FEASIBILITY STUDY OF POLYSILOXANE FILLED SILICA AS A HEAT INSULATOR APPLICATION

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ABSTRACT

Polysiloxane or so called polymerized siloxane is basically silicones which are mixed of inorganic-organic polymers. Based on the previous study referred, there were limitation of the study on the elastomer as heat insulator, because researches more interested in investigation of the application of electrical insulator. The main objective of this study is to investigate and compare the performance of heat insulator produced by rice husk and synthetic silica as the filler. In this study, silica was used as the matrix filler of polysiloxane as the application of heat insulation. Polysiloxane were mixed with different percentage of both types of silica powder, which ranges of silica weight percentage from 0 wt% to 12 wt%. Casting process was conducted for the preparation of polysiloxane mixed with silica. The silica powder itself was evaluated based on its physical property and crystal structure by XRD analysis. As for the polysiloxane filled with silica, several testing were done such as density test, tensile test, thermogravimeric analysis and also heat insulation test. As for XRD analysis, phase identification was achieved by comparing the diffraction patterns of silica powder with JCPDS 46-1045 as for standard synthetic silica. Density test show that rice husk amorphous silica filler shown higher density than the synthetic silica filler. For tensile strength, both silica filler show different pattern of highest tensile strength, as rice husk filler shown at 10 wt%, while synthetic at 2 wt%. These percentages provide highest stress before it breaks at some point. TGA testing and heat insulation testing are the thermal testing which undergo to know the capability and how the polymers react with heat. Higher percentages of silica prove to be better heat insulator than without addition of silica.

ABSTRAK

Polysiloxane atau dipanggil siloksan berpolimer pada dasarnya adalah silicon yang dicampurkan polimer organik-organik. Berdasarkan kajian yang dirujuk sebelum ini, terdapat batasan kajian di elastomer sebagai penebat haba, kerana kajian lebih tertumpu kepada penyiasatan penggunaan penebat elektrik. Objektif utama kajian ini adalah untuk menyiasat dan membandingkan prestasi penebat haba yang dihasilkan oleh sekam padi dan silika sintetik sebagai pengisi. Bagi kajian ini, silika digunakan sebagai pengisi matriks polysiloxane bagi aplikasi penebat haba. Polysiloxane telah bercampur dengan peratusan yang berbeza bagi kedua-dua jenis serbuk silika, yang bermula daripada silika peratusan berat dari 0 wt% kepada 12% berat. Proses penuangan telah dijalankan bagi penyediaan polysiloxane bercampur dengan silika. Serbuk silika sendiri telah dinilai berdasarkan sifat fizikal dan struktur kristal dengan analisis XRD. Bagi polysiloxane dicampur dengan silika, beberapa ujian telah dijalankan seperti ujian ketumpatan, ujian tegangan, analisis Termogravimetri dan juga ujian penebat haba. Bagi analisis XRD, pengenalan fasa telah dicapai dengan membandingkan corak pembelauan serbuk silika dengan JCPDS 46-1045 sebagai standard silika sintetik. Ketumpatan ujian menunjukkan bahawa silica dari sekam padi amorfus menunjukkan kepadatan lebih tinggi daripada pengisi silika sintetik. Untuk kekuatan tegangan, kedua-dua menunjukkan pengisi silika corak yang berbeza Kekuatan tegangan paling tinggi, sebagai pengisi sekam padi ditunjukkan pada 10% berat, manakala sintetik pada 2% berat. Peratusan ini menyediakan tekanan tertinggi sebelum ia terputus pada satu ketika. Ujian TGA dan ujian penebatan haba adalah kumpulan ujian haba yang dijalani bagi mengetahui keupayaan dan bagaimana polimer bertindak balas dengan haba. Peratusan yang lebih tinggi daripada silika terbukti menjadi penebat haba lebih baik daripada tanpa penambahan silika.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

At present time, after years of development, insulators tend to consist entirely of preferential silicone rubbers. However, the presents of silicone rubber alone does not result in better thermal insulation. Based on previous study reffered, it had showed that most of silicone rubber contain fillers that allows for better enhanced of elecrical and also thermal properties. Nonetheless, the usage of elastomeric material which is reinforced with silica fillers that is designed as heat insulator is still districted, because most of the research covers on electrical insulator application.

Modern composites are usually made of two components, the fiber or so called the filler, and the matrix. There are several types of fibers, for example glass fiber, aramid or para-aramid fiber, graphite, and also boron fiber. Research efforts in this area shown that the properties of filled elastomers are influenced by the nature of both the filler and the matrix, as well as the interactions between both of them. In the rubber industry, there is specific interest in understanding how fillers reinforce elastomers. There is a wealth of knowledge regarding the synthesis of these fillers, the mechanisms that govern the synthesis, and the characterization of the resulting filler structures (Kohls et al., 2007).

Elastomers like polyisoprene, polyisobutylene and also polysiloxane have completely different mechanical behavior from other types of materials. Basically, polysiloxane is an elastomeric polymer or so called silicone elastomer compound that will be filled with silica as the reinforcement. A polymer is defined as a long-chain molecule containing one or more repeating units of atoms joined together by strong covalent bonds. On the other hand, silicone elastomers are elastic substances which contain linear silicone polymers which is crosslinked in 3-dimensional network.

In this study, polysiloxane used is rubber-like silicone, which is filled with silica that was then based on two conditions, one is silica that derived by rice husk, and the other condition is using synthetic silica. These produced mixture is then tested for heat insulation. Both different filler were analyzed based on its performance as heat insulator, which also considers the most optimum mixture between polysiloxane and silica. The findings of this study could lead to improve the quality and functionality of products such as electric and electronics equipment, automobiles and leisure products.

1.2 Problem Statement

From previous research, the author demonstrated and proved that polysiloxane is compatible with filler; which in this study, refers to silica. In past few years, thermal insulation standards and the market demand of insulator for buildings and technical equipment has risen considerably (Hoyt-Lalli, 2002).

The study of the mechanical and physical properties of polymer composites is a challenging and crucial topic for both fundamental science and industrial application. However, based on the previous study referred, there were limitation of the study on the elastomer as heat insulator, because researches more interested in investigation of the application of electrical insulator. This study explore feasibility of the application of elastomer filled with silica as a heat insulator because the usage of heat insulator is substantial for house, cars and also daily appliances.

1.3 Objectives of Study

The purpose of this study are:

1) To investigate the performance of heat insulator produced by rice husk and synthetic silica.
2) To compare the performance of heat insulator which filled by rice husk with synthetic silica.
3) To obtain the optimal percentage weight of polysiloxane and silica as a heat insulator.
4) To determine the polysiloxane and also silica mechanical properties.

1.4 Scope of Study

In order to ensure the objectives of this project were completed in time, this study will focus on several scopes which are listed as follow:

1) Casting process will be conducted to produce polysiloxane filled silica as an application of a heat insulator.
2) The silica will then varied into two types which are silica that derived from rice husk, while the other is filled with synthetic silica.
3) The casting process will undergo at room temperature with preform time of less than 2 hours, and curing time of 24 hours.
4) Different percentage of weight which is from 88 wt% to 100 wt% for polysiloxane and 0 to 12 wt% for both different types of silica will be varied as to obtain the most optimum compound to be a heat insulator.

5) From the two silica filled, the performance of heat insulator will be analyzed based on which are able to minimize the heat lost most after applying the polysiloxane filled silica. This analysis is called the Heat Insulation Test.
6) The scope of testing for mechanical test is Tensile Test by referring to ASTM D412 method A which is for dumbbell specimens.
7) As for testing the physical properties, testing that are conducted is X-Ray Diffraction Test (characterisation of SiO_2), while for the panel are Thermogravimetric Analysis (thermal properties), and Density Test referring to ASTM D792.

1.5 Significance of Study

The importance of this study is basically to improve the usage of heat insulator in industry. There are no other materials that could match the versatility of polymeric materials. As thermal insulators, polymer foams help to conserve energy. Because of their molecular structures, they can variously be stiff, elastic or soft, permeable or impermeable. Furthermore, polymers can be readily processed by injection molding, blow molding, extrusion, casting, or compression molding.

Based on this study, polysiloxane which is an elastomeric polymer is filled with silica that has high thermal stability will make it as a better heat insulator. The significance of conducting both natural sources, which is rice husk and also synthetic silica as the filler can conclude which types of filler will produce a better insulator based on different weight percentage. Moreover, because of their versatility, polymers have large numbers of applications includes the things that are close to our daily usage such as appliances, packaging, fabrics, automotive parts, and telephones. Others are less visible, including circuit boards, composites for space ships, and medical uses. However, as for polysiloxane which is silicone elastomer, it consumed more on automotive components (Advani and Hsiao, 2012).

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Literature review is mainly a comprehensive review of any other kind of literature which is related to the case study being done to give a thoroughly understanding about this research. This review provides the readers with a complete overview of the crucial theory and also from the previous research that are related to the subject of this study. The chapter reviews comprehensively about the idea of material used in this thesis, for us to understand about the features and the background of the materials, whether it would be suitable to be applied as a heat insulator. Not only that, this chapter also discussed the background of the method that were applied, as well as the previous study on elastomer as heat insulator itself.

2.2 Composite

According to the Malaysian Industry-Government Group for High Technology (MIGHT), a composite material is defined as combination of two or more materials with distinct interface from each other, acting in concert to give unique and superior properties. A composite typically includes a matrix (either polymer, metal or ceramic) plus reinforcing fibers (e.g. glass, aramid, boron or carbon) (MIGHT, 1997). Advanced composites are a class of structural materials as a result of the development of high modules, high strength, with low density reinforcing fibers, embedded in a matrix. Figure 2.1 shows the classification of composite materials.

Composite or basically known composite material is defined as materials made from two or more material component with difference in physical or chemical properties. After combined, it produces a material with characteristics different from the base components. Both components remain separative and different after it becomes the finished structure. Engineered composite material applied in this study is fiber-reinforced polymer. However, the use of traditional composites made of glass, aramid or carbon fiber reinforced plastics have recently been discussed critically because of increasing environmental consciousness.

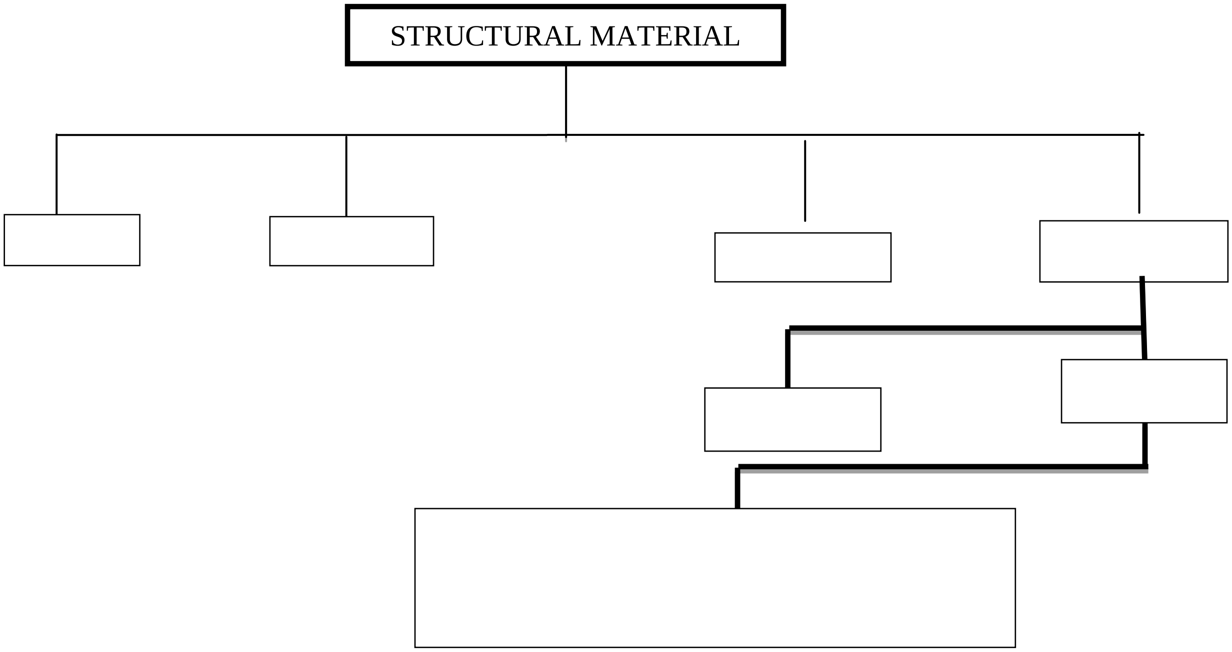


Figure 2.1: Structural Material (MIGHT, 1997)

There were various types of families of composite materials which are polymer matrix composites (PMCs), metal matrix composites (MMCs), carbon-carbon composites (CCCs), ceramic matrix composites (CMCs) and intermetallic matrix composites (IMCs) (Schwartz, 1997). Advanced composites are generally been classified into three basic categories according to the matrix material, which is polymer, metal, or ceramic. Certainly, advanced composites had been used widely where it significantly improved performance or significantly lower life-cycle costs (Strong, 2008).

In this study, it will be focusing on polymer matrix composites. Polymer composites are basically composites that are made from polymer along with other kinds of materials. A study by Dierkes and Noordermeer has mentioned that, mixing of rubber compounds is a rather complicated process as components differing in structure, viscosity, and rheological behavior have to be homogenized (Dierkes and Noordermeer, 2007). Moreover, the use of silica as reinforcing filler is difficult, as when silica is mixed with the commonly hydrocarbon rubbers, there will be a greater tendency towards hydrogen-bond interactions between surface silanol-groups of silica aggregates than to interactions between polar siloxane or silanol-groups on the silica surface and the rubber polymers. As for this reason, there is a great interest in enhancing the compatibility of hydrocarbon rubbers and precipitated silica by modification of the silica. Bifunctional organosilanes are commonly used as coupling agents to chemically modify silica surfaces in order to promote interactions with hydrocarbon rubbers.

2.2.1 Polymer

A polymer is a substance composed of molecules characterized by the multiple repetitions of one or more species of atoms or group of atoms linked to each other

(Geddie, 1999). The word polymer originates from Greek words ‘poly’ literally means ‘many parts’ (Smith and Hashemi, 2006).

To form a solid, a polymeric solid material may be considered to be one that contains many chemical units that are bonded together. Two industrially important polymeric materials are plastics and elastomers. Plastics are a large and varied group of synthetic materials which are processed by forming or molding into shape. Just as there are many types of metals such as aluminum and copper, there are many types of plastics, such as polyethylene and nylon. On the other hand, elastomers or rubbers can be elastically deformed a large amount when a force is applied to them and can return to their original shape or almost to their original shape, when the force is released (Sperling, 2006).

2.2.2 Polymer Matrix Composite (PMCs)

Nowadays, polymer matrices are the most widely used as for composites not only in commercial, but also on high-performance aerospace applications. Polymer matrix composite (PMC) is often used to describe the systems in which a continuous phase is polymeric which refer to the matrix, and another phase which is the reinforcement, has at least one long dimension. Other definition is that it consists of particles or fibers embedded in polymer matrices. PMCs are highly valued in the aerospace industry as for their stiffness, lightness, and also heat resistance. The particles or/and fibers are introduced to enhance selected properties of the composite.

Continuous fiber reinforcements usually provide the highest improvements in mechanical properties such as stiffness and strength. It can be introduced in various forms such as continuous random mat, woven fabric, and stitched fabric, unidirectional or bidirectional fabric (Advani and Hsiao, 2012). Polymer matrix composites are divided into two broad types, namely thermosets and thermoplastics. There are three main types of PMCs, namely glass-fiber reinforced composites, carbon-fiber reinforced composites, and aramid-fiber reinforced composites.

Glass-fiber reinforced composites (GFRC) are strong, corrosion resistant and lightweight, but not very stiff and cannot be used at high temperatures. Applications include automotive and boat bodies, as well as the aircraft components (Astrom, 1997). Carbon-fiber reinforced composites (CFRC) use carbon fibers, which have the highest specific module (module divided by weight). CFRC are strong, inert and allow high temperature use. Applications include fishing rods, golf clubs and aircraft components (Ebelewa, 2000). Besides that, aramid-fiber reinforced composites can be used as textiles fibers. Applications include bullet-proof vests, tires, brake and clutch linings.

Basically, polymers are the most widely used matrix material in the composite industry and they were selected because polymers are easily processed and offered good mechanical and dielectric properties. Most polymers have good wetting properties to the reinforcements. Compared to metals, polymers have lower softening points, but they are low densities. Because of the lower processing temperature and production techniques, many organic based reinforcements may be used, both synthetic and natural fibers. Various inorganic, non-metallic fibers are in service, such as glass, carbon, asbestos and graphites (Ebelewe, 2000). Figure 2.2 shows the overview of PMCs.

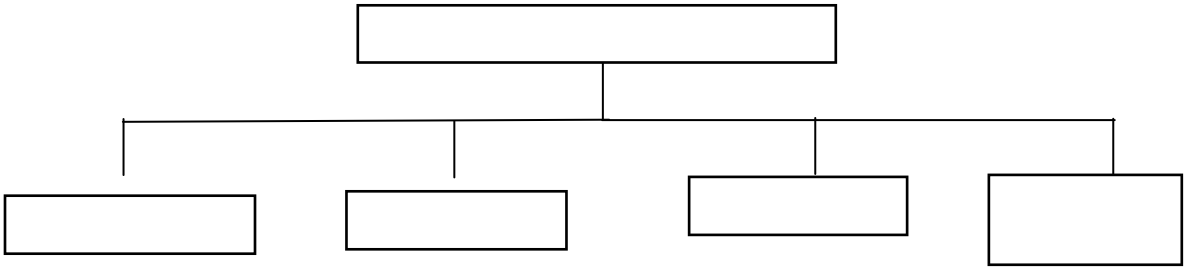


Figure 2.2: Overview of PMCs

Today, there are three levels of composite applications, such as:

- Low level composite (e.g. plastics, pipes, hoses, tanks, etc.)
- Medium level composite (e.g. boat, hull, off-shore structures, furniture)
- High level composites (e.g. light aircraft parts (eagle aircraft), and high performance sports goods (hockey sticks, bicycle frames, surf boards).

2.2.3 Matrices

Basically, there are two main categories of constituent materials: matrix and reinforcement. There should be at least one portion of each type that is required. The relationship is that matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The matrix of a composite has several functions. It is a binder that holds the reinforcement in place, transfers external loads to the reinforcement, and protects the reinforcement from adverse environmental effects. The matrix also redistributes the load to surrounding fibers when an individual fiber fractures and literally supports the fibers to prevent buckling in compression (Hoa, 2009).

Composite materials require the use of a polymer resin. The primary consideration in the selection of a matrix is its basic mechanical properties which include tensile modulus, tensile strength, and fracture toughness (Schwartz, 1997). Other factors such as thermal properties, processability, cost, availability, and health concerns are also of a great importance (Valenti, 1998).

Resins that are widely used could be either a thermoplastic or a thermoset. Thermoplastics can be separated into two subgroups, semi-crystalline and non-crystalline or so called amorphous. As for thermosets, it is cross-linked network polymers which are amorphous and cannot be melted once the network is formed during curing. Table 2.1 and Table 2.2 show the different types of both thermoplastic and thermoset respectively.

Table 2.1: Types of Thermoplastic (Ebelewe, 2000)

i. Polyethylenes (PE)	PE can be either commodity and engineering plastic depending on grade, but is rarely used as a matrix due to low temperature tolerance and modest mechanical properties
ii. Polypropylenes (PP)	PP is the chemically least complex and cheapest polymer used in composite matrix. PP is usually reinforced with glass fibers and such composites are often hidden from view since the surface finish tends to be poor.
iii. Polyamides (PA)	PA is often called nylon. PA may be used at moderately increased temperatures, thus greatly increasing its usefulness as a matrix. The biggest drawback of PA is that it is hygroscopic, meaning that it absorbs water. PA is normally reinforced with glass fibers and used in similar applications as glass-reinforced PP.
iv. Thermoplastic polyesters	Polyesters are also available in thermoplastic forms, for example poly(ethylene terephthalate) (PET) and poly(butylenes terephthalate) (PBT). The properties of PET and PBT are similar to PA, except that they do not have the hygroscopic disadvantage. It is usually reinforced with glass fibers.
v. Poly(phenylene sulfides) (PPS)	PPS has good tolerance to most chemicals and fire. PPS exhibits moderate mechanical properties and temperature tolerance. It is normally reinforced with glass or carbon fibers used in high-performance applications.

vi. Polyketones	The most common of polyketones is poly(ether ether ketone) (PEEK). Polyketones possess high mechanical properties, high temperature tolerance, good solvent resistance, with a high price. PEEK is reinforced with glass or carbon fibers and is used in critically high-performance applications.
vii. Polysulfones	Polysulfone (PSU), poly(ether sulfone) (PES) and poly(aryl sulfone) (PAS) are high-performance amorphous polymers with good tolerance to high temperatures and fire. These properties come at a very high price, and the melt viscosities are also very high. Since polysulfones are amorphous, they are not resistant to all solvents though their resistances are nevertheless very good. Its applications are in the same area of polyketones.
viii. Thermoplastic polyimides	The polyimide family includes poly(ether imide) (PEI), polyimide (PI) and poly(amide imide) (PAI), which are all amorphous. Polyamides have the highest temperature tolerance among the thermoplastics mentioned, and despite that, it is very tolerant to solvents and environmental exposure and has good mechanical properties with the disadvantage of very high melt viscosities and high price. The polyimide families are normally reinforced with glass and carbon fibers and are used in the same applications of polyketones and polysulfones.

Table 2.2: Types of Thermoset (Ebelewe, 2000)

i. Epoxies	Epoxies (EP) are often used due to their significant superiority in temperature tolerance and mechanical properties. Epoxies are more often seen in fields where the cost tolerance is the highest, for example in aerospace, defense and sports applications.
ii. Unsaturated Polyester	Unsaturated polyester (UP) has an attractive combination of low price, reasonably good properties and uncomplicated processing. Basic UP formulations have drawbacks in terms of, e.g. poor temperature and UV-light tolerance, but additives can significantly reduce these disadvantages.
iii. Vinylester	Vinylester (VE) are chemically closely related to both unsaturated polymers and epoxies and in most respects represent a compromise between the two. It is normally used in the corrosive industrial environment.
iv. Phenolics	Phenolics have been extensively used in unreinforced and short-fiber reinforced applications. It is also used in continuous-fiber reinforced applications due to processability improvements. Phenolics composites which are nearly exclusively glass fiber reinforced, are likely found in applications where the structural requirements are modest, but where high-temperature and fire tolerance is valued, e.g. aircraft interiors and off-shore oil plants.

The other matrices that are usually applied are metal matrix composites (MMCs), carbon-carbon composites (CCCs), ceramic matrix composites (CMCs).

Densified non-continuous carbon is one of the most unique matrices. It forms the matrix in carbon/carbon (C/C) composites. This C/Cs withstand extreme high temperatures that is suitable for space and aircraft components, race car braking components, missile engines and exhaust nozzles.

Moreover, metals (e.g., aluminum, titanium and magnesium) and ceramics (such as silicon carbide) are used as matrices, as well, for specialized applications, such as spacecraft components, where minimal CTE and an absence of outgassing are required. They also are used in engine components, where polymer matrices cannot offer the extremely high temperature resistance that such applications require.

2.2.4 Reinforcement

In the early stage of composites development, the only reinforcements available were actually derived from traditional textiles and also fabrics. The main idea of applying reinforcement in composites is fundamental as it will increase the mechanical properties of the orderly resin system. Reinforcement is usually applied as an additive or co-polymer filler to modify the structure, physical and mechanical properties of the material. There are various types of fiber reinforcement that can be used to reinforce polymer matrix composites. These reinforcements can vary by its materials.

There are several different types of composites used today. The most common are fiber reinforced composites and particulate reinforced composites. The reinforcement also, to a certain degree determines stiffness and strength of the composite as well as several other properties (SIRIM, 1999). As matrices, this reinforcement will be selected according to the application used. However, reinforcements are often confused with fillers because some materials may act as reinforcing agent or filler, such as glass and asbestos. The presence of filler as reinforcement agents can reduce costs, modify color and improve the texture surface. Fillers then can be divided into organic and inorganic.

2.2.4.1 Particulate

Particulate composites have many different forms. The particulates could be very small particles which can be less than 0.25 microns, chopped fibers (such as glass), and can generally have spherical, polyhedral, or irregular in shape. In every case, the particulates provide desirable material properties and the matrix acts as binding medium necessary for structural applications (Rothon, 2002). The main reasons for using particulate fillers are:

- Cost reduction
- Improved processing
- Control of thermal expansion
- Improved mechanical properties, notably hardness, stiffness, abrasion and tear resistance.

Usually, the finer the particulates are, the better the properties of the reinforced polymer will be. There are then two kinds of particulate composites, which are the large-particle composites and dispersion-strengthened. Here, large particle indicate that the particle and matrix interaction cannot be treated on the atomic or molecular level. This type involves large particles that are harder or stiffer than the matrix itself. While as for dispersion-strengthened composites, it is containing 10-100 nm particles, with the matrix endure the major portion of the applied load and also the small particles hinder dislocation motion, limiting plastic deformation to occur. Furthermore, particulate composites can often use more traditional manufacturing methods such as injection molding which can apparently reduce cost besides powder and also granulation processing.

Regardless of the selection of matrix and disperse phase such as the material and the type of any composite, there are many options that will affect properties. Figure 2.3 shows the various geometrical and spatial characteristics of particles of the dispersed phase that may influence the properties of composites (Flinn and Trojan, 1990).

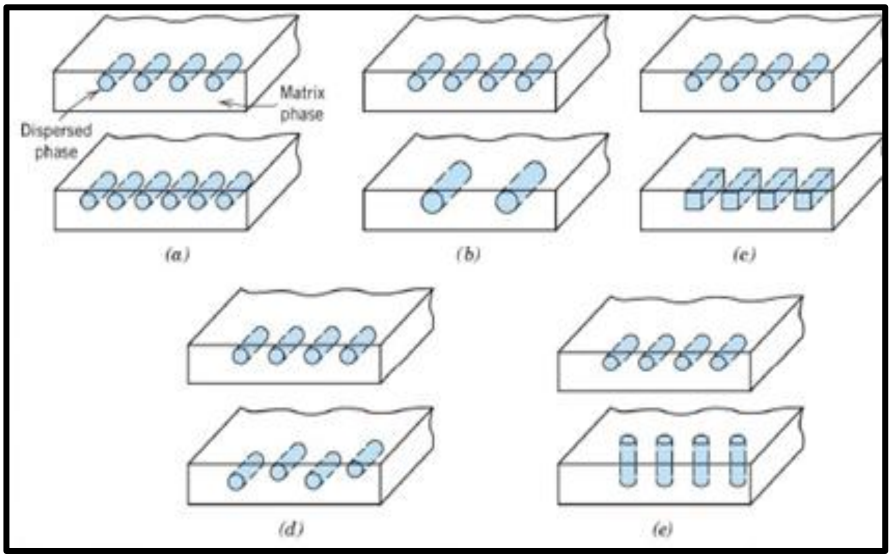


Figure 2.3: Characteristics of particles that influence properties of composites: *(a)* concentration, *(b)* size, *(c)* shape, (*d)* distribution, and *(e)* orientation (Flinn and Trojan, 1990).

As particulate filler is used for the heat insulator in this study, the principle thermal properties of this type need to be understood. These particulate composites have several of advantages. As mentioned before, they can act as a reinforcement to the matrix material which strengthening the base material, besides high specific stiffness, greater strength, and also good fracture properties. The huge application of particulate composites of polymer is tires, as the example of elastomer matrix that been added with carbon black particles. This application has improved the tensile strength, tear and also toughness. The particulate silica filler that was be used in this study is characteristically in the shape of powder.

2.2.4.2 Other Reinforcement

There are actually various other formats available for reinforcing phase. Figure 2.4 shows the schematic of different types of reinforcing that are usually chosen as reinforcing material. Figure 2.4 (a) to (d) show plan views while Figure 2.4 (e) and (f) are edge views. These different names are called according to sizes, for example fibers are in the range of 0.025 to 0.8 mm in size.

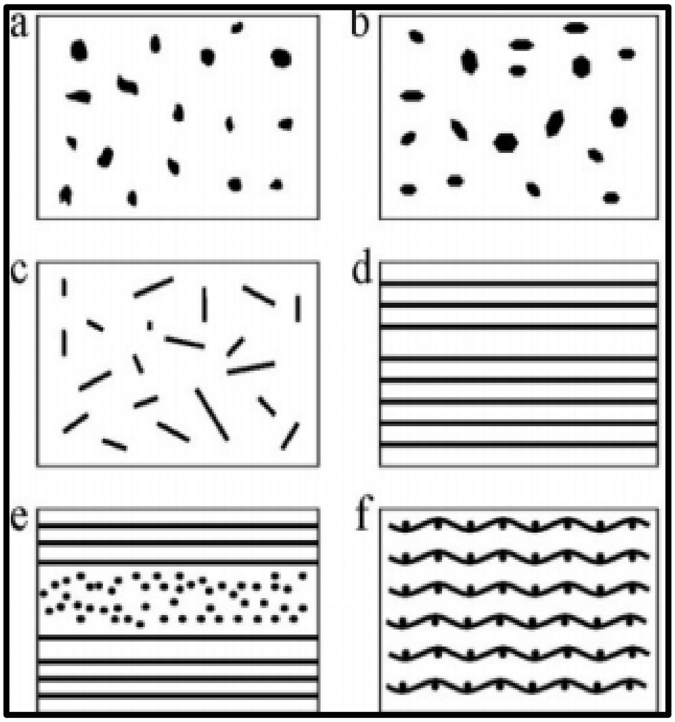


Figure 2.4: Schematic diagram showing various formats of reinforcing phase: (a) particles, (b) platelets, (c) whiskers or short fibers, (d) unidirectional continuous fibers, (e) cross-ply continuous fibers and (f) woven tows of fibers (Strong, 2008).

Based on these various reinforcement types, continuous fibers provide the best mechanical properties during loaded parallel to the fiber direction. On the other hand, short fiber types are often planar isotropic, while continuous fiber exhibit considerable anisotropy. This anisotropy is very useful in certain applications but if a more isotropic behavior is desired then laminates may have to be assembled. Figure 2.5 show the example of carbon fiber that is reinforced by plastic. Carbon fibers have very high strength and stiffness and are tolerant towards high temperatures and corrosive environments, as well as lack of moisture sensitivity. However, carbon fibers are expensive, brittle and have conductive properties.

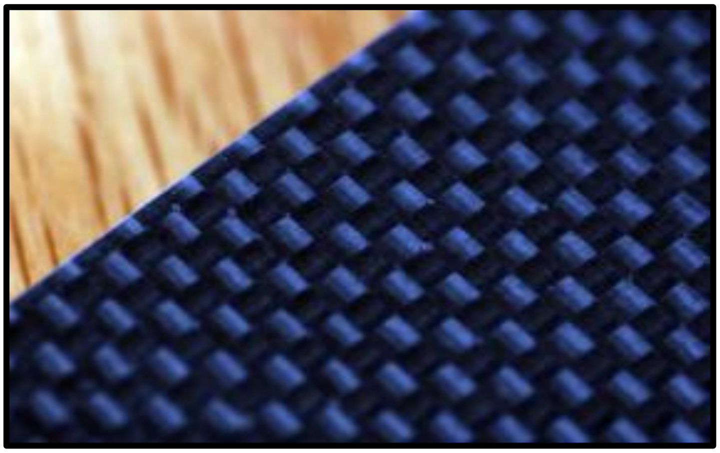


Figure 2.5: Example of carbon fiber reinforced plastic (Strong, 2008).

2.3 Silicone Rubber

Silicone rubber is an elastomer which appears as rubber-like material, defined as polymer containing silicon together with carbon, hydrogen, and oxygen. Moreover, silicone rubbers are often contained fillers to improve properties or can also reduce cost. Besides that, it is also a frequently employed biomaterial that is prone to bacterial adhesion and biofilm formation. In the rubber industry, there is a specific interest in understanding how fillers reinforce elastomers. There is interest in using fillers that are both highly dispersive and highly reinforcing as evidenced by new fillers that have been marketed over the last decades (Kohls et al., 2007).

The wide industrial use of polysiloxane rubbers arises from the combination of interesting properties presented by these elastomers that include excellent thermal and oxidative stability, good weatherability, good electric isolating properties, a wide interval of temperatures of use, resistance to oil, solvents, acids, fungi, etc (Sereda et al., 2003). Generally, the mechanical properties of polysiloxane elastomers are usually lower compared to other organic elastomers, such as natural rubber. However, the mechanical properties of polysiloxane elastomers only show a slight dependency on temperature, while the properties of natural rubber and other elastomers undergo a great decrease with time at temperatures above 50˚C. In other words, polysiloxane elastomers exhibit better thermal properties than other organic ones (Hardman and Torkelson, 1986).

According to Wang, it is reported that the degraded surface hydrophobicity of silicone rubber after severe environment stress can recover to some extent after a drying period of 30 hours at moderate temperatures (Wang, 1998). However in this study, polysiloxane used is an elastomeric (silicone rubber) polymer type. During manufacture, heat may be required to vulcanize (set or cure) the silicone into its rubber-like form. There are some disadvantages such as have too low of an elastic modulus to serve as a matrix for rigid structural composites. In order to improve these disadvantages is by the modification of main chain of silicone rubber or by the blending of polysiloxane with other organic polymers or inorgannic fillers.

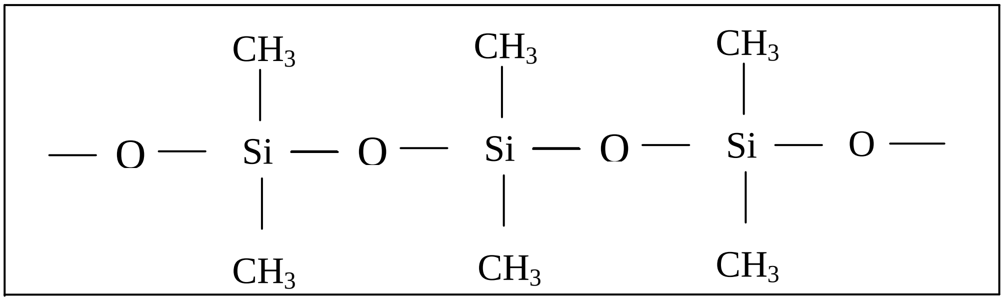
Based on previous studies, it is very rare to find silicon by itself in nature. It is usually were bounded to oxygen as either SiO_2 or SiO_4. There are actually various “classes” need to be referred according to ASTM D1418-10a, that is defined based on the substituent group on the polymer chain prior to the silicone designation. The following classification of the “Q” class is as follows:

- FMQ - Silicone rubber having both methyl and fluorine substituent groups on the polymer chain.
- FVMQ - Silicone rubber having fluorine, vinyl, and methyl substitute groups on the polymer chain.

- PMQ - Silicone rubbers having both methyl and phenyl substituent groups on the polymer chain.
- PVMQ - Silicone rubbers having methyl, phenyl, and vinyl substituent groups on the polymer chain.
- MQ - Silicone rubbers having only methyl substituent groups on the polymer chain, such as dimethyl polysiloxane.
- VMQ - Silicone rubber having both methyl and vinyl substituent groups on the polymer chain.

As for the application of silicone rubber, the specific requirements of car builders and their system suppliers have made silicone rubber an indispensable raw material for automotive components. Heat resistance, cold flexibility, oil and chemical resistance mainly account for the use of silicones in the engine and areas close to the engine. Long-term properties such as low compression set make silicones the perfect choice for airbag coatings, gasket, bellows, profiles, etc. (Jerschow, 2002).

Nowadays, polysiloxanes are the most common and one of the most important organosilicon polymers that been used in polymer chemistry. According to Jerschow, silicone elastomer consisting of bond crosslinking polydimethylsiloxane (PDMS), which includes molecules, fillers and catalysts (Jerschow, 2002). Polysiloxane or so called polymerized siloxane is basically silicones which are mixed of inorganic-organic polymers, where the specific terms of polysiloxane is any polymeric structure that contains repeating silicon-oxygen groups in the backbone, side chains or cross links regardless of the substitution on the silicon atom. Figure 2.6 shows the example of polysiloxane chemical bonding, polydimethylsiloxane. Polydimethylsiloxane is the basic and most commonly available silicone.



$$-O-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{Si}}-O-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{Si}}-O-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{Si}}-O-$$

Figure 2.6: Polydimethylsiloxane chemical bonding

According to Seyedmehdi, researchers have been working on improving silicone rubber coatings for insulators (Seyedmehdi, 2011). The wide industrial use of polysiloxane rubbers arises from the combination of interesting properties presented by these elastomers that include excellent thermal stability, which is one of the most important characteristic to be an insulator. Silicone rubber is frequently reinforced by assimilation of filler to improve its mechanical properties such as tensile strength, modulus, tear strength, elongation at break, hardness, compression set, rebound resilience, and abrasion resistance. Figure 2.7 shows the silicone rubber chain.

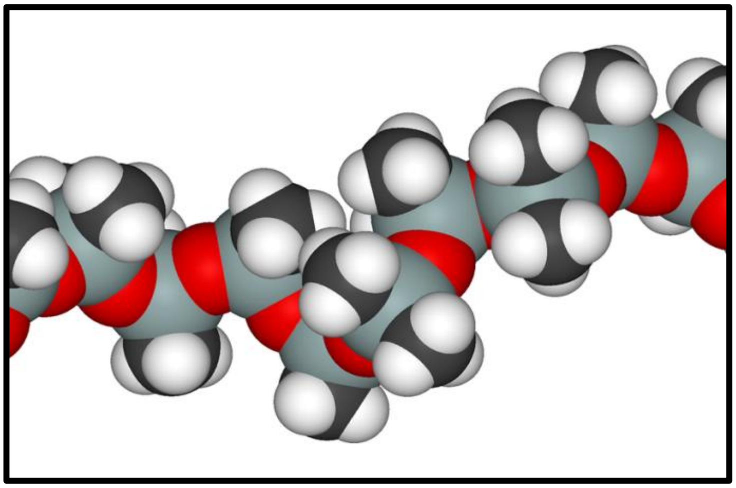


Figure 2.7: Silicone Rubber Chain (Hardman and Torkelson, 1986)

2.3.1 High Temperature Vulcanizing (HTV)

Vulcanizing is actually a chemical process for converting rubber or others related polymers into more durable materials via the addition of sulfur or other equivalent “accelerators”. High temperature Vulcanizing (HTV) rubbers are mainly so called solid silicone rubbers. They have a very high viscosity in the uncured state and appear as solids. This behavior has also led to the creation of the term ‘High Consistency Rubber’ (HCR) (Jerschow, 2002).

Almost 30 years ago, a new group of materials appeared that was intended for processing in injection moulding machines. Because of their low viscosity and patch-like behavior, they were named as liquid silicone rubbers (LSR) or just liquid silicone (LR). It is common to use LSR or LR as an abbreviation instead of HTV, even though they vulcanize at high temperatures as in the case of solid silicone rubber.

2.3.1.1 Liquid Silicone Rubber (LSR)

For the most part, all liquid silicone rubber (LSR) or liquid rubber (LR) is having 2 component systems which cure after mixing and at elevated temperatures. People tend to confused LSR with silicone oil. It is different as LSR is a high purity platinum cured silicone. Injection molding of LSR is often the preferred choice of producers of rubber parts. That is because LSRs offer better end-product performance, and the injection molding technique offers high levels of automation. Besides, LSRs also are ideal for rubber parts in general applications, as well as for specific market demands.

As mentioned before, liquid silicone rubber is a high purity platinum cured silicone with low compression set, great stability and ability to resist extreme temperatures of heat and cold ideally suitable for production of high quality parts. Due to the thermosetting nature of the material, liquid silicone injection molding requires special treatment, such as intensive distributive mixing, while maintaining the material at a low temperature before it is pushed into the heated cavity and vulcanized. The vulcanization speed of liquid silicone rubber depends on four main factors:

- Temperature of mold, temperature of possible inserts
- Temperature of the silicone upon reaching the cavity
- Geometry of the part (relation between surface area and volume)
- General vulcanization behavior and the chemistry of the curing

Typical applications for liquid silicone rubber are products that require high precision such as seals, electric connectors, medical applications as well as kitchen goods. Figure 2.8 shows the chemical bond of liquid silicone rubber of vinyl- and hydrogen-functional polysiloxanes that are cured using a platinum catalyst (Pt).

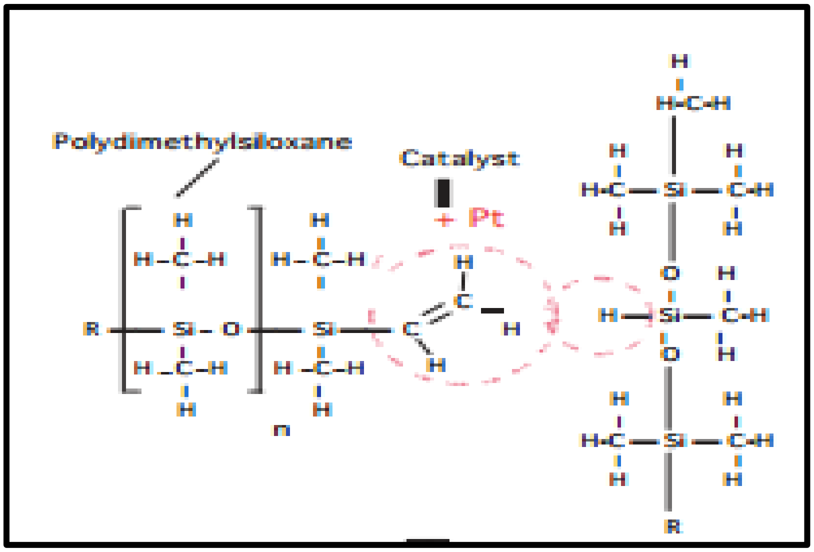


Figure 2.8: Chemical bonding of vinyl- and hydrogen-functional polysiloxanes (Jerschow, 2002).

2.3.1.2 Solid Silicone Rubber (SSR)

Solid silicone rubber (SSR) consistency is reminiscent of plastilline. Thus, its viscosity is lower than the viscosity of organic rubbers. This consistency means that it is possible to supply solid silicone in almost any shape. Geometries range of this type of silicone rubber is such as simple strips, coils, blocks to pellets. The fact that SSR is possible to pelletise, it opens up a very wide spectrum of possibilities for automation (Jerschow, 2002).

High tear solid silicone rubbers HTV have a hardness that is much higher than the standard grades with a range values of 40 to 50 N/mm according to ASTM 624B. Such grades have been developed to cope with the requirements for medium to high tear strength. Their main advantage is a high performance mechanical spectrum coupled with cost savings relative to high tear strength products.

Moreover, HTV solid silicone rubber is a highly crosslinked super heat stable that enables it to have freely pigmentable and heat stable. This material is heat stable without the need for a further stabilizer. Hence, it can be used at up to 300˚C. However, a standard HTV also would require a very good heat stabilizer to merely reach this level of stability.

2.3.2 Room Temperature Vulcanising (RTV)

Many RTV systems are widely used as silicone sealants or adhesives. However, their individual function is not typical of the application of silicone elastomers. It is more related to sealants used in structural glazing and in the building industry. In silicone elastomer technology, these systems are used for joining silicones and moulded parts. Gorur, mentioned that room temperature vulcanized (RTV)

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