



**REVIEW OF FRICTION, WEAR AND MECHANICAL PROPERTIES OF
ULTRAHIGH MOLECULAR WEIGHT POLYETHYLENE USED IN TOTAL
JOINT REPLACEMENT**

M.Sc. PROJECT WORK

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ARBA MINCH, ETHIOPIA

REVIEW OF FRICTION, WEAR AND MECHANICAL PROPERTIES OF ULTRA
HIGH MOLECULAR WEIGHT POLYETHYLENE USED IN TOTAL JOINT
REPLACEMENT

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ARBA MINCH, ETHIOPIA

DECLARATION

I hereby declare that this M.Sc. Project Work is my review work and has not been presented for a degree in any other university, and all sources of material used for this work have been duly acknowledged.

Name: _____

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This is to certify that the project work entitled “**Review Of Friction, Wear And Mechanical Properties Of Ultra High Molecular Weight Polyethylene Used In Total Joint Replacement**” submitted in partial fulfillment of the requirements for the degree of **Master’s** with specialization in **Physics**, the Graduate Program of the **School of Graduate Studies**, and has been carried out by **BabisaBazula**, Id. No **SMSc/117/06**, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the project work to the department for defense.

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We, the undersigned, members of the Board of Examiners of the final open defense by Babisa Bazula have read and evaluated his project work entitled “**Review Of Friction, Wear And Mechanical Properties Of Ultra High Molecular Weight Polyethylene Used In Total Joint Replacement**” and examined the candidate’s oral presentation. This is, therefore, to certify that the project work has been accepted in partial fulfillment of the requirements for the degree with **minor/major corrections**.

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LIST OF ABBREVIATIONS

AFM	Atomic Force Microscopy
ASTM	American Society For Testing And Materials
DSC	Differential Scanning Calorimetry
GUR	Granular UHMWPE Ruhrchemie
HC	High Crystallinity
ISO	International Organization for Standardisation
LC	Low Crystallinity
RMS	Root Mean Square
SEM	Scanning Electron Microscope
TEM	Transmission electron microscopy
TJR	Total Joint Replacement
UHMWPE	Ultra High Molecular Weight Polyethylene

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ABSTRACT

This project work is a review of the experimental techniques that can be applied to ultrahigh molecular weight polyethylene (UHMWPE), which is commonly used in total joint replacement (TJR). The limitations of these techniques caused by the inherent properties of the material or the instruments for characterization are discussed. The friction, wear and mechanical properties of UHMWPE as a function of polymer crystallinity in both micro and nano scale are reviewed.

Keywords: Total joint replacements; Ultra-high molecular weight polyethylene (UHMWPE); Crystallinity; Friction; Wear

CHAPTER ONE

INTRODUCTION

1.1 Background

Total joint replacement (TJR) is a surgical procedure in which certain parts of an arthritic or damaged joint, such as a hip or knee joint, are removed and replaced with a plastic or metal device called prosthesis. The prosthesis is designed to enable the artificial joint to move just like normal, healthy joint. It can be performed on any joints of the body including the hip, knee, ankle, foot, shoulder, elbow, wrist, and fingers. Of these procedures, the hip and the knee total joint replacements are by far the most common. Typical total joint replacement of hip and knee is shown in Figure 1.1

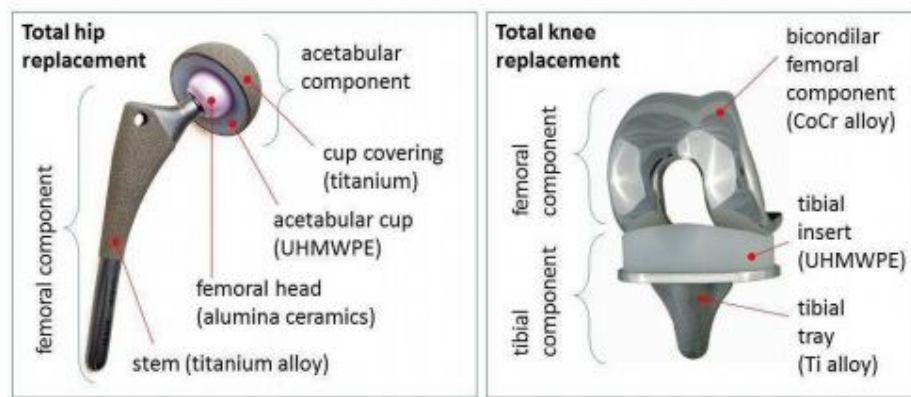


Figure 2.1. Typical total joint replacements of two most frequently replaced joints: hip (left) and knee (right) [23].

TJRs can become loose and require a revision surgery due to several reasons such as mechanical failures (fracture), surgical problems (misalignment, contamination) and friction and wear of contacting surfaces resulting in aseptic loosening. Of all these reasons, it has been recognized that wear is the major cause of long term failure of joint replacements. Specifically, friction and wear at interface between the femoral head (usually a hard metal alloy) and acetabular cup lining (usually a soft polymer) and the fretting corrosion at the interface between the head and the stem.

Many different material pairs have been used for TJRs. Ultra-high molecular weight polyethylene (UHMWPE) paired with a metal (cobalt-chrome (Co-Cr) or Titanium

alloys) or ceramic (alumina or zirconia) are the most common combination of materials used in Total Hip Replacements (THR). Although UHMWPE has a wear rate lower than many other materials, the average lifetime of artificial hip joints incorporating the polymer are only 15-20 years. Considerable amount of research is being devoted to increasing the wear life of the prosthesis [1-7]. Another factor affecting the performance of UHMWPE in implants is its processing. Medical grade UHMWPE stock material may undergo a variety of processing techniques during implant manufacturing, including melting, extrusion and milling or turning. These manufacturing processes can affect the surface morphology and mechanical properties of the UHMWPE which in turn can affect its friction and wear performance [8-9].

The materials used in a total joint replacement are designed to enable the joint to move smoothly with low friction. A joint implant is generally composed of two parts that articulate during the joint motion. In a hip, for example a metal ball (cup covering) is usually used to fit closely into a matching counter surface composed of UHMWPE.

Several metals are used, including stainless steel, alloys of cobalt and chrome, and titanium. The UHMWPE is durable and wear resistant. It has been widely accepted for its low friction and high wear-resistance. Examples of total hip and knee replacements are Co-Cr alloy and UHMWPE. While these materials are mostly used, combinations of ceramic-ceramic, metal-metal and ceramic-UHMWPE total joint systems are some other alternative materials used under special situations. Bone cements made by polymers are usually used to anchor the prosthesis into the bone. Joint replacements also can be implanted without cement when a porous surface on the stems of joint replacements can allow bone to grow into it.

1.2 Statement of the problem

The friction of the articulating metal on UHMWPE surfaces in TJRs have been recognized as critical factors affecting their durability and reliability. Specifically, the characteristics of the softer, polymeric material have become an important area of study to reduce the problem of material wear in hip replacements, without compromising its advantages of low friction and high impact strength. Studies have shown that a polymer's resistance to wear is directly related to its mechanical properties, which have been linked to the polymer morphology or crystallinity. Understanding how morphology and

crystallinity affect friction and wear behavior should give useful insight in the pursuit of developing a superior joint material.

1.3 Objectives

1.3.1 General Objectives

To review the crystallinity, friction, wear and mechanical properties of UHMWPE

1.3.2 Specific Objectives

- To review the techniques used to measure Young's modulus, hardness, tensile strength, friction and wear of UHMWPE
- To review the crystallinity of UHMWPE and its relationship with the material properties

1.4 Significance of the study/Benefits and Beneficiaries

Total joint replacement (TJR) is a surgical procedure in which the ailing and the injured human joints are replaced with artificial joint components. Over the last 40 years, TJR has been increasingly performed in many countries around the world which has brought relief to millions of people. Based on trends collected from both past decades and projected future ones, TJR is now becoming an important treatment for arthritis, trauma and joint disorders amongst the young active and elderly patients.

1.5 Delimitation/Scope

This work is theoretical review only using books, articles, magazines and other literature.

CHAPTER TWO

REVIEW OF RELATED LITERATURE

UHMWPE is a type of polyolefin. It is made up of extremely long chains of polyethylene, which all align in the same direction. It derives its strength largely from the length of each individual molecule (chain). Van der Waals bonds between the molecules are relatively weak for each atom to overlap between the molecules. But because the molecules are very long, large overlaps can exist, adding up to the ability to carry larger shear forces from molecule to molecule. Each chain is bonded to the others with so many van der Waals bonds that the whole of the inter-molecule strength is high. In this way, large tensile loads are not limited as much by the comparative weakness of each van der Waals bond. When made into fibers, the polymer chains can attain a parallel orientation greater than 95% and a level of crystallinity from 39% to 75%. In contrast, Kevlar, which is used in bullet-proof vest, derives its strength from strong bonding between relatively short molecules.

The weak bonding between olefin molecules allows local thermal excitations to disrupt the crystalline order of a given chain piece-by-piece, giving it much poorer heat resistance than other high-strength fibers. Its melting point is around 266 to 277 °F according to differential scanning calorimetry (DSC). It is not advisable to use UHMWPE fibers at temperatures exceeding 176 to 212 °F for long periods of time. It becomes brittle at temperatures below -240 °F. The simple structure of the molecule also gives rise to surface and chemical properties that are rare in high-performance polymers. For example, the polar groups in most polymers easily bond to water. Because olefins have no such groups, UHMWPE does not absorb water readily, nor wet easily, which makes bonding it to other polymers difficult. In a similar manner, aromatic polymers are often susceptible to aromatic solvents due to aromatic stacking interactions. UHMWPE is a member of the polyethylene family of polymers with the repeat unit $[C_2H_4]_n$, where n denotes the degree of polymerization. The International Standards Organization (ISO) defines UHMWPE as having a molecular weight of at least 1 million g/mole, resulting in a minimum degree of polymerization of $n \approx 36,000$ [20]. The American Society for Testing and Materials (ASTM) specifies that UHMWPE has a molecular weight greater than 3.1 million g/mole ($n \approx 110,000$)[15]. The UHMWPEs used in orthopedic applications typically have a

molecular weight between 2-6 million with a degree of polymerization between 71,000 and 214,000.

UHMWPE is a linear (non-branching) semi-crystalline polymer which can be described as a two phase composite of crystalline and amorphous phases. The crystalline phase contains chains folded into highly oriented lamellae, with the crystals being orthorhombic in structure [16]. The lamellae are typically 10-50 nm thick and 10-50 μm long. The amorphous phase surrounding the lamellae consists of a random entanglement of polyethylene chains. Some of these amorphous chains are incorporated into one or more lamellae which serve to interconnect the crystalline phase. These incorporated chains are called tie molecules, have a density of about 1 to 30 volume percent, and are thought to be responsible for the high ductility of UHMWPE. The two resins of UHMWPE that are currently used in orthopaedics are GUR 1020 (3.5 million g/mole) and GUR 1050 (5.5-6 million g/mole) [17]. These resins can either be compression molded into sheets or ram-extruded into rods. Both resin and conversion methods are significant predictors of tensile mechanical properties and impact strength. It is also important to note that studies have reported subtle differences in the morphology and fatigue crack propagation resistance between the two conversion methods.

In a work done by Sara Anne Atwood [12], both mechanical properties and wear rates were evaluated on nine distinct groups of medical-grade UHMWPE, including GUR 1020 and GUR 1050, which had undergone clinically-relevant processing treatment. It was found that the mechanical properties (yield strength, elastic modulus, and ultimate true stress and strain) of the cross-linked materials depended on the type of heat treatment, the gamma-radiation dose, and the resin. The GUR 1050 materials had lower yield strength, elastic modulus and fatigue crack propagation compared to GUR 1020 materials with the same heat treatment and gamma-radiation dose, but ultimate properties were about the same. The differences in elastic and fatigue behavior may be due to the lower molecular weight of the GUR 1020 compared to GUR 1050. With a lower molecular weight, the long-chain molecules are more mobile and may be more easily incorporated into lamellae. Microstructural parameters such as lamellar size and percent crystallinity were also studied and it was found that these depended on the heat treatment, the radiation dose, and the resin. The GUR 1020 materials had slightly smaller lamellae but higher crystallinity than the GUR 1050 materials with the same heat treatment and radiation

dose. The higher crystallinity is correlated with higher yield strength, modulus and fatigue resistance. The differences in resin are also confounded by differences in consolidation method, which has been shown to impart directionality and to affect fatigue crack propagation resistance and tensile properties [13]. This directionality explains the lower fatigue crack propagation resistance of the highly cross-linked GUR 1050 material, which was tested in the weak orientation in which crack propagation direction is aligned with the ram-extrusion direction. Multidirectional sliding wear tests were also performed and the wear rate was not significantly correlated to any of the microstructural parameters and was dominated by the gamma-radiation dose. In a similar study on the relationship of microstructural parameters to rolling-sliding wear rate, it was found that there is a correlation between wear rate and lamellar size normalized by yield strength [14]. Cross-linking has been shown to inhibit the ability of the lamellae to align [15-16], which is in agreement with the observation that sliding wear rate decreased with increased radiation dose. These results suggest that the number, size, and thickness of the lamellae are not as important for inhibiting sliding wear as is cross-linking the amorphous phase.

CHAPTER THREE

METHODOLOGY OF THE PROJECT WORK

3.1 Source of materials for the project work

The project work consisted of literature review in which several journal papers, review articles, conference proceedings, book chapters, and dissertation work were used. The literature is available in the internet and a thorough search was done using Google Scholar and web of Science.

3.2 Method of characterization of materials used in total joint replacement

3.2.1 Friction and wear

Various instrumental techniques are used to characterize the friction, wear and mechanical properties of materials used in total joint replacement (TJR). These materials include stainless steel, cobalt-chromium alloys, titanium alloys, ceramics like alumina and zirconium and polymer (UHMWPE). Atomic Force Microscope (AFM) is commonly used to study the friction and wear at nanoscale level. In this technique, a sharp cantilever-tip assembly is placed at the end of a piezo tube. The probe is scanned over the surface in a raster pattern. A laser beam is focused on the end of the cantilever during raster-scanning and is reflected onto a quadrant photodiode. A constant force on the sample is maintained by a feedback loop control system to compensate for the topographical features of the surface. This results in a three-dimensional map of the sample. For any meaningful quantitative analysis of the friction signals obtained with an atomic force microscope, one has to accurately determine the normal force constant and the lateral calibration factor of the cantilever to convert the measured friction signal in volts to force units (nanoNewton). Also, for contact theories to be obtained for the friction measurements, the radius of the probe is essential [1-2]. Figure 3.1 shows the basic operating principles of an AFM.

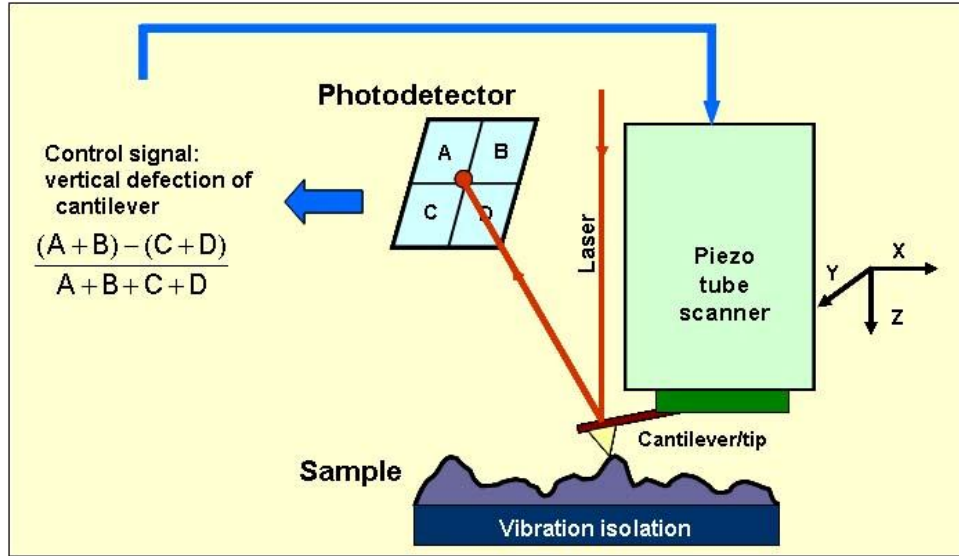


Figure 3.1. Operating principles of an Atomic Force Microscope [1].

3.1.2 Tensile strength

Understanding material mechanics is critical for engineering. The uniaxial tension and compression tests provide a simple and effective way to characterize a material's response to loading [17]. By subjecting a sample to a controlled tensile or compressive displacement along a single axis, the change in dimensions and resulting load can be recorded to calculate a stress-strain profile. From the obtained curve, like the one shown in Figure 3.2, elastic and plastic material properties can then be determined. For uniaxial tests, the displacement is typically held at a constant rate, and displacement and resulting load are recorded. The load is measured by a series of strain gages, or load cell, while the displacement can be recorded as displacement of the crosshead, or the beam on which the specimen load frame is mounted. For more precise load measurements, strain gages or an extensometer can be directly fixed to the specimen. To make direct comparisons between materials, loading responses must be normalized against sample geometry. Therefore, the dimensions of each sample are noted to compute stress and strain from load and displacement, respectively. Strain can be calculated as [17]:

$$\epsilon_e = \frac{\Delta L}{L_0} \quad (3.1)$$

where ΔL is the measured displacement and L_0 is initial sample length along a single axis in the loading direction.

Stress can be calculated as [17]:

$$\sigma_e = \frac{P}{A_0} \quad (3.2)$$

where P is the applied load and A_0 is the initial cross sectional area of the sample normal to the loading direction.

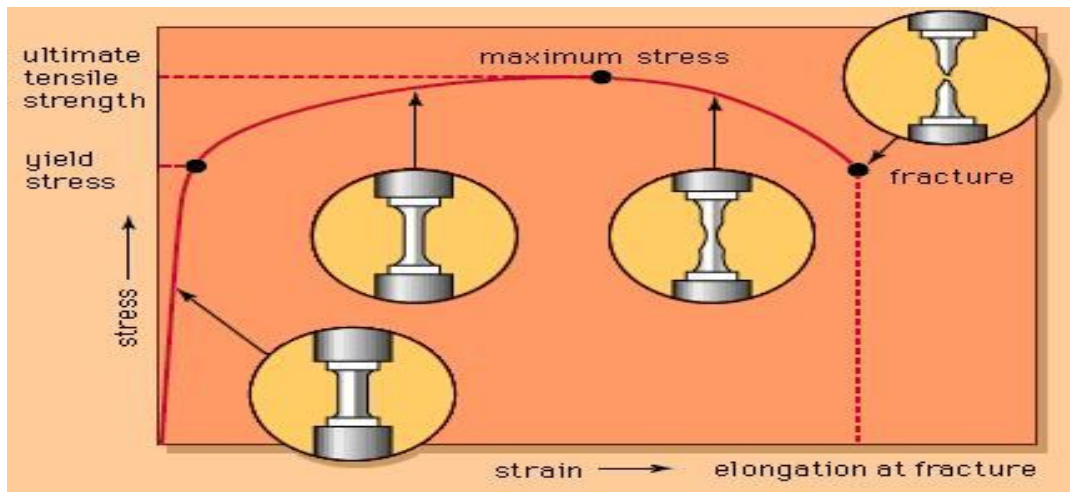


Figure 3.2. Typical stress vs. strain curve for a ductile material showing tensile properties like yield stress, ultimate tensile strength, maximum stress and fracture. (Source: [www.britannica/science/tensile strength](http://www.britannica/science/tensile%20strength)).

Figure 3.2 shows a typical stress vs. strain curve of a piece of a ductile material under load (or stress). The piece stretches at an increasing rate after it is loaded to a point beyond its yield stress. It is possible to see the typical ductile behavior: the maximum stress of the elastic region (yield point) gives way to the start of the necking and then, the stress is progressively increasing along with the strain until the total fracture. The engineering stress and strain data were used to determine the yield strength, where the stress decreased slightly with increasing strain, and the elastic modulus (the secant modulus at 2% strain). Similarly, Figure 3.3 shows the stress vs. strain behavior of UHMWPE where the tensile properties are also quite prominent.

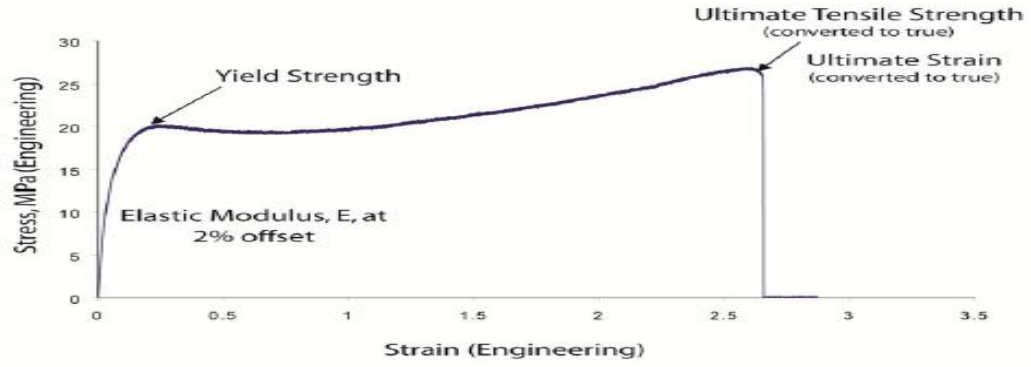


Figure 3.3. Typical stress vs. strain curve for ultra high molecular weight polyethylene (UHMWPE) showing tensile properties like yield strength, ultimate tensile strength and ultimate strain.

3.1.3 Young's modulus and Hardness

A mechanical property that may be important to consider is hardness, which is a measure of a material's resistance to localized plastic deformation. Hardness is the characteristics of a solid material expressing its resistance to permanent deformation. Hardness can be measured on the Mohr's scale or various other scales like Rockwell, Vickers, and Brinell hardness.

Nanoindentation is a versatile technique for measuring mechanical properties (Young's modulus, hardness, interfacial adhesion and film fracture toughness). It works using the same principals as conventional hardness tests, but is performed on a smaller scale using sensitive load and displacement sensing equipment (Figure 3.4 (a)).

According to the Oliver and Pharr model [18], which is the most commonly used method to obtain the Young's modulus and the hardness of a material by instrumented nanoindentation, the Young's modulus is obtained by:

$$S = \frac{dP}{dh} = \frac{2}{\sqrt{\pi}} E_r \sqrt{A} \quad (3.3)$$

where, S is the experimentally measured stiffness from the load-unload curve (Figure 3.4 (b)), A is the projected area of the elastic contact and E_r is the reduced modulus given by:

$$\frac{1}{E_r} = \frac{(1-\nu^2)}{E} + \frac{(1-\nu_i^2)}{E_i} \quad (3.4)$$

where, E and ν are Young's modulus and Poisson's ratio of the specimen and E_i and ν_i are the same parameters of the indenter.

The hardness (H) is expressed as:

$$H = P_{\max} / A_r \quad (3.5)$$

where, $P_{\max}$ is the maximum applied load and A_r is the real contact area between the indenter and the material.

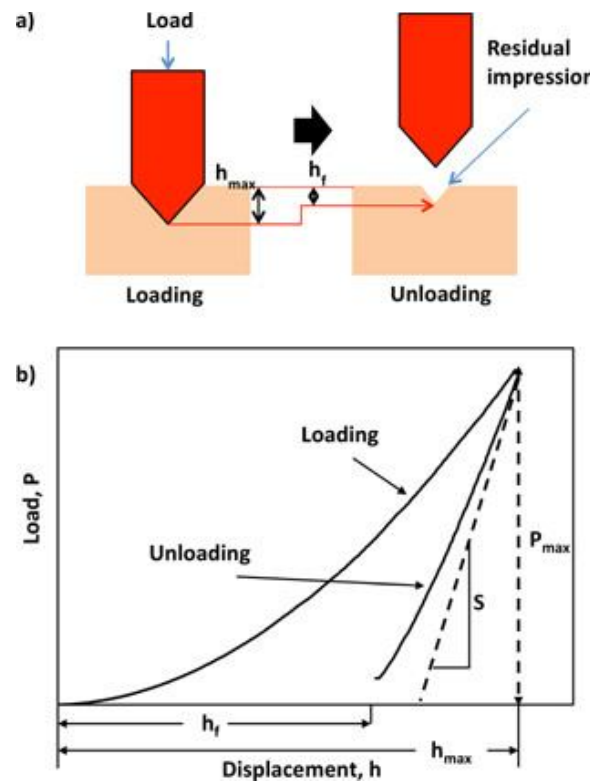


Figure 3.4. Schematics of a nanoindentation test. (a) The working principle of a nanoindenter, (b) load vs. displacement curve showing the process of loading and unloading. (Source: www.researchgate.net/profile/Tulashi_Dahal).

CHAPTER FOUR

DISCUSSION

4.1. Friction and wear of UHMWPE

To simulate the wear of total joint replacement in the human body, wear studies of UHMWPE were performed in bovine serum at ranges of contact pressure and sliding speed encountered in real situations [10]. Scanning electron microscopy results have demonstrated that surface damages of UHMWPE include adhesion wear, abrasion, and delamination wear. The contributions of these mechanisms to the overall wear rate and the generation of wear particles depend predominantly on the contact pressure and secondarily on the sliding speed.

Transmission electron microscopy has provided the micro structural morphology of UHMWPE obtained from sliding [19]. Alignment of crystalline regions in the polyethylene microstructure parallel to the sliding surface was found to occur during sliding even at low contact pressures. The worn polymer surface and debris have been extensively characterized for structural changes with X-ray diffraction and differential scanning calorimetric technique.

It has documented that wear of a material is directly related to its hardness relative to the hardness of the mating materials [1]. This is a method for an improvement in the wear resistance of UHMWPE.

4.2. Crystallinity of UHMWPE

The mechanical and physical properties of UHMWPE are influenced by its crystallinity, which is related to the atomic or molecular arrangement, confirming a specific crystal structure. The crystallinity of polymers is attributed to the specific arrangement of the molecular chains, forming crystalline regions or crystalline lamellae which are chain-folded molecules. Polymers are not totally crystalline and these lamellae are normally surrounded by random distributed molecules with amorphous regions. Since the mechanical and physical properties of UHMWPE are highly affected by its microstructure and grade of crystalline, it is expected that the wear performance can be improved by altering the micro structural conditions. Karupiah et al. [1] evaluated the influence of crystalline on the wear resistance of UHMWPE and reported that, with

increasing the crystalline, the friction force and the scratch depth tended to decrease. They found that the wear resistance increased with the degree of crystalline. Similar results were reported by Wang and Ge[11] through varying mould pressures during the sample formation process. Furthermore, it was reported that the degree of crystallinity can be increased by controlling the material formation pressure and temperature. Heating the UHMWPE (with a molecular weight over 400,000) under high pressure followed by a posterior cooling process induces the formation of the crystalline structure. Lamellae with a thickness less than 12 nm were formed. It was also reported that by holding the temperature above the melting point (around 110 °C) the chains of the polyethylene are able to fold and the crystalline lamellae is formed, resulting in an increase in the crystallinity of the material.

The degree of crystallinity in the material is estimated using differential scanning calorimetry (DSC) which determines the temperatures when the material experiences phase transitions such as crystallization and melting point. The phase transitions are evidenced by peaks in DSC thermograms. The UHMWPE melting temperature is revealed by a sudden increase of the heat at around 137 °C. The degree of crystallinity (ΔX_c) of UHMWPE is calculated based on the melting heat of crystallinity, ΔH_m , which is the energy per unit mass required to melt the lamellae in the material. The crystalline regions can be detected using transmission electron microscopy (TEM), which identifies the lamellae based on the white and gray contrast made with uranyl acetate. In TEM images, the lamellae are revealed as white lines with defined dark borders and the amorphous region with grey contrast. As stated before, the mechanical properties and the wear performances of UHMWPE are affected by its microstructure. Being a semi crystalline material, the degree of crystalline of UHMWPE was estimated between 39% and 75%. The lack of full crystallization imposes a limitation on its mechanical property enhancement. It is also known that the crystalline of polymers is affected by temperature. It was found that, above 60 to 90 °C, small crystallites could be dissolved, which might affect the mechanical performance at relatively low temperatures.

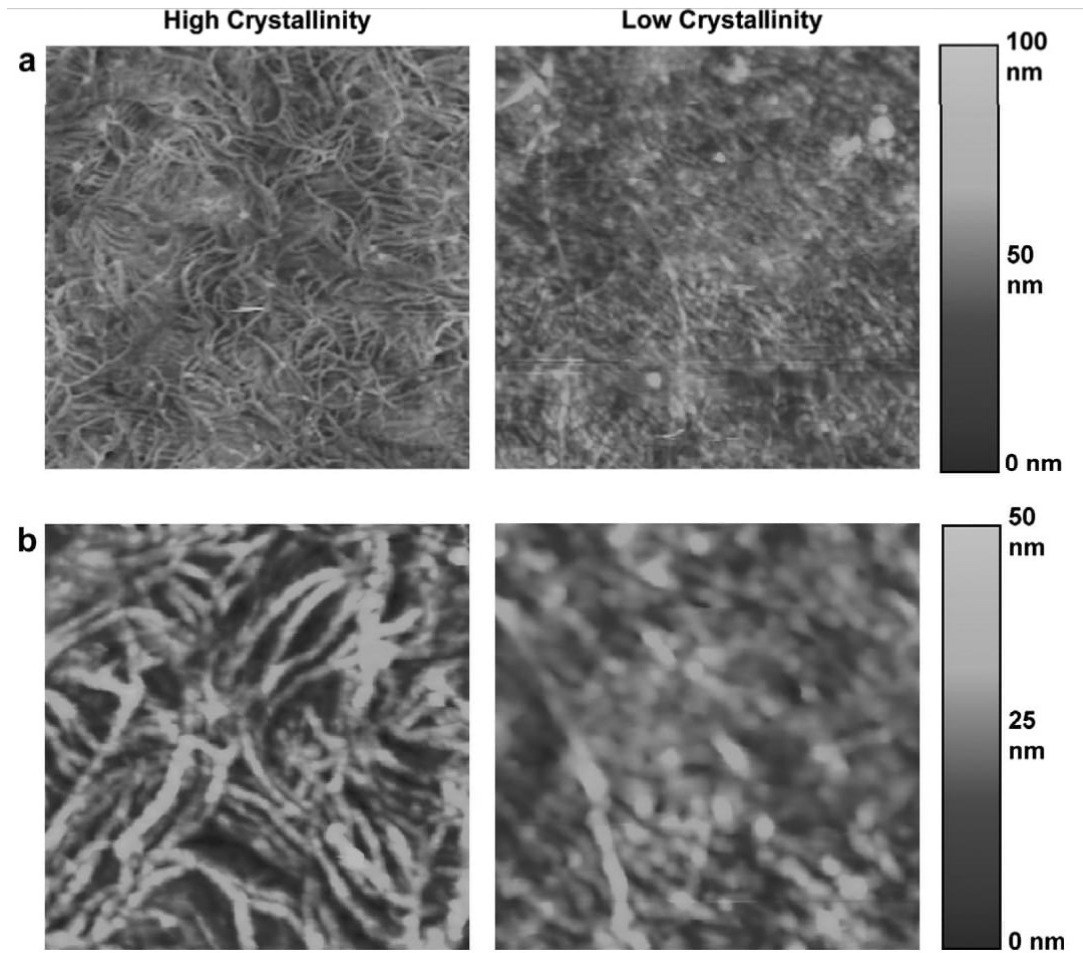


Figure 4.1. Topography maps of high-crystallinity and low-crystallinity samples at (a) 5 $\mu\text{m} \times 5 \mu\text{m}$ and (b) 1 $\mu\text{m} \times 1 \mu\text{m}$ scan sizes obtained using an atomic force microscope [1].

Topography images of two samples with high and low crystallinity were taken using the AFM and are shown in Figure 4.1. The surface of UHMWPE of the higher crystallinity (HC-PE) sample displayed a lamellar type of structure that is indicative of crystalline regions in semi crystalline polymers. The lower crystallinity (LC-PE) sample did not display any distinct lamellar structure at this scale. The final surface roughness (RMS) of the HC-PE and LC-PE samples were $4.58 \pm 0.18 \text{ nm}$ and $3.18 \pm 0.18 \text{ nm}$ (1 $\mu\text{m} \times 1 \mu\text{m}$ scan) respectively, as measured using the AFM. The difference in roughness levels between the two samples is small and, hence, can be considered to have negligible impact on the observed difference in the friction and wear behavior at either scale. Physical

parameters of UHMWPE as a function of crystallinity, average elastic modulus and hardness of five indentations for the two samples are shown in Table 4.1.

Table 4.1. Summary of physical parameters of UHMWPE as a function of crystallinity [1].

Sample	Crystallinity (%)	RMS surface roughness (nm)	Elastic modulus ^a (GPa)	Hardness ^a (GPa)
HC – PE	55.1	4.58 ± 0.18	2.42 ± 0.014	0.25 ± 0.03
LC – PE	45.6	3.18 ± 0.18	1.71 ± 0.03	0.14 ± 0.004

^aMeasured using nanoindentation at a peak load of 25 μ N.

Figure 4.2 shows the typical load-penetration depth curves of nanoindentation tests with trapezoidal profile (Figure 4.2 (a)) and partial loading and unloading profile (Figure 4.2 (b)). The elastic modulus and hardness are determined from the loading-unloading curves at different peak loads. The variations of average elastic modulus and hardness with the average indentation contact depth of five indentations for the two samples are also plotted. Both elastic modulus and hardness for all the polymers decrease with the increase of contact depth. When contact depth is less than 80 nm, partial loading and unloading tests show similar trends that elastic modulus and hardness of HC-PE are higher than LC-PE. For contact depth larger than 80 nm, both samples give almost the same elastic modulus and hardness.

The friction responses of the UHMWPE at the micro scale and nanoscale are shown in Figure 4.3(a) and 4.3(b) respectively. For both the samples and across scales, the friction force increased with an increase in normal load. The data indicates that HC-PE results in a lower friction response than LC-PE at both the micro and nanoscale.

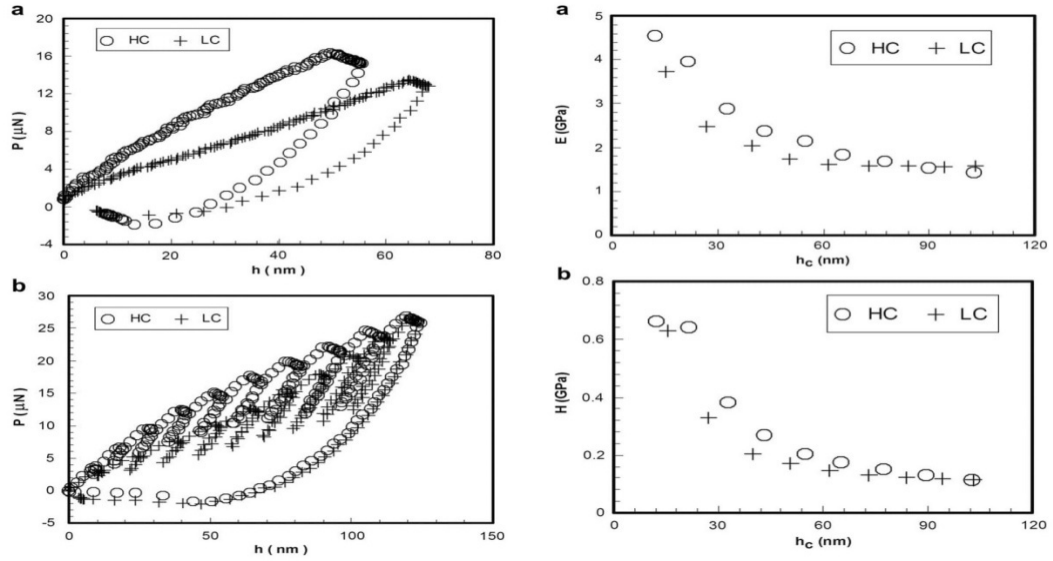


Figure 4.2. (Left) Load-penetration depth (P - h) curves from nanoindentation tests on both low-crystallinity and high-crystallinity samples with (a) standard loading-unloading profile and (b) partial loading- unloading profile. (Right) (a) Elastic modulus (E) and (b) hardness (H) as a function of indentation contact depth(h_c) [1].

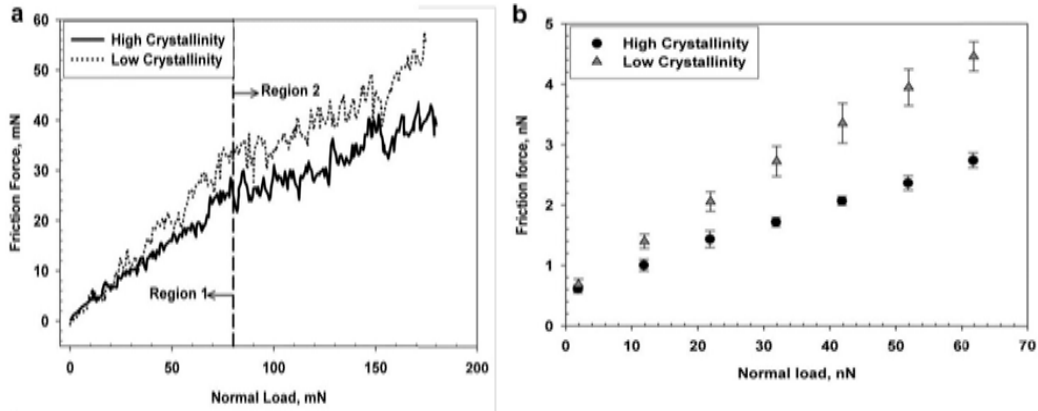


Figure 4.3. (a) Microscale and (b) nanoscale friction response as a function of normal load for both the high-crystallinity and low-crystallinity samples. Friction response is higher for the low-crystallinity sample in both cases.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Total joint replacement (TJR) is a procedure in which osteoarthritis joints, such as the knee or hip, are surgically replaced with an artificial device (prosthesis). Researchers have estimated that the demand for TJR is expected to increase dramatically in the next 25 years. Though these procedures are common and generally successful, the life-span of a hip TJR with UHMWPE is often limited in patients, typically only 15-20 years. After awhile, the joints can become unstable and fail from material wear. In a hip prosthesis, a metallic femoral head component articulates with a polymer lined acetabular cup is embedded into the former hip socket. Ultra-high molecular weight polyethylene (UHMWPE) paired with a metal (cobalt-chrome or Titanium alloys) or ceramic (alumina or zirconia) are the most common combination of materials used in Total Hip Replacements (THR). Low friction and resistance to cracking make the polymer especially advantageous for enduring stresses occurring in the hip joint. However, the polymeric nature of UHMWPE makes it susceptible to wear, releasing tiny particles into the joint capsule, causing osteolysis which leads to aseptic loosening and eventual failure of the implant.

Friction and wear of the articulating metal on UHMWPE surfaces in TJRs have been recognized as critical factors affecting their durability and reliability. Specifically, the characteristics of the softer, polymeric material have become an important area of study to reduce the problem of material wear in hip replacements, without compromising its low-friction and high impact strength advantage. It has been documented that adhesive, abrasive, and fatigue are the primary mechanisms of wear in polymers. Studies have shown that a polymer's resistance to wear is directly related to its mechanical properties, which have been linked to the polymer's physical morphology, such as crystallinity. Energy caused by viscoelastic deformation is absorbed by shear yielding in the crystalline regions of polymers, where the lamellar structure unfolds and allows the energy to dissipate more efficiently than the amorphous regions where chain motion is restricted by entanglements. Hence, a higher degree of crystallinity should give higher elastic modulus, toughness, and elongation to break.

Researchers have shown increase in yield strength and elastic modulus of crosslinked UHMWPE with an increase in crystallinity. Increase in Young's modulus, yield strength, as well as hardness and fracture toughness have also been established through increasing crystallinity in UHMWPE independent of crosslinking. Studies compared mechanical properties of virgin, rod-stock UHMWPE to a pressure-induced high crystallinity UHMWPE, without the effects of crosslinking, and confirmed higher mechanical properties such as yield stress and elastic modulus corresponded to higher crystallinity. However, this material did not show significantly higher wear resistance.

Increasing the surface crystallinity of UHMWPE decreases the friction response of the polymer at both the microscale and nanoscale. Increased crystallinity also results in increase in hardness and Young's modulus. This review suggests that increasing the crystallinity of UHMWPE may be beneficial to the durability of a TJR that uses this polymer.

5.2 Recommendations

Although this review elucidates the relationship between processing treatments, microstructure, and mechanical behavior, our understanding is limited because many of the microstructural parameters are mystified. The relationship between mechanical properties and microstructural parameters needs to be investigated using computational modeling. Understanding the shortcomings of the current materials available in market and the relationship of mechanical performance to processing and microstructure through experimental and computational techniques, allows for significant improvements needed to produce materials and designs that can withstand meticulous in vivo performance and improve the longevity of total joint replacement.

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