Evaluation of surface degradation under cyclic loading conditions

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Eurecat is the major Technology Centre of Catalonia, in Spain, and the result of the integration, since the 1st May 2015, of the most important Catalan technology centers.
Our R&D activities focus on the development of high performance materials solutions, to obtain LIGHTWEIGHT / RESISTANT materials and FUNCTIONAL SURFACES able to withstand severe mechanical and environmental requirements.

- Cold forming
- Cutting technologies
- Hot stamping
- HPDC of light alloys
- Casting
- Forging
- Tooling

- Fatigue, fracture
- Tribology
- Corrosion
- Formability
- Micromechanical properties

- Advanced microstructural characterization (OM, FE-SEM, EDX, EBSD)
- Second phase particles, microtextures, density of dislocations, crystallography, recrystallization degree
Advanced Solutions for LIGHTWEIGHTING and high MATERIALS PERFORMANCE

- Mechanical Behaviour, Fracture and Fatigue
- New Processes for Advanced Materials
- Light Alloys Casting

Customized FUNCTIONAL SURFACES for harsh environments

- Corrosion & Degradation
- Tribology: Wear, Friction and Lubrication
- Surface Technology & Coatings
Tribology is focuses on friction, wear and lubrication of interacting surfaces in relative motion.

R&D Activities

- Wear & Friction
- Wear resistance materials
- Abrasives & Sacrificial materials
- Enhancement of adhesion

Tribology Research line
Tribology Research line

R&D Projects

Industrial Process

Damage mechanisms characterization

Optimization

Analysis of results

Lab Tests Design

- HERMES
- GEOFIT
- HARSHWORK
- eit Raw Materials
- LUBRINTEL
- AVINT RIS3CAT
- ALUTOOL
- TECNIO spring
- forma
Why fatigue wear is important in mining and mineral handling?
Optimizing raw material handling and processing under harsh working conditions.

Identification of the most relevant degradation mechanisms and relevant mechanical properties subjected to severe wear conditions.

Obtain wear rates for different materials, as raw material handling processing and urban waste management

- Field inspection: damage characterization of components

Lab tests design wear & friction test, contact fatigue.
The main damage mechanisms

Buttons extracted from a bucket shell

High-chromium white cast iron

Button microstructure
- Fe-Cr carbides
- Martensite
The main damage mechanisms

- Large cracks
- Chipping
- Micro-deformations due to impacts
- Micro-spalling

Buttons extracted from a bucket shell

Cross-sectioned view
• The main damage mechanisms

- Surface crack initiation
- Sub-surface crack propagation
- Secondary crack initiation
- Propagation to spalling formation

Fatigue wear!

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- **Contact fatigue (at different scales)**

- Indenters: 20 µm to 28 mm of diameter
- Sample size: less than 40 mm (diameter) or 40 x 40 mm
- Different pressure levels
- No. of cycles: between 1 up to $10^6$ cycles
- Maximum shear stress can be adapted as a function of applied load

R&D Activities

- **Mining**

  - Large carbides
  - Carbides + metal matrix
  - Agglomerates

  - Micro
  - Meso
  - Macro

  - Load (gr)
  - No. of cycles

  - Max. shear stress

  - Load (gr)
  - No. of cycles
**Contact Fatigue**

- **Monotonic tests**
  - Spherical indenter: Diameter = 2.5 mm
  - Frequency: 20 Hz
  - Hardmetal
  - Load: \( P_{\text{max}} = 1000 \text{ N}, 2500 \text{ N} \) and 5000 N

- **Cyclic test**
  - Frequency: 20 Hz
  - Number of cycles: 1 cycle, 1000 cycles, 10 000 cycles, 100 000 cycles

**R&D Activities**

**Mining**

- **Circumferential cracks**
- **Radial cracks**
- **Spalling/chipping**

**Servohidraulic testing machine**

- **Spherical indenter:** Hardmetal
- **Frequency:** 20 Hz
- **Number of cycles:**
  - 1 cycle
  - 1 000 cycles
  - 10 000 cycles
  - 100 000 cycles

**Samples extracted from components**

- **40 x 40 mm**
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- Lab tests design

High-chromium white cast iron

White cast 1

White cast 2
Lab tests design

- White cast 1: High-chromium white cast iron
  - Radial cracks
  - Broken carbides

- White cast 2
  - Radial cracks
  - Broken carbides + metal matrix crack propagation
Adapt drilling techniques in geothermal based retrofitting in urban environment.

Improve drilling parameters, tool performance and selection of materials to reduce tool damage and maintenance.

(i) reduce drilling times
(ii) improve rate of penetration (ROP)
(iii) improve abrasion and chipping/spalling resistance of drill bit

- Identify main damaging mechanisms (wear mechanisms and patterns) of representative drilling tools employed in industrial drilling operations.

- Wear tests design at laboratory level in order to reproduce the same identified wear mechanisms.
Identify main damaging mechanisms

Conglomerates of quartz (quite common in Catalonia)

Drill bit

Segment of tricone

Button

Hardmetal
Tribology Research line

• Identify main damaging mechanisms

<table>
<thead>
<tr>
<th>Properties</th>
<th>Drill bit buttons</th>
<th>Tricone buttons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness (HV30)</td>
<td>1444 ± 17</td>
<td>1162 ± 23</td>
</tr>
<tr>
<td>Grain size (µm)</td>
<td>1.4 ± 0.6</td>
<td>1.4 ± 0.5</td>
</tr>
<tr>
<td>Cobalt content (wt %)</td>
<td>7</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Hardmetals
• Co-based binder
• WC carbides
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• Identify main damaging mechanisms

<table>
<thead>
<tr>
<th></th>
<th>(a) Micro-cracking</th>
<th>(b) Detachment of grains</th>
<th>(c) Crushing, reptile skin</th>
<th>(d) Detachment of fragments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill bit button</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
</tr>
</tbody>
</table>

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• Contact Fatigue

Monotonic tests

Cyclic test

Servohidraulic testing machine

Spherical indenter:

Diameter = 2.5 mm

Hardmetal

Load:

P_{max} = 400 N, 1000 N, 2000 N and 3600 N

Frequency:

20 Hz

Number of cycles:

1 cycle

100 000 cycles

Drill buttons  Tricone buttons  Sample 1  Sample 2

Samples extracted from components

10 x 10 mm
• Lab tests design

Hardmetals

<table>
<thead>
<tr>
<th>Drill Bit</th>
<th>400 N at 10^5 cycles</th>
<th>1000 N at 10^5 cycles</th>
<th>2000 N at 10^5 cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tricone</td>
<td><img src="Hardmetal1.jpg" alt="Image" /></td>
<td><img src="Hardmetal2.jpg" alt="Image" /></td>
<td><img src="Hardmetal3.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Sample 1</td>
<td><img src="Hardmetal4.jpg" alt="Image" /></td>
<td><img src="Hardmetal5.jpg" alt="Image" /></td>
<td><img src="Hardmetal6.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Sample 2</td>
<td><img src="Hardmetal7.jpg" alt="Image" /></td>
<td><img src="Hardmetal8.jpg" alt="Image" /></td>
<td><img src="Hardmetal9.jpg" alt="Image" /></td>
</tr>
</tbody>
</table>

- Contact fatigue test allowed to evaluate the susceptibility of the Hardmetals to cyclic loading conditions.
- Sample 1 seems to be no susceptible to Radial Cracks appearance.
Roller on Roller test configurations is used for friction, fatigue and wear testing of materials that experience rolling and sliding.

- High load units (1000 N)
- Speed up to 2000 rpm
- Lubricant cup (RT or 120 °C)
- Pure rolling (100 % slip), sliding / rolling and pure sliding (0% slip).
- The experiments can be conducted in lubricated or dry state.

Multifunctional system
**R&D Activities**

**Mining**

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- **Fracture analysis**

- **Compression test**
  - Fracture analysis
  - Compression test: Fracture resistance of pellets
  - Multi-impact test: Wear resistance of pellet and material transportation (i.e. conveyors)
  - Size & Morphology: Wear Quantification

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**Pellets characterization**

- Damage mechanisms under industrial conditions
- Compression test: Fracture resistance of pellets
- Multi-impact test: Wear resistance of pellet and material transportation (i.e. conveyors)
- Size & Morphology: Wear Quantification

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**Morphology & Size after impact test**

- Number of pellets vs. Average diameter (mm)
• **Particles damage mechanisms**

Four main damage mechanisms of particles [1]:

1. **Fragmentation** is fracture due to normal force. The local stresses generated beneath the contact area generates the splitting of the granule into several parts.

2. **Chipping** is fracture caused by tangential forces. The granule loses large fragments leading to a rougher surface. The decline in mass is less drastic than the Fragmentation mechanism.

3. **Abrasion** is wear caused by low magnitude tangential force. Shearing of a granulate causes the generation of fine particles and the mother particles become spherical and smoother with time.

4. **Attrition** is wear caused by low magnitude normal forces acting on a particle, which results in the removal of sharp edges, producing more spherical shape.

Damage mechanisms of iron ore pellets

- Fragmentation
  - Compression Test (Monotonic & Cyclic)
- Chipping
  - Contact Fatigue
- Abrasion
  - Multiple impact test
- Attrition
  - Multiple impact test
• **Multiple Impact Test**

Parameters:
- Evaluated samples: 10 pellets
- Average diameter: $12.4 \pm 0.4$
- Cyclic sinusoidal waveform
- Displacement control.
- Displacement amplitude:
  - $10 \text{ mm}$
- Frequency: $15 \text{ Hz}$

The number of impacts can be calculated as:

$$2 \times t \times f \quad [3]$$

$t = \text{time}$

$f = \text{frequency}$. 

Initial and final pellets characterization

- Characterization of 100 pellets:
  - Three images were acquired by stereoscopic microscope.

- Particle analysis software to acquire:
  a) Equivalent Diameter
  b) Feret Max & Min
  c) Sphericity
  d) Shape factor
  e) Mean Diameter
• Damage evolution of iron ore pellets
• Why multiple impact test?

• Relation of intrinsic defects with wear damage mechanisms

Particle with high grade of sintering: Transgranular fracture

Particle with middle grade of sintering: Intergranular fracture

Particle with poor grade of sintering
Why is multiple impact test?

- Quality evaluation of pellets obtained from different production batches.

- Evaluation of iron ore pellets properties at different production line stations:
  - At the end of Pelletizing process
  - At different stages during the transport (at the end of silos, conveyors, wagons, etc.)
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**R&D Activities**

**Mining**

**Surface improvement**: to develop a novel coating for the interior surface of cargo wagons.

**Reduction of friction coefficient** (leading to an increase of bulk discharge speed at terminals), but at the same time, it must show **high resistance to abrasion and corrosion due to potash**.

- **Field tests**: replicas system, loading & unloading inspection, pressure sensors.
- **Lab tests design**: abrasion test, roughness measurements, friction.

**Field tests**

**Pressure sensors**

**Topography inspection**

**Lab tests**

**Abrasion test**

**Roughness**

**Coefficient of Friction**
Thank you for your attention!!!