HARD ROCK TRIBOLOGY SEMINAR

eurecat
Centre Tecnològic de Catalunya

"innovando con las empresas"

Evaluation of surface degradation under cyclic loading conditions

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12th TWC International Wear Seminar on March 18th 2021

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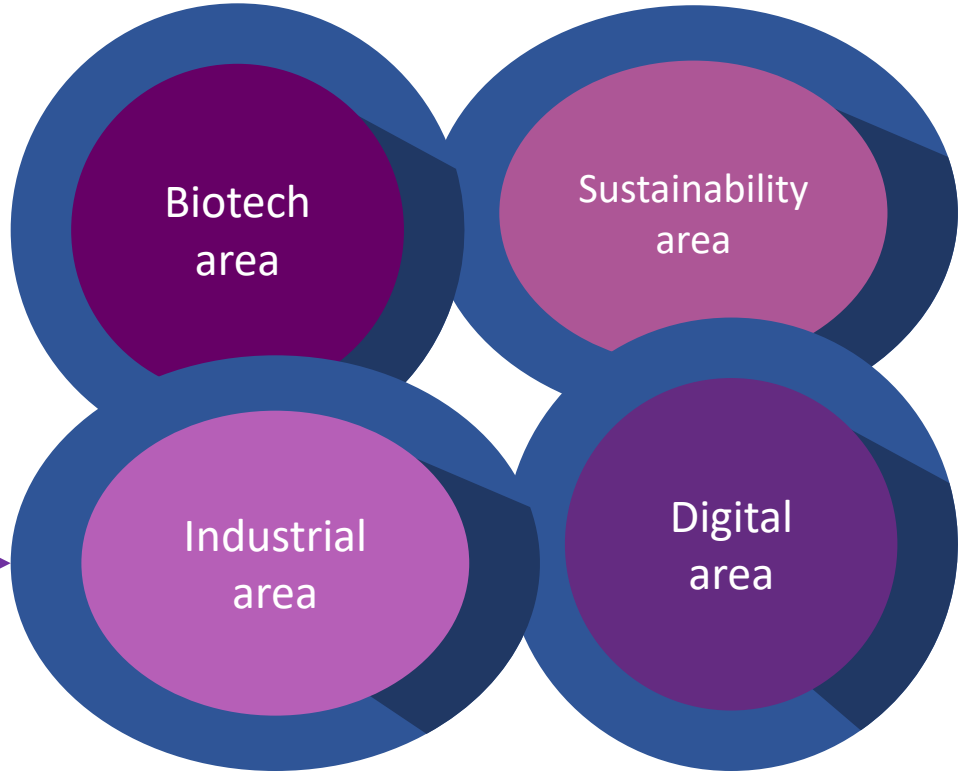
Centre Tecnològic de Catalunya

Corporate offices

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.

Metallic and Ceramic Materials Unit



Barcelona, Cerdanyola, Girona, Lleida, Manresa Mataró, Reus, Amposta

Metallic and Ceramic Materials Unit

R&D Activities

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.

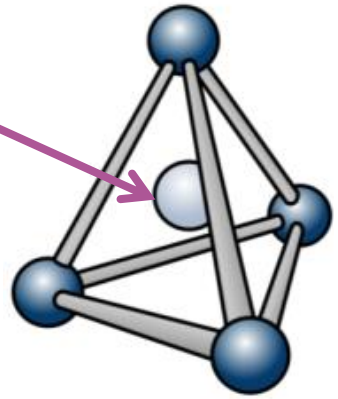
ADVANCED CHARACTERIZATION

BEHAVIOUR

- Part performance prediction
- Evaluation of mechanical damage
- Part performance assessment by NDT

FORMING

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



PROPERTIES

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

MICROSTRUCTURE

- Advanced microstructural characterization (OM, FE-SEM, EDX, EBSD)
- Second phase particles, microtextures, density of dislocations, crystallography, recrystallization degree

Metallic and Ceramic Materials Unit

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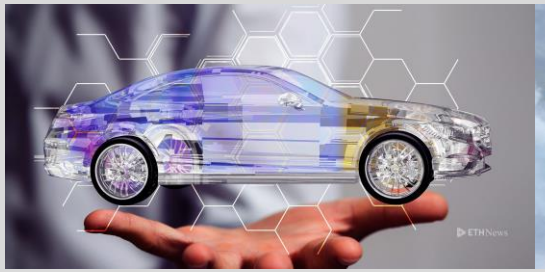
R&D Activities

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 Research line

R&D Activities

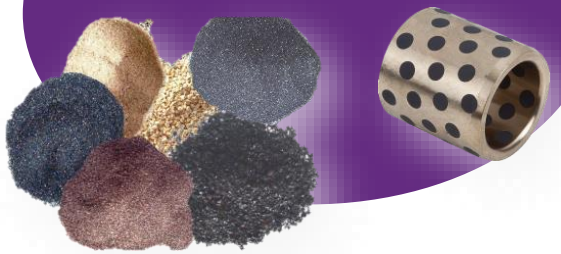
Tribology is focuses on friction, wear and lubrication of interacting surfaces in relative motion

Wear & Friction

Surface coatings & lubrication

Wear resistance materials

Abrasives & Sacrificial materials



Enhacement of adhesion

Tribology Research line

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R&D Projects

HERMES

GEOFIT SMART GEOTHERMAL

HARSHWORK

eit RawMaterials

AVINT

RIS3CAT Indústries del futur

ALUTOOL

LUBRINTEL

TECNIOspring Tech transfer through researchers' mobility

forma

Industrial Process

Damage mechanisms characterization

Lab Tests Design

Analysis of results

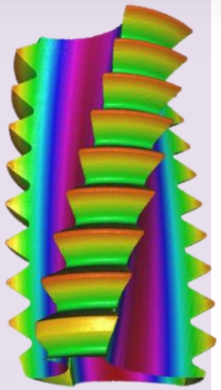
Optimization

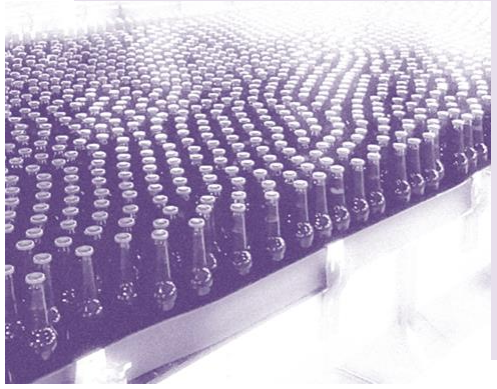
Tribology

Tribology Research line

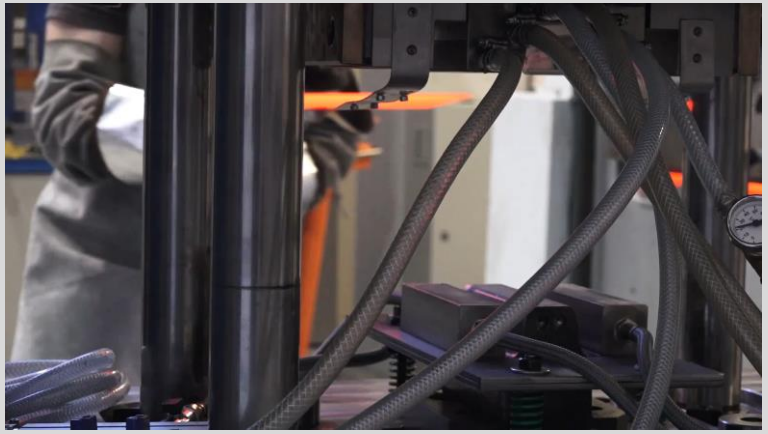
R&D Activities

Field test

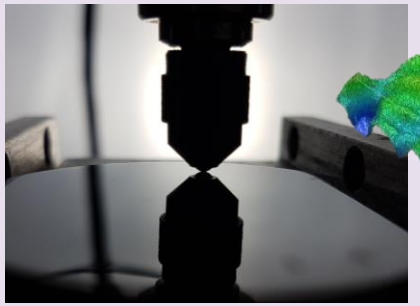


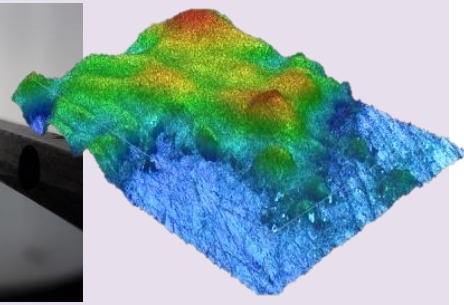


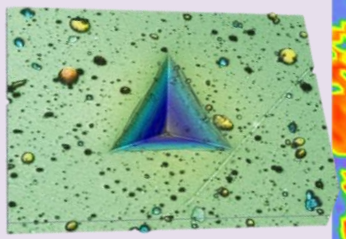
Pilots

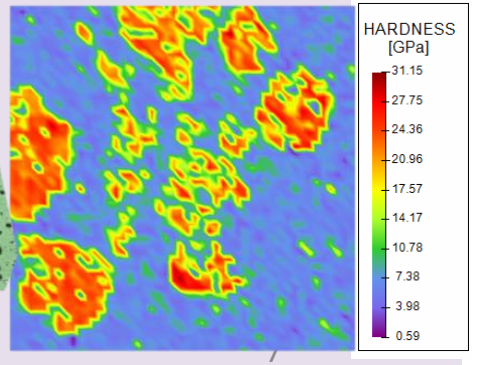


Lab test design









Why fatigue wear is important in mining and mineral handling?

Tribology Research line

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R&D Activities
Mining

HARSHWORK RawMaterials

Bucket shell

Buttons

NEW BOLIDEN

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.

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R&D Activities

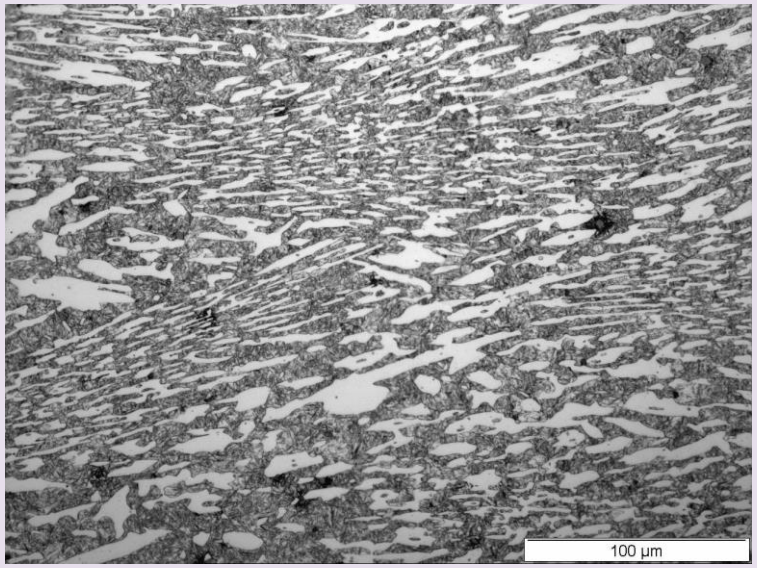
Mining

HARSHWORK RawMaterials

- **The main damage mechanisms**

Buttons extracted from a bucket shell

High-chromium white cast iron



Button microstructure

- Fe- Cr carbides
- Martensite

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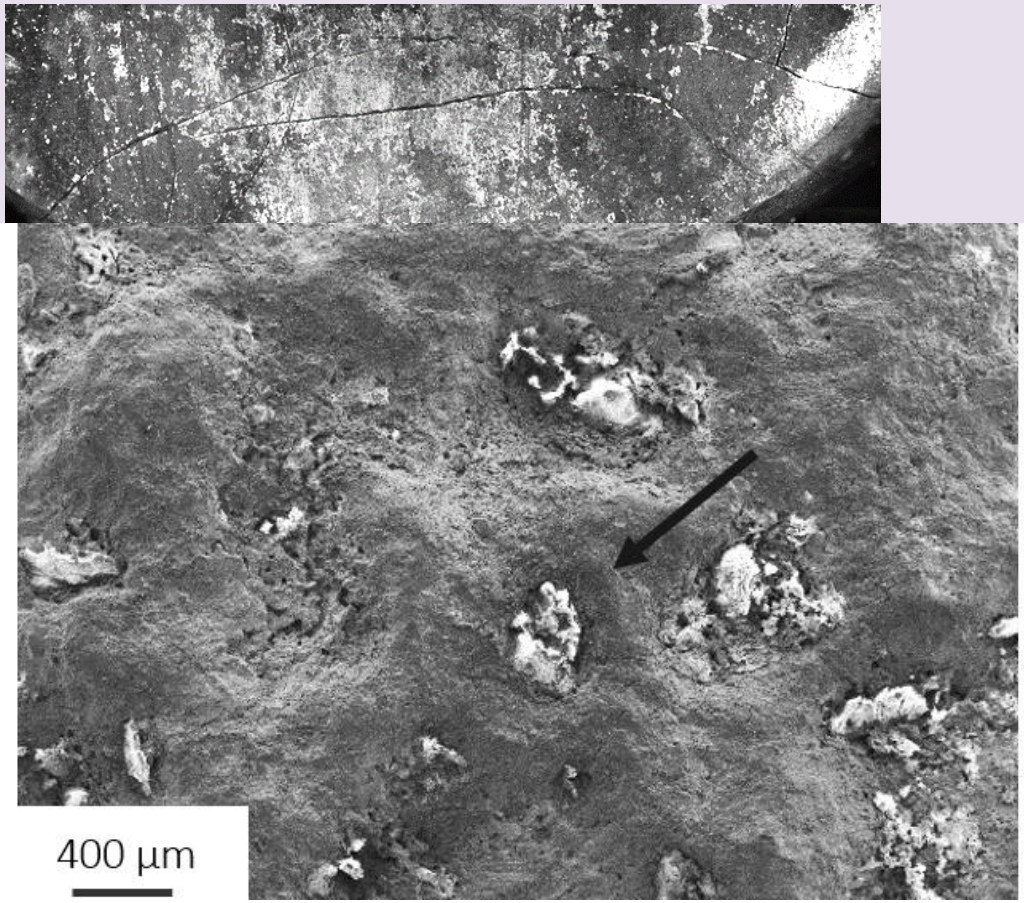
R&D Activities

Mining

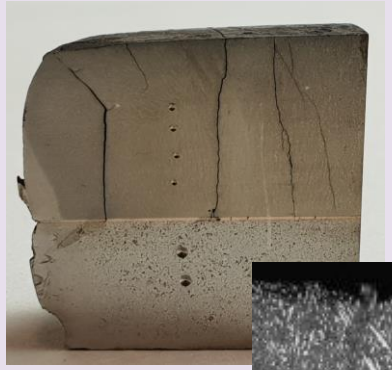
HARSHWORK RawMaterials

- **The main damage mechanisms**

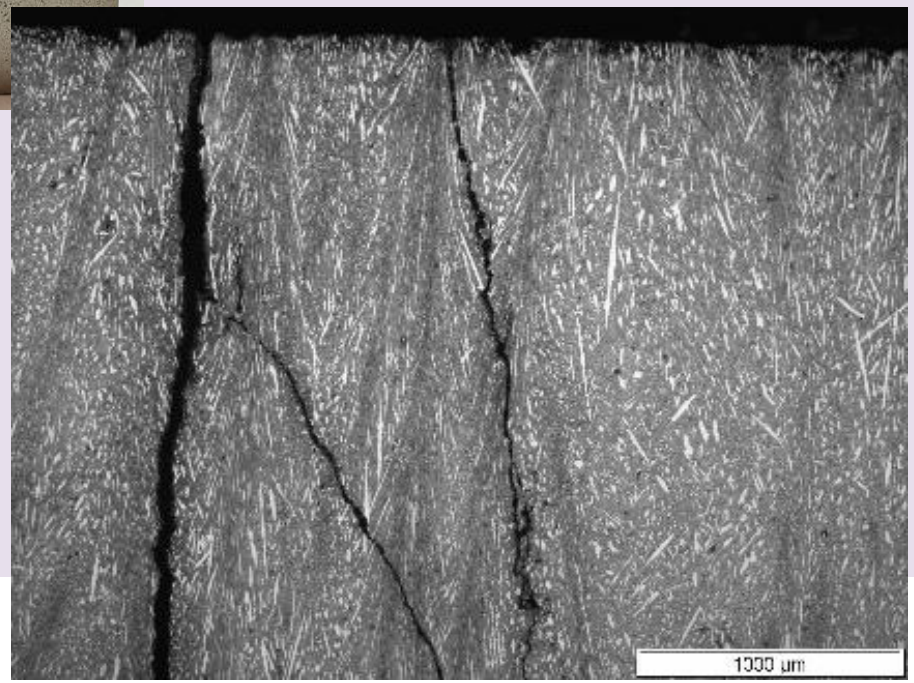
Surface view



Buttons extracted from a bucket shell



Cross-sectioned view



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

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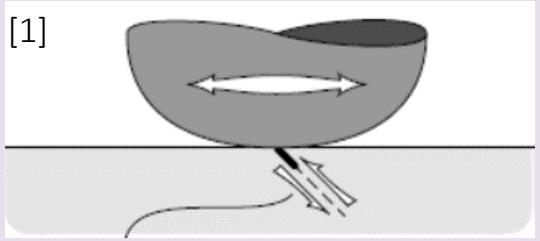
R&D Activities

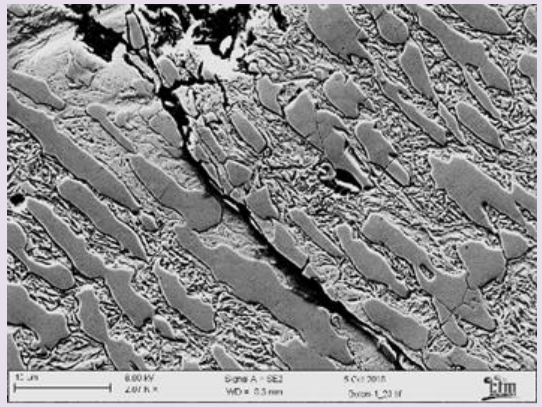
Mining

HARSHWORK RawMaterials

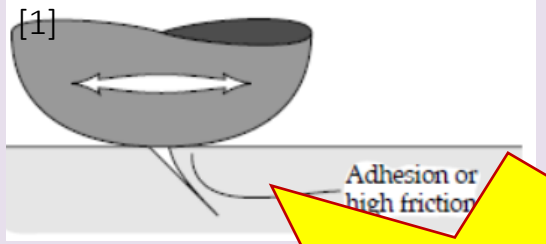
- **The main damage mechanisms**

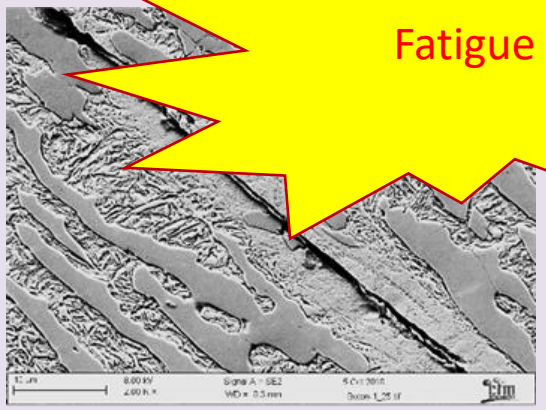
Surface crack initiation



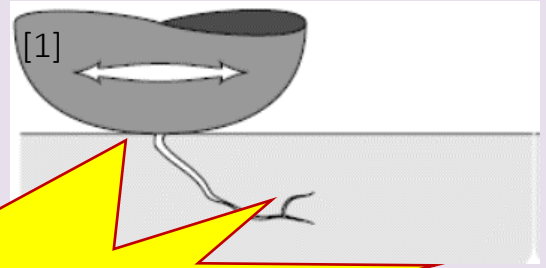


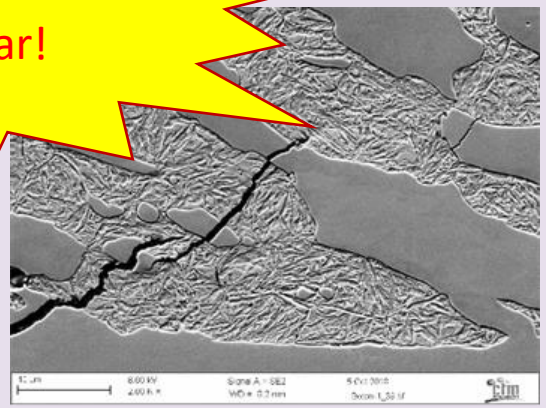
Sub-surface crack propagation



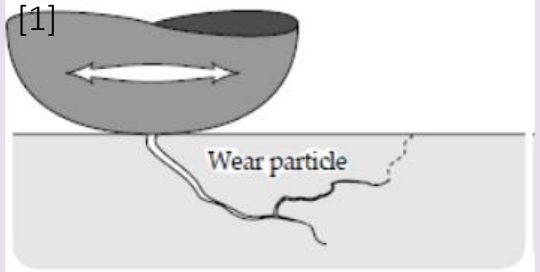


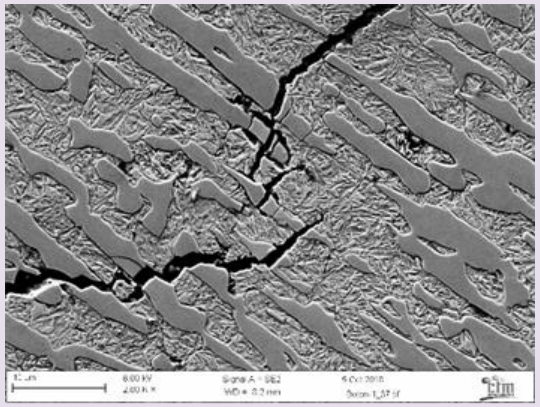
Secondary crack initiation





Propagation to spalling formatic





Fatigue wear!

[1] G. W. Stachowiak and A. Batchelor, Engineering Tribology, Boston: Butterworth-Heinemann, 2001

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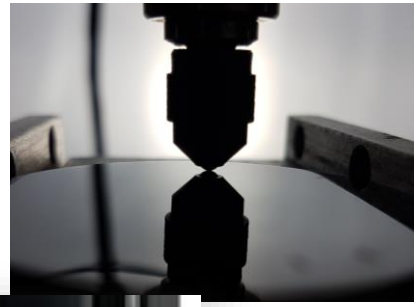
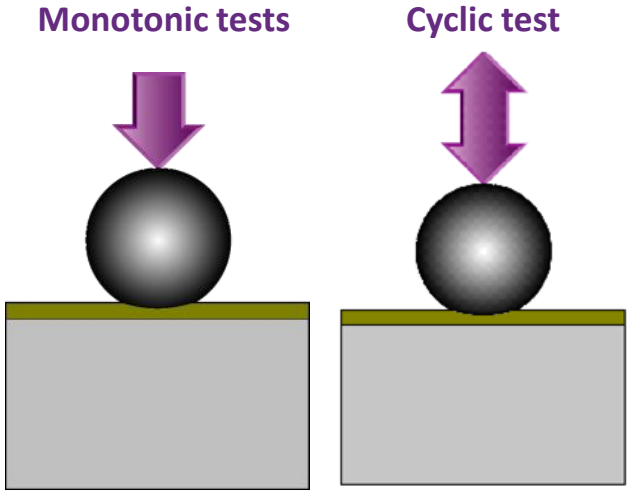
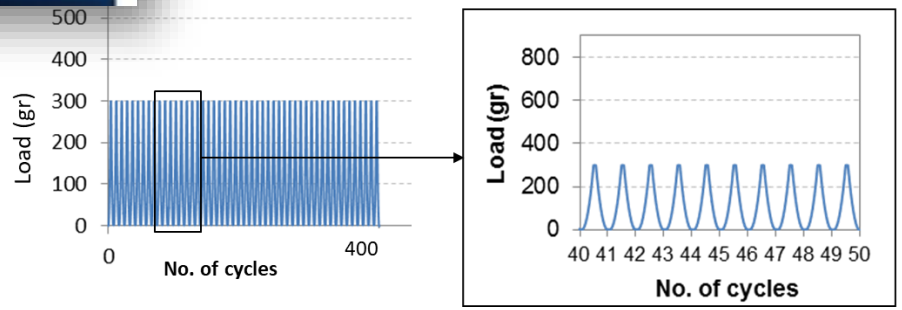
R&D Activities
Mining

- *Contact fatigue (at different scales)*





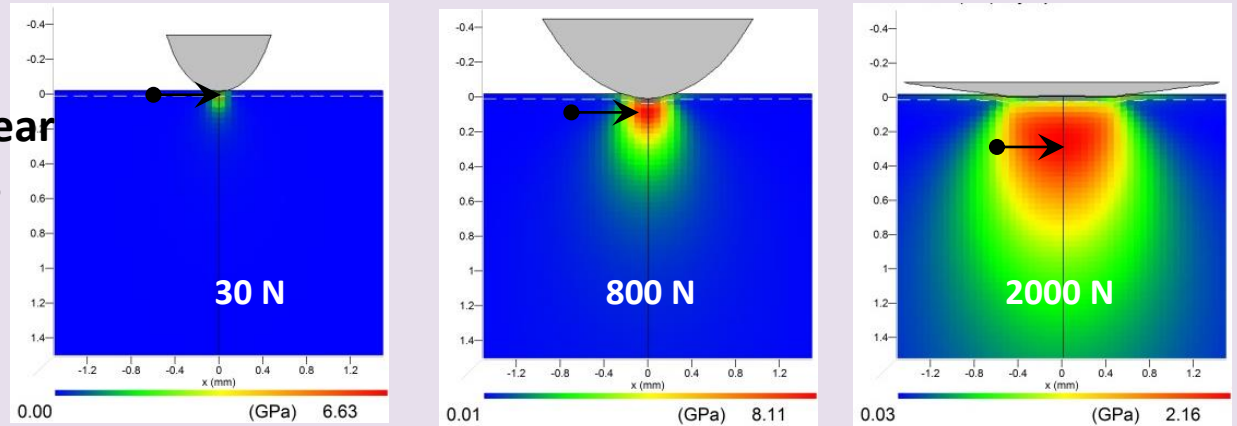


- Indenters: 20 µm to 28 mm of diameter
- Sample size: less than 40 mm (diameter) or 40 x 40 mm
- Different pressure levels
- No. of cycles: between 1 up to 10^6 cycles
- Maximum shear stress can be adapted as a function of applied load

Micro → Meso → Macro

Max. shear stress

Large carbides | Carbides + metal matrix | Agglomerates



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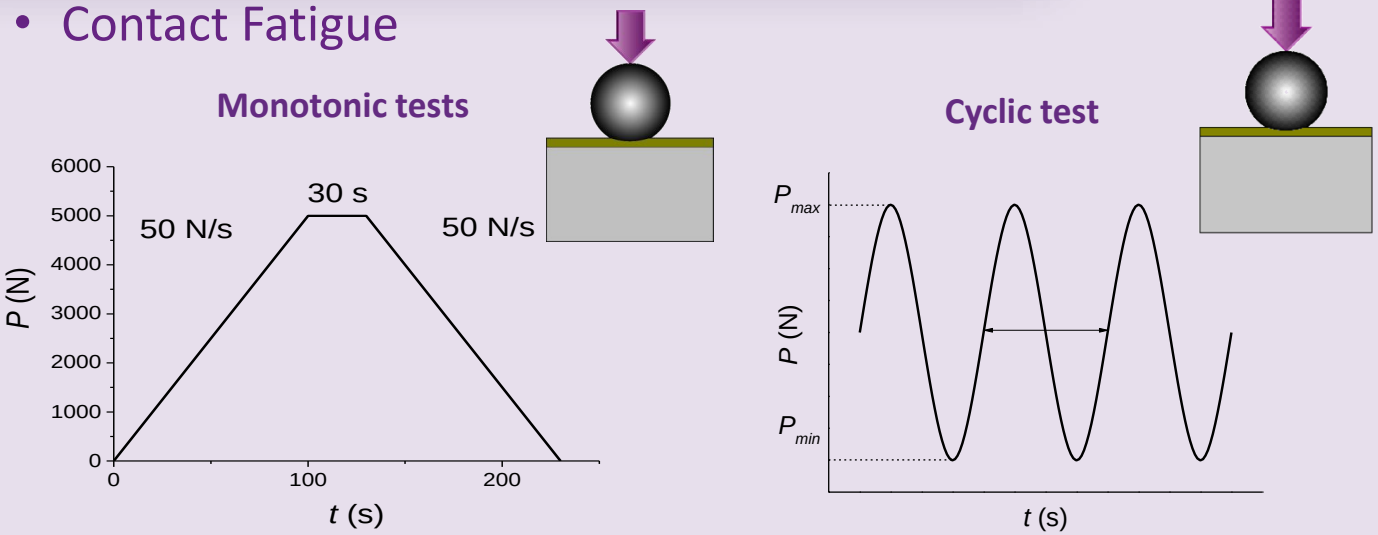
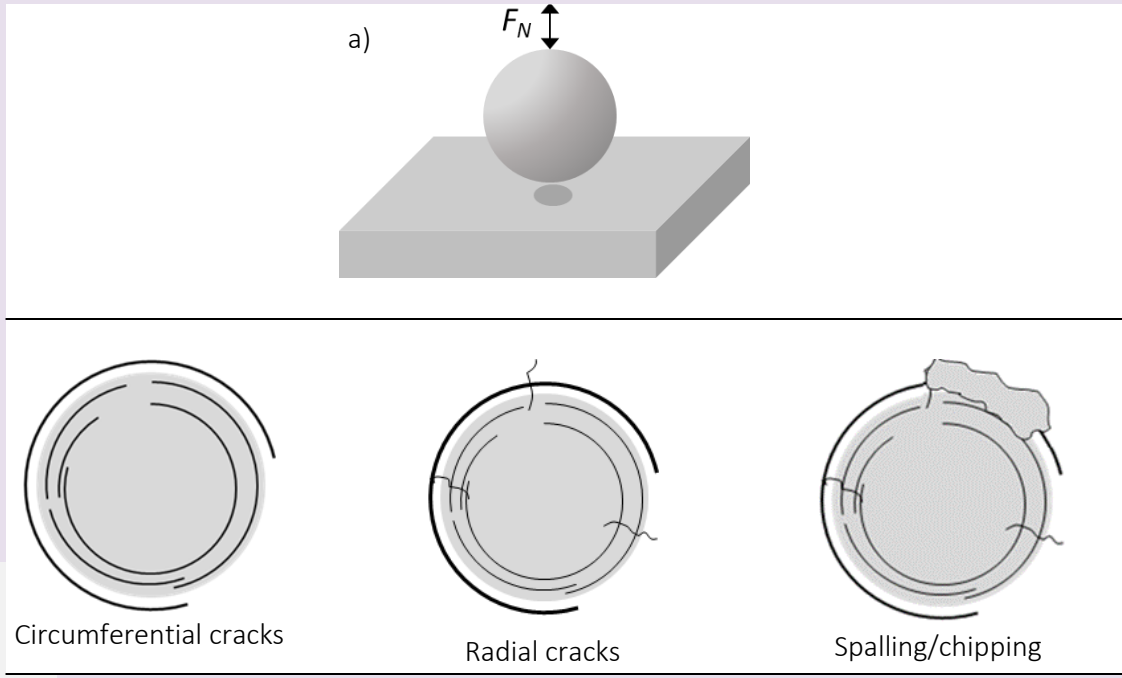
R&D Activities
Mining

- Contact Fatigue





Servohidraulic testing machine

Spherical indenter:

Diameter = 2.5 mm
Hardmetal

Load:

Pmax = 1000 N, 2500 N and 5000 N

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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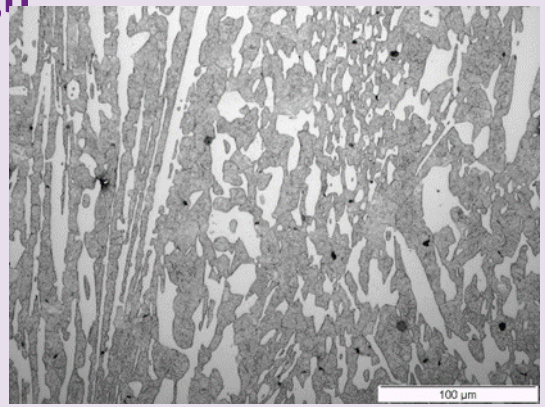
R&D Activities
Mining

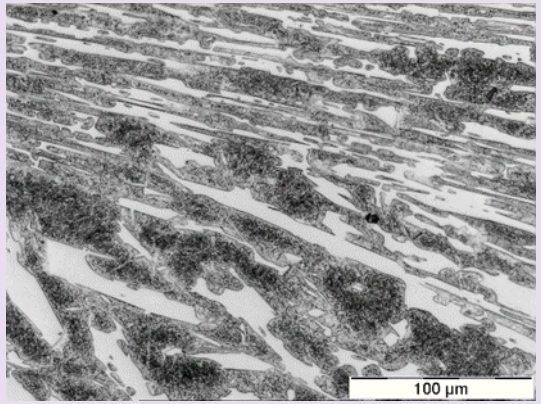
- **Lab tests design**

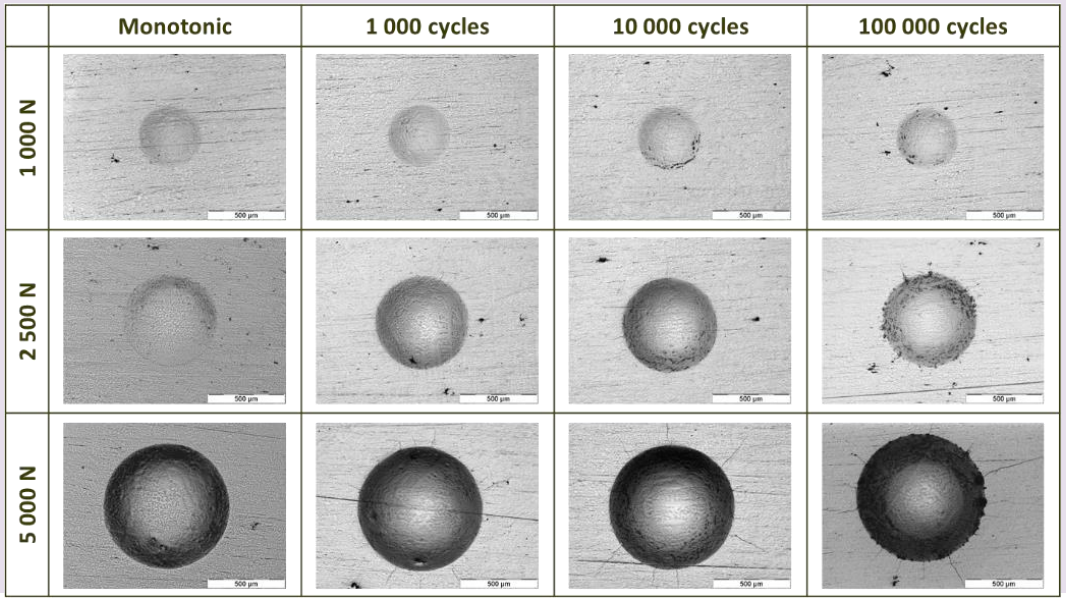
High-chromium white cast iron

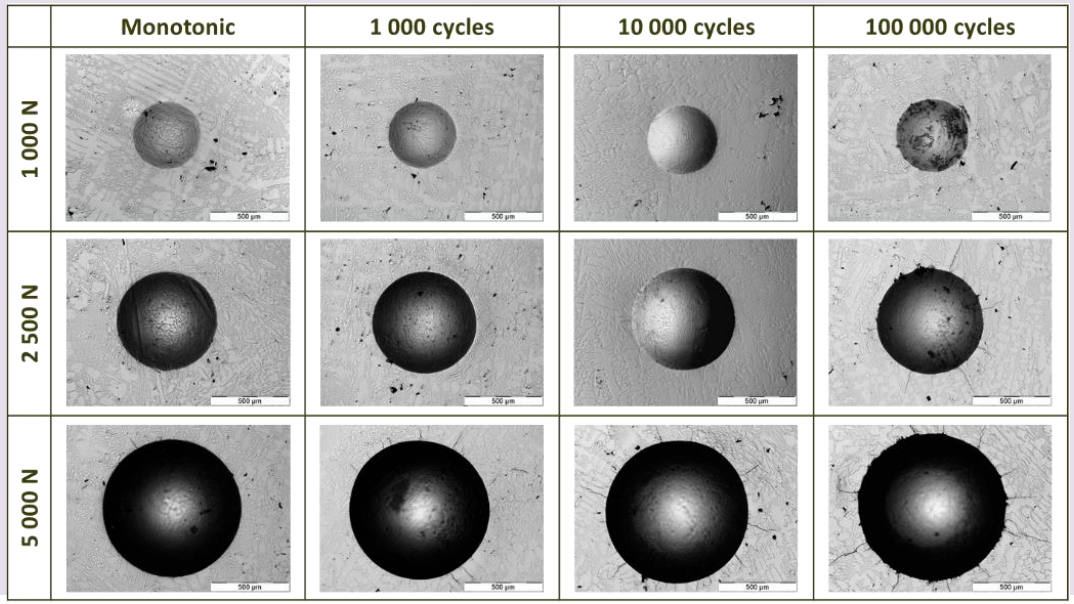
White cast 1



White cast 2







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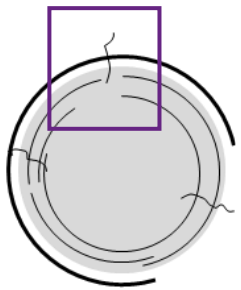
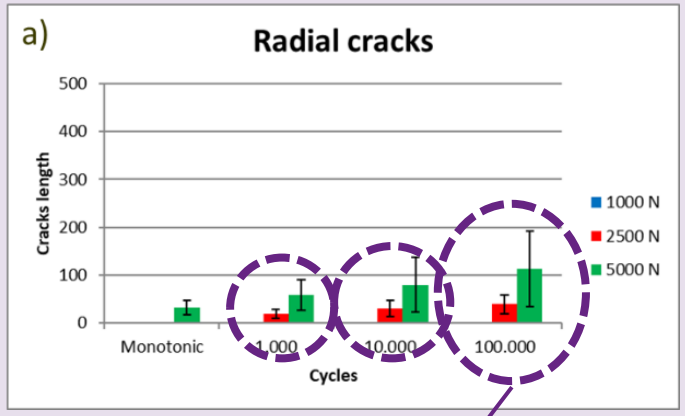
R&D Activities
Mining

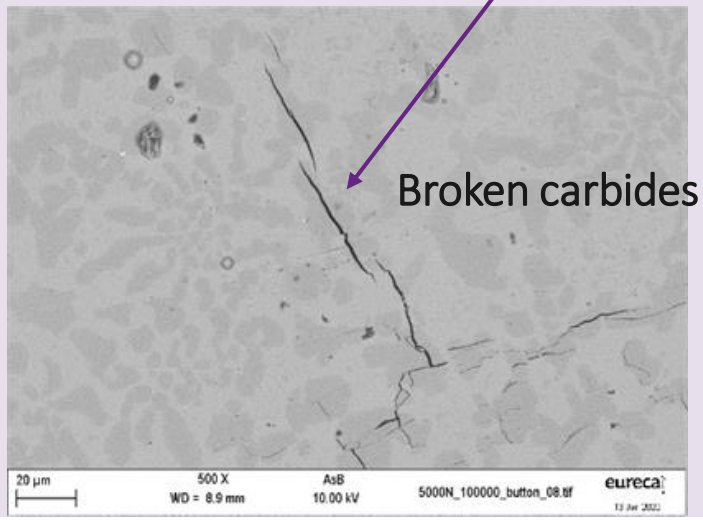
- **Lab tests design**



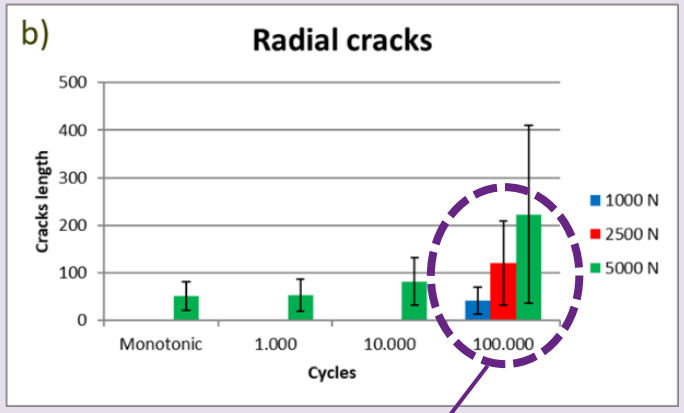
High-chromium white cast iron

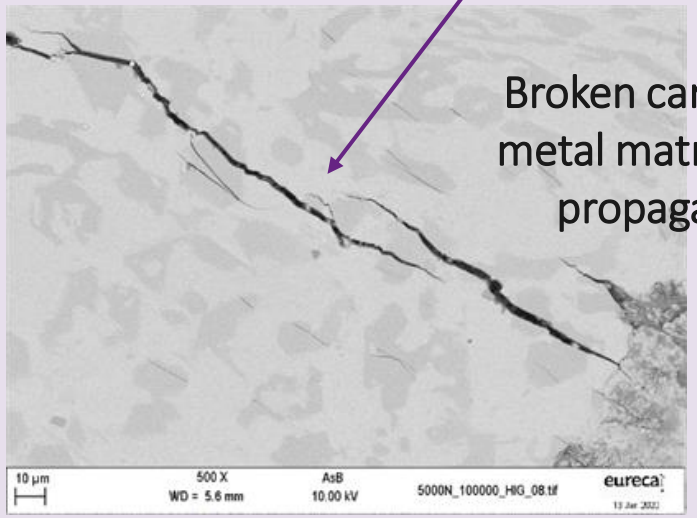
White cast 1





White cast 2





Tribology Research line

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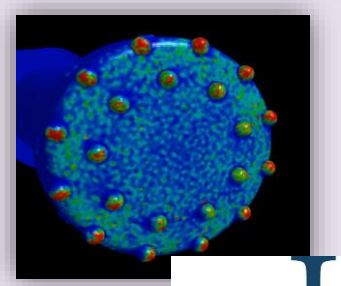
R&D Activities
Mining

GEOFIT SMART GEOTHERMAL



LULEÅ UNIVERSITY OF TECHNOLOGY

Down the hole (DTH) hammer

Tricone

catalanade PERFORACIONS

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.

Tribology Research line

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R&D Activities
Mining

GEOFIT SMART GEOTHERMAL

- **Identify main damaging mechanisms**

Conglomerates of quartz (quite common in Catalonia)

Drill bit

Segment of tricone

Button

Button

Hardmetal

catalanade PERFORACIONS

Tribology Research line

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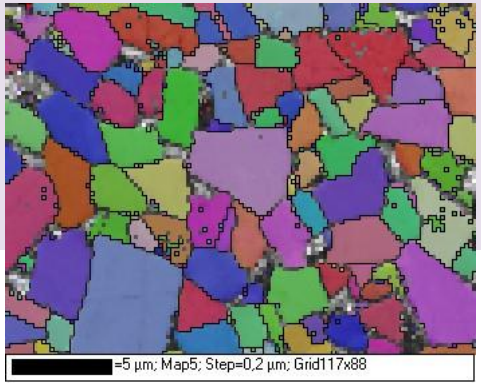
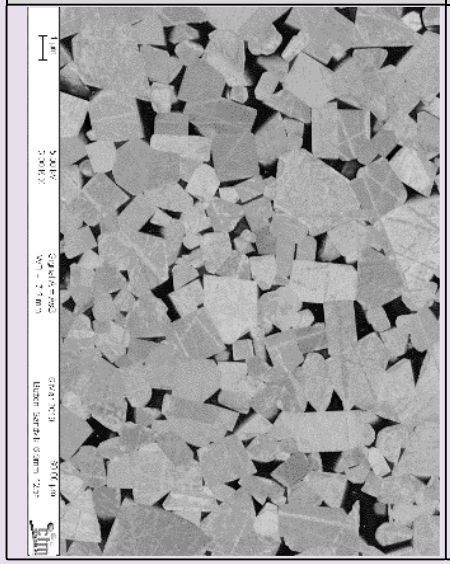
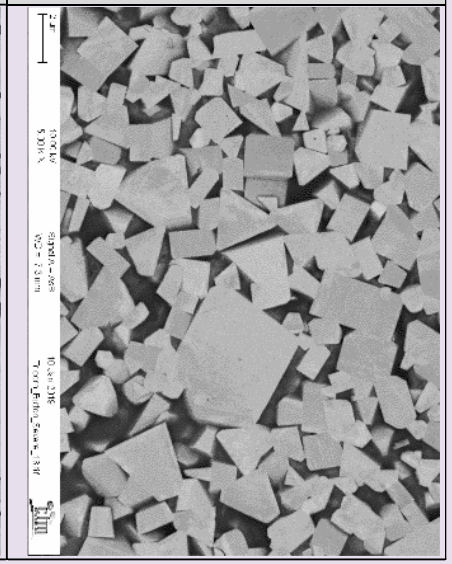
R&D Activities
Mining

GEOFIT SMART GEOTHERMAL

- **Identify main damaging mechanisms**

Properties	Drill bit buttons	Tricone buttons
Hardness (HV30)	1444 ± 17	1162 ± 23
Grain size (µm)	1.4 ± 0.6	1.4 ± 0.5
Cobalt content (wt %)	7	6.6



Drill buttons	Tricone buttons
	

Hardmetals

- Co-based binder
- WC carbides

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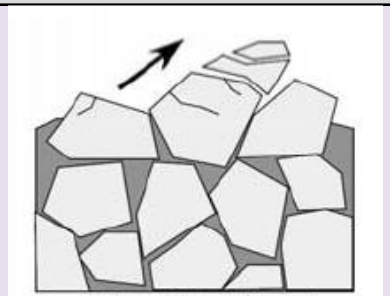
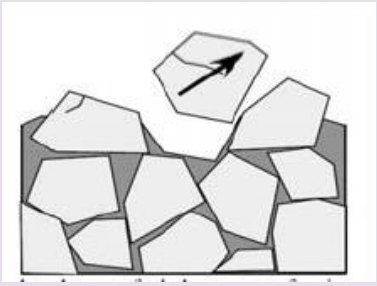
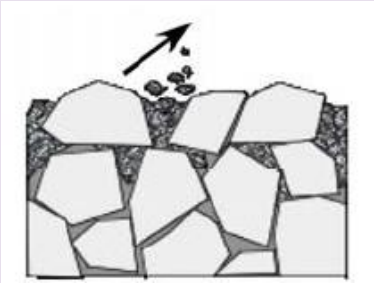
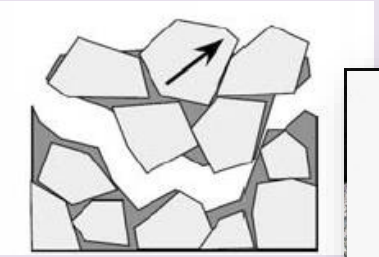
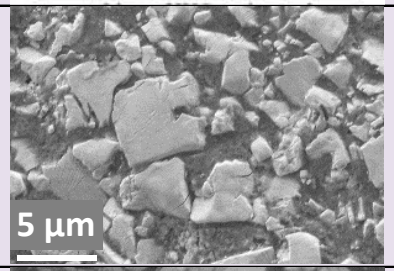
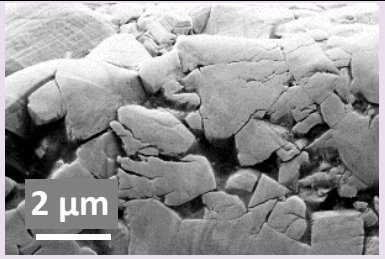
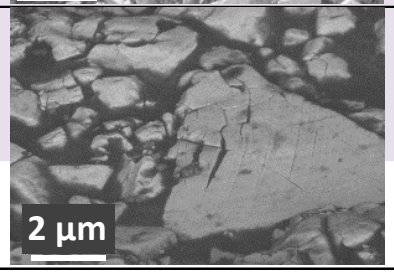
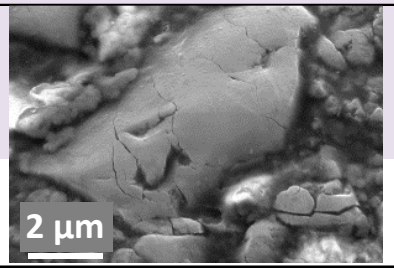
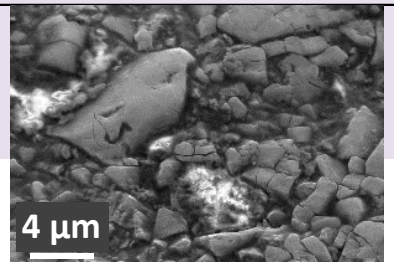
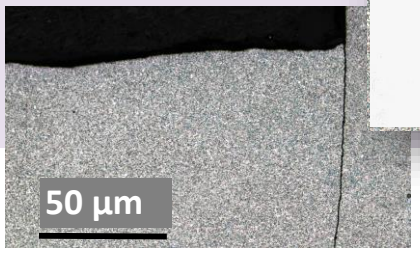
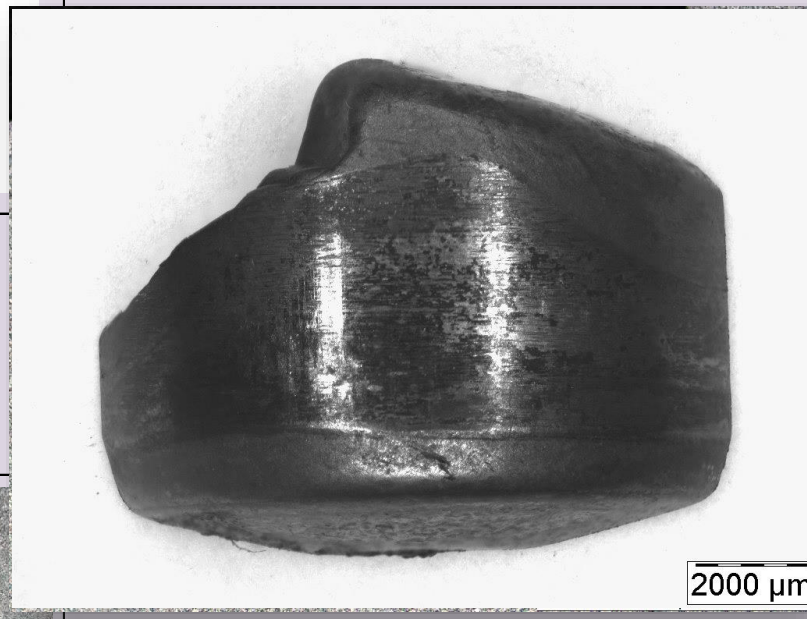
R&D Activities
Mining

GEOFIT SMART GEOTHERMAL

- **Identify main damaging mechanisms**

	(a) Micro-cracking	(b) Detachment of grains	(c) Crushing, reptile skin	(d) Detachment of fragments
[1]				
Drill bit button				
Tricone				



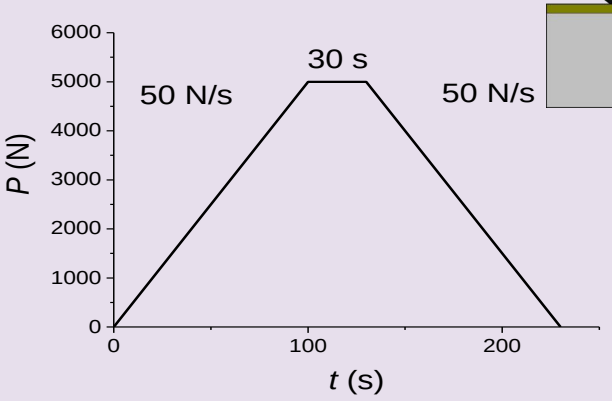
[1] Afonso Moura, C. F. (2009). Final Project – Mechanical Engineering Master. Porto, Portugal: Universidade do Porto Faculdade de Engenharia.

Tribology Research line

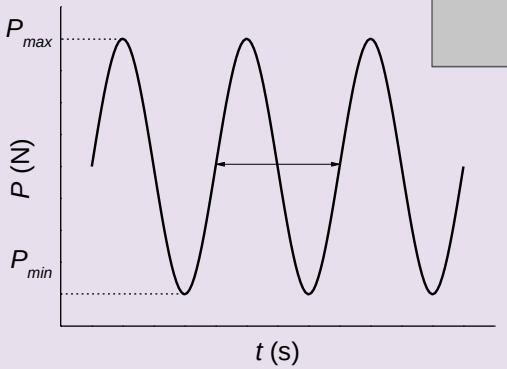
R&D Activities
Mining

- Contact Fatigue

Monotonic tests



Cyclic test



Servohidraulic testing machine

Spherical indenter:

Diameter = 2.5 mm
Hardmetal

Load:

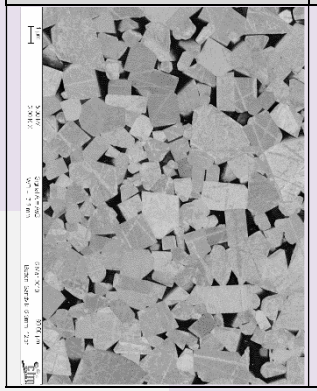
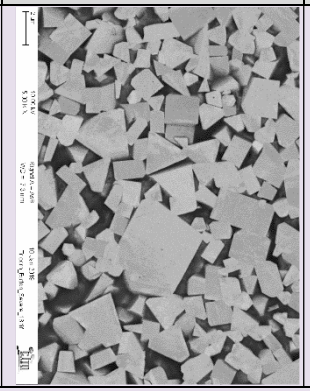
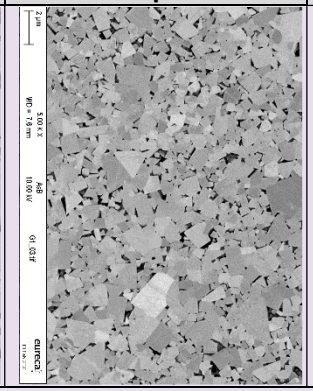
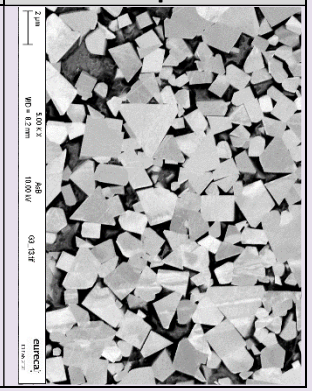
Pmax = 400 N, 1000 N, 2000 N and 3600 N

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

Tribology Research line

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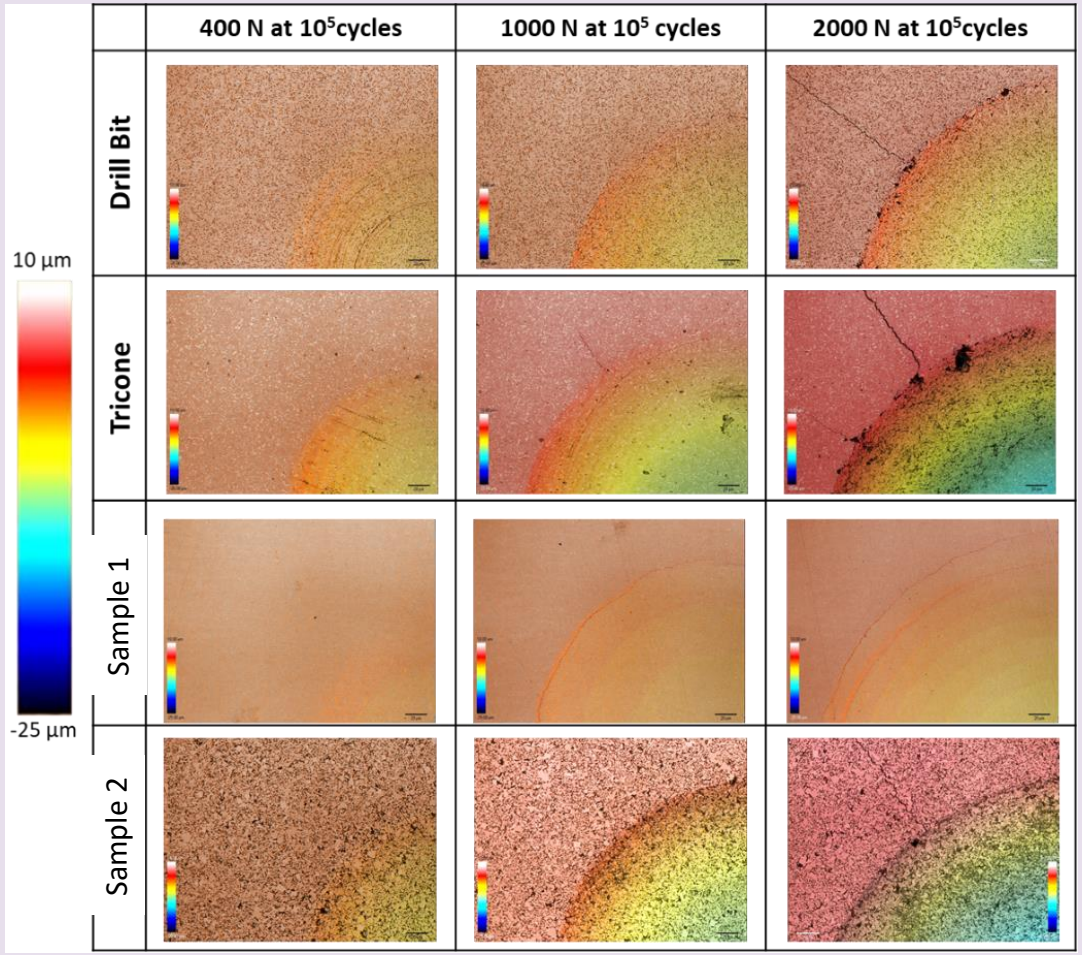
R&D Activities
Mining

- **Lab tests design**

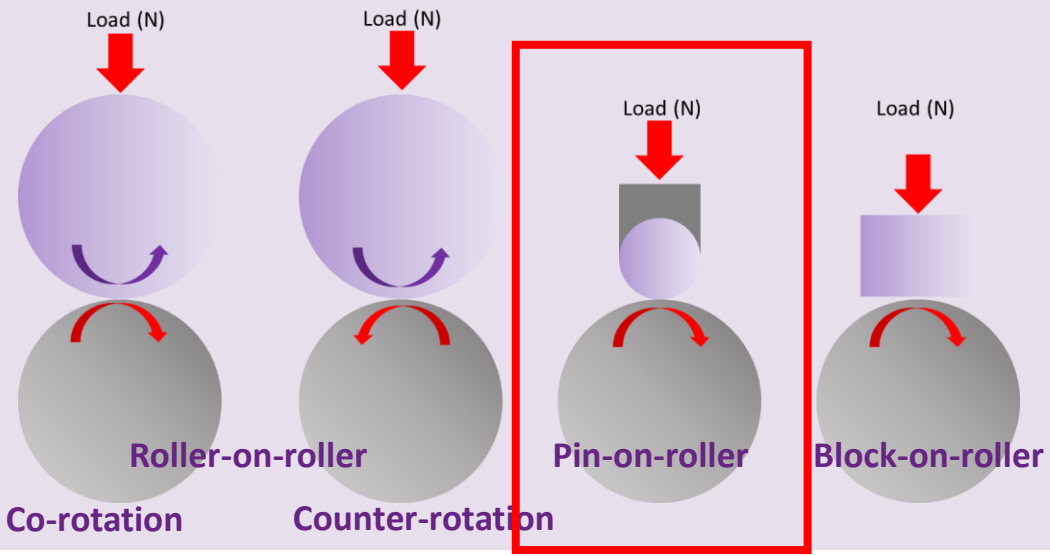
Hardmetals



- 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.

Tribology Research line
What is next…?

- 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



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R&D Activities

Pin on Roller Test

Pin holder

Pin
(Half button)

Silestone
(synthetic granite)

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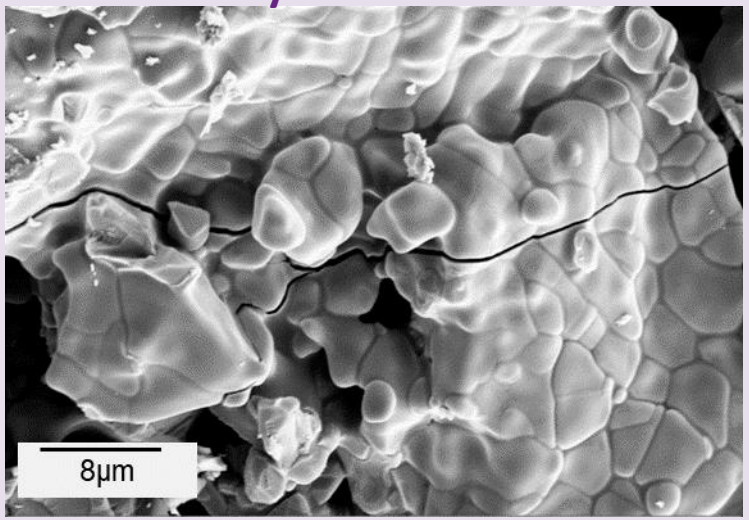
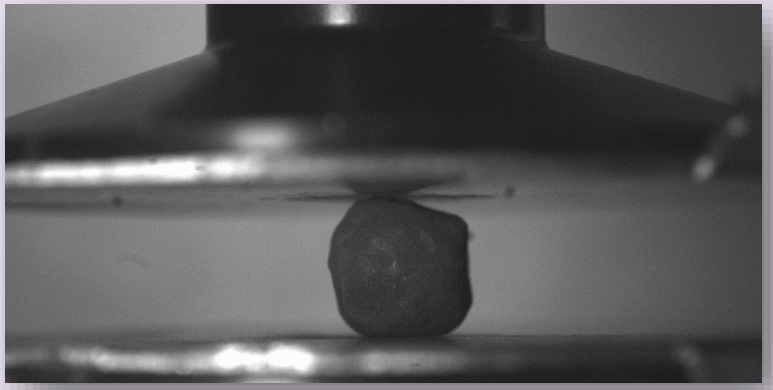
R&D Activities
Mining

Fracture analysis



Compression test

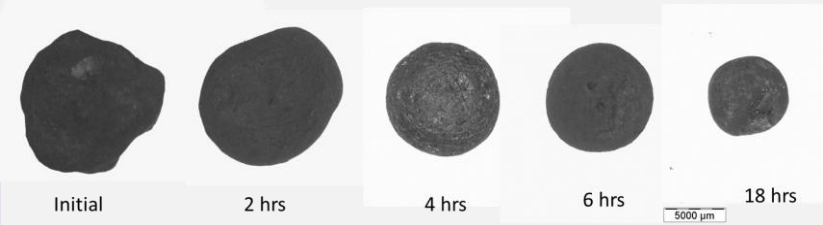


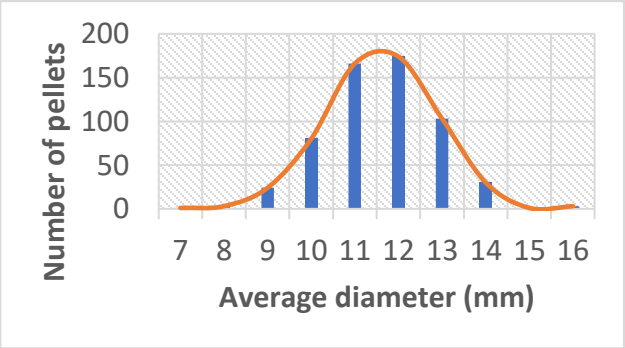
Pellets characterization

- 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

Multi-impact test

Morphology & Size after impact test

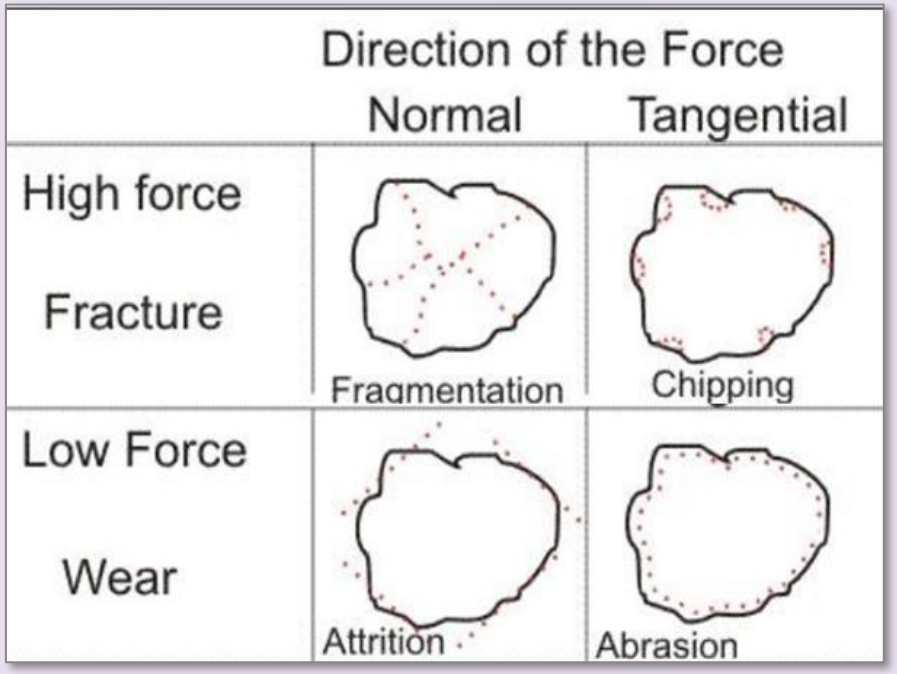




- **Particles damage mechanisms**

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 magnitud normal forces acting on a particle, which results in the removal of sharp edges, producing more spherical shape.



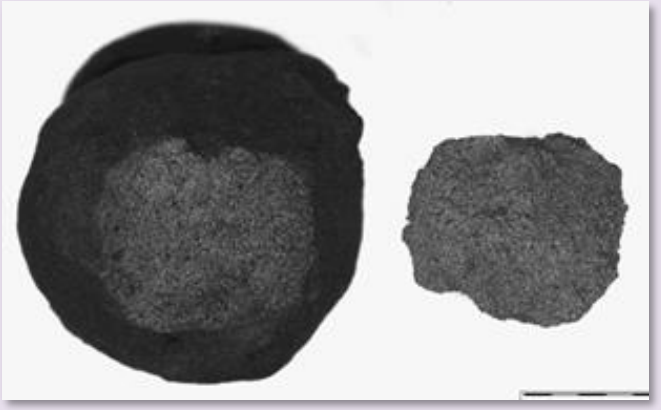
[1] W.J.B van den Bergh, B. Scarlett. Powder Technology, 67:237-247,1991.

Tribology Research line

R&D Activities
Mining

- **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 ± 0.4
- Cyclic sinusoidal waveform
- Displacement control.
- Displacement amplitude:
  - 10 mm
- Frequency: 15 Hz

The number of impacts can be calculated as:

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

t= time

f = frequency.

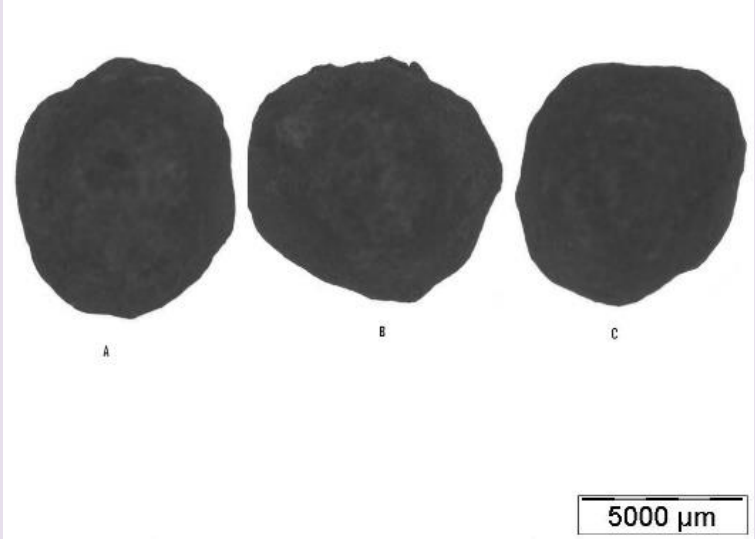
Pellets
(Initial state)

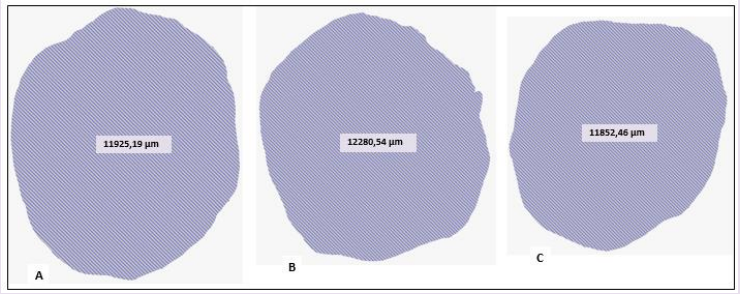
Worn Pellets
(After 4 hrs)

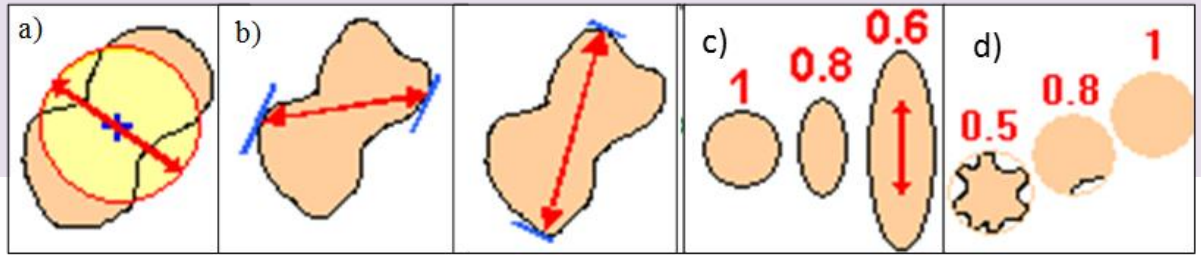
[3] R. Pitchumani, N. Gupta, Gl M. H. Meesters, B. Scarlett. Part. Part. Syst. Charact. 20 (2003) 323 ± 326

• 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



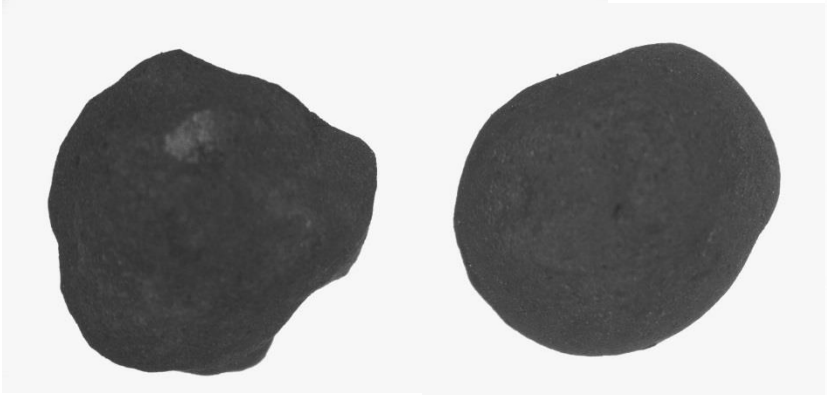


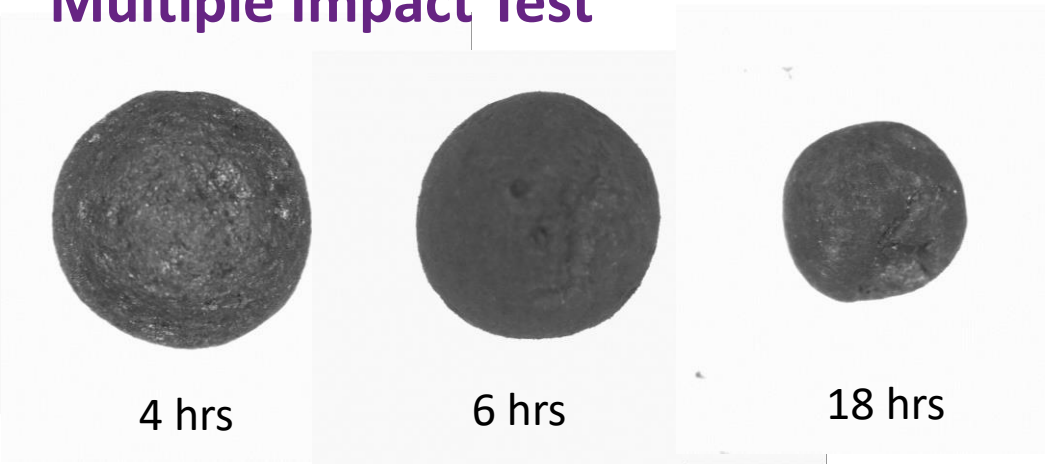


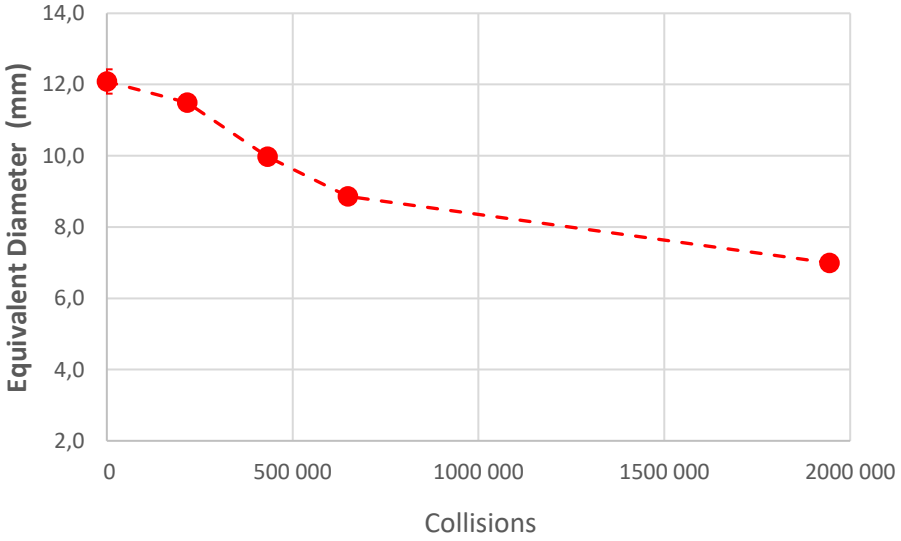
R&D Activities
Mining

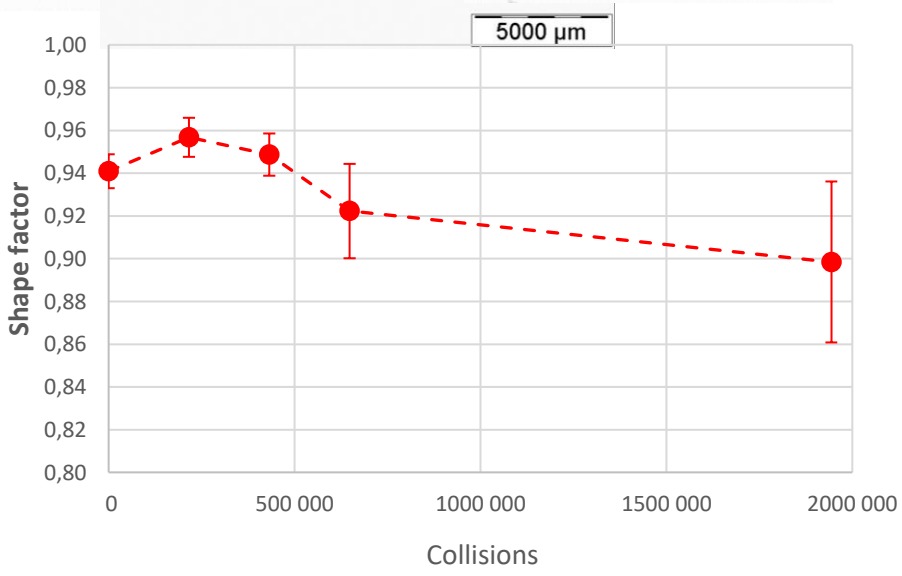
- Damage evolution of iron ore pellets

Multiple Impact Test





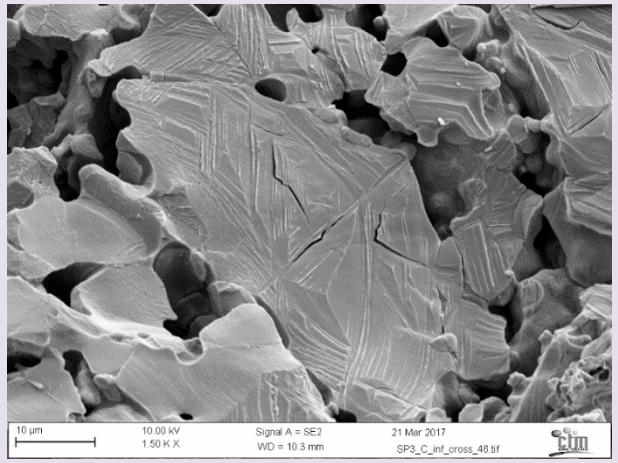




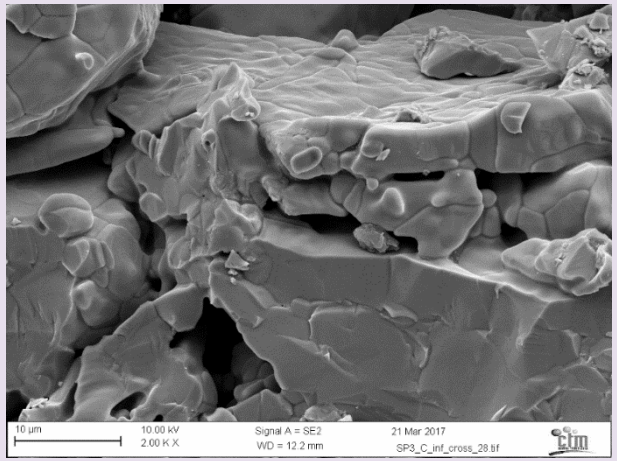
• Why multiple impact test?

- Relation of intrinsic defects with wear damage mechanisms

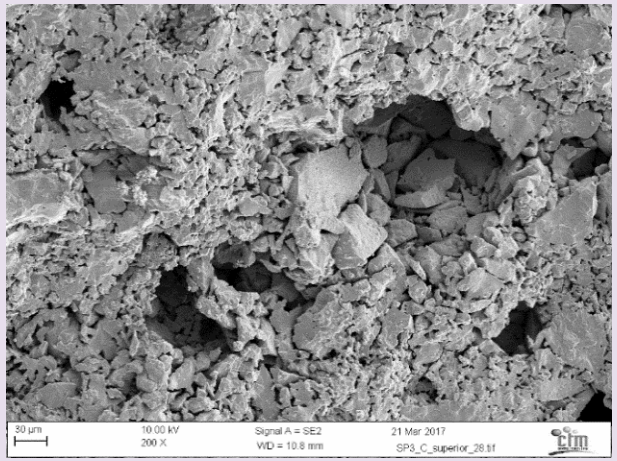
Particle with high grade of sintering: Transgranular fracture



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.)

Tribology Research line

R&D Activities
Mining

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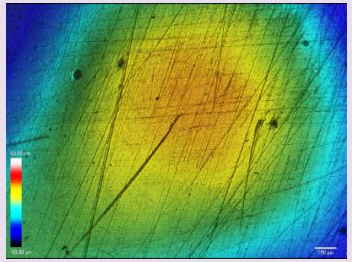
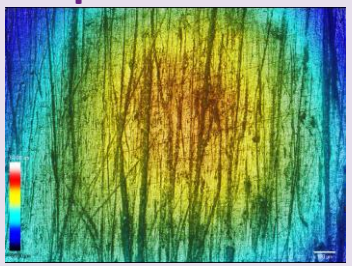
Field tests

Pressure sensors

Topography inspection



Before



After

HERMES

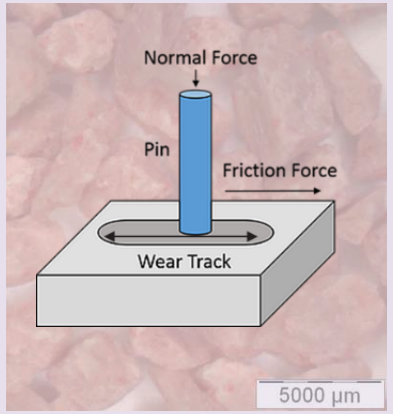
Surface improvement: to develop a novel coating for the interior surface of cargo wagons.

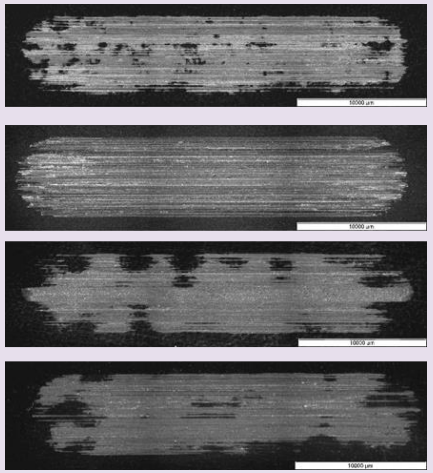
Reduction of friction coefficient (leading to an increase of bulk discharge speed at terminals), but at the same time, it must show **high resistance to abrasion and corrosion due to potash**.

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

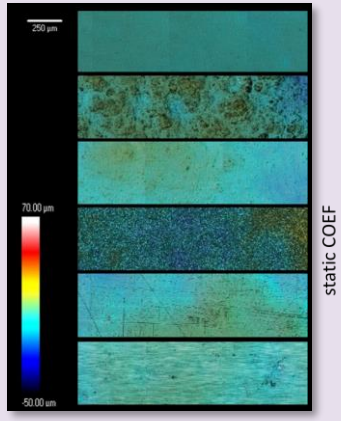
Lab tests

Abrasion test

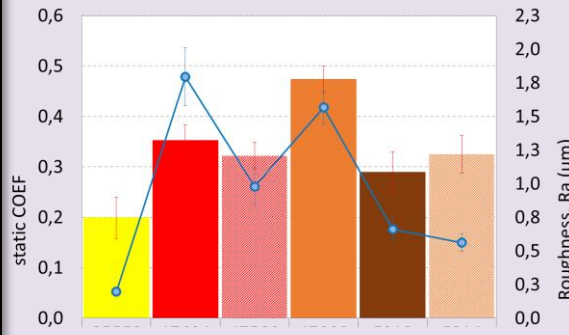




Roughness



Coefficient of Friction



Thank you for your attention!!!

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" innovant amb les empreses "