Tribological behaviour of DLC and Si-DLC films deposited on nitrile rubber for piston seals

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Sustainable handpump technologies
About 1 billion people do not have access to safe water; with sub-Saharan Africa accounting for about 33% [JMP Report, 2010].
Water Situation – Makondo Parish

Less than one-third of the handpumps were functional
### Handpump Component Repairs

#### Percentage of repairs for handpump components

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage of Repairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other</td>
<td>20%</td>
</tr>
<tr>
<td>Foot valve</td>
<td>15%</td>
</tr>
<tr>
<td>Pumping element</td>
<td>10%</td>
</tr>
<tr>
<td>Piston seal</td>
<td>25%</td>
</tr>
<tr>
<td>Rising main</td>
<td>15%</td>
</tr>
<tr>
<td>Pump rod</td>
<td>10%</td>
</tr>
<tr>
<td>Rod hanger</td>
<td>5%</td>
</tr>
<tr>
<td>Bearings</td>
<td>10%</td>
</tr>
<tr>
<td>Handle</td>
<td>10%</td>
</tr>
</tbody>
</table>

[Bar chart showing the percentage of repairs for each handpump component]
Dry and Wet Sliding

- Direction of motion (reciprocating)
- Cylinder
- Connecting Rod
- Plunger Yoke body
- Piston Seals
- Upper valve guide
- Dry Sliding
- Check valve guide
- Wet Sliding

Direction of motion (reciprocating)
Wear Mechanisms

\[ V_{wear\_total} = V_{abrasive\_wear} + V_{adhesive\_wear} + V_{fatigue\_wear} \]
Functional Sustainability

• Handpump reliability is defined as mechanical availability [Reynolds, 1992]

• A trade off has to be made between reliability and maintainability

• Maximum pump functionality; minimal number of maintenance interventions

• Increased pump availability through longer operation time of the seal [Aspegren et al. 1987]
Surface Engineering Approach

The systems in place are not altered:

1. Labour
2. Training
3. Design, development and manufacturing
4. Supply chain systems
Research Objectives

- To quantify field and user operating conditions relating directly and indirectly to piston seal failure
- To deposit DLC and Si-DLC films, with and without Si-C interlayers onto NBR substrates and actual piston seals using an industrial closed field unbalanced magnetron sputtering ion plating (CFUBMSIP) rig.
- To characterise the structural and mechanical properties; and tribological behaviour of DLC and Si-DLC films, with and without Si-C interlayers deposited on NBR substrates
- To determine the wear mechanisms of actual piston seals coated with DLC and Si-DLC films, with and without Si-C interlayers, using a purposely designed and developed test rig.
Coating Process Design

Diagram showing different layers and thicknesses:
- DLC
- Si-DLC
- Si-C Interlayer
- NBR SUBSTRATE
CFUBMSIP

- Field lines “closed” with another magnetron
- Plasma confined around substrates
- Electrons and ion loss to chamber walls minimised
- Possibility to produce low temperature coatings
- Dense, non-columnar, adherent coatings
- Coating deposition is carried out using a high density of low energy bombarding ions
- Teer Coatings UK (Miba coating group)
CFUBMSIP Sputtering Rig and Interior Set-up
# Coating Deposition Parameters

<table>
<thead>
<tr>
<th>Coating Type</th>
<th>Ion process</th>
<th>Clean Ar (sccm)</th>
<th>C(<em>4)H(</em>{10}) (sccm)</th>
<th>C (A)</th>
<th>Si (A)</th>
<th>Bias (V)</th>
<th>Coating time (min)</th>
<th>Coating time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLC</td>
<td>200V for 10 min</td>
<td>12</td>
<td>8</td>
<td>2</td>
<td>0</td>
<td>30</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Si-DLC</td>
<td>200V for 10 min</td>
<td>12</td>
<td>8</td>
<td>2</td>
<td>0.5</td>
<td>30</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Si-DLC with Si-C interlayer</td>
<td>200V for 10 min</td>
<td>12</td>
<td>8</td>
<td>2</td>
<td>0.5</td>
<td>30</td>
<td>35 for Si-C/ 40 for DLC</td>
<td>40 for DLC</td>
</tr>
<tr>
<td>DLC with Si-C interlayer</td>
<td>200V for 10 min</td>
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Raman Spectra

![Raman Spectra Graph](image)

- DLC coated on NBR
- Si-DLC coated on NBR
- DLC coated on NBR with SiC interlayer
- Si-DLC coated on NBR with SiC interlayer

Intensity (Arb. units)

Raman Shift (cm$^{-1}$)

G-peak

D-peak
Surface Morphology

- DLC
- Si-DLC
- DLC with Si-C
- Si-DLC with Si-C
Coefficient of Friction – Dry Sliding, 1 N
Wear Analysis

DLC

Si-DLC

DLC with Si-C

Si-DLC with Si-C
Piston Seal Wear Test Rig
Piston seal testing - context

- Average number of strokes to fill 20 l container = 115 strokes
- Test rig set up to fill a 20 l container in 113 strokes
- Water delivered during one half of stroke = 57 mm in test rig design
- For 100000 strokes (24 hour testing regime), 17768 l delivered
- This test period covers 1776 10 l containers
Coated Piston Seals Before Wear Testing (side)
Coated Piston Seals After Wear Testing

Top
- DLC (a)
- Si-DLC (b)
- DLC with Si-C (c)

Lower
- DLC (d)
- Si-DLC (e)
- DLC with Si-C (f)
Conclusion

- DLC and Si-DLC films with and without Si-C interlayers were deposited onto nitrile rubber and actual piston seals using CFUBMSIP.
- This Surface Engineering approach offers a method for reducing the wear rate of piston seals.
- Various characterisation techniques have been successfully applied.
- Wear testing on actual coated piston seals on-going.
Acknowledgement

• Water is Life Project
• Irish Aid
• HEA
• Dublin City University
• Makerere University
Publications


Questions

Thank You