TENSILE PROPERTIES OF GRAPHENE NANOPLATELET REINFORCED ULTRA-HIGH MOLECULAR WEIGHT POLYETHYLENE COMPOSITES

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in fulfillment of the requirement for the degree of
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DECLARATION

I declare that this project report entitled "Tensile Properties of Graphene Nanoplatelet Reinforced Ultra-High Molecular Weight Polyethylene Composites" is the result of my own work except as cited in the references.

Signature	:	……………………………….
Name	:	……………………………….
Date	:	……………………………….

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Honours.

Signature	:	……………………….
Supervisor’s Name	:	……………………….
Date	:	……………………….

DEDICATION

To my beloved mother and father.

ABSTRACT

Ultra-high Molecular Weight Polyethylene (UHMWPE) has been used extensively in orthopaedic implant fabrications as a component in total joint replacement especially for hip and knee replacement. A good reinforcing filler, Graphene Nanoplatelet (GNP) with different amounts (0.1, 0.3, 0.5, and 1.0 wt. %) were used to fabricate the GNP/UHMWPE composite. The composites were fabricated by the dry mixing process as a technique to mix these two materials followed by the hot-pressing with reference to ASTM D638 Type 1 standard. The process continued with several tests in order to fulfil the objective of the study. The objectives of this study are to fabricate the sample of Neat UHMWPE and GNP/UHMWPE composite, to investigate the effects of GNP on tensile properties of GNP/UHMWPE composite and to evaluate the effects of GNP composition in GNP/UHMWPE composite. From density analysis, the result shows that the density between theoretical and experimental have slightly different. The microhardness test shows that the GNP can increase the hardness of the composite with increasing amounts of GNP. The conductivity test shows that the small amount of GNP added do not conduct electric while at higher wt. % can conduct electric. The key findings from tensile test included the GNP with 0.1 wt. % can increase the tensile strength and tensile strain of the composite and decreased from 0.3 to 1.0 wt. %. The addition of GNP up to 0.3 wt. %. also enhanced the Young's modulus of the composite. The GNP/UHMWPE displayed a remarkable combination of enhanced the tensile properties and others which making the composites safe to be used as material in arthroplasty implant in human body.

ABSTRAK

Ultra-high Molecular Weight Polyethylene (UHMWPE) telah digunakan secara meluas dalam fabrikasi implan ortopedik sebagai komponen dalam penggantian sendi terutama untuk penggantian pinggul dan lutut. Bahan penguat yang bagus sepereti Graphene Nanoplatelet (GNP) dengan jumlah yang berbeza (0.1, 0.3, 0.5, dan 1.0 wt. %) telah digunakan untuk membuat komposit GNP/UHMWPE. Komposit dibuat melalui proses pencampuran kering sebagai teknik untuk mencampurkan kedua-dua bahan ini diikuti dengan proses penekanan panas dengan merujuk kepada piawai ASTM D638 Jenis 1. Proses ini diteruskan dengan beberapa ujian untuk memenuhi objektif kajian. Objektif kajian ini adalah untuk menghasilkan spesimen Neat UHMWPE dan komposit GNP/UHMWPE, mengkaji kesan GNP pada sifat tegangan komposit GNP/UHMWPE dan mengkaji kesan jumlah GNP dalam komposit GNP/UHMWPE. Dari analisis ketumpatan, hasilnya menunjukkan bahawa ketumpatan antara teori dan eksperimen sedikit berbeza. Ujian mikrokekerasan menunjukkan bahawa GNP dapat meningkatkan kekerasan komposit dengan peningkatan jumlah GNP. Ujian kekonduksian menunjukkan bahawa sejumlah kecil GNP yang ditambahkan tidak mengalirkan elektrik manakala pada jumlah wt. % yang tinggi boleh mengalirkan elektrik. Penemuan utama dari ujian ketegangan termasuk GNP dengan 0.1 wt. % dapat meningkatkan tegangan tegangan dan regangan tegangan komposit dan menurun dari 0.3 hingga 1.0 wt. %. Penambahan GNP hingga 0.3 wt. % juga meningkatkan modulus komposit Young. GNP/UHMWPE memperlihatkan kombinasi yang luar biasa untuk meningkatkan sifat tegangan dan lain-lain yang menjadikan komposit ini selamat digunakan sebagai bahan dalam implan artroplasti dalam tubuh manusia.

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LIST OF ABBREVIATIONS

ASTM	-	American Society for Testing and Materials
CMC	-	Ceramic Matrix Composite
CNT	-	Carbon Nanotubes
CVD	-	Chemical Vapor Deposition
GNP	-	Graphene Nanoplatelet
GO	-	Graphene Oxide
HDPE	-	High Density Polyethylene
LDPE	-	Low Density Polyethylene
MMC	-	Metal Matrix Composite
MTT	-	3-(4, 5-di-methylthiazol-2-yl)-2, 5-diphenyltretrazolium bromide
MWCNT	-	Multi-Walled Carbon Nanotubes
PMC	-	Polymer Matrix Composite
PMMA	-	Poly-methyl-methacrylate
PSM	-	Projek Sarjana Muda
PTFE	-	Polytetrafluorethylene
SEM	-	Scanning Electron Microscope
SWCNT	-	Single-Walled Carbon Nanotubes
TEM	-	Transmission Electron Microscope
UHMWPE	-	Ultra-High Molecular Weight Polyethylene

LIST OF SYMBOLS AND UNITS

GPa	-	Giga Pascal
g	-	Gram
h	-	Hours
HV	-	Hardness Vickers
Hz	-	Hertz
kJ	-	Kilo Joule
M	-	Mass
m	-	Meter
min	-	Minutes
ml	-	Mililitre
mm	-	Milimeter
m/s	-	Meter per second
MPa	-	Mega Pascal
N	-	Newton
nA	-	Nanoampere
nm	-	Nanometer
psi	-	Pound square inch
rpm	-	Revolution per minute
S	-	Siemens
sqr	-	Square
TPa	-	Tera Pascal
wt. %	-	Weight percentage
ρ	-	Rho
Ω	-	Ohm
µm	-	Micrometer
°C	-	Degree Celsius

CHAPTER 1

INTRODUCTION

1.1 Background

Composite is a combination of two or more materials (reinforcing elements, filler and composite matrix binder), differing in form or composition on a macro scale. Composite components are commonly used in many applications such as in sporting equipment, aerospace, medical field as well as military. The uses of composite over monolithic materials are due to its characteristic which are light in weight, high stiffness and strength, low thermal expansion and high fatigue resistance. Composite can be classified into two classes; classification of composite based on matrix material and classification of composite based on reinforcement geometry. Examples of classification of composite based on reinforcement geometry are Particle Reinforced, Fibre Reinforced and Structural. While classification of composite based on matrix material are Polymer Matrix Composite (PMC), Metal Matrix Composite (MMC) and Ceramic Matrix Composite (CMC) as shown in **Figure 1.1.**

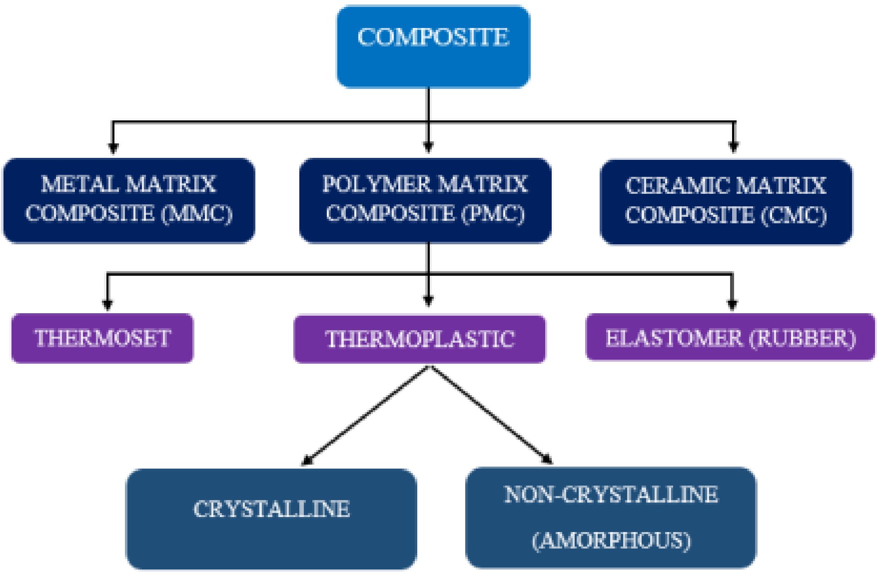

Figure 1.1: Classification of composite based on matrix material.

1.1.1 Polymer Matrix Composite

Polymers can be identified as long chain materials (macromolecules) consisting of many repeat units. Polymers can be either naturally produced or synthetically produced. Physical properties of the polymer are including molecular weight and molecular structure. Average molecular weights for most polymers are in the range of 10,000 up to more than 1,000,000 g/mol. There are four types of polymer molecular structures such as **(a)** linear, **(b)** branched, **(c)** crosslinked, and **(d)** network polymers as shown in **Figure 1.2** [1].

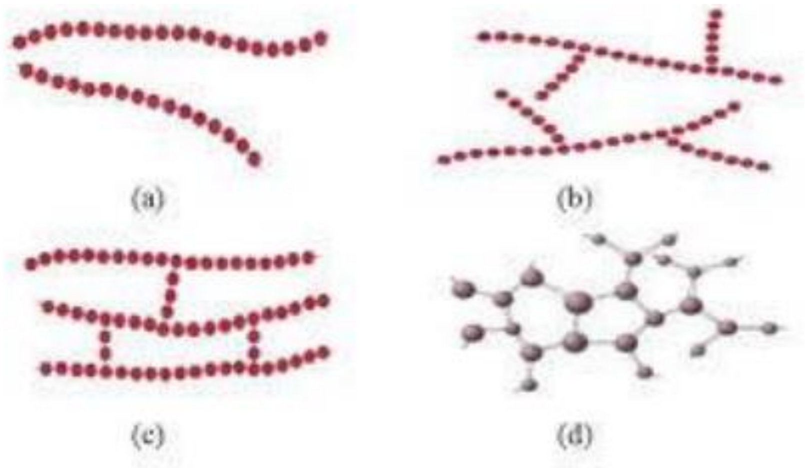

Figure 1.2: Type of polymer molecular structure [1].

The repeat units in linear polymers are covalently linearly bound in single chains and the molecule chains are flexible, as shown in **Figure 1.2(a).** Van der Waals or hydrogen bonding are the bonding between the chains. Example of linear polymer is poly-methyl-methacrylate (PMMA) [1].

There is side branch chain connected to the main chains in branched polymer, as shown in **Figure 1.2(b).** Polymer density is low due to formation of side branches that can reduce chain packing efficiency. A polymer that forms linear structure may also be branched. As example polyethylene. High density polyethylene is a linear polymer while low density polyethylene is a branched polymer [1].

The main linear chains are covalently bonded to each other in cross-linked polymers, as shown in **Figure 1.2(c).** During synthesis or through a chemical reaction, the crosslinking process is achieved. Examples of cross-linked polymers are rubber-elastic materials [1].

Monomers form three-dimensional networks in network polymers, as shown in **Figure 1.2(d).** It may also be possible to identify a strongly cross-linked polymer as a network polymer. Mechanical and thermal properties of network polymers are relatively better. Polyurethane is an example of network polymers [1].

Polymers are commonly used in many applications because it is easy to process (do not require high temperature and pressure). Some applications of polymer that used in everyday life are electrical wire insulation, safety helmets, anti-adhesive coating and many more. However, in general polymer deteriorate due to physical, thermal and chemical factors. It has low stiffness and strength. Other disadvantages of this material are low working temperature, high coefficient of thermal expansion and it is sensitive to moisture and radiation. Polymer can be classified into thermoplastics, thermosets, and elastomers.

Thermoplastics

Thermoplastics are linear or branched polymers that can be either amorphous, crystalline or mixed and act in a ductile manner. When heat is applied, thermoplastics become soft and melt and solidify upon cooling [1]. Thermoplastics are reversible reaction which means recyclable. Some applications of thermoplastic in daily life are sterilisable bottles and film wrapping materials. Commonly known thermoplastics are polypropylene and polyethylene. Other examples of thermoplastic are shown in **Table 1.1.**

Thermosets

Thermosets are linear or branched molecules of polymers which can be cross-linked to form three-dimensional network structures. Generally, thermosets are stronger but more brittle in comparison with thermoplastics [1]. Thermosets cannot be recycled. Well known thermosets are polyester, epoxy resin and many more as shown in **Table 1.1.** Epoxy resins used for application with superior performance and it is relatively costly compared to polyester.

Elastomers

Elastomers, also known as rubbers, are materials with more than 200 % elastic deformation. Elastomers may be thermoplastics, or thermosets that are lightly cross-linking. In elastomers, the polymer chains consist of coil-like molecules which can stretch reversibly when a force is applied [1]. Example of elastomers is natural rubbers. Other examples of elastomers are shown in **Table 1.1.**

Table 1.1: Example of Thermoplastics [1], Thermosets [1] and Elastomers [2].

Thermoplastics	Thermosets	Elastomers
Polyamide (nylon)	Phenolic	Polyisoprene
Polycarbonate	Polyurethane	Ethylene Propylene Rubber
Polystyrene	Vinyl Ester	Nitrile Rubbers

1.1.2 Biomaterial

Biomaterial can be defined as any material used to make devices to replace a part or a function of the body in a safe, reliable, economic and physiologically acceptable manner. It is a synthetic material (man-made). The Clemson University Advisory Board for Biomaterials has formally defined a biomaterial to be *a systematically and pharmacologically inert substance designed for implantation within or incorporation with living systems.*

In recent times, the arena of nanoscience, nanotechnology and nanocomposites has flourished, and the importance of this topic has increased in other applications such as automotive, aerospace, packaging, biotechnology, biomedical, electronics, flexible sensors and many more. The innovations on polymer composite based on reinforcing materials has been an interested and become a significant addition especially in biomedical field. For example, some devices and implants are used to replace or improve the function of the original parts or organs in body, e.g. contact lenses, cardiac pacemaker, dental implants, and orthopaedic implants.

There four groups of synthetic material used for implantations in human body. As example, composites, metals, ceramics, and polymers. The important aspects of study on biomaterial are biological material, implant material, and interaction between the material added and the organs or parts in body. This interaction needs to be considered in order to know the biocompatibility of material in body.

Metallic implant materials such as stainless steel, titanium and titanium alloy can be used in dental roots implant and for bone plates and screw. The uses of metal because it is strong and ductile but there are some problems regarding this material which are metal tend to corrode in our body, heavy and difficult to fabricate. For ceramic implant materials such as alumina zirconia and hydroxyapatite also include in contributing to be as a material for orthopaedic and dental implants but need to be highlighted that these materials are brittle and weak in tension.

The success of a biomaterial or an implant is highly dependent on factors such as the properties and biocompatibility of the implant, and the health condition of the recipient. Polymeric implant materials such as ultra-high molecular weight polyethylene has been used extensively for orthopaedic implant fabrications especially for such load-bearing surfaces as total hip and knee joints as shown in **Figure 1.3(a)** and **Figure 1.3(b)**, respectively.

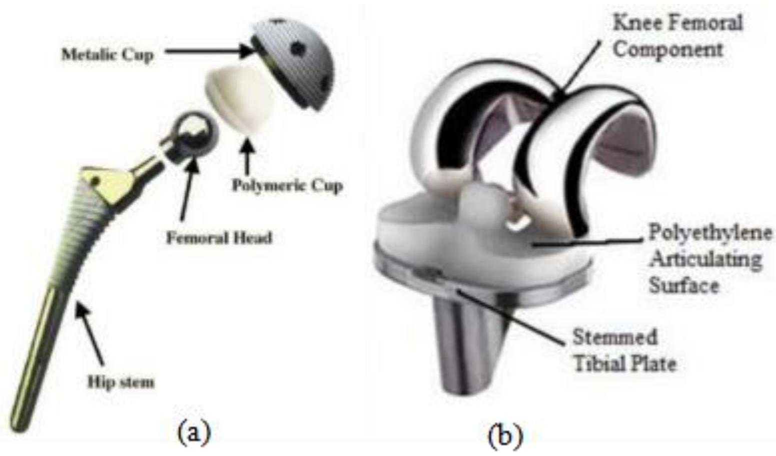

Figure 1.3: Application of polymer in **(a)** total hip and **(b)** knee replacement.

1.2 Ultra-High Molecular Weight Polyethylene

Polyethylene is under thermoplastic class. Polyethylene is available commercially in three major grades: Low Density Polyethylene (LDPE), High Density Polyethylene (HDPE) and Ultra-High Molecular Weight Polyethylene (UHMWPE). LDPE is a branched polymer and it is produced by high pressure Ziegler polymerization process. LDPE has an amorphous structure and low crystallinity. In the polyethylene group, LDPE is the largest volume production material. Nearly 50% of LDPE are transformed into thin films for the packaging industry. The rest is used for other applications. HDPE is a linear polymer produced by low pressure Ziegler process and it has high crystallinity. Blow-moulded containers for liquid product packaging are a major market area for HDPE [3].

UHMWPE is a subset of polyethylene thermoplastic. UHMWPE has high molecular weight usually around 2-6 million g/mole. The material is almost completely inert. The uses of UHMWPE because it is low wear rate and high impact strength. Recently, cross-linked UHMWPE has been developed for the use of articulating joint materials such as the acetabular cup of a hip joint prosthesis. Other differences between these three types of polyethylene are shown in **Table 1.2** [3].

Table 1.2: Properties of LDPE, HDPE and UHMWPE [3].

Properties	**LDPE**	**HDPE**	**UHMWPE**
Specific gravity	0.910 – 0.925	0.941 – 0.965	0.928 – 0.941
Tensile strength, MPa	4.1 – 15.8	21.9 – 38	38 – 48
Elongation at break, %	90 – 800	20 – 1000	200 – 500

1.3 Carbon-based Fillers

There are several types of carbon-based fillers such as graphite, graphene, carbon nanotube (CNT) and many more as shown in **Figure 1.4.** In order to synthesize the graphene and its derivatives, it has their own methods.

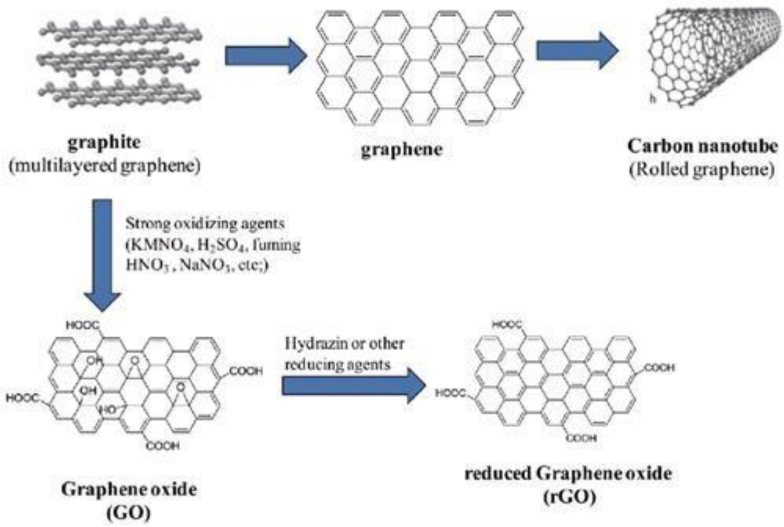

Figure 1.4: Type of carbon-based fillers.