Tribological behavior of graphene/UHMWPE-coated UHMWPE for arthroplastic applications

Andrei Ming-Xiao Chih
Outline

- Introduction
- Motivation
- Methodology
- Results and discussion
- Conclusions and future work
Introduction

Total Joint Arthroplasty

- Improves the quality of life of patients with joints damaged by disease or trauma
- Involves replacing a dysfunctional joint with an orthopedic prosthesis
- The majority of prostheses currently implanted consist of Metal-on-Polyethylene (M-o-P) or Ceramic-on-Polyethylene (C-o-P) bearing system

Source: Nature Reviews Rheumatology 7(10):600-8 · September 2011

THR

TKR
# UHMWPE characteristics

- Wear resistance
- Low coefficient of friction
- High toughness and stiffness
- Oxidative degradation
- Wear debris particles
- Osteolysis
- Aseptic loosening

<table>
<thead>
<tr>
<th>HXLPE (1st generation)</th>
<th>HXLPE (2nd generation)</th>
<th>Composite materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>High dose γ-irradiation + Thermal treatment</td>
<td>Vitamin E antioxidant</td>
<td>Carbon fiber reinforced UHMWPE</td>
</tr>
<tr>
<td>Enhanced wear resistance</td>
<td></td>
<td>Poly II®</td>
</tr>
<tr>
<td>Reduce oxidative degradation</td>
<td></td>
<td>Generally, short-term clinical failures</td>
</tr>
<tr>
<td>Decreased mechanical properties</td>
<td></td>
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</table>
Objective

- Develop a composite material as a potential alternative to HXLPE to extend the lifespan of the artificial joints

- Coating: improve the mechanical and tribological properties of the bearing surface while preserving the ones of the raw UHMWPE

- Graphene-based composite material
  - Young modulus 0.5-1 TPa
  - Tensile strength 130 GPa
  - Tribological potential as a lubricant
  - Biocompatibility
Composite materials coatings

- **Matrix:** UHMWPE GUR1050 medical grade resin

- **Fillers:**
  - avanPLAT-40 Graphene multiplatelet (<30 layers)
  - avanGRAPHENE 1-2 layers

<table>
<thead>
<tr>
<th></th>
<th>0.1 % wt</th>
<th>0.3 % wt</th>
<th>0.5 % wt</th>
<th>1 % wt</th>
<th>1% wt T240</th>
</tr>
</thead>
<tbody>
<tr>
<td>avanPLAT-40</td>
<td></td>
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<tr>
<td>avanGRAPHENE 1-2</td>
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</tr>
</tbody>
</table>

- **Spray-painting coating:** 50 mg avanPLAT-40

**Consolidation method:** Hot press moulding at

- Pressure 15 MPa
- Temperature: 175°C (T-175) and 240°C (T-240)
- Time: 30 minutes
Morphological characterisation

1% GR-T175

1% GR-T240

Composite Coating

SP-T175

Spray coating

Ra ≈ 1μm
Chemical characterisation

Raman spectroscopy

Graphene (G), Graphene R (GR), 1%wt Graphene R (1%wt GR), and UHMWPE (UHMWPE) are shown in the spectroscopic graphs. The spectra display absorbance against wavenumber (cm$^{-1}$) with peaks at specific ranges indicating the vibrational modes of the materials.
Chemical characterisation

- **D-band (1380 cm\(^{-1}\))**
- **G-band (1590-1620 cm\(^{-1}\))**
- **2D-band (2700 cm\(^{-1}\))**
Results

**Tribometer: Ball-on-disc → Coefficient of friction**

- Load: 5 N
- Lubricant: distilled water
- Radius: 4 mm
- Linear velocity: 0.03 m/s
- Ball: Al₂O₃ d=6 mm
- Disc: d=20 mm

**Influence of %wt GR**

![Graph showing the coefficient of friction over distance for different GR concentrations.](image-url)
Results

Coefficient of friction

Influence of type of GR

Influence of consolidation temperature
Results

Coefficient of friction

Influence of coating type

![Graph showing the coefficient of friction over distance](image)

- **GUR1050+50mg_GR_r4mm**
Results

Nanoindentation test

<table>
<thead>
<tr>
<th>Material</th>
<th>Elastic modulus (GPa)</th>
<th>Hardness (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GUR 1050</td>
<td>1,1 ± 0,1</td>
<td>0,05 ± 0,01</td>
</tr>
<tr>
<td>GUR 1050 +0,1% GR</td>
<td>1,2 ± 0,3</td>
<td>0,06 ± 0,02</td>
</tr>
<tr>
<td>GUR 1050 +0,3% GR</td>
<td>1,2 ± 0,1</td>
<td>0,07 ± 0,02</td>
</tr>
<tr>
<td>GUR 1050 +0,5% GR</td>
<td>1,2 ± 0,2</td>
<td>0,07 ± 0,02</td>
</tr>
<tr>
<td>GUR 1050 +1% GR</td>
<td>1,3 ± 0,3</td>
<td>0,07 ± 0,02</td>
</tr>
<tr>
<td>GUR 1050 +1% GR 1-2 layer</td>
<td>1,2 ± 0,3</td>
<td>0,06 ± 0,03</td>
</tr>
<tr>
<td>GUR 1050 +1% GR T240</td>
<td>1,3 ± 0,3</td>
<td>0,07 ± 0,02</td>
</tr>
<tr>
<td>GUR 1050 + 50mg GR</td>
<td>1,0 ± 0,2</td>
<td>0,04 ± 0,01</td>
</tr>
</tbody>
</table>

- +18% Elastic modulus
- +40% Hardness

Enhanced wear resistance

\[ V = \frac{k' \cdot F_n \cdot x}{3 \cdot H_{softer \ component}} \] (adhesive wear)
Conclusions

- Graphene nanoplatelets (GNP) enhances the mechanical properties of the UHMWPE surface
- GNP presents better tribological behaviour than 1-2 layered graphene
- Spray-coated material performs the best coefficient of friction, yet lower stability of the layer

Future work

- Evaluate the wear rate of the composite materials
- Improve the graphene/UHMWPE mix by surfactant addition
- Increase the graphene %wt of composite coating
This project has been developed in GBM Biomaterials Group of Zaragoza University, leaded by Prof. Dr. J.A. Puértolas, and ICB-CSIC (Dr. A. Ansón-Casaos)