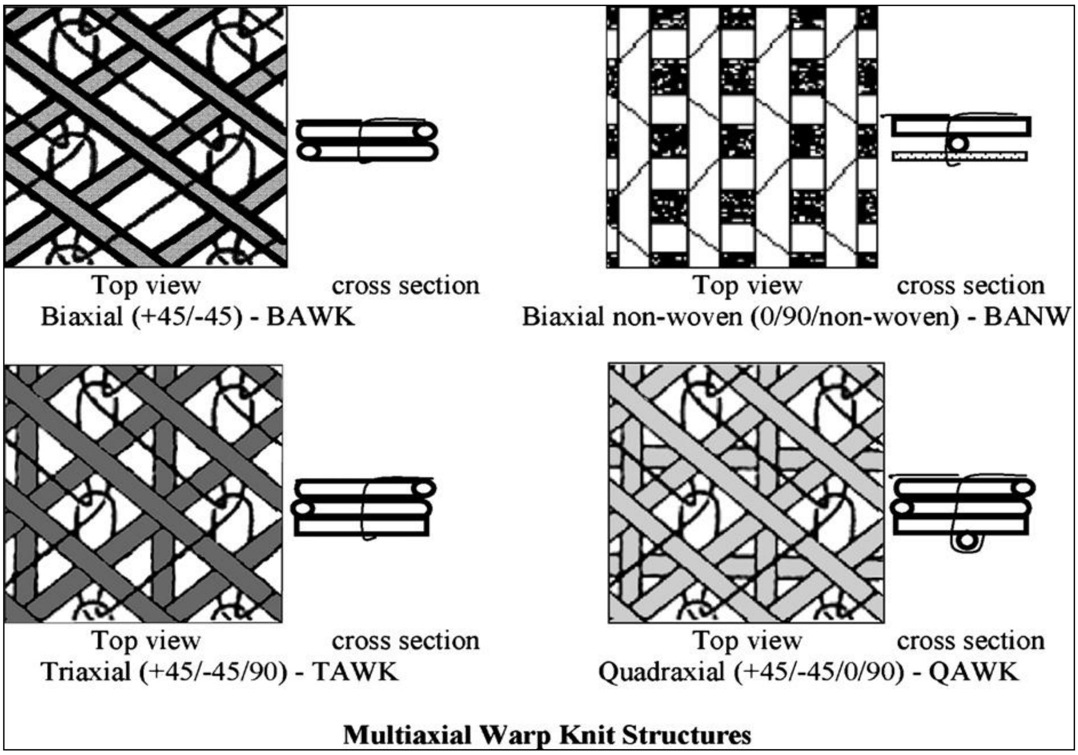
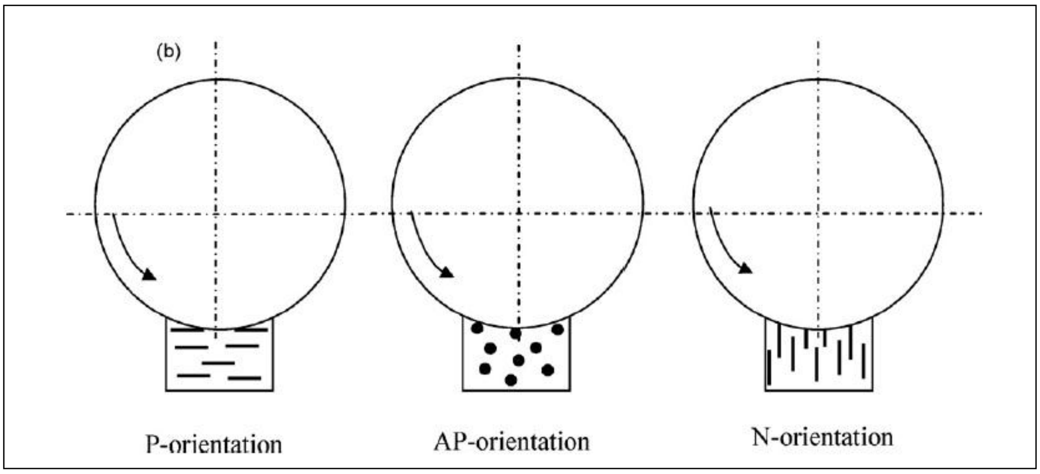


Figure 2.4-2: Variation of Multiaxial Warp Knit Structures

To define wear volume under four types of multi-axial knit performs i.e. biaxial (BAWK), biaxial non-woven (BANW), Triaxial (TAWK) and Quadraxial (QAWK) oriented warp knit. **Biaxial warp knit (BAWK)** preformed composites and composites with epoxy resin are showing the **best tribological properties**.

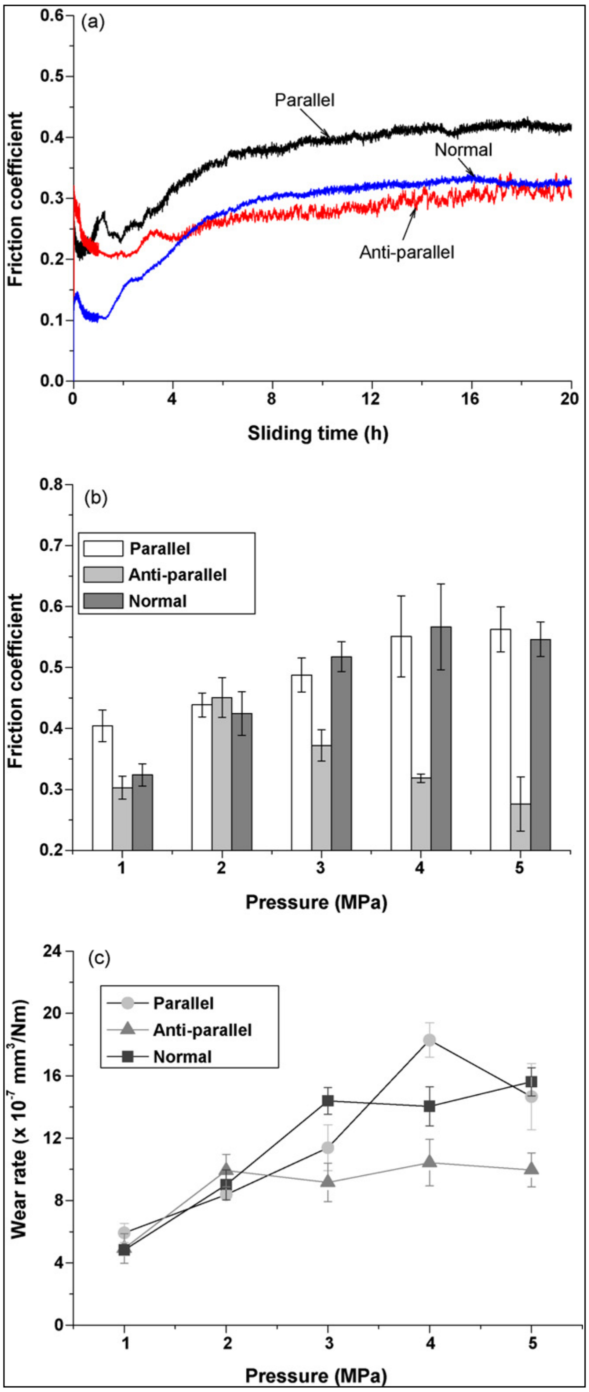
2.5 Fiber Orientation and Nominal Contact Pressure

Effects of fiber orientation and nominal contact pressure on the tribological behavior were studied under different nominal pressures ranging from 1MPa to 5MPa. There were 3 orientations have been carried out which were parallel, anti-parallel and normal relative to the sliding direction [14].



2.5-1: Designation of Fiber Orientations

The study was carried out to indicate which orientation exhibited the optimum wear resistance under nominal pressures. At low pressures, i.e. 1-2 MPa, the fiber orientation had little effect on the wear rate, sliding direction. At low pressures, i.e. 3-5 MPa, the composite displays a higher wear resistance when the fibers are orientated at the anti-parallel rather than the parallel and the normal directions. While under most conditions, lower friction coefficients occurred when the fibers were orientated at the anti-parallel. However, a further increase in pressure from 2 MPa to 5 MPa does not significantly change the wear rate. But under high pressures, i.e. 3 MPa to 5 MPa, the wear rates in the AP-orientation are remarkably lower than those in the N- and P-orientations.



2.5-2: Variation of Wear Rate Due to Different Orientations

Under most conditions**, lower friction coefficients** occurred when the fibers were orientated at the **anti-parallel**. A further increase in pressure from **2 MPa** to **5 MPa does not significantly** change the wear rate. But under **high pressures**, i.e. **3 MPa** to **5 MPa**, the wear rates in the **AP-orientation** are remarkably **lower** than those in the **N-** and **P-**orientations.

2.6 Vinyl Ester Resins

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 crosslinked network with or without the addition of a comonomer. In many industrial products, vinyl ester resins are comprised of 40-50 wt.% styrene.

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.

2.7 Polyester Resins

The first family of resin and probably the most common type of resin is polyester. This is sometimes called an unsaturated polyester resin and is the material commonly used to bond fiberglass fabrics into hard sheets. 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"[16]. In other words, it means the linking of several esters within the fibers. 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.

2.7.1 Characteristic of Polyester

- 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

2.8 Phenolic Resins

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.

2.9 FRP in Offshore Structures

Abrasive wear can be described as the removal of a softer material by a harder material sliding over its surface under load.

Erosive wear on the other hand is defined as the loss of material resulting from repeated impact of small, solid particles.

The most successful offshore applications for composites have been in pipework for aqueous liquids. Performance-based guidelines for the design of glass fibre reinforced epoxy (GRE) pipes have significantly accelerated these applications. Another important application is in panelling for both floors and walls. The first significant tonnage on a North Sea platform involved fire protection panels for the heli-deck of the Amerada Hess Rob Roy rig.

The types of glass based-based composite most often used in structural applications are compared in *Table 2.9-1*. Besides cost, the most important issues relating to materials selection are smoke and toxicity in fires and, of course mechanical properties, including resistance to impact and adverse environments.

2.9-1: Candidate resin systems for use in offshore composites

Resin	Mechanical integrity	Low smoke and toxicity in fire	Cost
Polyester	•••••	•	•••
Vinyl ester	•••••••	•	••••••
Epoxy	•••••••••	•	•••••••••
Phenolic	•••••	••••	••••
Mod. Acrylic	••••	•••••••	••••

Epoxy and vinyl ester systems are relatively immune to attack by CO2 and H2S, as well as the main organic components of crude oil. Vinyl ester-based piping (often referred to as 'epoxy vinyl ester') is a strong competitor to epoxy in some highly corrosive applications and at lower temperatures. Its water resistance at higher temperature, however, is generally not as good as amine-cured epoxy.

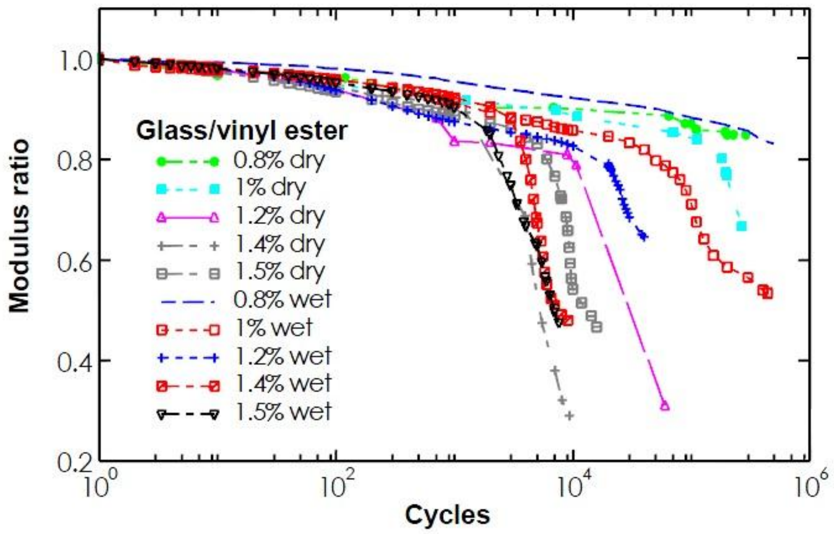
Pultruded composite gratings, and stairways have been used offshore since the 1980s. In the early days of polyester and vinyl ester resins were favoured, and these are still employed today for many applications. Recently, however, successful pultrusion techniques have been developed for phenolic resins, as a result of which phenolic-based gratings have achieved significant offshore usage, in situations where fire integrity is important [19]. The main advantage of phenolic gratings lies not only in their performance during fire, but in their ability to retain a significant level of functionality after fire exposure.

2.10 Environmental and Fatigue Behavior of FRP Materials

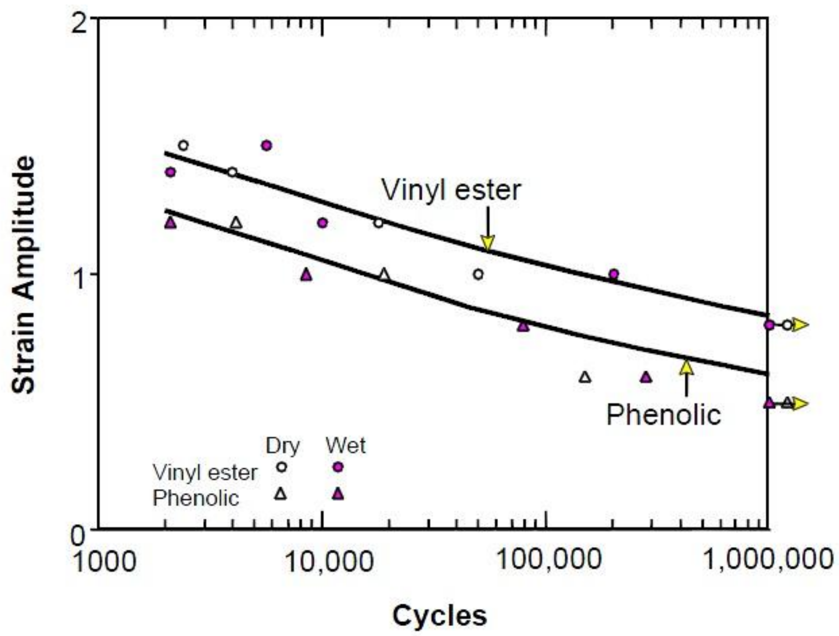
Effective structural use of composites offshore requires an accurate knowledge of their behaviour under repeated loading and their response to marine environments. Figures 8 and 9 show the effect of both strain amplitude and environment on this transition for woven E-glass with three different generic resin systems: vinyl ester (as shown in *Figure 2.10-1, 2.10-2, 2.10-3*), phenolic and polyester. The results show that the vinyl ester system is immune to the effects of seawater, attributable to a good hydrolysis resistance bond between resin and glass. The phenolic system, which is weaker, also shows little effect of environment, presumably because the bond is poor irrespective of the presence of water. The isophthalic polyester, however, shows a significant effect of environment. The *e*-*N* curves of Figures 8 and 9 can be fitted to an empirical power law relation of the form:

$$e = AN^{-n}$$

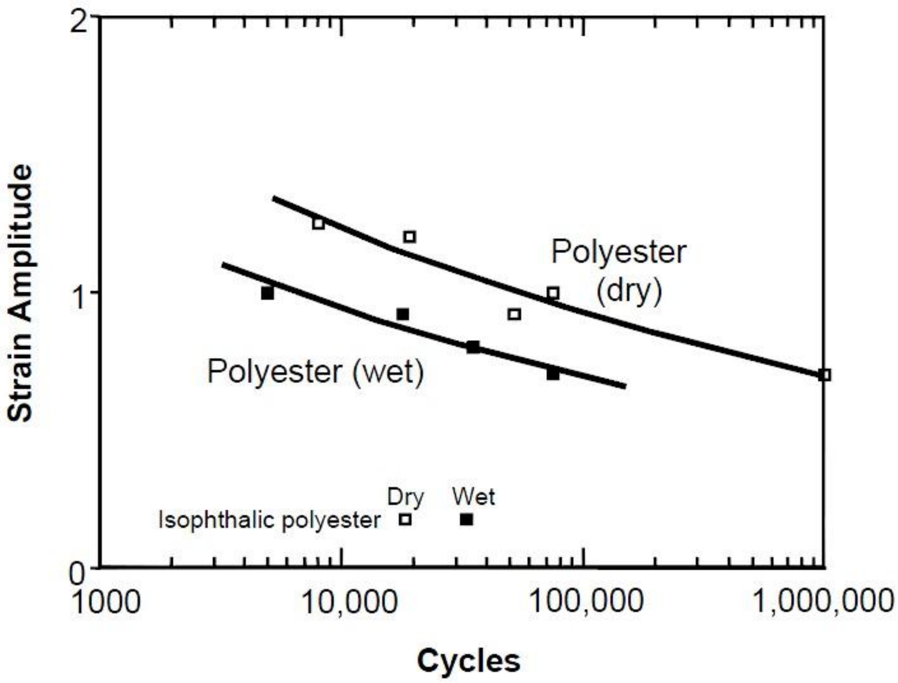
Where *e* is the flexural strain amplitude, *N* is the number of cycles and *A* and *n* are empirical constants.



2.10-1: Reversed strain-based flexural fatigue of woven E-glass/vinyl ester laminates, both dry and wet (conditioned and immersed in seawater). Figure shows the decay in modulus ratio (final/initial modulus) with number of cycles [20].



2.10-2: Strain-based flexural fatigue of woven E-glass/vinyl ester and phenolic laminates, both dry and wet (conditioned and immersed in seawater)



2.10-3: Strain-based flexural fatigue of woven E-glass/isophtalic polyester laminates, both dry and wet (conditioned and immersed in seawater)

3 METHODOLOGY

3.1 Research Methodology

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 rate of revolution of (200 $\pm$ 10 rpm) 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 $\pm$ 4N (TL=Test Load) and 6000 revolutions of the rubber wheel at 200rpm for 30 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 0.0001g as required in ASTM G65 between and after the test.

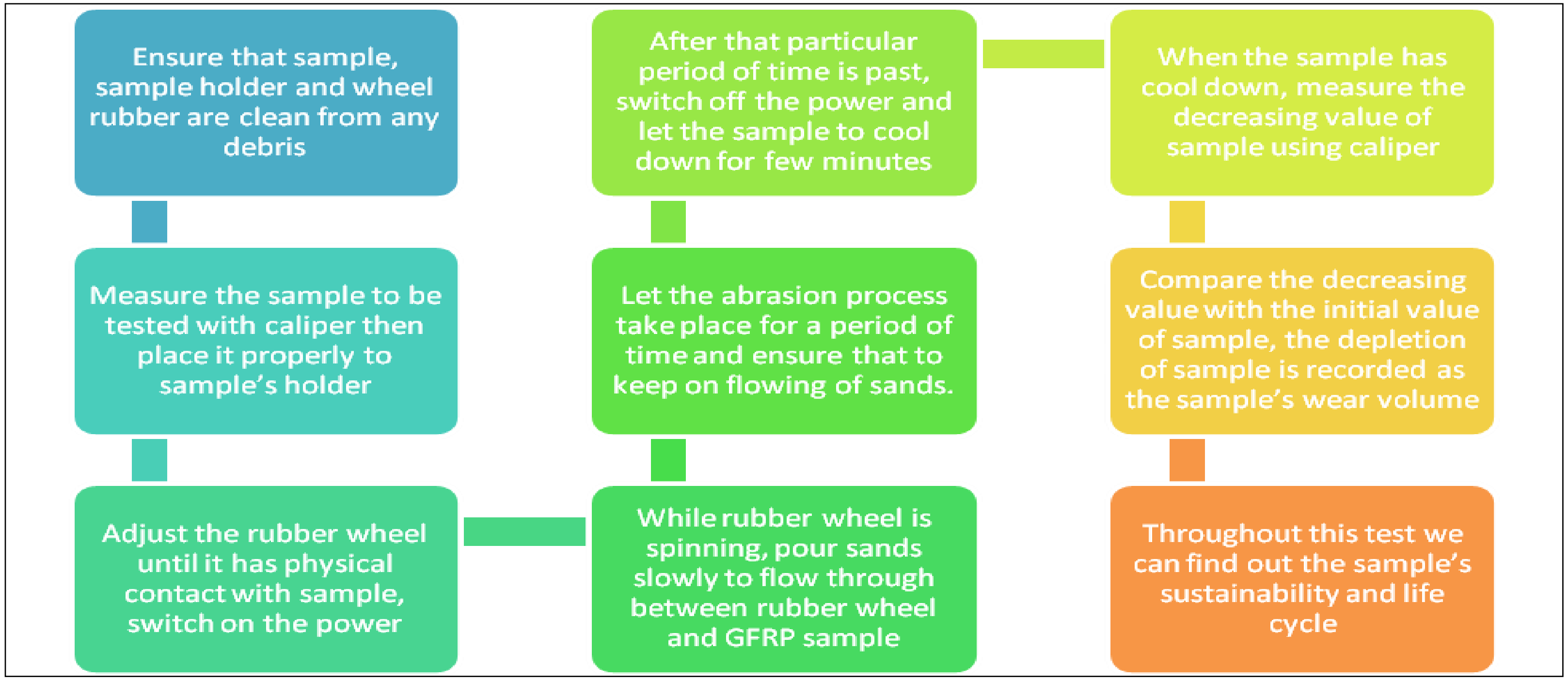
3.2 Tools and Equipments

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 (20N)
- Calliper
- Stopwatch

3.3 Test Procedure

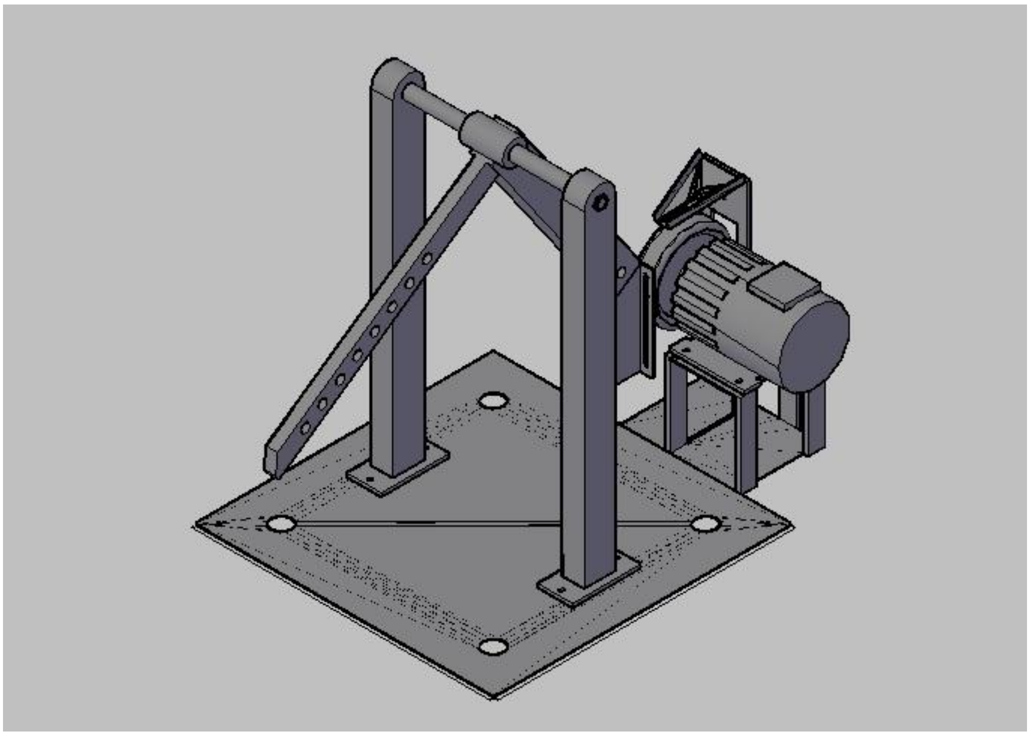
Chart below shows the test procedure for abrasion test on GFRP material:



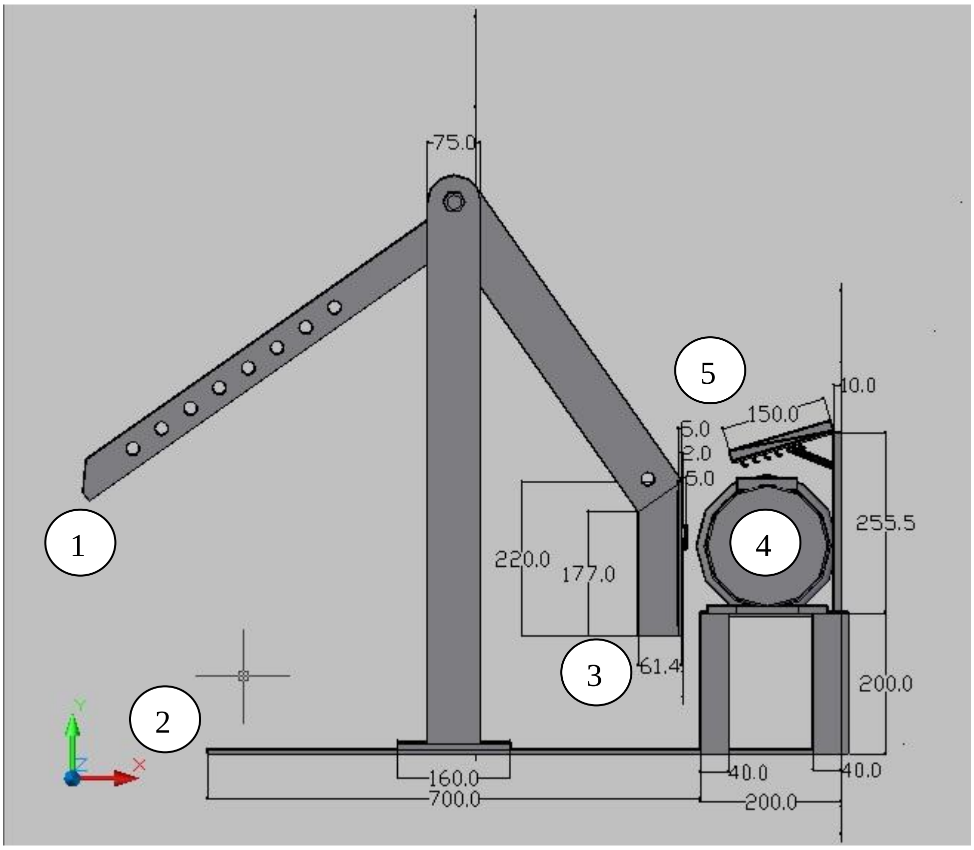
3.3-1: Test Procedure for GRP

3.4 Designing Stage

Picture below shows the sample testing machine. The author needs to design the base plate using AutoCAD 3D.



3.4-1: SE Isometric View



3.4-2: Right View

1= Load to be applied

2= Base plate

3= Sample's holder

4= Rubber wheel

5= Sand slider

3.5 Findings of the study

Test Process

3.5-1: Forces Exerted From Different Loads & Distances

Distance (m)	Load (N)											
	20		40		80		130		200		250	
	Force Exert (N)											
	x	y	x	y	x	y	x	y	x	y	x	y
0.55	21.4	34.0	42.9	68.0	85.7	135.9	139.2	220.9	214.2	339.9	267.8	424.8
0.5	16.9	31	33.7	61.8	67.4	123.6	109.6	200.8	168.6	309.0	210.7	386.2
0.45	12.2	27.8	24.5	55.6	48.9	111.2	78.5	180.7	120.8	278.1	151.0	347.6
0.4	6.9	24.7	13.7	49.4	27.4	98.9	44.6	160.7	68.5	247.2	85.7	309.0
0.35	2.4	22	4.8	43.3	9.5	86.5	15.4	140.6	23.7	216.3	29.6	270.3
0.3	-2.2	18.5	-4.3	37.1	-8.6	74.2	-14.0	120.5	-21.6	185.4	-26.9	231.7
0.25	-6.8	15.4	-13.6	30.9	-27.2	61.8	-43.6	100.4	-67.1	154.5	-83.9	193.1
0.2	-11.6	12	-23.2	24.7	-46.4	49.4	-75.4	80.3	-116.1	123.6	-145.1	154.5
Negative value means force exert backward												

3.5-2: Test Process According to ASTM G65

Wheel Revolution	100	200	300	1000	1200	1300	1380	1400	1600	1800	2000	2500	3000	4000	5000	7000	8500
Wheel Perimeter (m)	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
Meter Value	3.41	6.82	10.23	34.09	40.91	44.32	47.05	47.73	54.55	61.36	68.18	85.23	102.27	136.36	170.45	238.64	289.77
Sliding (m)	52	104	156	520	624	676	717.6	728	832	936	1040	1300	1560	2080	2600	3640	4420
Time (min)	0.5	1.00	1.5	5.00	6	6.50	6.9	7.00	8	9.00	10	12.50	15	20.00	25	35.00	42.5
							← Distance need to cover based on ASTM G65 standard →										

3.6 Gantt Chart

To keep track on the progress of the project, Gantt chart was prepared to provide a visual timeline for starting and finishing specific task. Table below shows the timelines for the project.

3.6-1: Gantt Chart

Detail/Week	1	2	3	4	5		7	8	9	10	11	12	13	14
Installation of the Abrasion Testing Machine						Mid Semester Break								
Sand/Abrader Preparation														
Submission of Progress Report														
GFRP Sample Testing														
Analysis Of The Outcome Results														
Submission of Final Report/Dissertation														

Process
Suggested Milestone

4 RESULT AND DISCUSSION

4.1 Results

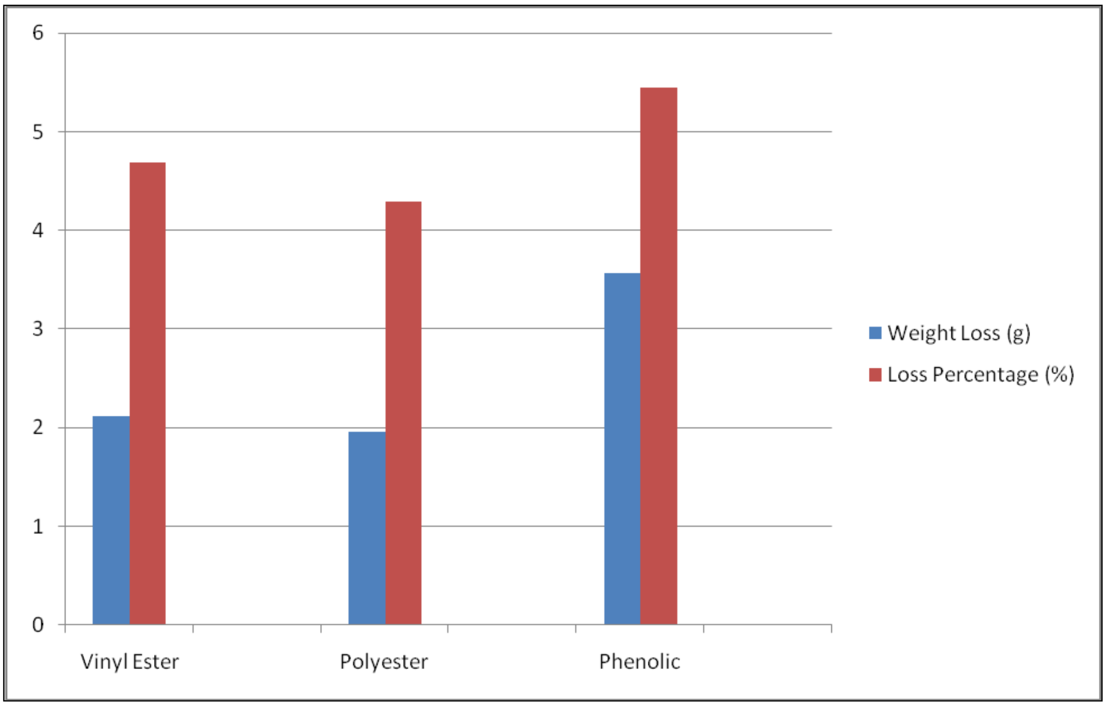
The results for abrasion experiment for control samples are tabulate in table. Results were varies depending on their resins in the sample. Each resin provides different stiffness against rough surface.

4.1.1 Results on Control Samples

Based on *Table 4.1.1-1* and *Figure 4.1.1-1*, it can be observed that polyester resin has the higher abrasive resistance which was 4.29% of weight loss percentage followed by vinyl ester 4.69% and phenolic 5.45% resin. Test was conducted under same parameters and conditions. Duration of the test for each samples were 42 minutes which equivalent to 4420m of sliding distance according to ASTM G65 standard. While speed of the rubber wheel was 200 rev/min.

4.1-1: Control Samples Test Results

Sample / Parameters	**Vinyl Ester**		**Polyester**		**Phenolic**	
	VE1	**VE2**	**PE1**	**PE2**	**PHE1**	**PHE2**
Sand Rate (g/min)	360-380	360-380	360-380	360-380	360-380	360-380
Sand Size (mikrons)	Pass 212	Pass 212	Pass 212	Pass 212	Pass 212	Pass 212
Wheel Speed (rev/min)	200	200	200	200	200	200
Initial Weight (g)	45.55	44.39	44.85	47.14	65.67	65.24
Final Weight (g)	44.08	43.09	43.56	45.81	63.17	63.1
Weight Loss (g)	1.47	1.3	1.29	1.33	2.5	2.14
Average Loss (g)	**2.12**		**1.96**		**3.57**	
Loss Percentage (%)	3.23	2.93	2.88	2.82	3.81	3.28
Average Percentage (%)	**4.69**		**4.29**		**5.45**	



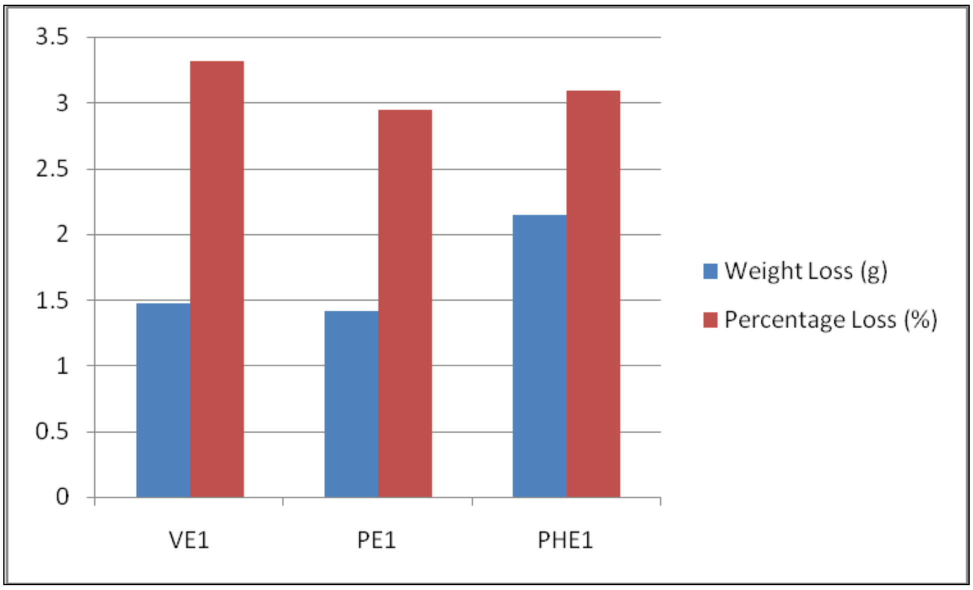
4.1-1: Graph for Control Samples

4.1.2 Results on 1 Month Aging Samples

Meanwhile as for aging samples, which was previously immersed in salt water and temperature (60ºC) for 1 month shows the same abrasive resistance leading by polyester (2.95%), and it was observed that phenolic (3.09%) performs well than vinyl ester (3.32%) under aging condition. Therefore we can conclude that polyester resin is a better selection of material in fiber composites.

4.1-2: Aging Samples (1 month) Test Results

	Vinyl Ester	**Polyester**	**Phenolic**
Sample / Parameters	**VE1**	**PE1**	**PHE1**
Sand Rate (g/min)	360-380	360-380	360-380
Sand Size (mikrons)	Pass 212	Pass 212	Pass 212
Wheel Speed (rev/min)	200	200	200
Initial Weight (g)	44.34	47.83	69.27
Final Weight (g)	42.87	46.42	67.13
Weight Loss (g)	1.47	1.41	2.14
Loss Percentage (%)	**3.32**	**2.95**	**3.09**



4.1-2: Graph for 1 Month Aging Samples

4.1-3: Samples after Test

5 CONCLUSION AND RECOMMENDATION

The variation between control samples and aging samples results seems like only small differences. Longer aging period should taking into consideration in order to get exact amount of differences. Therefore we can see which samples either polyester, vinyl ester or phenolic resins can withstand the condition of salt water and temperature longer than any other samples. Further research should be done in order to get the fiber life-cycle.

Meanwhile variation of loads should be taken into account, heavier loads will exert different or more forces against the samples. As for current progress, only 20N of load were tested. According to the ASTM G65, loads that should be taken into consideration were 20, 130 and 250N and coarser abrader could be helpful to find the behavior of those samples. For this test only 212mikrons or pass U.S. sieve 70 were used. Eventually for now, the overall winner for abrasion testing is won by the polyester resins.

The 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. On top of it, fibers are low cost, recyclable, low density and eco-friendly material. Their tensile properties are very good and can be used to replace the conventional fibers such as carbon in reinforcing plastic materials.

In order to improve fiber-matrix interfacial bonding and enhance tensile properties of the composites, novel processing techniques, chemical and physical modification methods are developed. Also, it is obviously clear that the strength and stiffness of the natural fiber polymer composites is strongly dependent on fiber loading. The tensile strength and modulus increase with increasing fiber weight ratio up to a certain amount. If the fiber weight ratio increases below optimum value, load is distributed to more fibers, which are well bonded with resin matrix resulting in better tensile properties.

REFERENCES

[1] Clarke, John. *Materials World,* February 1998. pp. 78-80.

[2] Matweb. www.matweb.com. Blacksburg, VA: Automation Creations, Inc, 1996.

[3] Wikipedia. May 6, 2005. http://en.wikipedia.org/wiki/Fiber_reinforced_plastic.

[4] Na W.B., Kundu T., Ehsani M.R. (2002) "A Comparison of Steel/Concrete and Glass Fiber Reinforced Polymers/Concrete Interface Testing by Guided Waves". 155.

[5] Na W.B., Kundu T., Ehsani M.R. (2002) "A Comparison of Steel/Concrete and Glass Fiber Reinforced Polymers/Concrete Interface Testing by Guided Waves". 155.

[6] *SAE J965Abrasive Wear, Information Report,* Society of Automotive Engineers, Warrendale, 1966.

[7] Kotecki D.J., Ogborn J.S. (1995) "Abrasion Resistance of Iron-Based Hardfacing Alloys", 269.

[8] Kotecki D.J., Ogborn J.S. (1995) "Abrasion Resistance of Iron-Based Hardfacing Alloys", 269.

[9] Jankauskas V., Skirkus R. (2013) "Steel Abrasive Wear Forecasting by Wearing Surface Microgeometric Parameters", p486.

[10] Jankauskas V., Skirkus R. (2013) "Steel Abrasive Wear Forecasting by Wearing Surface Microgeometric Parameters", p486.

[11] Johansen, G.E., Wilson, R. J., Roll, F., and Gaudini, G. (1997). "Design and construction of long span FRP pedestrian brdges." *Building to last, Proc., Structures Congress XV,* L.Kempner and C.B. Brown, eds., ASCE, New York, 46-50.

[12] Hayes, M. D., Lesko, J. J., Haramis, J., Cousins, T. E., Gomez, J., and Massarelli, P. (2000a). "Laboratory and field testing of composite bridge superstructure." *J. Compos. Constr.,* 4(3), 120-128.

[13] M.T. Matthew, N.V. Padaki, L.A. Rocha, J.R. Gomes, R. Alagirusamy, B.L. Deopura, R. Fangueiro (2007). " Tribological properties of the directionally oriented warp knit GFRP composites." Wear., 263, 930-938.

[14] G. Zhang, Z. Rasheva, A.K. Schlarb (2010). "Friction and wear variations of short carbon fiber (SCF)/PTFE/graphite (10 vol.%) filled PEEK: Effects of fiber orientation and nominal contact pressure." Wear., 893-899.

[15] R. E. Young, in *Unsaturated Polyester Technology*, P. E. Bruins, Ed., Gordon and Breach. New York, 1976, p.315.

[16] www.whatispolyester.com

[17] http://www.gp-chemicals.com/Composite_Resins_Product_Category

[18] Masakatsu A., Michael S. (2010) "Phenolic Resin: A Century of Progress". 307

[19] T. Carlson, Product data on pultruded phenolic gratings, Strongwell, 1999; also in proceedings of Composites in Fire Conference, ed. A.G. Gibson, University of Newcastle upon Tyne, 15-16 September 1999

[20] Gibson, J.T. Evans, G. Kotsikos, S.D. Speake and J.M. Hale, *Plastics, Rubber and Composites*, 2000, **29**, 10, pp 533-538.