

RECYCLE ROVING FIBRE KIT FOR ROVING GLASS COMPOSITES



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RECYCLE ROVING FIBRE KIT FOR ROVING GLASS COMPOSITES

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DECLARATION

I declare that this "RECYCLE ROVING FIBRE KIT FOR ROVING GLASS" is the result of my own research except as cited in the references. The dissertation has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Manufacturing Engineering Technology (Process and Technology) with Honours.

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DEDICATION

Dedicated to

My beloved mother, Ruzaiha Binti Abd Aziz My beloved father, Abd Wahid bin Mohd Yusof My lovely sister, Nur Syazana and Nur Farzana Aida

My generous friends, Muhammad Fikri, Muhammad Ayyub, Muhammad Afiq and Shamsu

Hazmirul My apprentice, Ts. Mohd Fadli Bin Hassan

For giving me moral support, cooperation, encouragement and understandings.

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ABSTRACT

Composite materials have been the subject of study mainly synthetic fibers because of their high strength and light weight but non-bio-degradable nature. The waste of the machine pultrusion process in the composite industry has produced waste material in the form of roving, and usually this waste will be discarded, since there are no further studies that applied this waste to convert into application of glass fibre woven mats. Therefore, this study will explore the glass roving waste generated by pultrusion machine to the application of mat weaving patterns. This idea is for fibre waste that can used to make the something to be the product. In this research, the Recycle Roving Fibre Kit (RRF kit) is self-designed hand loom was produced to facilitate users to convert roving waste into glass mat plain weave patterns (RWR). Recycled mat samples (RWR) and commercial mat samples WR 600/(CWR) reinforced Epoxy and hardener using a hand -layup technique to produce test specimens for flexural, impact, density and water absorption testing based on ASTM standards. This study found that the 3 -plies RWR samples produced a maximum increase of 428.11% compared to the 3 -plies CWR in impact properties. Additionally, 1 ply RWR has a 74 % higher impact strength than 2 plies CWR, and 2 plies RWR has a 92 % higher impact strength than 3 plies CWR. Despite the RWR samples' excellent impact performance, its flexural properties were inferior to CWR. The density properties of the 3 plies RWR were almost the same as the 3 -plies RWR sample with a slight difference of 0.5%. The best result for water absorption is 2 plies among the RWR samples, but its performance had an insignificant difference when compared to the 3 plies of CWR which were not more than 30%. It can be concluded, RWR can still be function similar to CWR while having better energy absorption result.

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ABSTRAK

Bahan komposit telah menjadi subjek kajian terutamanya gentian sintetik kerana kekuatannya yang tinggi dan ringan tetapi sifatnya tidak boleh terurai secara bio. Sisa proses pultrusion mesin dalam industri komposit telah menghasilkan bahan buangan dalam bentuk roving, dan biasanya sisa ini akan dibuang, kerana tiada kajian lanjut yang menggunakan sisa ini untuk ditukar kepada aplikasi gentian kaca anyaman tikar. Oleh itu, kajian ini akan meneroka sisa kaca roving yang dihasilkan oleh mesin pultrusion kepada aplikasi corak anyaman tikar. Idea ini adalah untuk sisa serat yang boleh digunakan untuk membuat sesuatu untuk menjadi produk. Dalam penyelidikan ini, Kit Kitar Semula Fiber Roving (RRF Kit) Semula adalah alat tenun tangan rekaan sendiri telah dihasilkan bagi memudahkan pengguna menukar sisa kaca roving kepada corak anyaman biasa tikar kaca (RWR). Sampel kitar semula (RWR) dan sampel tikar komersial WR 600/(CWR) diperkukuh Epoksi dan pengeras menggunakan teknik hand-layup untuk menghasilkan spesimen ujian bagi ujian lenturan, hentaman, ketumpatan dan penyerapan air berdasarkan piawaian ASTM. Kajian ini mendapati sampel RWR 3-lapisan mehasilkan peningkatan maksimum sebanyak 428.11% berbanding CWR 3-lapisan dalam sifat impak. Selain itu, RWR 1 lapis mempunyai kekuatan hentaman 74 % lebih tinggi daripada CWR 2 lapis, dan RWR 2 lapis mempunyai kekuatan hentaman 92 % lebih tinggi daripada CWR 3 lapis. Walaupun prestasi impak cemerlang sampel RWR, sifat lenturnya adalah lebih rendah daripada CWR. Sifat ketumpatan RWR 3-lapisan hampir sama dengan sampel RWR 3-lapis dengan sedikit perbezaan 0.5%. Keputusan terbaik untuk penyerapan air ialah 2 lapis antara sampel RWR, tetapi prestasinya mempunyai perbezaan yang tidak ketara jika dibandingkan dengan 3 lapis CWR yang tidak melebihi 30%. Dapat disimpulkan, RWR masih boleh berfungsi sama dengan CWR di samping mempunyai hasil penyerapan tenaga yang lebih baik.

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LIST OF SYMBOLS AND ABBREVIATIONS

CWR	-	Comercial Woven Roving
RWR	-	Recycle Woven Roving
D,d	-	Diameter
FRP	-	Fiber Reinforced Polymer
EU	-	European Union's
RRF	-	Recycle Roving Fibre kit
ASTM	-	American Society for Testing and Materials
MMCs	-	Metal Matrix Composites
CMCs	-	Ceramic Matrix Composites
PS	-	Polystyrene
РР	1	Polypropylene
PC	-	Polycarbonate
PEI	-	Polyetherimide
RTM	-	Resin Transfer Moulding
RFI	'n	Resin Film Infusion
Polyvinyl	-	PVC
chloride	م	اويوم سيتي تيكنيكل مليسيا
Polyester-ether		PEEK
ketone	VE	ERSTIT TEKNIKAL MALAYSIA MELAKA
Acrylonitrile-	-	ABS
butadiene-		
styrene		
Polyvinyl	-	PVC
chloride		

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CHAPTER 1

INTRODUCTION

This chapter will elaborate and explain about the background, introduction to pultrusion process, waste generated, and methods of handling composite waste. This research is an idea consisting of basic theories about past research, books, journals and online resources. Therefore, information and problems were collected to identify the improvements needed for this research.

1.1 Background

The pultrusion process in the manufacturing industry is plain glass (GF), carbon (CF), or aramid (AF) reinforcing fibres are pulled through a thermoset resin bath for impregnation (typically a polyester, vinyl ester, or epoxy resin), and then permitted to enter a heated forming die, where it attains the shape of the die cavity and cures. Finally, outside the die, a continuous pulling mechanism pulls the already solidified composite part (GFRP, CFRP, or AFRP profile), which is subsequently trimmed to the necessary length by a cut-off saw (Meira et al., 2014).

Pultrusion manufacturing has progressed dramatically over the last 60 years, from its conception and early phases in the early 1950s to its present status as a well-established and efficient industrialized process (Lindahl et al., 2014). In reality, even when thermoplastic-based material is included, production wastes such as (glass roving's) (Yazdanbakhsh and Bank, 2014), non-conformance, and end-of-life items are often landfilled in the pultrusion sector, and in general in the composite materials business, due to their weak recycling capacity. Until now, companies have been quickly utilizing these materials without enough knowledge on how to dispose of them.

Incineration, thermal and/or chemical recycling technologies, and mechanical recycling procedures are currently available procedures that can be utilized to extract some value from thermoset FRP waste products. Because of the high calorific power of FRP materials, incineration is the most preferred method for recovering energy from the heat produced during the combustion process. Incinerator facilities, on the other hand, charge more for incinerating FRP wastes because the high calorific content and hazardous fumes overwhelm the system, limiting their ability to treat as much domestic waste. In addition, the air pollution caused by the combustion of FRP scrap must be considered (Conroy et al., 2006).

Various studies have been conducted in recent decades to estimate market requirements for new composites as well as the quantity of accumulating wastes in order to minimize the unavoidable negative repercussions. With an annual growth rate of 6.6 percent, the market for fibre-reinforced composites (FRC) in the market will reach \$12 billion by 2020 (Naqvi et al., 2018). As a result, the pultrusion industry will give its fair part to this scenario. Due to increases of production, there will be more production waste generated and, in the near future, more end-of-life items.

As a result, collaborating with other organizations to valorize by-products and production wastes, as well as encouraging recycling and repurposing of recyclates into new added-value goods, are crucial and necessary measures toward improving the sector's ecoefficiency. Furthermore, landfill and disposal will no longer be viable options due to more stringent EU waste management regulation, which includes higher landfill costs and capacity limitations (Pickering, 2006). FRP scrap materials will be set aside for recycling and reuse; as a result, FRP makers and suppliers must solve this issue if they do not want to lose market share to metal and other more readily recycled materials (Conroy et al., 2006).

Therefore, the current composite waste management system is insufficient to meet the problem of waste from composite manufacturing, particularly the waste addressed in this study, which is raw material waste from the pultrusion machine process (glass roving). This had decided to come out an idea to overcome the problem by creating a modelling Recycle roving fiber kit. The main material used to make this kit uses tools that are readily available, easy to make and do not require high costs. This kit is a small -scale and early stage model that uses basic weaving operations to weave waste into recycling mats so that this study can be a reference for researchers to create large -scale machines in the future because there are no previous studies examining fibre roving waste from the process of pultrusion machines converted to woven mats. In this study the weaving patterns of commercial mats such as plain, satin and twill are studied based on past studies to find out the type of weave that produces the best mechanical and physical properties. The best type of pattern based on past studies will be used to apply roving glass waste on the RRF kit to make a recycling mat. Then, this recycled mat pattern will be compared to the same pattern on commercial mats. This idea is for fibre waste that can used to make the something to be the product that can save costs and can overcome the problem of waste from the pultrusion process (glass roving) which can lead to global composite waste pollution reduction.

1.2 Problem Statement

Due to limited recycling capabilities, manufacturing wastes such as glass roving, inappropriate products, and end-of-life are often disposed of in the pultrusion sector, and in general in the composite materials industry (Meira et al., 2014). Various studies have been carried out in recent decades to anticipate market requirements for new composites as well

as the volume of accumulated waste in order to reduce the unavoidable negative consequences. The market for fibre-reinforced composites (FRC) is expected to reach \$ 12 billion by 2020, with an annual growth rate of 6.6 percent (Naqvi et al., 2018). As a result, the pultrusion sector will play a significant role in this scenario. Increased production will result in more production waste and, in the not-too-distant future, more end-of-life products and this can result in pollution to the environment because fiberglass is a synthetic material and its non -biodegradable.

This problem is further augmented by owing to stricter EU waste management regulations, which include increasing landfill fees and capacity constraints, dumping and disposal will no longer be feasible solutions (Pickering, 2006). FRP production waste materials will be set aside for recycling and reuse; as a result, if FRP manufacturers and suppliers do not want to lose market share to metal and other more easily recycled materials, they must address this issue (Conroy et al., 2006).

Besides that, the problem found is before starting the pultrusion machine the first step of the procedure is set up glass roving through the resin reservoir area, die and finally puller will pull of glass roving. The result of this setup is a roving fiber glass that is wasted 25 meters in each cycle to produce a product according to the shape of the die. This waste glass roving will usually not be used and cannot be recycled because Pultrusion process is a continuous process and produce continuous product. Waste from the pultrusion process of this machine will result in an increase in waste in the composite industry which increases the cost because the glass roving waste cannot be recycled.

The most common is incineration, which allows some energy to be recovered from the heat produced during the combustion process due to the high calorific power of FRP materials; however, incinerator facilities charge more for incinerating FRP wastes because both the high calorific content and toxic emissions tend to overload the system, limiting how much domestic waste they can process, which can result the air pollution (Conroy et al., 2006). Pyrolysis is the most common thermal process, which involves heating scrap material in an inert atmosphere to recover the polymer material as oil. Because this type of atmosphere prevents combustion, the air pollution effects are less harmful than incineration (Pimenta and Pinho, 2011).

Due to the difficulties faced, the aim of this study is to develop a model kit that can help reduce composite waste, with a focus on glass roving fibre recycling from the pultrusion process. The purpose of producing the Recycle Roving Fiber Kit is to reduce fiber waste for the pultrusion process in the composite industry and can even introduce other alternatives in recycling glass roving waste with user -friendly without involving the use of a lot of cost, energy and environmental pollution to produce recycled products compared to recycling methods such as incineration, thermo and/or chemical recycling.

1.3 Research Objective

The main objectives of this project:

- a) To fabricate Recycle Roving Fibre kit (RRF).
- b) To produce fiber mats from roving fibre glass waste resulting from the pultrusion process using Recycle Roving Fibre kit (RRF).
- c) To study the comparison of mechanical and physical properties between recycle mat and commercial mat.

1.4 Scope of Research

In order to achieve the objectives this research is focusing on the following scopes:

 a) To designed a Recycle Roving Fibre kit that has a user-friendly design using SolidWorks software.

- b) To fabricate self-designed handloom (RRF) which has an overall dimension of 1000 mm x 540 mm x 191 mm (L x W x H).
- c) The fabricated Recycle Roving Fibre kit will be produced using low cost materials.
- d) To produce a recycle mat using Recycle Roving Fibre kit.
- e) To laminate the recycle woven mat and comercial mat using hand lay-up technique.
- f) Tests will be conducted in accordance with ASTM standards to compare the mechanical and physical properties between woven recycled mats and woven commercial mats using impact, flexural, density and water absorbtion tests.
- g) The results obtained from the tests are analyzed by comparing their properties and discussed to make a conclusion.

1.5 Rational of Research

In the rationale for this research, there are various important measures to examine,

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- a) In the composites industry, mostly the roving waste generated by the machine pultrusion process being disposed of through landfill, instead it can be reused by converting it to another product such as in the form of a woven mat.
- b) Recycle Roving Fibre Kit is another new alternative to overcome the problem of recycling waste to reduce roving fiber waste for pultrusion process in the composite industry by introducing user -friendly recycle roving fiber kit without involving much cost, energy and environmental pollution.

- c) Produce and generated advanced research based on experiments and technical research by converting pultrusion process material waste into reusable materials.
- d) To be studied comprehensively so that this study serves as a reference point for future analysis by making this model to researchers to develop large-scale machines.

1.6 Thesis arrangement

The major purpose of this research is to investigate the waste problem from pultrusion machines by converting the waste into a fibre mat that can be reused and reduced in cost utilising the Recycle Roving Fiber kit (RRF). Chapter 1 is primarily concerned with the study's introduction, which comprises the background, problem statement, objectives, scopes, research rationale, a synopsis of the methodology, and the thesis arrangement. For Chapter 2, Analysis of literature relevant to previous studies including introduction of loom and composites whereas containing reinforcement types, synthetic fibres, fibre forms and roving, composite laminated, applying a review of mat weaving patterns from synthetic fibres is also included. Otherwise, the description of the physical and mechanical testing is included. Followed by Chapter 3 as the methodology used in this research to explain proper process flow and methodology is used to produce RRF kits and recycling mats of different weaving patterns using roving waste. These methods include preparation of raw materials, manufacture of products and testing with standard tests namely impact test, flexural test and density test and water absorption. Data from of the experimental results are gathered and analysed in Chapter 4 for data analysis. The results of several types of testing would be analysed and discussed.

CHAPTER 2

LITERATURE REVIEW

This chapter is an overview of theory and knowledge based on the previous researchers, related to a study on roving fibre waste to be generated by the Recycle Roving Fibre kit. This work was done to investigate the potential use of commercial woven mats so that they can be compared with recycled woven mats.

2.1 Introduction of Loom

A handloom is a machine or device that produces woven fabric and is constructed of wood and iron (to some extent) is analyzed by Islam and Hossain (2015). In addition, according to author handlooms are typically powered by a man's hand and foot, instead of an electronic motor. A loom, in other words, is a device or equipment that is used to weave yarn and thread into textiles. Looms come in several of sizes. They come in Manual/hand loom, Conventional power loom and modern loom. Raina et al. (2015) added that the basic weaving principle illustrates Figure 2.1, which consists of two yarn families, warp and weft, that are brought together to make a fabric. At the rear rail, the warp threads are taken from the warp beam and guided into the weaving plane.



Figure 2.1: A weaving loom's principle (Engin, 2009) 19

Study by Hani et al. (2013) found that Shedding, picking, and beating are the basic operational concepts for interlacing yarns to make textiles on any type of loom. Shedding is the process of opening vertical (warp) yarns in order to allow horizontal (weft) yarns to enter and heddles part is designed for this specific function. Weft insertion of yarns or carrying yarns across the loom, on the other hand, was referred to as a "picking" mechanism. For basic handloom, a 'shuttle' mechanism was generally used to assist with picking. Beating was the last step in the weaving process. Beating allows in-coming weft yarns to produce fabric by staying close to the other weft yarns and this is what a'reed' or a 'comb' was made for.

According to a Engin (2009) the shedding process is important for deferring the pattern of the generated fabric, and it may be divided into two types: fixed and programmable shedding. Heald or heddles frames move in the opposite way for fixed shedding, bringing all yarn to the respective frame and this creates a pathway for the shuttle to interweave the yarns together. In contrast to programmable shedding uses loose heddles that can only be moved according to a programmed programme.

The simplest method of picking or wefting is to manually move the shuttle over the warping yarns. The motion of the shuttle is propelled by various mechanisms such as pneumatic or hydraulic drives in advanced designs. The finding is consistent with findings of past studies by Islam and Hossain (2015), which the thickness discrepancies in natural fibres, the author used a shuttle handloom for weft insertion and fabric is formed by the beating process. As highlighted by author, larger reed sizes resulted in porous textiles, whereas lower reed sizes led in increased friction between the reed wire and yarns, resulting in hairiness and loose warp yarn tensioning as shown in Figure 2.2. Author added that the another factor to consider is the reed's balance pulling force, as any uneven force

during the beating process might result in a fabric with excessive porosity and fabric disorientation.



Figure 2.2: Weaved fabric failure (Islam and Hossain, 2015)

Since the Industrial Revolution, there have been several complicated weaving loom mechanisms and equipment designed for mass manufacturing. Despite the development of various machines, the basic of the weaving principle remains within the three processes outlined been applied so far mentioned by several researchers. Therefore, based on previous studies, it is understood that the basic concept used by the weaving machine as Islam and Hossain (2015) will be applied in the construction of the RRF self-handloom kit. Reed or comb parts also should be taken into account to avoid problems to the resulting textile.

2.2 Composite Material

Composites are materials made up of two or more materials that have been mixed together but remain distinct and identifiable (Park and Seo, 2011). Composite materials are generally made up of two phases: reinforcement and matrix, which have differing characteristics (Sharma et al., 2020). According to Park and Seo (2011) found when two different materials are combined, a new form of composite is created with structural properties that vary from the original components that are different from the original components thus producing a product that achieves physical, chemical and other performance.

The mechanical and physical features of the composite's components, such as low weight, high strength, high corrosion resistance, high stiffness, high impact resistance, extended fatigue life, and superior thermal conductivity, are desirable benefits (Priyanka et al., 2017). Koohestani and Bashari (2020) pointed out that composite materials are well-known for their excellent strength-to-weight ratio. The weight, strength, stiffness, thermal expansion and fatigue resistance of composite materials, steel, and aluminium are all compared in Figure 2.3.



Figure 2.3: Traditional monolithic and composite materials are compared (Tamizharasan et al., 2019)

To summarise, composite materials are the lightest among other materials while yet providing a significant mechanical advantage. Table 2.1 provides further information on the characteristics of fibres and traditional materials. Therefore, as shown in Figure 2.4, the rising demand for high-strength and lightweight materials has driven composites to develop in the worldwide market.

Material	Tensile modulus (E) (Gpa)	Tensile strength (σ)	Density (ρ) (g/cm ³)	Specific modulus (Ε/ρ)	Specific strength (σ/ρ)
E-glass	72.4	3.5	2.54	28.5	1.38
S-glass	85.5	4.6	2.48	34.5	1.85
Kevlar 49	240	1.3	1.83	131	0.71
Steel	210	0.34-2.1	7.8	26.9	0.043-0.27
Aluminium alloys	70	0.14-0.62	2.7	25.9	0.052-0.23
Tungsten	350	1.1-4.1	19.30	18.1	0.052-0.21
	1.5				

Table 2.1 Fibre and conventional material properties (Naik, 2011)

Based on Figure 2.4, Onuegbu et al. in 2011 summarized that composites materials utilized in transportation (car panels, bumpers, engine components, ducting, and fuel), aerospace (bulk head and floor, landing gear door, rotor blade, satellite structure, cargo liner), and boat decking, among other things (Boat hull, submersible pressure hull, propeller, shaft), Architecting (pipe system, power transmission drive shaft storage tank, air duct work, pressure vessel), Sporting events (bike frames, canoe, finishing rods, ski poles, racquets surf band), Both for health (artificial teeth) and for home use (shower unit, furniture, sanitary wear, bath).



Figure 2.4: Shows the global distribution of composite materials (\$ million) by market sector in 2017. (İşmal and Paul, 2017)

A composite material contains three phases: matrix, filler/reinforcement, and interface. The interaction and composition of all three phases has an impact on the performance and qualities of composite materials (Bingham, 2015). Polymer matrix composites (PMCs), Metal matrix composites (MMCs), and Ceramic matrix composites (CMCs) are the three classes of a matrix, according to Mistry and Gohil (2017) in the composite as shown in Figure 2.5.



Figure 2.5: Categorization of composites based on matrix material (Ibrahim et al., 2015)

Sharma et al, (2020) stated that the characteristics of composite materials are influenced by the reinforcements and matrix used for composite. It is necessary to utilise matrix to keep the reinforcement together in order for it to maintain the correct form. Polymer matrix (PMC) composites are the most prevalent matrix utilised in the composite industry. Fibres reinforced with polymer matrix composites (PMCs) are progressively replacing traditional materials, according to Fallahi et al, (2020), because to their high stiffness, superior fatigue, light weight and corrosion resistance. According to La Rosa and Cicala (2015), thermoplastics and thermosets are two types of polymeric matrices; thermoplastics can be melted and solidified and moulded, but thermoset materials cannot be re-melted or reformed once polymerized as shown Table 2.2 based on bond type and detailed classification.

 Table 2.2: The most common polymers used as composite matrix (Yashas Gowda et al., 2018)

Thermoplastics	Thermosets
Nylon	Phenolic.
Cellulose acetate	AL MALAYSIA Epoxy
Polystryrene (PS)	Polyester
Polypropylene (PP)	Polymide
Polycarbonate (PC)	Polyurethane
Polyvinyl chloride (PVC)	
Polyester-ether ketone (PEEK)	
Acrylonitrile-butadiene-styrene (ABS)	

2.2.1 Type of reinforcement

The matrix must be reinforced for the composite component to be complete. According to Qin et al, (2015) reinforcing materials' principal role is to enhance stiffness and considerably hinder fracture progression. They specifically enforce the matrix's mechanical properties by providing reinforcements that are tougher, stronger, and stiffer than the matrix alone. The Figure 2.6 below show several types of reinforcement in general.



Figure 2.6: Different forms of composite reinforcement: (a) particles, (b) short fibres, (c) continuous fibres, and (d) plates (Pastuszak and Muc, 2013)

Arumugaprabu et al, (2018) citing earlier studies, indicate that reinforcing material is added to the matrix material to improve the physical characteristics of the final composite material. According to the researcher aramid, glass, carbon, and Kevlar fibres were utilised as reinforcement for the matrix material, despite the fact that synthetic fibre offers several desirable features such as high strength, stiffness, wear resistance, and fatigue resistance. There are also significant drawbacks, such as high cost, low recyclability, and biodegradability which limit the use of synthetic fibres by researchers. Owing to environmental factors and other factors such as biodegradability, synthetic fibre reinforced composite materials lost market share in the quest to replace traditional materials.

2.2.2 Synthetic fibre composites

Synthetic fibres are commonly used in textile and other applications that need tenacity, abrasion resistance, chemical resistance, durability, and cheap cost (Karthik and Rathinamoorthy, 2017). Because of these characteristics, the cheap cost of synthetic fibres cannot be guaranteed in the future due to rising raw material, energy, and transportation prices.

Salit et al. (2015) mentioned that FRP tanks, aircraft components, vehicle parts, and building panels are all examples of high-performance polymer matrix composite products made with synthetic fibre. In support of the findings earlier Sanjay et al. (2015) stated that synthetic fibre composites have been widely employed in aerospace applications due to their lesser weight than metal and ceramic. Moreover, according to Salit et al, (2015), glass, carbon, and aramid are comparable synthetic fibres that are quite popular in the composites industry. The woven types of glass fibre, carbon fibre, and aramid fibre are shown in Figure 2. 7.



Figure 2.7: Plain weave of (a) glass, (b) carbon, and (c) aramid fibres (Salit et al., 2015)

According to Hollaway (2014) the efficiency of any synthetic fibre is determined by measuring the sustained load, weightage percentage of fibres, orientation, and straightness, as all of these main factors can have a significant impact on the mechanical properties of the composite, as shown in Table 2.3. Glass fibre is commonly utilised in applications that need toughness, electrical insulator, and wear resistant material.

Fibre	Density (gm/cc)	Tensile strength (Mpa)	Young's modulus (Gpa)
Aramid	1.40	300	124
Kevlar	1.30-1.44	2900-3620	70-83
Nylon	1.14	54	0.94-3
Glass (E)	2.50	2000-3000	70
Carbon	1.40	4000	230-240
Boron	100 ALAYSIA 2800	285	2.5-2.6
	7.		

Table 2.3: The mechanical characteristics of a variety of synthetic fibres (Begum et al.,2020)

According to Prashanth et al. (2017), aramid fibres were shown to be acceptable for ballistics and as a substitute for asbestos since Kevlar fibres are used in high-performance composite applications that need light weight, high strength and stiffness, damage resistance, and fatigue resistance. On the other hand, carbon fibres have the highest specific modulus and strength of all reinforcing fibres. However, despite the good mechanical properties of the following synthetic fibres, it also has the disadvantage that it is not environmentally friendly as it has non -biodegradable properties and can contribute to the accumulation of existing composite waste.

2.2.3 Form of fibre

There are many on the market have various forms of glass fibre and each form has different uses and properties to be applied to the manufacture of a product that is suitable for the manufacturing process. The issue with the recycle reinforcing forms is how the fibres may be joined. According to the Meyer et al. (2019) single filaments (or fibres) with diameters of roughly 10 microns are seen on a smaller scale. As illustrated in Figure 2.8, the fibres used in composite materials come in a variety of forms. Author identifies for adhesiveness, tows (or strands) made up of thousands of single untwisted filaments can be joined with or without the presence of resin. Yarns, on the other hand, are the twisted tows. Bijwe et al. (2007) identifies prepregs come in a variety of forms, including unidirectional and multi-directional tape prepregs, as well as woven fabric prepregs. In addition, according to author prepregs are suited for hand and machine lay-up since the fibres are wrapped and collimated like a tape.



Figure 2.8: Variety forms of fibre (Ngo, 2020)

To produce fibre preforms, the tows can also be woven together to produce woven textiles, or braided or knitted together to generate fibre preforms is analysed by Meyer et al. (2019). Previous studies have primarily concentrated on modulus of elasticity for forms of fibre and the results showed that unidirectional fibre types in the longitudinal direction and woven reinforcement fibre types in the any direction had the best modulus of elasticity for reinforcement composites (Jweeg et al., 2012). As a result, a stiffer material has a higher value of elastic modulus. After being exposed to a force, stiffness indicates the tendency for an element to revert to its original form. Therefore, to weave roving waste into a typical fabric style, the type of weave is important to take into account in building a recycling mat because the type of weave affects the mechanical properties.

2.3 Roving

The number of fibres in a bundle, also known as roving, tow, or strand, is determined by melting glass in a furnace and then extruding it through a bushing plate with numerous nozzles is analysed by (Zangenberg and Brøndsted, 2015). Venkataraman et al. (2019) noted that multifilament's, which are strands created by a mixture of filaments (filaments) of low fineness (diameter below 10 m) necessary for low bending stiffness, are the beginning material for composites. Besides, the number of cross-sectional fibres in roving varies from 1 to 24k, which thousands are the number of filaments. Generally, glass roving is available in two different forms; direct roving and assembled roving as shown in Figure 2.9.

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Figure 2.9: Direct Roving (L) and Assembled Roving (R) (Cevahir, 2017)

Cevahiret al. (2017) found that assembled roving, the application for this type of roving is for gun roving and SMC (sheet mould compound), while Direct draw roving generally used in filament winding, weaving applications and pultrusion processes using epoxy resins, vinyl ester and unsaturated polyester. Generally the E-glass fibre is employed in roving's because of its resistance to sustained high temperatures of up to 550°C, outstanding electrical insulating capabilities, corrosion qualities, ability to tolerate the main chemical agents, and dimensional stability under extreme humidity and temperature changes (Bingham, 2015). The properties of fibreglass are listed in Table 2.4.

Yarn property	E-glass	S-glass
Tensile strength (Gpa)	3.4	4.5
Initial modulus (Gpa)	72-80	87-90
Elongation (%)	3-4	5.4
Density (g/cm^3)	2.55	2.49

Table 2.4: Typical fibreglass properties (Fiberglass) by (Tam and Bhatnagar, 2016)

Roving's can be found in a variety of applications. For example, Wallenberger et al, (2001) found that roving's used in a spray-up fabrication process, filament winding and

pultrusion are processes that use single-end roving's in continuous form. According to Wallenberger et al, (2001), woven roving is made by weaving fibre-glass roving's into a fabric form, and there are a variety of weave configurations depending on the laminate's needs and will be discussed on the next subtopic which is topic 2.4 typical fabric style.

2.4 Typical Fabric Styles

Kashani et al. (2017) indicated that due to its superior formability and better out-ofplane stiffness, woven fabric reinforced composites have been rapidly replacing unidirectional (UD) fibre reinforced composites in recent years. However, Pujar et al. (2021) have proposed at least two arrangements of strands are required at the right edge corner to another one known as a warp and another one known as a welf course to form the texture of the weave. Weft and warp are interlaced in a repeated woven pattern that might be plain, twill, or satin is analysed by (Kashani et al., 2017). The research study by Li and Goyal (2021) also found a strong woven texture, typically woven in a variety of weaves, widths and loads. Various types of weaving for fabrics are shown in Figure 2.10.



Figure 2.10: Various types of weaving for fabrics by (Pujar et al., 2021)

The research results from Cavallaro (2015) show that weave type choices and CGs can have a positive impact on the spatial and temporal distributions of stress arising from extreme loading events, and that the fibre/ matrix cohesive zone stresses that often trigger delamination's can be minimised. From the book Li and Goyal (2021) states that the type of fabric style Plain weave is usually the most used because it has good resistance to slipping and deviation of the fabric during the laminate process. Similarly, Bijwe et al. (2002) found related to the effect of fibre geometry from glass fabrics consisting of twill, plain and woven using Polyetherimide (PEI) matrix and some additional fillers (PTFE and Cu powder) to produce composites, has observed plain weave can improve PEI wear behaviour by three times and found a low coefficient of friction (reduction of 50% at higher loads compared to PEI and other composites). The study noted twill weave glass fabrics were weak in wear and woven roving showed an increase in wear properties at high loads.

In 1991 Vishwamath et al. Concluded that The draping properties of woven roving made from weaving grade roving are outstanding. They are less costly than conventional textiles since they do not require yarn preparation and do not require heat treatment or finishing because the reinforcement is treated with a size. Each yarn in a plain weave fabric is crimped over and under the cross-yarns. Yarns are utilized where a single curve and flat sheeting work of consistent strength through 360" in the fabric plane are required. Therefore, this study would like to emphasize that yarn-based textiles plain weave fabrics and woven roving are the same type of weave orientation. Figure 2.11 shows the same geometry of the weave pattern between Plain weave and woven roving.



Figure 2.11: Fabric geometry: (a) woven roving; (b) plain weave woven fabric

The thing that differentiates it is that yarn-based textiles have higher strengths per unit weight than roving, and because they're finer, they generate fabrics at the lighter end of the weight spectrum. Weaved rovings are less expensive to make and wet out faster. However, because they only come in heavier texes, they can only make textiles in the medium to heavy weight range, making them better suited to thicker, heavier laminates. Table 2.5 shows that the mechanical properties between weaved glass Woven roving and Plain weave fabric and satin weave fabric. اونىۋىرىسىتى تىكنىكا ملىسىا

Table 2.5: Mechanical properties	between between	weaved glass	Woven roving	and Plain
IINIVERSI-weave	fabric and satin v	weave fabric	FLAKA	

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Poperty	Woven roving composite	Plain weave fabric composite	Satin weave fabric composite
Tensile strength (MPa)	473.00	376.05	383.41
Tensile modulus (GPa)	42.70	47.69	40.50
Flexural strength (MPa)	468.00	210.10	281.22
Flexural modulus (GPa)	42.40	45.50	38.12
Interlaminar shear strength (MPa)	49.50	23.39	25.35

Charpy impact strength ($kJ m^{-2}$)	378.00	254.44	256.26
Barcol hardness number	80-85	59-62	72-82
Density $(kg m^{-3}x 10^3)$	2.01	2.16	2.02

According to the strength test results, composites constructed with plain weave glass woven roving have greater mechanical properties than composites made with plain or satin weave woven fabric. In contrast, it can be concluded that weaved glass Woven roving composites are strength than various type of pattern fabrics due to its composition and the fibre orientation angles. Table 2.6 summarises the research on the potential of weave glass woven roving and various orientation patterns composites.

Table 2.6: Reported work on various of types orientation in composite

Finding	Matrix	Reinforcement	Weave pattern	References
plain weave can improve PEI wear behaviour by three times and found a low coefficient of friction, noted Twill weave glass fabrics were weak in wear and woven roving showed an increase in wear properties at high loads.	Polyetherimide (PEI) matrix	ی سطح MALAYSI	- Twill weave - Plain weave -Woven Roving	(Bijwe et al., 2002)
woven roving fabric gives good results from tests conducted including flexural, tensile, interlaminar shear and impact strength whereas plain weave have higher resistance to wear, lower coefficient of friction and have larger crimp shows compared to woven roving and satin types.	-Phenolic resin	Glass Fibre	-woven roving - plain weave -satin weave	(Vishwanath et al., 1991)
plain weave can provide tensile strength to the specimen compared to the eight satin harness which shows the highest value for Modulus	-Epoxy	- carbon fibre	-Plain Weave (PW) -Eight Harness Satin (8HS)	(Pujar et al., 2021)
Tensile testing composite under various temperature 30°C to	-Unsaturated polyester	-Glass fibre	- Mat chopped strand	Al-turaihi and Hunain,

70°C. The elasticity, tensile strength, and fracture toughness of E-glass woven roving fibre are higher than those of E-glass mat chopped fibre		-Woven roving	(2021)
Examined using three-point bend testing and the findings of this testing indicated that woven roving shows 10% higher of properties than unidirectional composites. Comparison between experimental data and finite element reveals the different of woven glass fibre 2.72% and unidirectional fibre is 0.29%.	- Polyester -Glass fibre resin	- woven roving - uni-directional fibre	SABĂU et al. (2021)

Previous research has shown that emphasise the importance of the selection of fabric weave style for the reinforcement arrangement in manufacture of composites to improve the mechanical properties of the processed components. From the studies reviewed by various researchers, it can be concluded that the mechanical and tribological properties can be altered through the use of different fibre geometries and also show that composites made with plain weave glass woven have better mechanical properties than composites made of different types of woven fabric patterns (plain, satin and twill).

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2.5 Composites Laminate

One of the processing processes used to create polymer matrix composites is hand lay-up is analysed by (Arifin et al., 2014). Avila and Morais in 2005, mentions that the cure might be done in an autoclave, under pressure (vacuum bagging), under compression (pressing), or on air. There are several approaches to evaluate the composite performance, according to Bader (2002). The simplest method, on the other hand, is based on stiffness or strength. According to Bader, the manufacturing process utilised to create the composites has a direct impact on performance. In Bader studies evaluated five distinct processes, including autoclaving, resin transfer moulding (RTM), resin film infusion (RFI), pultrusion, and compression moulded sheet. Furthermore, the process must be chosen not only based on the materials utilised, but also on the component geometry, size, and mechanical qualities required. Mostly the laminated fibre-reinforced composite materials are widely used in the marine industry, ducting and piping industries, and many other industries due to their good environmental resistance, better damage tolerance for impact loading, and high specific strength and stiffness studied by (Faizal et al., 2008).



Figure 2.12: The processes involved in producing polymer matrix composites sample

Several studies have revealed that the composite laminate process described by Arifin et al. (2014) and Faizal et al. (2008) are shown in Figure 2.12. The preparation of sample fibre mat and resin for the utilization of the hand lay-up techniques is shown in the Figure 2.13. As describe by previous researchers begins with resin being placed to the surface of the mould, then a layer of fibre mat is placed down, followed by liquid resin. Author describes, usually this process uses brush or spiral hand rollers to eliminate voids trapped in the fibre structure and to spread the resin uniformly throughout the fibres.



Figure 2.13: The illustration of hand lay-up technique.

According to Arifin et al. (2014) the curing period of composite laminate employing an epoxy resin is 23-24 °C, roughly 9-12 hours, and the samples are exposed to typical ambient conditions. This method was used to make a coupon sample of a composite laminate with epoxy and glass fibres. Finally, using a grinding machine, the samples are cut out and tested according to ASTM standards.

Early studies by Onuegbu et al. (2014) has demonstrated that study in the preparation of composites using hand lay-up technique and noted with the increase in the number of plies and resulted in tensile strength and tensile modulus also increased. This is also followed by an increase in the number of plies on the tensile strength showing an increase at the beginning and the subsequent addition will be able to decrease the tensile strength. Similarly, Al-turaihi & Hunain, (2021) provides in-depth analysis of the work of tensile testing on E-glass/unsaturated polyester that using two form of fibre (mat chopped strand/woven roving) found that increasing the laminated layers for the same type of fibre will enhance the modulus of elasticity, tensile strength, and fracture toughness of the composite independent of fibre orientation. Therefore, past studies have shown that the number of different layers of plies and orientation will affect the mechanical properties of a product. Therefore, it is up to the researcher to determine the total number of plies used for the study.

There have been several studies in the literature reporting most types of resins used to make laminated reinforced fibres are polyester, vinyl ester and epoxies. Strength, modulus, adhesion, cure shrinkage, and water absorption are all varied on this type of resin. Rassmann et al. in 2011 discovered polyesters are the most often used resins for fibre reinforced plastics because they are affordable, simple to use, and have strong mechanical qualities such as impact resistance. However, they have drawbacks such as poor adhesion and high cure shrinkage. Epoxy resins offer good mechanical properties, minimal cure shrinkage, good adhesion, and compatibility with a wide range of fibres and other materials. Properties of the three resin systems are shown in Table 2.7.

Table 2.7: Properties of various resins (Rassmann et al., 2011)

Property	Unit	Polyester	Vinyl ester	Epoxy
Tensile strength	Mpa	69	86	73.3
Elastic modulus	Mpa	3800	3200	3470
Elongation at break	%	2.3	5-6	4.5
Density	Kg/m ³	1140	1140	1139

Therefore, based on the findings of the study Epoxy resin is the best in terms of cost and mechanical properties to be used on recycling mats for the preparation of samples for testing.

2.6 Mat/Fabric Application

Due to its unique properties, fibreglass mats or textiles are used in a variety of areas. The fibreglass mat and fabric market is in high demand around the globe due to the numerous properties that include being strong and corrosion resistant, making it a viable alternative to metal as it can reduce weight, and it is commonly used in car parts, water infrastructure, aerospace and many more. The usage of fibreglass mats and textiles in automobiles is to reduce weight, as the weight of the vehicle accounts for 75% of fuel

consumption. Fiber-reinforced plastic mats and textiles (FRP) may be utilised to generate reduced weight in automobile components since they have several benefits over metal materials, including high stiffness/specific strength, fatigue resistance, and corrosion resistance. Glass Fiber mats and textiles are also becoming more popular in the automobile sector since they are low-cost, recyclable, and have the largest capacity analysed by (Kashani et al., 2017).

According to Hollaway (2014) the employment of mats and textiles in the environment, particularly pipelines, has shifted away from metal and toward composite materials. This is due to the fact that metal is readily rusted, which can decrease the product's life and necessitate the costly replacement of corrosion-resistant metal parts. Finally, fibreglass is utilised for two components known as nacelle and blade in the wind power industry, which is the largest user of composite materials. The nacelle component sections serve as housing coverings for the gearbox, generator, and drive train, protecting them from the weather. Due to their strength, corrosion resistance, and light weight, both of these components are composed of fibreglass textiles and mats.

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2.7 Testing

Composites are becoming commonly used in a variety of industries due to their light weight and exceptional mechanical properties. Mechanical testing for composite materials is important, to understand their strength and durability, as well as to determine whether the material is suitable for its intended purpose. The ASTM specification is typically used as a guide for composite mechanical testing. Therefore, all research specimens must be thoroughly tested in terms mechanical and physical of different testing such as flexural, impact, density and water absorption is required to determine its performance.

2.7.1 Testing of flexural

The mechanical properties of resin and laminated fibre composite materials are determined by flexural testing is analysed by (Mehndiratta et al., 2018). However, both rigid and semi-rigid materials can be tested using these techniques. According SABĂU et al. (2021) that both polymer matrix composites and woven composites have their flexural properties measured experimentally using three-point tests according to ASTM D7264. In comparison to ASTM D790, a three-point flexure for plastics, which utilises a standard 16:1 span-to-thickness ratio, this test technique employs a standard 32:1 span-to-thickness ratio. The composite plates were made using a manual lay-up approach. Five samples as shown in Figure 2.14 were cut from each composite plate to determine the mechanical properties during flexure testing.



Figure 2.14: Bending specimens for testing (SABĂU et al., 2021)

According to manufacturing and testing standard ASTM D7264, it has dimensions of 84 mm length x 13 mm width x 4 mm thickness, whereas polymer matrix composite materials are suited for this approach. The universal testing machine Instron 1196 was utilised, and the speed for three-point bending tests was set at 1 mm/min, with no protection supplied to the ends of the specimen. Figure 2.15 shows how the specimen is simply supported on both ends, with the test machine's punch positioned in the middle of the space between the support points.



Figure 2.15: Sample that has been flexural tested (SABĂU et al., 2021)

Hence, bending tests of composite materials are useful as an alternative or additional method for determining tensile and compressive properties, where visual inspection of failure behaviour and analysis of medium bending stresses allow the use of bending strengths to calculate recycled mat strength values. Therefore, glass roving waste from the pultrusion process can be applied to recycling mats so that the material that should be discarded can be turned into something else that can be beneficial.

2.7.2 Testing of impact strength

The charpy impact test is performed to evaluate the resistance of plastics to breakage by flexural shock according to standard test method ASTM D6110 Is analysed by (Memon et al., 2019). It shows how much energy is required to shatter standard test specimens under certain specimen, mounting, notching, and swing velocity at impact circumstances. Many aspects influence impact qualities, matrix type, ductility matrix, fibre type, fibre architecture, fibre orientation, fiber-matrix consistency interaction, laminar thickness, and arrangement pattern. For the composite physical components, it's also crucial to consider the panel's geometry and dimensions, as well as the limitation conditions and impact geometry.



Figure 2.16: Illustration for charpy impact test. (Valarmathi et al., 2021)

According to an investigation by Memon et al. (2019), the impact of the pendulum is released on the test materials used to estimated impact properties such as impact strength and energy absorption. In addition, the surface of the test material hit by the pendulum is opposite to the notching part as shown in figure 2.16. Therefore, to make comparisons across commercial mats, this test is necessary to assess whether recycled mats can withstand the impact forces required to break polymer composite specimens, as well as the amount of strength or energy the specimen absorbed to the breaking point.

2.7.3 Testing of density

Recently, Hashim et al. (2017) gave a comprehensive review on the density of the material must first be established in order to quantify the weight fraction and volume fraction of fibre and matrix in produced composite laminates. The density test is performed according to ASTM D792 guidelines. Figure 2.17 illustrates how the composite laminates are chopped into small pieces, tied with a string, and submerged in distilled water.

Figure 2.17: Composite material density test (Hashim et al., 2017)

The amount of distilled water must be sufficient to thoroughly submerge the item, and the substance must not touch the water container's bottom. The density of the composite material may be calculated assuming that the string's weight is minimal. Meanwhile, the final weights of the laminates are measured after they have been fully cured to calculate the fibre weight fraction Wf and fibre volume fraction Vf. Equation 1 is used to calculate the weight fraction of fibres, where wf and wc refer to the mass of the composite laminate and the mass of the fibres, respectively. Using Equations 2 and 3, the volume fraction of fibres, Vf, is calculated using the weight fraction of fibres obtained. The volume percent of the matrix in composite laminates is denoted by Vm.

$$W_f = \frac{w_f}{w_c} \qquad (1)$$

$$V_m = (1 - W_f) \frac{\rho_c}{\rho_m} \qquad (2)$$

$$V_f = 1 - V_m \qquad (3)$$

Figure 2.18: Formula to calculate density (Hashim et al., 2017)

2.7.4 Testing of water absorption

The study by Dan-mallam et al. (2015) described the water absorption test step by step to determine of the relative water absorption rate and the percentage water absorption of fully composites saturated specimens. Based on this studies, following moisture content measurements, the oven-dried specimens were utilised to perform a water absorption test according to ASTM D570 requirements. As indicated in Figure 2.19, the specimens were put in a jar containing distilled water and kept at a temperature of around 24°C.

Figure 2.19: Fully composites saturated specimens in distilled water (Dan-mallam et al., 2015)

Each specimen is taken from the distilled water after every 24 hours, wiped dry using a dry towel to eliminate any surface moisture, and weighed to the closest 0.0001 g. This method was performed for 6 days in a row until the composites were completely saturated. The difference between the weights of fully saturated specimens and the weights of dry specimens was used to compute the % water absorption and the weight changes are documented so that they can be studied to identify the amount of water content in the materials. Hence, this test is important to determine the properties of recycled mats whether swelling on the specimen composite due to water absorption can have a negative impact on the mechanical properties of the composite material.

2.8 Summary

This chapter compiles information and knowledge related to this research from previous studies, including theoretical elements, to serve as a guide and reference for better understanding of looms and composites. There have been several complicated weaving loom mechanisms and equipment intended for mass manufacture since the Industrial Revolution. Despite the advancement of numerous machinery, the three essential operating ideas for interlacing yarns to create textiles on any type of loom remain the same: shedding, picking, and beating. Based on previous studies, things to take into account when fabricate self-design hand-loom, larger reed sizes resulted in porous textiles, whereas lower reed sizes led in increased friction between the reed wire and yarns, resulting in hairiness and loose warp yarn tensioning. According to previous research, because this manual/hand loom uses basic operations, the Heddle used for shedding process can only produce one weaving pattern on the fabric and this is different to Conventional power loom and modern loom machines can produce different weaving patterns of fabric because using programmable shedding can loose heddles that can only be moved according to a programmed. The heddle part of the self-design hand loom is crucial since it determines the weaving pattern that will be produced.

As a result, prior researches were reviewed in order to determine the mechanical and physical properties of the types of weaving patterns to be used in RRF kits in this study. Therefore, Table 2.8 elaborated the application of typical fabric style. Unfortunately, there are no studies examining the glass fibre roving waste that is reused for weaving patterns. On the contrary, most of the studies as shown are more towards testing the weaving patterns of commercial mats to compare and to find out the mechanical properties. Based on the different weaving patterns of commercial mats, it is found that plain weave woven roving has good mechanical and physical properties as shown by SABĂU et al. (2021) and Al-turaihi & Hunain, (2021).

Finding	Matrix	Reinforcement	Weave pattern	References
plain weave can improve PEI wear behaviour by three times and found a low coefficient of friction, noted Twile weave glass fabrics were weak in wear and woven roving showed an increase in wear properties at high loads.	Polyetherimide (PEI) matrix	Glass Fibre	- Twill weave - Plain weave -Woven Roving	(Bijwe et al., 2002)
woven roving fabric gives good results from tests conducted including flexural, tensile, interlaminar shear and impact strength whereas plain weave have higher resistance to wear, lower coefficient of friction and have larger crimp shows compared to woven roving and satin types.	-Phenolic resin	Glass Fibre	-woven roving - plain weave -satin weave	(Vishwanath et al., 1991)
plain weave can provide tensile strength to the specimen compared to the eight satin harness which shows the highest value for Modulus	-Epoxy TEKNIKAL	- carbon fibre	-Plain Weave (PW) -Eight Harness Satin (8HS)	(Pujar et al., 2021)
Tensile testing composite under various temperature 30°C to 70°C. The elasticity, tensile strength, and fracture toughness of E-glass woven roving fibre are higher than those of E-glass mat chopped fibre	-Unsaturated polyester	-Glass fibre	- Mat chopped strand -Woven roving	Al-turaihi and Hunain, (2021)
Examined using three-point bend testing and the findings of this testing indicated that woven roving shows 10% higher of properties than unidirectional composites. Comparison between experimental data and finite element reveals the different of woven glass fibre 2.72% and uni- directional fibre is 0.29%.	- Polyester resin	-Glass fibre	- woven roving - uni-directional fibre	SABĂU et al. (2021)

Table 2.8: Summary of previous researcher	Table 2.8:	Summary	of previous	researcher
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CHAPTER 3

METHODOLOGY

3.1 Introduction

The right planning and techniques employed in this research are discussed in Chapter 3 to ensuring that all of the objectives are achieved. This chapter explains the materials utilized, the designs, the fabrication method, the related experimental testing, and the research analysis. All of the processes in this study are guided by the American Society for Testing and Materials (ASTM), which comprises standard testing methodologies, equipment, and techniques. The research started with the design and raw materials, followed by the preparation method and related testing. The materials for the Recycle Roving Fiber Kit were chosen after the design was created using SolidWorks software. After the Recycle Roving Fiber kit is fabricated, weaving patterns such as plain weave is woven from the glass roving waste using the RRF kit to convert the waste into recyclable mats. Epoxy resin was used as matrix, followed by the hand lay-up technique which is to form a reinforced composite. Then after it cured, the sample will be cut into specimens that follows all dimension guidelines using ASTM Standard. Next, mechanical tests which are tensile tests, flexural tests, water absorption test and density tests based on the ASTM standard will be carried out. Specimens representing recycled mats to be compared between specimens representing commercial mats will be tested and conclude all findings in this research. For future improvement and innovation, the conclusion and recommendations are documented. Figure 3.1 shows the entire course of this study in a flow chart.

Figure 3.1: Flow chart of methodology

3.2 Fabrication of Recycle Roving Kits (RRF)

Figure 3.2: Design of Recycle Roving Fiber Kit (RRF)

The design for this RRF kit was created based on past studies made. The RRF kit is designed using 3 basic operations such as shedding, picking and battening that use fundamental operation on any type of loom to convert pultrusion machine glass waste into mats. All 3 fundamental weaving operations are handled by manual actuators in the proposed design. The ability of this RRF kit is to produce fabric with dimensions of 125 cm x 370 cm. The design for this RRF kit was designed through SolidWorks software. The RRF kit's overall dimensions are 1000 mm x 540 mm x 191 mm (L x W x H) is shown in Figure 3.2. The comb is located 410 mm from the front alignment so that the samples produced on the work surface have lengths of about 33 cm and 46 cm in the Y and X axes respectively. The materials used to make this RRF kit are Pallet wood, Perspex acrylic sheet, PVC pipe and screws used as connectors. Part names, part quantities, materials and functions are shown in table 3.1.

Table 3.1: RRF Kit	part information
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PART	PART NAME	QUANTITY	MATERIAL	FUNCTION
1.	Gear Stopper	4	Perspex Acrylic Sheet	To stop the gear from rotate
2.	Main Body	2	Pallet wood	As main part to hold all the components on the RRF kit.
3.	Gear	2	Perspex Acrylic Sheet	To rotate the holder.
4.	Fibre Holder	1	Pallet Wood	Use to loom the Fibre
5.	Comb	1	Perspex Acrylic Sheet	To hold the weaving guide from moving.
6.	Comb Holder	ala and	Pallet Wood	To hold the comb from moving.
7.	Connecting Stick	6	White Postal Rubber Band	To hold stick from moving.
8.	Stick Stimm	2	Pallet Wood	To tie the fibre
9.	Holder .	کل مليس	PVC pipe	To hang the fiber roving when process looming.
10.	Connecting RS Main Body	ITI TI2KNIK	Pallet wood YSI	To make the kit more stable

Figure 3.3: Dimension of RRF kit

3.3 **Raw Material for RRF Kit Fabrication**

Materials or components will be chosen for this topic based on their suitability and use in making a complete and fully working product. Cost, physical properties and mechanical properties will all be considered when establishing all of the goals to be met. All of these factors are taken into account as much as possible when choosing the amount and kind of material to be utilised depending on the design. This selection procedure is carried out with the goal of preventing the use of erroneous and inappropriate resources, which would be a waste. This is to guarantee that each process flow runs smoothly and according to plan. The table below shows the selection of materials that will be used in the construction of this RRF kit.

Table 3.2: Material used in fabricated of RRF kit

Name	Description	Image
		* 1

Pallet wood is a low-cost alternative to Pallet Wood

> other woods since it is both lightweight AMELAKA and readily shaped to the desired shape, as well as having tremendous strength to bear bigger and greater loads. PalletXpert provides a wooden pallet measuring 20mm (H) × 400mm (W) x 1975mm, which costs RM 60 and is utilised for the main body of the RRF kit.

PVC pipe PVC pipes are more popular than other pipes due to their strength, low cost, and low energy consumption when compared to galvanised steel pipes. If used with steel pipe, the RRF kit holder will add weight and even require high cost as well as use a large amount of energy to shape it to the desired length. As a result, using PVC pipe on the roving fibre holder saves money and makes it simple to shape to the appropriate length. The holder is made of PVC pipe that is one metre long and five inches in diameter. This pipe's dimensions are priced at RM 5 and are supplied from

Sekupangmen vendors.

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PerspexPerspex Acrylic Sheet come in a variety ofAcryliccolors, sizes and thicknesses. It is clearSheetand hard suitable for making the weaving
guide part because it is transparent and
durable. The Comb part will also use
perspex material but with a thick thickness
so that the stopper part is not easily broken
as this part receives a lot of load to
promote the separate of the roving fiber

during the weaving process. The Comb part material is perspex size A2 (420mm x 594mm x 5mm) and costs Rm46, whereas the gear part will use the same sized perspex but has a different thickness of 10mm which is priced at RM105 distributed by Shopexcat supplier.

Screw Screws will be used to join the RRF sections of the kit as they're more stronger than nails, which might loosen when the connected material expands or shrinks, which happens a lot with wood-based materials. As a result, the screws come in a variety of sizes and thread patterns that are specially suited for wood. Using the

proper sort of screws may help boost the

long-term strength of the wood. To joining the wood material for the body of the RRF kit using screws of size (4 x 25 mm) and (4 x 45mm) with phlips heads priced at rm 3.00 provided by Maju Quality CSK supplier.

Nylon cableThe options for the use of this nylon cabletightare strict due to its strong ability and ease

of installation. The elastic nature of this tight nylon cable is able to provide tension to the roving Glassfiber during the embroidery process for prevent the fibers sagging during the weaving process. This Nylon cable tight will be purchased at the Turbot6 supplier at a price of RM 6.60 for 50pc in one pack.

3.4 Raw Material Preparation for Recycle Mat Fabrication

It is important to prepare the raw materials in order to provide a higher-quality result. Waste glass roving, the technique of weaving according to the weaving pattern, and the binder system also were used in this study to prepare the raw materials. The matrix was Epoxy and the reinforcing was waste glass roving from the pultrusion process. It will go into the specifics and properties of each raw material utilised in this study in great depth. The raw material's size and quantities would be detailed later. Following that, the epoxy resin preparation will be detailed. The fabrication method employed in this study is based on earlier research and is proposed as a result of this research.

3.4.1 Glass roving

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Fiberglass Roving is a discrete strand made up of a single bundle of continuous filaments as shown in Figure 3.4. The chemistry on each strand of fibreglass supports the mechanical properties and excellent processing. Many resins, such as vinyl ester, polyester, and epoxy resin, are compatible with it. This material is widely utilised in the filament winding and pultrusion industries, and it may be employed in a variety of textile applications. Pultrusion process, raw materials like roving will usually end up as waste in the composite sector as shown in Figure 3.5. The most common approach to dealing with this waste in industrial composites is disposal. This type of disposal, if not correctly handled, might pollute the environment since this roving is a synthetic substance that is non - biodegradable, whereas the composite industry needs substantial expenses to treat waste by following the Malaysian government's waste schedule.

Figure 3.4: Glass fibre roving

Figure 3.5: Waste of glass fibre roving from pultrusion process.

As a result, roving waste is necessary for this study to convert roving waste to recycling mats and will be given by the institution Kolej Kemahiran Tinggi Mara Masjid Tanah (KKTM) since this institute has a pultrusion machine that is utilised as a learning model for students. This roving waste will be converted into plain weaving patterns using the RRF kit. Subtopic 3.5 will go through the process of converting waste into recycled mats for these various weaving designs in great depth.

3.4.2 Epoxy and hardener

A resin and a curative are the two most important components of an epoxy system. According to Saba et al. (2016), one of the resins that arise from thermosetting matrix is epoxy, which is known to include at least one additional epoxide group in the molecule. Epichlorohydrin molecules combine with bisphenol A to form the most mutual glycidyl epoxy resins (BPA). Epoxies are commonly combined with a combination of co-reactants, curing agents, or hardeners. Epoxy resins, according to Gu et al. (2016), have great mechanical properties, great thermal and dimensional stability, cheap cost, and are simple to produce. The ratio of Epoxy resin to hardener is 2:1. The weight of the woven mat determines the epoxy potion utilised. The resin is combined with the hardener in the ratios stated before, and the mixture is manually mixed for 4-6 minutes before being applied to each woven fabric.

Figure 3.6: Epoxy and hardener

The epoxy to be used costs RM 150 per kilogramme, however only 2 kg is required for this research. This sort of matrix will be utilised to laminate recycled woven mats and comercial woven matsto produce ASTM specimens for tensile, flexural, density, and water absorption tests to compare the mechanical and physical properties of commercial and recycled woven mat. According to Arifin et al. (2014) the curing period of composite laminate employing an epoxy resin is 23-24 °C, roughly 9-12 hours.

3.5 Development of Recycle Mat

Plain, basket, twill, leno, satin, and mock-leno are just a several of the weave patterns that have been employed and examined by previous researchers. Among the several weave designs, plain weave is the most suited and durable. The waste glass roving strands are arranged in the weft and waft directions to make a recycling mat where the fibres cross one other. The waste roving glass from the pultrusion machine process is woven into a new product, which is a mat, using the RRF kit. In this study, types of recycled weaving patterns such as plain woven will be created. These weaving patterns were selected and compared with similar weaving patterns for commercial mats to carried out experimental testing in this research.

The RRF kit can weave fibres up to 125 cm x 46 cm for a single stretch of mat weaving pattern over the area of the RRF kit's weaving part, and when the weaving area is filled, the mat will be rolled using a gear to continue weaving. RRF kit utilizes the basic weaving concepts of shedding, picking, and batting to create plain weave mats. Firstly, shedding process in RRF kit where using the comb part to opening vertical (warp) fibre in orders to allow horizontal (weft) fibre to enter. After that, picking process is the fibre holder part is used for Weft insertion of waste roving by carrying it across the loom. The next step, the beating process is used comb to allows in-coming weft fibre to produce mat by staying close to the other weft fibre. These 3 concepts are repeated until a plain weave woven roving recycling mat is produced as illustrated in Figure 3.7.

Figure 3.7: Warp and weft direction of woven roving

3.6 Specimen Preparation

In this study, recycled woven mat and commercial woven mats will be laminated at dimensions of 540 mm x 370 mm using hand lay-up technique. Commercial woven roving mats cost RM 13 per size (1m x 1m) and this study will require 2 commercial mat sizes as shown in Figure 3.8.

Figure 3.8: Plain weave Woven Roving comercial mat.

These recycled woven and comercial mats will be sealed with epoxy in a 2:1 reinforcement to matrix ratio. Silicon spray is sprayed to the mould surface as a release agent, making it easier to demould after the hand lay-up process. Manual hand lay-up is then used to apply the epoxy to the recycle woven mat and comercial mat as illustrated in figure 3.9. Then, the laminated panel will be left to cure 9 to 12 hours and stabilize 23-24 °C. After the panel is fully cured, the panel will be cut for experimental testing according to the prescribed ASTM form for tensile, flexural, density and water absorption tests.

Figure 3.9: Schematic diagram of hand lay-up (Kudachi et al., 2016) 61

3.7 Mechanical and Physical Testing

The purpose of conducting experimental testing is to ascertain the specimen's mechanical and physical properties. Flexural test, impact charpie test, water absorption test, and density test are four related tests. To acquire the finest analytical and interpretative findings, all of these tests were carried out in line with ASTM standards and procedures. The ASTM requirements for each type of test are shown in Table 3.3.

	Testing	Testing Standard
NL MA	Charpy impact	ASTM D6110
Kulle	Flexural	ASTM D790
U TE	Density	ASTM D792
ANT ANT	Water absorption	ASTM D570
ملاك	کل ملبسیا Trast	ونيومرسيتي تيكنيا
ملاك rpy Impac	کل ملیسیا t Test	ونيومرسيتي تيكني

Table 3.3: Testing standard for mechanical and physical testing.

Impact testing determines how many energy a material expends during fractures. This absorbed energy is a measure of the material's hardness and may be used to investigate the temperature-dependent brittle-ductile change. The purpose of this test is to determine if the object is brittle or ductile. The Charpy V-notch test, the Izod test, and the Tensile Impact test are the three most common forms of single impact tests. Charpy impact tests were used in this study to measure the impact absorbed by the reinforced composites. The notches and shape of the specimen for the impact test are shown in Figure 3.10. The sample was then placed horizontal on the Charpy impact equipment, and the hammer is dropped from a height to strike it. Figure 3.11 depicts an Instron impact testing equipment.

Figure 3.10: dimensions of the charpy impact test specimen

3.9 Flexural Testing

Flexure measurements are commonly used to determine a material's flexural modulus or flexural strength. The defined sample's flexural power is the maximum force observed. The specimen is placed horizontally over two contact points (lower support span), and force is applied to the specimen by one or two contact points (upper load span) until the sample fails. A flexure test is often performed before the sample fails, making it ideal for testing fragile materials. Plastics, composites, concrete, and ceramics are the most often tested components in flexing. Because these materials have such a low ductility, they fracture before the sample is permanently deformed, allowing for precise measurement of the flexural module and strength. The flexural test machine is shown in Figure 3.13.

The flexural testing will be carried out using the Universal Testing Machine UTM and the three-point bending technique in accordance with ASTM D790. The goal is to evaluate the specimens' flexural strength and flexural modulus on two supports at a constant speed of 5 mm/min with a typical dimension of support span on RWR and CWR as shown table 3.4 and figure 3.10.

Type of sample	Length, a (mm)	Width, b (mm)	Support span, c (mm)		
RWR	152	28	112		
CWRLAYSI	88	12	48		
اونور سنج Figure 3.12: Geometry for flexural test UNIVERSIT TEKNIKAL MALAYSIA MELAKA					

Table 3.4: Specimen dimensions for the sample type

Figure 3.13: The flexural testing machine

3.10 Density Testing

To measure the weight fraction and volume fraction of fibre and matrix in created composite laminates, the density of the material must first be determined. The density test is carried out in accordance with ASTM D792 standards. The composite laminates are cut into small pieces, tied with a string, and submerged in distilled water according to ASTM standards as shown in Figure 3.15. The amount of distilled water used must be enough to completely submerge the item, and the substance must not touch the bottom of the water container. When the string's weight is small, the density of the composite material can be computed. However, when the laminates have been fully cured, the final weights are measured to determine the fibre weight fraction Wf and fibre volume fraction Vf according to formula. The specimen dimensions for the density test are shown in Figure 3.14.

UNIVERS Figure 3.14: Geometry of density test

Figure 3.15: Testing Specific Gravity

3.11 Water Absorption Testing

Water absorption test is to measure relative water absorption rate and % water absorption of completely composited saturated specimens. The oven-dried specimens were used to perform a water absorption test according to ASTM D570 criteria after moisture content determinations. The specimens were stored at a temperature of about 24°C in a jar containing distilled water as shown in figure 3.17. Every 24 hours, each specimen is removed from the distilled water, wiped dry using a dry towel to remove any surface moisture, and weighed to the nearest 0.0001 g. This technique was repeated five times until the composites were thoroughly saturated. The percent water absorption was calculated using the difference between the weights of fully saturated specimens and the weights of dry specimens, and the weight variations were logged so that they could be investigated to determine the amount of water content in the materials. The dimensions of the specimen for the water absorption test are shown in Figure 3.16.

Figure 3.16: Geometry of water absorption test

Figure 3.17: Water absorption test (a) the specimen is immersed in a container and (b) the specimen is weighed on a scale
CHAPTER 4

RESULTS AND DISCUSSION

This chapter will show and discuss RRF kits fabrication, RWR mat fabrication using RRF kits and the comparative properties of common weave patterns on RWR and CWR based on the test experiments conducted. First, the fabrication process of RRF kit and RWR mat with weaving process using RRF Kit and, then RWR and CWR are reinforced with thermoset matrix. Tests were performed to find out the mechanical properties of RWR and CWR to study and compare the mechanical and physical properties.

4.1 Fabrication and characteristic Recycle Roving Fibre Kit (RRF)

The fabrication process of RRF kit parts uses several methods such as CNC process, and assembly of RRF kit parts. Among the parts of the RRF kit that use CNC machines for the cutting process are the main body, Gear, Gear lock, shuttle, Comb and comb holder. These fabrication parts do not use hand fabrication because it is time consuming, requires high carving skills and is risky to produce inaccurate RRF kit components due to human error. Therefore, the use of CNC 3-axis router machine is selected for the fabrication of RRF kit components due to being able to save time and produce accurate components based on the actual drawing design. The result of RRF kit components that were fabricated using a CNC cutting machine are shown in Table 4.1. However, the CNC machine also has a shortcoming in the component cutting output which shows the Gear produced by the CNC machine is not 100% the same as the design drawing because the lack of CNC machine capability found on its round cutting tool point will

cause the angled area to be radius as shown in the figure. 4.1. However, the shortcomings found in the eyes of these CNC tools do not affect the functionality and aesthetics.



Figure 4.1: The output produced differs between (a) the design and (b) the actual component

As shown in table 4.2 Components of a fabricated RRF kit using a CNC cutting machine marked with a red circle as it was found to leave an excess of uncut parts around an average of 5mm because those parts were the area for clamps to lock the movement of the block during the cutting process. Furthermore, during the design using the Catia software, this excessive part was purposefully left around 5 mm on average to provide space between the tool eye and the clamp during the block cutting operation so that the clamp does not come into contact with the tool tip.

The CNC cutting process may be employed to remove the excessive part, but it will require a re-design of the NC code programmed by just eliminating the part. Therefore, it is not recommended to use a CNC cutting process to remove excess parts on components because creating the NC code design consuming time, whereas cutting the part with finishing processes such as milling or lathes is much easier to produce compared to CNC process because it saves time, the machine is easy to operate, and the process of removing excess parts only involves one axis of the plane surface. Table 4.1 shows the results of the

RRF kit components after the excess parts are removed using a milling and lathe machine to obtain the actual shape of the components.

Part name	Results after CNC process	Results after the finishing process
Gear	Excess part	C
Gear Lock	Excess part	اويوم سيتي
UNIVERS Comb Holder	TYTEKNIKAL MALAY	SIAMELAKA
	Excess part	

Table 4.1: Component results after CNC process and after finishing process

The finishing process for Shuttle, Comb Holder, and Gear lock components requires a milling process to eliminate excess parts, but not on Gear components, which use a lathe cutting process. This is owing to the cylindrical form of the Gear, which makes it unsuitable for milling machine clamps but ideal for lathe machine clamps during the process of removing unnecessary excessive parts as shown in Figure 4.2. As a result, the finishing process involves the use of a lathe or milling machine to obtain the actual product based on the drawing design, and the usage of this machine varies depending on the shape of the RRF kit components.



Figure 4.2: A lathe process is used on the Gear to remove excess parts

Figure 4.3 below is the result after all the component parts of the RRF kit have been assembled. The connection methods for the components used by the RRF kit are screw, epoxy glue and nylon cable tight. Since the main body of the RRF kit, the Comb Holder, and the Gear Lock parts are made of pine wood, the assembly method is screw because it has been discovered that screws hold pine wood better than nails and do not leave any flaws like cracks on the surface of pine wood when applied. Next, the connection between the PVC Pipe and the Gear uses the epoxy glue method. To ensure the adhesion between the surfaces of the adhesive epoxy glue method is strong, the surface area of the pipe and the adhesion gear should be rubbed using sandpaper until the surface becomes rough so that the epoxy glue does not easily pull off or slip. Finally, the stick and PVC pipe are connected using nylon cable tight because it is flexible, sturdy, and easy to repair if it breaks while receiving heavy loads from roving glassfiber tension.



Figure 4.3: Results of RRF kit after the installation

This RRF kit is able to produce a 125 cm x 46 cm RWR mat in 40 minutes. The RRF Kit designed for this study is not intended for fabric production efficiency. In fact, the purpose of this RRF kit is designed to allow easy weaving of complex yarn structures from coarse such as glass roving waste. This RRF kit is user friendly using the basic operation of the main movement on any type of loom to produce RWR mats such as Shedding, Picking and Batting for user convenience. The materials used in the fabrication of this RRF kit use low cost and easily available materials. These three processes are described in subtopic 4.2 in more detail.

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4.2 Fabrication and Characteristic of RWR mat

The looming concept using RRF Kit for the weft and warp directions had been applied in the fabrication of the RWR mat. The fibers used were waste of roving glass fiber from pultrusion machine that oriented on the warp (0°) and weft (90°) directions. The RRF kit has produced 2 samples of RWR mat size of 125 cm x 46 cm length and wide. The basic concepts of looming processes such as shedding, picking and beating for weft and warp direction have been used in the fabrication of RWR samples. The Shedding, Picking, and Battening results shown in table 4.2, are the three main weaving operations used in the RRF kit to fabricate Plain weaving pattern RWR mats. The Shedding process is where the warp threads (ends) are separated by raising or lowering the heald frame (part of the Comb) to form a clear space where the weft (Shuttle) can go through the warp. The picking process is where the weft or pick is driven across the loom by shuttle to produce yarn/roving in the direction of the weft. In this process it was found that the shuttle section is quite narrow when passing between the warps causing the fiber filaments on the thread/roving section to break easily when in contact with the Shuttle as (shown in figure 4.4). The solution is to reduce the filament on the thread/roving break, the Shuttle and Comb design at an early stage needs to be redesigned by reducing the thickness of the shuttle section. While the cavity on the Comb section also needs to be redesigned because the path between warps during the picking process becomes small due to the length of the Comb cavity short.





Figure 4.4: Filament on thread/roving breaks during the picking process

The last basic process of weaving is Battening where the weft is pushed up against the fell of the mat by the reed (Comb part). At the battening process it was found that the yarn/roving filaments were micro -broken and at the end of the weaving process showed clumps of filaments accumulated on the Comb part as shown in figure 4.5. This is possible from the design of the Comb section which has a sharp-angled cavity and fits only for the thread so that there is friction between the Comb section which causes the filament to break. As a result, the Picking and Battening process probably will result in the fabricated RWR mats experiencing a decrease in mechanical properties and this study is similar to Jamal (2017) which states the decrease in flexural strength properties is influenced during the weaving process.



Figure 4.5: Clumps of glass fibre filaments found on the comb section at the end of the weaving process.

As a result of the pultrusion machine disposal process in the composite manufacturing industry has produced waste in the form of roving, and usually this waste will be disposed since there are no further studies that use this waste to be converted into recycle woven mats. Thus the glass roving waste obtained from the pultrusion process is woven into RWR mats using RRF kits resulting in a much cheaper price compared to the price of commercial mats sold at Rm 13 for 1m x 1m. Figure 4.6 Results after weaving process of RWR mats is completed. The samples were fabricated by using RRF Kit weaved into plain weave pattern. The samples for RWR and CWR type were illustrated in Figure 4.7 while table 4.4 exhibited the characteristic type samples between RWR and CWR.



Figure 4.6: Results after weaving process of RWR mats is completed.



Figure 4.7: Samples (a) RWR (b) CWR

Based on table 4.3 shows the results for the characteristic of different mat, area of 2-inch x 2-inch RWR and CWR were taken to differentiate the number of total weft and warp. Weaving type RWR measured a same weft yarn count per 2-inch length as weaving type CWR, 14 yarn/ 2-inch. However, the warp yarn count for RWR is less compared to CWR with 8 yarn/ 2-inch and 11 yarn/ 2-inch respectively. The recorded RWR mat weight was 1469 (g/m^2) high compared to the CWR which was only 600 (g/m^2). This shows that the RWR mat has a heavier weight due to its higher tex compared to CWR mat of 2400 and 1200 respectively. The glass roving waste obtained from the pultrusion process is woven into RWR mats using RRF kits resulting in a much cheaper price compared to the price of commercial mats sold at Rm 13 for 1m x 1m.

	Table 4.3: Characteristic of different mat											
Mat type	Weft Yarn Count (2-inch x 2 inch)	Warp Yarn Count (2 Inch x 2 Inch)	TEX	Mat Weight (g/m ²)								
RWR	14	8	2400	1469 (g/ m^2)								
CWR	14	11	1200	$600 (g/m^2)$								

Based on the observation the number of wefts between RWR and CWR is the same and different on the warp due to the weaver using strong pressure to ensure there is no gap between the weft. Figure 4.8 shows the beating process and the beating process uses a comb to allow in-coming weft fibres to stay near to the other weft fibres, for fabrication a RWR mat. When the weaver exerts too much pressure on the weft during the beating process can result the number of welf will become increased and cause RWR does not absorbed much of the resin as the gap between fibres on weft directions were increased. The effect of this occurs during the panel fabrication process, as shown in figure 4.9, where part of the RWR panel's surface is unevenly exposed to Epoxy resin, resulting in defects that might severely influence the mechanical properties. As a result, to provide a gap between the wefts for RWR mats that are easy to absorb epoxy, the solution is to minimize the pressure force on the comb during the beating process.



Figure 4.8: Shows (a) beating process and (b) the incoming weft and the after weft become close during the beating process.



Figure 4.9: shows the effect of increased weft on RWR cause low resin -absorbing.

In the fabrication process, there were some defects occurred to the fibres such as fibre misalignment, entangled, drafting and spun-in. The defects on the woven samples would been observed and removed from been used for the experiments. Figure 4.10 illustrated defects occurred on sample RWR such as fibre misalignment. The fibre misalignment would affects the performance of the samples. In order to achieve highest performances for each sample, the defected parts would be rejected from the sample. These findings were consistent to the findings from Kalantari (2017) in their research on the fibre misalignment and thickness variation. They proposed that fibre misalignment have a negative effect on the performance of composites and undesired dissimilarity in the consequential mechanical properties.



Figure 4.10: Roving fiber misalignment on RWR sample

4.3 Mechanical and Physical Properties Performance of RWR and RWR composite

The properties of sample RWR and CWR must be determined by mechanical and physical testing of the plain weave pattern reinforced by epoxy in order to compare them for application performance analysis. To evaluate the RWR to the CWR, this was subjected to a series of mechanical tests include flexural and impact and the physical testing includes water absorption and density to determine its strength, properties, and performance. The American Testing and Materials Association (ASTM) is applied to standardized test procedures for all of the tests.

4.3.1 Flexural performance of RWR and CWR composite

The mechanical properties of the RWR and CWR reinforced Epoxy samples were determined using flexural testing. The samples produced for this flexural test were 3 layers of RWR and CWR mats were reinforced with epoxy resin to produce RWR and CWR composite specimens. Composites specimens with dimensions of 152 mm x 28 mm x 7mm for RWR and 88 mm x 12 mm x 3mm for CWR were cut according to ASTM D790, and the average of the samples were recorded. The flexural strength and elastic modulus of the samples were determined using an Instron 150 kN Universal Tensile Testing machine. The flexural test speed was adjusted to 5mm/min, which is a suitable testing speed for standard test specimens.

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4.3.1.1 Comparison of flexural Performance for RWR and CWR reinforced epoxy

Flexural strength of the RWR and CWR samples are shown in figure 4.11. Flexural strength comparisons were made using CWR samples as a benchmark. The maximum flexural strength produced by the CWR sample is around 186.99 MPa. The overall flexural strength of RWR is (93.701 MPa) about half that of CWR flexural strength. There is a 49.89 percent difference in bending strength between CWR and RWR samples, with RWR samples having lower flexural strength.



Figure 4.11: Sample of RWR and CWR reinforced epoxy against flexural strength.

The modulus of elasticity of the RWR and CWR samples are ability of a material to bend is measured by its flexural modulus as shown in figure 4.12. It's the stress-to-strain ratio during flexural deformation, or bending in mechanical terminology. Sample CWR has the highest flexural modulus of 9.362 GPa, compared to RWR's 4.516 GPa. However, sample RWR's differential flexural modulus was 51.763 percent lower than CWR's. The overall flexural modulus and flexural strength achieved best with the CWR samples referenced in Figure 4.11 and 4.12.



Figure 4.12: Sample of RWR and CWR reinforced epoxy against flexural strength.

Since the increases warp and weft in synthetic fibre, Jamal (2017) claims that it can improve flexural properties. The study proved that the high-density number of warp weaves of CWR compared to RWR showed significant differences in flexural strength and elastic modulus at CWR. In addition, the cause that contributes to the decrease in flexural properties may be from the thinning of the RWR mat glass fiberglass due to breakage during the weaving process. Figure 4.13 shows the fiberglass roving residue left on the comb part of the RRF kit as a result of breakage during the beat-up process. This can be support by (Jamal (2017) discovered that weaving processes such as shedding, insertion, and beat-up cause fibre yarn breakage. The continuous process throughout the weaving process caused scrape on the fibre yarn, which impacted the mechanical strength of the composite. These findings are consistent with the findings of previous studies that the mechanical properties of composites are affected by the knitting weaving process, such as fiber braid tension, number of weaving densities of warp yarn layers, and fiber type.



Figure 4.13: Fiberglass residue that breaks during the weaving process of the RWR mat.

4.3.2 Impact performance RWR and CWR composite

The ASTM D6110 standard for epoxy-reinforced RWR and CWR was used to conduct the Charpy pendulum test. RWR and CWR samples were cut to dimensions of 125 mm x 12.7 mm x actual thickness with 45-degree notches, and an average of three specimens for each Layer were recorded. The final dimensions of the Charpy specimen are obtained using a band saw machine during sampling. The Charpy impact test is used to assess how much pendulum energy the sample absorbs when the force is delivered, as well as the composite's failure mode.

4.3.2.1 Comparison of impact performance of RWR and CWR reinforced epoxy

Figure 4.14 and figure 4.15 shows the impact performance of Epoxy reinforced RWR and CWR as an effect of increasing of layer plain weave pattern. From ply 1, plies 2, and plies 3 samples, Epoxy reinforced RWR and CWR exhibited an increasing trend. This trend improvement, according to Yahaya (2014) was attributable to an increased proportion of high-strength fibres that can efficiently transmit impact stress. As shown in Figure 4.14, RWR is the highest absorption energy recorded by 3 plies samples, with a value of 21.721 J and a significant increase of 428.106 percent above 3 plies CWR. This is due to the larger mass weights of fabric and increasing number of plies recorded in the sample, the 3 plies RWR absorbs the most load. With 15,785 J two -plies RWR has the second highest absorbent energy among RWR samples. Compared with the 1 -ply CWR, the 1 -ply RWR sample obtained 3.097 J for energy absorption, and a significant increase of 1185.062%



Figure 4.14: the number of layers of the CWR and RWR samples against impact energy.

Figure 4.15 shows that the 3 plies RWR sample had the highest impact strength, at 200.01 kJ/m2, which was 98.339 percent more than the 3 plies CWR sample. The two - plies RWR occupies the second highest impact strength of 193.417 kJ/m2. Compared with the 1 -ply CWR, the 1 -ply RWR sample obtained 76,877 kJ/m2 for impact strength, and improved by 369.134%. The mechanical properties on increasing the number of fiber plies on CWR and RWR improve the impact performance. the results of this study were found to be similar to the results of the study of Yahaya (2014) with their finding that increased composite glass reinforcement layer can increase impact strength and energy absorption.



Figure 4.15: the number of layers of the CWR and RWR samples against impact strength

Overall, performance for every plies RWR can be noted that the absorbed energy and impact strength were higher than sample CWR reinforced Epoxy. The impact performance of the RWR sample was higher than that of the CWR sample, possibly due to the effect of the thickness of the composite specimen being significant because the RWR yarn was denser than the CWR. The results are supported by Yahaya (2014) who stated that the impact performance is influenced by the sample thickness, fiber content and high void content in the tested samples. The absorption energy and impact strength of one RWR ply sample were 3.097 J and 76.877 (kJ/m2), respectively, when compared to two CWR plies, with a percentage difference of 73.99 percent and 11.54 percent, respectively. Similarly, when compared to the 3 CWR layers, the absorption energy and impact strength of the 2 RWR layer samples were 15.785 J and 193.417 (kJ/m2), respectively, with percentage differences of 283.783 percent and 92.129 percent.

Based on these findings, it can be inferred that 1 ply RWR can absorb more impact and has a greater impact strength than 2 plies CWR. The same goes for the results with 2 plies RWR when compared to 3 plies CWR. As a result, manufacturers can save cost on materials by employing RWR material with low ply to produce a product, because 1 ply RWR has a greater impact performance than 2 plies CWR, and 2 plies RWR has a stronger impact performance than 3 plies CWR.

4.3.3 Water absorption performance for RWR and CWR composite

The ASTM D570 standard for epoxy-reinforced RWR and CWR was used to conduct the water absorption test. The different plies 1, 2 and 3 on each composite's samples RWR and CWR with dimensions of 25 mm x 25 mm were cut according to ASTM D570 specimens. Each sample was soaked in water for 5 days and readings were

taken every 24 hours five times to determine the value of water absorption of RWR and CWR samples.

4.3.3.1 Comparison of water absorption performance for RWR and CWR reinforced epoxy

The water absorption behavior of RWR samples having each ply of 1, 2 and 3 reinforced by Epoxy was determined in terms of weight gain for composite specimens immersed in water at room temperature. The weight percentage increase of the RWR samples of each ply was compared and shown in Figure 4.16. The water absorption behavior ply 1, 2 and 3 of Epoxy composites showed an increasing trend on the first to fifth day. The RWR composite with 2 plies had the lowest water absorption compared to the RWR composite with 3 plies, with a difference in the absorption rate decrease of 13.72%. The findings of this study on 3 plies RWR samples showed an increase in water absorption compared to 2 plies RWR in contrast to Barkoula (2008), which found that when a reinforcement ply was added to the composite, the water absorption rate decreased. This is cause by 3 plies on these RWR samples was found to be probably due to individuals being less skilled on the hand layup process during panel fabrication resulting in a lack of resin moisture between the fiber layers resulting in uneven adhesion. The result gives the effect of delamination where the existence of air bubbles between the plies of reinforcement that affects the increase in water absorption.



Figure 4.16: Shows the water absorption percentage for RWR samples throughout ply 1, plies 2, and plies 3.

Figure 4.17 shows water immersion on the first to fifth day showing an increase in the percentage rate of water absorption in each of the 1, 2, and 3 CWR plies samples. 1 ply exhibited maximum water absorption and the increase in the ply showed a decrease in water absorption, the difference in water absorption in 1 ply compared to 2 ply showed as much as 16.766%. While the difference in water absorption of 1 ply compared to 3 plies showed 37.014%. Therefore, 3 plies on the CWR sample has the lowest absorption rate to water and the findings of this study show similar results to the findings of previous researchers Barkoula (2008). The water absorption ply on the lowest RWR and CWR samples was selected for comparison. It was found that 3 plies RWR is almost the same as the performance of 3 plies CWR with a difference value not exceeding 30% and the percentage of water absorption is at a minimum.



Figure 4.17: Shows the water absorption percentage for CWR samples throughout ply 1, plies 2, and plies 3.

4.3.4 Density testing performance for RWR and CWR composite

This test is carried out at room temperature in accordance with the (ASTM-D792) standard. The RWR and CWR samples were cut into 25 mm \times 25 mm squares, and the measured density (t) was estimated using the equation of the Archimedes base method of immersion in water.

4.3.4.1 Comparison density performance for RWR and CWR

The densities for the RWR and CWR samples are shown in figure 4.18. The CWR sample showed lower density of 1,433 g/cm3 compared to the RWR sample showed a slightly higher density of 1.44 g/cm3, about 0.488 % denser than CWR. It can be seen that higher densities have been found for RWR specimens possibly influenced by RWR mat tex having a higher tex volume of 2400 than CWR of 1200. Therefore, The RWR mat's high Tex value results in a 1469 (g/m2) weight, whereas the CWR mat's weight is merely 600

(g/m2). Overall, the higher RWR density than CWR is due to the heavy weight of the reinforcement mat, and this study is similar to the Hussein (2019) study, which stated that the density of the composite material increases as the reinforcement increases due to the heavier density of RWR glass fibres when compared to the density of CWR glass fibres. This difference possibly as well due to presence of voids and pores in the composites. The observation shows that more voids are found in the composites with the addition of fibre.



4.4 Summary of Analysis Findings

In summary, RRF kit components were selected fabrication through CNC process compared to hand fabrication because it was found to save time and more accurate component results. In addition to the finishing process is chosen compared to the CNC process because it is easy to operate, the time can be shortened because the finishing on the component involves only one plane surface. The RRF kit is designed using 3 basic operations that use fundamental operation on any type of loom to convert pultrusion machine glass waste into mats (RWR) at a production capacity of 125 cm x 46 cm in 40 minutes. Hence, the RRF Kit designed for this study uses low -cost materials and is not intended for fabric production efficiency but allows easy weaving of complex yarn structures from roving glass waste from the pultrusion process. Therefore, RWR mats produce a much cheaper price than the price of commercial mats.

However, the design of the designed RRF kit affects the outcome of the mechanical properties on the produced RWR mat. This is because the design of the main RRF kit components involved in the weaving process gives a tendency to the yarn/roving to suffer micro damage due to not taking into account the design factors. Therefore, make sure the components are involved throughout the weaving process by designing the components to take into account all the elements that can cause the yarn to be damaged. Additionally, when weaving RWR mats on RRF kits, it is important to keep the weaving process controlled to avoid defects that cause weak bonding between the reinforcement and the matrix, lowering the mechanical properties. Therefore, the controlled weaving process can produce high quality performance of RWR weaving mat in terms of mechanical and aesthetic.

The impact test results showing the mechanical properties of the 3 -layer RWR sample were higher than the 3 -layer CWR sample because it is due to the increase of the high -strength fiber section which can transmit the impact pressure efficiently. Based on this study, 1 layer of RWR can absorb more force and has a higher impact strength than 2 layers of CWR. When comparing 2 layers of RWR to 3 layers of CWR, the findings are similar. As a result, the use of RWR can be economical in terms of material and cost because 1 -layer RWR has better impact performance than 2 -layer CWR, and 2 -layer RWR has better impact performance than 3 -layer CWR.

Water absorption on 2 -layer RWR is the best result of 1.68% among other layer RWR but it is almost similar to 3 -layer CWR performance with difference value not exceeding 30%. In the RWR sample, the water absorption of 2 layers was the lowest but in

contrast to the CWR sample, the lowest is 3 layers as it may due to the 3 layer RWR sample being influenced by the material density and void content. The density on the RWR composite showed a yield of 1.44 g/cm3 and it was equal to the density value of the CWR composite with only a small difference value of 0.5% possibly due to RWR mat tex and the presence of voids and pores. The RWR sample yielded almost half of the bending strength and the modulus of a 50%CWR sample. This is due to the number of high -density warp weaves of CWR compared to RWR as well as the thinning of RWR fiberglass mats due to breakage during the weaving process.

Therefore, the RRF kit fabricated in this study is in the early development stage to convert roving waste to recycling mats on a small scale by study its mechanical and physical properties. Overall, RWR mats showed similar results on density and water absorption tests, a significant increase on impact testing and a decrease on flexural mechanical properties. In conclusion, instead of roving waste being discarded and can lead to environmental pollution, it is better to apply RWR mat to something that can reused because its performance can be categorized as good on recycled materials. The results obtained from this test on RWR can be used as a reference for researchers to develop it on a large scale.

CHAPTER 5

CONCLUSION

5.1 Conclusion

This study was carried out to develop a Recycle Roving Fibre (RRF) kit for converting waste glass roving fibre from a pultusion machine into a plain woven type RWR mat. On the same type of plain weave, the RWR mat sample which was woven from the RRF kit and the CWR sample which was a commercial type WR 600 mat, were reinforced by epoxy matrix to make a comparison. In accordance with the objectives, the particular findings and contributions of this thesis are summarized. The first objective of this research is to fabricate Recycle Roving Fibre kit (RRF). The first objectives that can be drawn are:

- i. The Recycle Roving Fiber Kit (RRF) has been successfully fabricated.
- ii. The RRF kit is user friendly using the basic operation of the main
 movement on any type of loom to produce RWR mats such as Shedding,
 Picking and Batting for user convenience.
- iii. The materials used in RRF kit use low cost and easily available materials.
- iv. A 3-axis CNC machine is used for the RRF kit component cutting process as it can save time and produce precise components based on the actual drawing design.
- v. For finishing process, the RRF kit components use milling and lathe process rather than CNC because it saves time and easy to operate.

This research's second objective was to produce fiber mats from roving fibre glass waste resulting from the pultrusion process using Recycle Roving Fibre kit (RRF). For this objective the main conclusion can be drawn:

- i. Converting roving waste generated by the pultrusion process to fiber mat applications using RRF kits has been successfully fabricated.
- ii. The ability of the RRF kit to facilitate the user to weave the roving waste generated by the complex pultrusion process into a 125cm x 46cm RWR mat in just 40 minutes.
- Glass roving waste woven into RWR mats using RRF kits resulting in a much cheaper price compared to the price of commercial mats.
- iv. Sample's mechanical performance is affected by defect such as fiber mismatch and seams which occurs during weaving process.

The third objective of this research was to study the comparison of mechanical and physical properties between recycle mat and commercial mat. Through a set of tests and the results collected, the following conclusion may be drawn:

- Impact strength is increased upon the addition in plies of RWR to 2 and 3 plies compared to 1 ply by 151% and 160% respectively.
- ii. The 3 -plies of RWR sample had the highest impact absorption among the RWR samples which can withstand of 21.721 J whereby it is a substantial improvement of 428.106 % over the 3 plies of CWR.
- iii. The impact strength of 1 RWR ply is 74% improved compared to 2 plies CWR.Similarly, 2 plies RWR have significant increases of 92% impact strength compared to 3 plies CWR. Therefore, impact strength 1 ply RWR is better than 2 plies CWR, as well as 2 RWR compared to 3 CWR.

- iv. Water absorption on RWR 2 plies produces the best result of 1.68% among the RWR layers but it was almost similar to the performance of 3 plies CWR with difference value not exceeding 30%.
- v. On the RWR sample, water absorption of 2 plies is the lowest but contradictory to the CWR sample is the lowest 3 plies. This is due to the sample 3 plies RWR influenced by material density and void content.
- vi. The density on the RWR composite produced a yield of 1.44 g/cm3 and it is equal to the density value of the CWR composite with only minor difference value of 0.5% due to RWR mat tex and presence of voids and pores.
- vii. The 3 plies of RWR samples produced only half of the flexural strength and modulus of elasticity to CWR sample. This is due to high -density warping weaves in CWR. As well as the thinning of the fiberglass mat for RWR due to breakage during the weaving process.

5.2 Recommendation

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Several recommendations for further research were made based on the findings of the study. The following are some recommendations:

- i. For future research, the design of the Comb part during the baitting process should be given priority in terms of material used and design appearance as it is found that the narrow design on the comb hole causes the filament to undergo micro breakage on the yarn/roving during the weaving process and this can leading to a decrease in mechanical properties.
- ii. This created RRF kit uses the basic method of weaving. It is used to convert pultrusion waste into mats and these findings are provided for future research

reference to make improvements to the process in looms for achieve efficiency in terms of output capacity and speed for mat production.

5.3 Green Element

The pultrusion machine uses roving fiber as a raw material to produce a continuous product. The waste produced by the pultrusion machine is a composite material that is roving fiber waste. Evidently, production wastes glass roving's often landfilled in the pultrusion sector and in general in the composite materials business, due to their weak recycling capacity. The disposal of this roving waste is not bio-degradable because it is made of synthetic material and might harm the environment. Existing waste management systems at present do not fully optimize such as Incinerator facilities caused air pollution because the high calorific content and hazardous fumes by the combustion of composite production waste. As a result, using the self-designed handloom RRF kit, it is possible to address the problem of composite waste in the pultrusion industry by converting it to other products at low cost and without harming the environment.

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APPENDICES

Appendices A Gant Chart PSM 1

Na	Drojaat Task	Dlan / A atual	Week													
INO	No Project Task		1	2	3	4	5	6	7	8	9	10	11	12	13	14
		Plan														
1	Selection of supervisor and PSM title	Actual														
	DCM title briefing	Plan														
2		Actual														
2 Chapter 1's problem statement and shire tive being discussed	Plan			4												
3	Chapter 1's problem statement and objective being discussed	Actual				_										
4 Chapter 2 research and writing (literature review)	Plan															
	Chapter 2 research and writing (Interature review)	Actual	_													
5 Submit and present the chapter 2 progression.	Plan															
	Submit and present the chapter 2 progression.	Actual														
6 Chapter 3 methodology research and writing	Chapter 2 methodology research and writing	Plan	÷.		100		1.1									
	Chapter 5 methodology research and writing	Actual	-	6	9			4		1	2					
7	Writing chapter 4 and chapter 5, expected outcome and															
/	conclusion	Actual		N	0						1					
9 Submission of DSM 1 first droft	Submission of DEM 1 first droft	Plan	.,P	LT.	C I	A	IV		-	A	2	1				
		Actual														
9 Submission of PSM 1 second draft		Plan														
		Actual														
10 Preparation and presentation of PSM 1		Plan														
		Actual														
Appendices B Gant Chart PSM 2

No	Project Task	Plan/Actual	Week													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Task discussion and planning with supervisor	Plan														
		Actual														
2	Purchase essential raw materials and equipment.	Plan														
		Actual														
3	Fabricating process	Plan		1					1							
		Actual	1							1						
4	Testing	Plan							T							
		Actual			1											
E	Data analysis	Plan														
3		Actual														
6	Chapter 4 research and writing, outcome, and discussion	Plan														
		Actual	3		~		0	1	1	5	0					
7	Chapter 5 research and writing, conclusion, and suggestions	Plan		0	2.0		6	-	1		/					
		Actual														
8	PSM 2 first draft submission IVERSITI TEKNIKA	Plan	AY	'S	14		MI		A	K	A					
		Actual														
9	PSM 2 second draft submission	Plan														
		Actual														
10	PSM 2 preparation and presentation	Plan														
		Actual														



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA

TAJUK: RECYCLE ROVING FIBRE KIT FOR ROVING GLASS COMPOSITES

SESI PENGAJIAN: 2021/22 Semester 1

Saya MUHAMMAD HAZIQ HAZMAN BIN ABD WAHID

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