Characterization of additive manufactured materials

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Brief Overview of Our Organization

eurecat
Centre Tecnològic de Catalunya

We believe **that collaboration** is essential to accelerate innovation.

We build alliances with **universities, research centres, public administrations and companies** in all regions to address shared challenges.



11 locations

Eurecat is organized into several Research Areas

Industrial Area



Metallic and Ceramic Materials

New manufacturing processes

Plastic Materials and Composites

Robotics and Automation

Product innovation & Multiphysics Simulation

Functional Printing & Embedded Systems

Chemical Technology

Functional Textiles

Digital Area



Applied Artificial

Big Data & Data Science

Quantum Computing

Digital Health

IT&OT Security

Multimedia Technologies

Biotechnology Area



Nutrition and Health

Omic Sciences

Sustainability Area



Climate Solutions and Ecosystem Services

Water, Air & Soil

Waste, Energy and Environmental Impact

Eurecat is organized into several Research Units

Industrial Area



Metallic and Ceramic Materials

Several Research Lines



Advanced solutions for WEIGHT REDUCTION and HIGH MATERIAL PERFORMANCE:

- Mechanical behaviour, fracture and fatigue
- New processes for advanced materials
- Light alloys



Customised FUNCTIONAL SURFACES for extreme requests:

- Corrosion and degradation
- Tribology and micromechanics
- Surface and coating technology

Capabilities of Tribology and Micromechanics Research line

Our Tribology research line covers a wide range of tests and characterisation

Surface integrity

Microtensile test

Instrumented indentation

3D characterization

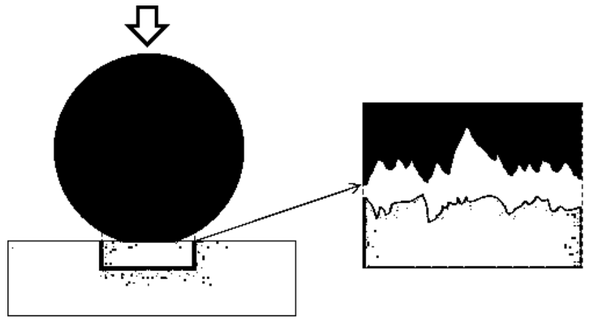
Pin-on-disc test

Roller on Roller Test

Wheel abrasion test

Multiple configuration wear test

What is tribology?
Tribology is the science that study the interaction between different surfaces in relative motion.



Tribological

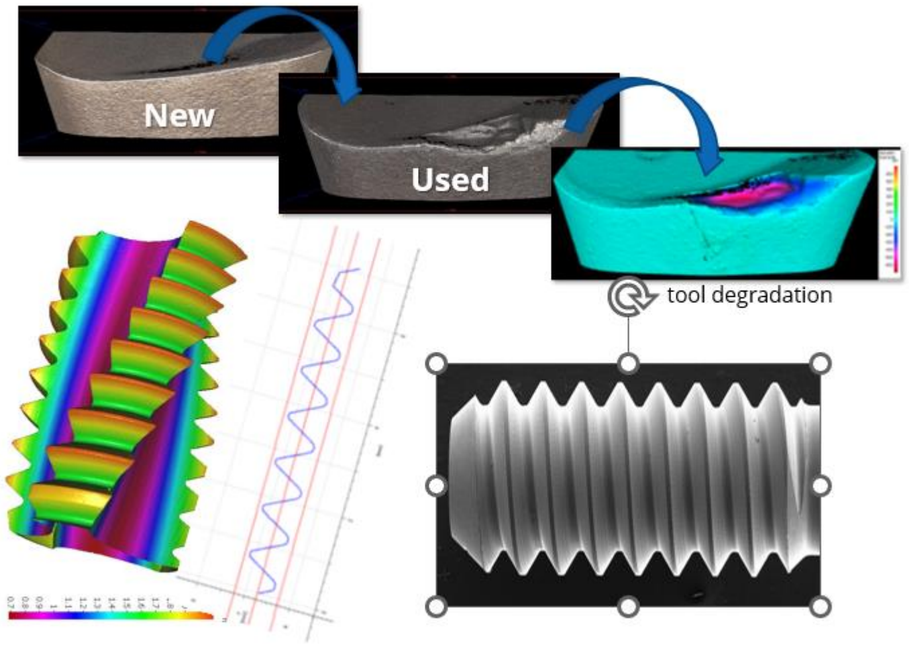
Tribology and Micromechanics Research line

3D characterization

– Evaluate the wear of industrial tools, such as cutting and punching tools.

  - i.e. usually cutting and punching tools.

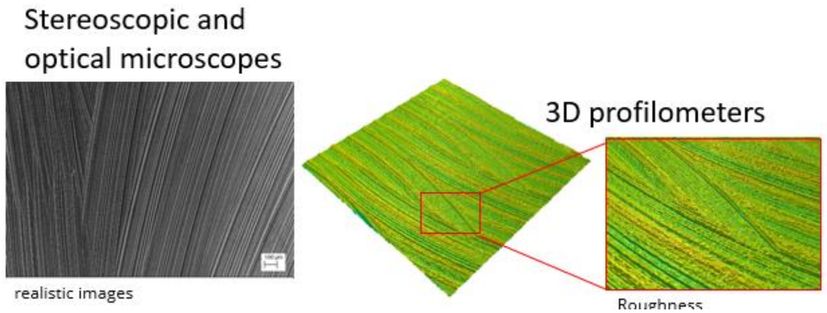
– Analise the **geometry** of the tool.

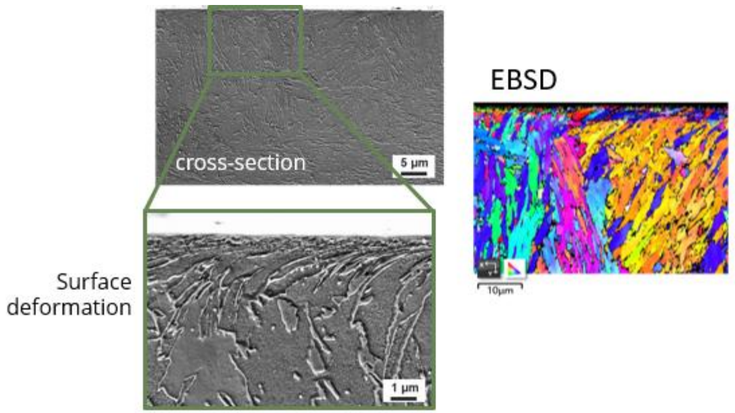


Surface integrity

– **Stereoscopic** and optical microscopes

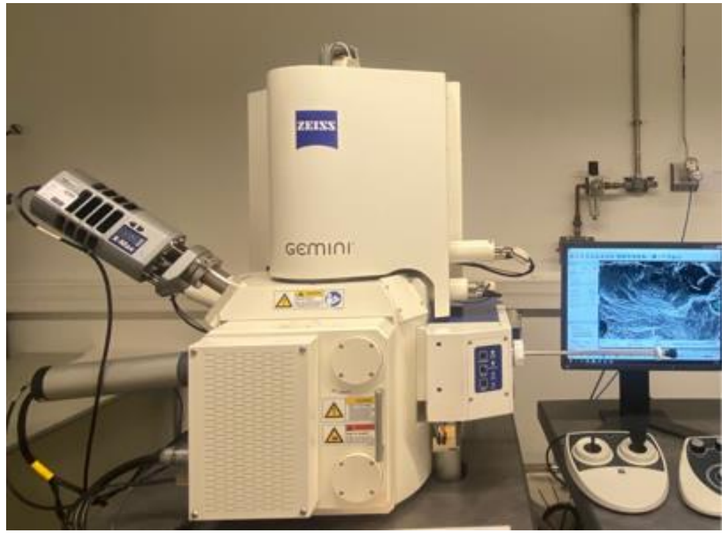
– **3D profilometers** to measure roughness and worn material.





- **EBSD** to determine the local crystal structure and crystal orientation at the surface of a specimen

Tribology and Micromechanics Research line

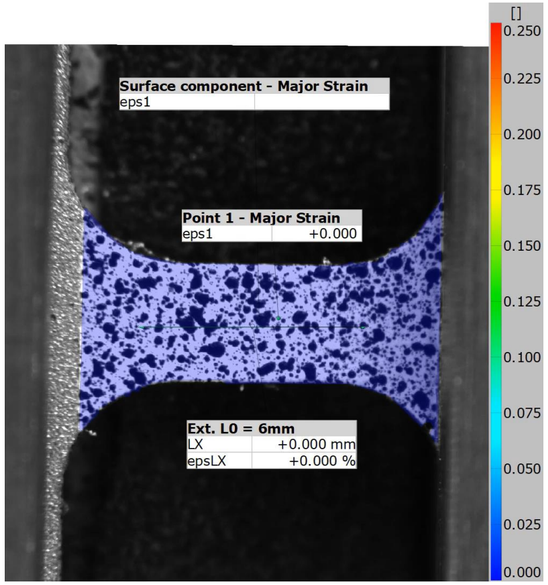


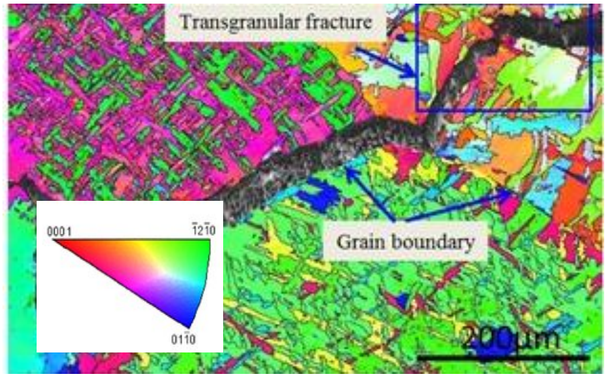


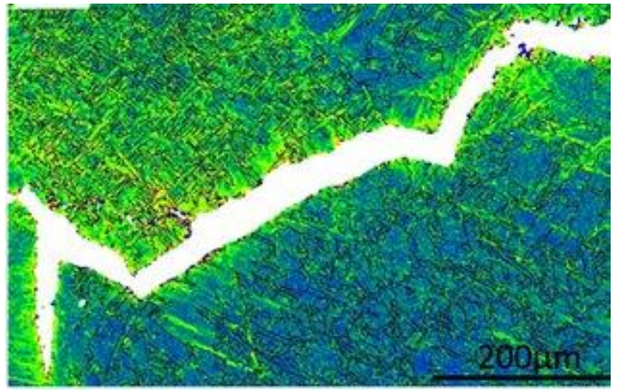
Microtensile test inside the SEM

The resulting **stress-strain curves** were used to determine:

- Yield strength, Ultimate tensile strength, Elongation to failure.
- Detect surface defects and analysing it during the application load

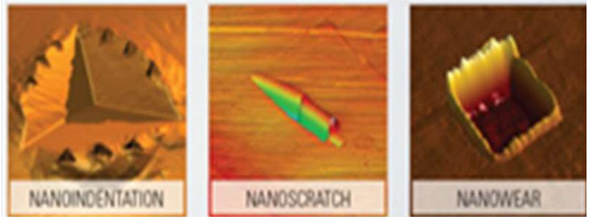


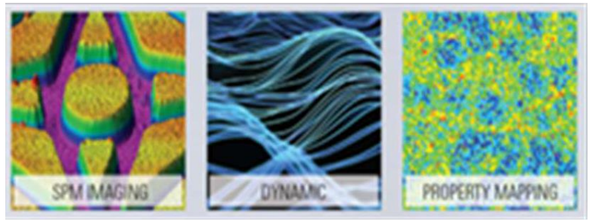




Tribology and Micromechanics Research line

- **Two-dimensional transducer assembly** (quasi-static indentation and scratch testing)
- **NanoDMA® IV** (dynamic nanoindentation)
- **XPM II** (accelerated mechanical property mapping)
- **TriboScanner™** (tribological/topographical mapping, scratches)
- **Temperature Nano (**temperature quasi-static indentation)

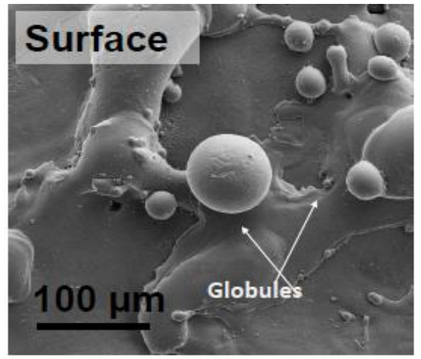


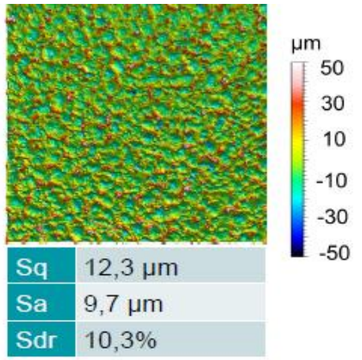


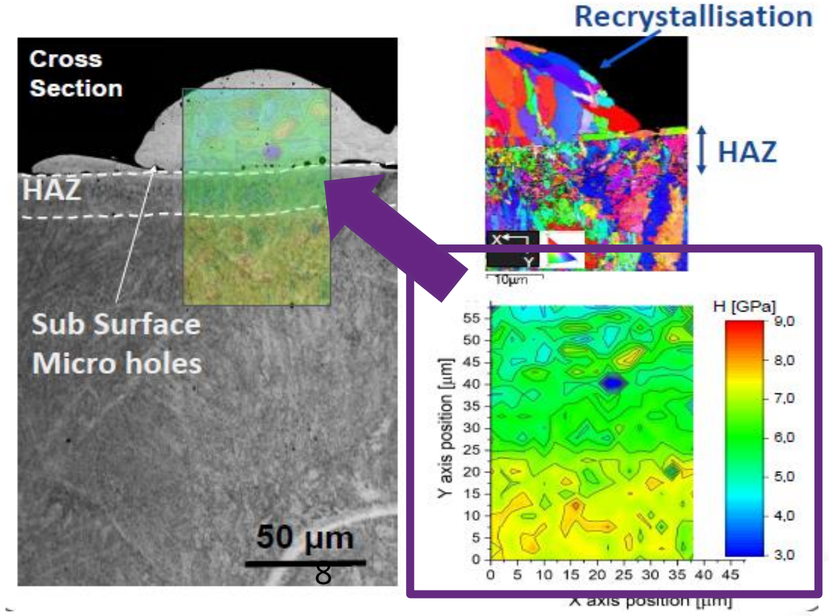
SPM+ (in-situ scanning microscopy)



Instrumented indentation



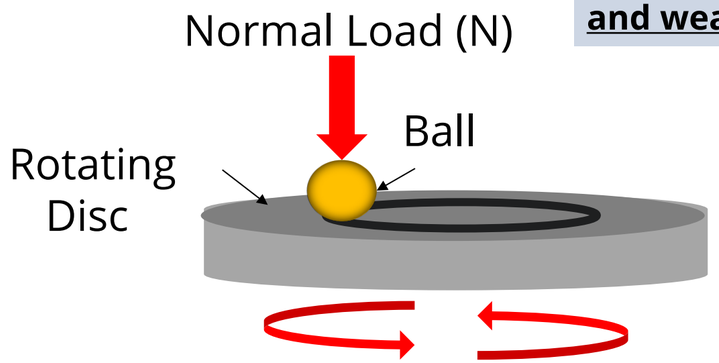




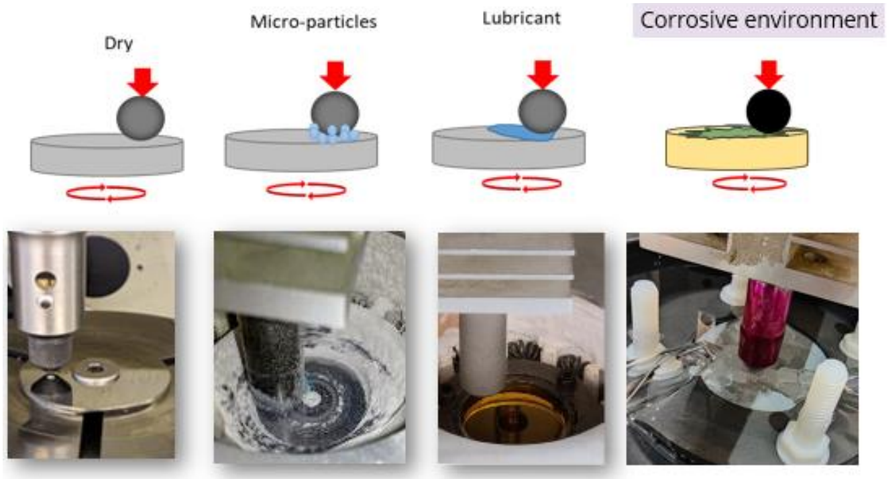
Tribology and Micromechanics Research line

Pin-on-disc test

To characterize friction and wear of materials.



Several configurations

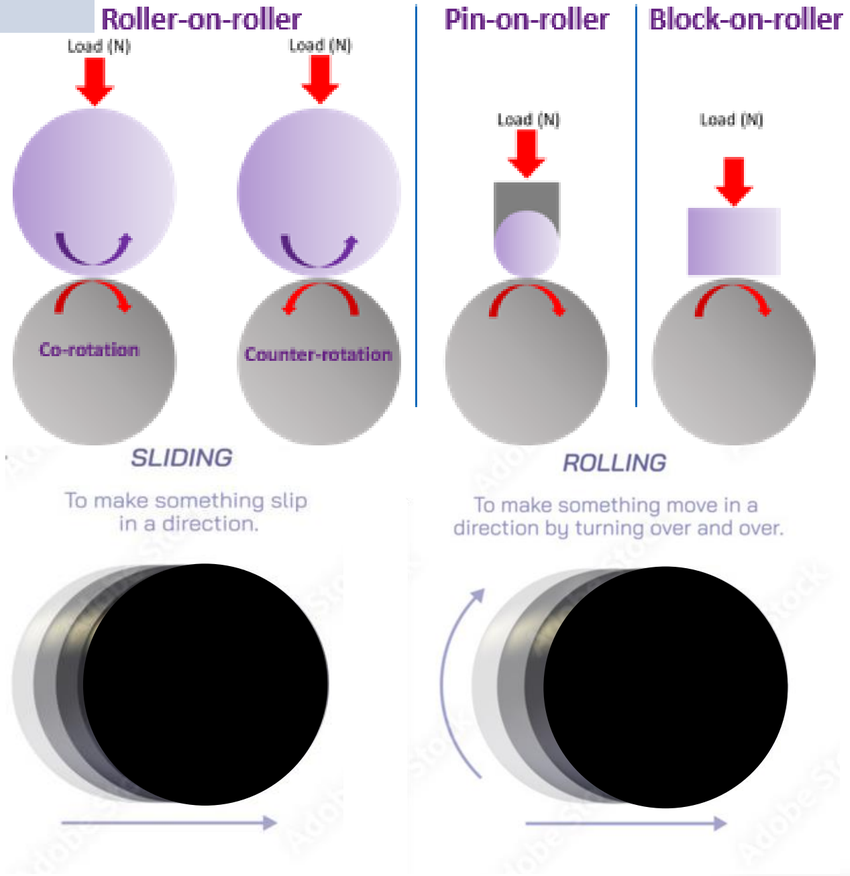


Roller on Roller Test

To characterize friction, fatigue and wear of mat that experience rolling and sliding.



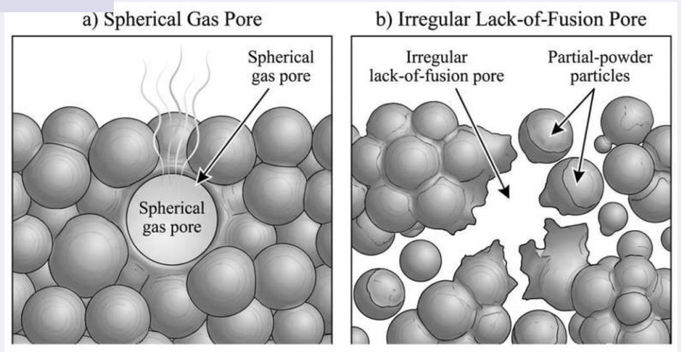
Several configurations



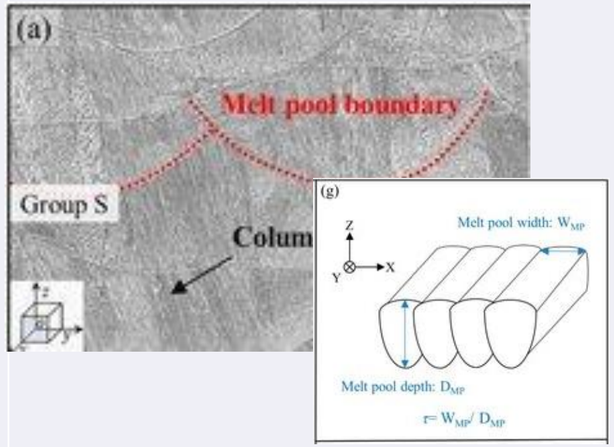
Characterization of additive manufactured materials

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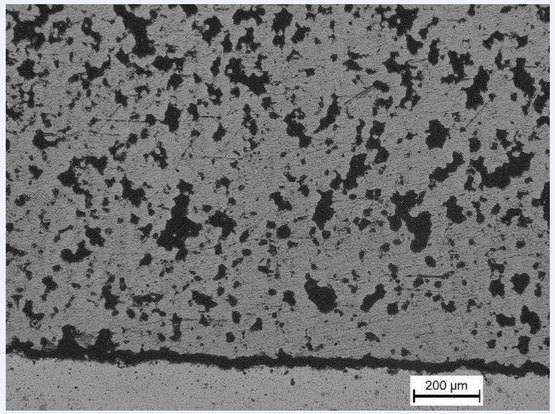
AMT	LPBF (Laser Powder Bed Fusion)	EBM (Electron Beam Melting)	DED (Directed Energy Deposition)	Cold Spray
Key defects to be characterised	Topography, **porosity**, **melt pools**, anisotropy		Dilution, **porosity, bonding between beads** and residual stresses	**Adhesion**, residual porosity and particle deformation



Metal Additive Manufacturing Defect Formation and Mitigation: Shrinkage Dynamics, Porosity Control, In-Situ Monitoring, and Post-Processing Strategies



The role of overlap region width in multi-laser powder bed fusion of Hastelloy X superalloy



Enhancing Cold-Sprayed Ti6Al4V Coatings: Impact of N2, He or N2-He Mixed Gas Propulsion

By analysing these defects, we can predict the final quality of a component.

Produce coupons using DED CrNiMoN 25-7-4 (1.4410)

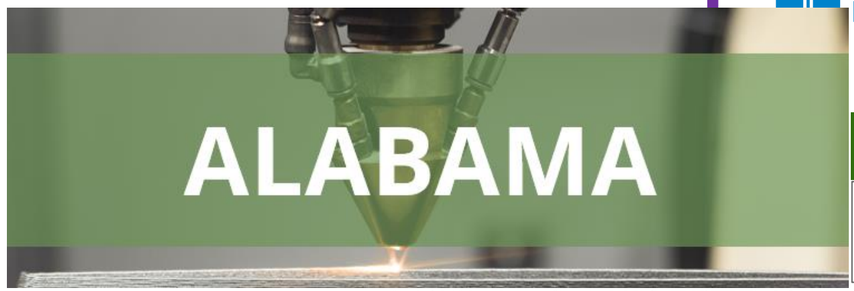


C1

C2

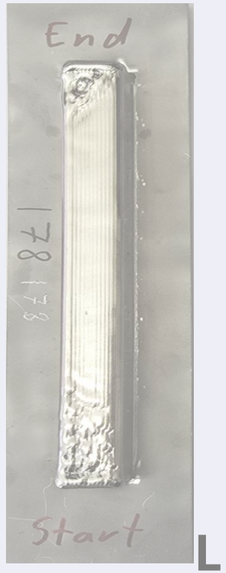
C3

Laser shape



ALABAMA - Adaptive Laser Beam for Additive Manufacturing

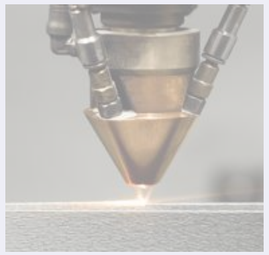
Produce coupons using Multi beam laser system – Ti64



Laser config.

Produce coupons using a high-speed oscillating - AlSiMg





Laser power.

Characterization of additive manufactured materials

eurecat Centre Tecnològic de Catalunya

Escola Enginyeria Barcelona Est

Workflow of the project

1 SPECIMENS

3 conditions

2
Porosity / SEM / EBSD
Nanoindentation

→ Local properties

3
Fatigue:
Stiffness method
CWA 18107-2:2024

→ General properties

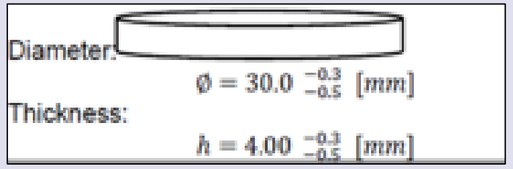
4 Predict

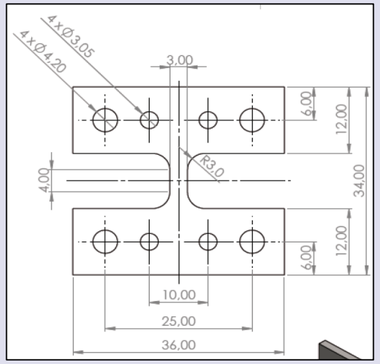
The best condition

COMMON TEST BASIS

Mirco-tensile Test

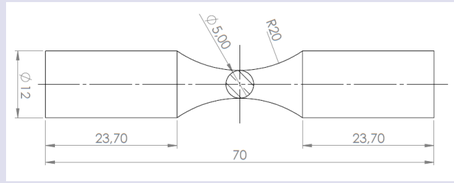
SEM/EBSD
Nanoindentation





COMMON TEST BASIS

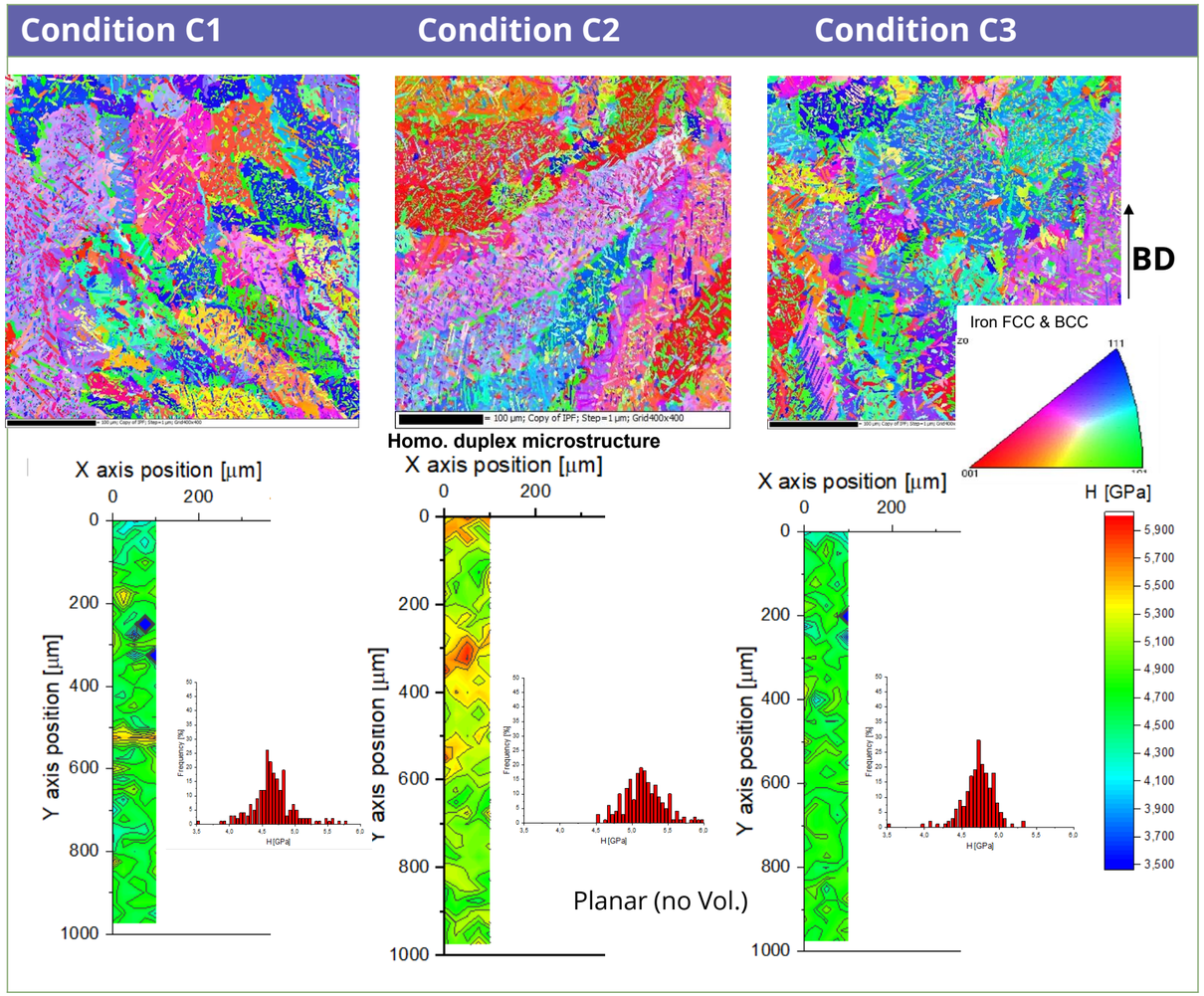
- Fully polished hourglass specimens, Ra < 0.2 μm
- Stress control: R = 0.1, 30 Hz



Characterization of additive manufactured materials

Micromechanical properties evaluation

CrNiMoN 25-7-4 (1.4410) printed using DED:



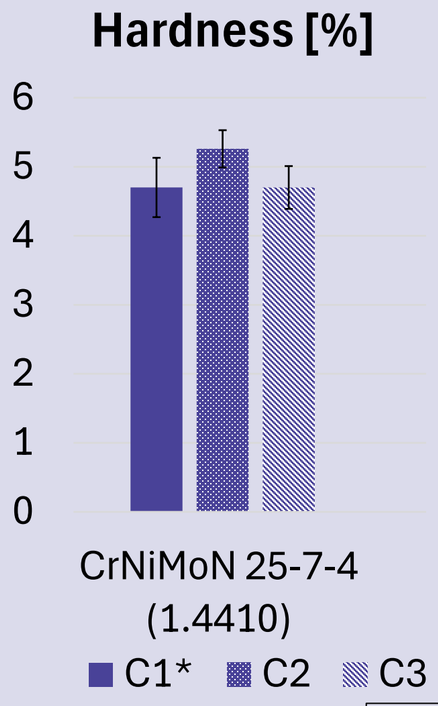
Material	Condition	Porosity [%]	H [GPa]	BCC/FCC
CrNiMoN 25-7-4 (1.4410)	C1*	0.73 ± 0.30	4.62 ± 0.43	55/45
	C2	0.33± 0.33 ↓	5.16 ± 0.27 ↑	53/47
	C3	1.03 ± 0.74	4.70 ± 0.31	50/50

Challenges & Lessons Learned

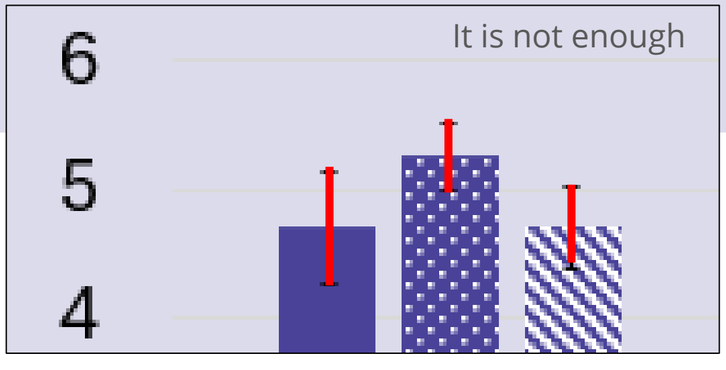
C2 combines the lowest porosity, the highest hardness, and the most homogeneous refined duplex microstructure.

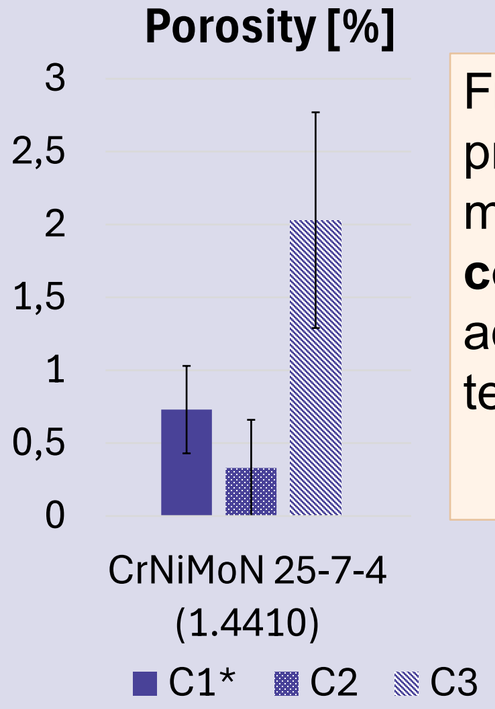
Characterization of additive manufactured materials

Micromechanical properties On a microscopic level



Regarding hardness, we can identify differences between conditions, but we need to consider that in all cases there is quite a bit of variation in the results, which **minimizes the difference between conditions**



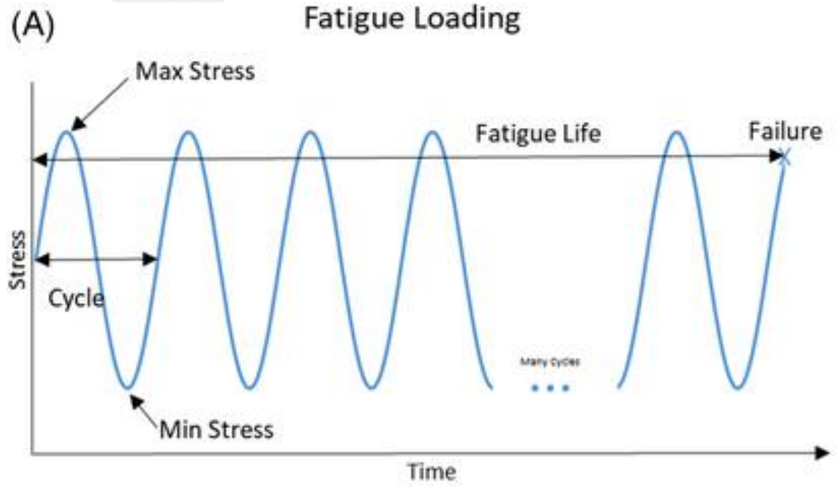


Finally, porosity is the property that shows the most **differences between conditions** within the same additive manufacturing technologies.

Characterization of additive manufactured materials

Mechanical properties

What is their macroscopic behaviour?



Progressive damage

01 Stress concentrator

Notches, section changes, threads, welds and surface defects raise local stress. That nucleates a micro-crack

02 Nucleation of micro-cracks

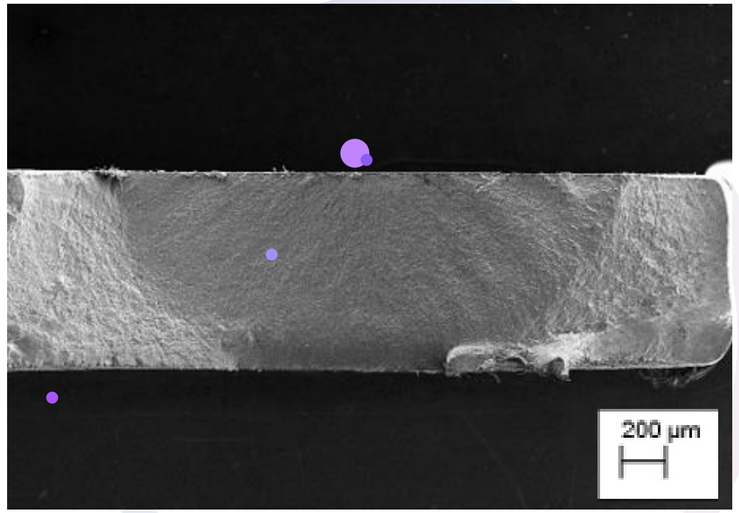
Local cyclic plasticity generates persistent slip bands and micro-cracks.

03 Continuous propagation

The crack grows with each cycle.

04 Catastrophic fracture

When the crack reaches a critical size, the sample do not have enough effective area to support the applied stress.



The fatigue life depends on:

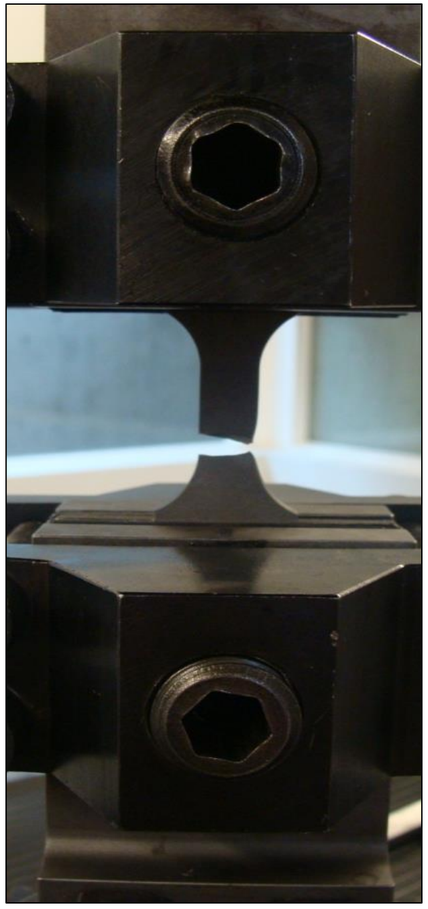
- **the amplitude and stress of the cycle,**
- **the number of cycles,**
- **the geometry,**
- **the surface finish,**
- **the environment,**
- **internal defects of the material, etc.**

Characterization of additive manufactured materials

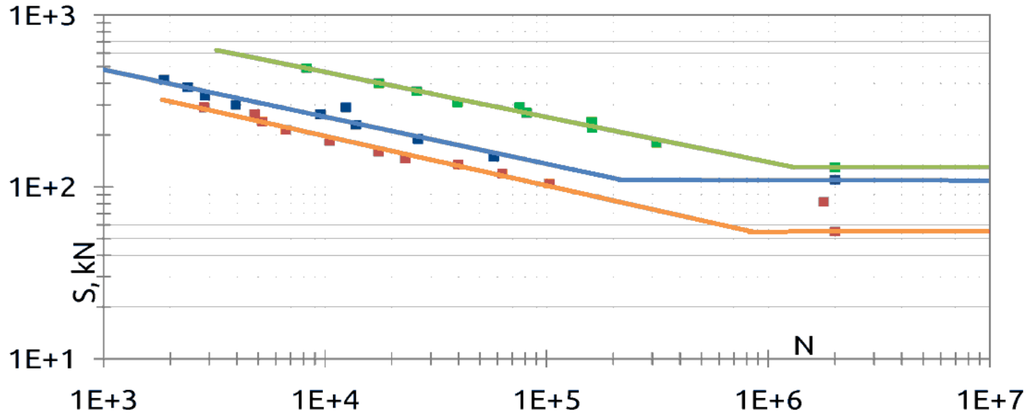
Mechanical properties

What data do we obtain from Fatigue Testing?

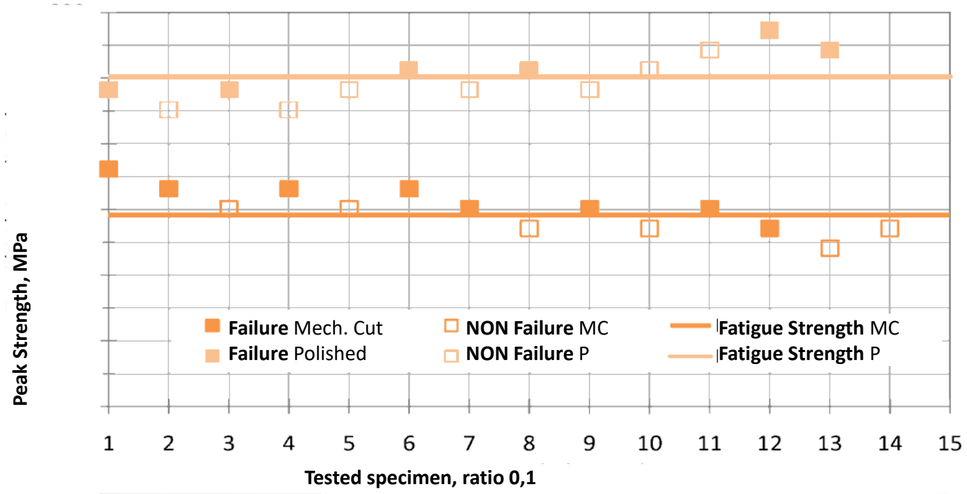




SN or WÖHLER curves



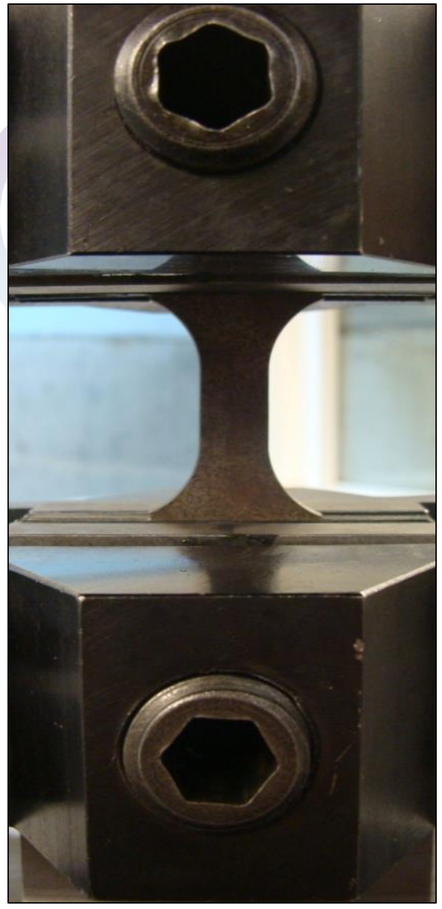
STAIR CASE method

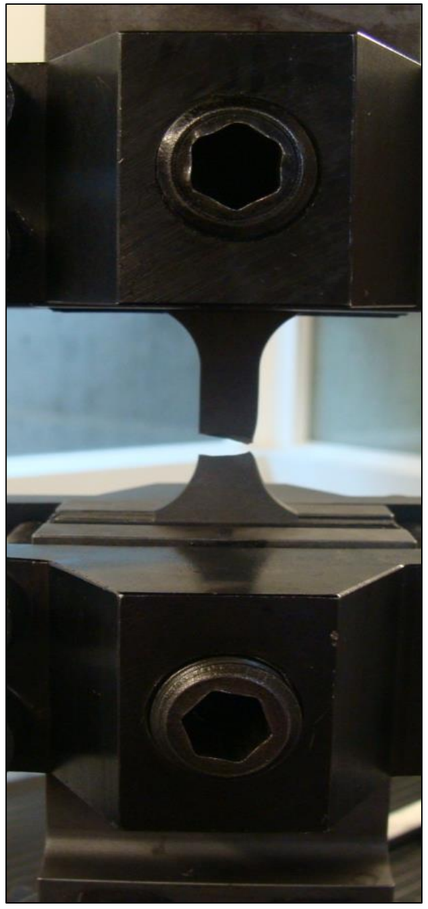


Characterization of additive manufactured materials

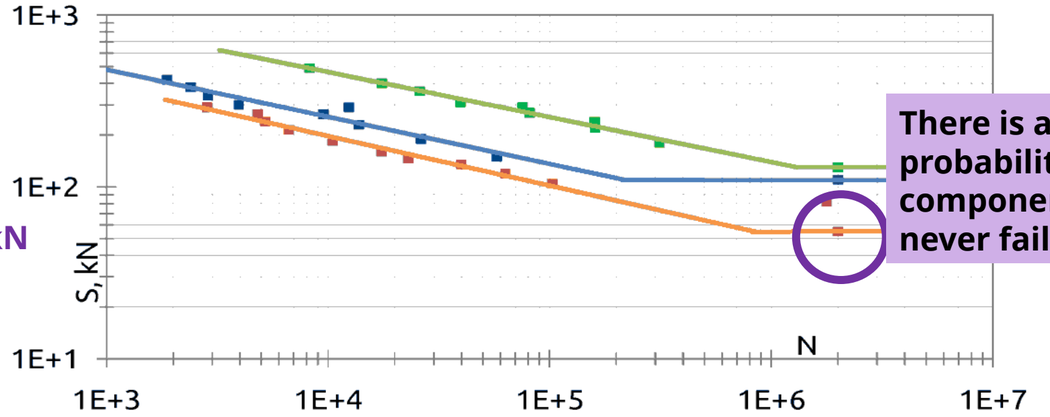
Mechanical properties

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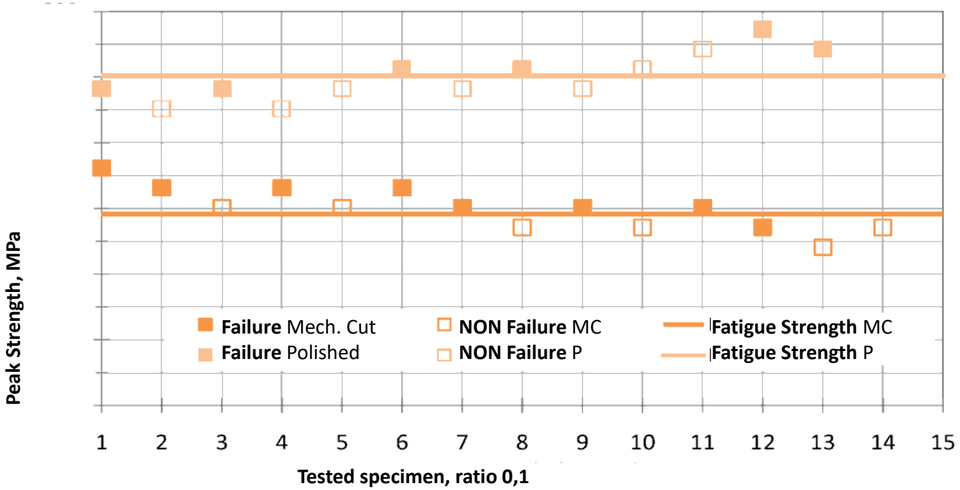


30kN

There is a 50% probability that the component will never fail.

More accuracy

Statistic STAIR CASE method

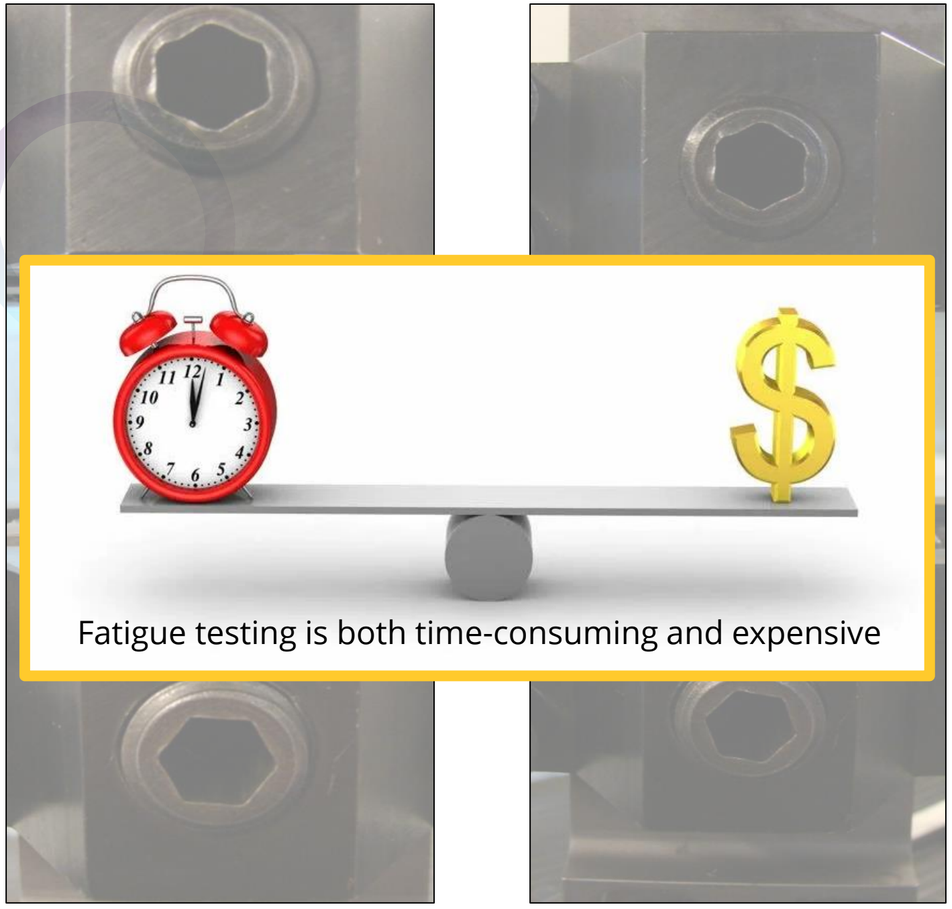


Confidence of 95%

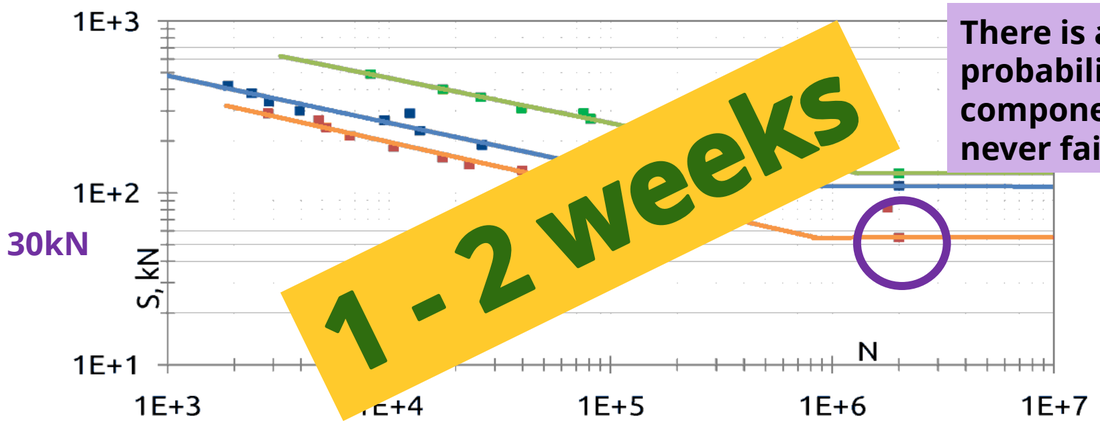
Characterization of additive manufactured materials

Mechanical properties

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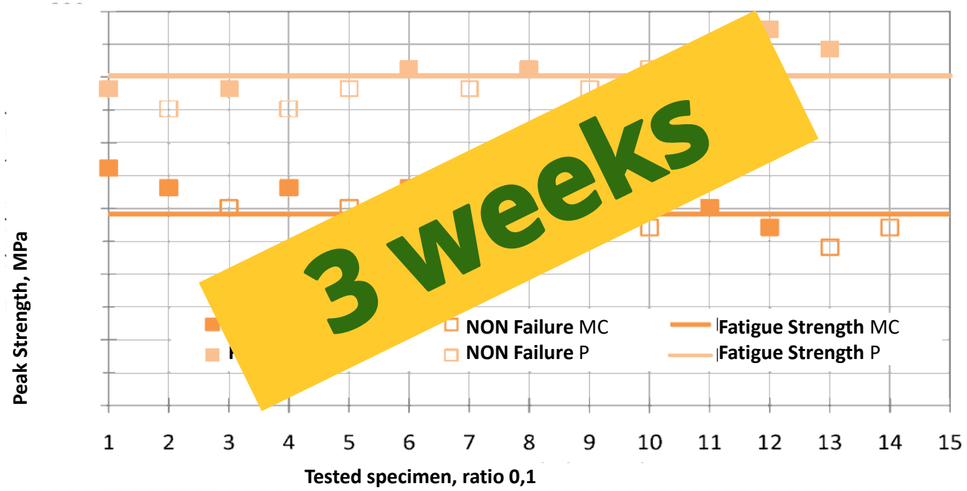
SN or WÖHLER curves



There is a 50% probability that the component will never fail.

More accuracy

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Confidence of 95%

Characterization of additive manufactured materials

Mechanical proprieties

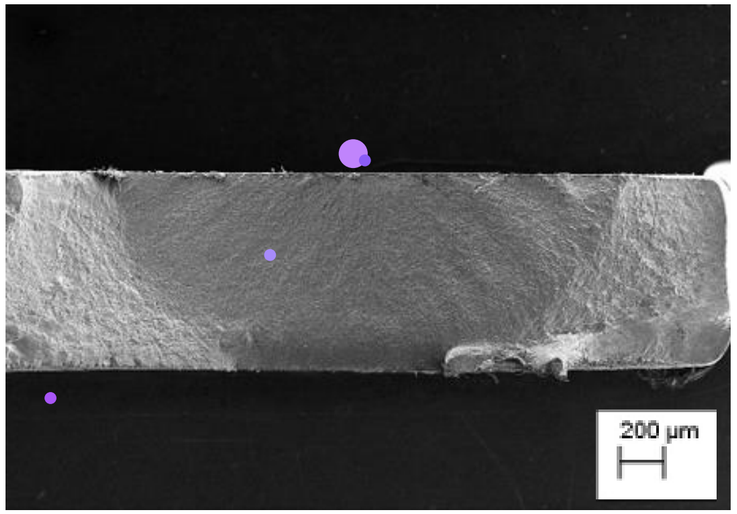
Can we reduce the test-time?

01 **Stress concentrator**

02 **Nucleation of micro-cracks**

03 **Continuous propagation**

04 **Catastrophic fracture**



Research line

Mechanical behaviour, fracture and fatigue

New method

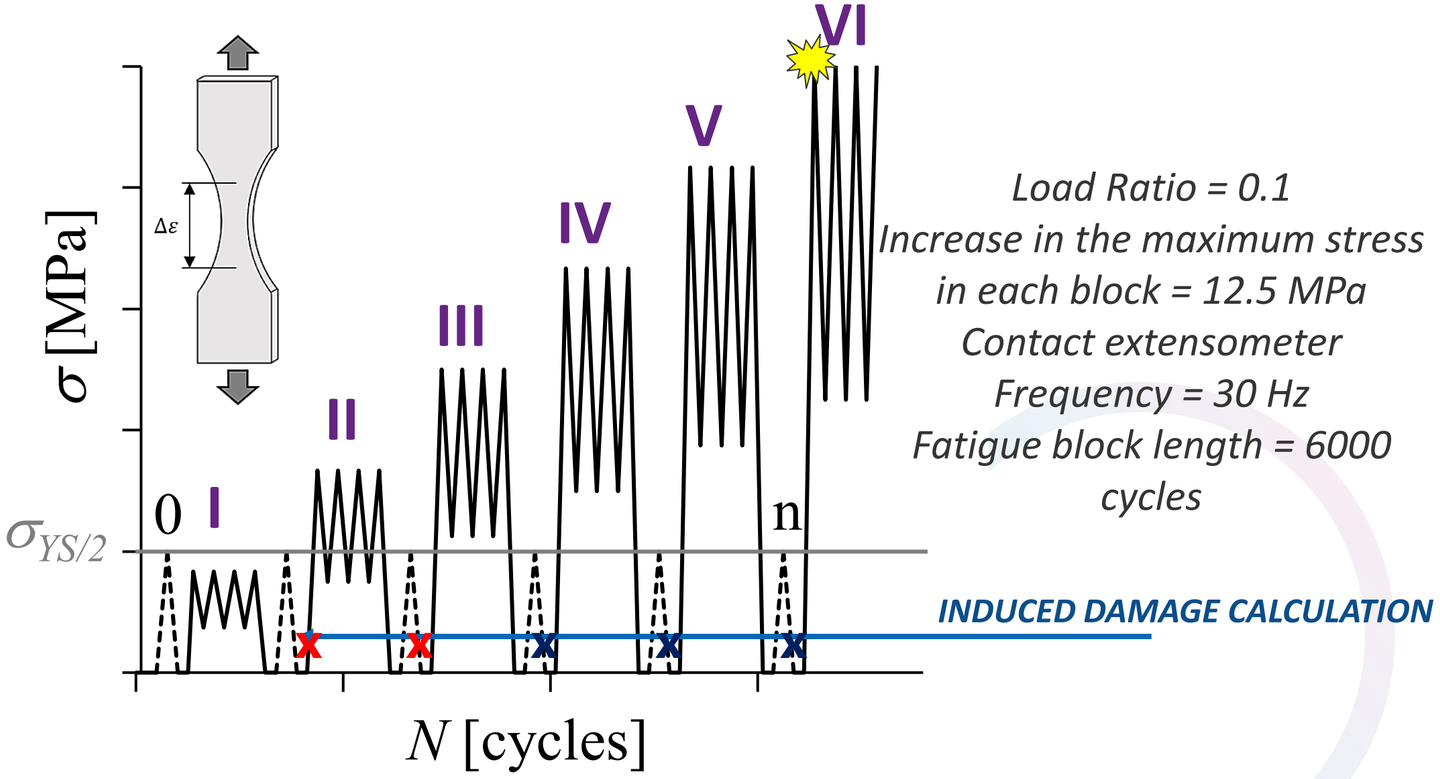
The evolution of **microcracks** reflects the **damage** accumulated in the Sp can be calculated through **Stiffness** measurements

Method developed at Eurecat

Characterization of additive manufactured materials

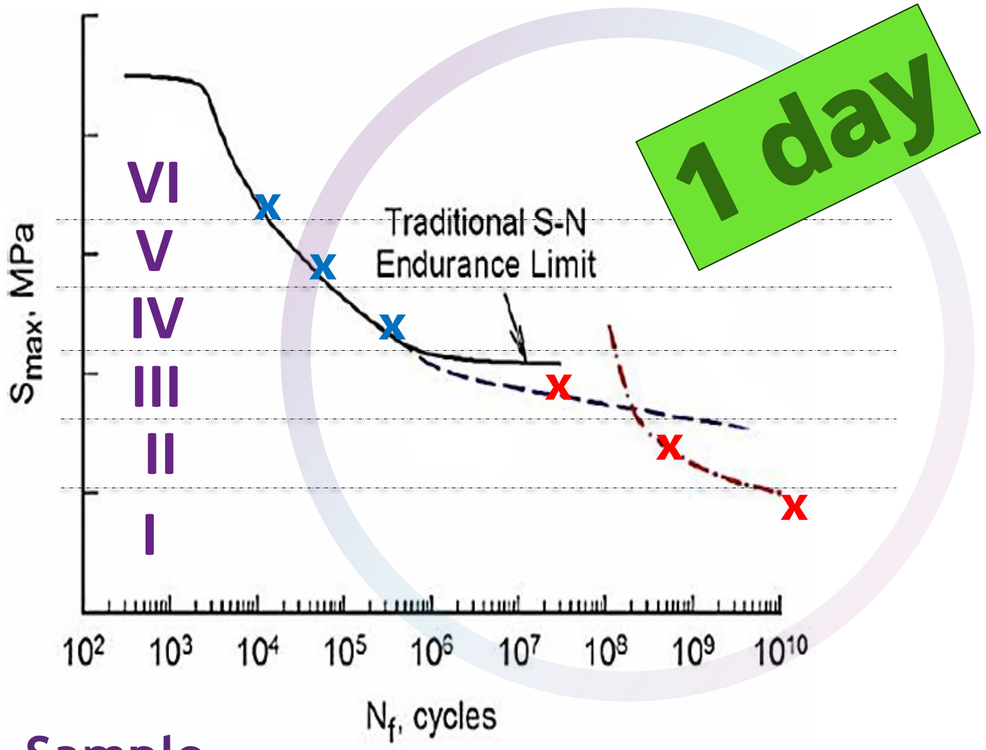
Mechanical properties

New method



Load Ratio = 0.1
Increase in the maximum stress in each block = 12.5 MPa
Contact extensometer
Frequency = 30 Hz
Fatigue block length = 6000 cycles

INDUCED DAMAGE CALCULATION



1 Sample

↳ **Load vs. Damage Monitoring**

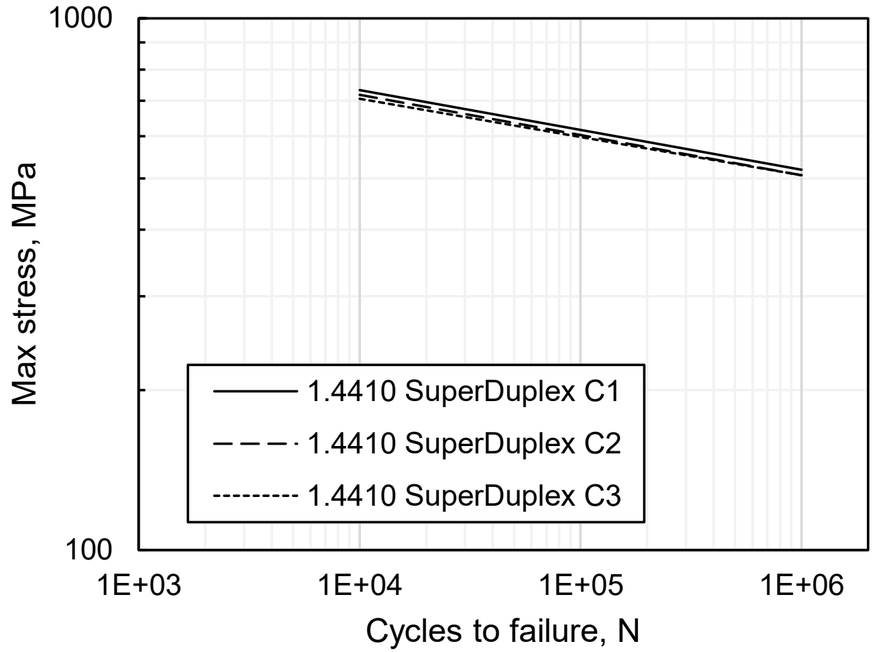
↳ **Fatigue limit**

Characterization of additive manufactured materials

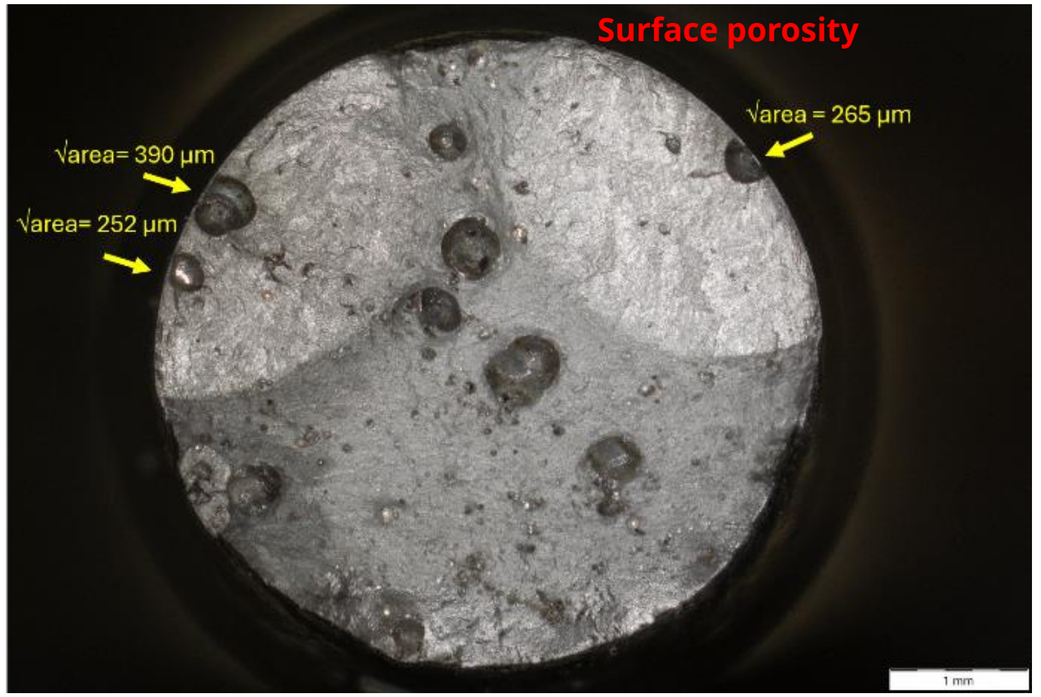
Mechanical properties

Rapid screening differentiated route-specific fatigue responses and identified the critical fatigue-controlling features.

CrNiMoN 25-7-4 (1.4410) printed using DED



Material	Condition	σ_f [MPa]
1.4410 SuperDuplex	C1	**519 ± 9**
1.4410 SuperDuplex	C2	506 ± 9
1.4410 SuperDuplex	C3	506 ± 9



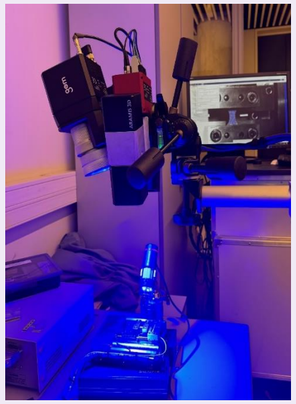
Main result: total porosity alone does not predict fatigue.
It is more important **where is located the porosity** (-)

Characterization of additive manufactured materials

Mechanical properties

COMMON TEST BASIS

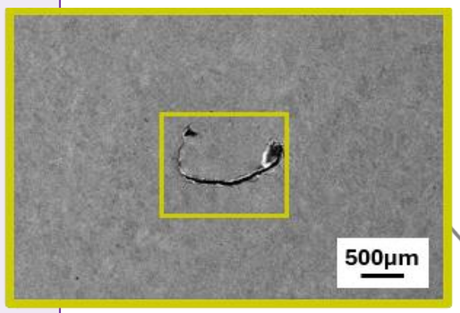
- Constant displacement rate of 1mm/min
- High-resolution video camera was used to record the test at a frame rate of 2 images/second
- Virtual extensometer with an initial length of 6 mm

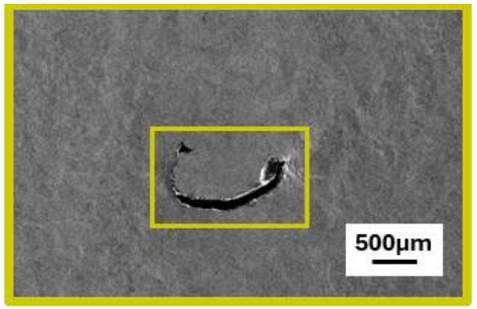


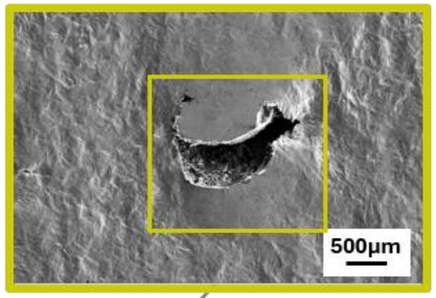


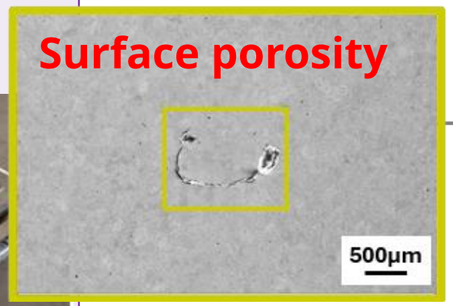


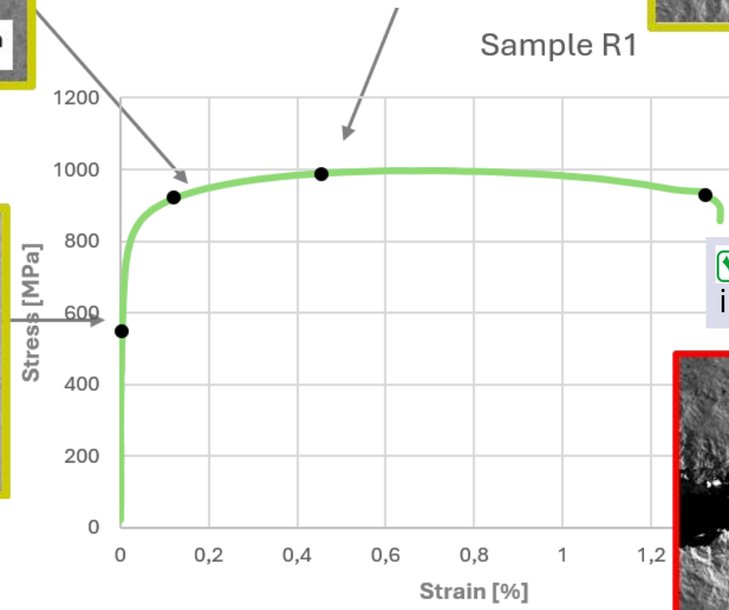
CrNiMoN 25-7-4 (1.4410) printed using DED



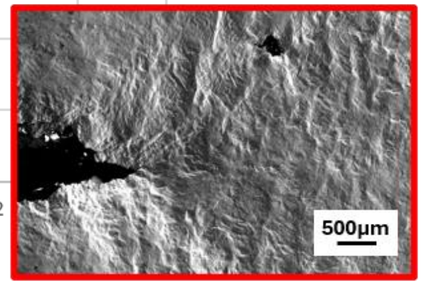








✅ The surface defects initiate the fracture

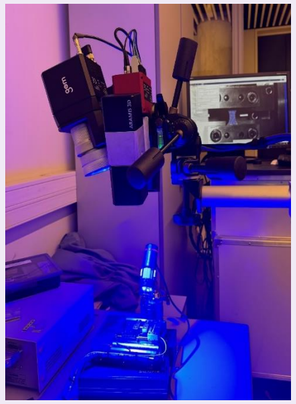


Characterization of additive manufactured materials

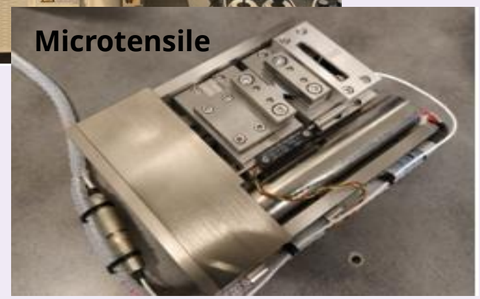
Mechanical properties

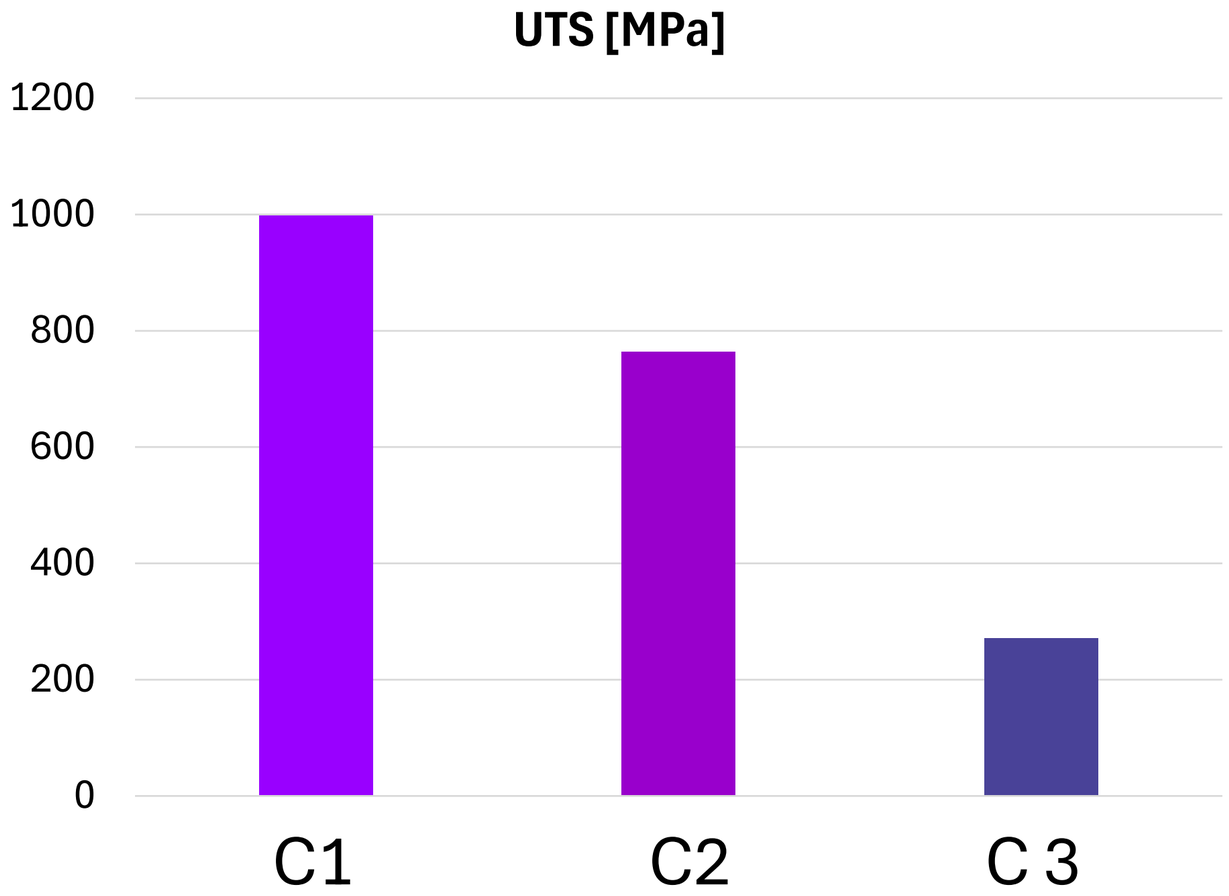
COMMON TEST BASIS

- **Constant displacement rate of 1mm/min**
- **High-resolution video camera was used to record the test at a frame rate of 2 images/second**
- **Virtual extensometer with an initial length of 6 mm**







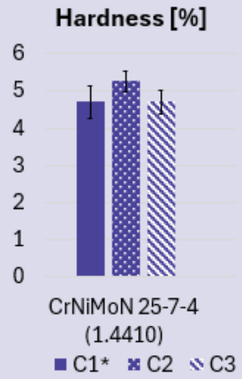


Main result:. It can be clearly observed that the C1 specimen support higher monotonic tensile loads than the other conditions.

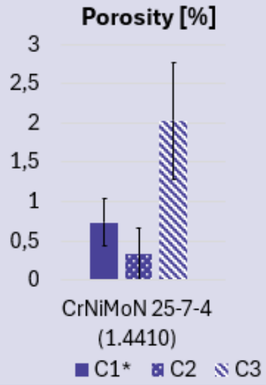
Characterization of additive manufactured materials

Summary

Hardness and porosity

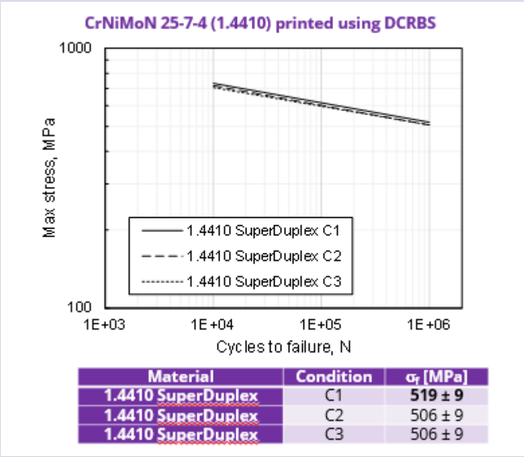


Regarding hardness, we can identify differences between conditions, but we need to consider that in all cases there is quite a bit of variation in the results, which minimizes the difference between conditions

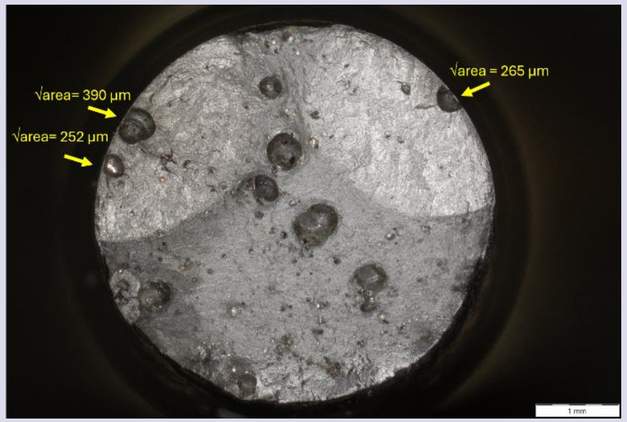


Finally, porosity is the property that shows the most differences between conditions within the same additive manufacturing technologies.

Fatigue resistance

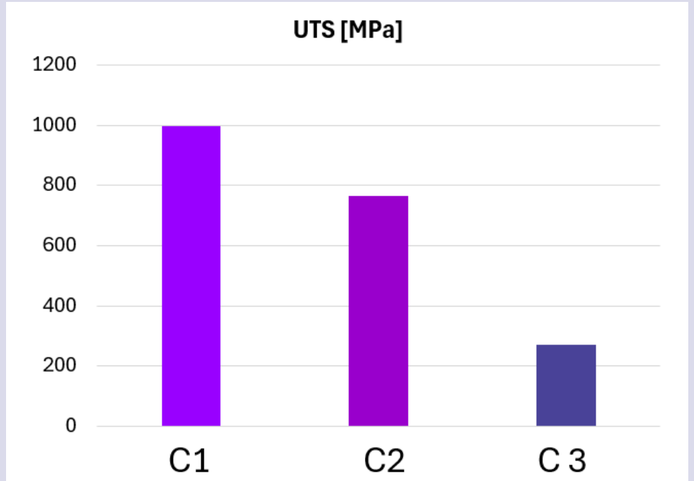


Material	Condition	σ_f [MPa]
1.4410 SuperDuplex	C1	**519 ± 9**
1.4410 SuperDuplex	C2	506 ± 9
1.4410 SuperDuplex	C3	506 ± 9



Main result: total porosity alone does not predict fatigue. Critical-defect size, morphology and **location must be considered.**

Microtensile



Main result:. It can be clearly observed that the C1 specimen support higher monotonic tensile loads than the other conditions.

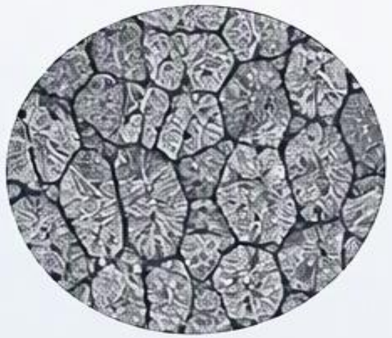
The location of the porosity is more important than the amount of it

Characterization of additive manufactured materials

Additive manufacturing is not only a new way of producing components, but also a **fascinating** opportunity to better understand the relationship between **process, microstructure, and properties.**



PROCESS



MICROSTRUCTURE



PROPERTIES

Same materials. New possibilities.

CHARACTERIZE
UNDERSTAND
OPTIMIZE
INNOVATE

Characterization of additive manufactured materials

Thank you for your attention!

Anna Barrero Pijoan
Researcher of Tribology and micromechanics line
anna.barrero@eurecat.org