PREPARATION AND CHARACTERIZATION OF SiR/EPDM FILLED WITH WASTE GLASS POWDER (WGP) RUBBER BLEND COMPOSITES

Submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

NURUL ISMAHANI ADILAH BT ABU HASSAN

FACULTY OF MANUFACTURING ENGINEERING

2021

DECLARATION

I hereby, declared this report entitled "Preparation and Characterization of SiR/EPDM Filled with Waste Glass Powder (WGP) Rubber Blend Composites" is the result of my own research except as cited in references.

Signature : ……………………………………………

Author's Name : NURUL ISMAHANI ADILAH BT ABU HASSAN

Date : 29 JULY 2021

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

………………………………………………… 1/8/2021

(Supervisor Name)

TS. DR. JEEFFERIE BIN ABD RAZAK

ABSTRAK

Adunan getah silikon (SiR) dan getah *Ethylene Propylene Diene Monomer* (EPDM) telah dipilih secara meluas bagi aplikasi penebat voltan tinggi (HV). Kelebihan yang ditunjukkan melalui kombinasi ini adalah seperti meningkatkan sifat mekanik penebat dengan kestabilan terma yang jauh lebih tinggi dan rintangan terhadap voltan tinggi. Adunan getah SiR / EPDM juga memberikan ciri ringan, meningkatkan sifat elektrik dan kekuatan lenturan. Penyelidikan ini dijalankan bagi menyediakan dan menilai ciri dan prestasi adunan komposit getah SiR / EPDM yang diperkuat dengan pengisi serbuk sisa kaca. Pengisi itu adalah berasal dari sisa kaca sebagai sumber SiO_2. Kira-kira 0, 10, 20, 30 dan 40% berat serbuk sisa silika kaca ditambah ke dalam formulasi aduan getah SiR / EPDM bagi pembuatan komposit SiR / EPDM- SiO_2. Kesan penambahan pengisi tersebut dinilai dari aspek prestasi mekanikal dan fizikal mereka. Penemuan ini, membuktikan potensi sisa kaca silika sebagai pengisi berfungsi yang bermanfaat apabila keputusan ujian mengenalpasti bahan mentah XRD,PSA dan SEM mennjukkan sifat sebenar kaca yang amorf, bersaiz lingkungan 60-90 μm dan berbentuk berpanjangan dan bersudut yang memudahkan ia menjadi pengisi adunan SiR / EPDM untuk aplikasi HV yang luar biasa. Adunan SiR/EPDM dan sisa kaca pada berat 30% menunjukkan kesan paling positif apabila keputusan kekuatan tegangan dan pemanjangan utama membuktikan ianya komposisi terbaik dengan nilai 6.2MPa dan 531.5%.Ini jelas menunjukkan sisa kaca merupakan kombinasi terbaik untuk adunan getah SiR/EPDM sebagai penebat terhadap voltan tinggi.

ABSTRACT

Silicone rubber (SiR) and Ethylene Propylene Diene Monomer (EPDM) rubber blends have been widely selected for high voltage (HV) insulating applications. The advantages shown through this combination are such as improving the mechanical properties of the insulator with much higher thermal stability and resistance to high voltages. SiR / EPDM rubber blends also provide lightweight properties, improving electrical properties and flexural strength. This research was conducted to prepare and evaluate the characteristics and performance of SiR / EPDM rubber composite blends reinforced with glass waste powder filler. The filler is derived from glass residue as a source of SiO_2. Approximately 0, 10, 20, 30 and 40% by weight of glass silica waste powder were added into the SiR / EPDM rubber complaint formulation for the manufacture of SiR / EPDM- SiO_2 composites. The effect of the addition of such fillers is evaluated from the aspect of their mechanical and physical performance. This finding, proves the potential of silica glass waste as a useful functional filler when test results identify XRD, PSA and SEM raw materials show the true properties of amorphous glass with size range 60-90 μm and elongated and angular shape that facilitates it to be SiR / EPDM for exceptional HV applications. SiR/EPDM blends with glass waste at 30% showed the most positive effect when the main tensile strength and elongation results proved to be the best composition with values of 6.2MPa and 531.5%. This clearly shows that glass waste is the best combination for SiR/EPDM rubber blends as high voltage insulator.

DEDICATION

To my beloved father, Abu Hassan bin Sobiran

My appreciated and one and only mother, Habibah binti Yusof

My adorable siblings, Azizul,Azrul,Azhar,Azizul,Nora,Piza

For giving me moral support, money, cooperation, encouragement and understanding

Thank You So Much & Love you to the moon and back

ACKNOWLEDGEMENT

In the name of ALLAH, the most gracious, the most merciful with highest praise to Allah. Finally, I manage to complete this final year project victoriously with all the effort I made. I would like to thank to my respected supervisor, Ts. Dr. Jeefferie bin Abd Razak, for the most beautiful mentoring session that was given to me throughout the project, endless motivation for me to keep striving, humble advice and full support of guidance throughout the study. Also, to all the technician that giving me full support and always help me hand in hand from the scratch. Without them, I may not stand where I am right now.

Not to forget, I would like to thanks to my best friends and also a family to me who always pushing me to my highest limit in completing this report especially to Ashikin, Adilla, Sofiah and all of you that being there for me. The beautiful journey that given to me in term of friendship and knowledge will never be fade from my memory.

Last but not least, I would like to thank to Faculty of Manufacturing Engineering UTeM for letting me to have this gold opportunity as a student in the faculty and permitted me to use all the equipment for this project. The memory, knowledge and skills that I obtained here will I use in my future career.

TABLE OF CONTENT

CHAPTER 3: METHODOLOGY

CHAPTER 4: RESULT AND DISCUSSION

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

SiR	-	Silicone Rubber
HV	-	High Voltage
SiO_2	-	Silica
EPDM	-	Ethylene Propylene Diene Monomer
UV	-	Ultra Violet
CFL	-	Compact Fluorescent Lamp
PSA	-	Particle Size Analyzer
XRD	-	X-ray Diffraction Analysis
SEM	-	Scanning Electron Microscope
CE	-	Cycloaliphatic Epoxy
PDMS	-	Polydimethylsiloxane
CNTS	-	Carbon Nanotubes
HTVSR	-	High-Temperature Vulcanized Silicone Rubber
GNR	-	Graphene Nanoribbon
DBA	-	Dry Band Arcing
ASTM	-	American Society for Testing Materials
IRHD	-	International Rubber Hardness Degree
IPT	-	Inclined Plane Tracking
AC	-	Alternative Current
DC	-	Direct Current
phr	-	Parts per Hundred Rubber
WGP	-	Waste Glass Powder

LIST OF SYMBOLS

Ω	-	Ohms
wt	-	Weight
%	-	Percentage
cm	-	Centimetre
kV	-	Kilovolt
mm	-	Millimetre
mg	-	Milligram
W	-	Watt
°	-	Degree
°C	-	Degree Celsius
Mpa	-	Megapascal
SG	-	Specific Gravity

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Electrical insulation is regarded as a significant criterion to be recognized for high voltage applications. In the last few years, many classifications of high voltage insulators have been produced for outdoor transmission lines. In the 20th century, the history of high voltage insulators has started with porcelain as the only material used for high voltage isolation purposes. The needs for replacement were to minimize the use of expensive porcelain products to reduce production costs and most importantly, to improve the tracing and corrosion resistance of insulator (Khan et al., 2017). Due to its hydrophobic properties, polymer material was chosen to replace previous insulator types which support the dry band arcing phenomenon which resulted in flashing phenomena (Prasenjit et al., 2015). Polymer also have light weight and flexible features that make it easier to erect and operate isolators even at the remote areas, including resistant to vandalism (Xuguang et al., 2000).

Today, polymer-based isolators are rising in most countries due to technological development and attractive potential benefits for their end users (Ramirez and Hernandez, 2016). Since polymer insulations are well accepted for high voltage application, many researchers worldwide have carried out huge number of major academic and practical activities to improve the high voltage effectiveness. Tracking and erosion are critical things to consider as it contributes to a stronger insulating strength (Kannan et al., 2015). Furthermore, the hydrophobicity property of polymeric insulators is ideal for the use in polluted environments.

This kind of properties are required for the use of polymer insulating material. However, the polymeric based isolators also have several limitations and weaknesses.

If the polymer insulator agonizes for a long time from monitoring and erosion, it can cause the debacle in the insulator (Yaacob et al., 2013). Therefore, an effort should be taken to solve these problems. Since silicone rubber (SiR) had a lower stiffness, some practical fillers have been purposely added in order to increase the resulting electrical isolation and mechanical strength for polymer-based composites (Amin and Salman, 2006). As many previous researchers have stated, the addition of functional fillers to the polymer matrix could boost some properties enhancement and also could reduce the costs of production process (Ali et al., 2017).

Polymer-based composite insulators have increased demand in recent years and have been recognized worldwide (Momen and Farzaneh, 2011). According to Rowland et al. (2010) The failure of polymer composite insulators is due to inadequate design and incorrect production processes that normally will prematurely occur. To address these advantages, a full understanding of their function and involvement of synthetic and mineral fillers is still to be realized. It should be noted that the contribution of filler in polymer composite was significant in HV application as it could increase the mechanical strength and other electrical isolation attributes of the resulting polymer composites (Bian et al., 2013). In general, fillers or reinforcement material are often used to enhance based polymer properties and to reduce the final cost of final products (Aman et al., 2013).

For this study, the blending between ethylene propylene diene monomer (EPDM) and silicone rubber (SiR) with the selected fillers of waste silica glass (SiO_2) filler were evaluated. Previously, silicone rubber industries had become extremely commercialized and covering a wide range of uses, including cable applications and insulation pads (Hamdani, 2010). Incorporating silicone rubber with fillers had driven the market from scientific and common industries. SiR rubber was also known for its great electrical and mechanical properties, despite of good hydrophobicity on the surface and was the key choice for high voltage applications (Du et al., 2011). As for EPDM rubber, it is well known as excellent water resistant along with very good with ozone, UV and oxidation for resistance (Martin, 2015). Blending of SiR with EPDM rubber could complement the weakness of each rubber phases.

In addition, fillers or reinforcement material are added to the rubber blend to improve the polymeric composite characteristics and also to decrease the final cost of final products (Aman et al., 2013). The most common filler is calcium carbonate and silicas for the electrical high voltage insulation. In this study, the full focus is to add on the waste glass as fillers as it contents the silicon (SiO_2) component. To be more intriguing, the raw material used was obtained from the waste resources. Disposing glass waste material also an issue in waste management. Difficulty was occurred in disposing solid waste via land-filling due to most of land-fills had already exceeded its maximum volume (Manaf et al., 2009).

This problem has been the main reason for companies and researchers around the globe to develop an improve technologies to reduce or eliminating the waste glass as industrial or domestic wastes (Thoo et al., 2013). This can be one of practical way of recycling activity as the environment issues faced by this country. Furthermore, the waste glass is used as silica, which has higher particular surface, is primarily due to the probability of increasing the number of silica bonds with the elastomer and thus increasing the amount of reinforcement of the silica (Olivier Durrel, 2008). Also, it will enhance the properties of composites to be used as the best candidate high voltage insulation purposes.

To decide whether or not such materials are used for high voltage insulators few criteria must be met. The material was considered to have failed according to BS: EN 6085 standard, if the tracking duration on the material's test surface was 2.50 cm. Thus, the effects of the waste glass powder loadings in SiR/EPDM rubber blend matrix to the mechanical and physical properties were further evaluated in this study.

1.2 Problem Statement

The problem in preparing the SiR/EPDM rubber as a matrix and waste glass fillers as a strengthening component are related with SiR/EPDM rubber matrix and SiO_2 filler powder interaction, due to improper mixing. The quantity and accuracy of the filler added would be a prime challenge since the right one is remains unspecified. The smallest size of fillers could cause problems of non-homogeneous dispersion, and could typically lead into inhomogeneity of interaction and distribution due to higher surface energy, which could then result into inhomogeneous filler dispersion. The research also has enormous effort to make the waste glass filled SiR/EPDM as one of the versatile and sustainable insulators for high voltage applications.

For high voltage applications, an effort has been made to recycle waste resource of the waste glass to be incorporated in SiR/EPDM rubber blend, for the high voltage (HV) electrical insulation application. Hence, the heat resistance and mechanical strength behavior of produced SiR based composites are crucially important. Recycling of waste glass as a filler source has been a novel attempt to monitor its potential output when combined with SiR/EPDM rubber matrix for high voltage insulation purposes. Researchers have learned more about recycling the waste capital because it can save the world from overwhelmed disposal waste. In addition, plenty of waste glass was generated annually but the recycling effort has still very low. This has motivated us to develop the sustainable rubber blend composites which utilizing waste filler for better electrical insulation, thermal resistance and superior mechanical strength and physical properties.

On the use of high-voltage insulators, it was good for the fabricated composites to have a better hydrophobic surface as it could minimize the leakage current that caused total failure (Prasenjit et al., 2015). Thus, in this study, a focus has been given to evaluate the result mechanical and physical performances of SiR/EPDM with different waste glass filler loading which will effects for the purpose of high voltage (HV) insulator application.

1.3 Objectives

1. To characterize the waste glass powder (SiO_2) as rubber blend composite filler by using a Particle Size Analyzer (PSA), Scanning Electron Microscope (SEM) and X-ray Diffraction Analysis (XRD) methods.

2. To evaluate the effects of waste glass powder (SiO_2) filler loading to the mechanical and physical properties of SiR/EPDM rubber blend composites.

1.4 Scope of Works

This research has been performed to focus on the preparation and testing of silicone rubber with ethylene propylene diene monomer-based composites filled with waste glass powder as filler, for use of high voltage insulators. At an early point, the fillers are extracted from the waste capital of waste glass bottle. The technique used is basically manual crushing and ball milling in order to obtain finer powder particles. Particle size analysis (PSA) machine was used to analyse the size range of produced powder particles while the XRD observation to understand further their morphological behaviour of waste glass powder (WGP) fillers.

The SiR/EPDM with fillers composites are then successively prepared by using an open two roll mill for compounding process and has been cured by using a peroxide-based vulcanization technique through a hot compression process. The filler formulations that being added into SiR/EPDM blend matrix are in the composition of 0 wt.%, 10 wt.%, 20 wt.%, 30 wt.% and 40 wt.% of SiO_2 waste glass powder filler loadings. Mechanical tensile testing was conducted to the composite samples for tensile strength and elongation of break (EAB) determination. Other tests like hardness tests (Shore A) are basically conducted to determine the physical behavior of developed SiR/EPDM-based rubber blend composites with different SiO_2 filler loadings. The resulted mechanical tensile strength and physical properties of SiR/EPDM based composites are to comply the entire stated research objectives of this study.

1.5 Significance of Research

Numerous advantages can be gained after the completion of this research. The first thing that can be relevant is the properties enhancement of polymeric materials in order to sustain the HV exposure. Therefore, this study was performed to enhance the mechanical and physical characteristic of ethylene propylene diene monomer and silicone rubber as insulation materials with a special focus on improving the endurance and mechanical strength at the high voltage exposure. The filler is taken from the waste source of used glass bottle to comply with the green and sustainable environmental concept of waste recycling.

In Malaysia, the key explanation for the selection of waste source filler is to support the sustainable production of industrial materials. Recycling efforts was world-famous for attempts to reduce the problem of waste disposal and recycling costs. The benefit of using composite materials will also reduce the costs and weight for the resulting composites materials. Composite materials have also been shown to be able to tackle the material weakness primarily due to the intrinsic filler added. This was an attempt to propose new high voltage insulation materials by using a sustainable material. In the near future, the final product and the results of this research could provide the potential of cost-effective alternative and recyclable improvements for the high voltage (HV) polymer composites as a replacement for ceramic-based porcelain insulators.

1.6 Thesis Organization

The overall organization of this thesis is including of five main chapters, as it starts with an introductory chapter. For chapter 1, it had discussed on the background of study and the problems statement that are identified through multiple searches by using previous journals, articles and current news. It was then followed by the objectives that is set to be achieved according to the resource scope which narrows down the area of study. Several scope revision has been made in accordance to uncertain current COVID-19 pandemic situation.

Chapter 2 begins with reviewing the material revolution that being used for high voltage application and followed by the overall explanation pertaining to the silicon rubber which will be used throughout of this research. Then, the ethylene propylene diene monomer, also being discussed. Furthermore, the most highlighted part in this research is the waste glass explanation which to be utilized as fillers. Also, the rubber blend composite application is being discussed in a way to understand the rubber blend system. Last but not least, the high voltage testing and its performance study were also being explained.

Chapter 3 has described the materials, methods and procedures applied to achieve the objectives mentioned in this study. The flow starts from explaining the materials used, and the methods used to compound raw materials into a hybrid composite. This is followed by the analysis or experiments to determine the structure and the exact composition of silicon rubber and ethylene propylene diene monomer with the waste glass powder as filler.

Chapter 4 discussed the experiments results and data collected throughout the experiments after conducting the methods and procedure mentioned in Chapter 3. The raw material characterization testing which include SEM, XRD and PSA. Followed by the mechanical and physical testing of the composites. Chapter 5 summarizes the ensure results related to mechanical and physical testing for the of SiR/EPDM filled with waste glass powder-based rubber blend composites.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Description of Silicone Rubber (SiR) with Ethylene Propylene Diene Monomer (EPDM) filled with waste glass powder (SiO_2) based composites for high voltage application was explained in this chapter. The following sub-chapter established details and review related to SiR/EPDM blend system and the waste glass powder (WGP) as the promising inorganic mineral filler. Furthermore, few investigations related to mechanical and electrical testing of high voltage insulators have also been extensively reviewed.

2.2 Material Revolution for High Voltage Application

Numerous materials have been developed since the first introduction of insulator for high voltage application. The material seems to be revolutionized by times with the improvement of material that taking into account the problematic issue and important criteria such as able to withstand overvoltage, low moisture-vapor permeability and cost reduction. These important points help the researches to expand their study in creating the best insulator for high voltage application.

2.2.1 High voltage insulator

Insulator is a crucial aspect in the field of electricity as it functions to store a charge when voltage is applied. The role of an insulator is to support bare conductors and to supply high-voltage conductors with metal structures with safe insulation. One cannot imagine what transmission and transmission stations will be like without the various forms of insulators (Obi PI, 2016). Insulator is an essential part of electrical transmission line that has a dual function of mechanically supporting the transmission lines and providing electrical insulation to the transmission line (Andy, 2010).

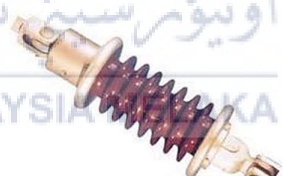
According to Andy and Schwalm (2010) Air gap is maintained by an insulator in the transmission line, as the line is isolated from the ground and equally resists the mechanical stress, electrical stresses and the environmental stresses on the transmission line. The isolators used in transmission and distribution systems are often required to transport large compressive or tensional current.

The concept of these lines aims at avoiding insulators with low reliability to ensure good operational efficiency in the high-voltage transmission line (Suhaimi, 2019). The isolators' surface conductivity can easily be greatly increased, leading to a wide stream of leakage along the insulating surface and a partial discharge between the dry bands (Salem, 2019).

Numerous developments of insulators can be used in this field. This may be attributed to core network deficiency, difficulties with the insulator production process, incorrect choice of insulation due to regional climatic conditions, insulator damage due to human or environmental events and unscheduled maintenance (Kuffel, 2000). It is necessary to identify and repair defective insulators on power transmission lines for the safe operation of the power supply system (Birlaskaran, 2000).

Based on Table 2.1, it represents some of the invention related to insulators that have been placed in the market. The growing and improvement of the design and materials of insulators can be clearly seen. This led to the increased demand for safe, productive and stable energy supplies which trigger the optimum insulators performance for the transmission of electricity (Sedigh, 2015).

Table 2.1: The different types of insulator invention

Types Insulators	Insulator Design
Pin Insulator	
Suspension Insulator	
Shackle Insulator	
Strain Insulator	
Disc Insulator	

2.2.2 Historical perspective on material for high voltage insulator

Based on Figure 2.1, it visualizes the progressive invention of insulator from the first invention in 1850s until 1970s. As for the development of insulators, it clearly be seen that the major changes are the materials used in the making of insulator. According to Bob Berry (1995) the invention of porcelain isolators began when local potteries started manufacturing telegraph insulators in the 1850s and 1860s. These early raw materials were typically threaded lower than their glass equivalents and were manufactured in far lower numbers, and only few had survived the years. Electrical porcelain insulator is made from clays and inorganic compounds which, after burning in a furnace, comprises of various oxide and silicate crystals in a glass matrix. Insulators are typically layered to have a smooth finish that prevents the permeability of pollutants. The glaze layer plays a secondary role in the development of a compressive outermost surface, thereby restricting the formation of surface cracks and boosting the mechanical strength (Wallace L Vosloo, 2013).

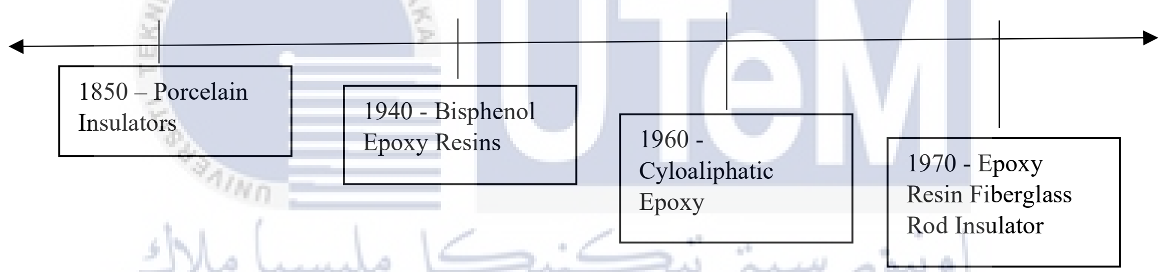


Figure 2.1: The time frame for insulator invention for high voltage application

In addition, bisphenol and cycloaliphatic epoxy resins were among the first composites used for insulating material. Bisphenol epoxy resins were commercially introduced in the mid-1940s and were the first electrical insulator polymers used as electrical insulators for interior and exterior applications (Kapal Sharma, 2001). However, epoxy resin is an organic substance and can suffer from deterioration due to partial discharge action on the soil. It should be carefully considered in the construction of insulators designed for special use in potentially polluted conditions (Wallace L Vosloo, 2013). In an early 1960s, cycloaliphatic epoxy (CE) delivery type isolators were first commercially available. This unit failed due to surface degradation and puncture. Since the mid-1960s, CE insulators in the United Kingdom have been validated at a service voltage of up to 400 kV as suspension/load insulators and cross-arms. The inability of the epoxy to achieve assistance was attributed to a number of failure cases, including low cold weather reliability and insufficient weight reduction. However, nowadays, indoor and even semi-closed EC power systems are widely used (Bernhard, 2011).

Later, in the same year, a porcelain insulator protected by an epoxy resin fibreglass rod was also made in the 1960s. Due to further developments in light polymeric insulation technologies, it was not widely used. Polymeric outdoor insulators were made in Germany as early as 1964 and by other factories in other countries (Klein, & Gafni, 2006).

According to Nzenwa (2019) The manufactures launched the first generation of commercial polymer transmission line isolators at the end of 1960s and early 1970s. Yet, the initial experience was misleading. These insulators were initially installed by utilities in short lines and trouble spots, mainly for experimentation and data collection. Polymer provides the mechanical strength, covered by a housing to protect the core from the environment and to yield the required electrical characteristics (Wallace L Vosloo, 2013).

Next, Table 2.2 shows the graphic of different materials used as an insulator based. Every material portrays different results in term of design, shape and function ability. Followed by Table 2.3 which explain the benefits and the limitation of each insulators. The polymer material is use in the insulators due to its strength in the mechanical properties that will directly increase the performance at the affected area. This has concluded the selection of polymer to be used as insulate compared to the porcelain.

Table 2.2: The types and graphic of the insulator

Material types of Insulator	The Graphic of The Insulator
Porcelain Insulator	
Cycloaliphatic epoxy Insulator	

Epoxy Resin Fiberglass Rod Insulator	

Table 2.3: The advantages and limitation of different insulators

	Advantages	Limitation
Porcelain	• Its inert, inorganic nature makes it resistant to degradation by environmental factors. • Its resistance to degradation due to the electrical discharge of the surface and to the leakage of the current • Its high compressive strength.	• Its delicate nature, which leaves it vulnerable to breakage. • Low tensile and cantilever strength to weight ratios.
Epoxy Resins	• Easy to design. • Integral metal ware may be provided, removing the need for additional fittings to be mounted.	• The risk of extreme current erosion leakage. • Potential electrical failure of the mold line that can contribute to material deterioration.
Polymer	• Very high tensile strength by weight ratio. • Enhancing output in heavily polluted environments (silicone rubber types). • An unappealing vandal object and very resistant to projectile injury.	• Subject to current erosion leakage if inappropriate content and/or dimensioning is used. • Potential electrical weakness of the mold line; (molded construction only).

2.2.3 Polymer material as new high voltage insulator

The polymer material is not a new invention used as a high voltage insulator. Space load tests were part of standard testing insulating technologies in the first decade of the 2000s, encouraging the ongoing production of products for high voltage delivery system applications (Maruyama, 2004). The polymer matrix can be divided into three major groups, thermoplastics, thermosets and elastomers, and can be assembled into the shape of micro-composites used in high-voltage implementations (Xanthos, 2010). Polymeric insulators also substituted ceramic units owing to a broad variety of desirable properties, such as formulation of lightweight materials, ease of transport and installation, strong mechanical strength to weight ratio, tendency to fight vandalism, aesthetic appearance and superior insulation efficiency (Gorur, 1999). This high-voltage polymer insulator has gained substantial interest from the science community (Gorur, 2001).

The electrical insulator is one of the most critical elements of the power transmission line. Any weakness present in the insulator system may cause leakage current and eventually, deterioration of insulator, resulting in a partial or full shutdown of power in the grid depending on the failure scale (Diphankar Ghosh, 2018). Several various polymeric housings have been tested over the years, with somewhat different results. For example, polytetrafluoroethylene (or teflon) that seems promising at first and was used to produce insulators. However, this is not necessary. Other polymers that claimed greater efficiency to porcelain or glass included ethylene propylene diene monomer (EPDM), silicone rubber (SiR) and various blend of these polymers (Biacini, 2012).

Polymeric insulators have good hydrophobic retention under damp conditions and surface pollution, resulting in better efficiency in contaminated areas and improved vandal tolerance (Shcumann, 2016). In such conditions, the recovery of hydrophobicity may not be fast enough to completely nullify this gain. This activity was confirmed after various insulator designs and materials were subjected to different stress conditions for 1000s of hours, involving salt fog, rain, clean fog, drying times and UV (Alberto Pigini, 2017).

Examples of degradation encountered are shown in Figure 2.2. In order to obtain an indication of the insulator state after ageing, the tolerance to contamination was calculated using the 'fast flashover' process. This shows that resistance to polymeric material monitoring and degradation is more important than the transition of hydrophobicity in these types of environments.

Next, Figure 2.3 indicates the role of polymer in high voltage insulation. It is used as a film in the middle of a resistive coating due to its benefits as an insulator. Research and manufacturing of composites and nano-composite materials used in high-voltage applications is complex. While much effort has been made over the last two decades to investigate the possible electrical benefits of such new materials and several results in the field have been published, several uncertainties remain unresolved and much remains to be studied (IIlona, 2016).

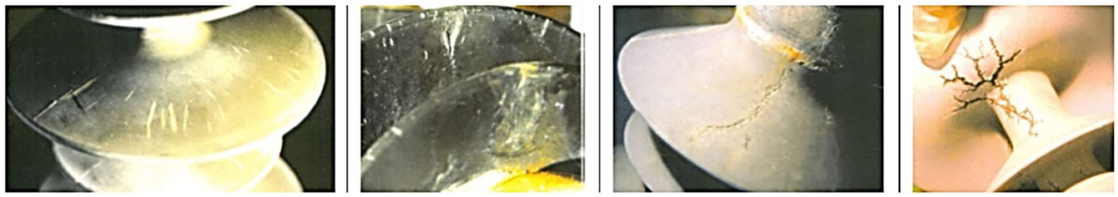


Figure 2.2: The Examples of insulator deterioration after 2000h ageing test under DC voltage (Alberto Pigini, 2017)

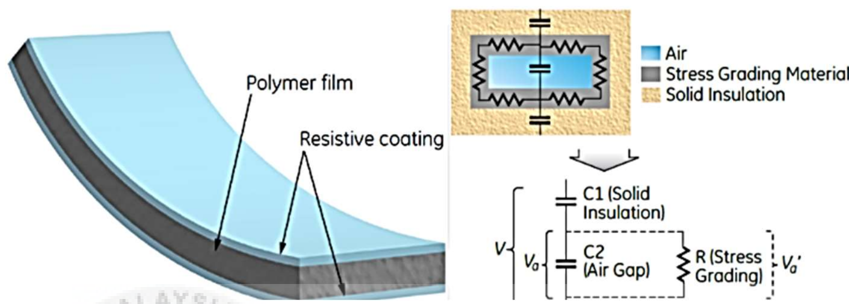


Figure 2.3: The Use of Polymer "Stress Graded Insulation" in High Voltage (Malcom, 2020)

2.3 Silicone Rubber (SiR)

Recently, there is a high demand for the presence of Silicon Rubber (SiR) in the treatment of insulation device. This is attributed, in fact, to its enhanced properties of high hydrophobicity, which has been significantly increased for high voltage electrical insulation in the outdoor climate. However, being organic in nature, the products are impacted by several pressures resulting in loses of desired properties having a direct effect on their lifespan. It also has more benefits than the limitation.

2.3.1 Synthesis of silicone rubber as insulator for high voltage application

According to David Ryan (2013) Silicone rubber is an organic or man-made, weather-proof substance with a wide range of temperatures that have been shown to hold useful properties. Back in the 1960s, silicone rubber was commonly used in medical, automotive, electrical, building and industrial applications (Matbase, 2013). SiR was also known for its tolerance to weathering and its ability to preserve valuable properties over a wide temperature range (Bernstorff et al., 2007). Silicone rubbers serve as an insulator due to their fine thermal and electrical properties. It is oxidising resistant, low surface energy and resistant to ultraviolet (UV) radiation degradation (Bok Hee, 2005). These properties have made silicone rubber as good alternative for electrical insulators.

SiR possessed greater tolerance to heat and chemical stability and could have improved electrical insulation (SinEtsu, 2013). Silicone rubber consists of the main chain of inorganic siloxane linkages (Si-O-Si) plus side chains containing organic groups. Siloxane bonds (-Si-O-Si-) which form the backbone of silicone (dimethylpolysiloxane) are highly stable. SiR belongs to an essential class of special-purpose synthetic rubbers that are partly inorganic and partly organic (Nelson et al., 2004). SiR has been listed as an organic silicone compound (Niedermier et al., 2000). In addition, the SiR used for high voltage insulation was primarily based on polydimethylsiloxane (PDMS) which is a synthesised polymer widely used in SiR formulations for high voltage outdoor insulation applications. Figure 2.4 illustrates the interaction between the-Si-O-chain composed of the silicone rubber and the methyl group CH_3. This relationship reveals the connection between the organic and the inorganic structure.

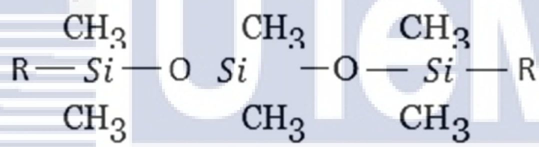


Figure 2.4: Chemical structure of SiR (Nelson et al., 2004)

Silicones are the right alternative for insulating applications in the transmission and distribution field because SiR has shown greater hydrophobicity and lower surface energy than most other organic polymers (Thong et al., 2011). Hydrophobicity is one of the most key elements of monitoring and erosion resistance (Ansorge et al., 2012).

Furthermore, even when submerged in water, SiR still has no decrease in efficiency, rendering SiR an ideal insulating material. It has especially good tolerance to corona discharge and arc at higher voltages. Arcing is an electrical breakdown of a gas that produces a constant flow of electrical discharge (Bruce et al., 2010). This provides a clear explanation why silicone rubber is preferred as a possible high voltage insulator-based composite. Output and quality would be measured for the mixture of the SiR with EPDM and the filler powder.

2.3.2 Properties of silicone rubber

Insulators nowadays that are using materials based on silicone rubber due to its incombustible and weather resistance. However, the problem concerned was their mechanical durability under the flame to maintain circuit integrity and energy supply during fire when evacuation or emergency landing (Dul et al., 2008). In composite, the electrical current could flow through continuous chains of filler particles and also could passes through a material only if there was sufficient conducting network available in the macromolecule's matrix. Basically, the conductivity of material can be determined based on filler volume fraction (Song et al., 2015). Furthermore, as compared than other types of rubbers, SiR have relatively weak in terms of their mechanical properties and thus their applications are significantly limited.

Essentially, the mechanical properties of SiR-based composites such as tensile strength, elongation at break and stiffness are dependent primarily on the form of filler, filling and bonding strength of the polymer matrix (Khan et al., 2017). Generally, there are many innovative approaches to improve the mechanical properties of silicone rubber compounds. For example, silicone smoked silica has sometimes been applied to strengthen silicone rubber (Xu et al., 2010). The concept of blending was explored in a few research findings because the distribution of crosslinking points may have an effect on the resulting mechanical properties of the silicone rubber compounds produced (Xu et al., 2010).

Mechanical properties of SiR-based composites can also be enhanced with the inclusion of chitosan salt as it has played a key role in making high-temperature vulcanised SiR carbon nanotube nanocomposites more conductive under higher strain (Shang et al., 2014). With the aid of chitosan salt, the carbon nanotubes (CNT) could diffuse well, thereby improving the resulting mechanical properties of high-temperature Vulcanized Silicone Rubber (HTVSR) (Shang et al., 2014). On either hand, an increase in the monitoring and corrosion resistance of polymeric insulators may also be found by applying nano-sized fillers to the base material (Kannan P,2015). Various research findings on the mechanical properties of silicon rubber have been described in Table 2.4.

Table 2.4**:** Summary of recent studies on the mechanical properties of silicone rubber compounds and nanocomposites

Authors	**Research**	**Findings**
Xu eta. (2010)	Mechanical properties evaluation by preparing the silicone rubber composed of diverse vinyl content of silicone gums	Young modulus higher by 20.5% and 31.0% at M100 and M300, respectively than unfilled SiR
Gan el. (2015)	Improving thermal and mechanical properties using graphene nanoribbon (GNR) filled silicone rubber nanocomposites	Elongation at break increased by 64% with an addition of GNR. T_s increased by 67%. Young's modulus increased by 93%. Thermal stability of SiR/GNR increased slightly compared to pure SiR.
Hadi et al. (2015)	Mechanical properties of silicone rubber-alum composites using in manufacturing of prosthetic liners	E_{ab} decreased about 8% from 1-5 wt.% of alum content. T_s decreased about 5.7% from 1-5wt.% of alum content. Hardness decreased 14% from 1-5wt.% of alum content.

The principle of electrical conductivity starts as a diffusion molecule is transferred in the case of conductivity which is called electrical charges (Siegmund and Leuenberger, 1999). At any critical filling, conductivity increases with very little increase in filler quantity. The formation of this conductive network was based on the concepts of percolation theory. Figure 2.5 displays the schematic diagram of the creation of a conductive network in silicone rubber. This hypothesis was suggested as an alternative to spontaneous processes directly linked with a flow phase within a diffusion phenomenon (Clingerman, 2001).

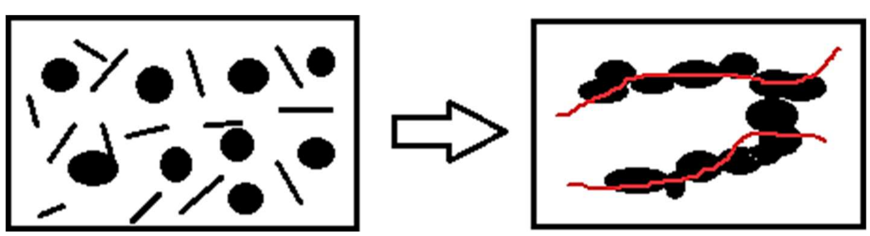


Figure 2.5: Schematic illustration of network conductive formation (Clingeman, 2001)

In terms of resistivity, the main factor that might influence their value was due to the interfacial interaction which produces energy barrier and blocks the electron transport. By having higher transport barrier could lead into higher resistive condition of produced composites (Dang et al., 2011). Basically, most of the filler particles are in contact with at least two of their closest neighbours, forming a continuous chain or network. Many observations on the electrical properties of polymeric composites have drawn a great deal of interest in this important hypothesis (Luheng et al., 2009). SiR based composites has been widely used in many applications due to their interesting properties including the electrical resistance properties (Yang, 2012).

A study by Wang et al. (2012) Proved that the electrical conductivity of produced composite could be enhanced by adding carbon nanotube as a filler. While Venkatesulu and Thomas (2010) Had discovered that the lower loadings of alumina filler can give better electrical insulation performance. Vijayalekshmi and Abdul (2013) Also supported that fillers play eminent role in enhancing the desired electrical properties of polymer. While in terms of relative permittivity also might be affected by frequency range and filler content. That means, the value of relative permittivity might change due to constant frequency at different filler loading (Hartomy et al., 2011).

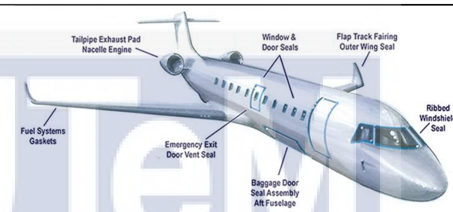
2.3.3 Applications of silicone rubber

Silicone rubber was used in large vehicle applications. It was chosen for its outstanding electrical insulation properties, thermal and chemical strength, weather, adhesive properties and tear strength. Silicone rubber is useful for automotive makers and producers of parts. For example, in automotive applications, silicone rubber is used for screens, dips, connectors, spark plugs, radiators, heat exchangers, water pump joints, cylindrical head gaskets, engine covers, valve covers or oil pumps (Shin, 2017).

As a result, the use of SiR is widely used for aviation and aerospace in terms of extreme temperature tolerance, environmental and chemical stress resilience and durability are some of the factors that support aviation and aerospace applications. Silicone rubber sealants tie doors, windows and panels indoors and outside. Fluid resistance makes the rubber ideal for diaphragms, hydraulic lines and cable clamps. Silicone rubber keypads have also been used on earth and space computers (Amin, 2007).

In general, bakeware and cookware are more sturdy, convenient, easy to use and sturdy when made from silicone rubber. The lightweight, non-stick surface was easy to clean and tasteless (Subhas Shit, 2013). Flexibility over large temperature ranges, strong compression resistance, a wide variety of durometers and inert and stable compounds are among the reasons for its success. Popular silicone medical components and assemblies shall include airways, balloon catheters, pipes for feeding, draining and use of peristaltic pumps (Johnson, 1999). Table 2.5 displays the graphics of the silicone rubber used in the industry. Each industry uses silicone rubber with a variety of functions and designs. This shows that silicone rubber is a versatile substance to be used.

Table 2.5: The application of silicone rubber in different industry

Application of Silicone Rubber	The picture of Silicone Rubber Application
Automotive	
Aviation	
Medical	
Bakeware	

2.3.4 SiR for high voltage insulator application

Recently, hybrid structures are widely used by researchers for a number of applications. Silicone rubber (SiR) material was an appealing alternative to conventional ceramic-based insulators in nearly all new constructions, replacements and improvements (Ansorge et al., 2012). Due to its high performance, silicone rubber (SiR) composites have been widely used for electrical and non-electrical high voltage (HV) applications over the last three decades. However, SiR was vulnerable to long-term ageing. In addition, SiR erosion occurs in polluted areas where exterior insulation housing has been subjected to Dry Band Arcing (DBA), resulting in a lack of insulation and a power supply disruption (Ghunem et al., 2013).

In addition, Momen & Farzaneh (2011) Reported that pure SiR exhibits little tracking and erosion resistance, which has a strong indicator of improved electrical and thermal insulation properties. SiR itself has a superior mix of insulating properties and better versatility for electrical insulator applications (Bielinski et al., 2011).

Nevertheless, SiR was also able to tolerate a slight amount of tension encountered by the electrical insulator. This forms of external stress on exterior insulation are seen in Table 2.6 below. This can be clearly confirmed by Cherney (2005) that SiR also exhibits non-conductive properties and is ideally suited for lightweight insulation applications than other insulating organic polymers due to the longer bonding of silicone-oxygen elements in the SiR polymeric macromolecular chain. In addition, SiR has many attractive properties that are ideal for their applications.

Table 2.6: Stresses on outdoor insulation (Cherney, 2005)

Classification	Stresses
Environmental	UV, moisture, temperature, chemical
Electrical	Dry band arcing, partial discharge, corona
Mechanical	Cyclic loads

Venkatesulu and Thomas (2010), have defined that SiR insulators could provide good versatility in product design compared to their ceramic equivalents. This can be easily seen in Figure 2.6(a) and Figure 2.6(b). Rubber housing with several weather sheds protected the rods for protection from outdoor conditions such as moisture, noise and corona discharge. Weather sheds have been used to raise the leakage distance between the energised and field ends of the insulator.

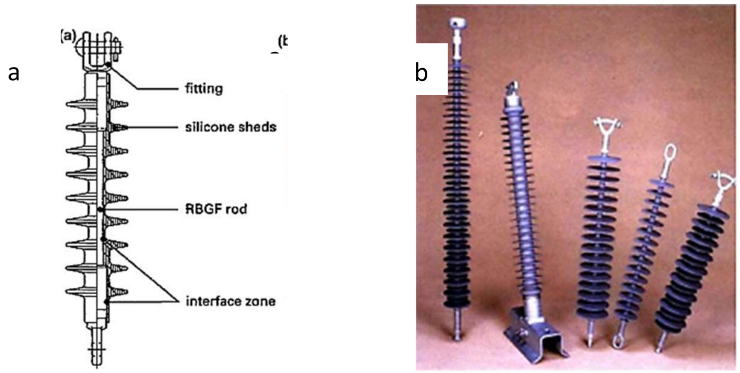


Figure 2.6: (a) Schematic illustrating the construction of a typical composite insulator and (b) photograph showing various shapes of composite insulators (Anwar, 2007)

2.4 Ethylene Propylene Diene Monomer (EPDM)

EPDM rubber compound has outstanding ozone resistance, thermal resistance and electrical insulation properties. It is used in particular for the manufacture of high-pressure electrical insulation materials. As a consequence, it can be seen that this compound is presently available in several applications. However, the application is smaller than the market for silicone rubber owing to its poor weather resistance.

2.4.1 Overview of EPDM rubber

EPDM stands for ethylene propylene diene monomer, which is part of the leading rubber family of synthetic rubber made up of ethylene, propylene and diene monomers. Its molecular structure has a single bond, chemically saturated backbone, making it highly resistant to outdoor conditions (Thomas, 2020). EPDM is a copolymer of ethylene, propylene and a small number of non-conjugated diene monomers (3-9%) to provide vulcanization cross-linking sites as shown in Figure 2.7. This terpolymers can be vulcanised using conventional techniques (Bryan, 2015). Its flexibility and outstanding longevity make it a top option for all types of jobs, from sealing against ingress of water to supplying insulation in freezer room seals (Nesty, 2019).

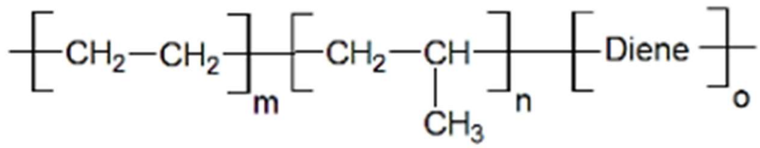


Figure 2.7: Chemical structure of EPDM (Bryan, 2015)

Moreover, EPDM is an especially good choice for external applications. Its resistance to weathering ensures that it would not decay in the manner any other substance is subjected to UV (Nesty, 2019). The EPDM mix allows it to have strong electrical properties, costs, flexibility over a large temperature spectrum and its resistance to moisture and weather is also used as an electrical insulating material (Prabu, 2007).

EPDM's influential characteristics are excellent electrical properties due to its non-polar composition and saturated spine, making it oxidative and thermally tolerant and simple to process at low temperatures (Sharkel, 2013). This work was primarily dedicated to the development of EPDM composites for high voltage outdoor insulation. Inorganic fillers play a crucial role in improving the desired properties of polymers (Cherney, 2005). Modification of organic inorganic fillers results in better dispersion properties (Janowska, 2011).

2.4.2 Properties of EPDM rubber

EPDM elastomers have excellent heat, ozone and ageing resistance. They also show excellent electrical insulation, compression setting and low temperature properties, but only fair physical strength properties (Bryan, 2015). Due to its non-polar structure and saturated backbone, EPDM is extremely oxidative and thermal tolerant and fast to process at low temperatures (Sarkhel, 2013).

While EPDM compounds do not possess the excellent low air permeability of butyl rubbers, they have strong low-temperature properties, ageing and enhanced processability (Chellappa, 2017). This work was mainly concerned with the development of EPDM composites for outdoor high voltage insulation. Inorganic fillers play a crucial role in improving the desired properties of polymers (Cherney, 2005). By applying a filler to the EPDM, the mechanical properties in term of rigidity would be improved. The filler plays a crucial role in the electrical properties of the EPDM insulating material in such a manner that the voltage of the filler rises by up to 30% (Tamer, 2020). Figure 2.8 displays the motion graph of the tensile strength relative to the ratio of the filler. The highest result of EPDM with a filler is C with a composition of 80:20 EPDM with a filler based on Figure 2.9.

The specific gravity of EPDM is the lowest of all synthetic elastomers capable of mixing significant volumes of inert fillers. Ethylene-propylene monomer/ethylene-propylene terpolymer (EPM/EPT) rubber shall be included in this group (Chellappa, 2017).

SAMPLES		A	B	C	D	E
EPDM %		100	90	80	70	60
ATH %		0	10	20	30	40
1	Tensile Strength (MPa)	1.8	1.9	2. 7	2. 4	2. 0
2		1.7	2. 2	3.0	2. 3	1.6
3		1.5	2. 3	3. 1	2. 6	1.7
Average Tensile Strength		1.66	2.13	2.93	2.43	1.76

Figure 2.8: The tensile composition of EPDM with fillers addition (Tamer, 2020)

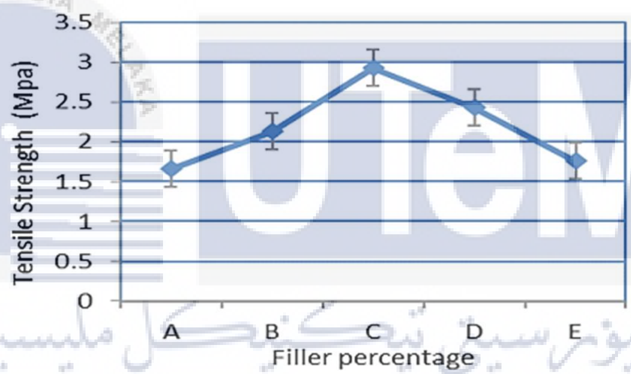


Figure 2.9: The tensile strength graph of EPDM with fillers addition (Tamer, 2020)

However, the key downside of EPDM is its susceptibility to solvents, hydrocarbon oils and other lubricants that may cause harm. In comparison, unlike silicone, it is not flame resistant and is therefore not recommended for food use (Thomas, 2020). The properties of EPDM have varying effects when combined or prepared with a different compound or filler. Table 2.7 summarises a few findings on EPDM properties.

Table 2.7: Summary of researches related to EPDM properties

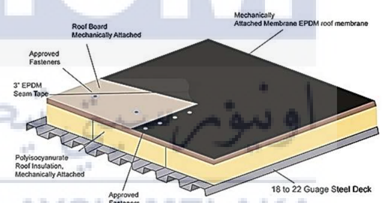
Authors	Research	Findings
Inpil Kang (2011)	Preparation and properties of ethylene propylene diene rubber/multi walled carbon nanotube composites for strain sensitive materials	The added number of nanotubes, both the modulus and the tensile strength of the composites, increases dramatically, while the elongation at breakage reduces. The TS estimated was 49,313 kgf/cm^2 at 5.00 wt. % of the content of MWCNT.
Asaad (2013)	Evaluation of SiR / EPDM Blends for High Voltage Insulators	The combinations improve the mechanical properties and thermal stability. The dielectric strength values of the blends increase by increasing the percentage of EPDM.
Jun Soong (2020)	Mechanical Behavior of Aged EPDM Insulation of High-Voltage Cable Joints in Thermal-Oxidative Environment	During the ageing process, the EPDM content is increasingly weakened. At the later stage of the ageing process, large holes and cracks appear on the surface of the EPDM sample which directly affect the mechanical properties of the sample.
Tamer Sheta. (2020)	Evaluation of dielectric strength of EPDM elastomer loaded with ATH filler	The dielectric strength of EPDM reached 37 kV/mm by adding 30 per cent ATH under dry conditions, which means that the dielectric strength is increased by almost 23%.

2.4.3 Application of EPDM rubber

EPDM was introduced as a commercial polymer. The automotive industry was able to consider areas where the use of component output could be increased. Significant uses included sponge and hard weather stripping for doors, windows and trunk lids (Allan, 2000). This rubber has been made ideal for automobiles due to the toughness and weatherability of EPDM. It may be used for insulation of vehicles, caps, cables and braking systems. It is also used to rub strips, and car bumpers with other materials (Thomas, 2020). Not just that, EPDM easily binds to metal, which provides a good barrier to both the atmosphere and the environment, road surface and engine vibration (Alan, 2020).

Today's polymerization and catalyst technology allows the design of EPDM rubber to satisfy unique and challenging product and processing needs. This resulted in extensive use of EPDM rubber in houses. EPDM roofing is an important application due to its insulation, weatherproof and waterproof capability (Junsoong, 2020). However, EPDM has low tolerance to petroleum products when it starts to break down as it comes into contact (Bob Behrend, 2019). Table 2.8 demonstrates the application of EPDM to both the automobile and construction sectors.

Table 2.8**:** Application of EPDM in industry

<table>
<tr><th>The application of EPDM</th><th>Graphic view</th></tr>
<tr><td>Vehicle - window seal</td><td></td></tr>
<tr><td>Building – roofing system as membrane</td><td>
</td></tr>
</table>

2.5 Waste Glass as New Alternative Composite Filler

Fillers are primarily used in rubber compounds to strengthen the physical properties of rubber compounds. They can also be used to reduce the expense of rubber compounds. Waste glass (SiO_2) is preferred since it includes the volume of silica required as a filler.

2.5.1 The overview of the waste glass

Glass waste is one of the contributions on waste material statistics in the world due to large scale of production and widely used in various products. The characteristics of glass waste are difficult to disposed, solution to recycle the glass waste is very important on the sustainable development and resource recovery (Harrison et al., 2020). The huge number of glass waste is recognised as a global issue because constitutes a significant proportion of solid waste and the cheapest value of glass waste is a reason receive high demand of production (Guo et al., 2020).

According to Dong (2021) Glass is one of the commonly used materials in every corner of life, the multiple type of glass waste leads to various properties of material and not all of the waste glass is suitable for the production of new glass. However, glass waste frequently dumped in a landfill or just stacked someplace due to the multiple types, colours, and contaminations.

In addition, glass producing process involves various types of materials and commonly glass made from silica, $CaCO_3$ and soda ash. The material undergo several processes such as melting process, all material are melting and blended each other at higher temperature then allow it to cool down in this period solidification happens in the absence of crystallization and transform to the transparent (Rani et al., 2021). Table 2.9 shows the chemical properties based on the commonly type used of glass waste.

Table 2.9: Physical properties of glass waste (Rani et al., 2021)

Chemical Properties	Value (%)
SiO2	62.41
Al2O3	2.65
CaO	12.24
SO3	0.10
MgO	1.74
Fe2O3	0.42
Na2O	18.64
Loss of Ignition 0.9	0.90

2.5.2 Introduction of compact fluorescent lamp

The compact fluorescent bulb or lamp is a type of fluorescent lamp typically designed to replace incandescent or halogen lamps. There are two main types of compact fluorescent lamp that are screw-in and plug-in (Ethan, 2019). This substitution is made for the key purpose of saving electricity. CFL decreases oil consumption and global warming, human toxicity and the risk for resource degradation by nearly 80 per cent across the usage and development periods (Osram, 2009). Figure 2.10 displays the images of the driver modules used in the CFL.

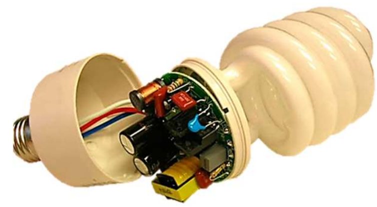


Figure 2.10: Compact fluorescent lamp conductor (Oladele, 2010)

Nevertheless, it has a different downside, which is that the electronic ballasts of the CFL are non-linear and thus a current waveform rich in harmonics is drawn. This harmonic current flowing through the network poses a power quality problem, since these harmonic currents flowing through the grid distort the waveform of the voltage (Neville, 2006). Furthermore, the real problem is the mercury found in the CFL and the disposal of relevant issues pertaining to the proper disposal of the fluorescent bulb and its internal ballast. Mercury is a naturally occurring compound that can be particularly toxic to humans and animals (Abbe Abbas, 2020). However, based on the Khazova (2010) when the cFL is broken down in the inner-room region, the emission is beyond the range of workplace exposure limits for only a very short period based on the concentration of room air. Owing to extremely low concentrations and very short durations, even vulnerable subgroups in the adult population should be covered. Table 2.10 displays the mercury content of various types of lamps. Shows that the portable fluorescent lamp has the lowest mercury content.

Table 2.10: The mercury contents in different type of lamps (Morris, 2020)

	Incandescent lamp	Compact fluorescent lamp	Halogen lamp
Mercury content	54W	13W	30W
Mercury emission during use phase	0.86mg	1.31mg	1.60 mg
Mercury emission during end life phase	0	0	3.20 mg

2.5.3 Waste management issue on glass waste

Environmental contamination is a major problem due to the mismanagement of solid waste. Open dumping and open burning are the main waste treatment and final disposal schemes placed in operation (Vithayasrichareon, 2012). Dumping of waste in open fields and rivers is still normal until today, and an analysis of waste disposal activity in Kuala

Lumpur showed that 31.9 per cent of the waste was disposed of by open fire, while 6.5 per cent was dumped in the river system (Murad and Siwar, 2007). As a result, the environmental protection issue in Malaysia was secondary and most municipalities had a difficult time locating new disposal sites as existing disposal sites were almost depleted (Hassan et al., 2000).

However, energy efficiency and mercury leakage from compact fluorescent lamps and used fluorescent lamps is the main issue that causes mercury emissions (Zhongguo Li, 2018). In consequence, there is a need to recycle or at least dispose of light bulbs appropriately, although there are actually few choices open to the general public. There are actually no clear rules or laws regarding the disposal of light bulbs. Due to the liquid mercury content, light bulbs are known as "scheduled waste" (Environmental Development Malaysia,2009). Indeed, the EPA recommended process for the safe handling of all forms of fluorescent light bulbs is being recycled. But it is a smart idea to take a few measurements of the local and state laws before start to determine how to handle unused fluorescent lamps (Environmental Protection Agency, 2020). The recycling of compact fluorescent lamp and other fluorescent lamps enables the re-use of glass, metals and other components that make up fluorescent lamps. Almost all elements of a fluorescent lamp can be recycled.

2.6 Rubber Blend Composite for High Voltage Application

Rubber blend is a method in which two or more rubbers are mixed on the basis of three key reasons: enhancement of mechanical properties, increased processing and reduced cost of compounds. The mixing of different rubbers is one of the most efficient methods for achieving the necessary performance characteristics in the final products.

2.6.1 Theory on rubber blend

The blending of polymers is a very fascinating science that focuses on a variety of diverse applications (Adel, 2016). Blending of polymers and primarily elastomers is mostly carried out for two reasons: first, improvement of the mechanical properties of the base elastomer and, second, improvement of the manufacturing activity of compound polymers (Rodgers, 1995). The blending of two or more forms of rubber is a useful and important way for the preparation and production of superior properties of rubber mixtures to improve damping and physical properties (Wang, 2018).

Production would include the blending, extrusion and calendering of rubber compounds that often contain oils, black carbons and other organic and inorganic chemicals. Functional properties, such as mechanical and dynamic characteristics, are influenced by the collection of elastomers in the blend, the distribution of the vulcanization process ingredients in the blend and the distribution of the filler between the elastomer phases (Brendan, 2011).

Typical rubber comprises styrene butadiene rubber (SBR), natural rubber (NR) and butadiene rubber (BR). Rubber blends are mostly used in the tyre industry as binary or ternary blends in the stated 'phr' (parts per hundred rubber) (Zhang, 2001). The morphology of rubber mixture is dependent on the preparation methods used and also on the form of additives in the rubber mixture. The morphology of the mixtures of rubber is influenced by the degree of mixing between the two rubbers (Abitha, 2019).

The word morphology in a rubber compound indicates the scale, form and consistency of small rubber phases, fillers and additives, the size distribution and the mixture of fillers and additives or structural units within the macromolecular system as explained in Figure 2.11 (Sawyer, 1996). Optimizing parameters for the stability of morphology is thus the uniformity of dispersion in batch-to-batch and is of paramount significance in batch processing of rubber mixtures.

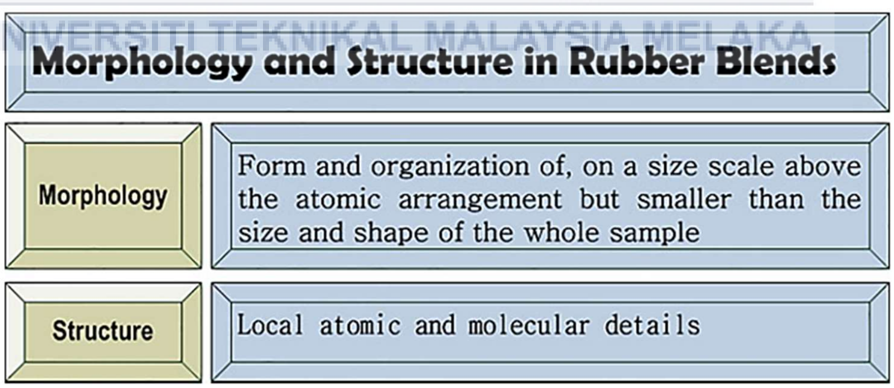


Figure 2.11: The definition of term in rubber blends (Abitha, 2019)

The morphology of the mixtures of rubber is influenced by the degree of mixing between the two rubbers. The thermodynamic flaw of the mixture relies on the temperature and structure of the mixture (Abitha, 2019). Figure 2.12 displays three step diagrams for mixtures of rubber at certain compositions and temperatures. The mixture becomes immiscible (two-phase) below the solid line and is known as the upper critical solution temperature. In addition, Table 2.11 includes a description of the rubber blend studies on blending and structure.

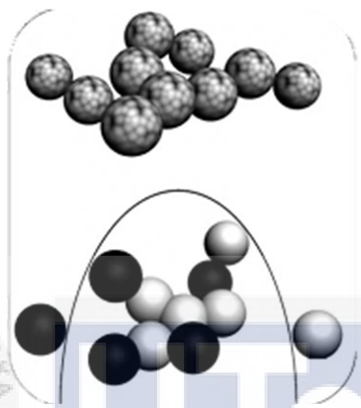


Figure 2.12: The phase image for a rubber blend (Abitha, 2019)

Table 2.11: The summary of past research of rubber blend

Authors	Research	Findings
Mente (2016)	Natural Rubber and Reclaimed Rubber Composites – A Systematic Review	The involvement of the filler demonstrated increased maximum torque and decreased scorch and healing time. In general, two extreme ends of the filler material, i.e. very low (~3 per cent) and very heavy filler loads (~20 per cent), resulted in comparatively weak mechanical properties of the composites.
El-Sabbagh (2017)	Rubber nanocomposites with new core-shell metal oxides as nanofillers	The quality of the pigment as a booster filler improved the curing rate in mixtures containing 12phr TS1. As pigment loading increases, mechanical properties such as tensile strength, modulus, hardness and Young's modulus have also been shown to improve, whereas elongation at breakage has decreased.
Mensah (2018)	Preparation and Characterization of Rubber Blends for Industrial Tire Tread Fabrication	High ENR material (~70 phr) significantly increases crosslinking density, Young's modulus and hysteresis loss (lower rolling resistance) (lower rolling resistance).

Abitha (2019)	Rubber–rubber blends: A critical review	The consistency between the two rubbers can be increased by minimizing the size of the dispersed step in the rubber mixtures contributing to improved final properties.
Tuo Lei (2019)	Preparation and Properties of Rubber Blends for High-Damping-Isolation Bearings	The mixing has good vulcanization and mechanical properties. The inclusion of EVA decreases the mechanical characteristics of the NBR/BIIR system. However, blends can also follow the minimum criteria.

2.6.2 Properties and testing

Studies by Ezema et al. (2014) Showed that tensile strength, tear strength, durability and compound modules packed with natural rubber increased by increasing the filler quality and decreasing the filler particle size. These mechanical properties have also been improved relative to unfilled natural rubber. The fillers improved the mechanical properties of vulcanised rubber. Since, unlike black carbon, organo-montmorillonite retained natural rubber elasticity (Arroyo, 2007). The performance of the rubber relies on its strength and hardness, and the properties cannot be changed purely by the use of chemical modifications. It can be strengthened with the use of a filler that is thicker and stiffer to compensate for its apparent low strength and modulus (Khalil, 2013).

The integration of reclaimed rubber into styrene butadiene rubber has been documented to improve the tensile strength, modulus, elongation at breakage and hardness with a growing content of reclaimed rubber. The improvement in tensile strength and modulus was stated to have been attributed to the presence of black carbon and high crosslink density in reclaimed rubber (Debaprriya, 2011). Figure 2.13 demonstrates the association between the tensile strength and the carbon content of black and reclaimed rubber in virgin rubber/reclaimed rubber mixtures.

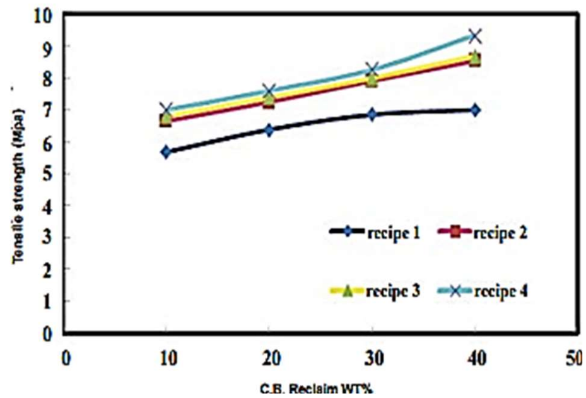


Figure 2.13: The relationship between the tensile strength and the filler in rubber (Muniandy, 2012)

The addition of polybutadiene to natural rubber may result in improved thermal stability, decreased tensile strength, reduced modulus by 300 per cent and increased elasticity (Brendan, 2011). However, when the composites are packed, the stress is transferred from the matrix along the filler particles, resulting in an efficient and consistent distribution of stress that strengthens the mechanical properties. With low filler content with poor orientation, effective load transfer is difficult to achieve and tension accumulates in parts that contribute to lower tensile strength (Fidelis C, 2013).

2.6.3 Past studies on rubber blend for high voltage application

High voltage composite insulators are increasingly used in outdoor installations (Yaasin, 2006). Polymeric insulators have been reported to have performed better than porcelain and glass in laboratories and outdoor research sites. The rubber blending of silicone-modified polymer, which involves silicone rubber (SiR), ethylene-propylene-diene monomer (EPDM) and SiR-EPDM blends, analyses the electrical capability of the blending process. The mixture of these two rubbers would directly impact the silicone rubber, which is affected by the degradation of the tracking resistance caused by the lack of hydrophobicity due to the action of the water salinity tension (Ehsani, 2005).

Furthermore, there is a possibility of combining SiR with EPDM, which has lower UV and weather resistance and lower thermal stability. However, it has better volume resistance than that of silicone and has superior electrical insulation properties (Mohseni, 2003). Therefore, an acceptable blend of SiR and EPDM can give either rubber a product with generally superior properties (Asaad, 2013). The use of rubber mixtures has shown that the optimum treatment time of the rubber is shortened (Sabbagh, 2017). Sufficient percentage composition of the rubber mixture can yield enhancements within the dielectric strength of the polymer as well as enhancements to the properties suggesting its mechanical properties, such as elongation at breakage (Nasrat, 2007).

Table 2.12 also includes some of the rubber blending for high voltage application. It is clear that the most commonly used rubber blend is between the Silicone Rubber and the EPDM. Luckily, both of the rubber will be used in this research. The effectiveness of this blending together with the waste glass powder fillers was demonstrated.

Table 2.12: The summary of past research of rubber blend in high voltage application

Authors	**Research**	**Findings**
Ehsani. (2005)	Modified Silicone Rubber for Use as High Voltage Outdoor Insulators	The results of the contact angle measurement show that the water repellency of the polymers decreases with the salinity of the water. This study shows that the silicone-modified polymer is more hydrophobic than other samples under different conditions and that the silicone rubber resistance decreases with salt water ageing.
Nasrat (2007)	An Investigation into the Electrical Properties of Rubber Blends for Insulators	Tensile intensity and elongation at breakage for SiR/EPDM mixtures were not lower than for SiR. SiR samples are decreased in elongation value after 300 hours of UV exposure. Almost 6.6 percent and 500 hours after exposure to UV. Almost 13.7% of the population.
Asaad (2013)	Evaluation of SiR / EPDM Blends for High Voltage Insulators	Blending (SiR) with EPDM was found to be an effective way to improve mechanical, thermal and electrical properties and the appropriate percentage was found to be 50/50 (SiR)/EPDM.
Shata (2017)	Epoxy/Silicone Rubber Blends for Voltage Insulators and Capacitors Applications	The addition of silicone rubber polymer to the epoxy matrix increases thermal electrical properties as the addition of silicone rubber (0.75 Wt. per cent) to the epoxy matrix shows higher values for glass transition temperature and electrical resistance.

2.7 High Voltage Insulator Testing and Performance

Electrical devices must be able to tolerate overvoltage during operation. Therefore, an acceptable evaluation protocol is used to ensure that the relevant criterion is followed. The object of this test is to decide the puncture voltage. The insulator to be checked shall be suspended in the insulator liquid. High voltage testing is commonly known as testing of insulating materials and testing of finished equipment.

2.7.1 Insulation principle in high voltage

Insulation is subject to several elements that which allow it to work at a less than satisfactory standard. Excessive heat or cold, moisture, friction, soil, oil and corrosive vapours may all lead to oxidation. For this purpose, routine isolation tests are required (Jim, 2004). Insulator materials tested for their susceptibility to surface discharge detection and erosion (Heger, 2010).

The function of insulation around the conductor is more like that of a water-borne wire, and Ohm's electricity law can be more readily understood by comparing it to the flow of water (Meger, 2006). Based on Figure 2.14(a), the pressure on the water from the pump is seen to induce flow along the tubing. If there was a leak in the tubing, the water was wasted and any water pressure was lost. Figure 2.14(b) indicates that with electricity, voltage is like pump pressure, which allows electricity to flow along the copper wire. There is some resistance to movement, as through the water tubing, but there is much less around the wire than in the insulation.

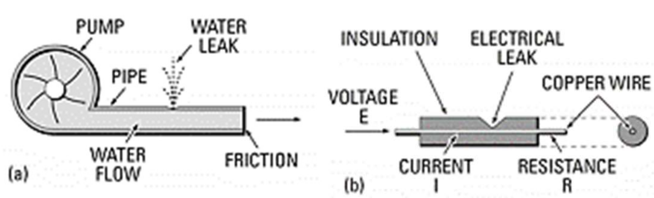


Figure 2.14: (a) The effect of leak to water pressure. (b) shows that the implication of electrical leak to the current flow (Magger, 2006)

2.7.2 Related testing for high voltage (HV)

Tests conducted on dielectric samples usually consist of the calculation of the permittivity, the dielectric loss per unit volume and the dielectric strength of the specimen. The first two can be measured with the High Voltage Schering Bridge (Lucas, 2001). The basic test involves only an AC voltage test and a comparable test for DC voltage has not yet been standardised. However, the inclined plane experiments carried out on polymeric housing materials use the AC process and the adapted equipment to conduct the DC tests. They only used positive polarity DC since it was usually perceived to be more extreme than negative polarity (Moreno and Gorur, 2000). In addition, the inclined plane experiments provided valuable information on the efficiency of widely used insulator materials when energised by AC voltage and DC voltage in both polarities. EPDM rubber does better under DC voltage than rubber-based silicone. It also indicates that the DC test is more extreme than the AC test for all components, including the peak AC voltage exceeding the steady DC voltage by 40% (Heger, 2010).

However, the time resistance test method can produce reasonably conclusive results without the luxury of previous test measurements. The test method is based on successive readings at set time intervals and then plotting the measurements. This is an especially successful approach for the presence of moisture and other contaminants (Jim Gregorec, 2004).

Last but not least, a one-minute rain test is carried out as the insulator is flooded with simulated rain from the source of supply at temperatures below 10°C during the test of the ambient temperature of the insulator region. The insulator is sprayed at an angle of 45° at the recommended speed of 3.00 mm/minute. The water resistance should be 100 m ± 10%. The voltage required shall be maintained for one minute (Lucas, 2001).

2.8 Research Gap and Summary

The review is research of SiR/EPDM based rubber blend composite with the addition of compact fluorescent lamp is being discussed. In this study, the limitation was established in the previous work. The differences between previous works are described in Table 2.13.

Table 2.13: Summary of Research Gap

Novel Research	Description
Replacing Silicone Rubber with Silicone Rubber/EPDM Insulator	By blending these two composites it will increase the tensile strength, thermal properties and the elongation at break. By blending SiR with high percent of EPDM, it will increase the dielectric strength values and tracking times. This will definitely increase the performances of the insulator.
Improved final product of SiR/EPDM with filler.	By adding the fillers in the polymer matrix, this will definitely lower the production cost. Polymer composite designs for high-voltage insulators possessed those lightweight, fewer cracks, increased seismic efficiency and greater flexibility than ceramic insulators in actual. These features offer the benefits of lower installation costs, improved durability and more aesthetic.
Filler from waste	In this country, the issue regarding the dumping of waste lamp is still in a debate. Majority of the western country already build a center for lamp disposal. So, one of the initiatives is by recycling the waste. The waste that can be used from the compact fluorescent lamp is the bulb which producing silica. Glass waste materials have been recycled for silica because of their harmful environmental effects and lowered disposal costs worldwide.

CHAPTER 3
METHODOLOGY

3.0 Introduction

Overall research methods, materials and techniques involved in this study was explained in further details in this chapter. Essentially, this research has focused on studying the effects of waste glass powder (WGP) fillers to high voltage insulation behaviour of SiR/EPDM-based composites, focusing to the resulted physical and mechanical properties of SiR/EPDM-based composites based on various characterization testing.

Basically, for this chapter, it emphasised the experimental procedures involved in the preparation and testing of the produced samples. The first step was begin with the preparation and characterization of waste glass powder by performing grinding process and was followed by several characterizations such as Particle Sample Analysis (PSA), X-ray Diffraction (XRD) and Scanning Electron Microscope (SEM) methods. The explanations have covered the methods applied, the experimental setting and some of related consideration while performing the research and characterization process. The main raw material used are silicone rubber (SiR) and ethylene propylene diene monomer (EPDM) as a matrix phase. While waste glass powder (SiO_2) is used as the reinforcement phase.

Moreover, it followed with the performance evaluation for hybrid SiR/EPDM rubber matrix filled with SiO_2 filler to get outstanding resulted mechanical and physical properties. The amount of filler added was basically at ranged between of 0.00 wt.% - 40.00 wt.%. The following Figure 3.1 has simplified the overall methodological view of this study in the form of flow chart.

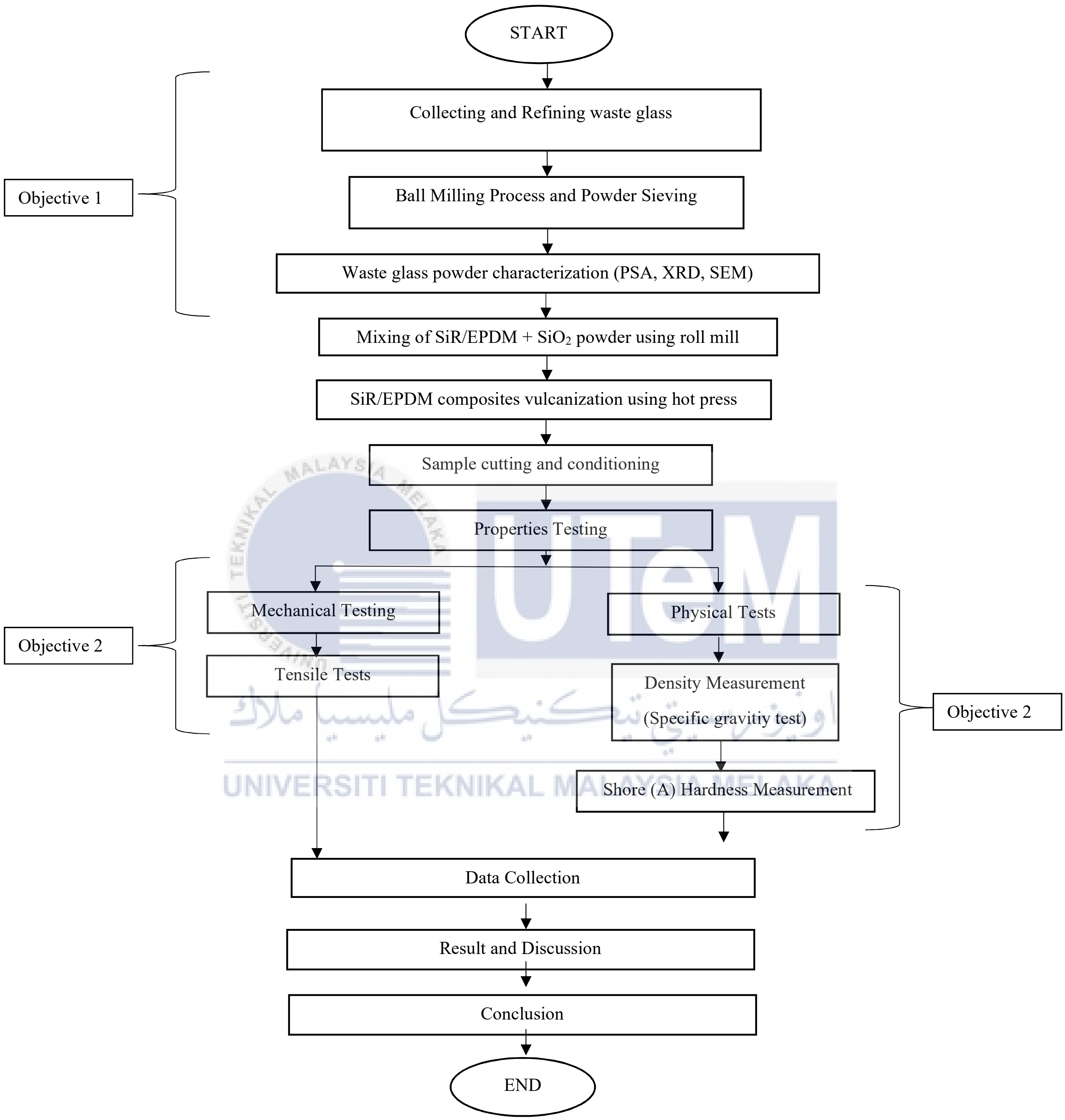


Figure 3.1: Flow chart of an overall research

3.1 Raw Materials and Characterization

The raw material used in this research study is Silicon Rubber (SiR) and Ethylene Propylene Diene Monomer (EPDM) as the matrix phase, while the waste glass powder (SiO_2) as a filler reinforcement phase. The filler used is basically a waste material from the household's glass bottle. The glass bottle is taken for the silica (SiO_2) filler source. The following section has briefly described the procedural involving, collecting, refining and crushing/grinding the waste glass.

3.1.1 Waste glass powder (SiO_2) preparation and characterization

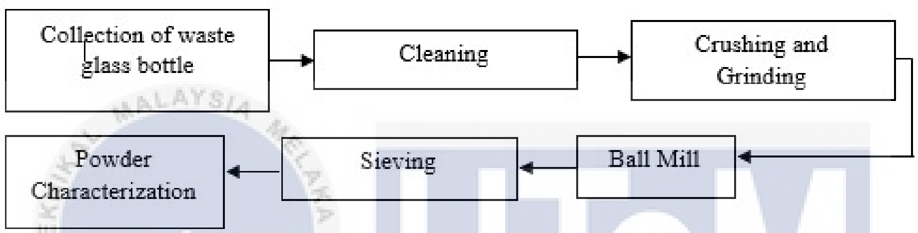


Figure 3.2: Process flow of solid glass bottle to powder particles

The overall flow chart of the process in characterizing the waste glass powder is shown in Figure 3.2. The waste glass bottles are obtained from the recycling centre located in Melaka state. The waste glass bottle used is approximately five medium size ketchup sauce glass bottles. Waste glass are cleaned with soap solution and water and properly dried using the air gun at the laboratory before it ready to be used. Next, the hammering step was taking place to break down the solid waste glass into smaller fine particles. This is manually done using the 25mm claw hammer. This process taking around 2 hours of working as to ensure the glass in the smallest size as shown in Figure 3.3 (a)(b).

Figure 3.3: (a) The hammering using claw hammer (b) The final size of manual crushing

After the size is suitable for the machine to crush into powder particles, the next step is by using the crusher machine. This machine will turn the small pieces of the glass into smaller particle sizes. The following method of ball milling was conducted to ensure that the waste glass could be converted into finer powder form. The type of the machine used is planetary ball milling that will operate in rotational movement is the self-rotation of the grinding container superimposed. The resulting centrifugal and acting acceleration forces lead to strong grinding effects. The speed of the machine is 200rpm with the time duration 60 minutes for one complete process. Both grinding jars is used to maximize the results and minimize the time taken for all glass particles to be crushed. The ball used is stainless steel with the same amount of ball used for both jar which is 30 balls with different sizes. This process is depicted in Figure 3.4 (a)(b).

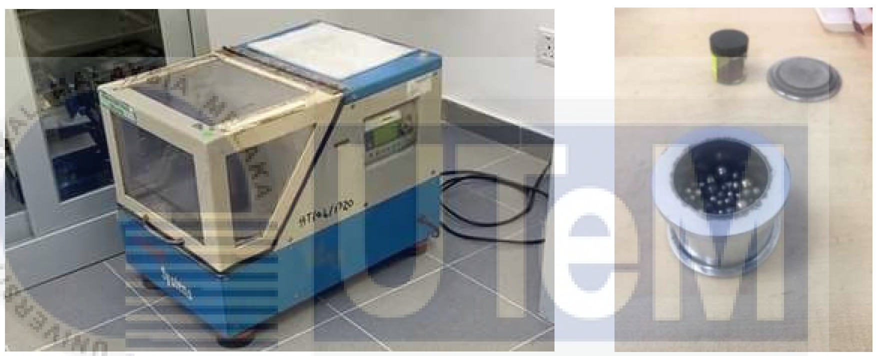


Figure 3.4: (a) Planetary ball mill (b) The stainless ball used in jar

The next process after the glass pieces turn into the SiO_2 powder is the sieving process. Sieving process is done to ensure the powder is in the same size. This is an important step as the mixture of different powder sizes might affect the mechanical and physical properties of the composite. The sieving machine used is shown in Figure 3.5. The time taken for 50g of powder is 60 minutes with speed of 0.5min with zero-time interval. The total time taken for 1kg of SiO_2 powder is around 24 hours. The sieving dish use is in size 40 µm.

Figure 3.5: The sieving machine

After all the process in preparing the glass powder is successfully done as shown in Figure 3.6. The following process is the characterization process for SiO_2 powder was carried out by using the X-Rayy Diffraction (XRD) and Particle Size Analysis (PSA).

Figure 3.6: Silica (SiO_2) powder made from glass bottle

3.1.2 WGP observation under the X-ray Diffraction Analysis (XRD)

The X-Ray Diffraction (XRD) machine is used to prove the presence of silica element in waste glass. The type of machine used is PANalytical X'Pert Pro as shown in Figure 3.7. The machine is multipurpose X-Ray Diffractometer equipped with a Cu Kα source. The X'Pert Pro is capable of both high-resolution and lower-resolution measurements and enables a wide range of thin film and powder sample analysis. The X-rays are generated by a cathode ray tube, filtered to produce monochromatic radiation, collimated to concentrate, and directed toward the sample. The sample used for this testing is only 10 grams of SiO_2 powder. The sample is placed on the round flush surface sample holder, then sample holder is placed on the sample fixture to undergo the process. The technician will be setting all the important data in the XRD Wizard Application in the desktop to control the process such as power generator that can be set up to 40kV.Also, it will select the suitable parameter for the powder type in the software library. Then the graph data will be achieved.

Figure 3.7: The X-ray Diffraction (XRD) Machine

3.1.3 WGP observation under the Particle Size Analysis (PSA)

The next characterization process is the Particle Size Analyser (PSA). The type of machine used is Malvern Particle size analyzer Mastersizer 2000 as shown in Figure 3.8. This machine can measure from 0.2 µm until 2000 µm. The machine allows access to all of the system functions and extensive analytical capabilities. The Mastersizer software provides control and management of all size measurement and data management tasks. This process will be used to assess the particle size of ball milled SiO_2 powder using the laser dispersion approach. The combination of red laser and blue laser to different wavelength of light to create the large particle size range. The sample used for this machine is only around 10 grams of glass powder. The glass powder is place on the tips of the trays and the sample will mixed with the compressed air inside the machine. The machine directly closed after insert the powder as to reduce any potential toxic to enter the machine. The powder will be dispersed and travel through the laser beam to measure the size.

Figure 3.8: The Particle Size Analysis (PSA) Machine

3.1.4 Waste Glass Powder (WGP) Observation via scanning electron microscope (SEM)

The last characterization is the Scanning Electron Microscope (SEM). The type of machine used is Zeiss Evo 40 as shown in Figure 3.9. This machine used was to investigate the morphological behavior of the waste glass powder. This SEM machine allowing samples to be examined in their natural state under a range of conditions including very high-water vapor pressure up to 3000 Pa. The SiO_2 sample used for this process is approximately 20 grams. Before being coated with gold palladium, the powder is dispersed and scattered on the carbon tape. This procedure was carried out in order to prevent the electrostatic charging during the observation process, which hinders the accuracy of the observation. The observation by scanning the sample was conducted with strong electron beam at an average acceleration voltage of approximately 40 kV. The magnification used for observation was defined at 50x, 100x, 300x, 500x, 1000x. Three spots were taken for each magnification scale.

Figure 3.9: Scanning Electron Microscope (SEM) for fracture surface morphological observation

3.2 SiR/EPDM- SiO_2 Composites Preparation

The mixing and cure characteristic testing were performed in Saiko Rubber Sdn. Bhd., located in Senawang, Negeri Sembilan. The SiR/EPDM blend compounds were prepared by the open two roll mixing mill of Cope, model MT 2-2, as shown in Figure 3.10 and run at temperature of 35°C, 50 rpm mill rotation and a nip gap of 4 mm. The five samples took approximately 7 mins of mixing time each. Table 3.1 shows the composition of SiR/EPDM-SiO_2 rubber blend composites. The composition of blending of (SiR) with EPDM is found to be an effective way to improve mechanical, thermal and electrical properties and the suitable percentage for SiR/EPDM ratio was found effective to be at 50/50 (SiR) / EPDM based on previous literature (Asaad, 2013). The peroxide curing system was utilized for this blend system. For consistency, about 3.00 grams of dicum 1 peroxide (DLP) was added for each 500 grams of SiR/EPDM rubber formulations. Also, about 1.50 grams of black heat resistance paste was added together to each rubber blend formulation as stated at the following Table 3.1. All the combination of composites was milled together at the same time and the compounded rubber mixtures were conditioned for 24 hours prior to cure characteristics testing by using a rheometer as shown in Figure 3.11.

Figure 3.10: Open two roll mill (Saiko Rubber (M) Sdn Bhd)

Table 3.1: The composition of the rubber blending

Sample	SiR	EPDM	Waste Glass Powder
1	50	50	0%
2	50	50	10%
3	50	50	20%
4	50	50	30%
5	50	50	40%

Figure 3.11: Rheometer machine (Saiko Rubber (M) Sdn Bhd)

Furthermore, the melt-compounded of SiR/EPDM- SiO_2 were vulcanized using a hot press machine in Figure 3.12 (Gotech-GT 7014) for composite sample formation with an optimum cure time (Tc 90) determined by oscillating disk rheometer (ODR), Rheometer UR-2010 for compression, 60kg/ cm^3 hydraulic pressure and 175°C temperature. The mould size for dielectric test composite is 200 x 200 x 3 mm^3 size. The composite sheet is cooled with two internal waterflow for 12 mins. The sample were cut and condition for the testing (Figure 3.13).

Figure 3.12: Hot Press Machine


Figure 3.13: The sample specimen for testing

3.3 SiR/EPDM – SiO_2 Rubber Blend Composites Testing

Testing is performed to ensure the composition of rubber blend composite is optimum for maximum resulted performances. The test is conducted based on several criteria and required experimental results in line with the stated objectives in Chapter 1.

3.3.1 Mechanical tests

For mechanical testing, only one main test was performed which is the tensile test. The objective of tensile test was to evaluate the tensile strength and the elongation at break (EAB) of SiR/EPDM based composites at different SiO_2 waste glass powder loadings. The tensile testing was carried out using the Universal Testing Machine (UTM) that complies with the ASTM Standard of Rubber Tensile Test Process. The BS 6746 rubber standard has been specifically selected for the tensile testing of rubber-based composites specifically for insulator applications. The tensile tests are conducted using the UTM Universal Testing Machine (Shimadzu brand, Japan) at room temperature condition. The system was specifically designed with a high tower frame for rubber testing, as shown in Figure 3.14. According to the BS 6746 standard, the specimen shall be cut into a dumbbell shape of 10 mm x 64 mm x 2 mm. The length of the gauge used was 10 mm based on the initial sample size. The full load applied was 25 kN at a crosshead speed of 300 mm/min. The mean value was taken by duplication of five (5) tested samples.

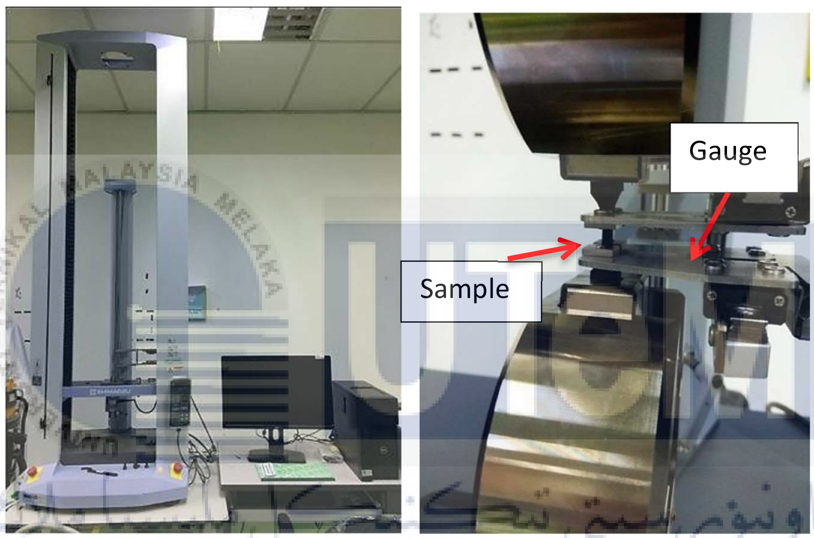


Figure 3.14: Universal testing machine (UTM) model Shimadzu 20 kN

3.3.2 Hardness measurement

Hardness calculation by using SHORE-A hardness scale, measured the resistance of local deformation of the test piece against the standard rigid ball indenter under room temperature condition. The hardness reading was obtained from the dial gauge which was measured earlier according to the International Rubber Hardness Degree (IRHD). The durometer test of SHORE-A hardness was used in conjunction with ASTM 2240 as shown in Figure 3.15. The penetration of a rigid ball valve into a rubber test piece was determined. Test pieces with a diameter of 12 mm and a desirable thickness of 4-6 mm shall be used. Samples are first conditioned at a standard laboratory-controlled temperature of 25°C for at least three hours prior to the test. The depth of the indentation has been measured, which provides a measure of the hardness of the sample. Values are based on a scale of 100 points (accuracy of ±1.00 points). However, as time has elapsed, the sensor will fall back so that it was read a few seconds after the indenter touched the sample.

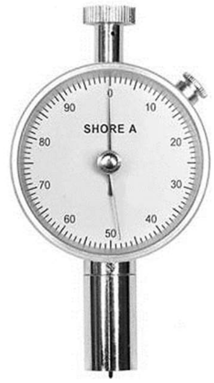


Figure 3.15: Shore (A) hardness indenter dial gauge

3.3.3 Density measurement

The purpose of density measurement is to measure the weight per unit volume of the specimen. Electronic balance is required to weight the specimen. Besides, vernier calliper is required to measure the dimensional volume of specimen based on calculation. Density measurement will reflect the consistency of hybrid blend homogeneity between the SiR and EPDM rubber phases as well as the powder at different loadings.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \underset{\text{solids}}{\frac{g}{cm^3}} = \underset{\text{liquids}}{\frac{g}{mL}} \qquad \text{eq (1)}$$

3.5 Conclusion

In conclusion, in order to achieve all the objectives stated in Chapter 1, all the important measures in this research must be adhered. The preparation and characteristic of the SiO_2 waste glass powder is done by using the ball milling and sieving process. It was necessary to do the sieving process as to ensure the homogeneous particle in the same size. Thus, all the characterization process taken such as PSA, SEM and XRD were conducted as to ensure the powder form of SiO_2 followed the standard requirement before blending. The evaluation of SiO_2 powder loadings is strictly measured as to observe the mechanical and physical result from the conducted mechanical and physical tests. In overall, the research has successively done all the steps and testing to get the desired result.

CHAPTER 4

RESULT AND DISCUSSION

4.0 Introduction

This chapter has discussed and evaluated the experimental results obtained in this research work. Technical discussion in regards to the observation and experimental results was performed in assessing the performance of SiR/EPDM with various loading of waste glass powder filler. The wastes mineral fillers silica (SiO_2) was acquired from waste glass. The experimental results and the related discussion divided into physical and mechanical testing. There are TWO (2) significant parts throughout this chapter which uphold the objectives expressed in Chapter 1.

i. The analysis and discussion on raw materials characterization.
ii. The analysis and discussion on mechanical and physical properties of SiR/EPDM filled with various loadings of waste glass composites.

4.1 Raw Materials Characterization

4.1.1 Structural analysis using X-Ray Diffraction (XRD) method

Characterization on raw materials are significantly important as filler produced and used for this study are produced using waste resource of utilized glass bottles. Essential structural characterization on raw materials produced was performed by using an X-Ray Diffraction (XRD) method. Other than that, Particle Size Analysis (PSA) and Scanning Electron Microscope (SEM) observation are likewise utilized in this research, with the end goal of raw materials characterization. Figure 4.1 depicts the X-Ray diffraction (XRD) patterns for SiO_2 from waste glass powder.

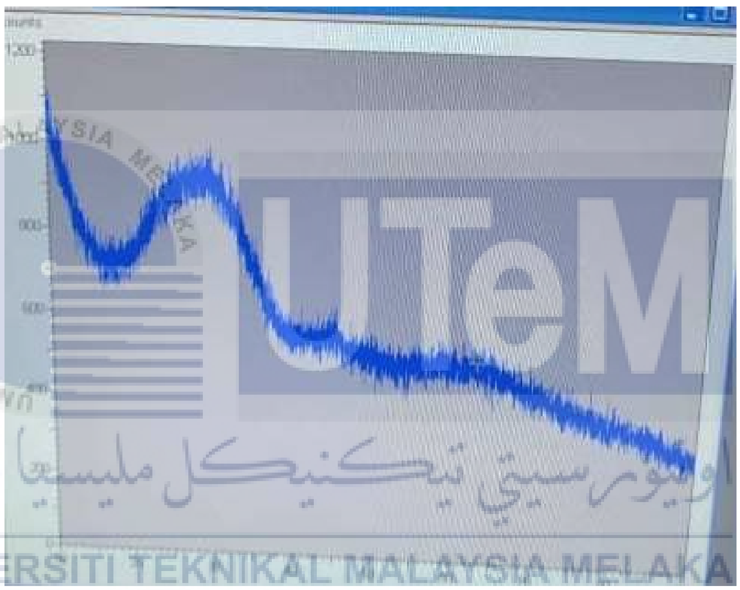


Figure 4.1: XRD diffraction of SiO_2 from waste glass

From the XRD Diffraction, it can be confirmed that the presence of SiO_2 was matched with the software library. This is affirmed by the coordinated with technique performed with the XRD software library that show the presence of SiO_2. Based on Figure 4.1, it is clearly seen that the intensity of diffraction peaks was relatively low, and there was a diffuse peak. This confirmed that the powder is the silica since its shows the amorphous behaviour. This is supported by Joni (2016) The XRD showed that it exhibits a crystalline nature with characteristics crystalline phase with an average crystallite size of about 28 nm as shown in Figure 4.2. Silica will show it amorphous result, if it diffractograms and featureless. However, at higher temperatures, as silica crystallizes, cracks are likely to arise in the shell, thereby allowing diffusion of oxygen and oxidation of the core (Liu,2020). The SiO_2 diffraction peak distinctly increased at 20°- 30° which is the phase transition interval for silica which indicate that cristobalite starts to form at this level. The broad peaks give a meaning that the coherent scattering arising from non-random interatomic distances in the material and it represent the variations in morphology. Next, at 40° until 90° it showed a broadened diffraction. The plotted diffraction pattern showing no huge pinnacle which demonstrate presence of no translucent material. This finding can be firmly upheld by research finding acquired by Aman (2013) Where the non-translucent kind of SiO_2 glass was dominantly presence.

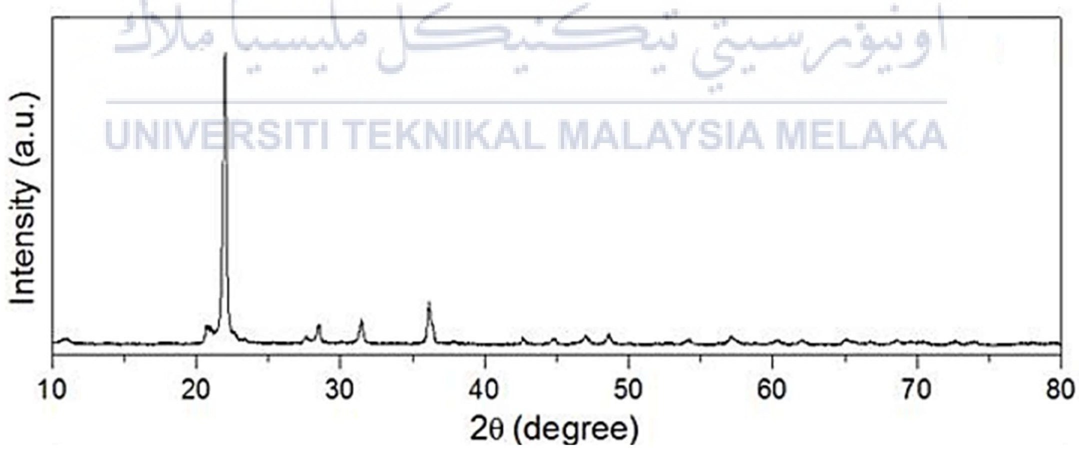


Figure 4.2: XRD result of SiO_2 testing (Joni,2016)

4.1.2 Particle size analysis (PSA) characterization

Particle Size Analysis is conducted to dissect and describe the size conveyance and shape of mineral filler powder, produced using waste resources, that are utilized as significant filler in SiR/EPDM matrix composites fabrication. It was clearly shown of having micron size dimension. From the PSA size distribution diagram, it was affirmed that, the most noteworthy size range of silica powder produced from waste glass, was dominated at ~60 µm, as appeared in Figure 4.3.

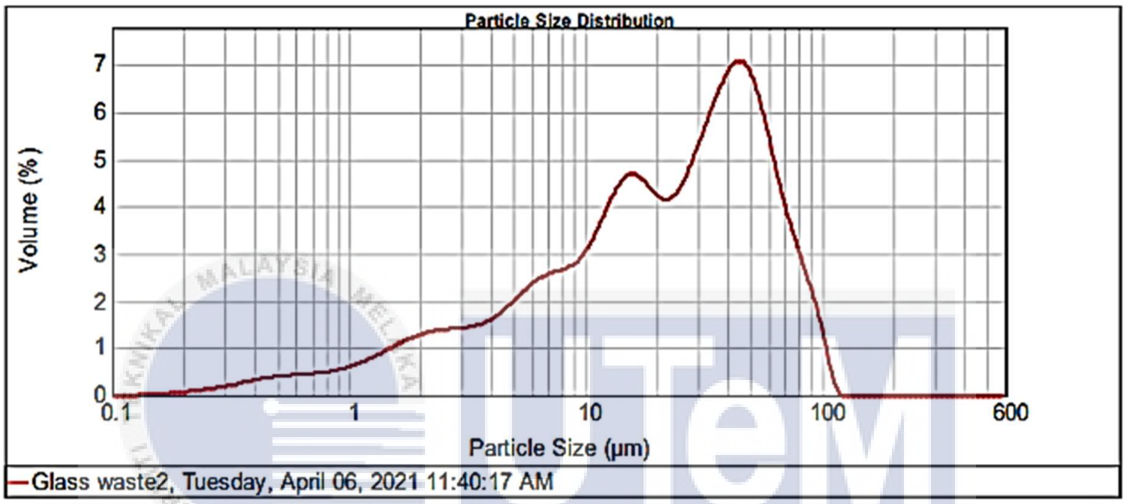


Figure 4.3: Particle Size Analysis graph of the SiO_2 at 2.558 µm, 22.124 µm and 63.209 µm

In view of testing, three distinctive size is distinguished which is at 2.558 µm, 22.124 µm and 63.209 µm. This shows that the grinded silica powder is made up from various size. The different consistency of the SiO_2 powder is achieved due to the crushing method done. The size of the inconsistent crushed glass that was manually crushed before enter the auxiliary ball milling might be one the reason for this phenomenon. The particle diameter was influenced by the existence of many agglomerations of particles on the sample which was detected by PSA (Hakim,2018). Nevertheless, the result from the PSA testing is still worthy as it still in the expected range which is below 60 µm. This is the range that is set for this study. Figure 4.4 and Figure 4.5 shows the size of the particle with the volume from 0 to 2000 m^3. The particular surface region is 1.07 m^2/g which bring the bigger space of contact filler. The higher the surface region, the lower the scattering. This outcome is most likely because of the way that high surface region ordinarily has more modest totals, which will foster more associations with their fillers in the dry state (Jean,2013).

Size (µm)	Volume In %
0.010	0.00
0.013	0.00
0.016	0.00
0.021	0.00
0.027	0.00
0.034	0.00
0.043	0.00
0.055	0.00
0.070	0.00
0.090	

Size (µm)	Volume In %
0.090	0.00
0.115	0.01
0.147	0.05
0.187	0.13
0.239	0.24
0.305	0.40
0.389	0.58
0.497	0.68
0.634	0.74
0.810	

Size (µm)	Volume In %
0.810	0.75
1.000	1.30
1.320	1.59
1.684	1.98
2.150	3.02
3.000	1.47
3.503	2.57
4.472	1.38
5.000	5.81
7.287	

Size (µm)	Volume In %
7.287	4.30
9.302	5.16
11.874	6.89
15.157	13.97
24.698	0.35
25.000	7.48
31.527	10.03
40.244	11.18
51.371	9.09
65.575	

Size (µm)	Volume In %
65.575	5.73
83.707	2.48
100.000	0.66
120.000	0.00
174.110	0.00
222.251	0.00
283.704	0.00
362.148	0.00
462.281	0.00
590.102	

Size (µm)	Volume In %
590.102	0.00
753.265	0.00
961.542	0.00
1227.408	0.00
1566.785	0.00
2000.000	

Figure 4.4: Result of PSA in overall

Figure 4.5: Particle Size Analysis graph from 0 to 2000 µm

4.1.3 Scanning electron microscope for the glass waste

The shape of silica from waste glass source was portrayed as in the accompanying in Figure 4.7. From careful observation, the acquired silica powder shape morphology is essentially as elongated and angular shapes, with sharp edges surface, that influences the usefulness the characteristic of rubber-filled interaction in the composites (Tan and Du 2013). This finding has very much upheld by work done by Aly et al. (2011) Where they had found comparable fine angular particles in waste glass. This is supported by Joni (2016) The morphology of SiO_2 depicts mostly in irregular rod- shape with agglomeration in shown in Figure 4.6. Chen et al. (2003) Has referenced that the shape of filler has assuming enormous parts in influencing the properties of filled composites. Consequently, these surface and shape highlight are significant factor in determining the rubber-filler interaction, between SiR/EPDM matrix and SiO_2 mineral fillers.

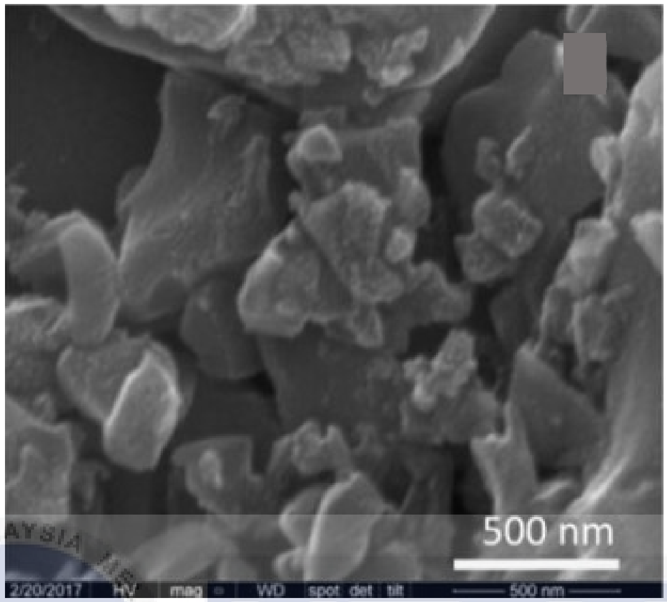


Figure 4.6: SEM observation under 500X magnification (Joni,2016)

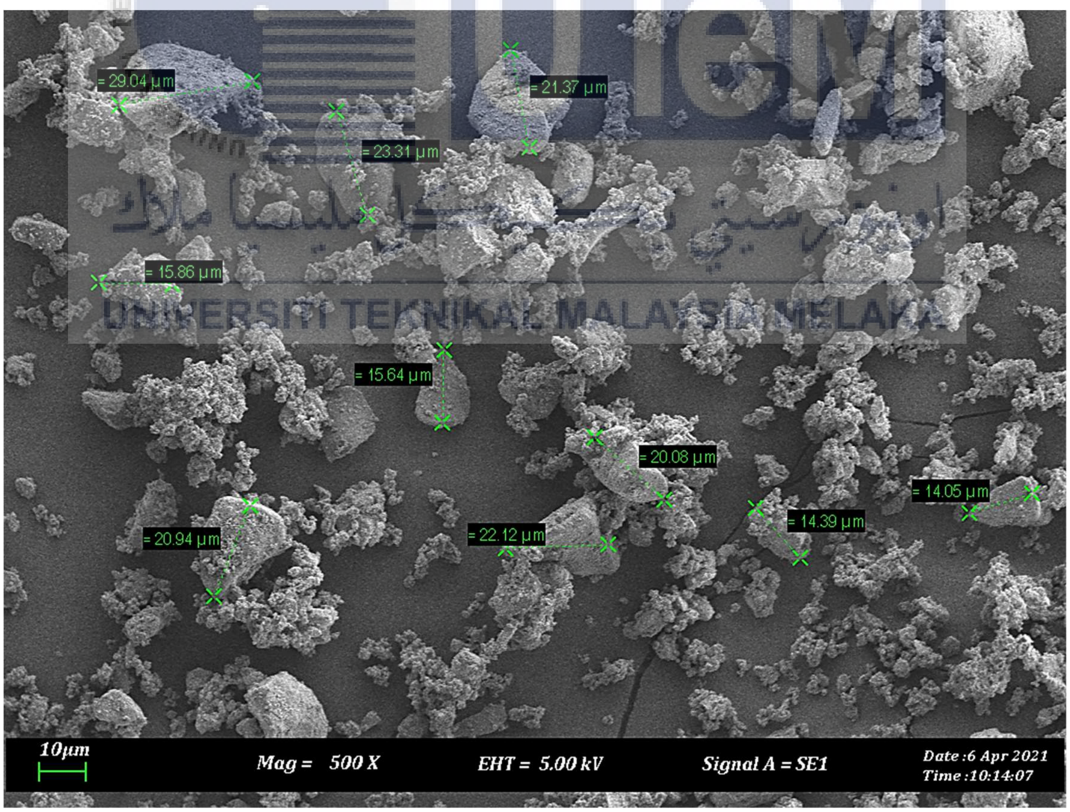


Figure 4.7: SEM observation of waste glass powder filler particles at 500X of magnification

Based on SiO_2 depicted in Figure 4.7, it shows that the size of the waste glass powder is in few ranges. The biggest size is 29.04 μm and the smallest size seen is 14.05 μm. This is due to the different concentration of the powder during the crushing process. However, the size of powder is in the range of the research. Based on Claire (2018) The smaller the particle, the more difficult it is to disperse. The dispersion rate of the powder is considered as well-dispersed with a small gap between one another. This will give the best combination with the rubber composite matrix. According to the results and in view of the functionalization cost, it is ultimately more advantageous to manufactured composites with well-dispersed and unmodified silica particles instead of composites with poorly-dispersed and modified silica particles (Azema,2018).Also, based on this 3D dimension view, it can clearly be seen the glass powder is in amorphous and crystalline structure. The surface structure of silica has been studied for decades, in crystalline and amorphous forms. Due to its surface roughness and insulating nature, amorphous SiO_2 is an especially challenging material for many surface science methods, as they often rely on charge transport 2D silica films are atomically flat and allow the unhampered investigation of this electrical insulator with surface science (Heyde,2017).

4.2 Mechanical and Physical Testing of The Composite

The mechanical and physical result of this SiR/EPDM-WGP composites is mandatory as to find the effectiveness of the rubber blend combination. The loadings percentage which is 0,10,20,30 and 40 wt.% of glass filler is tested for all testing. The mechanical testing involve is tensile and ultimate elongation at break is to find the strength quality of the composition. While, the physical testing was done for shore A hardness testing and specific gravity. These important results are important to determine the best combination of SiR/EPDM with waste glass filler as a product.

4.2.1 Tensile testing

Tensile strength is one of the important properties for describing the mechanical performance of the composite especially for this newly prepared composite material. Tensile test is performed to evaluate the tensile strength of produced composite of SiR/EPDM filled with SiO_2 filler. The universal testing machine was used to determine the tensile testing which based on BS 6746 rubber standard. During the test, the specimen is pulled from both the ends. As the pulling progresses, the specimen bar of composite elongates at a uniform rate that is proportionate to the rate at which the load or pulling force increases. Beyond proportional limit & elastic stress limit, pulling of specimen in opposite direction causes a permanent elongation or deformation of the specimen. The loading of 0,10,20,30 and 40 wt.% of glass filler were added to the SiR/EPDM composite. The tensile testing showing the pattern result of higher filler loading has yielded higher tensile strength which can be found in Figure 4.8. This is agreed by proclamation by Mahdi (2020) The normal strength of composites has increments somewhat for about 30% filler addition. Addition of filler into polymer matrix may increment or diminish the strength of produced composites.However, in this study the increment can be seen until 40 wt.% of glass filler.

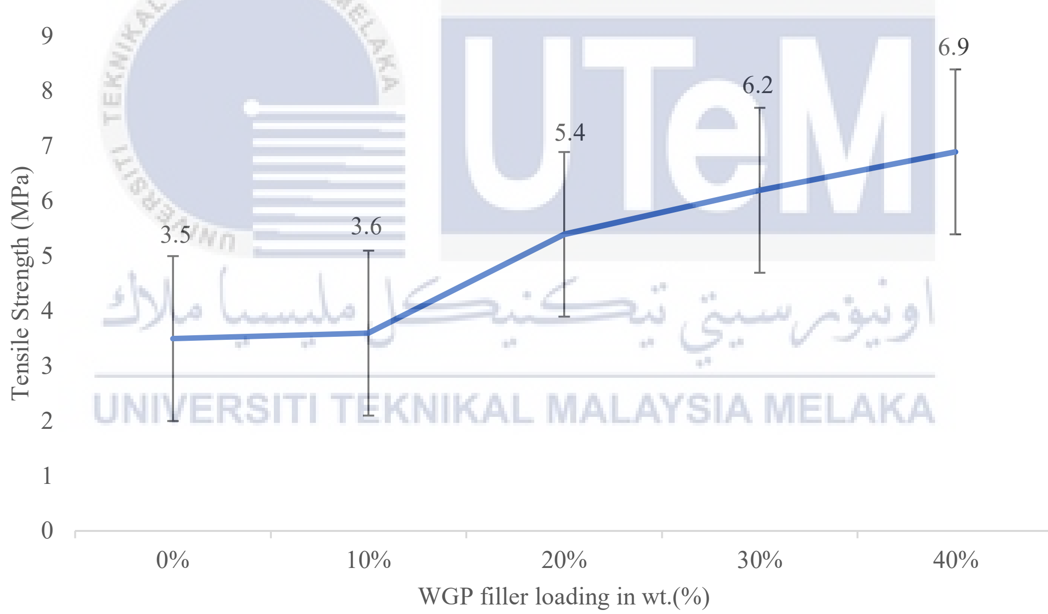


Figure 4.8: Tensile strength graph of the SiR/EPDM- SiO_2

Based on the Figure 4.8, the graph trend showing a high climb from 3.6MPa to 5.4Mpa at the filler loading of 10wt.% to 20wt.%. This increasing trend give about 150% rose for only 10wt.% different. However, the increasing became slower from 20wt.% to 30wt.% with only 114% of increasing. This conclude that 10wt.% is starting for the glass filler to interact with rubber composite. This is the point where the distribution and dispersion of the filler in the matrix begun and it directly increase the Young's Modulus of the composite. This improvement is probably due to the natural affinity between silica and composite (Alexandra,2018). Based on Wypph (2016) Glass may decrease or increase tensile strength depending on their interfacial adhesion. In this study, the glass filler showing a positive result in increasing the tensile strength, this mean that the glass filler is a good filler in increasing the adhesion of filler and composite. The strength has appeared to be increased in average of 5.1MPa with standard deviation of 1.5MPa all through the testing which based on the graph plotted.The calculation is achived using the basic mathematical formula in finding standard deviation. It was discovered that, as the mineral filler loading increase, the tensile strength has commonly increase. In any case, there was asserted that by adding inorganic filler into polymer network, it could enhance the tensile of produced composite material. This hypothesis can be regarded from the role of filler stop the crack propagation causing premature failure, during the mechanical testing (Rama ,2019). This concluded that addition of glass filler can increase the mechanical properties of the composite.

4.2.2 Ultimate elongation at break

The ultimate elongation is calculation of the percentage of permanent deformation remaining after the tensile rupture. This testing is done to identify the rate of the composite to withstand the bending and shaping of material without breaking. This testing is done for SiR/EPDM-WGP composite with five different samples. The constant sample is used at 0wt.% followed by another four loadings at 10,20,30 and 40wt.%. The outcomes show that the ultimate elongation for this study is in irregular pattern, this can be found in Figure 4.9. The stiffer the composite, the better the capacity of such composite to sustain given load. In view of Mahdi (2020) The ultimate elongation at break diminishes with increasing SiO_2 filler content. The decrease in lengthening occurred because of the diminished deformability of inflexible interphase between the composite and the grid material. In any case, their impact as support filler was not altogether clear in this examination as the aftereffect of unpredictable example.

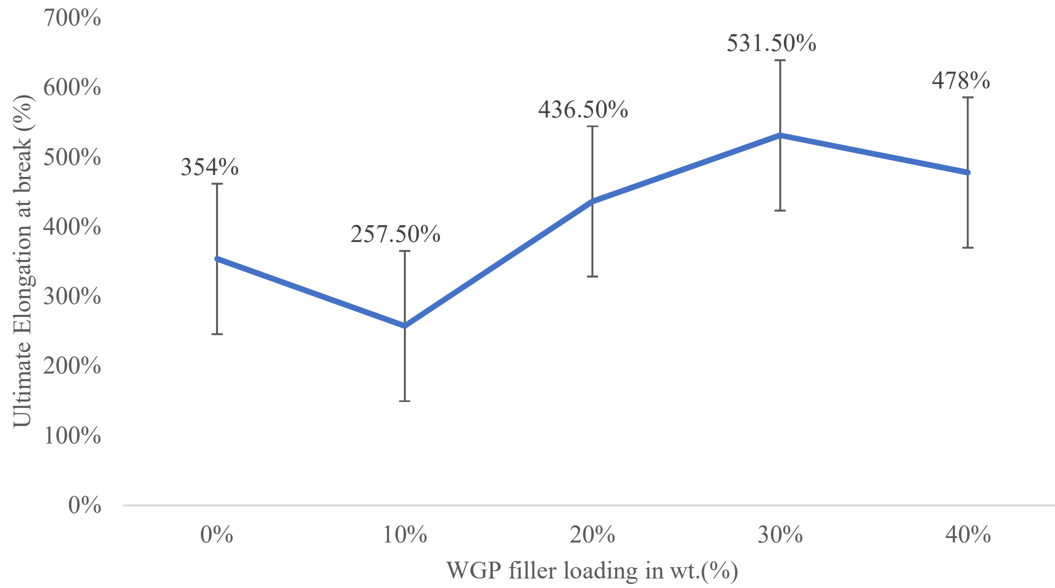


Figure 4.9: Ultimate elongation result of the SiR/EPDM with SiO_2

Based on Figure 4.9, the first 10wt.% showing a drop from 354% to 257.5% at the rate of 0wt.% to 10wt.%. This bring a reduction for about 72.74% from the constant sample. However, the graph showing a bright improvement with an abrupt increment to 436.50% at 20wt.% loading with a build-up of 169.51%. At the filler concentration of 30wt.%, the trend keeps the momentum to hike up to 531.50% which bring the increasing of 121.76%. However, the trend seems to meet the end of increasing when at 40wt.% the result showing a reduction of 89.93% to 478% elongation. The standard deviation for this graph is 1.08. This decreasing pattern is agreed with the statement made by Omne (2021) Where the elongation of composites decreases with an increase in the filler content. It as found that the increasement of filler content resulted in the reduction of deformability of a rigid interface between filler and rubber composite (Wang,2009). The characteristic of the SiO_2 give an effect to the mechanical properties of the SiR/EPDM rubber composite. There is reduction in the elongation at break of the composites with increase in the wt.% of the filler. This is due to the fact that the SiO_2 filler is hard and also highly brittle that give an effect to the high elongation of SiR/EPDM rubber blend composite.

4.2.3 Shore A hardness testing

Shore A Hardness is one of the methods to measure of the resistance of material to penetration of a spring loaded. This type of hardness which is Shore scales is basically a testing for polymers such as rubbers and plastics. This testing holds one of the important measures in a composite. The ability to quantify the hardness property is a great advantage in product liability and safety (Saba,2019). Hardness testing is significant to assess a material's properties, for example, strength and ductility and the impact of rubber crosslink physical condition of SiR/EPDM rubber with the presence of various loadings of waste glass fillers. Based Figure 4.10, the plot pattern for the shore A hardness are proportionally increased with the loading of the waste glass powder. This result is supported by the statement from Gruyter (2018) The amount increasing filler to composite caused significant increase in hardness, Young's modulus and flexural strength.

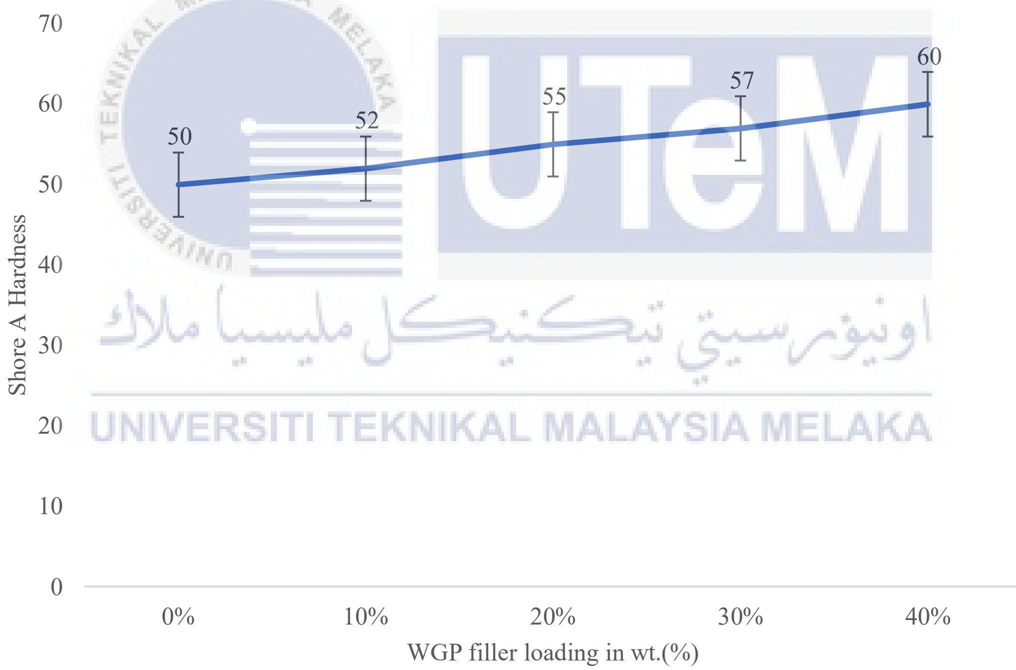


Figure 4.10: Shore A Hardness reading of the interaction SiR/EPDM with SiO_2

From the Figure 4.10, the constant reading started at 0wt.% with 50. It slowly showing an increasing to 52 at 10wt.% that bring approximately 104% from the constant. The graph trend is escalating with a small gap to 55 at 20wt.% and 57 at 30wt.%. The last plot is at 60 for the 40wt.%. This giving an average of 2.5 for each 10wt.% with percentage of 25% of loading increasing and standard deviation of 4.0. The more filler in the rubber, the greater the hardness of the rubber (Fajun,2019). This show that by increasing the loadings of waste SiO_2 filler, it will increase the hardness of produced rubber blend composite. This positive improvement has happened because of good interaction between SiO_2 filler with SiR/EPDM matrix. Likewise, an interfacial strength relies fundamentally upon the idea of the holding and the interaction applied (Chen et al., 2003). The glass waste filler acting as a harder block to increase the degree of hardness in the SiR/EPDM as it increases the physical properties of the composite. This highlighted the correlation between the tensile and hardness result. As tensile strength increases so does hardness testing (Miles,2018). This prove that the waste glass powder will produce a reliable rubber blend composite from its physical and mechanical properties benefit.

4.2.4 Specific gravity

The specific gravity is defined as the ratio of the density of the substances to the density of other substances for example pure water taken as a standard when both densities are obtained by weighing in air. Knowing the specific gravity of the composites allow to understand the determination of the characteristic of the SiR/EPDM filled with waste glass powder to the references. This will help to provide the approximate measurement of the physical properties of the composites (Isha,2021). The specific gravity for this study is done for all the five samples of waste glass filler at loadings of 0, 10,20,30 and 40wt.%. The graph result for the testing in Figure 4.11.

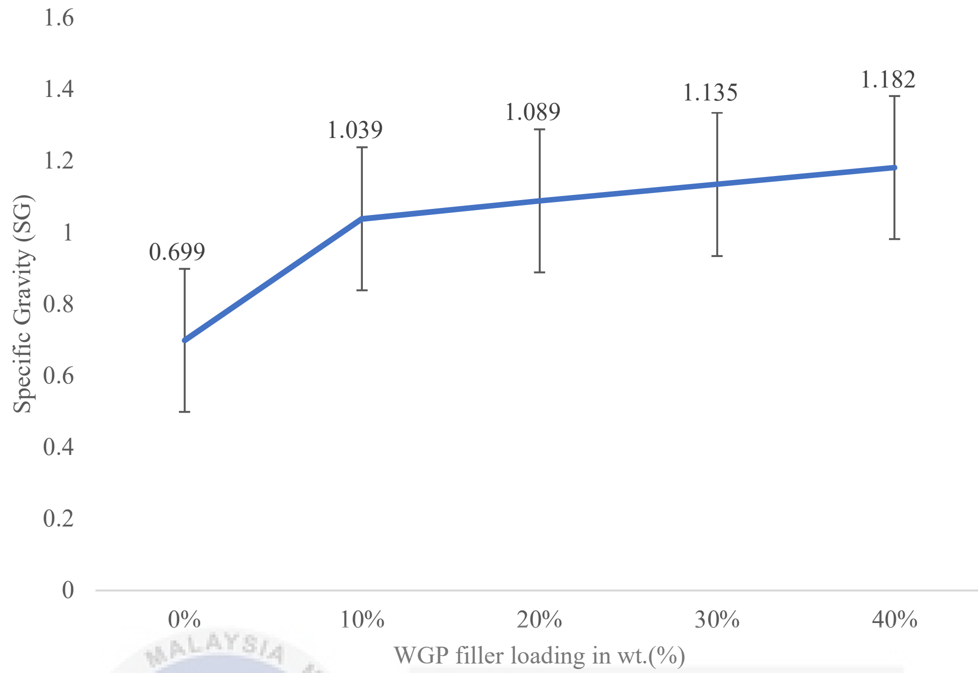


Figure 4.11: Specific gravity graph of the SiR/EPDM- SiO_2

Based on the Figure 4.11, the graph pattern for this specific gravity is in ascending order. The specific gravity value starts with 0.699 at 0wt.% of SiO_2 filler as the constant value for this research. The value escalates to 1.039 at 10wt.% with increasing of 148% from the constant. It continues to increase to 1.089 at 20wt.% then to 1.135 at 30wt.%. The final test at 40wt.% also give a positive value with an increasing of 104.14% with a value of 1.182. The average increasing for the composites is 1.029 for the five samples and standard deviation of 0.192 collected in the graph. The greater the percentage of the used glass waste powder, the greater the cavity in the composites (Zyafiqi,2021). This happen due to the glass waste powder has the character of zero water absorption that can fill the cavities scattered in the rubber maximally so that the rubber composite is watertight and reduce the open pores. This show that the SiO_2 is a poor water absorption but will be a good filler that bring the higher specific gravity to the SiR/EPDM rubber blend composites. Hence, it will improve the physical properties of the SiR/EPDM with waste glass filler.

4.3 Conclusion

In conclusion, all the testing done is this section is to answer every one of the significant measures that stated in the objectives in Chapter 1. The testing and characterization of the waste glass as a filler in the SiR/EPDM composite is completed by utilizing three important tests which are XRD, PSA and SEM. In the XRD testing, it shows that the tested SiO_2 powder produced using waste glass bottles, was amorphous or non-crystalline because of clear ordinary quality of wide amorphous diffraction design. While PSA demonstrated that the size of waste glass powder is in the range of below 60 µm when three sizes is distinguished which is 2.558 µm, 22.124 µm and 63.209 µm. The SEM technique clarify the morphology is chiefly as elongated and angular shapes, with sharp edges surface at 500X of magnification zoom. The tensile testing shows that the SiO_2 filler loadings increasing, the tensile results have commonly increasing. Next, the ultimate elongation gives an irregular pattern of graph that conclude that the higher concentration of filler will reduce the elongation rate. The hardness testing show that the increase the filler loadings, the increase the value of shore A hardness. To wrap things up, the increasing in specific gravity with expansion in filler stacking is seen most likely because of the upgraded scattering of the filler in the SiR/EPDM grid.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0 Introduction

This chapter was stated out the conclusion towards the significances of study and the findings of this research a par with the achievement of research objectives. The recommendations for future studies are also included in this chapter.

5.1 Conclusion

In conclusion, the rubber matrix of silicon rubber (SiR) and ethylene propylene diene monomer (EPDM) composites is filled with the waste glass powder filler reinforcements to evaluate the mechanical and physical properties with explicit accentuation to turn into the electrical insulation qualities. The impacts of mineral fillers addition and different loading were completely examined in this study. The material use in this examination is waste source glass was the waste glass bottle. This drive is taken out as to build up the sustainability esteem in the climate. The complex method to recycle the glass may be one of the issues why the glass is too hard to be consider for reprocessing.

To emphasize the utilization of the waste glass as a filler in the SiR/EPDM composites. Few numbers of testing were performed in the study research. The material characterization is finished by three significant testing on waste glass which is the XRD, PSA and SEM perception. These threes result show that the SiO_2 adequately viable to be use as filler for the SiR/EPDM rubber blend matrix. The XRD result shows that the waste glass is an amorphous because of clear common attribute of wide amorphous diffraction peak. The benefit results from the homogeneity of elements and phase compositions and the strictly specified geometrical dimensions of the glass waste filler. In the PSA perception, the size of the particle is found to be in the range of the research concentrate after go through the sieving process. This little particle size accepted to be a benefit in blending the matrix and built up filler. The SEM characterize the state of the filler under 500X magnification that found the elongated with sharp edges surface that will upgrade the properties of the SiR/EPDM with SiO_2 filler.

Based on the result of testing, the ideal loading of SiR/EPDM with SiO_2 filler is at 30wt.%. This can clearly be found in the tensile testing where it gives a result of 62 MPa that was sufficient to give better rigidity. This statement is upheld by the result of ultimate elongation when it gives the most elevated point contrasted with the other loading. The highest ultimate elongation proved that this filler loading will give the most ductile and better quality of product. This would simplify for the manufacturer to produce the specific product that will withstand the tension without easily breaking. The hardness testing uncovered an intriguing disclosure where the hardness worth of 57 at 30wt.% which is considered as higher for the hardness. The hardness testing revealed an interesting discovery where the hardness value of 57 at 30wt.% which is considered as high value for the hardness. Henceforth, due to higher interaction, crosslinking in composites was found better to improved hardness values. Last but not least, the specific gravity for 30wt% found to be slightly lower than the 40wt.%. However, this value will not really affect the whole filler dispersion in the SiR/EPDM composites.

All things considered, the best loading for waste glass filler with SiR/EPDM is picked to be at 30wt.%. of loading.

5.2 Recommendations

In view of the findings in this study, here are several recommendations that should be conducted to further improve this research

a) To propose any new thought of replacing the fillers with any waste resources as the fillers in the composites as to help fabricating sustainability and advance the green environment.

b) To perform the important electrical testing in regards to high voltage execution of the waste glass filler with SiR/EPDM elastic rubber blend composites.

c) To produce genuine product and model of the blend of SiO_2 filler with SiR/EPDM grid as one of the insulation materials. This would be an honourable endeavour by supplanting the current material with waste resources in the material.

d) To foster any replacement of rubber blend between SiR or EPDM with other rubber to additional investigations and comprehend the standard of rubber blending and cross linking of material.

5.3 Sustainability

The main highlighted material used in this research project is the waste glass powder. The material is taken from the waste resources of the glass bottle that being used in daily life. The idea of utilizing this waste as a filler in the composites will carry a novel attempt to the environment. This glass waste can be a turning point in using waste as one of the materials in the product. Thus, it will build up the sustainability esteem in the manufacturer and environment. Researches can come up with a new idea in substituting the raw material from waste and turn it into a product to support the manufacturing sustainability.

5.4 Complexity

The idea of combining glass waste with rubber blend composite is one of the thrilling actions in this project. Since, very few studies have done this research of combining two different rubber type with a glass as a filler. The issue arise as the correct method and correct composition is still an unknown. The technique in combining the SiO_2 with the SiR/EPDM rubber blend composite become the main issue as the improper mixing of these material will definitely failed the whole process. Also, the next issue is the difficulty in getting all the data for the testing result. This happen when all testing in mechanical, physical and electrical unable to run. Constraints of time and equipment influenced this matter to happen.

5.5 Engineering

The material selection for this research project is considered as the newest idea in implementing waste into material for manufacturing. The idea of combining the waste as the filler is totally a new innovation in the world of engineering. As one of the tasks as an engineer is to reducing the cost, utilizing the waste is practically answered to the problem. The waste glass has the same mechanical and physical properties as the new glass produce. By using this, it can reduce the capital cost of the manufacturer in buying the new glass. The glass can be obtained at the recycle centre with a very small cost. Many more invention can be made from this waste innovation.

REFERENCES

A. A. Salem and R. Abd-Rahman, (2018), "A Review of the Dynamic Modelling of Pollution Flashover on High Voltage Outdoor Insulators," in Journal of Physics: Conference Series, vol. 1049, no. 1, p. 012019: IOP Publishing

Ali, M., & Choudhry, M.A. (2015). Preparation and characterization of EPDM-silica nano/micro composites for high voltage insulation applications. Materials Science-Poland, 33, 213 - 219

Andy Schwalm, (2010) "“Insulators 101”," IEEE PES T&D 2010, New Orleans, LA, pp. 1-2

B. X. Du, Z. R. Yang, Z. L. Li and J. Li, (2017),"Surface charge behavior of silicone rubber/SiC composites with field-dependent conductivity," in IEEE Transactions on Dielectrics and Electrical Insulation, vol. 24, no. 3, pp. 1340-1348,

Cherney, E.A. (2005). Silicone rubber dielectrics modified by inorganic fillers for outdoor high voltage insulation applications. CEIDP '05. 2005 Annual Report Conference on Electrical Insulation and Dielectric Phenomena, 2005., 1-9

Chan, C.H., Joy, J., Maria, H., & Thomas, S. (2013). Chapter 1: Natural Rubber-Based Composites and Nanocomposites: State of the Art, New Challenges and Opportunities

Chandrasekaran, C. (2017). Practical Corrosion-Resistant Rubber Formulations

Chukwuemeka, Engr. Nzenwa & Adebayo, Engr. Adeniyi. (2020). Analysis of Insulators for Distribution and Transmission Network. 8. 138-145

Danafar, F., & Kalantari, M. (2018). A Review of Natural Rubber Nanocomposites Based on Carbon Nanotubes. Journal of Rubber Research, 21, 293-310

Deshmukh, P., Bhatt, J., Peshwe, D., & Pathak, S. (2011). Determination of Silica Activity Index and XRD, SEM and EDS Studies of Amorphous SiO2 Extracted from Rice Husk Ash. Transactions of the Indian Institute of Metals

Dhawan, Vikas & Sehijpal, Singh & Singh, Inderdeep. (2013). Effect of Natural Fillers on Mechanical Properties of GFRP Composites. Journal of Composites.

Dul, J., Parys, G., Pedzich, Z., Bielinski, D.M., and Anyszka, R., (2012). Mechanical Properties of Silicone-Based Composites Destined for Wire Covers. International Journal Advance Material Manufacturing Charactreization, 1, pp. 23–8

D. E. EL-Nashar, E. Gomaa, S. L. Abd-El-Messieh, (2009) ,J. Polym. Sci Part B: Polymer Physics, 47 1825

El-Sabbagh, S.H., Ahmed, N., Turky, G., & Selim, M. (2017). Rubber nanocomposites with new core-shell metal oxides as nanofillers

Farzaneh, Masoud & Chisholm, William. (2009). Insulator Electrical Performance in Pollution Conditions. 10.1002/9780470496251.ch4

Ghosh, Dipankar & Khastgir, Dipak. (2018). Degradation and Stability of Polymeric High-Voltage Insulators and Prediction of Their Service Life through Environmental and Accelerated Aging Processes. ACS Omega. 3. 11317-11330. 10.1021/acsomega.8b01560

Guia, T., Khechekhouche, A., & Teguar, M. (2020). Experimental study of high voltage insulator under discontinuous pollution and impulse voltage. Journal of fundamental and applied sciences, 12, 363-477

Guo, P., Meng, W., Nassif, H., Gou, H., & Bao, Y. (2020). New perspectives on recycling waste glass in manufacturing concrete for sustainable civil infrastructure. *Construction and Building Materials*, *257*.

Harrison, E., Berenjian, A., & Seifan, M. (2020). Recycling of waste glass as aggregate in cement-based materials. *Environmental Science and Ecotechnology*, *4*, 100064.

Khan, H., Amin, M., & Ahmad, A. (2018). Characteristics of Silicone Composites for High Voltage Insulations. Reviews on advanced materials science, 56, 123 - 91

Ibrahim, A., Nasrat, L., & Elassal, H. (2015). Improvement of Electrical Performance for Porcelain Insulators Using Silicone Rubber Coating

Jean-Baptiste Donnet, Emmanuel Custodero (2013), Chapter 8 - Reinforcement of Elastomers by Particulate Fillers, Editor(s): James E. Mark, Burak Erman, C. Michael Roland, The Science and Technology of Rubber (Fourth Edition), Academic Press

Jovanović, V., Samaržija-Jovanović, S., Budinski-Simendić, J., Marković, G., & Marinović-Cincović, M. (2013). Composites based on carbon black reinforced NBR/EPDM rubber blends. Composites Part B-engineering, 45, 333-340

Kaliyathan, A.V., Rane, A., Huskić, M., Kunaver, M., Kalarikkal, N., Rouxel, D., & Thomas, S. (2020). Influence of carbon black on cure properties and mechanical strength of natural rubber/butadiene rubber blends. Journal of Macromolecular Science, Part A, 1-12

K. Pal, V. Panwar, J. Bahadur, (2017), Rubber blend nanocomposites, In Woodhead Publishing Series in Composites Science and Engineering

Kandasamy, Selvi & Sharma, Mita & Paranji, Saranya & Akolkar, A. (2016). Environmentally sustainable management of fluorescent lamp sector in India: drivers and barriers

Kannan P, Sivakumar M, Mekala K,(2015), Chandrasekar S. Tracking / Erosion Resistance Analysis of Nano-Al (OH) 3 Filled Silicone Rubber Insulating Materials for High Voltage DC Applications. J Electr Eng Technol.;10(1):355–63

Lei, T., Zhang, Y., Kuang, D., & Yang, Y. (2019). Preparation and Properties of Rubber Blends for High-Damping-Isolation Bearings. Polymers, 11

M. G. Oliveira and B. G. Soares, (2004) , J. Applied. Polymer. Sci., 91 1404

Mahdi, S.H., Jassim, W.H., Hamad, I.A., & Jasima, K.A. (2017). Epoxy/Silicone Rubber Blends for Voltage Insulators and Capacitors Applications. Energy Procedia, 119, 501-506

Nazir, M., Phung, B.T., Yu, S., & Li, S. (2018). Effects of thermal properties on tracking and erosion resistance of micro-ATH/AlN/BN filled silicone rubber composites. IEEE Transactions on Dielectrics and Electrical Insulation, 25, 2076-2085

J. Choi, (2013),"LED Driver Compatible with Electronic Ballast", Ph. D. Dissertation, Dept. Elect. Eng. KAIST,

Pleşa, I., Noţingher, P., Schlögl, S., Sumereder, C., & Muhr, M. (2016). Properties of Polymer Composites Used in High-Voltage Applications. Polymers, 8

Pisani, J.A. (2006). Sustainable development – historical roots of the concept. Environmental Sciences, 3, 83-96

Rani, G. Y., Krishna, T. J., & Murali, K. (2021). *Materials Today: Proceedings Strength studies on effect of glass waste in concrete*. *xxxx*.

Sabarinathan, P., Annamalai, V., & Rajkumar, K. (2019). Evaluation of thermal stability and damping behavior of electrical insulator waste reinforced thermoset polymer composite. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 233, 3603 - 3618

Salleh, S.Z., Ahmad, M., & Ismail, H. (2016). Properties of Natural Rubber/Recycled Chloroprene Rubber Blend: Effects of Blend Ratio and Matrix. Procedia Chemistry, 19, 346-350

Sheta, T., Gad, A., Nasrat, L., & Eldebeiky, S. (2020). Evaluation of dielectric strength of epdm elastomer loaded with ath filler

Shit, S.C., & Shah, P. (2013). A Review on Silicone Rubber. National Academy Science Letters, 36, 355-365

S. M. I. Suhaimi, N. Bashir, N. A. Muhamad, N. N. A. Rahim, N. A. Ahmad, and M. N. A. Rahman,(2019), "Surface Discharge Analysis of High Voltage Glass Insulators Using Ultraviolet Pulse Voltage," Energies, vol. 12, no. 2, p. 204,

Song, Y., Yu, J., Yu, L., Alam, F.E., Dai, W., Li, C., & Jiang, N. (2015). Enhancing the thermal, electrical, and mechanical properties of silicone rubber by addition of graphene nanoplatelets. Materials & Design, 88, 950-957

Sun, D., Gurevich, A., Kaufmann, L.J., Bent, B.E., Wright, A., & Naasz, B. (1996). A new approach to understanding the Rochow process: synthesis of methylchlorosilanes from CH3+Cl monolayers on Cu3Si in vacuum. Studies in Surface Science and Catalysis, 101, 307-315

Teyssèdre, G., & Laurent, C. (2013). Advances in high-field insulating polymeric materials over the past 50 years. IEEE Electrical Insulation Magazine, 29, 26-36

Traian Zaharescu, Viorica Meltzer, Rodica Vîlcu,(2000) Thermal properties of EPDM/NR blends,Polymer Degradation and Stability,Volume 70, Issue 3

Vithayasrichareon, P., MacGill, I., & Nakawiro, T. (2012). Assessing the sustainability challenges for electricity industries in ASEAN newly industrialising countries. Renewable & Sustainable Energy Reviews, 16, 2217-2233

Xanthos,(2010), M. Chapter 1, Polymers and polymer composites. In Functional Fillers for Plastics, 2nd ed.; Xanthos, M., Ed.; Wiley-VCH Verlag GmbH & Co. KGaA: Weinheim, Germany, pp. 1–18

Xu, Z., Zhao, C., Gu, A., Fang, Z., & Tong, L. (2007). Effect of morphology on the electric conductivity of binary polymer blends filled with carbon black. Journal of Applied Polymer Science, 106, 2008-2017

Zhang, G., Zhou, X., Liang, K., Guo, B., Li, X., Wang, Z., & Zhang, L. (2019). Mechanically Robust and Recyclable EPDM Rubber Composites by a Green Cross-Linking Strategy. ACS Sustainable Chemistry & Engineering, 7, 11712-11720