METAL FILLED HIGH DENSITY POLYETHYLENE COMPOSITES:

MECHANICAL, ELECTRICAL AND THERMAL PROPERTIES

by

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LIST OF SYMBOLS

R_p	Effective radius of a polymer
R_m	Effective radius of a metal particle
V	Volume percent loading of metal particles in a composite
V_c	Critical volume percent loading of metal particles required for continuity
L	Length
W	Width
rpm	Round per minute
ρ_w	Density of water
W_1	Sample weights in air
W_2	Sample weights in water
ρ_c	Density of the composite
ρ_f	Density of the filler
ρ_m	Density of the matrix
ΔH_m	Melting heat of the sample
ΔH°_m	Melting heat of unfilled HDPE
W_f	Weight fraction of filler
V_f	Volume fraction of filler
V_m	Volume fraction of matrix
ρ_s	Surface resistivity
R_s	Surface resistance
π	Ratio of the circumference of a circle to its diameter
D	Inside diameter of the guard electrode
d	Diameter of the guard electrode
T_m	Onset melting temperature

ΔH	Melting enthalpy
σ_c	Tensile stress of the composite
σ_p	Tensile stress of the matrix
φ	Volume fraction of filler
σ_{Comp}	Conductivity of a composite
σ_{Pol}	Conductivity of the matrix
σ_{Filler}	Conductivity of the filler
X_{Pol}	Volume fraction of the matrix
X_{Filler}	Volume fraction of the filler
σ^{HS-}	Hashin-Shtrikman lower boundary
σ^{HS+}	Hashin-Shtrikman upper boundary

LIST OF ABBREVIATION

$CaCO_3$	Calcium carbonate
CMC	Ceramic matrix composite
DSC	Differential scanning calorimetry
EMI	Electromagnetic interference
ESD	Electrostatic discharge
FCC	Federal Communications Commision
HDPE	High density polyethylene
IC	Integrated circuit
LDPE	Low density polyethylene
LLDPE	Linear low density polyethylene
MFI	Melt flow index
MMC	Metal matrix composite
PE	Polyethylene
PVC	Poly(vinyl chloride)
RFI	Radio frequency interference
SEM	Scanning electron microscopy
TGA	Thermogravimetry analysis
UHMWPE	Ultra high molecular weight polyethylene
WAXD	Wide angle X-ray

KOMPOSIT POLIETILENA BERKETUMPATAN TINGGI TERISI SERBUK LOGAM: CIRI-CIRI MEKANIKAL, ELEKTRIKAL DAN TERMA

ABSTRAK

Komposit polietilena berketumpatan tinggi terisi serbuk logam disediakan dengan menggunakan pencampur dalaman Thermo Haake PolyDrive Rheomix dengan kelajuan rotor 50 pusingan per minit pada suhu 150 °C selama 15 minit. Pengisi serbuk logam yang digunakan adalah aluminum (Al), kuprum (Cu) dan ferum (Fe) yang mempunyai saiz dan bentuk partikel yang berbeza. Dengan memasukan serbuk logam ke dalam matrik polietilena berketumpatan tinggi, sifat matrik polietilena berketumpatan tinggi berubah daripada mulur ke rapuh. Secara amnya, dengan peningkatan kandungan pengisi serbuk logam ke dalam matrik polietilena berketumpatan tinggi kekuatan tensil akan berkurangan berbanding matrik polietilena berketumpatan tinggi tanpa pengisi. Modulus Young meningkat dengan peningkatan kandungan pengisi serbuk logam. Peningkatan ini menunjukkan peningkatan dalam kekakuan komposit yang terbentuk. Seperti yang dijangkakan, pemanjangan takat putus berkurangan secara mendadak dengan peningkatan kandungan pengisi serbuk logam. Imbasan mikroskop elektron (SEM) menunjukkan mod kegagalan berubah daripada kegagalan mulur ke kegagalan rapuh. Di dalam penyelidikan ini, didapati ciri-ciri mekanikal dipengaruhi oleh bentuk dan saiz pengisi, darjah kehabluran dan rekatan antara pengisi serbuk logam dengan matrik polietilena berketumpatan tinggi. Peningkatan pengisi serbuk logam menghasilkan pengaglomeratan serbuk logam dan mengurangkan rekatan antara serbuk logam dengan matrik dan meningkatkan sentuhan antara serbuk logam dengan

serbuk logam. Ciri-ciri keberaliran elektrikal bagi komposit yang terbentuk pula dipengaruhi oleh bentuk pengisi, jumlah kandungan pengisi dan jenis serbuk logam yang digunakan. Keberaliran elektrikal meningkat dengan peningkatan kandungan pengisi serbuk logam dengan komposit polietilena berketumpatan tinggi terisi aluminum mencapai keberaliran elektrikal tertinggi berbanding komposit polietilena berketumpatan tinggi terisi kuprum dan ferum. Gambar rajah imbasan mikroskop elektron menunjukkan penghasilan komposit polietilena berketumpatan tinggi terisi serbuk logam dengan menggunakan pencampur dalaman menghasilkan taburan rawak pengisi. Gambar rajah imbasan mikroskop elektron juga menunjukkan bahawa pada kandungan pengisi serbuk logam yang tinggi, partikel-partikel logam berada dalam keadaan bersentuhan antara satu sama lain yang menghasilkan laluan elektron. Daripada lengkungan permeteran kalori pengimbasan kebezaan (DSC), didapati penambahan pengisi serbuk logam tidak mempengaruhi suhu peleburan polietilena berketumpatan tinggi. Walau bagaimanapun, pada kandungan pengisi serbuk logam yang tinggi, kehabluran polietilena berketumpatan tinggi terganggu dan ini menjelaskan penurunan kekuatan tensil bagi komposit yang terhasil. Analisis permeteran graviti haba (TGA) menunjukkan bahawa pengisi serbuk logam tidak mempengaruhi kestabilan terma bagi komposit yang terbentuk.

METAL FILLED HIGH DENSITY POLYETHYLENE COMPOSITES: MECHANICAL, ELECTRICAL AND THERMAL PROPERTIES

ABSTRACT

Metal filled high density polyethylene (HDPE) composites were prepared in Thermo Haake PolyDrive Rheomix internal mixer with a rotor speed of 50 rpm at 150 °C for 15 minutes. The metal fillers that were used are aluminum (Al), copper (Cu) and iron (Fe) in the form of powders with different particle shapes and sizes. The incorporation of metal powders in the HDPE matrix changes the nature of the polymer from ductile to brittle. In general, increase of metal filler loading decreases the tensile strength compared to the unfilled system. However, Young's modulus increase with increasing filler loadings signifies the increase in stiffness of the composites formed. As expected, the elongation at break decreases dramatically with increasing filler loadings. Scanning electron micrographs (SEM) showed that the mode of failure has transformed from a ductile failure to a brittle failure. In this study, it was found that the mechanical properties are affected by the shape and size of the filler, degree of crystallinity and the adhesion between metal fillers and polymer. Increasing filler loadings resulted in filler agglomeration which reduces the adhesion between metal fillers and polymer and increase the metal-to-metal contact. For the electrical properties of the composites formed, it was found that the electrical conductivity of the composites is governed by the shape of the filler, the amount of filler content and type of metal powders used. The electrical conductivity increases with increasing filler loadings with Al filled HDPE composites achieved the highest electrical conductivity compared to Cu and Fe filled HDPE composites.

The SEM showed that the preparation of these composites with internal mixer has resulted in the random filler distribution. The SEM also shows that at higher filler loadings the particles are actually in contact with each other which resulted in the creation of the electron pathway. From the differential scanning calorimetry (DSC) curves, it was found that the addition of metal fillers in HDPE does not seem to have much influence on the melting temperature of HDPE. However, at higher filler loadings the metal fillers will disturb the crystallinity of HDPE and therefore it explains the reduction in tensile strength of the composites formed. The thermogravimetric (TGA) analysis shows that the incorporation of the metal fillers in HDPE matrix does not have any significant much on the thermal stability of the composites formed.

CHAPTER 1

INTRODUCTION

1.1: Introduction and background of the study

The 20th century really marks the beginning of man's conscious effort to devise true composites. Because plastics are used so frequently in composites today, the development of plastics technology had to precede the development of suitable composites. The need for new materials has led to today's drive for more and better polymer composites. Light-weight high-performance engineering plastics are ousting metals in many applications, just as synthetic polymers as a whole have already displaced, in total volume production, steel, hitherto the major structural material (Sheldon, 1982).

Today, the plastics industry is becoming very sophisticated, and growth is being driven by new product innovations and technical advancements. Entirely new thermoplastic resins have recently been introduced by the industry. Blending, alloying, and reactive processing of existing resins are increasing, as is sophisticated compounding with reinforcements and modifiers as methods of improving properties and performances of these resins. Much of the growth is attributed to the displacement of metal parts. This is true is the electronic industry, with the advent of miniaturization, and in the transportation industry, with the development of low-cost, low-weight, high-strength plastics that can withstand both processing and end use environment (Wright and Woodham, 1989).

Conductive polymer composites are of key interest in many fields of engineering application. Conductive polymer composites play an important part in the electrical-electronics industry for electrostatic discharge (ESD) protection and electromagnetic-radio frequency interference (EMI/RFI) protection. Electromagnetic interference (EMI) shielding is receiving increasing attention in electronic and communication industries because of devices becoming increasingly sensitive, dense, and abundant (Luo X et al., 1999). Other usages are for the appliance, medical, business machine, packaging, and aerospace industries which are also finding increased demands for conductive polymer composites (Kalyon et.al, 2002; Nazarenko, 1999; Wright and Woodham, 1989).

The combination of conventional polymers and conductive polymers or fillers allows creating new polymeric materials with unique electrical properties (Omastova et al., 1999). Major advantages are their technological and ecological properties and potentials. The physical profile of properties can be attained both by the choice of components and by a variation of the materials morphology. In order to attain an electrically conductive polymer, electrical conductive fillers can be established in the material to form a conductive pathway (percolation of the conductive fillers) (Markov et al., 2005).

Numerous factors are known to influence the percolation threshold. The percolation threshold depends on the filler type and its content, the form of filler particles, their ability to restructure and the physical-chemical condition of their surface. For electrical and mechanical properties of conductive polymer composites factors that play an important role are the type of polymer, its

physical properties, the conditions of manufacturing and processing of the composite, temperature, pressure, and the influence of an electrical and/or magnetic fields during processing contribute to the final properties of the composites (Markov et al., 2005; Psarras G. C., 2002; Nakamura et al., 1998; Pramanik et al., 1992)

1.2: Problem Statement

In this present study, high density polyethylene (HDPE) was used as the polymer matrix while three different types of metal powders was chosen as fillers namely aluminum (Al), copper (Cu), and iron (Fe). HDPE was chosen due to high stiffness, strong, and high abrasion resistant in the polyethylene family (Strong, 2000; Peacock, 2000). The linearity of HDPE also allows high degrees of crystallinity which in turn contribute to their high modulus and low permeability of all classes of polyethylene. When the matrix consists of a crystalline polymer, the degree of crystallinity determines to a large extend the particle concentration require in order to reach the percolation threshold. The higher the crystallinity, the lower the particle concentration needed to reach percolation (Bengtsson P., 1993). Therefore, these properties of HDPE make it suitable for the end use as housing of electrical devices for EMI/RFI and ESD protection not to mention that HDPE is easily obtained.

The metal fillers used in this study have relatively high electrical conductivity. Furthermore these metal fillers has different kind of particle shape where by Al is flaky, Cu is dendritic, and Fe is spherical. These metal fillers are also easily

obtainable and have a relatively high purity. Therefore, the combination of these materials will produce conductive polymer composites that will contribute in the advancement of EMI/RFI and ESD protection in the electronics industry. Thus offering the cost effectiveness and rapid fabrication rate with a wide range of design flexibility, lightweight, and non-corrosiveness.

1.3: Objectives of study

As this is a preliminary study to produce a conductive polymer composites, thus this study have been dedicated to understand the theory of conductive network formation. The primary objectives of this study are:

1. To study the effect of different type of metal fillers on the properties of the high-density polyethylene composites produced particularly on the mechanical and electrical properties.

2. To investigate the effect of filler loading on the properties of the high density polyethylene composites.

3. To study the effect of thermal ageing on the electrical properties of the metal filled high density polyethylene composites.

1.4: Outline of theses structure

Chapter 1 starts with the introduction and background of the study. The primary objectives and the general flow of the whole research program are also carefully outlined.

Chapter 2 introduces the fundamentals on the definition and general classification of composites, an introduction to the concept of reinforcements and fillers, an overview of polymer matrix composites emphasizing on thermoplastic matrix especially polyethylene and finally a detailed discussion on conductive polymer composites and its applications. Generally, Chapter 2 is a literature survey that was done on various published works that are closely related to this work.

Chapter 3 describes the experimental procedures employed, details of lab equipments used as well as any other processing techniques involved in generating any data that were used and presented in the course study.

Chapter 4 reports the effect of various types of metal fillers used on the mechanical and conductivity of the composites produced. The results on the mechanical, electrical conductivity, and thermal properties of these composites would be presented here and a detailed analysis would be carried out based on the data collected. Mechanical properties were analyzed based on the tensile test. Electrical conductivity data were based on the surface conductivity of the composites. DSC reports are depicted here to facilitate in thermal property

analysis. Scanning electron microscopy was used to study the fracture surface morphology and the formation of conductive network.

Chapter 5 presents some concluding remarks on the present work as well as some suggestions for future works.

CHAPTER 2

LITERATURE REVIEW

2.1: Composites: An Introduction

The 'composites' concept is not a human invention. Wood is a natural composite material consisting of one species of polymer —cellulose fibers with good strength and stiffness —in a resinous matrix of another polymer, the polysaccharide lignin. Nature makes a much better job of design and manufacture than we do. Although, mankind has been aware of composite materials since several hundred years ago and has applied innovations to improve the quality of life, but it is only in the last half century that the science and technology of composite materials have developed to provide the engineer with a novel class of materials and the necessary tools to enable him to use them advantageously (Harris, 1999).

Today, many of our modern technologies require materials with unusual combinations of properties that cannot be met by the conventional metal alloys, ceramics, and polymeric materials (Callister, 1997). Thus, composites have emerged as a valuable class of engineering materials.

2.1.1: Definition and Classification of Composite

A simple definition of composite materials are materials that are made up of two or more constituents and consisting two or more phases. The constituent

phases must be chemically dissimilar and separated by a distinct interface (Callister, 1997; Autar, 1997). However, this definition is not sufficient and three other criteria have to be satisfied before a material can be said to be a composite.

First, both constituents have to be present in reasonable proportions, say greater than 5%. Secondly, it is only when the constituent phases have different properties, and hence the composite properties are noticeably different from the properties of the constituents, that we have come to recognize these materials as composites. Lastly, a man-made composite is usually produced by intimately mixing and combining the constituents by various means. Thus, an alloy which has a two-phase microstructure which is produced during solidification from a homogeneous melt, or by subsequent heat treatment whilst a solid is not normally classified as a composite (Matthews and Rawlings, 1999).

As stated previously, composites have two or more chemically distinct phases and separated by a distinct interface, therefore it is important to be able to specify these constituents. The constituent that is continuous and is often but not always present in the greater quantity in the composite is termed the matrix. The second constituent is referred to as the reinforcing phase, or reinforcement, as it enhances or reinforces the mechanical properties of the matrix. The geometry of the reinforcing phase is one of the major parameters in determining the effectiveness of the reinforcement; in other words, the mechanical properties of composites are functions of the shape and dimensions of the reinforcement. Further discussion on the reinforcement will be discussed in

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Section 2.2. The matrix phase of composites may be a metal, polymer, or ceramic. The composite matrix is required to fulfill several functions, most of which are vital to the performance of the material. Some of the vital functions of the matrix are listed below (Harris, 1999):

i. The matrix binds the reinforcement together and holding them aligned in the important stresses directions.

ii. The matrix isolates the reinforcement from each other so that they can act as separate entities.

iii. The matrix protects the reinforcement from mechanical damage and environmental attack.

Composites can be classified by the geometry of the reinforcement; particulate, flake, and fibers —or by the type of the matrix; polymer, metal or ceramic. Figure 2.1 shows the classification of composites based on the type of matrices used.
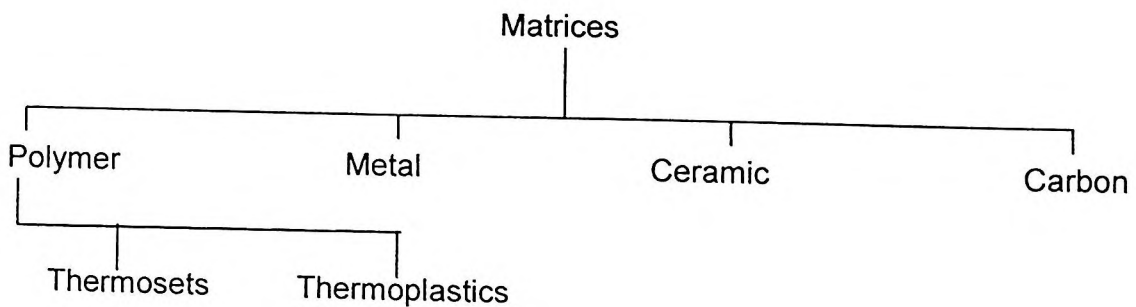
Figure 2.1: A classification scheme for the various composites based on the type of matrices used (Sharma, 2000)

2.1.2 Polymer Matrix Composites (PMC)

The most common matrix materials for composites are polymers. Polymers make an ideal matrix materials as they can be processed easily, possess lightweight, and offer desirable mechanical properties. Polymers in turn are divided into thermosetting polymer and thermoplastic polymer.

Thermosetting polymers formed into a permanent shape and cured or 'set' by a chemical reaction known as cross-linking. Cross-linking binds the polymer molecules together in a three dimensional network resulting in a part that cannot be reformed into another shape but degraded or decompose upon being heated to high temperature. Thus, the cross-linking reactions are not reversible. In contrast to thermosetting polymers, thermoplastic polymers may be repeatedly heated, fabricated and cooled to room temperature, allowing them to be reshaped (Stuart, 1990; Osswald and Menges, 1996).

Thermoplastic are those polymers that solidify as they are cooled, no longer allowing the long molecules to move freely. When heated, these materials regain the ability to 'flow', as the molecules are able to slide past each other with ease. Thermoplastic in turn are subdivided into commodity and engineering types (Osswald and Menges, 1996). Commodity thermoplastics are thermoplastic materials that are used in high-volume and widely recognized applications. Commodity thermoplastic are sought after due to their economical advantages and find applications where dimensional stability, stiffness, heat resistance, and toughness are not the primary requirements of the end products.

Examples of widely used commodity thermoplastic are polyethylene and polypropylene (Strong, 2000).

Engineering thermoplastics were originally identified by their ability to replace metallic parts in applications such as automobiles, appliances, and house wares. Engineering thermoplastics generally have better properties such as good heat resistance, retention of mechanical properties over a wide range of temperatures, high strength and stiffness, the ability to withstand environmental factors, and good dimensional stability throughout the temperature range of normal use. However, they also cost at least twice as much per weight as commodity thermoplastics (Strong, 2000).

2.1.2.1: Thermoplastic Matrix

Most applications using plastics take advantage of the inherent ease of processing and excellent balance of properties that thermoplastic polymers exhibit relative to thermosetting polymers. Thermosetting polymers are more time-consuming to process because of the chemical reaction required to cure them, and are generally less impact-resistant than thermoplastic polymers (Stuart, 1990).

An added feature of thermoplastic matrices is that they can potentially overcome some of the property limitations associated with thermosetting matrices. The major property limitations of composites produced with thermosetting polymers are brittleness, solvent susceptibility, and problems

associated with the fact that the polymers must be chemically reacted. While thermoplastic polymers have a considerable advantage in enhancing the toughness of a composite, are not limited with regard to shelf life, and need only heat and pressure to process, it is their potential for high volume processing, and the associated low cost per part, that has spurred the current research and development activities on thermoplastic matrix composites (Stuart, 1990; Strong, 2000).

In the following section detail explanation will be emphasized on thermoplastic matrix particularly on polyethylene since this material has been used in this study. On the other hand, the thermosetting will be discussed briefly.

2.1.2.2: Polyethylene (PE)

The polymer unit for polyethylene (PE) is given in Figure 2.2.

$$\left(-\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-\right)_n$$
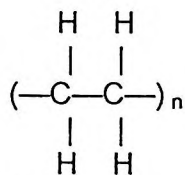
Figure 2.2: Polymer unit for PE

PE is the simplest of all polymers with just two carbons and four hydrogens in the basic polymer repeating unit. Some properties that are usually considered inherent advantages of PE are (Strong, 2000):

- PE is relatively insensitive to most solvents
- High electrical resistance

- Good thermal insulator

- Low cost (per unit volume)

- Ease of manufacture

- Low specific gravity

- Tough and flexible

- Low permeability

- Corrosion resistance

Properties usually considered being disadvantages of PE are:

- Joining or bonding of PE is a difficult process because of the inherent solvent resistance of PE

- Melting point of PE is quite low and so its use is limited in applications where high temperature is present

- Dimensional instability under prolonged load

The major differences in the shape of PE molecules arise from changes in the conditions that exist in the polymerization reactor during the polymerization reaction. Reactor conditions such as temperature, pressure, and catalyst type can have a major effect on the shape by either creating or suppressing the formation of molecular branching. Branching is the formation of side chains off the basic polymer backbone. Three general types of commercially made PE differ chiefly in the way the molecules interact, caused by the amount and type of branching and are illustrated in Figure 2.3 (Strong, 2000). Changes in the amount of branching result in major differences in the interactions between PE

molecules and also the physical and mechanical properties of PE which distinguish them from one another.

(a)

(b)

(c)
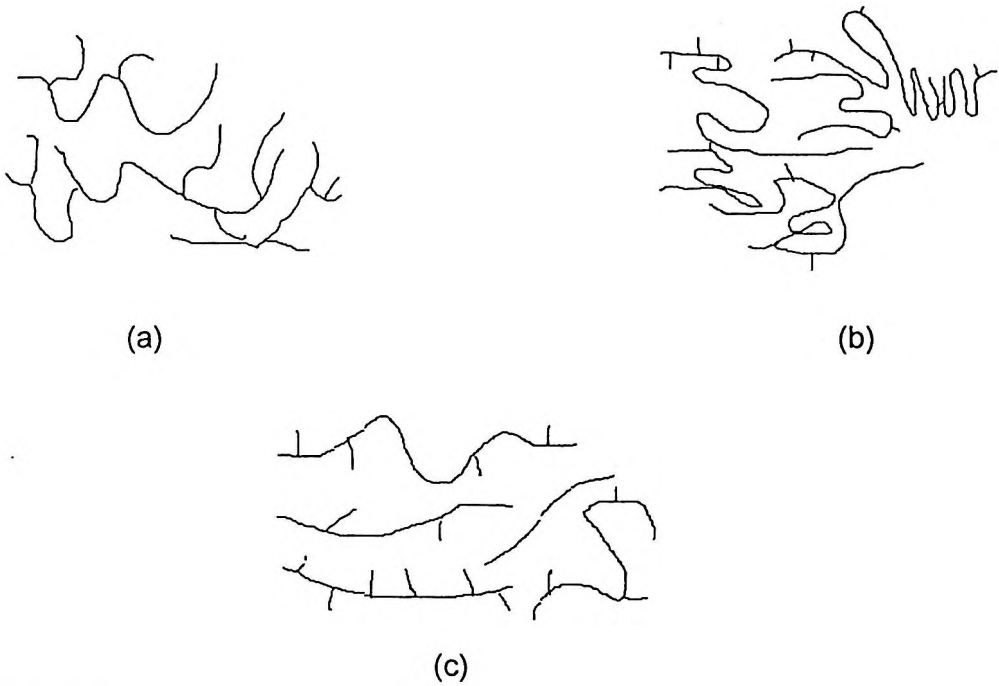
Figure 2.3: Different types of polyethylene showing the effects of branching (a) low density polyethylene (LDPE) (b) high density polyethylene (HDPE) (c) linear low density polyethylene (LLDPE) (Strong, 2000)

2.1.2.3: Low Density Polyethylene

Low density polyethylene (LDPE) is formed when high-temperature and high-pressure polymerization conditions are used. These conditions of polymerization give rise to the formation of many branches, which are often quite long and prevent the molecules from packing close together to form crystal structure. Hence, LDPE has low crystallinity (typically below 40%) and the structure is predominantly amorphous. (Strong, 2000)

Items molded from LDPE are generally translucent; at thickness up to 1/8 in., newsprint laid directly in contact is readable through LDPE. They feel somewhat waxy, and there may be a trace of surface bloom. LDPE is quite pliable; it is readily flexed by hand at thicknesses up to 1/8 in. Samples show much resilience, rarely taking on a permanent set unless deformed substantially. LDPE has no odor or taste unless chemically altered by degradation or some other process (Peacock, 2000).

2.1.2.4: High Density Polyethylene

If polymerization conditions are used that result in limited branching (that is, low temperature and pressure), the result is PE that is more linear, with only a few, short branches. This type of PE is known as high density polyethylene (HDPE). Comparing to LDPE, HDPE has a much higher density as the polymer chains in HDPE can easily pack tightly and crystalline structures are formed. In general, HDPE is stiffer, stronger, and more abrasion resistant than LDPE. HDPE is

used in preference to LDPE when greater stiffness or strength is required (Strong, 2000). The linearity of HDPE permits the development of high degrees of crystallinity, which endow them with the highest modulus and lowest permeability of all the classes of polyethylene. This combination makes them suitable for certain medium- and large- scale liquid holders such as drums, tight-head pails, and chemical storage tanks. On a smaller scale, a combination of stiffness, low permeability, and high environmental stress crack resistance makes HDPE admirably fit for bottles to contain household, industrial, and automotive chemicals such as liquid detergent, bleach, motor oil, and antifreeze (Peacock, 2000).

The HDPE molecules are essentially linear with little entanglement in the melt, at least compared to LDPE. Therefore, when processed in the melt, HDPE molecules tend to be aligned in the direction of flow, especially when the flow path is highly restricted. This orientation also leads to rapid crystallization and high shrinkage upon cooling. Hence, the cooling rate of HDPE is faster than LDPE which can be an advantage in very high-volume processes such as the manufacture of margarine tubs. This orientation in the melt also adds to the strength of the melt, which is useful in blow molding very large parts (Strong, 2000).

HDPE has the disadvantage of increased brittleness compared to LDPE. In applications where the high strength of HDPE and high impact toughness are required, a very high molecular weight grade of HDPE has been produced. This material is called ultra high molecular weight polyethylene (UHMWPE) and is

really a subgroup of HDPE. The use of UHMWPE is much smaller than the use of the other types of PE. The major problem with UHMWPE is the difficulty of melting the material. The molecular weight is so high that decomposition will often occur before melting. Hence, the material cannot be processed in traditional plastic molding equipment. It is generally sintered (Strong, 2000).

2.1.2.5: Linear Low Density Polyethylene

Linear low density polyethylene (LLDPE) is made by a low-pressure catalyst process similar to the HDPE process, but with longer and more branches. This branching in LLDPE is sufficient to prevent close-packing of the molecules. Therefore, LLDPE has a low density like LDPE but a linear structure much like HDPE. The molecular interactions between the LLDPE molecules are different from either LDPE or HDPE and yet are related to both. The effects of lack crystallinity and density are obviously similar in LLDPE and LDPE, while the linear shape of the LLDPE molecule is similar to the shape of HDPE molecules. These similarities and differences result in LLDPE properties which are generally between the properties of LDPE and HDPE (Strong, 2000).

Items molded from LLDPE resins are generally somewhat hazy white materials. Surfaces felt slightly waxy and have little if any surface bloom. They exhibit no discernible taste or odor. Depending on the co monomer content, they can vary from being quite pliable to being stiff materials that flex only slightly before a permanent set is achieved. LLDPE distinguishes itself by superior toughness, as measured by tear strength, impact resistance, and puncture resistance.

LLDPE films are used in many packaging and non-packaging applications, including grocery sacks, fresh produce packages, stretch-wrap, domestic trash can liners, and scientific balloon. It is also extruded to form wire and cable insulation, pipes, and sheet for use where the stiffness of HDPE is not required. Injection molding is used to convert LLDPE into such items as food container lids and toys, where flexibility combined with toughness is needed (Peacock, 2000).

2.1.2.6: Thermosetting

Thermosetting plastic or thermoset parts are made from polymeric resins that are capable of forming chemical cross links. These resins are shaped usually by placing them into molds and then are chemically cross linked. The process of cross linking is called curing. As stated earlier, cross linking reactions are not reversible. If the thermoset parts are heated, they may soften somewhat, but they will retain their general shape as the temperature is raised, not melting, until decomposition begins. Therefore, as opposed to thermoplastics in which molding and shaping only involves freezing the hot (melted) material, in thermosets the molding and shaping involve a chemical reaction that causes the material to harden and take a permanent shape (Strong, 2000).

Some properties are characteristics of most thermosets. As the number of cross links increases, the stiffness of the material also increases. Thus, many thermosets are typically stiffer and more brittle than the thermoplastic materials. The impact toughness of thermosets can be increased by adding fillers or

reinforcements, which can also increase strength. These fillers and reinforcements will also affect the viscosity of the molding resin and adjustments in the manufacturing method may have to be made to allow for the higher viscosities of these filled compounds. The cross links improve the creep resistance of thermosets over most of the engineering thermoplastics. Long-term thermal stability and dimensional stability with temperature are also improved with cross linking, although some thermosets soften with heat sufficiently that they cannot be used when high temperatures are encountered (Strong, 2000).

Examples of some important thermosetting resins are as follows (Strong, 2000):

- Phenolics material is very hard and stiff. These suggest that this material is highly cross linked and that the cross links are strongly three-dimensional.

- Epoxies are polymers with three-membered rings on the ends of the polymer chains. Epoxies are stiff and strong and are used extensively as adhesives and as the resin in advanced composite applications.

- Imides are somewhat like an aromatic group but are even stiffer and stronger. The imides are stiff, strong materials with very high thermal stabilities.

2.1.3: Metal Matrix Composites (MMC)

Metal matrix composites (MMCs), as the name implies, have metal matrix. Examples of matrices in such composites include aluminum, magnesium, and titanium. Metals are mainly reinforced to increase or decrease their properties to suit the needs of design (Autar, 1997). Typical fibers used as reinforcement in metal matrix include carbon and silicone carbide. Metal matrix composites have many advantages over monolithic metals including a higher specific modulus, higher specific strength, better properties at elevated temperatures, lower coefficients of thermal expansion and better wear resistance (Lee and Mykkanen, 1987;Matthews and Rawlings, 1999;).

2.1.4 Ceramic Matrix Composites (CMC)

Ceramic matrix composites (CMC) have a ceramic matrix such as alumina, calcium alumino silicate reinforced by fibers such as carbon or silicone carbide (Autar, 1997). Ceramics can be described as solid materials which exhibit very strong ionic bonding in general and few cases covalent bonding. High melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength, render ceramic-based matrix materials a favorite for applications requiring a structural material that doesn't give way at temperatures above 1500°C. Naturally ceramic matrices are the obvious choice for high temperature applications (Sharma, 2000).

2.2: The Reinforcements

Reinforcements for the composite can be fibers, particles or whiskers. Fibers are essentially characterized by one very long axis with other two axes either often circular or near circular. Particles have no preferred orientation and so does the shape. Whiskers have a preferred shape but are small both in diameter and length as compared to fibers (Sharma, 2000). The geometry of the reinforcing phase is one of the major parameters in determining the effectiveness of the reinforcement; in other words, the mechanical properties of composites are a function of the shape and dimensions of the reinforcement (Matthews and Rawlings, 1999).

Reinforcing constituents as stated earlier, provide the strength to the composite materials. But they also serve certain additional purposes of heat resistance or conduction, resistance to corrosion and provide rigidity. Reinforcement can be made to perform all or one of these functions as per the requirements (Sharma, 2000).

2.2.1: Fibers

A fibrous reinforcement is characterized by its length being much greater than its cross-sectional dimension. However, the ratio of length to the cross-sectional dimension known as the aspect ratio can vary considerably. In single-layer composites long fibers with high aspect ratios give what are called *continuous* fiber reinforced composites, whereas *discontinuous* fiber composites are

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fabricated using short fibers of low aspect ratio. The orientation of the discontinuous fibers may be random or preferred. The frequently encountered preferred orientation in the case of continuous fiber composites is termed *unidirectional* and the corresponding random situation can be approximated to by *bidirectional* woven reinforcement (Matthews and Rawlings, 1999).

Additions of fibers tend to enhance stiffness, strength, hardness, abrasion resistance, heat deflection temperature, and lubricity while reducing shrinkage and creep. The fiber aspect ratio and the orientation of fibers can have a profound influence on the properties of the composite. Generally speaking, the most effective reinforcing fillers are fibers which intrinsically have a high elastic modulus and tensile strength (Kusy, 1986).

2.2.2: Whiskers

Single crystals grown with nearly zero defects are termed whiskers. They are usually discontinuous and short fibers of different cross sections made from several materials like graphite, silicon carbide, copper, iron etc. Typical lengths of whiskers are in 3 to 55 N.M range. Whiskers differ from particles in that; whiskers have a definite length to width ratio greater than one. Whiskers can have extraordinary strengths up to 7000 MPa (Sharma, 2000). The high tensile strength in whiskers are due to the relative freedom of dislocations in the crystals; in fact they usually have only a single dislocation running along the longitudinal axis. Whiskers are difficult and costly to manufacture and are only used for special applications. It should be noted that there are health and safety implications when handling these materials, owing to carcinogenic risks.

Examples of the most common used in polymeric matrix are boron and carbon whiskers (Timings, 2000).

2.2.3: Particles

Particulate reinforcements have dimensions that are approximately equal in all directions with low aspects ratios. The shape of the reinforcing particles may be spherical, cubic, platelet or any regular or irregular geometry. The arrangement of the particulate reinforcement may be *random* or with a *preferred orientation*. In the majority of particulate reinforced composites the orientation of the particles is considered, for practical purposes, to be random (Matthews and Rawlings, 1999). The composite's strength usually depends on the diameter of the particles, the interparticle spacing, and the volume fraction of the reinforcements. The matrix properties influence the behavior of particulate composite too (Sharma, 2000).

2.3: The Fillers

In this study, metal fillers are used to increase the electrical property of the polymer Therefore, a different approach of classification of fillers and other usage of fillers will be discussed in this section.

According to Wypych (2000) fillers are defined as a solid material capable of changing the physical and chemical properties of materials by surface interaction or its lack thereof and by its own physical characteristics. Fillers are added to materials in the first place was probably to lower the costs. Fillers were inexpensive, thus using them would make the material cheaper. However, today, cost reductions are no longer the only, or even the most important consideration for using fillers in formulating composite materials.

These examples which follow list the usage of fillers in composite materials other than to reduce the cost (Wypych, 2000):

- Material density

  Fillers can be used either to increase or to decrease the density of a product. Thus a broad range of product densities can be obtained.

- Optical properties

  Optical properties of compounded materials depend on the physical characteristics of the filler and the other major ingredients including the polymer. Depending on how they match, one can obtain clear or opaque materials.