EFFECT OF WIRE CUT WASTE IN PARTICULATE FORM ON MECHANICAL PROPERTIES OF LAMINATED GLASS COMPOSITE

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2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Industrial and Manufacturing Technology and Engineering

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A thesis submitted
in fulfilment of the requirements for the degree of
Bachelor of Manufacturing Engineering Technology with Honours

Faculty of Industrial and Manufacturing Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

DECLARATION

I declare that this dissertation entitled “EFFECT OF WIRE CUT WASTE IN PARTICULATE FORM ON MECHANICAL PROPERTIES OF LAMINATED GLASS COMPOSITE” 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.

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Date : 10/1/2024

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 with Honours.

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My beloved father, Ahmad Noor Bin Majid

My appreciated late mother, Nur Azah Binti A. Wahab

My love, Nur Batrisyia Binti Razman Shah

For giving me moral support, encouragement, and understandings.

ABSTRACT

The utilisation of Wire Electrical Discharge Machining (WEDM) has been prevalent in the industrial sector for approximately half a century where most application used wire made of brass. The wire, a crucial component of the machine, is designed to be utilised only once during the operational cycle. As a result of this, it will inevitably amass within a designated receptacle, such as a box or bin, necessitating the need for periodic emptying. In the context of smaller job shops and manufacturing facilities with lower production volumes, it is a common practise to accumulate the utilised wire and subsequently discard it in designated landfill sites. Hence, the discarded wire was chosen as an option to further study their potential to be incorporated in products. This investigation used scrap brass wire from WEDM (Sodick VZ300L) as a component material and incorporate with fibreglass to serve as reinforcements for laminated composites. The collection of waste wire from the Universiti Teknikal Malaysia Melaka (UTeM) and then breaking it down into particulate form is a crucial step in the process of recycling and repurposing this material. The fabrication of composite specimens is achieved through the utilisation of the hand layup process. The mechanical properties of the laminated composites are then investigated through multiple testing namely tensile (Shimadzu Universal Testing Machine), flexural (Shimadzu Universal Testing Machine) and pendulum impact (Eurotech Charpoy-Izod Impact Tester) to evaluate the performance of the fabricated composite. It can be concluded in Phase 1 of this study that specimen with 50% wire weight, (P50) is the best wire content proven by its maximum ultimate tensile strength measuring 287.55 MPa. Phase 2 demonstrates that specimen with five layers of fibreglass, (P5) has the highest UTS achieving 297. 69 MPa when 23.89 kN of force was exerted which is comparably higher when compared to P50 panel sample UTS result in Phase 1.

ABSTRAK

Penggunaan Mesin Pembuangan Elektrik Wayar (Wire Electrical Discharge Machining atau WEDM) telah wujud dalam sektor industri selama lebih kurang setengah abad di mana kebanyakan aplikasi menggunakan wayar yang diperbuat daripada kuningan atau loyang. Wayar tersebut, sebagai komponen penting mesin, direka untuk digunakan sekali sahaja sepanjang kitaran operasi. Akibatnya, ia akan terkumpul dalam bekas yang disediakan, seperti kotak atau tong, dan memerlukan pengosongan secara berkala. Dalam konteks makmal atau bengkel yang lebih kecil dan fasiliti pembuatan dengan jumlah pengeluaran yang lebih rendah, adalah amalan biasa untuk mengumpulkan wayar yang digunakan dan kemudian membuangnya di tapak pelupusan yang ditetapkan. Oleh itu, wayar yang dibuang dipilih sebagai pilihan untuk dikaji lebih lanjut potensinya untuk digabungkan dalam komposit gentian kaca. Penyelidikan ini menggunakan wayar kuningan sisa daripada WEDM (Sodick VZ300L) sebagai bahan komponen dan digabungkan dengan gentian kaca untuk digunakan sebagai pengukuhan bagi komposit laminasi. Pengumpulan wayar buangan daripada Universiti Teknikal Malaysia Melaka (UTeM) dan kemudian menghancurkannya menjadi bentuk berbutir halus adalah langkah penting dalam proses pengitaran semula dan penggunaan semula bahan ini. Pembuatan spesimen komposit dicapai melalui proses penempatan tangan (hand layup). Sifat mekanikal laminasi kemudian diuji melalui beberapa ujian seperti ujian regangan (Shimadzu Universal Testing Machine), ujian lentur (Shimadzu Universal Testing Machine) dan ujian impak pendulum (Eurotech Charpoy-Izod Impact Tester) untuk menilai prestasi komposit yang diperbuat. Dapat disimpulkan dalam Fasa 1 kajian ini bahawa spesimen dengan berat wayar 50%, (P50) adalah kandungan wayar terbaik yang dibuktikan dengan kekuatan tegangan muktamad maksimumnya yang berukuran 287.55 MPa. Fasa 2 menunjukkan bahawa spesimen dengan lima lapisan gentian kaca, (P5) mempunyai UTS tertinggi mencapai 297. 69 MPa apabila 23.89 kN daya dikenakan yang lebih tinggi jika dibandingkan dengan keputusan UTS sampel panel P50 dalam Fasa 1.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First and foremost, I would like to thank and praise Allah the Almighty, my Creator, my Sustainer, for everything I received since the beginning of my life. I would like to extend my appreciation to Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform. Thank you also to the Malaysian Ministry of Higher Education (MOHE) for the financial assistance.

My utmost appreciation goes to my main supervisor, Ts. Mohd Razali Bin Md Yunos, of Faculty of Mechnical and Manufacturing Engineering Technology, Universiti Teknikal Malaysia Melaka for all his support, advice, and inspiration. His constant patience for guiding and providing priceless insights will forever be remembered. Also, to my co-supervisor, Prof. Ir. Ts. Dr. Mohd Yuhazri Bin Yaakob, Universiti Teknikal Malaysia Melaka (UTeM) who constantly supported my journey.

Last but not least, from the bottom of my heart I express gratitude to my fellow companions, Muhammad Nur Asyraf Bin Noor Azam, Mohamad Firdaus Bin Mohamad Ropidi, Abu Abbas Azimi Bin Abu Bakar, Wan Amanina Binti Wan Azmi, Shazmin Binti Shahrulzaman, Nur Syazwani Binti Azhar and Nurain Binti Zamri, for their unwavering assistance. I would also like to thank my beloved parents for their endless support, love and prayers. Finally, thank you to all the individuals who had provided me the relentless support and inspiration to embark on my study.

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LIST OF SYMBOLS AND ABBREVIATIONS

AP	-	Armour Piercing
ASTM	-	American Society for Testing and Materials
BPA	-	Bisphenol-A
BT	-	Boat Tail
CMC	-	Ceramic Matrix Composite
CNC	-	Computer Numerical Control
Cu-Zn	-	Copper-Zinc
EDM	-	Electrical Discharge Machining
FKM	-	Fakulti Kejuruteraan Mekanikal (Faculty of Mechanical Engineering)
ft	-	Feet
J	-	Joule
JHP	-	Jacketed Hollow Point
JSP	-	Jacketed Soft Point
kg	-	Kilogramme
kN	-	Kilonewton
m	-	Metre
MMC	-	Metal Matrix Composite
m/s	-	Metres per second
ms	-	Millisecond
mm	-	Millimetre
MPa	-	Megapascal
NATO	-	North Atlantic Treaty Organisation
NIJ	-	National Institute of Justice
Nmm2	-	Newton per Square Millimetre
Pb	-	Lead
PMC	-	Polymer Matrix Composite
RN	-	Round Nose
TaC	-	Tantalum Carbide
TiC	-	Titanium Carbide

UHMWPE	-	Ultra-High Molecular Weight Polyethylene
UTeM	-	Universiti Teknikal Malaysia Melaka
UTM	-	Universal Testing Machine
WC	-	Tungsten Carbide
WEDM	-	Wire Electrical Discharge Machining
wt%	-	Weight Percentage

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CHAPTER 1

INTRODUCTION

1.1 Background

Composites have been used for thousands of years to construct everything from simple shelters to complex electronic devices. Johnson, T. (2019). While the earliest composites were created from natural materials such as soil and straw, modern composites are manufactured in a laboratory using synthetic substances. The modern era of composites began in the twentieth century with the invention of Bakelite, vinyl, and engineered wood products such as plywood. Fiberglas, another important composite, was invented in 1935. It was significantly more robust than previous composites, could be moulded and shaped, and was incredibly lightweight and durable.

Wire electrical discharge machine (WEDM) is a non-conventional manufacturing process used by a variety of industries to precisely machine virtually any conductive material. Camposeco-Negrete, C. (2019). Wire EDM machining is extensively utilised in numerous industries for the precise slicing of metal components. The wire is consumed during the procedure and cannot be utilised due to its altered properties. As a result, a considerable quantity of discarded brass wire waste is produced. This research examines the properties of this waste material to determine its prospective composite applications value.

Laminated glass composites possess a number of desirable mechanical properties. These characteristics include a high tensile strength, a high modulus, a low density, exceptional resistance to fatigue, creep rupture, corrosion, and erosion, and a low thermal expansion coefficient. Nevertheless, composites reinforced with para-aramid fibres present certain difficulties, such as low compressive strength and interlaminar shear strength. These obstacles can have an effect on the cutting procedure and overall efficacy of composites.

In applications requiring protection against low-velocity projectiles, the mechanical properties of laminated glass composites are critical. While the specific mechanical properties of the aforementioned composites are currently unknown, they are typically evaluated based on their resistance to energy absorption, and deflection capacities.

No research has examined the use of EDM wire cut refuse in composite materials to date. Typically, the generated refuse wires are recycled or discarded. This research project seeks to close this knowledge deficit by examining the mechanical properties of laminated glass composites containing EDM wire-cut waste.

Utilising EDM wire-cut residue in laminated glass composites has a number of potential advantages. To begin with, it contributes to waste reduction by minimising the quantity of debris produced during wire EDM machining. As the wires are predominantly composed of brass, the incorporation of this waste material into composites can reduce the need to acquire or mine additional metals. Moreover, if the mechanical properties of the resulting composite prove to be adequate, it may be suitable for use as shielding material.

Despite the potential benefits, using EDM wire reduce waste in composite materials presents a number of obstacles and constraints. First, there is a lack of antecedent knowledge and data to inform the process, as no previous research has examined this specific application. Secondly, extensive testing is required to evaluate the composite material's viability for use in shielding materials. Various properties, such as tensile strength, impact resistance, and other physical characteristics, must be evaluated exhaustively.

Incorporating EDM wire-cut scrap into the laminated glass composite, the findings of this study could have significant implications for improving the physical and technical properties of existing shielding material. If the material demonstrates sufficient durability and passes stringent testing, it could be used to enhance the protective capabilities of shields, which would have wider applications in the defence and security sectors.

In conclusion, the purpose of this research is to investigate the mechanical properties of a laminated glass composite containing EDM wire cut scrap. This study seeks to contribute to waste reduction efforts and potentially improve the efficacy of body armour by investigating the potential applications of this waste material.

1.2 Problem Statement

The use of Electrical Discharge Machining (EDM) wire cut waste in composite materials is mainly unexplored, providing an opportunity to investigate its potential application in improving the mechanical properties of laminated glass composites. Despite the large amount of scrap brass wire generated during wire EDM, this valuable resource is typically recycled or disposed. By failing to capitalise on the latent value of this waste material, we miss the opportunity to reduce waste and create novel composite materials with enhanced performance characteristics.

This study will address the dearth of information regarding the use of EDM wire-cut refuse in composite materials and explore its potential benefits, challenges, and limitations. It seeks to contribute to efforts to reduce waste, optimise resource utilisation, and potentially advance the field of composite materials for use in defence materials and other protective systems.

Through comprehensive testing, analysis, and comparison with extant materials, this study aims to answer the following important questions: Can the used wire from EDM wire-cutting be successfully incorporated into a laminated glass composite? What are the mechanical properties of the composite material, such as its strength, modulus, and density? How do the mechanical properties, including resistance to tension, energy absorption, and deflection, compare to those of conventional composites? What are the implications and implementations of these findings for the development of high-performance defence materials and other protective systems?

1.3 Objectives

The objectives of the research are as follows:

a) To fabricate the composite of fibreglass incorporated with the waste brass wire of WEDM as the reinforcement.

b) To conduct mechanical testing for the effects of the particulate brass wire reinforcements in the composite panel.

c) To analyse the potential effects of utilizing EDM wire cut waste in composite materials, including waste reduction and resource optimization.

1.4 Scope of Research

The scope of this research are as follows:

- The utilisation of the particulate form of brass wire as a reinforcement material. This approach involves incorporating brass wire particles into a matrix material to enhance its mechanical properties.
- Epoxy resin as the matrix material. The unique properties of epoxy resin, such as its high mechanical strength, excellent adhesion, and chemical resistance, make it a suitable candidate for various applications.
- The ratio of percentage of reinforcement (waste brass wire) to percentage of matrix (Epoxy resin) for the composite. Development of laminated glass

composite using 10 different percentages which are 10% all the way to 100% without introducing any additional variables.

- The number of layers of reinforcement (Fibreglass woven roving) and weight of waste brass wire. Development of laminated glass composite using 2 layers up to 10 layers without introducing any additional variables.
- The testing conducted in this study is according to American Society for Testing and Materials (ASTM) standard such as tensile test (ASTM D3039), Charpy impact test (ASTM D256), flexural test (D790).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Wire Electrical Discharge Machining (WEDM)

Wire Electrical Discharge Machining (EDM) is a metal-working process whereby material is removed from a conductive work piece by electrical erosion. EDM is particularly well suited for parts which are made from materials that are difficult to machine and/or contain small or odd-shaped angles, intricate cavities or intricate contours. At times you may hear wire EDM referred to as spark machining, spark eroding, wire erosion, wire burning, or die sinking. These are all descriptions of the same manufacturing process (Joseph Kreuser, 2004). Figure 2.1 shows the WEDM machine in Universiti Teknikal Malaysia Melaka (UTeM) Advanced Manufacturing Laboratory.

Figure 2.1 WEDM machine in UTeM (SODICK VZ300L)

EDM cutting is always through the entire workpiece. To start wire machining, it is first necessary to drill a hole in the workpiece or start from the edge. On the machining area, each discharge creates a crater in the workpiece and an impact on the tool. Wire can be inclined, thus making it possible to make parts with taper or with different profiles at the top and bottom. There is never any mechanical contact between the electrode and workpiece. The wire is usually made of brass or stratified copper and is between 0.1- and 0.3-mm diameter. Figure 2.2 depicts the schematic diagram of WEDM.

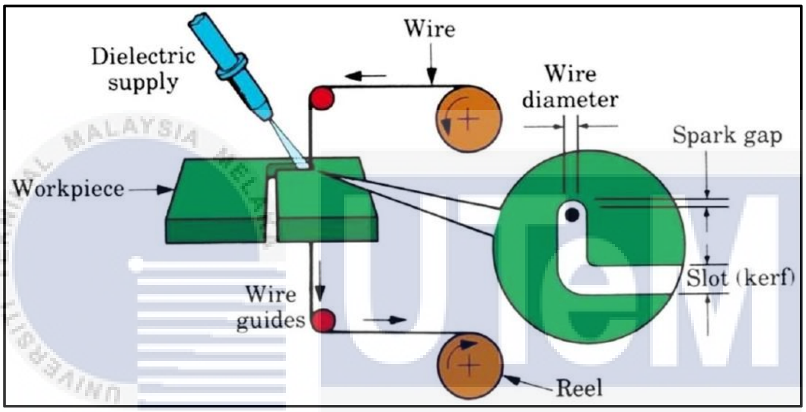

Figure 2.2 Schematic diagram of WEDM (Chaudhary *et al.*, 2020)

Depending on the accuracy and surface finish needed, a part will either be one cut, or it will be roughed and skimmed. On one cut the wire ideally passes through a solid part and drops a slug or scrap piece when it is done. This will give adequate accuracy for some jobs, but most of the time, skimming is necessary (Devin Wendorf, n.d.).

2.1.1 Wires Used in EDM Wire Cut

The process of wire electrical discharge machining (EDM) often involves using a steel wire that has been coated with materials such as brass or tungsten, which exhibit excellent electrical conductivity, high strength, and a high melting temperature. The selection of an appropriate electrode material (wire) is of the utmost significance in ensuring precise control of in-process variations. This is because the electrode material must be carefully matched to the work material, thereby enabling accurate regulation of said variations (G. Narendranath and J. Udaya Prakash, 2023). Table 2.1 shows the types of wire used in EDM wire cut.

Table 2.1 Types of wire used in EDM wire cut.

Material	Description	Advantages	Disadvantages
Brass	Probably the most frequently utilized wire for EDM wire cut. It is an excellent general-purpose wire that can be used with a variety of materials.	-Easy to machine -Can be die cast or extruded	-Does not wear as well as copper or tungsten
Carbide	Compound of metal/metalloid and carbon. Also known as hard metals: -Tungsten Carbide (WC) -Titanium Carbide (TiC) -Tantalum Carbide (TaC)	-High hardness -High melting point -Increased toughness compared to pure carbide or ceramic	
Copper	Frequently used when bulkier workpieces or a higher degree of precision are required for machining.	- Good wear resistance - Good for machining Tungsten Carbide - Useful for fine finish applications	-Difficult to machine compared to brass or graphite -Expensive
Copper Graphite		-Good conductivity -High strength -Thin sections easily machined	-Expensive
Copper Tungsten	Composites of tungsten and copper produced using powder metallurgy processes	- Deep slots under poor flushing conditions	-Expensive
Graphite	Most used electrode. Form of carbon with anisotropic hexagonal crystal structure. Non-metallic element with high sublimation temperature.	-Good machinability -Low wear -Low cost -High resistivity to high temperature arcs -Fine grain has low erosion and wear	-Fine grain costly
Molybdenum	Since it is so strong and rigid, this wire is used in the machining of tough or brittle materials.	-Good strength -High melting point -High arc erosion resistance	

	Refractory metal	-Low wear	
Silver Tungsten	Made of composites of tungsten and copper using powder metallurgy processes	-Useful for making deep slot under poor flushing conditions	-Expensive
Tellurium Copper	Similar to brass, better than pure copper.	-Fine finish applications	
Tungsten	Refractory material with high temperature strength. Most used for grinding	-High melting point -High arc erosion resistance -Low wear	-Brittle -Low conductivity
Tungsten Carbide	Compound of tungsten metal and carbon usually with a metal binder	-High hardness -Low wear -Relatively high toughness	

2.1.2 Workpiece Materials

Any conductive material such as steel, titanium, aluminium, brass, alloys, and superalloys can be cut using the EDM wire method (Dhananjay, n.d.). With its accuracy, the EDM wire cut technique has become a convention cutting method in all industries. Machine parts, logos and other metals can be cut and made with ease using EDM wire. The use of EDM wire for producing parts or its prototype depends on the thickness and size of the part to be cut and the length of cut to be created. Common shapes and materials you can cut with the machine include:

2.1.2.1 Aluminium

The element aluminium has been found to possess exceptional thermal and electrical conductivity properties. These properties have been extensively studied and documented in various scientific literature and have been attributed to the unique electronic structure of aluminium. The high thermal conductivity of aluminium allows it to efficiently transfer the inherent softness of aluminium renders it a challenging material to machine, as the cutting process may lead to the accumulation of a gummy residue.

2.1.2.2 Titanium

The utilization of WEDM for cutting titanium is a highly advantageous technique due to its ability to endure the adhesive nature of this alloy and effectively fragment extended chips. It is imperative to utilize deionized water as the dielectric medium in order to regulate the generation of heat during the machining process.

2.1.2.3 Steel

The inherent strength of steel is a well-established fact in the field of materials science. The preference for utilizing a wire EDM machine over a CNC machine is a common phenomenon among numerous manufacturers. It is crucial to exercise caution when handling the aforementioned material due to its propensity to produce a significant amount of thermal energy.

2.1.2.4 Brass

The high tensile strength of brass renders it suitable to facile cutting via machine. Given that the metal in question is of a soft nature, it is imperative that the cutting speed is maintained at a low level.

2.1.2.5 Graphite

The cutting of graphite using conventional cutting tools may present a challenging task. The utilization of the wire EDM process is deemed appropriate due to the sharpness of the wire, which effectively prevents the occurrence of particle pull-out, as posited by Anonymous (2022).

2.1.3 Applications of EDM Wire Cut

2.1.3.1 Automotive Industry

The parts in the automotive industry come in complex shapes and sizes and are mostly hard. As a result, the industry favors using wire EDM machines because the process does not rely on mechanical forces, and the wire electrode does not need to be stronger than the workpiece. The process applies to making holes and cavities to customize automotive car parts like bumpers, dashboards, car doors, and many more.

2.1.3.2 Medical Industry

Wire EDM machines produce complex parts with a high level of accuracy for use in all medical fields, including optometry and dentistry. Also, metals that work well with wire EDM services are frequently used to manufacture medical equipment.

Since the wire's diameter determines the cut's size, the wire EDM machine adds tiny features to parts like dental implants and syringe components without endangering their structural integrity.

2.1.3.3 Aerospace Industry

Wire EDM cutting produces parts with tight tolerances and is the go-to machining process for aerospace part manufacturers. This process, alongside the waterjet cutting process, is especially used for parts that cannot withstand the high temperature and stress associated with traditional cutting tools.

Parts in the aerospace industry need to have an excellent surface finish and be precise and accurate. Manufacturers use the wire EDM process for years to make engines, turbine blades, landing gear parts, and many more.

2.1.4 Spent Wire

Another waste produced in wire EDM production is the spent wire. The wire is only used once within the machine and will accumulate in a box or bin as depicted in Figure 2.3 that will need to be emptied periodically. The spent or used wire should be routinely checked and emptied per manufacturer recommendations. The wire is not classified as hazardous waste, and depending on the unit it is either reeled onto a spool or gathered to be chopped up for disposal as waste.

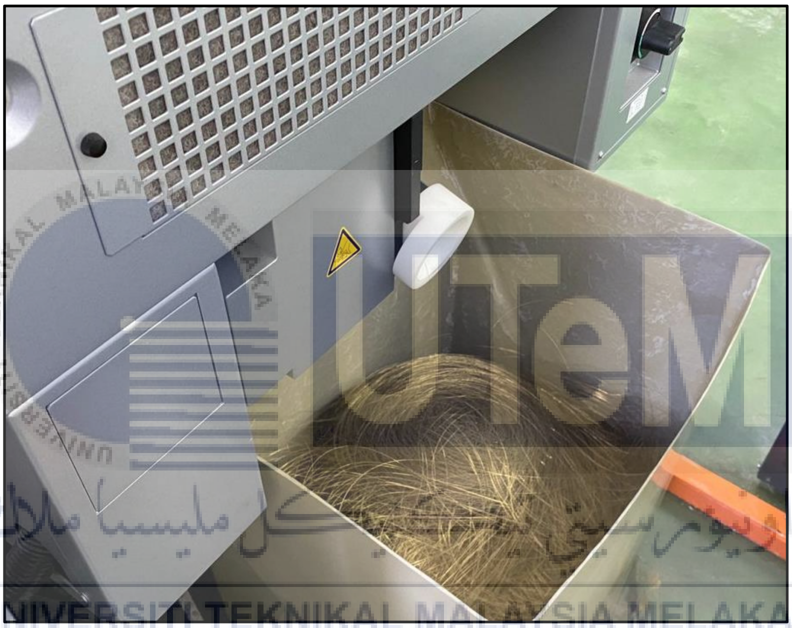

Figure 2.3 Scrap brass wire in EDM wire bin

Some EDM units have the option of wire choppers as an installed feature on the unit that cuts the used or spent wire into small pieces. Maintenance on this unit will include the sharpening or replacement of cutting blades and dies. The results of allowing these cutting edges to become excessively dull will lead to workpiece inaccuracies, excessive wire lines on the workpiece, and machine downtime (Joseph Kreuser, 2004).

According to interviews, many high-volume manufacturers outsource their recycling. Since the brass is recyclable, metal scrappers are willing to pay EDM manufacturers for the spent brass or copper (Joseph Kreuser, 2004). The named price changes the market price. In smaller job shops and lower-volume manufacturing, the used wire is amassed and disposed of in landfills (Pfluger, 2006). Some wire suppliers provide removal services for their customers. This consists of exchanging spent wire for new spools of wire.

2.2 Brass Wire

2.2.1 Properties of Brass

According to Helmenstine, A. M. (2020), brass is an alloy made primarily of copper and zinc. Because of its superior corrosion resistance, machinability, and strength to weight ratio, the copper-zinc (Cu-Zn) alloy known as brass has attracted a lot of interest in the industrial world (Trivedi M, 2015). Figure 2.4 shows brass plates having gold-like appearance. The proportions of the copper and zinc are varied to yield many different kinds of brass. Basic modern brass is 67% copper and 33% zinc. However, the amount of copper may range from 55% to 95% by weight, with the amount of zinc varying from 5% to 45%.

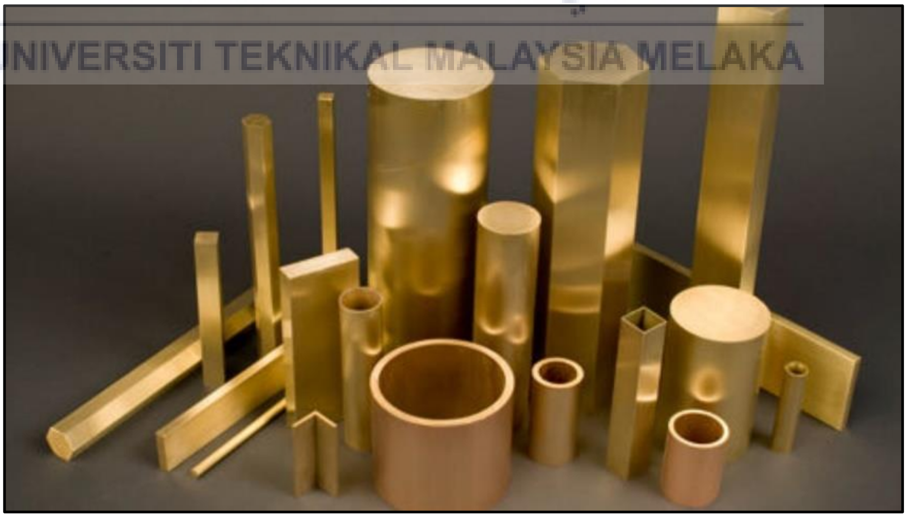

Figure 2.4 Brass products (Chaudhari, 2016)

Copper gives brass its high malleability. Although bronze has copper, too, it isn't as malleable as brass due primarily to the difference in their added content. In addition to being sold as flat sheets, brass is also available as tubing as shown in Figure 2.5. Zinc apparently has less impact on copper's properties in brass than tin. Apart from malleability, copper is also the one responsible for brass's heat and electrical conductivity. The only metal that's more conductive than copper is silver, although silver isn't recommended for conduction applications because of its poor thermal resistance. Brass is then utilized in many applications that require conduction in high temperature environments. Brass is a non-ferrous or non-iron-containing metal. None of brass's components are. This means it doesn't corrode via rusting. Some types of brass can even hold up to saltwater, which is ten times more corrosive than fresh water. For this reason, special brasses are used in outer sheathing of ships and dock posts (Anonymous, 2019).

Figure 2.5 Brass tubes (Ye, 2023)

Some additional elements, such as iron, manganese, tin, etc., can be found in a high strength brass alloy (Trivedi M, 2015). These elements produce a brittle intermetallic compound in brass, which increases the alloy's strength but decreases its ductility and workability. The mechanical characteristics, specifically the strength and ductility, of the metal alloy are impacted by the size and distribution of its crystallites. According to Kumar (2020), Zinc-coated brass wire demonstrated superior surface finish and increased material removal rate. The utilisation of brass wire coated with zinc during machining operations has been shown to improve both the surface quality attributes and the rate of material removal.

In neutral solutions, leaded brass exhibits higher corrosion resistance compared to other metallic components present in the alloy (Badawy *et al.*, 1969). The rise in lead concentration from 1.8 to 3.5% leads to an enhancement in the stability of the alloy. The alloy Brass II containing 3.5% lead (Pb) is deemed suitable for usage in chloride-based environments without posing any potential hazards.

2.3 Introduction to Composite

Composite materials are typically composed of multiple materials, including a matrix material and a reinforcement material as can be seen in Figure 2.6 (Dhinakaran *et al.*, 2020). Composites typically consist of three distinct types of materials, namely metals, polymers, and ceramics. They offer numerous advantages, such as high strength, stiffness, durability, low density, and biodegradability. The behavioural and properties of composites can be comprehended by key elements such as fundamental properties, structural configuration, and the interface among the reinforcements, based on their morphology (Manjunath *et al.*, 2021).

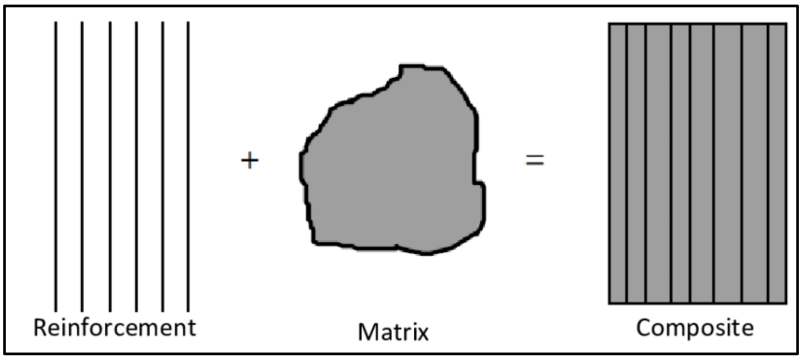

Figure 2.6 Formation of composite materials using reinforcement fibres and matrix resin. (Safri et al., 2014)

Over the past few decades, there has been rapid improvement in the polymer composites utilised for aerospace and automotive parts, sporting goods, structural components, and biomedical devices. Composites exhibit superior performance and properties compared to conventional materials due to their ability to be modified (Bhattacharjee and Roy, 2020).

These properties have led to an increasing demand for composites in various applic ations in our daily lives.

Polymeric composites are primarily utilised for structural purposes and are exposed to different forms of loading, such as tensile, compressive, bending, and impact. Polymeric composites may experience friction and wear, necessitating their ability to effectively withstand tribological forces.

Fibre reinforced plastics are typically categorised into two main types: glass fibre reinforced plastics and carbon fibre reinforced plastics. In the realm of matrix materials, composite materials can be categorised into two distinct groups: long fibre thermoplastics and short fibre thermoplastics (Ramnath, 2019).

2.3.1 Hybrid Composite

Dhinakaran (2020) also stated that hybrid composites refer to composite materials that result from the combination of two or more distinct materials within a shared matrix. These composite materials exhibit a diverse array of properties that are necessary to meet the diverse demands of various applications. The incorporation of diverse fibres with varying dimensions into a composite material result in enhanced properties that are unattainable in a monolithic polymer matrix composite.

According to Vinayagamoorthy (2020), the composite properties are enhanced to a larger extent when both man-made or natural reinforcements are used in hybrid form. Under this combination, the composite material acquires the superior properties of the individual fibres, and when subjected to varying loads, each fibre provides its own maximal resistance. Therefore, the composite would be preferable in every respect.

Ramasubbu & Madasamy (2022) in Mittal, Saini, and Sinha (2016) and Zivkovic (2017) suggest that hybrid composites exhibit a compensatory mechanism wherein the weakness of one fibre is offset by the other fibre. The fibres possess varying diameters, thereby augmenting the effective area for adhesion of the fibres matrix, thereby facilitating uniform transmission of stress. Fibres with low elongation may experience failure before those with high elongation, allowing the latter to bear the load without causing damage to the matrix. This results in improved stress transfer from the matrix to the fibres, leading to enhanced mechanical properties.

Hybridization can be achieved through two methods: the first involves the use of a blend of two synthetic fibres, as described by Irina et al. (2015), while the second involves the combination of a synthetic fibre with a natural fibre, as reported by Yusri Muhammad et al. (2015). In the production of a hybrid polymeric composite, various parameters must be taken into account to enhance the composite's overall performance. The production of fibres involves various crucial factors that need to be taken into account, such as the synthesis process, manufacturing technique, operational parameters, and fibre geometry (Vinayagamoorthy 2017).

2.3.2 Matrices

Polymer matrix composites (PMCs), metal matrix composites (MMCs), and ceramic matrix composites (CMCs) make up the major categories of man-made composites that exists today (Ramawat *et al.*, 2023). Figure 2.7 shows their classifications and examples.

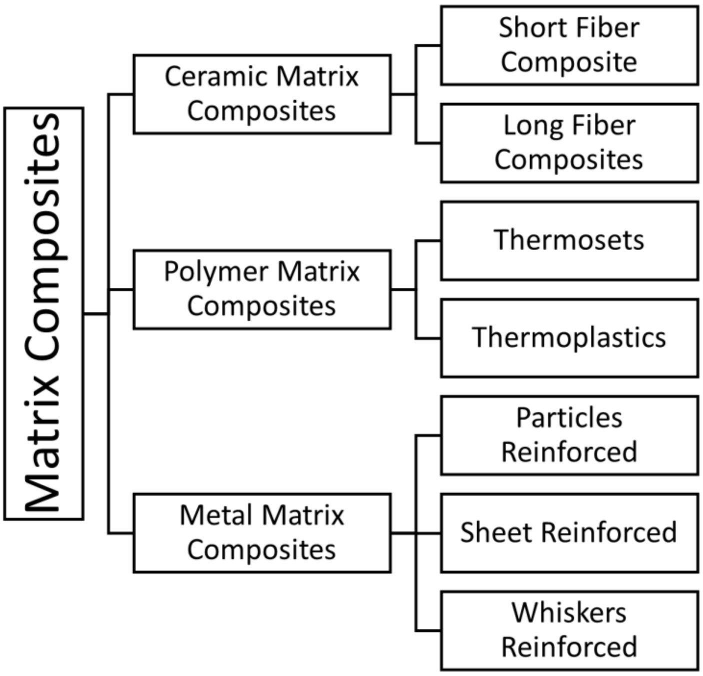

Figure 2.7 Classifications of matrix composites (Singh, Kumar and Singh Chohan, 2020)

The category of thermoset resins comprises several types, such as polyesters, phenolic, melamine, silicones, polyurethanes, and epoxies (Ramnath, 2019). Classifications of polymer matrix can be seen in Figure 2.8.

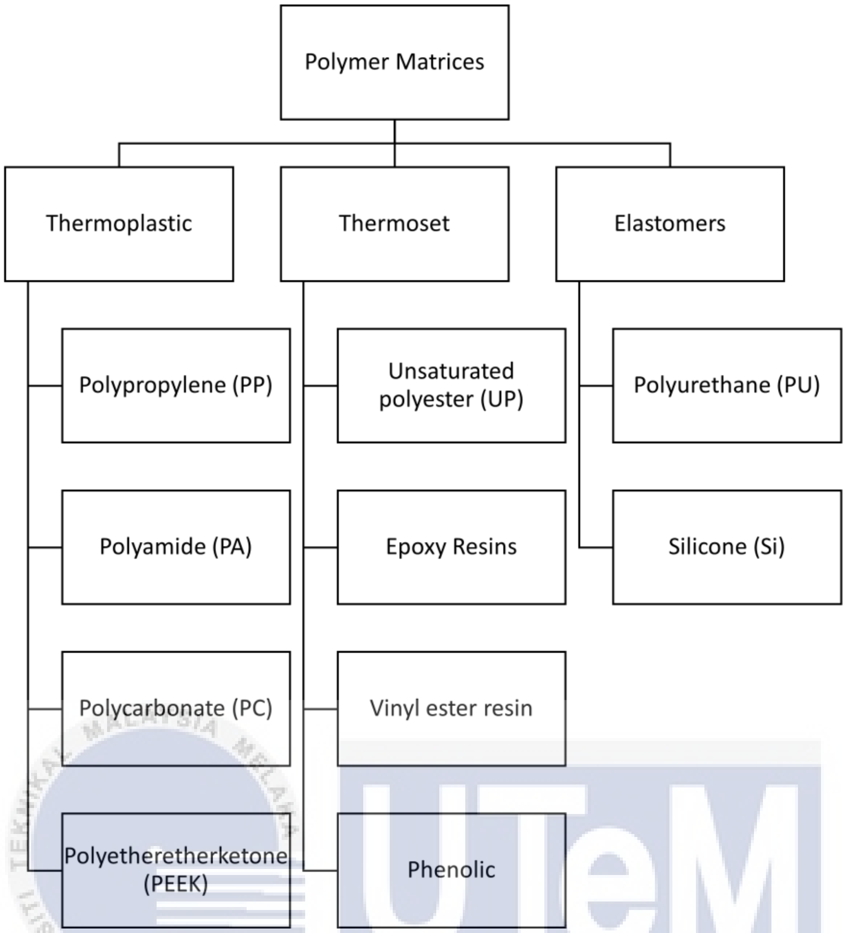

Figure 2.8 Classifications of polymer matrix (Sevilla, 2018)

In the realm of natural fibre composites, the jute-epoxy composites exhibit superior tensile and flexural strength when compared to jute-polyester composites. Conversely, the jute-polyester composites demonstrate a higher impact energy than their jute-epoxy counterparts (Sathees Kumar, 2020). The observed increase in hardness can be attributed to the improved dispersion of fibres within the polyester matrix and the resulting enhancement of interfacial adhesion between the fibre and matrix.

2.3.2.1 Epoxy Resin

Epoxy is a type of thermoset matrix material that is utilised in the production of composites (Ramasubbu and Madasamy, 2022). These materials exhibit favourable moisture resistance and reduced shrinkage upon curing. The epoxy matrix is composed of two distinct components, namely the resin and the hardener. Typically, they are combined in a proportion of 10:1.

Dhinakaran et al., (2020) claims that hybrid fibre reinforced polymer composites can utilise Epoxy adhesives as their matrix material. Epoxy adhesives belong to the category of structural adhesives, which are also referred to as engineering adhesives. The aforementioned adhesives exhibit superior performance and are commonly employed in the fabrication of aircrafts, automobiles, bicycles, golf clubs, skis, snowboards, and other domains that necessitate exceptional strength. Epoxy adhesives have the potential to be modified and optimised to meet the requirements of various applications. The thermal and chemical durability of said adhesives can be enhanced through thermal processing.

2.3.2.2 Hardener

The process of curing epoxy resin involves the addition of a catalyst, which initiates a chemical reaction while maintaining its own chemical composition. The catalyst serves as a trigger for the chemical reaction between the epoxy resin and monomer, causing the transition from a liquid to a solid state (Ramnath, 2019).

2.3.3 Reinforcements

2.3.3.1 Fiberglass

Glass, carbon, and Kevlar or aramid are commonly utilised by industries as manmade reinforcements due to their advantageous properties. According to research by R, Vinayagamoorthy (2020), the production of these materials involves a sequence of physical and chemical procedures primarily utilising silicon dioxide and incurs significant manufacturing expenses. Additionally, they contain small amounts of oxides of aluminium, calcium, magnesium, sodium, potassium, and boron. Man-made fibres include glass, carbon, kevlar, ceramic, boron, and silica.

Vinayagamoorthy also mentioned that numerous studies have been conducted to characterise composites reinforced with glass (Yunfu et al. 2016; Asi 2008), carbon (Liang and Wadley 2015; Shigeyuki, Suenaga, and Banno 1986), and kevlar (Singh. and Samanta 2015; Warbhe, Shrivastava, and Adwani 2016) fibres. Glass is considered superior in terms of its tensile strength, flexural strength, Young's modulus, density, breaking strain, usability, cost, and availability. As a result, many researchers use glass fibre as reinforcement in various polymeric composites (Devendra and Rangaswamy, 2013).

2.3.3.2 Natural Fibres

The field of composite materials has advanced from conventional synthetic fiber-reinforced materials, such as those made of glass or carbon fibres, to materials made of natural fibres (Paturel & Dhakal, 2020).

Ramasubbu & Madasamy (2022) in Sanjay et al., (2016) claims that composites reinforced with natural fibres find applications in various industries such as transportation, building and construction (for partition boards and ceiling panelling), military, consumer goods and packaging.

In comparison to glass fibres, the manufacturing of natural fibres results in lower environmental impacts. The reason for this is that the growth of natural fibres relies predominantly on solar radiation and requires a minimal amount of energy derived from fossil fuels during the manufacturing and extraction procedures (Sathees Kumar, 2020). In situations where the objective is to achieve products with low weight, natural fibres can be effectively utilised as reinforcement. These fibres possess the potential to serve as insulators for thermal and acoustic purposes. Effective resistance capability of the material is attributed to the strong adhesion between the natural fibres and the polyester matrix (Joshi et al. 2004). The homogenous distribution of natural fibres may lead to an augmentation in the flexural strength measurement.

Vinayagamoorthy (2020) as cited in Singha and Thakur (2010) claim that despite the positive properties of synthetic fibres, their recycling and biodegradation capabilities are limited. The researchers were prompted to seek an alternative reinforcement that fulfils both properties and biodegradable.

To address this issue, natural fibres obtained from diverse natural origins such as plants, animals, and minerals are employed as reinforcements. Various plant components, such as stems, leaves, fruits, and roots, have been utilised to extract natural fibres. These fibres are then incorporated as reinforcements in polymer resins in order to create composite materials (Vinayagamoorthy et al. 2016).

2.4 Mechanical Tastings

2.4.1 Tensile Testing

The tensile test is a destructive procedure that reveals the tensile strength, yield strength, and ductility of the metallic material. It examines the force needed for breaking a composite or plastic specimen, as well as the extent to which the sample stretches or elongates prior to fracturing. Composites are typically subjected to basic tension as well as flat-sandwich tension testing that complies with ISO 527-4, ISO 527-5, ASTM D 638, ASTM D 3039, and ASTM C 297 standards. These measurements generate stress-strain diagrams that are used to calculate tensile modulus (Jawaid *et al.*, 2018).

2.4.2 Flexural Testing

Flexural testing assesses the force required to deform a plastic beam and determines a material's flexural resistance or rigidity. Flex modulus indicates how much a material can bend before deforming permanently. In the case of plastic lock arms or snap-fit assemblies, the arm must flex to enable optimum seating, then flex back into place to secure the connection. When the securing mechanism is flexed, it is more likely to shatter if it is composed of brittle material. In the case of support beams, flex testing indicates the maximum strain that the beams can withstand before bending; therefore, a more rigid or stiffer material is preferable for this application (Shrivastava, 2018).

2.4.3 Pendulum Impact Testing

Numerous impact experiments with serrated bars of various designs and loads have been applied to predict the brittle fracture of ferritic steels.

The impact test is a method to quantify the amount of energy absorbed by a material during the process of fracturing. The energy that is absorbed can be used as an indication of the material's hardness and can be utilised as a means to investigate the temperature-dependent transformation from brittle to ductile. This is to determine the material's mechanical property of either being brittle or ductile. The single impact test comprises three widely used types of tests, namely the Charpy V-notch test, the Izod test, and the Tensile Impact test.

ASTM E23 (1999) standardises the Charpy specimen for impact three-point bend testing in the United States (Buschow, 2001). The Charpy three-point bend specimen is more practical for variable test temperatures and is the most widely accepted method for measuring notch durability. Evaluation of notch toughness involves calculating the fracture response of the impact specimen in terms of fracture energy received. Using a calibrated device which determines the total energy absorbed in fracturing the specimen, the change in potential energy of the impacting head (from before impact to after fracture) is determined. Along with to the fracture energy, other quantitative parameters such as fracture appearance (percentage of fibrous fracture) and degree of ductility/deformation (lateral expansion or notch root contraction) are frequently measured.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this chapter, the necessary strategy and procedures are used to this study to assure that all of the outlined goals were realized. The study and description in depth of the materials utilised, the design, the manufacturing technique, the necessary experimental testing, and the analysis of this research will be further explained in this chapter. The American Society for Testing and Materials (ASTM) code and standards are being followed as a guideline for the experiments namely; (i. tensile test, ii. flexural test, iii. impact test) in this study. These guidelines include standard testing methodology, tools, and techniques. The preparation of the waste material, the methods, and any relevant tests come first in this line of investigation. Figure 3.1 illustrates the flow chart of the process for this study. This procedure will include the use of epoxy resin as the matrix, the integration of wire cut waste and fibreglass, and then the hand layup technique, which will result in the formation of a reinforced composite.

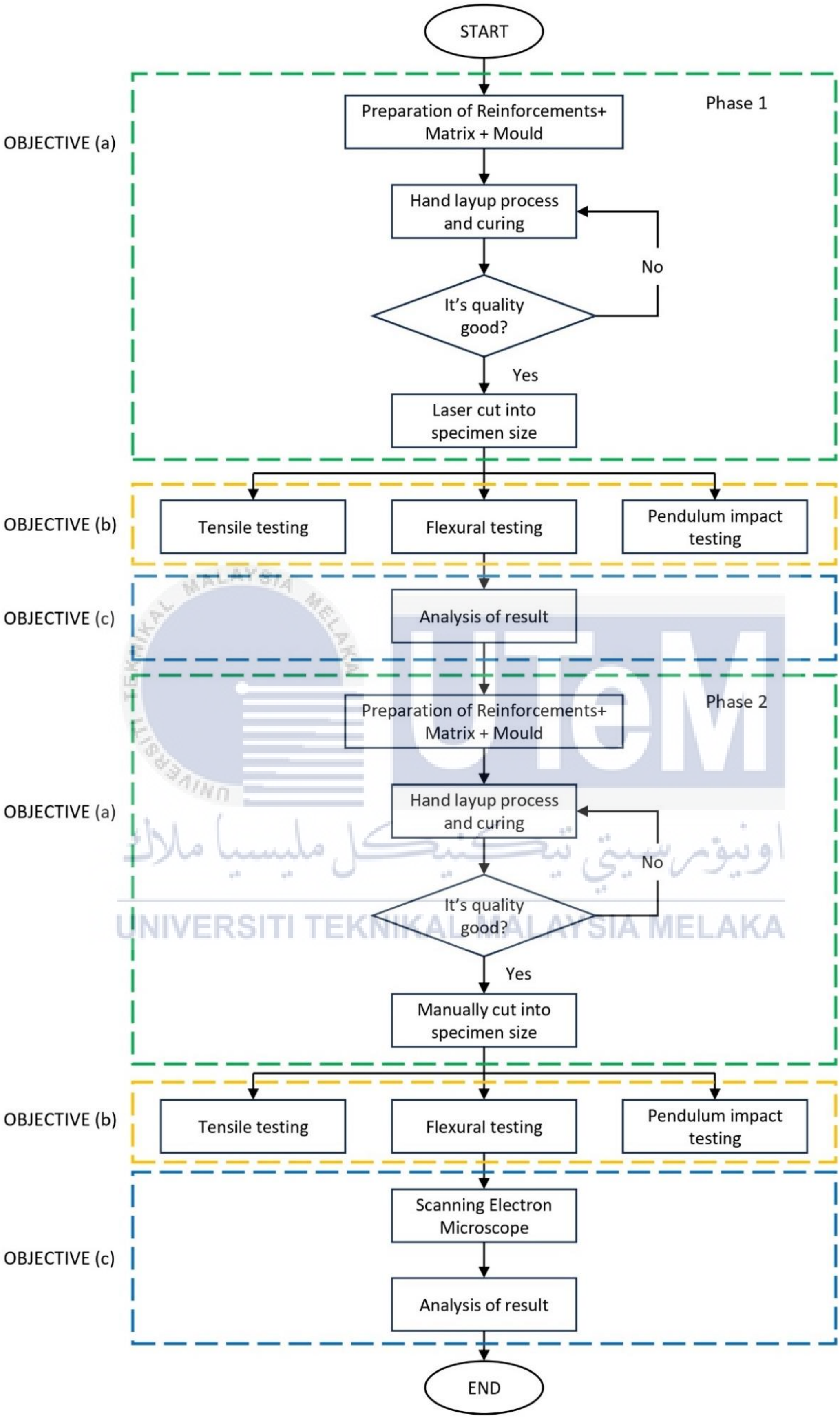

Figure 3.1 Flowchart of research study

This study involved two stages. The first stage was conducted to determine the optimum fibre loading ranging from 10% to 90% wt of waste brass wire sandwiched between two layers of fiberglass woven roving through hand layup technique. The optimum amount of fibre loading obtained from Stage 1 will then be further studied under Stage 2 to determine the optimum amount of fiberglass woven roving to be used to sandwich the fibre loading. After being properly cured, every composite panel was cut into specimen size accordingly to undergo three types of mechanical testing namely tensile test, flexural test and pendulum impact testing to evaluate the performance of the laminated glass composite.

3.2 Raw Materials Preparation

3.2.1 Collection of Waste Wire

In order to complete the specimen preparation for this experiment, numerous different raw materials will need to be produced. Scrap brass wire is collected from WEDM (SODICK VZ 300L) in UTeM's Advanced Machining Laboratory as shown in Figure 3.3.

Figure 3.2 Scrap wire collection from the wire bin

In order to turn the waste wire into particulate form, the long and continuous wire are cut manually using scissors into particulate size determined as no longer than 1 mm in length. Figure 3.3 shows the cutting process of used brass wire into particulate form.

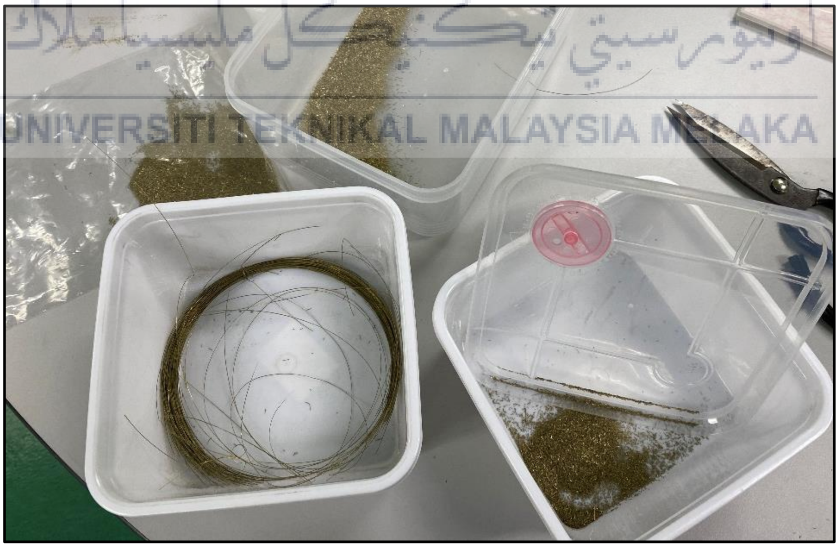

Figure 3.3 Process of cutting the brass wire.

3.2.2 Calculation for Amount of Raw Materials Needed

The type of resin used is Epoxy, specifically bisphenol-A (BPA) Epoxy. It acts as a bonding agent allowing the reinforcements to stay intact and also provides mechanical integrity. Furthermore, hardener comes in many different formulations to achieve specific curing properties. The hardener used is an amine-based hardener. Hardeners serves multiple functions namely as a curing agent, provides chemical resistance and provide thermal stability and resistance to high temperatures. The process of raw material preparation is shown in Table 3.1. Firstly, the amount of each raw material as shown in Figure 3.4 had to be considered.

Table 3.1 The process for raw material preparation.

No.	Process
1.	The ratio of Epoxy resin to hardener is 77.9% to 22.1%
2.	According to the ratio, the required amount of Epoxy and hardener will be presented.
3.	The appropriate dimensions of fibreglass fabric and procured the requisite material accordingly. The fibreglass to brass wire ratio is 1:1.
4.	Once the necessary quantity of specimens has been determined, it is possible to calculate the total amount of wire required.

(c)

Figure 3.4 Raw materials for hand layup process (a) used brass wire; (b) fiberglass; (c) epoxy resin and hardener.

A sum of 34 composite panels were fabricated. 18 pieces and 16 pieces are for Stage 1 which is fibre loading and Stage 2 which is fibre layers respectively. Table 3.2 shows the weight of materials prepared for Stage 1 in grams. While Table 3.3 shows the materials preparation for Stage 2.

Table 3.2 Weight of materials prepared for Stage 1

Sample	Fibreglass	Epoxy	Hardener	Waste wire
P10	60.00	46.74	13.26	6.00
P10	60.00	46.74	13.26	6.00
P20	60.00	46.74	13.26	12.00
P20	60.00	46.74	13.26	12.00
P30	60.00	46.74	13.26	18.00
P30	60.00	46.74	13.26	18.00
P40	60.00	46.74	13.26	24.00
P40	60.00	46.74	13.26	24.00
P50	60.00	46.74	13.26	30.00
P50	60.00	46.74	13.26	30.00
P60	60.00	46.74	13.26	36.00
P60	60.00	46.74	13.26	36.00
P70	60.00	46.74	13.26	42.00

P70	60.00	46.74	13.26	42.00
P80	60.00	46.74	13.26	48.00
P80	60.00	46.74	13.26	48.00
P90	60.00	46.74	13.26	54.00
P90	60.00	46.74	13.26	54.00
Total	1080.00	841.32	238.68	540.00

Table 3.3 Materials preparation for Stage 2

Sample	Fibreglass	Epoxy	Hardener	Waste wire
P3	180.00	140.22	39.78	90.00
P3	180.00	140.22	39.78	90.00
P4	240.00	186.96	53.04	120.00
P4	240.00	186.96	53.04	120.00
P5	300.00	233.70	66.30	150.00
P5	300.00	233.70	66.30	150.00
P6	360.00	280.44	79.56	180.00
P6	360.00	280.44	79.56	180.00
P7	420.00	327.18	92.82	210.00
P7	420.00	327.18	92.82	210.00
P8	480.00	373.92	106.08	240.00
P8	480.00	373.92	106.08	240.00
P9	540.00	420.66	119.34	270.00
P9	540.00	420.66	119.34	270.00
P10	600.00	467.40	132.60	300.00
P10	600.00	467.40	132.60	300.00
Total	6240.00	4860.96	1379.04	3120.00

Hence, the total weight of fibreglass, epoxy, hardener and used brass wire can be determined as illustrated in Table 3.4. The total weight of fiberglass used is 7.32 kg. According to the ratio of 77.9 : 22.1, the weight of epoxy and hardener can be calculated to 5.702 kg and 1.617 kg respectively.

Table 3.4 Total weight of fibreglass, epoxy, hardener and waste wire for Phase 1 and Phase 2 combined.

Material	Fibreglass	Epoxy	Hardener	Waste wire
Total of Weight (gram)	7320.00	5702.28	1617.72	3660.00

3.3 Preparation of Hand Layup Process

To develop the composite panels, mild steel sheet metal was used for the mould. Using a shearing machine as depicted in Figure 3.5, the sheet metals were cut into possessing a width of 240 millimetres and a length of 300 millimetres as illustrated in Figure 3.6. Figure 3.7 shows the sheet metals were sanded with sandpaper by hand to ensure a smooth surface, clean from rust and oil. This is important in order to obtain a laminated panel with an even and flushed surface.

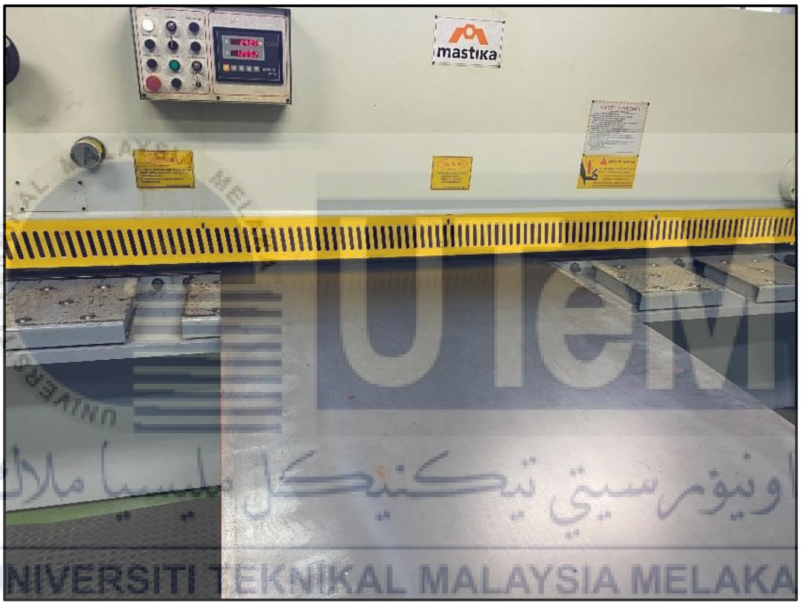

Figure 3.5 Shearing machine used to cut mild steel sheet metal for mould purpose.

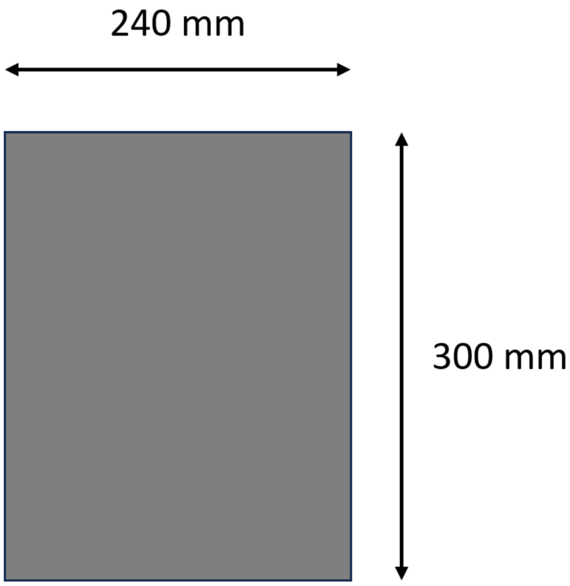

Figure 3.6 Dimensions of mould plate.

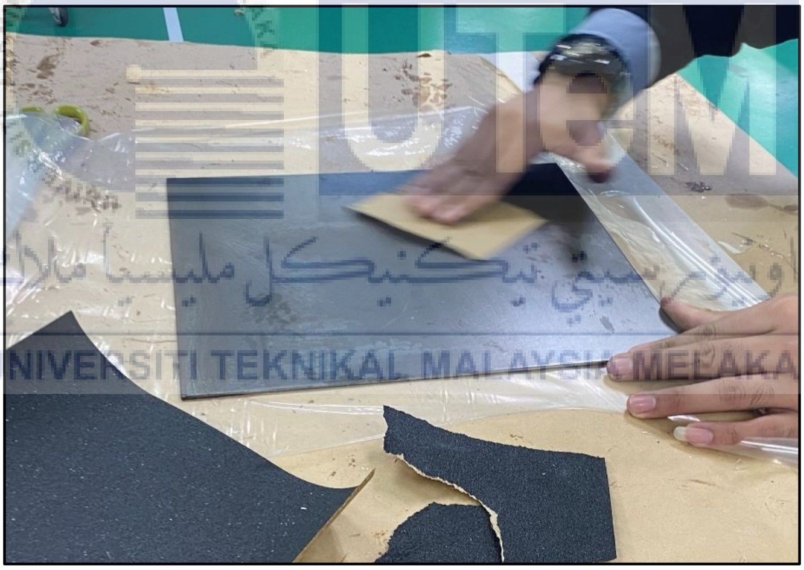

Figure 3.7 Sheet metal plate is sanded to achieve a smooth and clean surface.

After the mould is prepared, fiberglass woven roving is cut into rectangular shape that would fit into the mould. Figure 3.8 depicts the development of the fibreglass fabric as described. In total, as much as 16.8 m of fiberglass is needed for all 38 specimens where the fibre cloth cost RM 18.00 per meter.

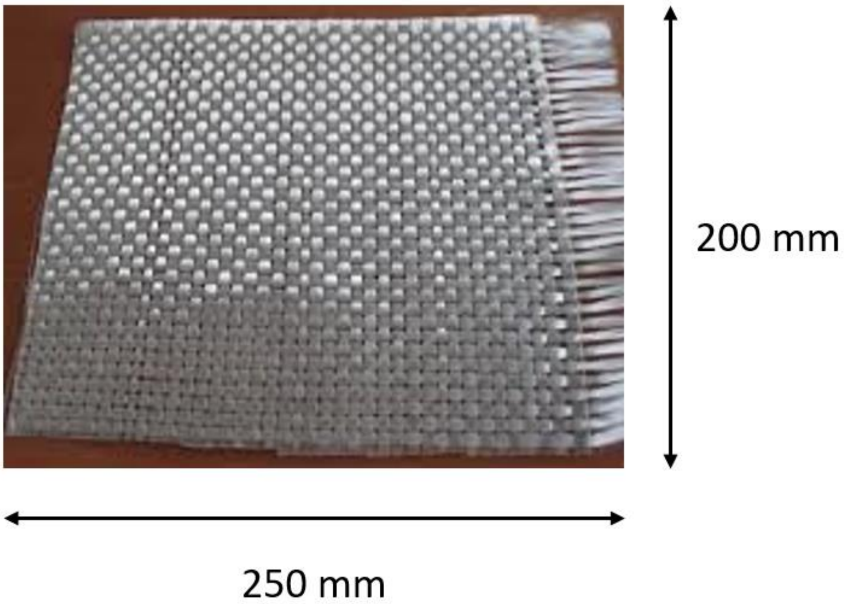

Figure 3.8 The geometric properties of fibre fabrics.

3.4 Hand Layup Process

By utilising a wire to fibreglass ratio of 1:1, the reinforcements will be embedded with epoxy resin and hardener via a hand layup technique. Before each hand layup process, the mould is double-checked for any debris or grease and wiped thoroughly. The right amount of epoxy and hardener were poured into separate cups according to the specified ratio. A silicone-based releasing agent is applied onto the surface of the mould to facilitate the demoulding process. Figure 3.9 shows the fibreglass cloth is placed onto the mould and when everything is prepared, only then will the matrix be mixed. The mixture is poured and spread evenly on the fiberglass as shown in Figure 3.10

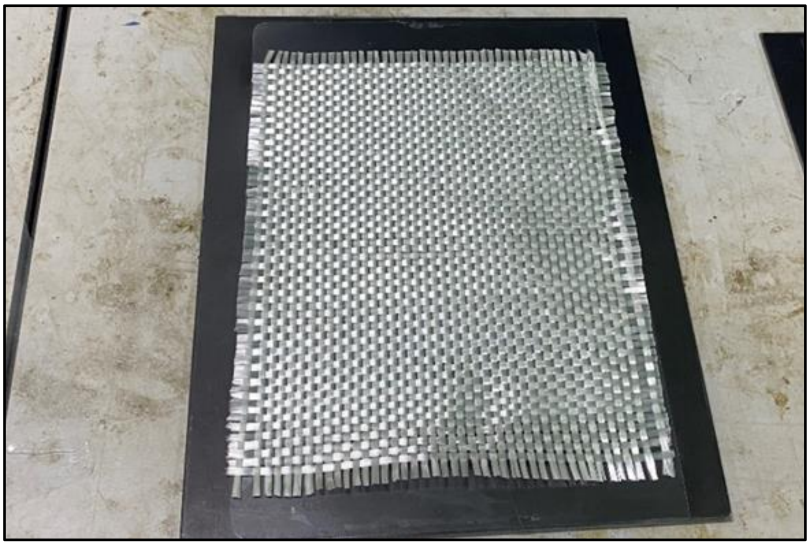

Figure 3.9 Placement of fibreglass cloth on mould.

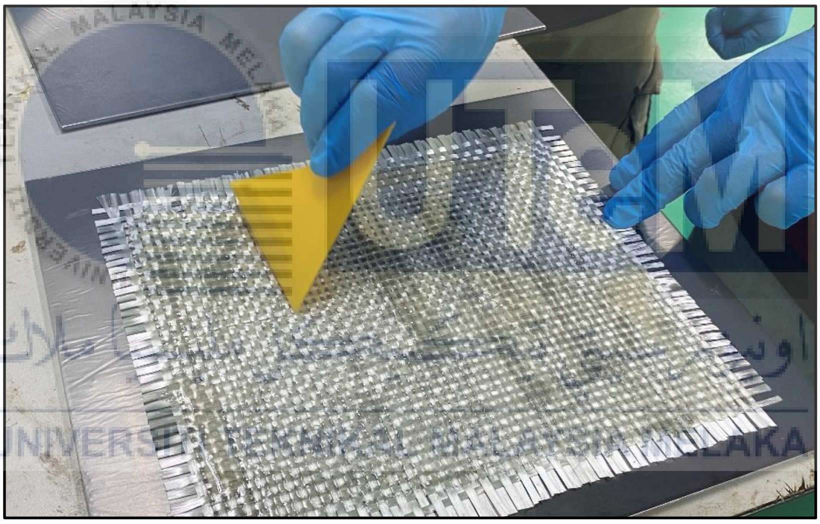

Figure 3.10 Matrix resin spread evenly.

Next, particulate form of waste brass wire is sprinkled in a random manner yet evenly all over the matrix resin on the fiberglass cloth. Figure 3.11 shows the arrangement of the wire. Another fiberglass cloth is then layered on top of it so the layer of wire is sandwiched between them.

Figure 3.11 Placement of particulate wire waste.

Finally, another piece of mould is placed on top and mild steel blocks were placed over the mould as cold press to ensure the composite panel remains evenly straight and not warped. Figure 3.12 shows three steel blocks arranged on each mould. Figure 3.13 illustrates the diagram of a hand layup process. The specimen will undergo a process of curing and drying. The sample achieves readiness upon completion of the curing process.

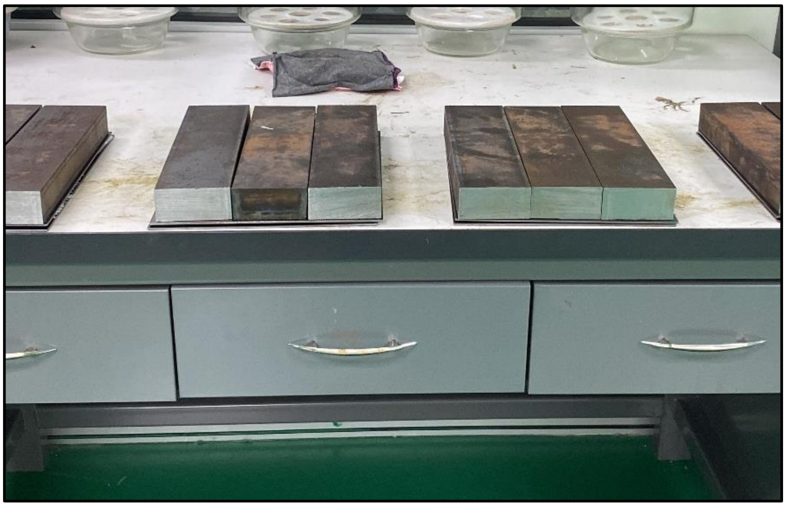

Figure 3.12 Mild steel blocks used as cold press to the mould.

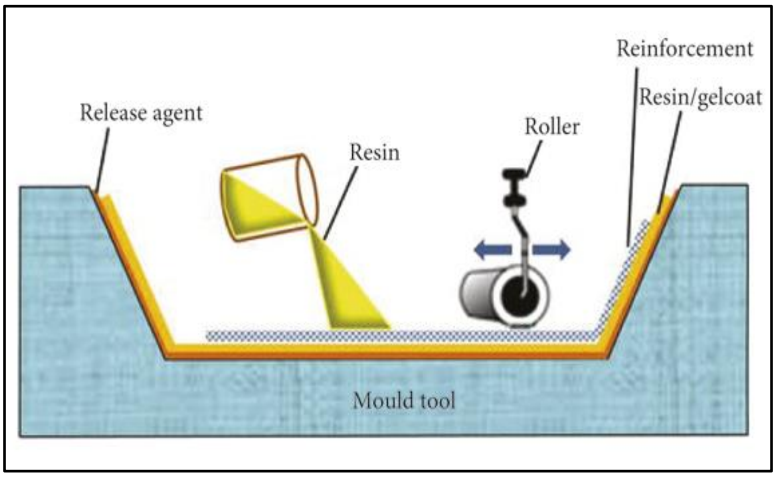

Figure 3.13 Diagram of hand layup technique

3.5 Development of Laminated Specimen

3.5.1 Ratio of Laminated Specimen in Stage 1

The ratio of matrix used is 77.9% for Epoxy and 22.1% for hardener in regard to fiberglass (FG). FG remains the same for all specimens in Stage 1 which is 30 grams per layer. Since each specimen uses 2 layers, 60 g of FG is used. The ratio of waste wire in the specimen starts from 10% and increases by 10% until 100% following the weight of FG. Table 3.5 shows the weight of the raw materials for each specimen.

Table 3.5 Weight of raw materials in Phase 1

Specimen	Percentage Weight of Wire to FG (%)	Weight of wire (gram)	Weight of FG (gram)	Weight of matrix (gram)	
				Epoxy	Hardener
P10	10	6			
P20	20	12			
P30	30	18			
P40	40	24			
P50	50	30	60	46.74	13.26
P60	60	36			
P70	70	42			
P80	80	48			
P90	90	54			
P100	100	60	0		

3.5.1.1 Stacking Sequence for Hybrid Laminated Composite

All specimens employ the same stacking sequence. The only variable that is altered during the lamination process is the weight of the waste brass wire in its particulate form. Figure 3.14 depicts the sequential arrangement of the stacking.

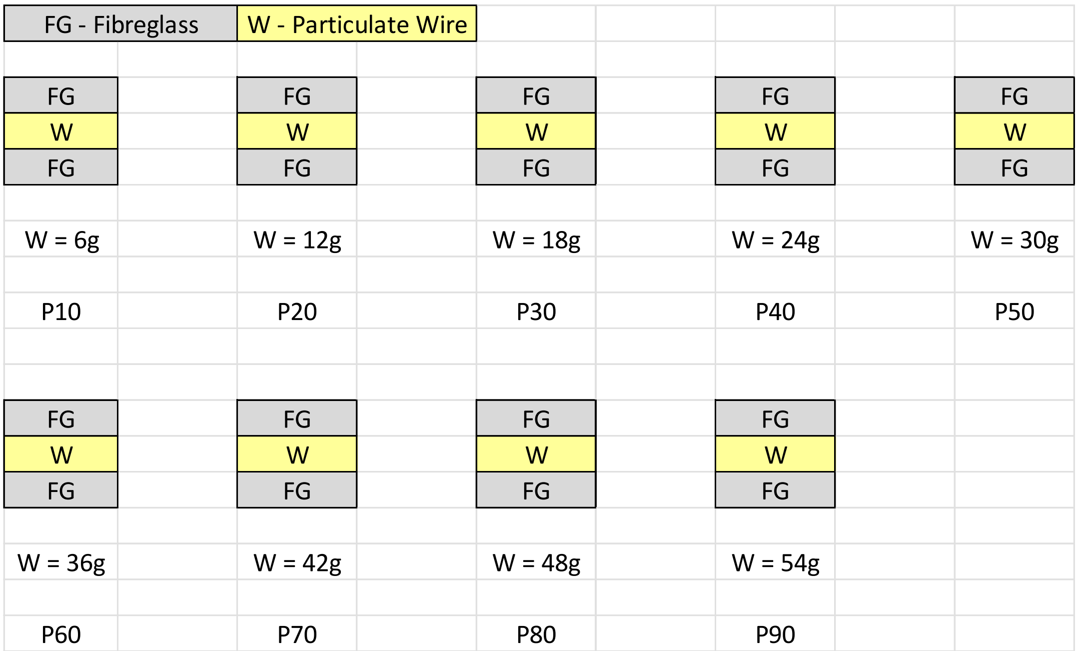

Figure 3.14 The order in which the stacking is arranged sequentially.

3.5.2 Ratio of Laminated Specimen in Stage 2

Specimen with the best mechanical testing result in Stage 1 will determine the ratio of waste wire for Stage 2. From the mechanical testing that will be explained further later, it was found that P50 (50%) has the best mechanical properties. Thus, it will be taken for calculation of waste wire. Table below shows the weight of the raw materials for each specimen. The ratio of matrix used in Stage 2 remains the same as in Stage 1. 77.9% for Epoxy and 22.1% for hardener in regard to fiberglass (FG).

Table 3.6 Weight of raw materials for each specimen

Specimen	No. of FG layers	Weight of FG layers (gram)	Weight of Wire (gram)	Weight of matrix 77.9% : 22.1% ratio	
				Epoxy	Hardener
P3	3	90	45	70.11	19.89
P4	4	120	60	93.48	26.52
P5	5	150	75	116.85	33.15

P6	6	180	90	140.22	39.78
P7	7	210	105	163.59	46.41
P8	8	240	120	186.96	53.04
P9	9	270	135	210.33	59.67
P10	10	300	150	233.70	66.30

3.5.2.1 Stacking Sequence for Hybrid Laminated Composite

In Stage 2, the stacking process begins with three layers and progressively increases by one layer for each specimen, until a total of 10 layers is reached. Figure 3.15 illustrates the sequential lamination process for P3 through P10.

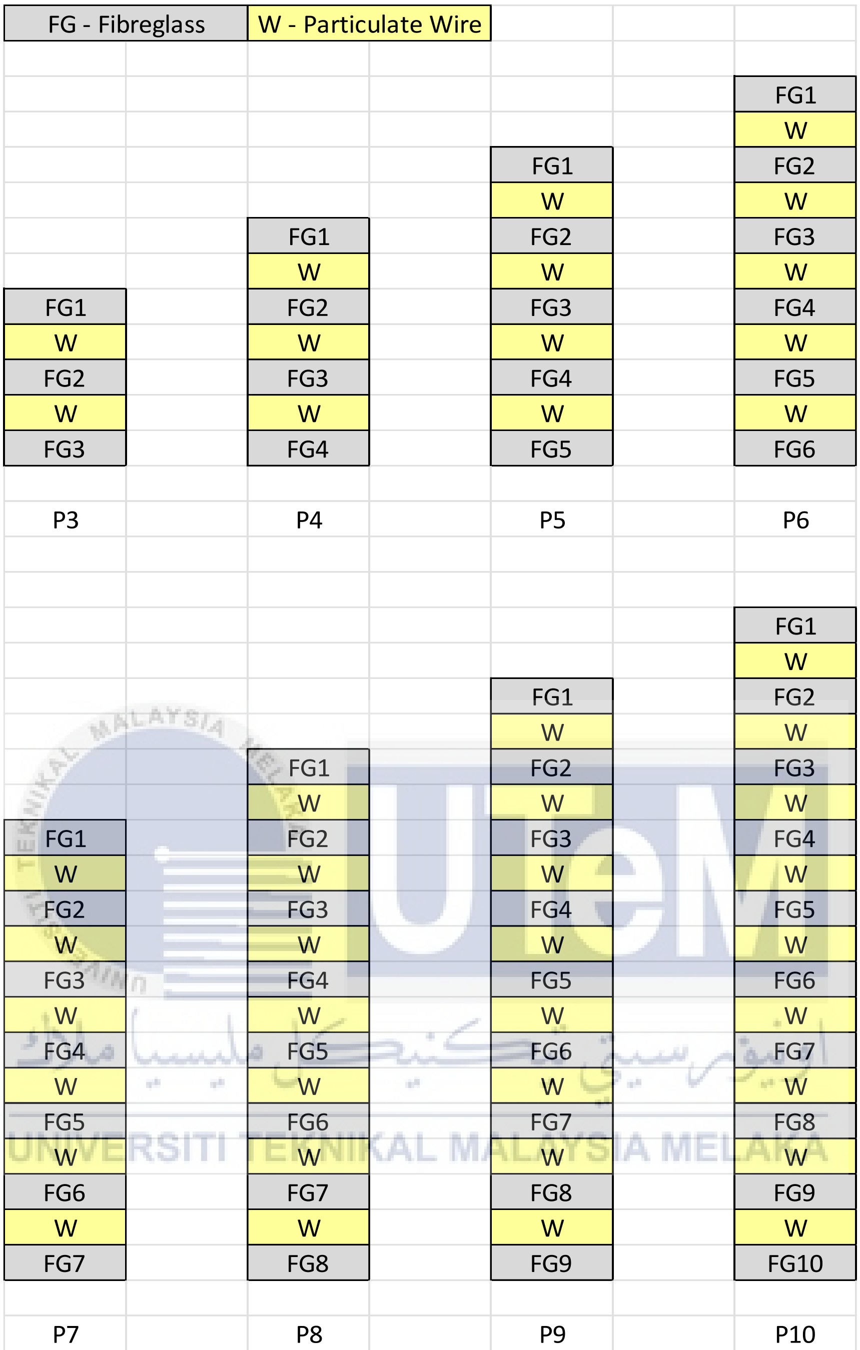

Figure 3.15 The lamination stacking sequence for P3 to P10.

3.6 Cutting of Specimen into Sample Size

The specimen size remains unchanged in both Stage 1 and Stage 2 as per the guidelines set by ASTM. Nevertheless, the cutting method employed is different. Table 3.7 displays the dimensions in accordance with their respective standards.

Table 3.7 Dimension according to ASTM

Test	Standard	Specific Dimensions (mm)
Tensile Test	ASTM D3039	Length: 250
		Width: 25
Flexural Test	ASTM D790	Length: 127
		Width: 12.7
Pendulum Impact Test	ASTM D256	Length: 55
		Width: 12.7

3.6.1 Stage 1 – Laser Cutting

In Stage 1, specimens exhibit minor variation. Specimen P10 has a thickness of 1.33 mm, whereas P90 is thicker only by 0.2 mm. The minimal range permits the use of a laser cutting machine to fabricate precise sample size.

The procedure starts with the process of drawing the specimen on AutoCAD, following the guidelines set by ASTM as shown in Figure 3.16. The laser cutting machine is configured with a 2 mm input thickness, designating the material as composite, and using gas for the cutting process. Prior to operation, a simulation is conducted to verify the machine's precise conformance to the drawing. The laser cutting equipment operates on a single specimen at a time to guarantee accuracy. Figure 3.17 shows the specimen being cut using a laser cutting machine.

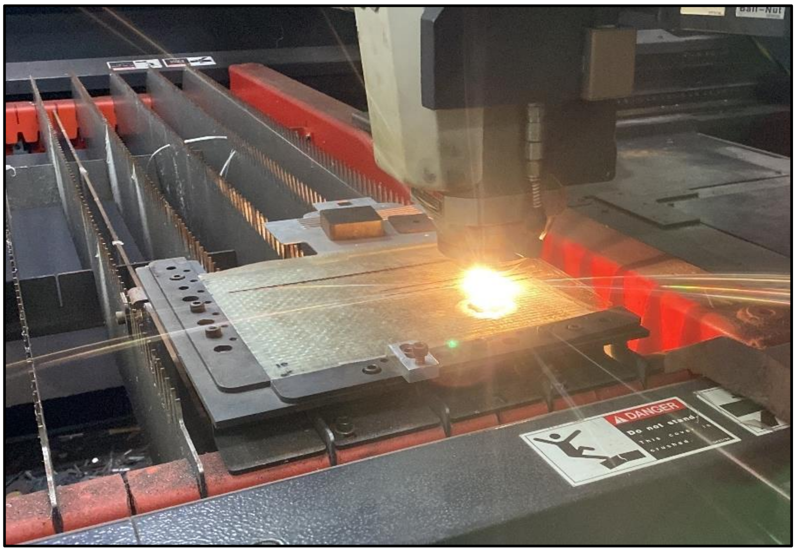

Figure 3.16 Laser-cutting the specimen in Stage 1

3.6.2 Stage 2 – Manually Cut Using Vertical Hand Saw

In order to reduce the possibility of wire burning, the second stage uses a vertical band saw. In Stage 2, the same design is hand-sketched on each specimen as shown in Figure 3.18, guaranteeing precise scaling of the dimensions. The vertical band saw machine is next adjusted and put to use to make cuts along the outlined pattern on the surface.

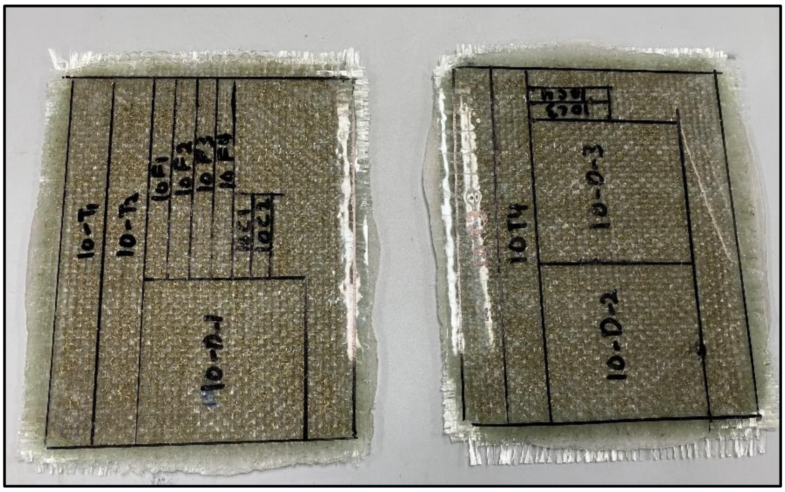

Figure 3.17 Drawing of sample is sketched on composite panels

3.7 Mechanical Testing

The results of the tests that were done on the material are the most important thing to think about when trying to find any changes in its properties. Following the guidelines set by the ASTM, the results of the running tests will be used to see if it is possible to reach the research objective by following the steps shown in Table 3.1.

Table 3.8 The ASTM guidelines used for conducting standardised test.

Testing	ASTM Standard
Tensile test	ASTM D3039
Flexural test	ASTM D790
Impact test	ASTM D256
Drop weight test	ASTM D7136

3.7.1 Tensile Testing

The tension test, also referred to as the tensile test, is a method used to evaluate the ductility of a material under controlled tensile loading until it reaches its point of failure. The specimens need to be cut into dimensions as shown in Figure 3.18 beforehand.

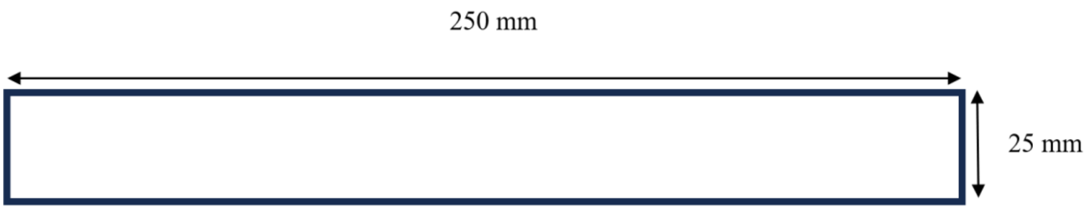

Figure 3.18 The dimensional specifications for a tensile test specimen are determined in accordance with the guidelines outlined in ASTM (D3039).

A crosshead speed of 2 mm/min will be used to pull the specimen to failure in accordance with ASTM D3039 standards. The specimens will undergo a tensile strength analysis using Shimadzu Universal Testing Machine (UTM). Tensile strain was measured with strain gauges attached along the specimen's longitudinal axis. The interaction between the matrix and fibre can be verified by tensile testing. In Chapter 4, the stress-strain curve will be drawn and assessed using test data.

Figure 3.19 Universal Testing Machine (SHIMADZU)

3.7.2 Flexural Testing

The goal of this experiment is to find out how well each layer in a layered composite material made of different threads does what it is supposed to do under a bending environment. Figure 3.20 shows the dimension of specimen for flexural test. According to the standard testing procedure set out in ASTM D790, a flexural load must be put on the layered composite material as shown in Figure 3.21. The diagrammatic representation of the flexural test can be seen in Figure 3.22.

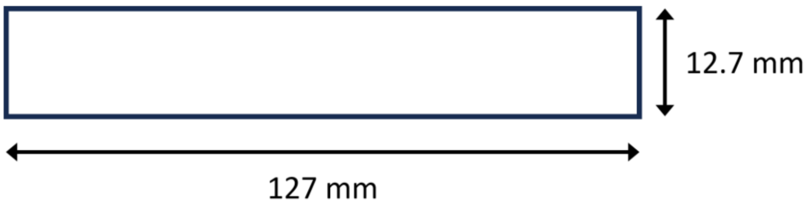

Figure 3.20 Dimension of specimen under ASTM D790

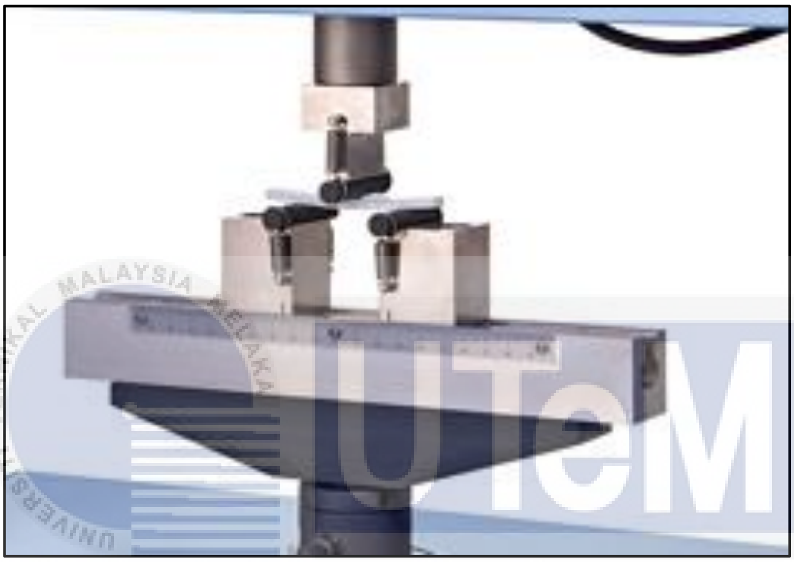

Figure 3.21 Bending the specimen under load

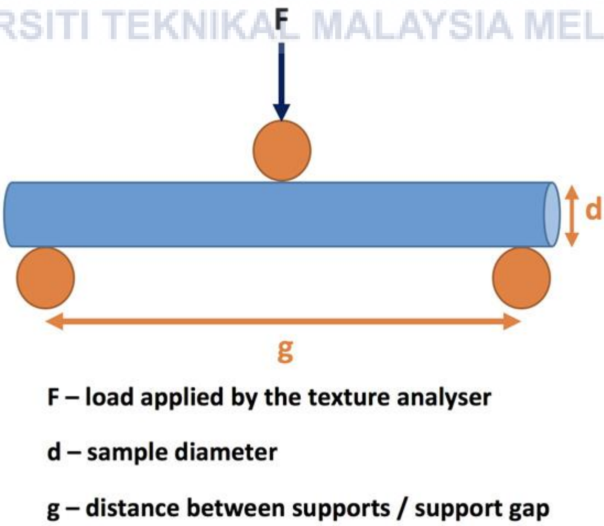

Figure 3.22 A diagrammatic representation of the flexural test (Texture Analysis Professionals, 2019).

3.7.3 Pendulum Impact Test

This study involved the implementation of the Charpy impact test to evaluate the impact absorption capacity of the reinforced composite material. The diagram presented in Figure 3.12 depicts the configuration of the specimen utilised in the impact test, including the notch and its geometry. The specimen is positioned in a horizontal orientation within the Charpy impact apparatus, following which the hammer is released from a specific height to collide with the specimen. Figure 3.13 displayed an apparatus for conducting impact testing.

Table 3.9 Work process for pendulum impact testing

No.	Process
1.	Setup the Instron Pendulum Impact Tester equipment in accordance with the guidelines provided by the manufacturer.
2.	Create a V-shaped incision on each specimen using a V-notch cutter. The positioning of the notch ought to be at the centre of one of the larger facets of the specimen.
3.	Use a lint-free cloth to eliminate any dirt or contaminants from the test specimens.
4.	Choose the suitable pendulum category according to the energy storage capacity needed for the experiment.
5.	Securely clamp the test specimen to the pendulum using the specimen holder. Ensure that the orientation of the notch is positioned in a direction opposite to that of the pendulum.
6.	Set the pendulum to its initial position, ensuring that it is at a sufficient height for the desired impact energy.
7.	Measure and record the average temperature and relative humidity levels within the designated testing zone.
8.	Release the pendulum, allowing it to swing freely and strike the test specimen at the V-notch.
9.	Conduct an observation and record the amount of energy that is absorbed by the specimen upon impact by measuring the angle of oscillation of the pendulum following to the collision.
10.	Repeat the test for five specimens to obtain statistically significant results
11.	Determine the average amount of energy absorbed by the specimens and show the results.
12.	Conduct a post-impact visual inspection of the test specimens to evaluate any observable damage or modes of failure.
13.	Perform an in-depth analysis of the test outcomes and compare them with the preexisting requirements and specifications for the laminated composite material.

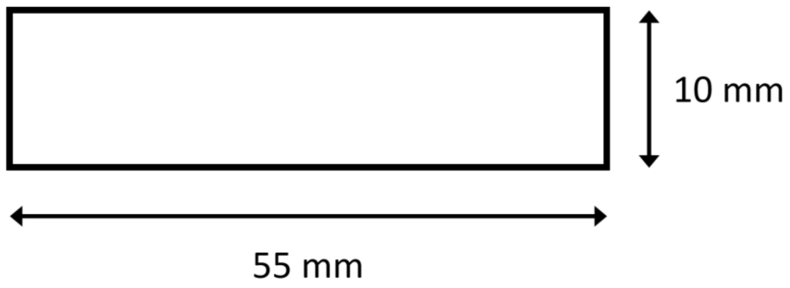

Figure 3.23 Geometry for impact Charpy test (ASTM D256) (Smewing, 2020)

Figure 3.24 EUROTECH Charpy-Izod Impact Tester Machine

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CHAPTER 4

RESULT AND DISCUSSION

4.1 Fabrication and Characteristics of Laminated Composite in Phase 1 and 2

The fabrication of laminated composite in this study involves the use of epoxy resin as the matrix, the integration of wire cut waste and fibreglass followed by the hand layup technique, which will result in the formation of a reinforced composite.

In the progress of fabricating the laminated composite with the best formulation, there are two stages of experiment involved which are; i) Stage 1 - Determining the optimum fibre loading ranging from 10% to 90% wt of waste brass wire sandwiched between two layers of fiberglass woven roving through hand layup technique; and ii) Stage 2 - Determining the optimum amount of fiberglass woven roving to be used to sandwich the fibre loading. Table 4.1 and Table 4.2 explains the content of wire waste in Stage and the number of FG layers in of a specimen in Stage 2 respectively. Every composite panel was cut into specimen size accordingly after being properly cured to undergo three types of mechanical testing namely tensile test, flexural test and pendulum impact testing to evaluate the performance of the laminated glass composite.

Table 4.1 Sample code in Stage 1

Sample code	Waste Wire Content in Specimen
EP	Matrix resin only
WW	Waste wire with matrix
FG	Fibreglass with matrix
P10	Wire weight 10% of FG and matrix
P20	Wire weight 20% of FG and matrix
P30	Wire weight 30% of FG and matrix
P40	Wire weight 40% of FG and matrix
P50	Wire weight 50% of FG and matrix
P60	Wire weight 60% of FG and matrix
P70	Wire weight 70% of FG and matrix
P80	Wire weight 80% of FG and matrix
P90	Wire weight 90% of FG and matrix

Table 4.2 Sample code in Stage 2

Sample code	Number of FG layers
P2	2
P3	3
P4	4
P5	5
P6	6
P7	7
P8	8
P9	9

4.1.1 Ratio of Laminated Specimen in Phase 1

The specimen for this study was made with hand layup method. To accommodate for all three types of testing, two panels of each ratio must be fabricated. For each ratio of waste brass wire, two panels have to be fabricated to accommodate for three testing – tensile test, flexural test, and pendulum impact test – to investigate the mechanical properties. The ratio of waste brass wire to epoxy resin is depicted in Table 4.3.

Table 4.3 Ratio of Waste Brass Wire, Woven Roving Fibre Glass, and Epoxy resin.

Samples	**Brass wire waste, %**	**Brass wire waste, g**	**Woven Roving Fibre Glass, g**	**Epoxy Resin Ratio**	
				Epoxy	**Hardener**
Epoxy (EP)	0	0	60	46.74	13.26
Waste Wire (WW)	100	60	60	46.74	13.26
Fiberglass (FG)	0	0	60	46.74	13.26
P10	10	6	60	46.74	13.26
P20	20	12	60	46.74	13.26
P30	30	18	60	46.74	13.26
P40	40	24	60	46.74	13.26
P50	50	30	60	46.74	13.26
P60	60	36	60	46.74	13.26

P70	70	42	60	46.74	13.26
P80	80	48	60	46.74	13.26
P90	90	54	60	46.74	13.26

4.1.2 Ratio of Laminated Composite in Phase 2

In this phase, it has been determined that Specimen P50 in Phase 1 will be selected based on the results of its mechanical properties. Therefore, the weight of wire for specimens P3 to P10 is 50% of the weight of each specimen's fibreglass. The manipulated variable in this phase shifts its focus to determining the best number of layers of fibreglass. Thus, the weight of matrix throughout the specimens will also change according to the weight of total number fibreglass layers. Table 4.4 below shows the proportions of each component that make up the specimen in Phase 2.

Table 4.4 Weight of materials for specimens in Phase 2.

Specimen	No. of FG layers	Weight of FG layers (gram)	Weight of Wire (gram)	Weight of matrix 77.9% : 22.1% ratio	
				Epoxy	Hardener
P3	3	90	45	70.11	19.89
P4	4	120	60	93.48	26.52
P5	5	150	75	116.85	33.15
P6	6	180	90	140.22	39.78
P7	7	210	105	163.59	46.41
P8	8	240	120	186.96	53.04
P9	9	270	135	210.33	59.67
P10	10	300	150	233.70	66.30

4.2 Mechanical Properties of Laminated Composite in Phase 1

This section is dedicated to presenting the findings and engaging in an in-depth discussion of the mechanical test. Tensile testing determined the material's ability to withstand axial forces, flexural testing assessed its behaviour under bending, and impact testing evaluated its resistance to rapid forces. The carefully obtained findings from these studies serve as the foundation for a comprehensive evaluation of the mechanical functionality and potential applications of the discarded brass EDM wire.

4.2.1 Sample Properties of Laminated Composite Specimen in Phase 1

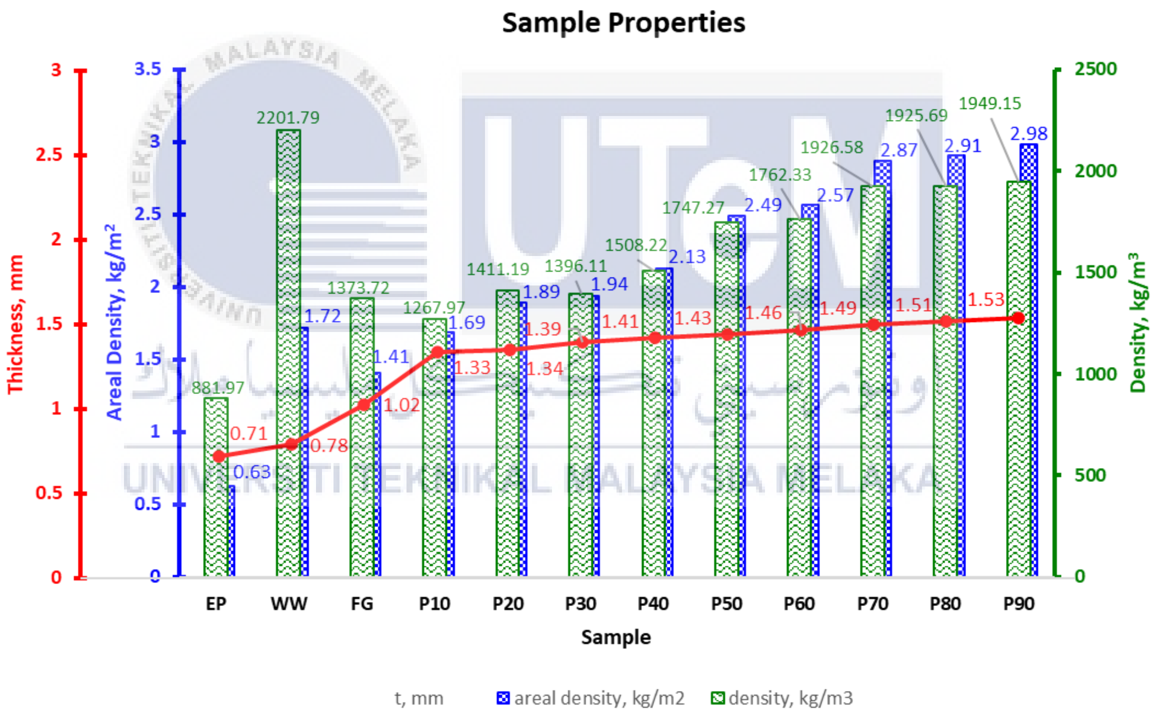

Figure 4.1 Sample properties for Phase 1

Figure 4.1 indicates the measurement of fabricated specimen properties where it focuses on the differences in thickness of all specimens. By using vernier calliper, EP, WW and FG has a thickness of 0.71 mm, 0.78 mm and 1.02 mm, respectively. When each of the three materials are incorporated together to form a panel of composite, there are changes have been observed on the thickness of the fabrication. Beginning with P10, the thickness of the panel gradually increases with an average thickness of 2.5 mm from 1.33 mm all the way to P90 with 1.53 mm. In between P10 and P90, the incorporated panel P20, P30, P40, P50, P60 and P70 obtained a thickness of 1.34, 1.39, 1.41, 1.43, 1.46, 1.49 and 1.51 mm, respectively. The small increment of thickness of the final composite panel may be due to the size of the waste wire that are cut into particulate form although there is a 10% increase of waste wire weight for each panel sample. It is also noticed that the density of the panels increases ranging from 1267.97 kg/m^3 to 1949.15 kg/m^3 as the thickness increases. It is also worth to mention that the density of waste EDM wire is quite high with 2201.79 kg/m^3 although the thickness of the panel is only 0.78 mm.

4.2.2 Tensile performance in Phase 1

The purpose of conducting tensile test onto the composite panels is to evaluate the tensile strength and modulus of the elasticity by measuring the amount of force required to break the specimen and the specimen's extension. The force was measured after the sample is subjected to stress until it breaks, and the tensile load is displayed against the change in length, or displacement, of the material. The load is then translated to stress, and the displacement to strain. To produce the composite specimen for testing, the ASTM D-3039 standard is applied. Figure 4.2 shows the tensile graph result obtained from the test.

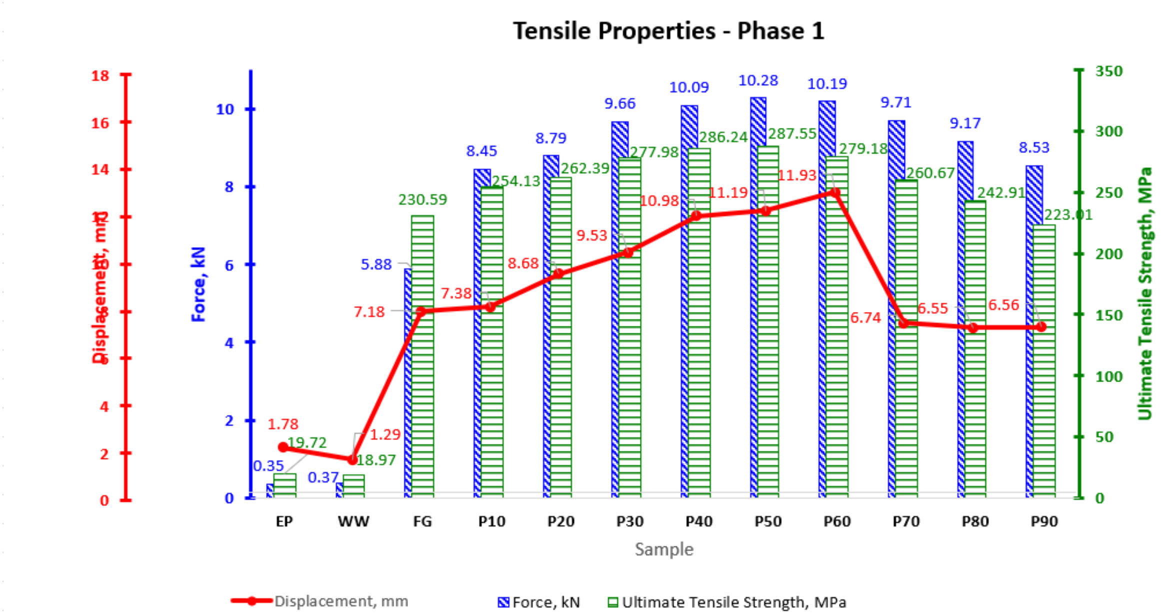

Figure 4.2 Tensile strength performance for laminated composite in Phase 1

The analysis of tensile strength indicates that EP, WW and FG material has a tensile strength of 0.33 kN, 0.37 kN and 5.88 kN, respectively. All of the modified panel samples with different weight percentages of waste EDM wire have been tested for the tensile strength test. Generally, the amount of force needed to break the specimen into two increases consistently from P10 with 8.45 kN until it reaches the highest amount of force at P50 with 10.28 kN, which is only 1.83 kN of difference. From there, the amount of force needed to break the modified specimen gradually decreased. This result suggests that the specimen layer has declining strength as the percentage weight of waste EDM wire increases. When more than 50% weight of wire is added, the increase in wire content might introduce too much load in between the two layers of FG thus creating more weaker points in the composite specimen. According to the results obtained from the test conducted, it took 10.19 kN, 9.71 kN, 9.17 kN and 8.53 kN of force to break P60, P70, P80 and P90 panel into two parts, respectively.

Referring to the same graph, ultimate tensile strength, GPa seems to present the same trend as the tensile strength. Starting at 254.13 MPa for P10 panel, the UTS increases steadily up to P50 with 287.55 MPa and starts to decrease slowly afterward to the lowest measurement of UTS which is 223.01 MPa for P90 panel. From the tensile strength test, it is confirmed that P50 panel will not easily get fractured upon torsion and required at least 10.28 kN of force to break into parts. Figure 4.3 shows samples after undergone tensile test.

Figure 4.3 Samples for tensile testing.

4.2.3 Flexural Performance in Phase 1

The flexural performance of the samples was assessed in this section using the Shimadzu Universal Testing Machine (UTM). The specimens used for experimentation have dimensions of 12.7 mm by 127 mm. The data was meticulously documented, and graphs were constructed to help in the study and comparison of flexural performance over nine various percentages of wire content in samples.

The testing adhered to the ASTM D790 standard, with the crosshead speed set at 2 mm/min. In addition, the lower support was positioned at a height of 60 mm. The utilisation of this standardised testing procedure ensures uniformity and dependability in the examination of the bending characteristics of composite samples, offering valuable understanding into their mechanical response when subjected to bending forces. Figure 4.4 shows the graph of flexural properties.

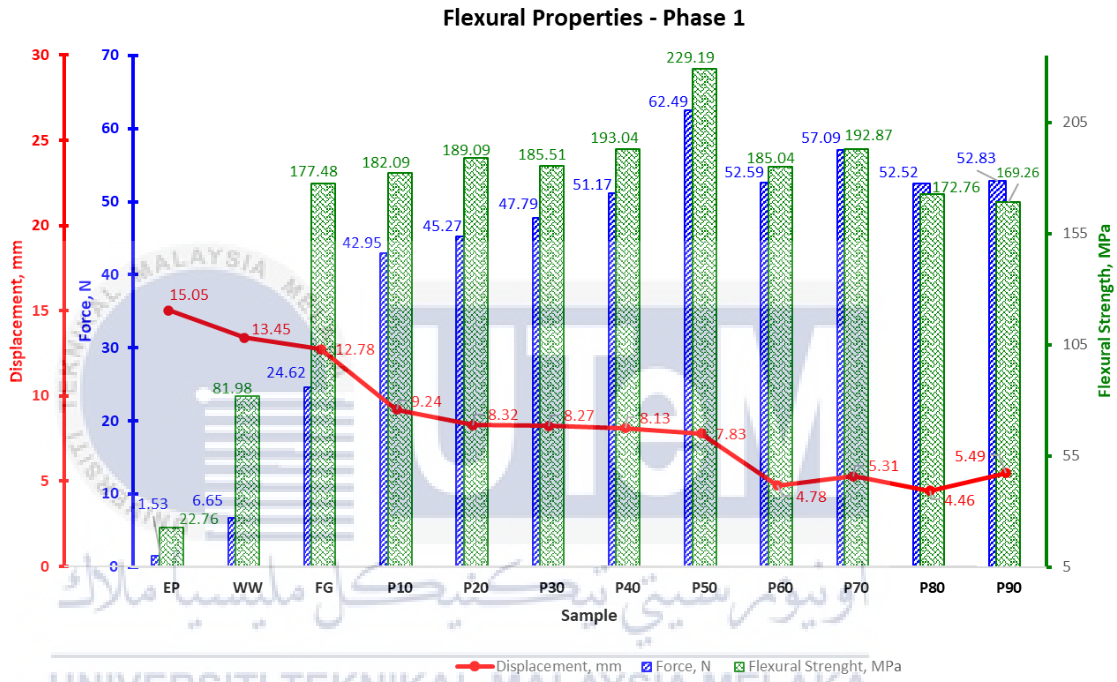

Figure 4.4 Flexural properties of specimen in Phase 1

According to the graph, P50 has the maximum flexural strength value of 229.19 MPa among the different percentages of used brass EDM wire content in the specimens while P90 has the lowest flexural strength value at 169.26 MPa. This shows a 35.41% difference in flexural strength of P90 compared to P50. The flexural strength at P20 (189.09 MPa) is approximately 4.01% higher than at P10 (182.09 MPa). There is an increase of flexural strength, from 185.57 MPa at P30 to 193.04 MPa at P40. The flexural strength at P50 (229.19 MPa) shows a significant increase of about 18.73% compared to

P40. This notable rise suggests a substantial improvement in the material's resistance to bending, potentially due to changes in composition or structure. There is a decrease of approximately 19.30% in flexural strength from P50 to P60 (185.04 MPa). This significant drop indicates a notable reduction in the material's ability to withstand bending forces.

The graph also shows the forces on applied to each specimen. Starting with P20 compared to P10, there is an increase in force from 42.95 N to 45.27 N, indicating a rise of approximately 5.37%. This suggests a moderate increment in the applied force required for flexural testing. Moving on to P30, there is a further increase in force to 47.49 N, representing another increase compared to P20. This demonstrates a continued trend of rising forces. The transition from P40 to P30 reveals a more pronounced increase in force, from 47.49 N to 51.17 N.

The most substantial change occurs between P50 and P40, where the force increases from 51.17 N to 62.49 N, indicating a remarkable rise of approximately 21.98%. This substantial increase in force may suggest a critical point in the material's behaviour, possibly reflecting a shift in its mechanical properties.

However, a notable decrease in force is observed between P60 and P50, where the force drops from 62.49 N to 52.59 N, representing a significant reduction of approximately 15.85%. This abrupt change suggests a decrease in the material's resistance to bending, possibly due to alterations in its internal structure. The force at P70, 57.09 N, is higher than at P60. The force decreases from 57.09 N at P70 to 52.52 N at P80. Finally, the force at P90, 52.83 N, is slightly higher than at P80.

The displacement data on the graph show a steadily decreasing pattern. The highest value recorded is P10 which is 9.24 mm. Meanwhile P80 records the lowest value at 4.46 mm. The biggest change is from P50 to P60 which has a 3.05 mm difference. Figure 4.5 shows the sample for flexural testing in Phase 1.

Figure 4.5 Sample for flexural testing in Phase 1.

4.2.4 Pendulum Impact Performance in Phase 1

The Charpy pendulum test was conducted on composite samples reinforced with wire waste, following the guidelines set by ASTM D6110 standards. The samples were meticulously prepared for testing, with dimensions of 10 mm x 55 mm. The Charpy test involved the application of an impact load of 8.8 kg using the Eurotech Charpy-Izod impact tester. The expected result for flexural performance can be seen in Figure 4.6.

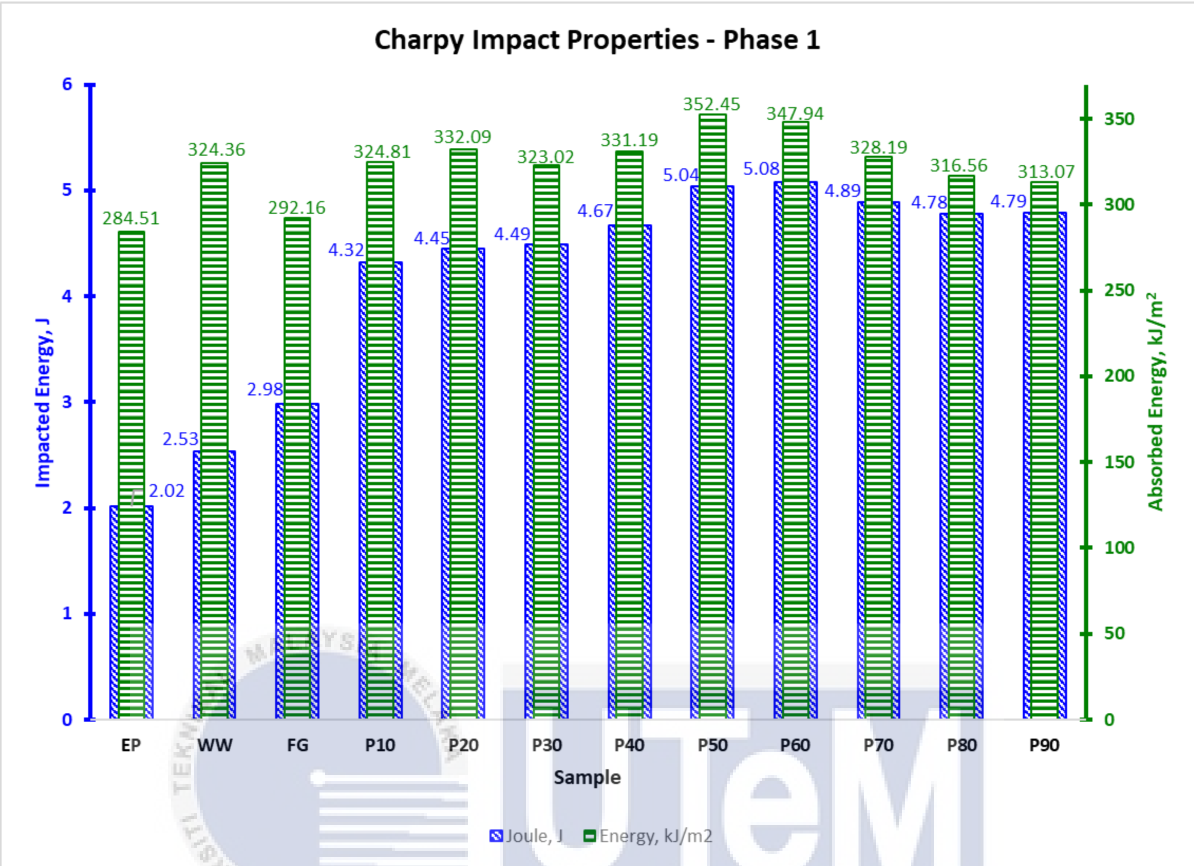

Figure 4.6 The Charpy performance of specimen in Phase 1

Beginning with the transition from P10 to P20, there is a modest increase from 4.32 J to 4.45 J. Moving to P30, there is a further increase to 4.49 J. The most significant change is observed between P40 and P50, where the impacted energy rises from 4.67 J to 5.04 J, representing a substantial increase of approximately 7.92%. This notable improvement suggests a critical point in the material's behaviour, potentially indicative of enhanced toughness and impact resistance.

Continuing to P60, the impacted energy remains relatively stable at 5.08 J. However, a noticeable decrease is observed between P60 and P70, where the impacted energy drops to 4.89 J. This decline indicates a reduction in the material's ability to absorb impact energy, possibly influenced by changes in its internal structure or composition. The impact energy at P80 (4.78 J) shows a modest decrease. Finally, the transition from P80 to P90 reveals a subtle increase to 4.79 J.

To summarise, the examination of impacted energy data reveals notable differences between P40 and P50, suggesting an enhancement in impact durability. Following transitions exhibit fluctuation, with a significant decline seen between P60 and P70, indicating a possible susceptibility to changes in the material's internal structure or composition during impact testing.

Analysing the absorbed energy data obtained from Charpy Impact testing offers valuable information about the material's ability to disperse impact energy. Starting from the shift from P10 to P20, there is a noticeable rise in the amount of energy absorbed, increasing from 4.32 kJ/m^2 to 4.45 kJ/m^2. The absorbed energy increases slightly to 4.49 kJ/m^2 as it progresses to P30.

The most notable alteration occurs between P40 and P50, with a large increase in absorbed energy from 4.67 kJ/m^2 to 5.04 kJ/m^2. This 7.92% increase is a crucial milestone in the material's performance, indicating improved ability to absorb energy.

From P50 to P60, the absorbed energy exhibits a rather consistent level of 5.08 kJ/m^2, with just a marginal rise. Nevertheless, a conspicuous reduction of 3.87% is evident from P60 to P70, resulting in a decrease in absorbed energy to 4.89 kJ/m^2. This decrease indicates a declining ability to disperse impact energy. The energy absorbed at P80 (4.78 kJ/m^2) exhibits a little reduction in comparison to P70. The change from the P80 to the P90 results in a marginal elevation to 4.79 kJ/m^2.

To summarise, the examination of absorbed energy data reveals notable differences between P40 and P50, indicating an enhancement in the material's ability to absorb energy. The following transitions exhibit oscillations, with a significant decline seen between P60 and P70, indicating a possible susceptibility to changes in the internal structure or composition of the material during impact testing. Figure 4.7 shows the specimens used in the Charpy Impact Test.

Figure 4.7 The samples for Charpy Impact Test

4.2.5 Summary of Mechanical Performance in Phase 1

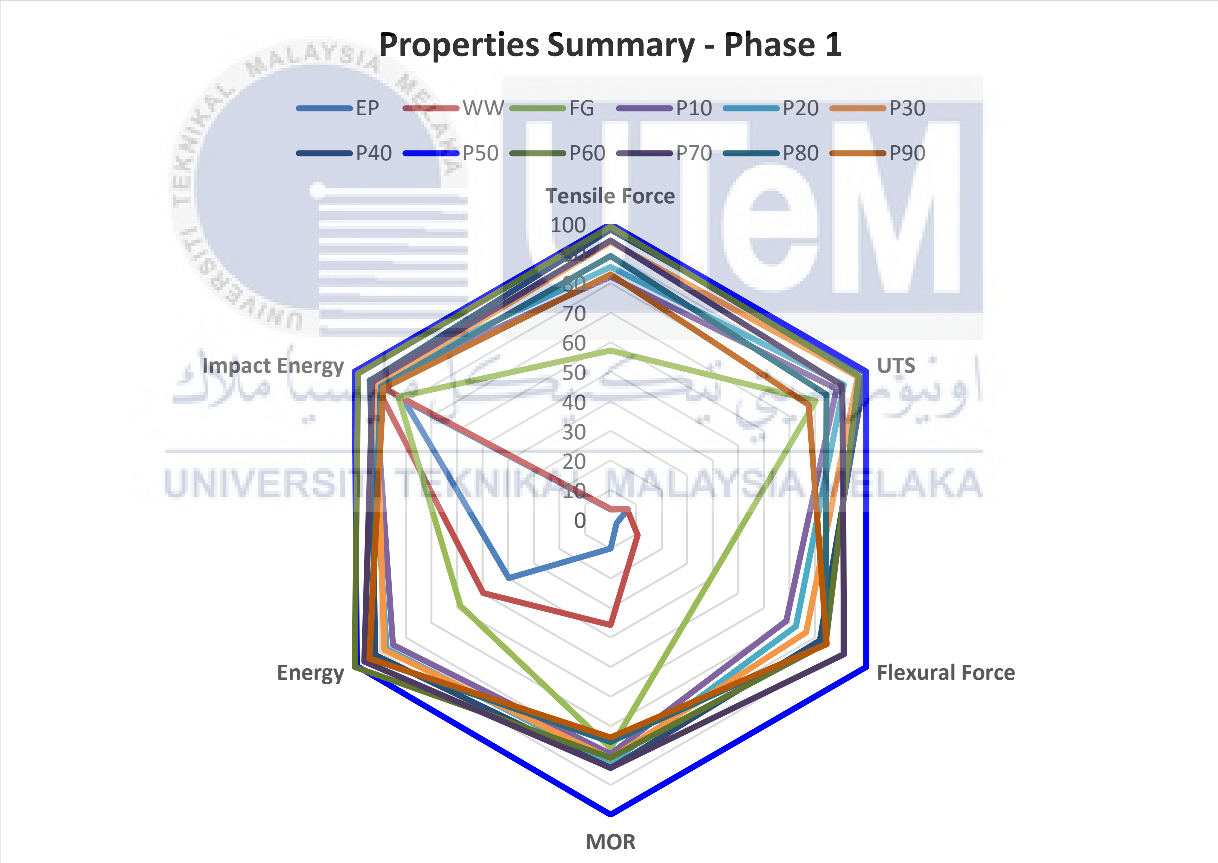

Figure 4.8 Summary of mechanical performance for specimen in Phase 1

The figure demonstrates that the tensile test, flexural test, and Charpy impact test together assess the strength, impact absorption, compression ability, and durability of the tested materials. These samples, which contain waste EDM wire, demonstrate numerous different levels of efficacy in improving material characteristics.

The material exhibited its maximum flexural strength at P50, with a remarkable force of 10.28 kN. This indicates a strong ability to withstand bending pressures, demonstrating the material's durability and structural soundness.

The tensile test revealed that the material achieved its maximum ultimate tensile strength at P50, measuring 287.55 MPa. This figure denotes the material's tensile strength, which demonstrates its capacity to resist pressures applied in a pulling or stretching manner.

The Charpy impact test determined that the maximum energy absorbed occurred at P50, with a measurement of 5.04 J. This highest value demonstrates the material's exceptional ability to absorb impact energy, hence improving its toughness and resilience.

Overall, the maximum data obtained from each test (P50) provides a complete overview of the material's mechanical capabilities. It exhibits remarkable strength in both bending and stretching aspects, together with great toughness and resistance to impact. This indicates that the material is adaptable and strong, making it suitable for applications that need both strength and resilience.

To summarise, the material's outstanding mechanical qualities are shown in its greatest performance metrics, which were recorded at P50 in flexural, impact, and tensile testing. The material's strong flexural strength, impact energy absorption, and tensile strength make it a flexible and durable option for applications that need strength, toughness, and resilience. Conducting more thorough research and tests may yield further insights into how the material behaves under various settings.

4.3 Mechanical Properties of Laminated Composite in Phase 2

The best weight percentage of waste EDM wire (P50) that was determined from Phase 1 was further studied to optimize the formulation. The amount of weight percentage of waste EDM wire was fixed throughout this phase while the number of fiberglass layers were varied. Once all the pristine materials were incorporated together to form the laminated composite, the panels were taken to several tests to evaluate their performances.

4.3.1 Sample Properties of Laminated Composite Specimen in Phase 2

Phase 2 experiment focuses on the optimization of the strength of laminated composite by varying the amount of woven roving fibreglass to be layered in a panel. The purpose of optimization is to attain the maximum level of strength while minimizing the cost and composite materials. In this phase, the number of FG layers starts from P3 and ends at P10 with a fixed weight of epoxy to hardener ratio, 77.9%: 22.1 %. The final laminated composite samples are taken to the similar tests as Phase 1 to evaluate their performance. Prior to the fabrication of composite, the properties of each woven roving fiberglass are measured and is shown in Figure 4.9.

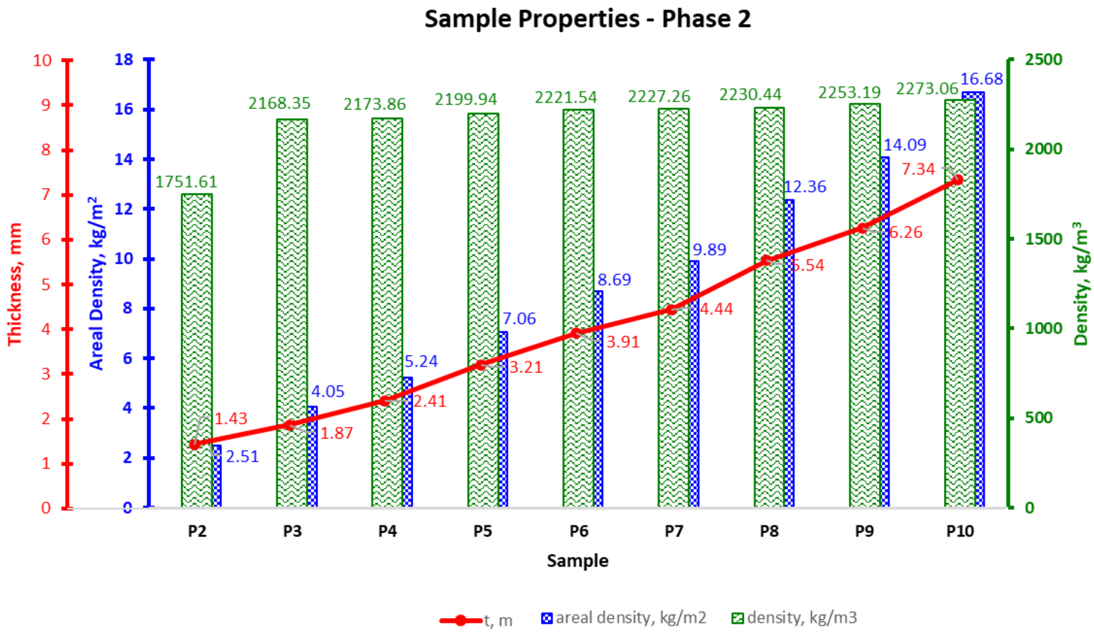

Figure 4.9 Sample properties of specimen for phase 2

Graph in Figure 4.9 reveals that the thickness of the specimen gradually increases as the number of layers of fiberglass woven roving increases. P10 apparently is the thickest specimen measuring at 7.34 mm while P2 has the least thickness with 1.43 mm. The thickness measurement increases averagely about 1 mm as one layer of fiberglass increases in each sample. P3, P4, P5, P6, P7, P8 and P9 has a thickness of 1.87, 2.41, 3.21, 3.91, 4.44, 5.54 and 6.26, respectively. As for the density of the composite, there is a very minimal of increment when the number of layer increases. However, P2 specimen has a quite low density measurement with 1751.61 kg/m^3 and abruptly increases to 2168.35 kg/m^3 when another layer of fiberglass is added at P3 sample.

4.3.2 Tensile Performance in Phase 2

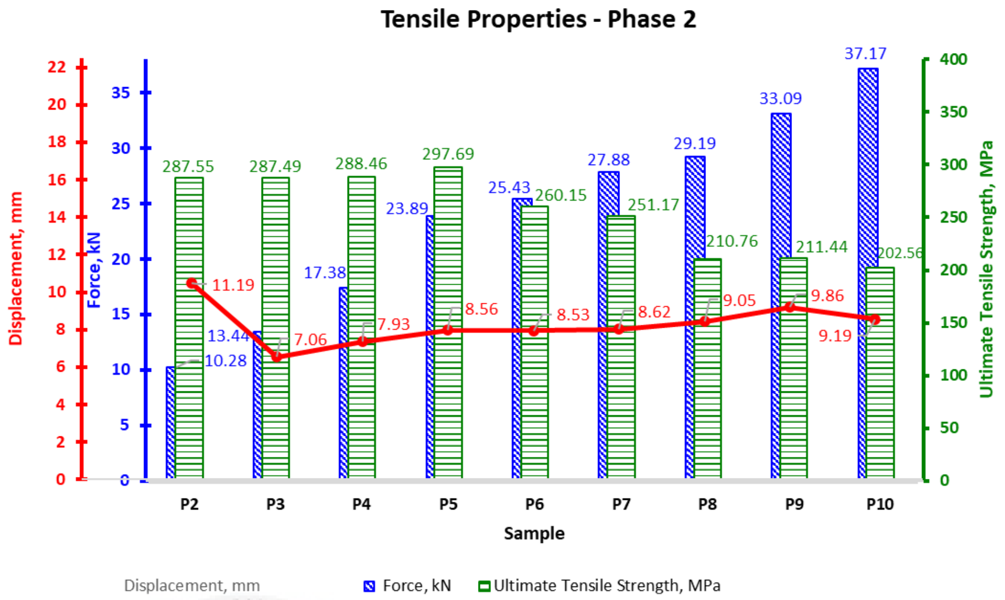

Figure 4.10 Tensile strength measurement for laminated composite in Phase 2

With similar execution of testing, the performance of laminated composite was evaluated to study the tensile strength and the modulus of elasticity. The purpose of this experiment is to determine the strength of a material and its maximum stretching capacity before reaching its breaking point. Figure 4.10 above indicates the measurement of tensile strength of the laminated composite. The analysis of the graph shows an interesting relationship between the two variables of the amount of force required to break the specimen and the ultimate tensile strength where they are in inverse relationship. From P2 composite panel, the force exerted on the specimen increases steadily starting from 10.28 kN to 37.17 kN for P10 panel. When compared to Phase 1, at most 10.28 kN of force is needed to break a 1.46 mm thick of laminated composite. However, as the amount of force required to break the specimen goes higher, the ultimate tensile strength trend slowly decreases towards P10. Noticeably, there is a slight increase of ultimate tensile strength on P5 but the trend continues to decrease slightly afterwards. This surge in the force required to break the specimen may due to the significant increasing of thickness of the panel. The thickness of laminated composite in Phase 1 were around 1.33 mm to 1.53 mm while the thickness of laminated composites in Phase 2 are ranging from 1.43 mm to 7.34 mm, which is ~7 times the width.

The strength of a material is directly impacted by its thickness, as it determines the amount of force it can endure. Thicker materials possess a remarkable ability to withstand greater forces without becoming susceptible to breakage or deformation. On the other hand, thinner materials exhibit a lower threshold for force and are more prone to fracture when subjected to stress. When it comes to material strength, the crucial factor that sets thickness and thinness apart is the level of force or stress that a material can handle before it breaks or deforms. Thicker materials tend to possess greater strength as they possess a higher mass and can effectively distribute force across a larger surface area. Conversely, thinner materials are more prone to breakage when subjected to stress, owing to their smaller mass and surface area. Although thicker materials offer increased strength, they come with the drawbacks of added weight and higher cost. In certain applications where weight and cost need to be minimised, this can pose a disadvantage. Figure 4.11 shows the specimen that went through tensile testing for Phase 2.

Figure 4.11 Sample for tensile testing in Phase 2

4.3.3 Flexural Performance in Phase 2

The flexural strength, also known as bending strength, is a crucial mechanical parameter that measures a material's capacity to withstand deformation when subjected to a load. Calculating the flexural properties involves utilising a three-point bending configuration. In this setup, the sample is supported at both ends, and the load is applied at the middle of the sample. The ultimate flexural strength of a sample's material is determined by the maximum stress applied to the tension side of the sample, causing it to break. For the fabrication of the samples, it is recommended to follow the ASTM D790 standard. Once fabricated, these samples can be tested on the Shimadzu Universal Testing Machine.

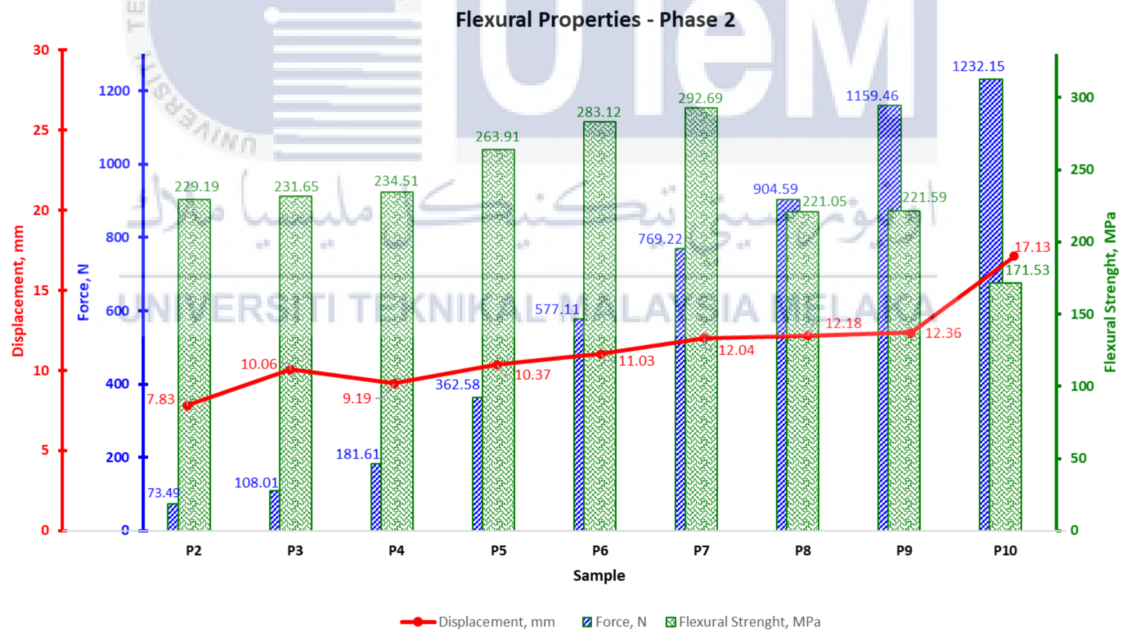

Figure 4.12 Flexural properties of laminated composite in Phase 2

The graph above in Figure 4.12 presents data on the flexural properties of the laminated composite. As seen in the figure, it is obvious that the amount of force required for the panel to start to flex increases consistently as the number of fiberglass layers increases.

With the least thickness size, P2 required at least 73.49 N of force to start to bend while P10, with the most thickness, was able to withstand 1232.15 N of force before it started to break. The amount of force needed for P3, P4, P5, P6, P7 and P8 are 108.01, 181.61, 362.58, 577.11, 769.22, 904.59 and 1159.46 MPa. In the same graph, the pattern of flexural strength shows an increment trend starting from P2 (229.19 MPa) and slowly decreasing from P7 (292.69 MPa) to P10 (171.53 MPa). With a displacement of 12.04 mm and a required force 769.22 MPa, P7 laminated composite is believed to have the highest flexural strength with 292.69 MPa. Looking at the trend shown by flexural strength, it is believed that the proportion of reinforcing fibres and their arrangement in the hybrid layup are the key elements that determine the improvement of flexural characteristics. While flexural strength and required force possess an inverse relationship, displacement on the other hand seems to fluctuate all over the graph although the overall trend shows an increment pattern. The highest value of displacement is obtained by P10 with a value of 17.13 mm. Figure 4.13 shows the samples that went through flexural testing.

Figure 4.13 Sample for flexural testing in Phase 2

4.3.4 Pendulum Impact Performance in Phase 2

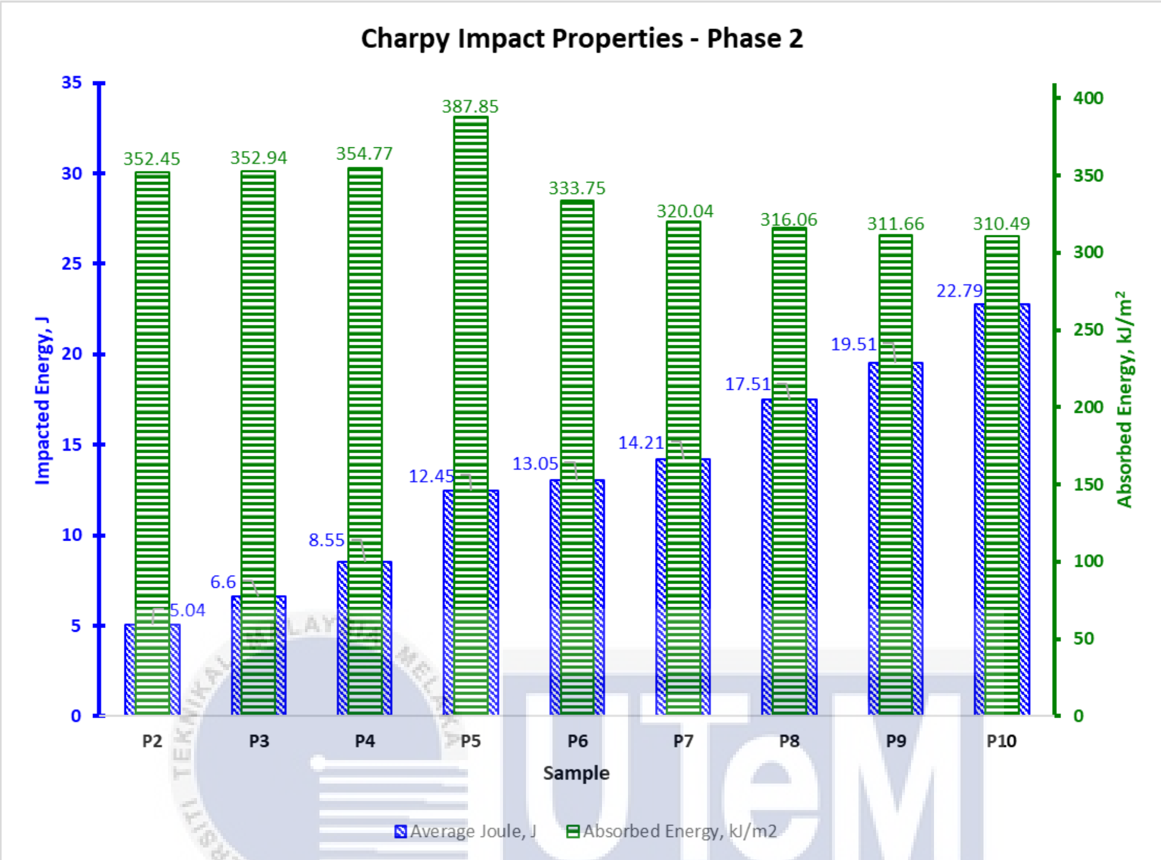

Figure 4.14 Charpy impact properties for laminated composite in Phase 2

At P2, the impacted energy is measured at 5.04 J. This value represents the material's response to Charpy Impact testing with two layers of fibreglass. Figure 4.14 shows the rest of Charpy impact properties of laminated composite in phase 2. Moving to P3, there is a notable increase in impacted energy to 6.6 J. At P4, the impacted energy rises to 8.55 J. P5 records a significant increase in impacted energy, reaching 12.45 J. This represents a critical point in the material's behaviour, indicating a remarkable improvement in its resilience against impact forces. The impacted energy at P6 is measured at 13.05 J. At P7, the material demonstrates an impacted energy of 14.21 J. P8 records an increase in impacted energy to 17.51 J, representing a substantial improvement in the material's ability to withstand and dissipate impact forces. he impacted energy at P9 is measured at 19.51 J. The highest impacted energy is observed at P10, reaching 22.19 J.

Examining the absorbed energy data from Charpy Impact testing provides insights into the material's ability to absorb energy per unit area. At P2, the absorbed energy is measured at 352.45 kJ/Nm². Moving to P3, a marginal increase is observed in absorbed energy, reaching 352.94 kJ/Nm². A more noticeable change occurs at P4, where the absorbed energy rises to 354.77 kJ/Nm². A substantial leap is observed at P5, with absorbed energy reaching 387.85 kJ/Nm². This significant increase marks a critical point in the material's behaviour, showcasing a remarkable improvement in its ability to absorb impact energy. The trend shifts at P6, where absorbed energy drops to 333.75 kJ/Nm². A further decrease is evident at P7, with absorbed energy measuring 320.04 kJ/Nm². This trend suggests a continued reduction in the material's energy absorption capacity. The decline continues at P8, where absorbed energy drops to 316.06 kJ/Nm². P9 records a decrease in absorbed energy to 311.66 kJ/Nm². Finally, at P10, the absorbed energy reaches 310.49 kJ/Nm², representing the lowest value in the dataset. This nadir suggests a continued decrease in the material's ability to absorb and disperse impact energy, reaching its minimum at this percentile. The percentage change from P9 to P10 emphasizes the culmination of the diminishing trend. Figure 4.15 shows the samples for Charpy Impact properties.

Figure 4.15 The sample for Charpy Impact testing in Phase 2

4.3.5 Summary of Mechanical Performance in Phase 2

Table 4.5 below shows the scoring of each sample in Phase 2 to conclude the best specimens among P2-P10 using tensile force, ultimate tensile strength (UTS), flexural force, modulus of rupture (MOR), energy and impact energy.

Table 4.5 Summary of mechanical properties in Phase 2

Samples	Tensile Force	UTS	Flexural Force	MOR	Energy	Impact Energy
P2	27.66	96.59	5.96	78.29	22.11	90.87
P3	36.16	96.57	8.76	79.14	28.96	90.99
P4	46.76	96.89	14.7	80.12	37.52	91.47
P5	64.27	100	29.43	90.17	**54.63**	100
P6	68.41	87.39	46.84	96.74	57.26	86.05
P7	75.01	84.37	62.43	100	62.35	82.52
P8	78.53	70.79	73.41	75.5	76.83	81.49
P9	89.02	71.03	94.09	75.71	85.61	80.35
P10	100	68.04	100	58.59	100	80.05

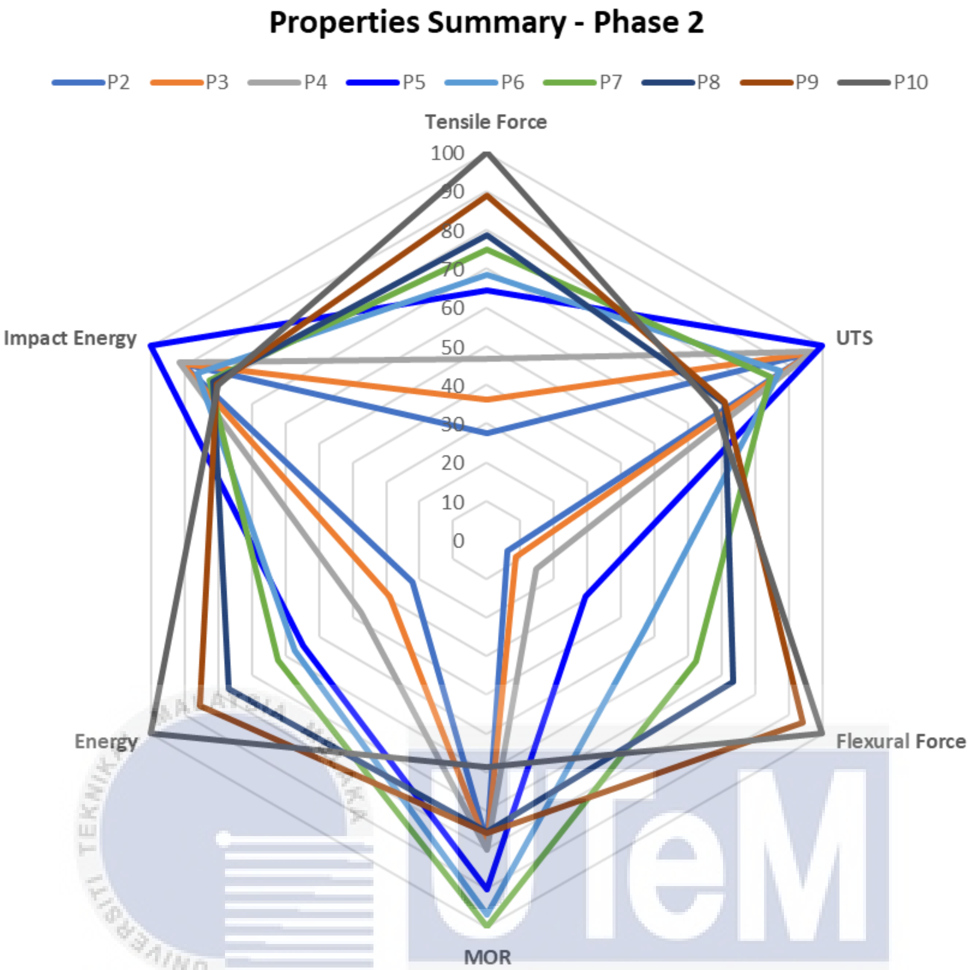

Figure 4.16 Summary of mechanical testing in Phase 2

The summary of the result performance result, however, is portrayed in Figure 4.16 spiderweb chart. The results obtained from the tensile testing revealed a progressive increase in tensile force as the specimen number increased. The values ranged from P2 with a force of 27.66, steadily climbing to P10 with the highest recorded force of 100. The ultimate tensile strength, a critical parameter in material analysis, exhibited fluctuations across the specimens. P5 recorded the highest ultimate tensile strength at 100, while P8 and P10 showed a considerable decrease with values of 70.79 and 68.04, respectively. These variations suggest differing material properties and strengths within the tested specimens. Moving on to flexural testing, the force required to induce bending in the materials increased consistently from P2 to P10. P5 has an acceptable flexural force of 29.43. P10 exhibited the highest flexural force at 100, highlighting its capacity to withstand bending stresses. This progressive increase in flexural force suggests a strengthening trend in the materials with higher number of fibreglass layers.

The modulus of rupture (MOR), a measure of a material's ability to withstand bending, showcased variations across the specimens. P7 reached the maximum MOR value of 100, indicating its superior resistance to bending stresses. P5 has one of the highest MOR at 90.17. However, P10 displayed a notably lower MOR value of 58.59, suggesting a potential weakness in its ability to endure bending forces. Energy absorption during flexural testing displayed an upward trend, with P10 absorbing the highest energy at 100. Showing a great and acceptable value as well is P5 at 54.63. Lastly, the impact Charpy test results demonstrated the materials' resilience against impact forces. P5 exhibited the highest impact energy at 100, indicating superior resistance to sudden impacts. P10, on the other hand, recorded a lower impact energy of 80.05, suggesting a reduced capacity to withstand sudden forces compared to other specimens.

In summary, the tensile testing, flexural testing, and impact Charpy test results collectively provide insights into the mechanical properties of the tested materials. The variations observed among the specimens highlight the diverse nature of these materials, offering valuable information for material selection and application considerations in engineering and manufacturing contexts. Considering economic factors, the decision to choose P5 as the best specimen is influenced by its competitive performance across the three tests, offering a well-rounded mechanical profile while maintaining cost-effectiveness. While P5 may not be the absolute best in every single parameter, it emerges as the most pragmatic choice when considering a combination of mechanical properties and economic feasibility.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This research study provides an overview of the mechanical properties of brass EDM wire cut waste incorporated into laminated fibreglass composite using a basic hand layup cold press technique. This research was inspired by the inexpensive materials in the development of advanced composite.

The first objective of this research is to fabricate the composite of fibreglass incorporated with the particulate form of waste brass wire of WEDM as the reinforcement using hand layup process is successfully accomplished with some highlights such as the following:

a) The particulate form of brass EDM wire cut waste is cut manually using scissors into a size not longer than 1 mm to be considered particulate size for this research study.
b) A fixed ratio of Epoxy to hardener which is 77.1:22.9 has been employed throughout the study for both Phase 1 and Phase 2 as instructed by the manufacturer.
c) In Phase 1, when the reinforcements (Fibreglass woven roving and particulate form of brass EDM waste wire) and matrix (Epoxy and hardener) are incorporated together, the thickness were measured to be ranging from 1.33 to 1.53 mm. As for Phase 2, the thickness of the composite panels from P2 to P10 ranges from 1.43 to 7.34 mm.

The second objective of the research which was to conduct mechanical testing for the effects of using particulate form of waste brass EDM wire reinforced in fibreglass composite panel is also a success. In both Phase 1 and Phase 2, the mechanical performance tests that were done on the laminated glass composite are tensile test, flexural strength test and pendulum test and the results can be concluded as below:

a) Tensile test in Phase 1 reveals that by adding 50% of waste EDM wire into the composite, the laminated glass composite achieved its maximum ultimate tensile strength at P50, measuring 287.55 MPa and could withstand at least 10.28 kN of force applied onto the body of the specimen before it breaks into parts. With the same amount of WW, P50 obtained the maximum flexural strength value of 229.19 MPa when 62.49 kN of force was applied suggesting a substantial improvement in the material's resistance to bending, potentially due to changes in composition or structure. Another performance test done under Charpy impact test confirms that among all of the varying weights of WW, P50 laminated glass composite is the best and can absorb a high energy impact of at least 352.45 kJ/m^2 of absorbance energy. This test specimen that demonstrates high absorption of force might be deemed superior in terms of impact strength. All in all, P50 is considered to be an excellent laminated glass composite sample in Phase 1 as it surpasses all the performance tests and tops other samples.
b) The best weight percentage from Phase 1, which is P50 is further tested under Phase 2 for optimization by varying the number of fiberglass layers. In the tensile test, the result demonstrates that P5 has the highest UTS by achieving 297. 69 MPa when 23.89 kN of force was exerted which is comparably higher when compared to P50 panel sample UTS result in Phase 1. When tested for flexural strength, the

same laminated glass composite achieved the highest value among other panel samples. P5 obtained a flexural strength of 263.91 MPa and a displacement of 10.37 mm when 362.58 kN of force was applied. In Charpy impact test, again, P5 attained the highest absorbance energy among other laminated composite layers and considered to have an excellent impact strength.

Overall, the findings from the tensile testing, flexural testing, and impact Charpy test provide valuable information on the mechanical characteristics of the materials under examination. From an economic standpoint, the selection of P5 as the optimal specimen is determined by its strong performance in all three tests, demonstrating a comprehensive mechanical profile while being cost-efficient. Although P5 may not excel in every individual aspect, it stands out as the most practical option when evaluating a blend of mechanical qualities and economic viability.

5.2 Recommendation

Several recommendations could be suggested to further improve this research. The proposed recommendations are as follows:

a) Study of other potential tools that provide a higher efficiency in raw material preparation especially in the cutting of the wire into particulate form,
b) Investigate the difference in machinability between utilising 0.02 mm and 0.025 mm brass EDM wire cut waste in terms of which one is easier to prepare.
c) Investigate the difference in mechanical properties between 0.02- and 0.025-mm brass EDM wire cut waste.

d) Investigate the application of the laminated in terms of defence system such as anti-riot shield, vehicle fender, motorcycle parts (front fairing, tank cover, side panels, tail fairing, downside panels, etc.).

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APPENDICES

APPENDIX A: Gantt Chart for PSM 1.

No	Task Project	Plan/ Actual	Week													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Registration of PSM title.	Plan														
		Actual														
2	PSM briefing and project explanation by supervisor.	Plan														
		Actual														
3	Discuss objective and developing research questions.	Plan														
		Actual														
4	Research on literature review and writing up draft	Plan														
		Actual														
5	Briefing of Chapter 1: Introduction	Plan														
		Actual														
6	Discussion and explanation of report formatting	Plan														
		Actual														
7	Submission of Chapter 1 to Supervisor	Plan														
		Actual														
8	Presentation of draft of Chapter 2 to Supervisor	Plan														
		Actual														
9	Chapter 2 corrections	Plan														
		Actual														
10	Submisison of Chapter 2 to Supervisor	Plan														
		Actual														
11	Research on Chapter 3: Methodology and draft	Plan														
		Actual														

12	Presentation of report progress to Supervisor	Plan														
		Actual														
13	Presentation of draft of Chapter 3 and correction	Plan														
		Actual														
14	Briefing of Chapter 4: Preliminary Result and drafting	Plan														
		Actual														
15	Submission of Chapter 3	Plan														
		Actual														
16	Submission of final draft of PSM report	Plan														
		Actual														
17	Final corrections of PSM report	Plan														
		Actual														
18	Submission of PSM report to supervisor and panels	Plan														
		Actual														
19	Preparation of presentation slide	Plan														
		Actual														
20	Presentation PSM 1	Plan														
		Actual														

APPENDIX B: Gantt chart for PSM 2

No	Task Project	Plan/ Actual	Week													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Discussion planning task with supervisor	Plan														
		Actual														
2	Mould preparation	Plan														
		Actual														
3	Raw material preparation (Phase 1)	Plan														
		Actual														
4	Fabrication Process (Phase 1)	Plan														
		Actual														
5	Cutting of sample (Phase 1)	Plan														
		Actual														
6	Mechanical testing (Phase 1)	Plan														
		Actual														
7	Analysis of the data (Phase 1)	Plan														
		Actual														
8	Raw material preparation (Phase 2)	Plan														
		Actual														
9	Fabrication Process (Phase 2)	Plan														
		Actual														
10	Cutting of sample (Phase 2)	Plan														
		Actual														
11	Mechanical testing (Phase 2)	Plan														
		Actual														
12	Analysis of the data (Phase 2)	Plan														
		Actual														
13	Draft and writing of Chapter 4	Plan														
		Actual														
14	Submission of Chapter 4	Plan														
		Actual														
15	Draft and writing of Chapter 5	Plan														
		Actual														
16	Submission of Chapter 5	Plan														
		Actual														
17	Final corrections of draft report	Plan														
		Actual														
18	Submission of PSM report to supervisor and panels	Plan														
		Actual														
19	Preparation of presentation slide	Plan														
		Actual														
20	Presentation PSM 2	Plan														
		Actual														

APPENDIX C: Turnitin Report

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