The 15th World Conference on Titanium

I·M3 Events

Research, Development, and Application of Titanium in France

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[1] Director R&D , Timet Savoie ,
[2] Professor, Université de Lorraine

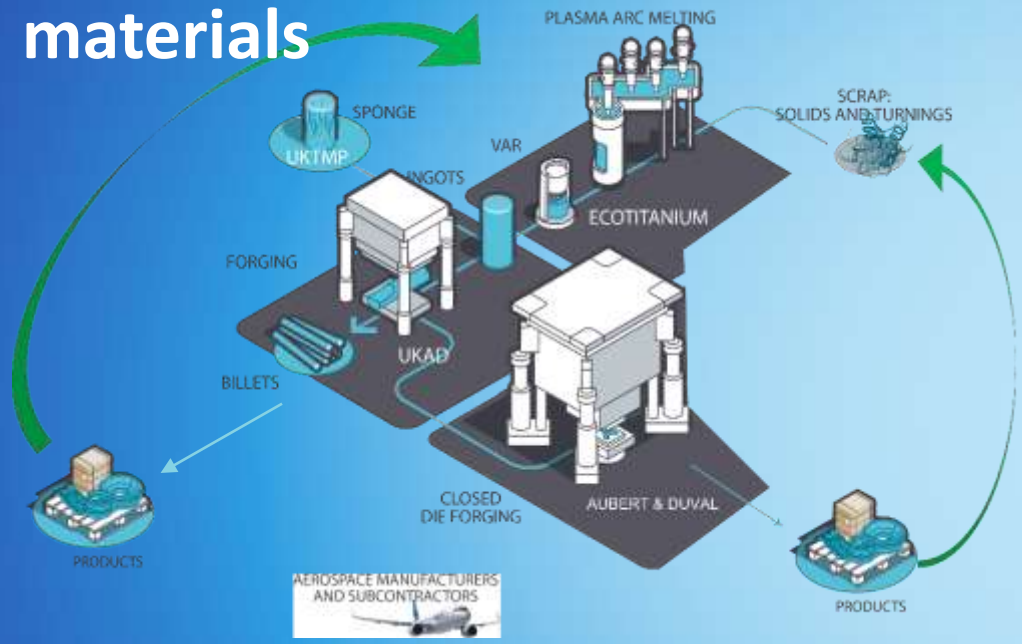
EDINBURGH

12-16 JUNE 2023

FRANCE TITANE
The French Titanium Association

Focus on the titanium channel:

a European solution for the processing of aerospace titanium grade from recycled materials



Circular economy model:

- ✓ Collect scrap from the processing stage (internally & from our customers)
- ✓ Process these shavings and large pieces of scrap
- ✓ Melting / Remelting to produce new ingots

AUBERT&DUVAL

100% **UKAD** *(France)*

ADEME
AGENCE DE LA TRANSITION ÉCOLOGIQUE

45%
43% **EcoTitanium** *(France)*
12%

- > **EcoTitanium** produces aeronautical quality titanium ingots (Ti6Al4V) out of scrap collected from the European aeronautical manufacturers and subcontractors
- > **UKAD** is specialized in the **forging of titanium semi-finished products** (billets, flat products and square bars)
- > EcoTitanium & UKAD is **qualified by the leading aerospace manufacturers**: AIRBUS, SAFRAN, BOEING, BOMBARDIER… and more to come
- > The titanium channel is starting its PQ qualification program, aiming for future validation

Christophe Petit (Aubert & Duval)
Titanium: a promising metal full of challenges *Thursday morning*

TIMET Savoie: production of billets

- Recycling of chips since 1980
- Increase capacity
- Upgrade of VAR furnaces

framatome

TIMET

IMET Alloys: preparing revert

Processing Capabilities for Titanium and Superalloys

- **Titanium Solids**
  - PQ/ Rotating and Standard Melting Applications

- **Titanium Turnings**
  - PQ/ Rotating and Standard Melting Applications
  - 2024

IMET Alloys

Excellence in Global Materials Management

DRIVING CHANGE. DELIVERING QUALITY. ADDING VALUE.

Powder: manufacture and recycling

ACNIS

New
Additive
manufacturing lab

ACNIS International

LISI AEROSPACE – LAFIS – forgings

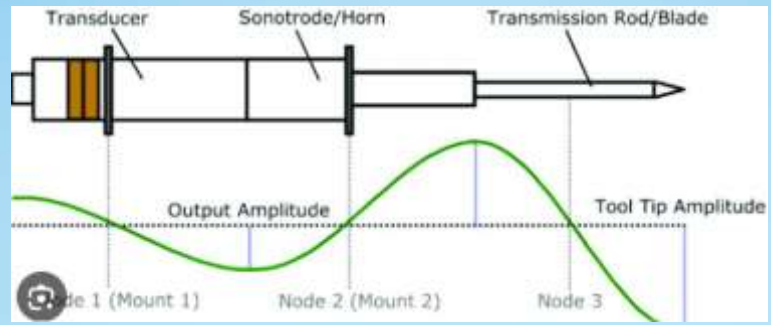
Transfer from Bologne to new plant in Chaumont 2023

lisi AEROSPACE
Structural Components

FORECREU: cannulated bars for medical application

- Challenge
- stabilize the Young's modulus to ensure the repeatability to avoid overheating

Ultrasonic cutters for bone & soft tissue



FORÉCREU
BUILDING CRITICAL PARTNERSHIPS

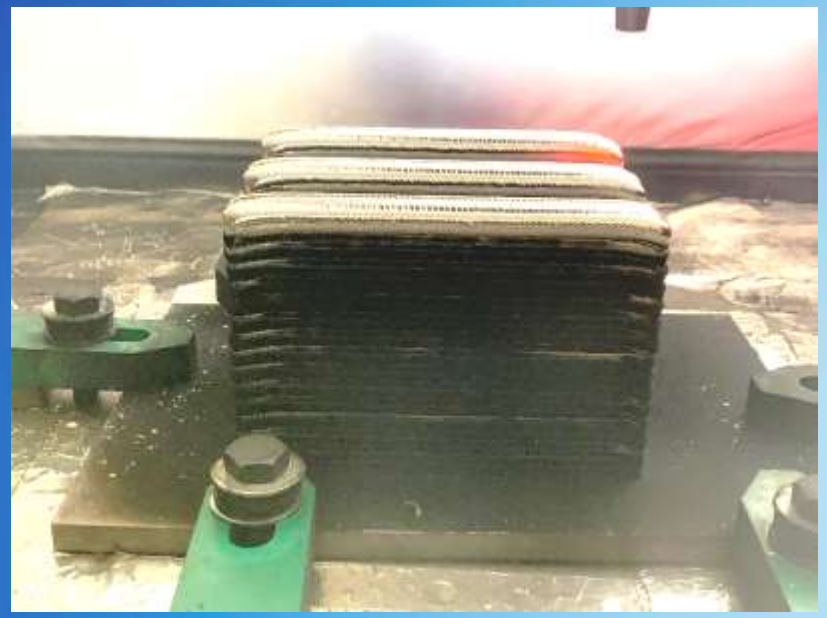
Safran Additive Manufacturing Campus

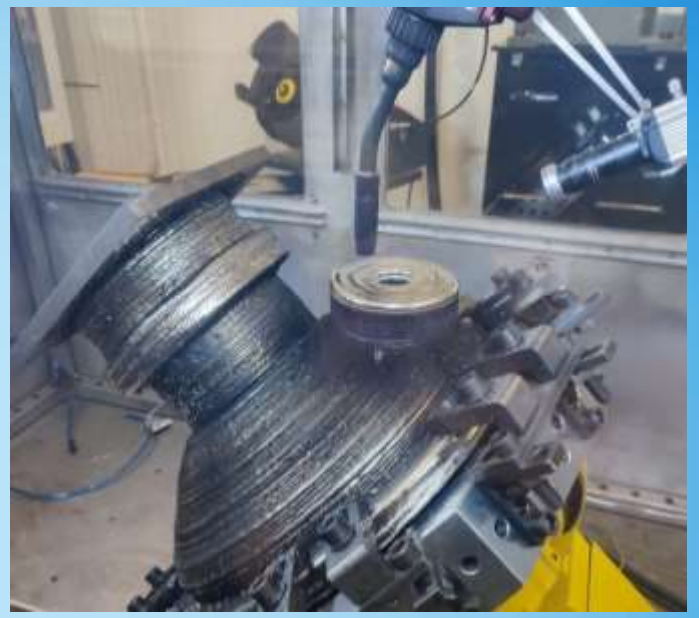
R&T and production centre of Safran

Hydraulic control of the braking system

- 12 500 m^2 fully dedicated to additive manufacturing
- Bring together in one place all stages of parts implementation for all the Safran companies: R&T, design, development, industrialisation, manufacturing
- Staff – 2026 objective: 200 people (PhDs, engineers, technicians and operators)

Navalgroup: DED trial parts





Other

- ACB : development of Versatile Linear Friction Welding for engine blisk
- Cefival now part of Montana Aerospace

Development of alloys

- TIMETAL®575 for landing gear and engine disk – Ti 5.3Al 7.7V 0.25Fe 0.3Si
- TIMETAL®18 for landing application – Ti 5.5Al 5Mo 5V 2.3Cr 0.8Fe
- TiZrO for medical application – Ti 4.5Zr 0.6O

Research Landscape in France (2019-2023)

- > 40 presentations
- 15 projects funded by ANR, 4 in assoc. with IRT
- 77 PhD works
  (54 defended, 23 in progress)

Topics

1. Alloy design
2. Processes
3. Mechanical properties
4. New processes
5. Environment
6. Biomedical
7. Intermetallics
8. Irradiation

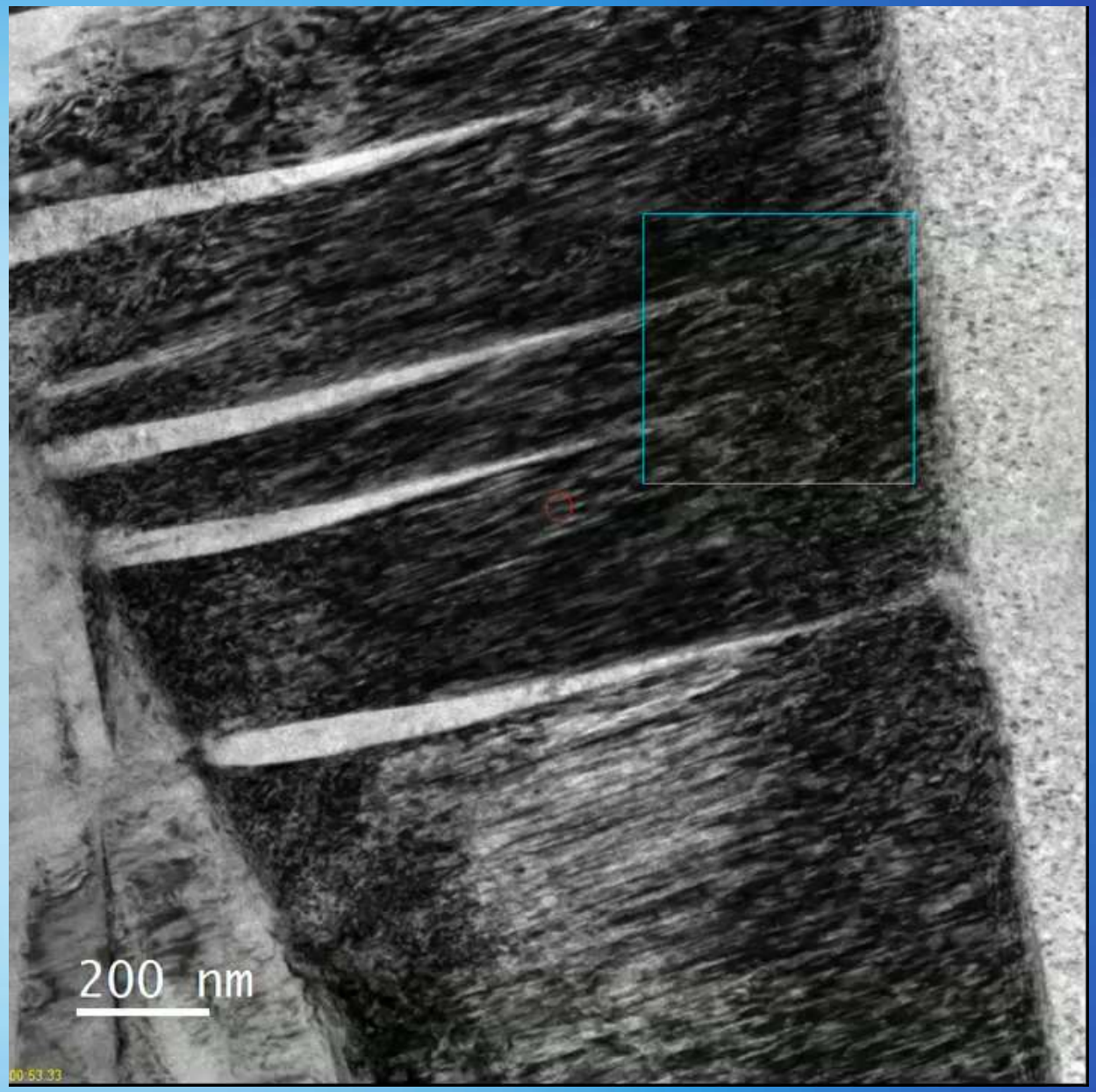
1. Alloy design 1/4

TRIP/TWIP

- Fan Sun (Paris)
  Early-stage isothermal omega precipitation and its influences on TRIP/TWIP effects in metastable beta Ti-12Mo alloy, *Thursday Morning*

- Lola Lilensten (Paris)
  - Mechanical properties of TRIP/TWIP and TWIP Ti-alloys during dynamic loading, *this morning*
  - Unveiling the contribution of the various interfaces to the work-hardening in TRIP/TWIP titanium alloys, *Thursday morning*
  - {332}⟨113⟩ mechanical detwinning as a new deformation mechanism in a TWIP Ti-alloy, *Thursday afternoon*

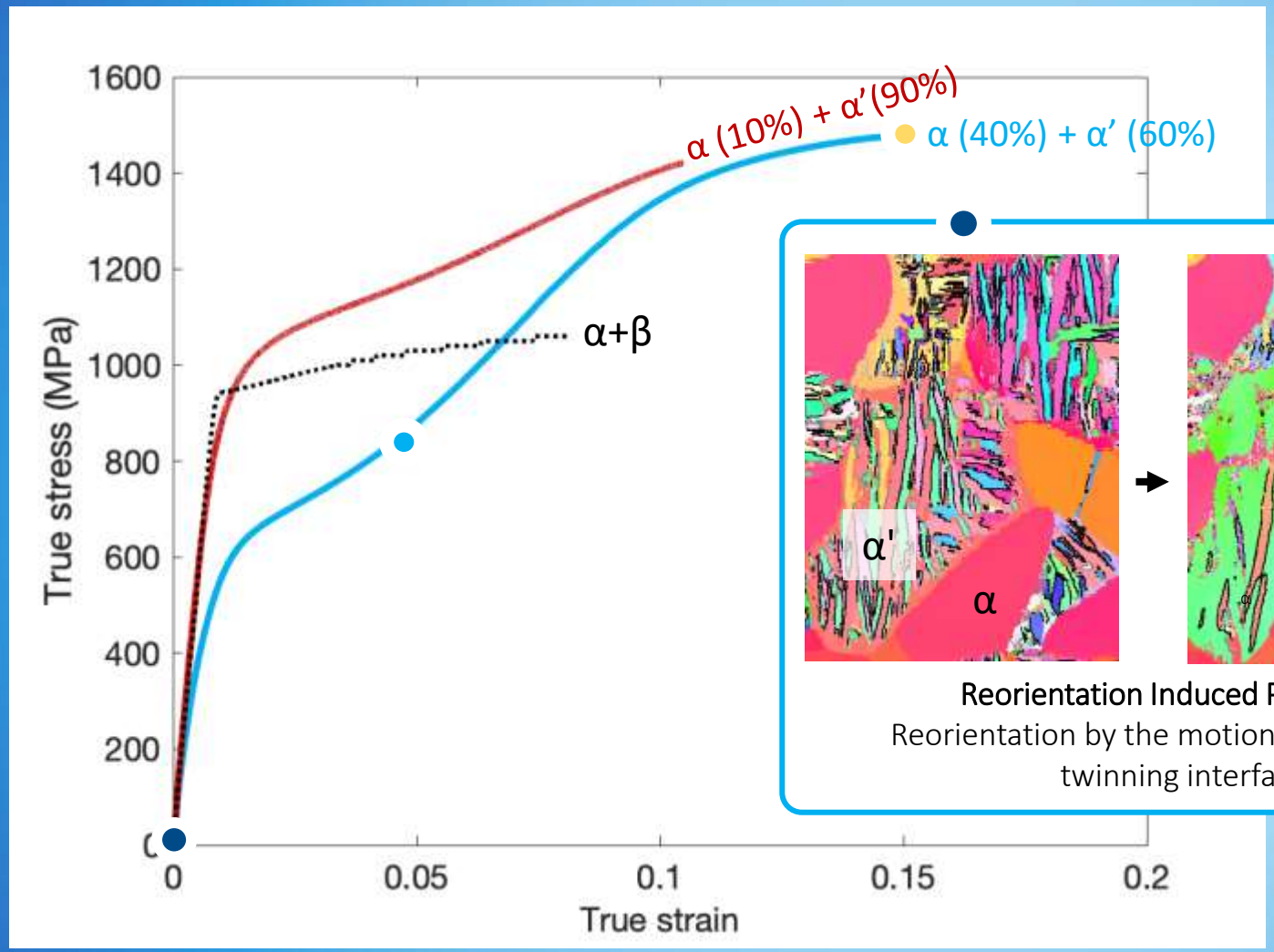
- Clémence Fontaine (Paris)
  Strategies for accelerated development of strain-transformable alloys by chemically graded materials: from process to local characterization, *Thursday morning*

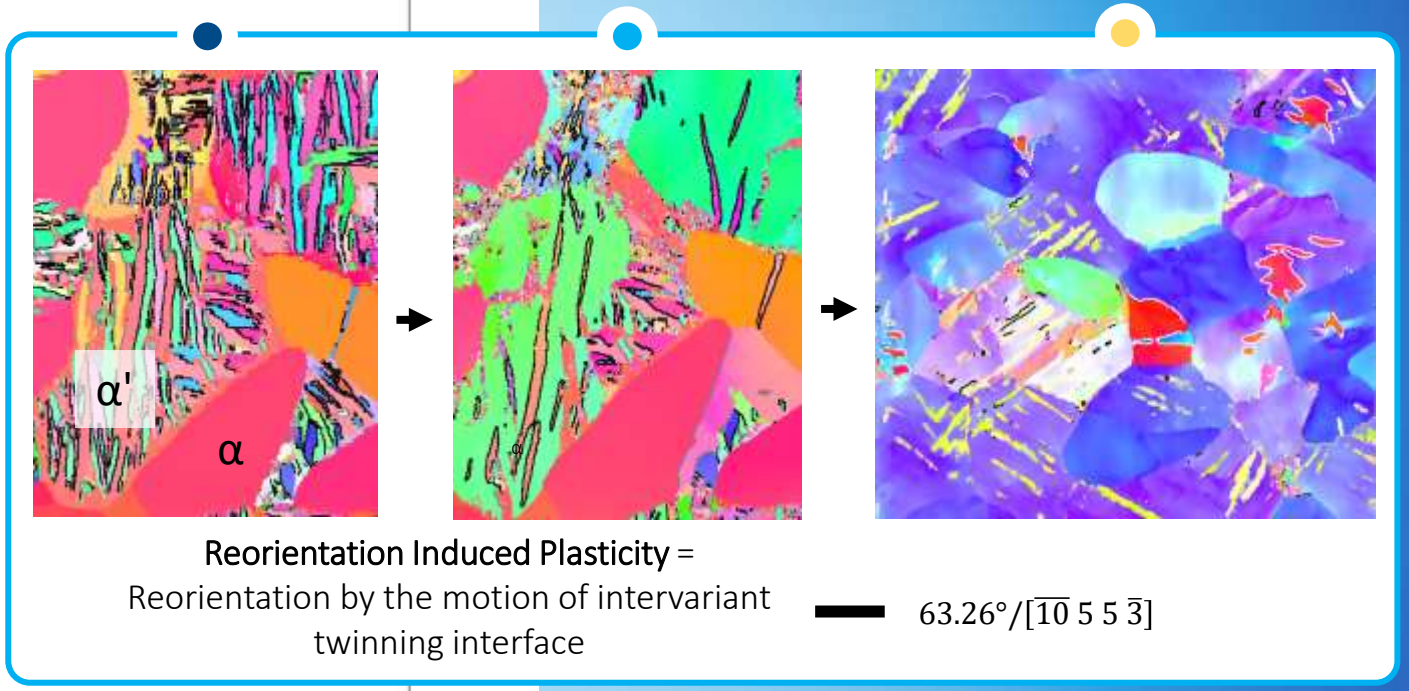


Qian et al. Acta Materialia 2023

1. Alloy design 2/4

RIP





Reorientation Induced Plasticity =
Reorientation by the motion of intervariant twinning interface

$63.26°/[\overline{10}\ 5\ 5\ \overline{3}]$

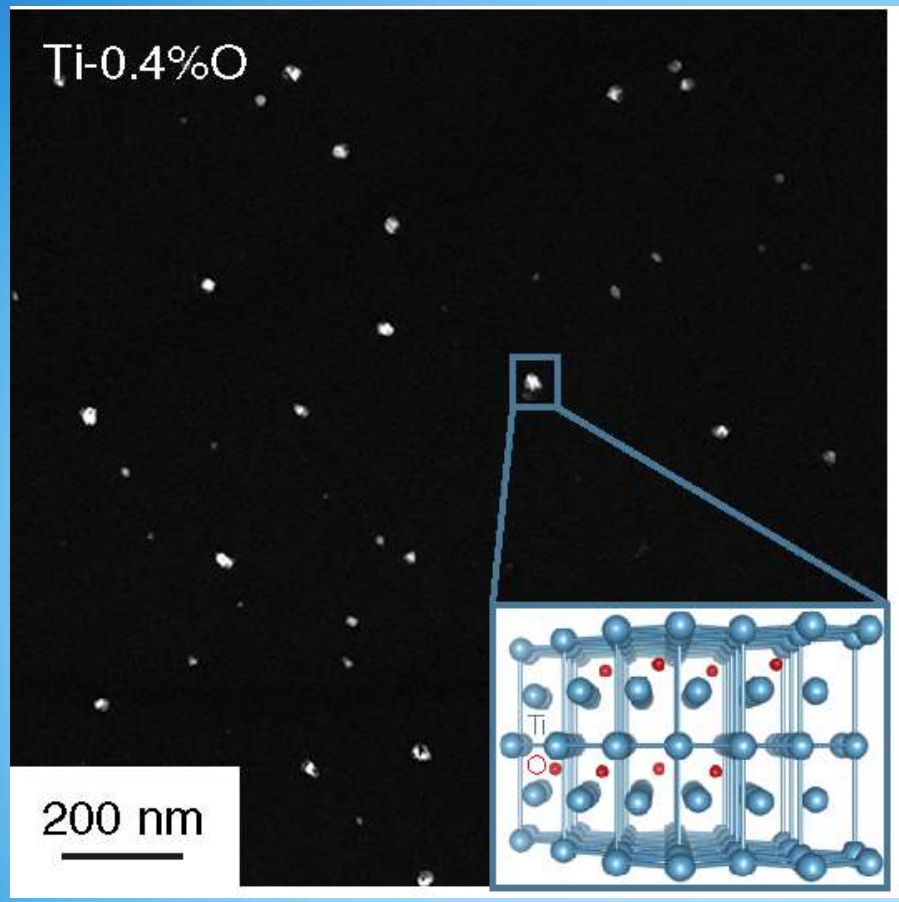
Dumas et al., Acta Materialia 2023

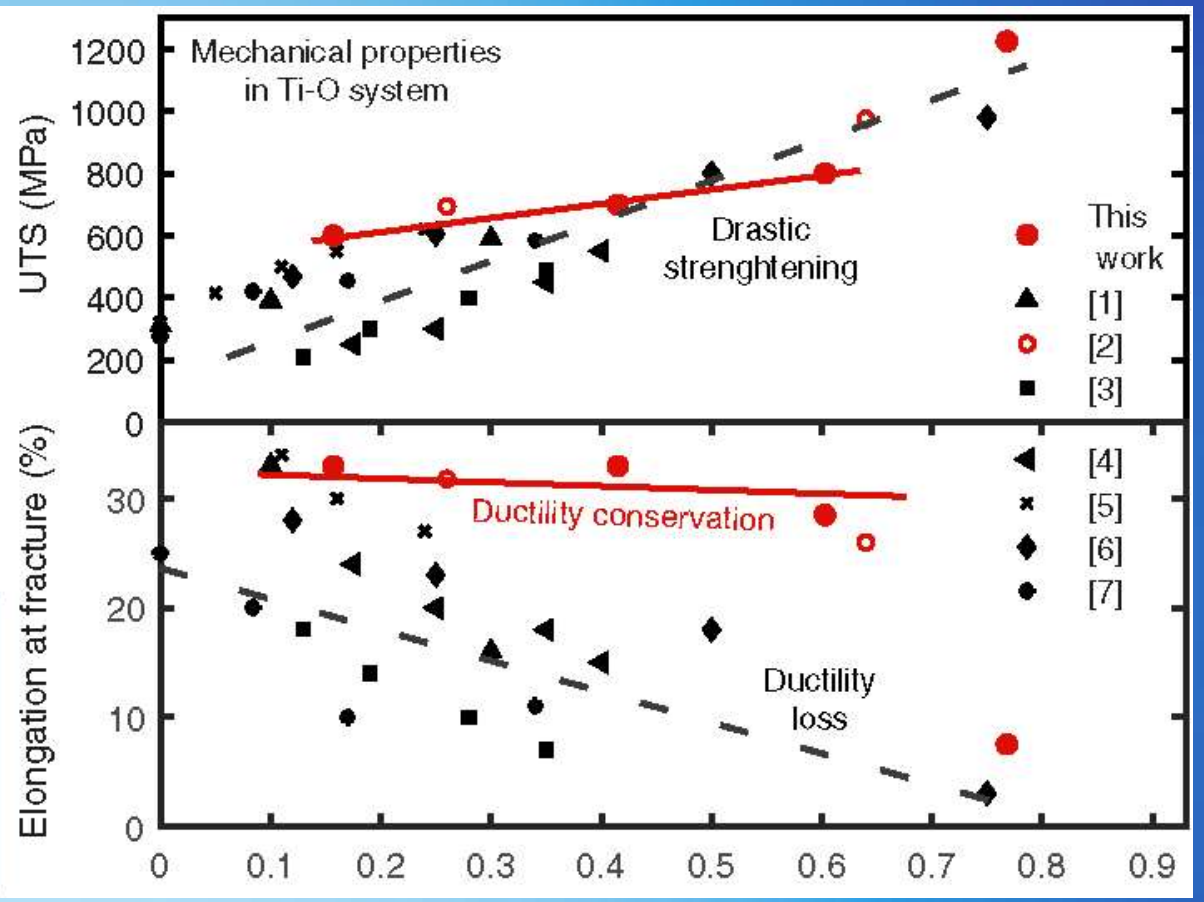
- Frédéric Prima (Paris) New strategies for strain-hardening improvements in titanium alloys, *tomorrow afternoon*

1. Alloy design 3/4

Poulain et al., Materials Research Letters 2022

Oxygen enriched alloys





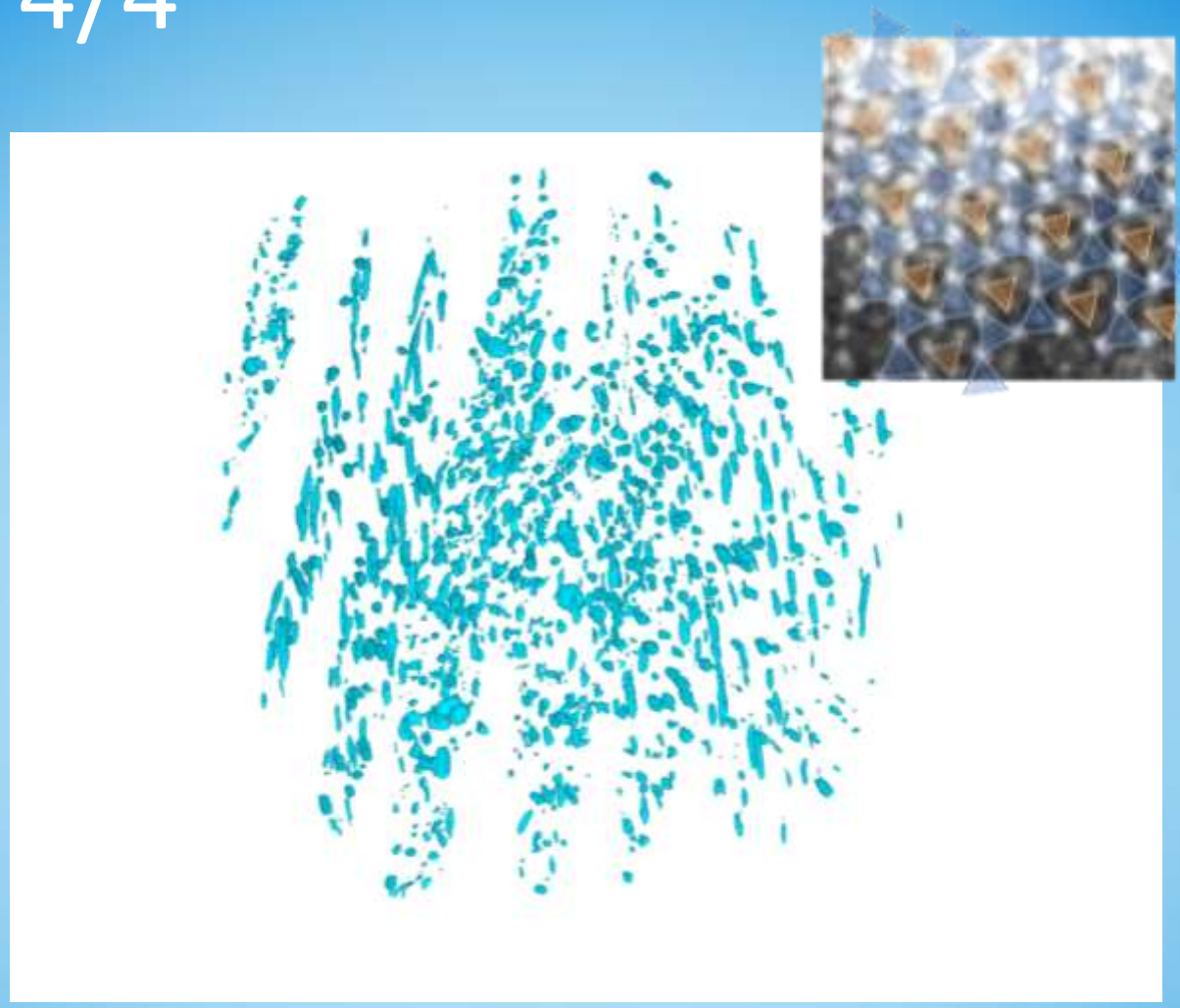
- Régis Poulain (Thiais) [awarded best PhD thesis of France Titane in 2021] Crystallographic insights into the oxygen ordering in Ti-O system: consequences on the mechanical properties, *tomorrow morning*
- Fabienne Amann (Paris) On the oxygen ordering mechanisms in dilute Ti-Zr-O systems, *tomorrow afternoon*
- Raphaëlle Guillou (CEA Saclay) Compositional effects on the formation and thermal evolution of ordered precipitates in oxygen rich Ti-Zr-O: an in-situ synchrotron XRD diffraction study, *tomorrow afternoon*

1. Alloy design 4/4

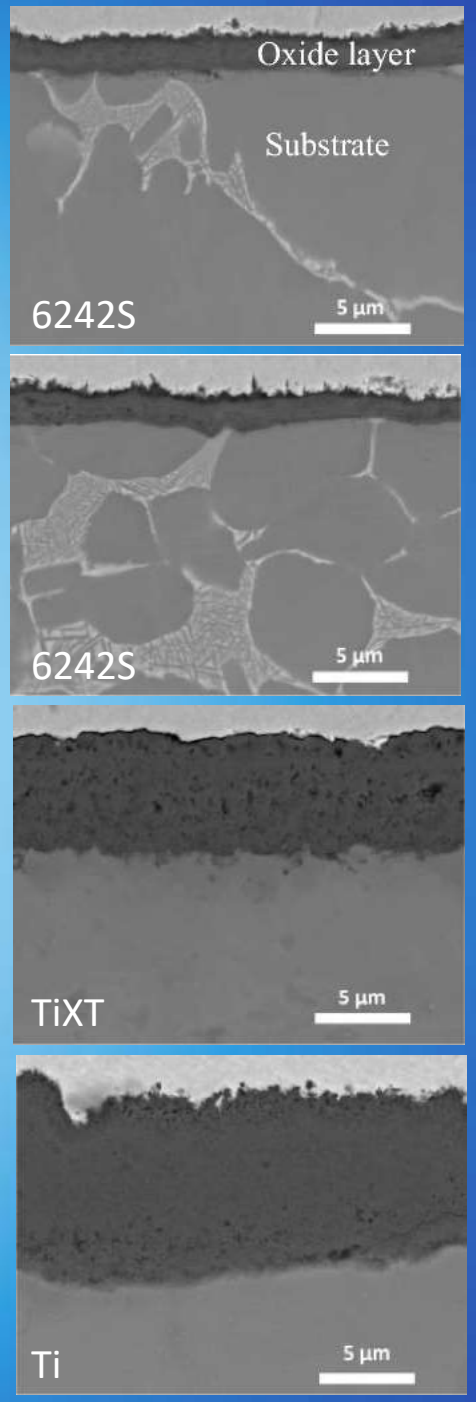
High temperature alloys

ANR project ALTITUDE: Designing new alloys with ML + full characterization

- Thibaut Armanni (Onera)
  Effect of silicon addition on deformation mechanisms of near-α titanium alloys,
  tomorrow after lunch
- Benjamin Vincent (Dijon)
  Effect of alloying elements on the high temperature oxidation of near-α titanium alloys,
  Wednesday morning



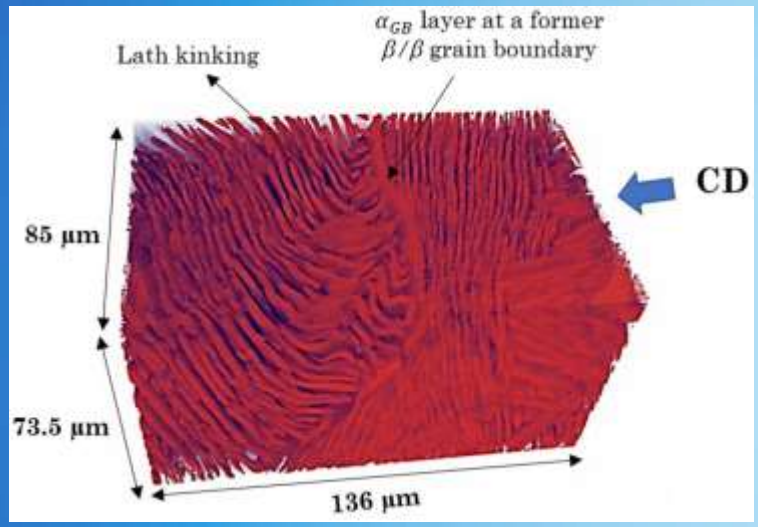
Armanni, Fossard (Onera/CNRS)

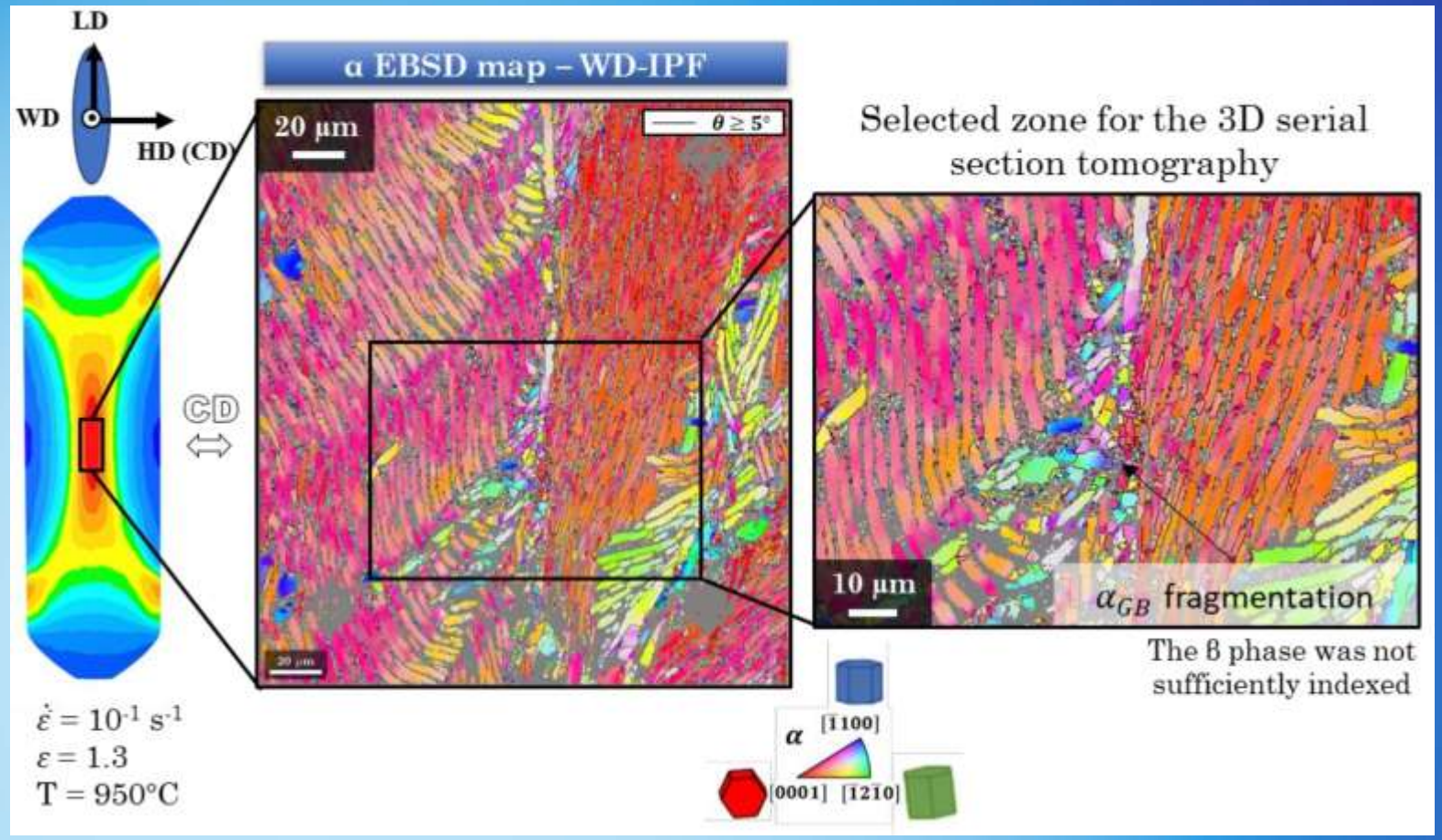


Vincent, Optasanu, Herbst, Chevalier, Popa, Montesin, Lavisse, Oxidation of Metals 2021

2. Processes 1/3

Thermomechanical





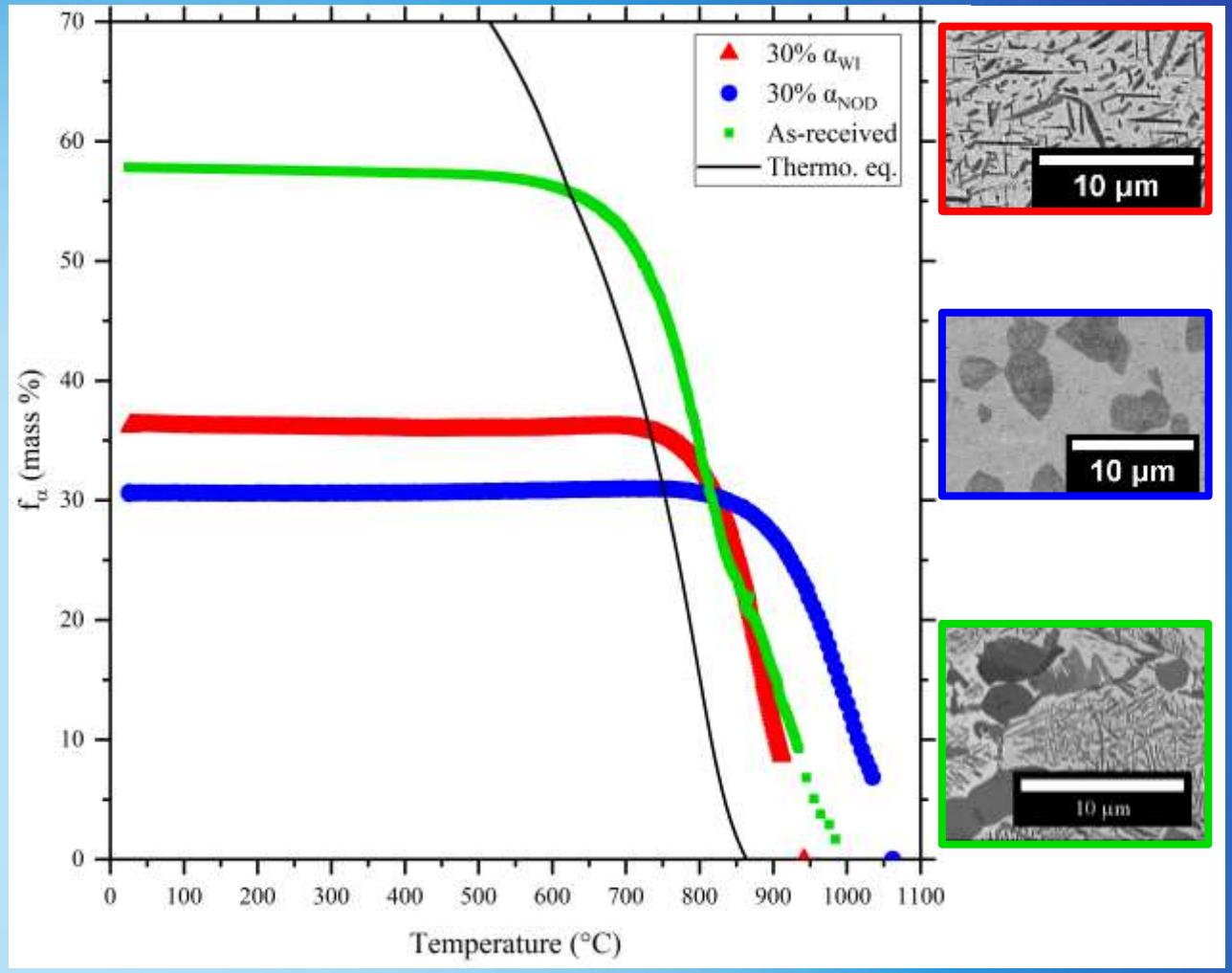
Brozovi Gariglio, PhD thesis Univ PSL. 2022, supervis. Nathalie Bozzolo (Nice)

- Matheus Brozovic Gariglio (Nice) Estimation of the dislocation density distribution, by microscopic and macroscopic approaches, in titanium alloys after hot-deformation in the α+β domain, *Thursday afternoon*
- Ioannis Skordilis (Paris, Nice) Recrystallization mechanisms and kinetics of forged Ti-10V-2Fe-3Al alloy: an in-situ resistometric investigation *Thursday morning*
- Denis Solas (Orsay) Influence of α/β-forging parameters on β-texture evolution and its consequences on coarse grain formation during β-annealing of Ti-6Al-4V, *tomorrow morning*

2. Processes 2/3

Heat treatments

- Moukrane Dehmas (Toulouse)
  - Effect of initial microstructure on phase transformation under rapid heating of the Ti-5553 titanium alloy, *Thursday afternoon*
  - Precipitation sequence during ageing in the Ti-5553 titanium alloy: effect of initial microstructure, heating rate and thermal cycling, *Thursday afternoon*
- Emmanuel Hoareau (Toulouse) Influence of the initial microstructure on the phase transformation kinetics during aging in the Ti-575 titanium alloy, *tomorrow morning*
- Aude Mathis (Navalgroup) Titanium at high temperature: a case study for thermal aging of titanium, *tomorrow afternoon*
- Stéphane Godet (Bruxelles) Enlarging the palette of mechanical properties of TI64 by a quenching and partitioning approach, *this morning*

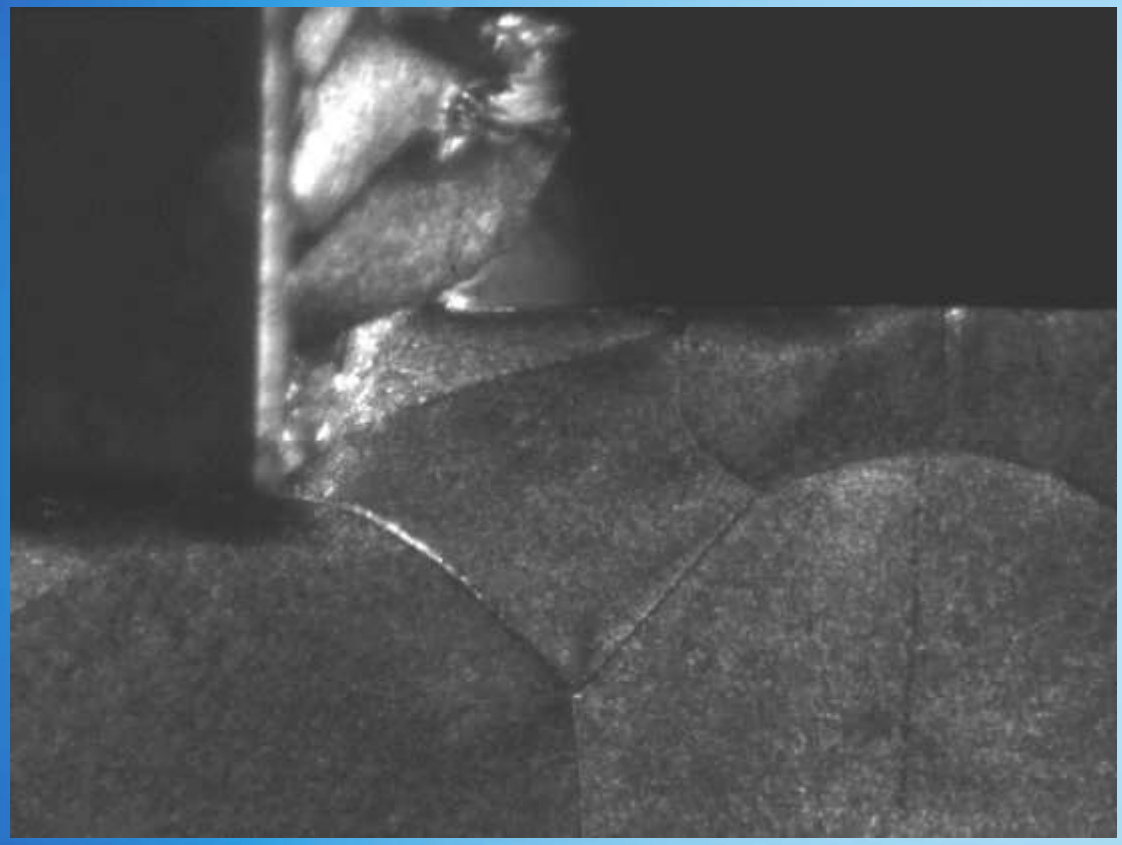


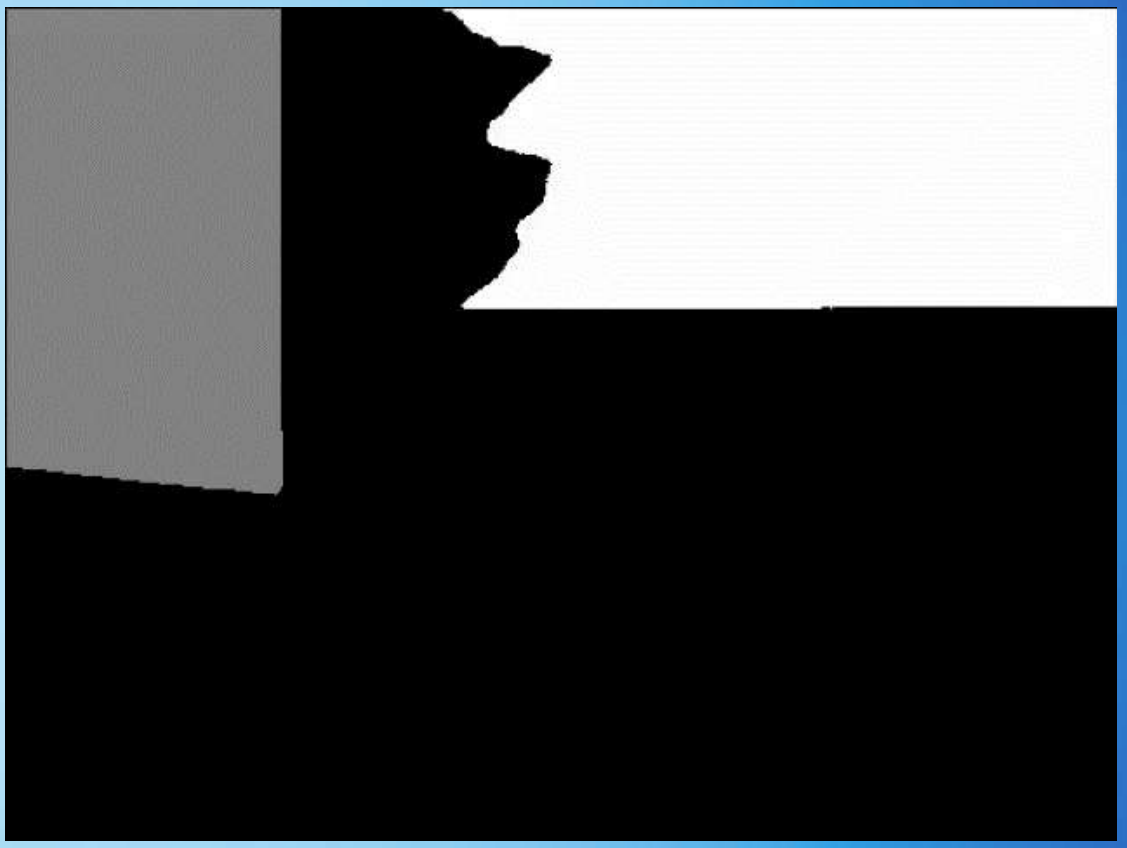
Chamfreau (Toulouse) et al., Journal of Materials Science 2022

- Benoît Denand (Nancy) Contribution of electrical resistivity to the quantification of α and ω_{iso} phase transformations in Ti15Mo and Ti10Mo titanium alloys, *Wednesday morning*

2. Processes 3/3

Machining





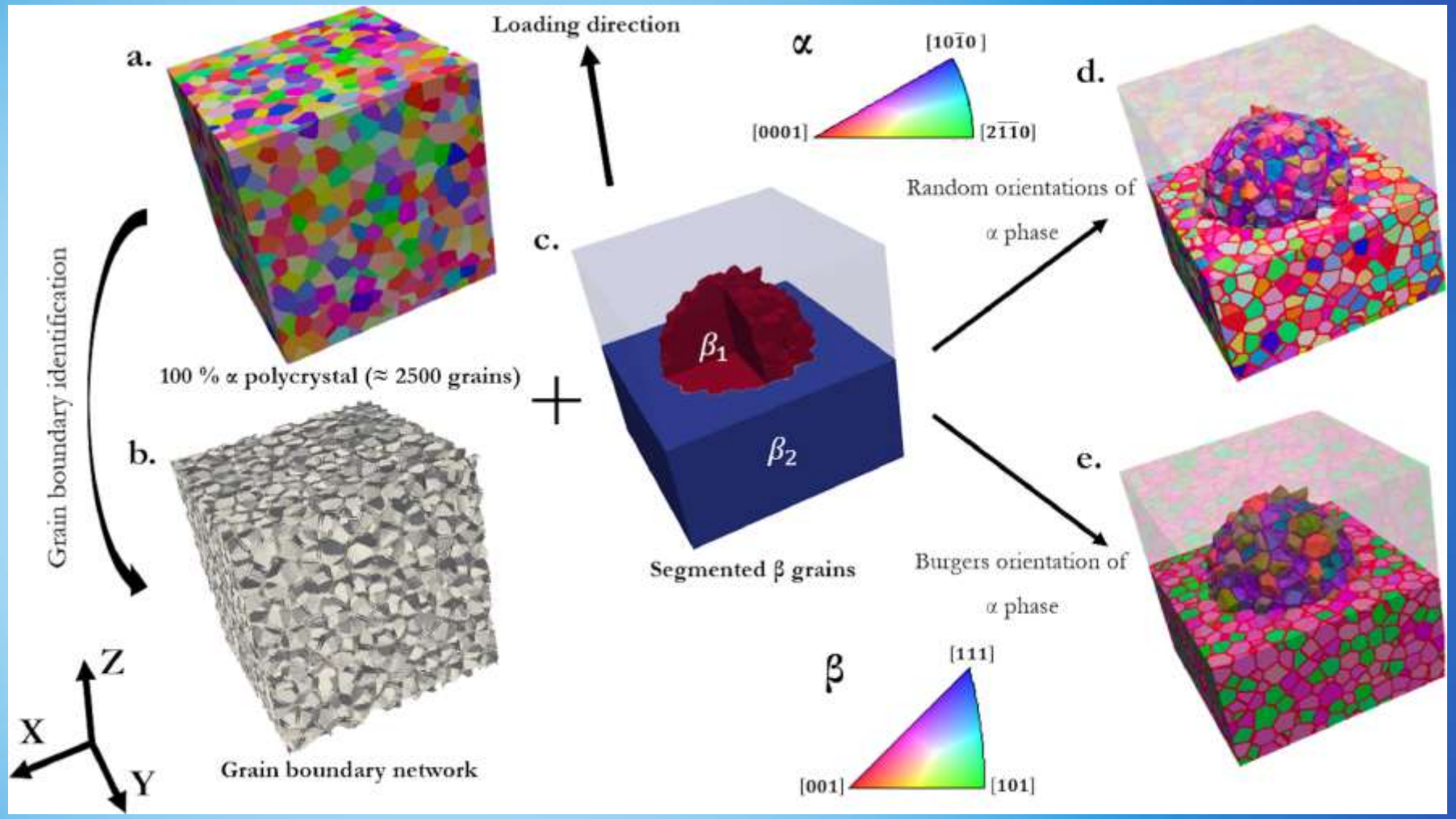
Pouliquen, PhD thesis HESAM Univ. 2022, supervis. Guénaël Germain (Angers)

ANR project DEMUTI: Designing microstructures for machining of Ti5553

3. Mechanical properties 1/3

Deformation mechanisms and texture

- Samuel Hémery (Poitiers)
  From strain localization to anisotropic tensile properties in Ti-10V-2Al-3Fe,
  Wednesday morning
- Mélaine Tournay (Metz)
  Investigation of the deformation behaviour of a CP-Ti sheet and a Ti-3Al-2.5V sheet during cold rolling and annealing, *this morning*
- Ali Rouwane (Albi)
  Strain localization in Ti and Ti-alloys using three-dimensional topographic imaging, *tomorrow morning*



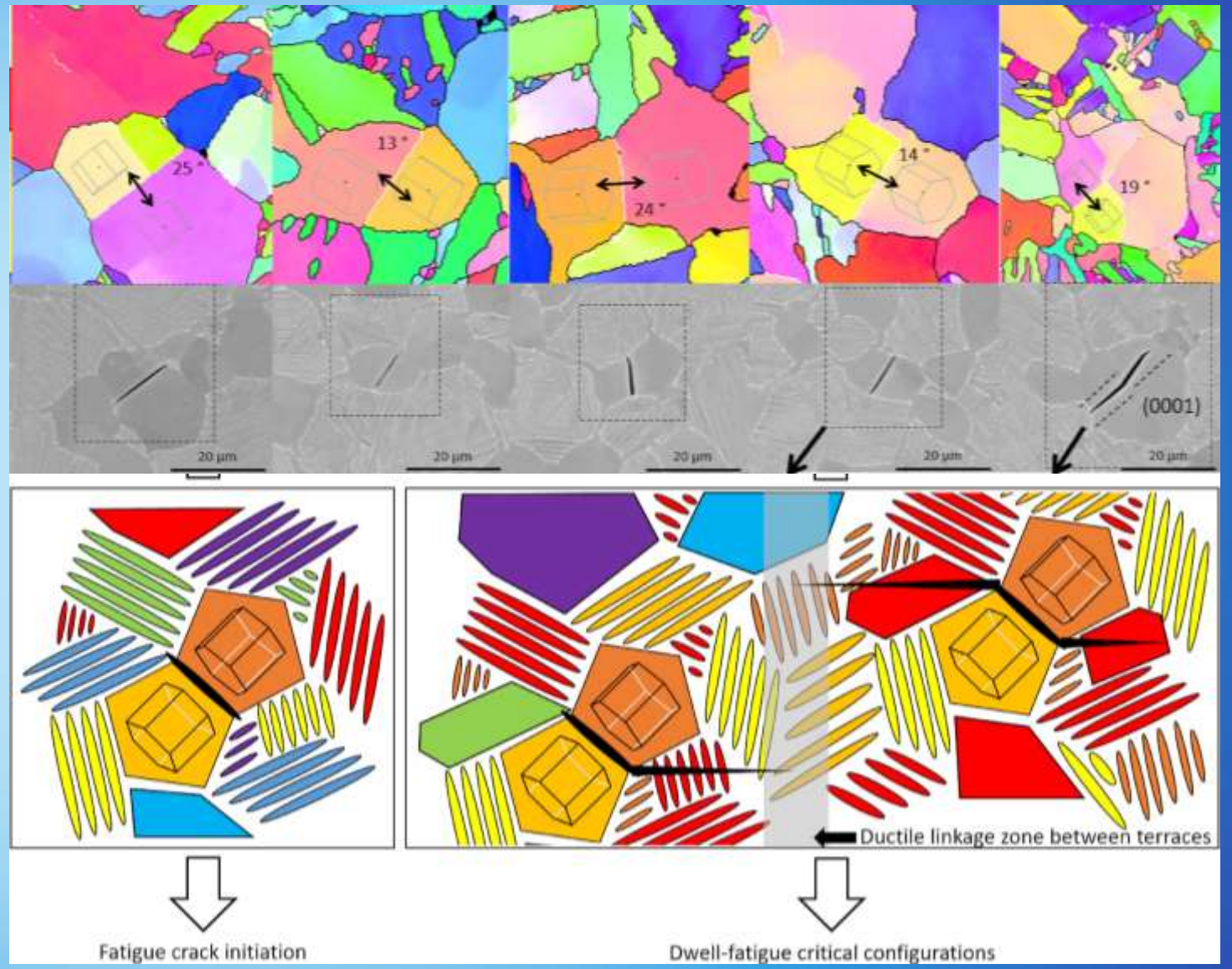
Huet et al., Acta Materialia 2022

3. Mechanical properties 2/3

Fatigue

- Samuel Hémery (Poitiers) From slip activity to fatigue crack nucleation at basal twist grain boundaries in titanium alloys, *Friday morning*
- Patrick Villechaise (Poitiers) Are fatigue crack initiation mechanisms dependent on microstructure, composition and cyclic loading conditions in α+β Ti alloys? *tomorrow morning*

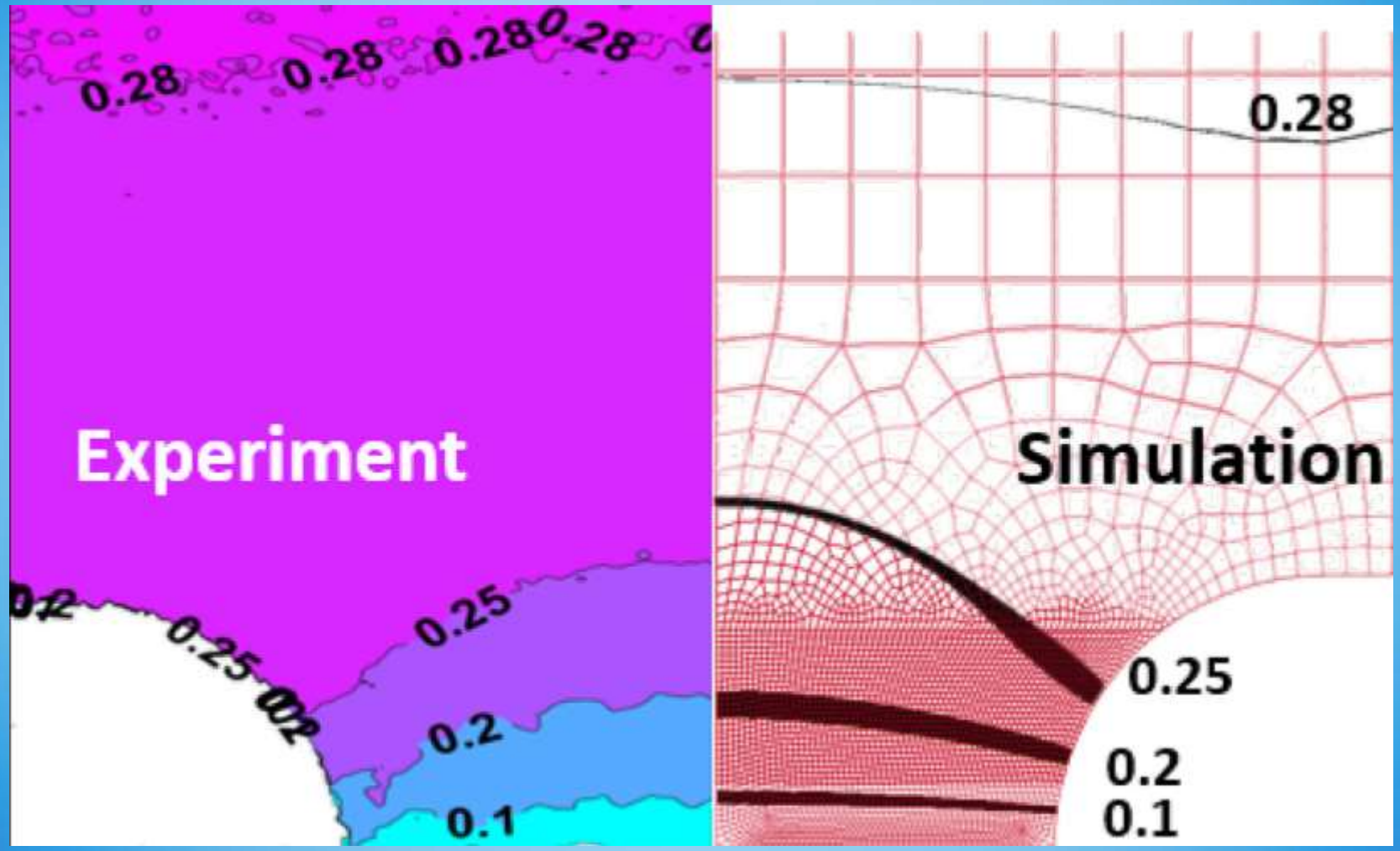
- Larissa Caroline Martins Moreira (La Rochelle) Some impact of hydrogen concentration and distribution on low cycle fatigue behavior of an alpha titanium alloy, *tomorrow afternoon*
- Martin Ferreira Fernandes (São Paulo) Fatigue behavior of fully lamellar Ti-6Al-4V alloy with Cr/CrN multilayer coating, *tomorrow morning*



Lavogiez et al., Acta Materialia 2023

3. Mechanical properties 3/3

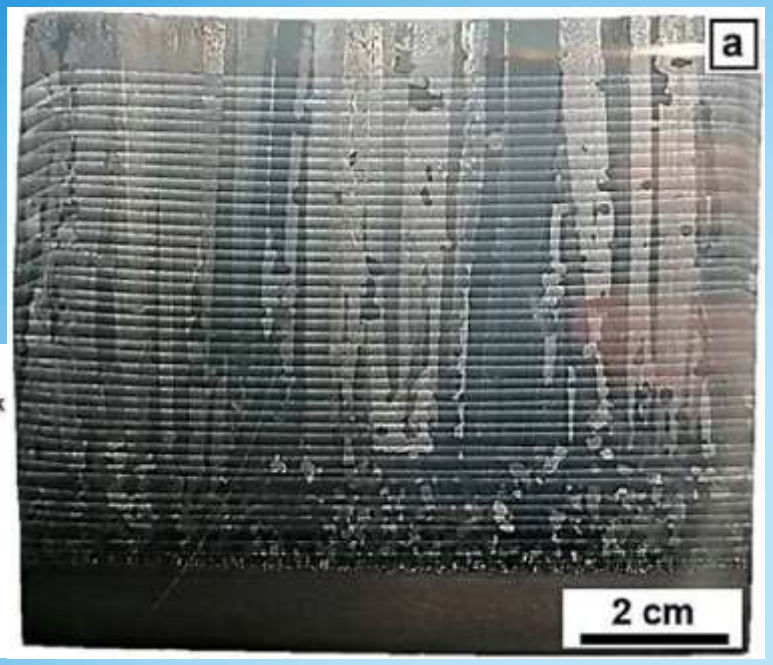
Constitutive laws



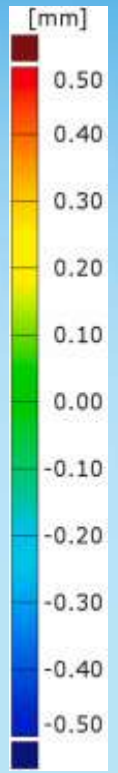
Ruiz de Sotto, Longère, Doquet (Palaiseau), International Journal of Damage Mechanics 2022

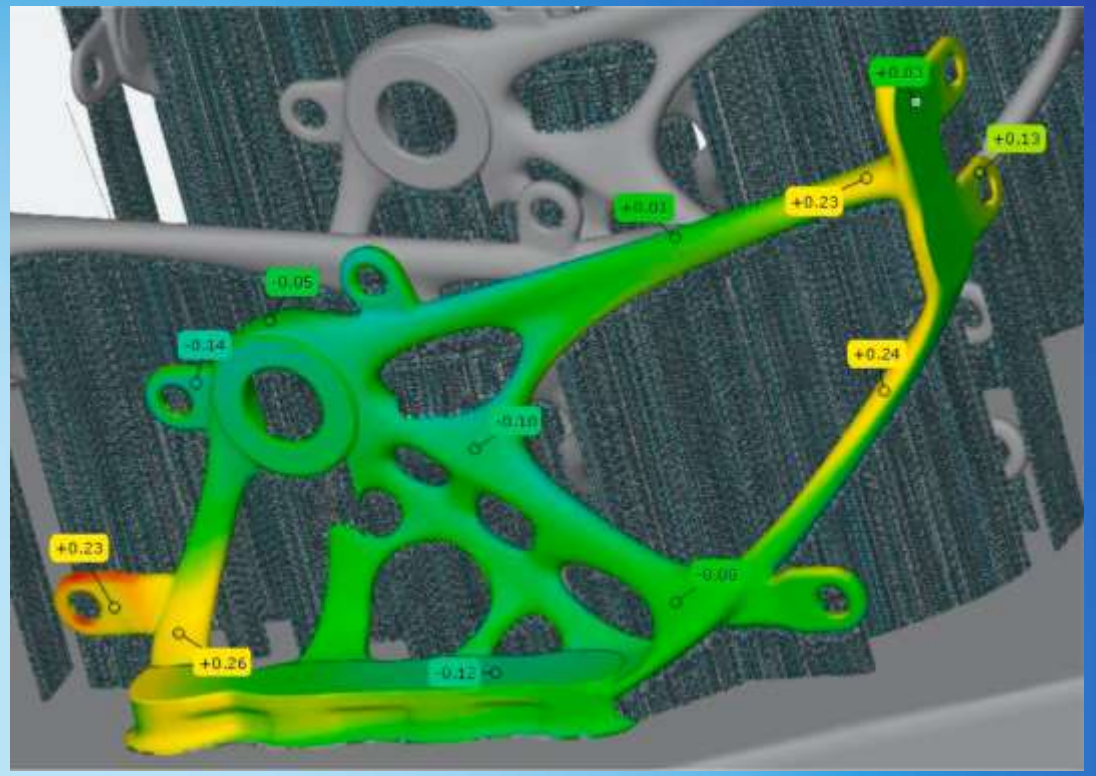
4. New processes 1/2

Additive: Ti64



Ayed , PhD Univ. Toulouse 2021 superv. Joël Alexis (Tarbes)





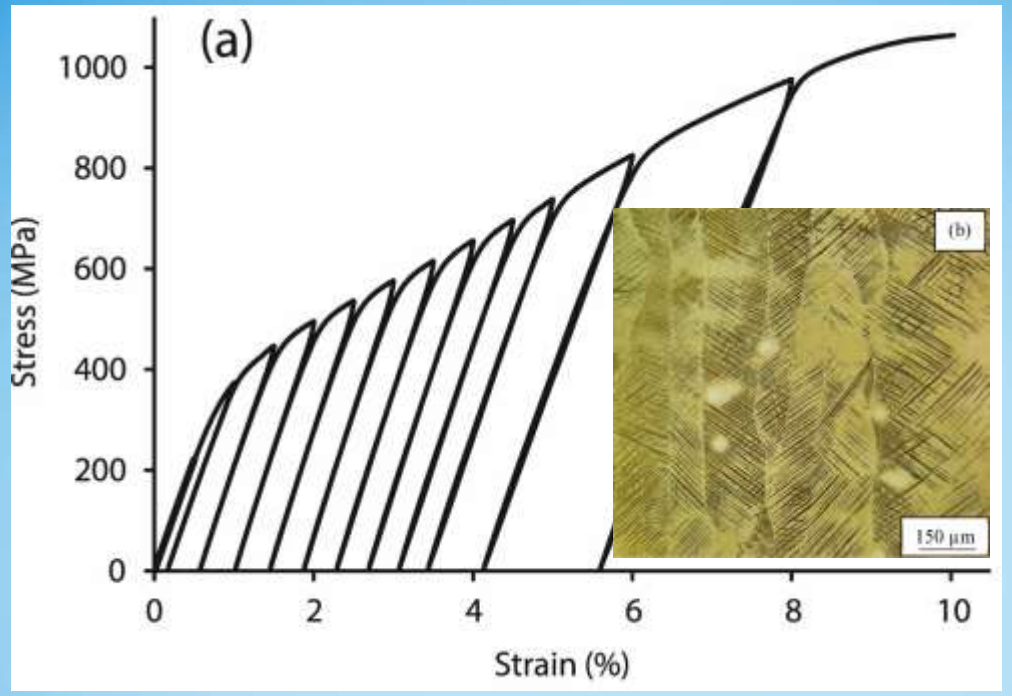
Cardon et al. (airbus + Angers), Additive Manufacturing 2021

- Nicolas Maury (Airbus) Advances in the development of direct energy deposition for the manufacturing of aerostructures, *Friday morning*
- Bernard Viguier (Toulouse) Microstructure evolution in an Additively Manufactured Ti64 related to thermo-mechanical loading during Small Punch Creep Test, *this morning*
- Moukrane Dehmas (Toulouse) Microstructural evolution during post heat treatment of the Ti-6Al-4V alloy manufactured by laser powder bed fusion, *Thursday morning*
- François Bourdin (Airbus) Understanding the relationships between heterogeneous microstructures and tensile properties through characterization of plastic strain localization in Ti-6Al-4V processed by WDED, *Wednesday morning*

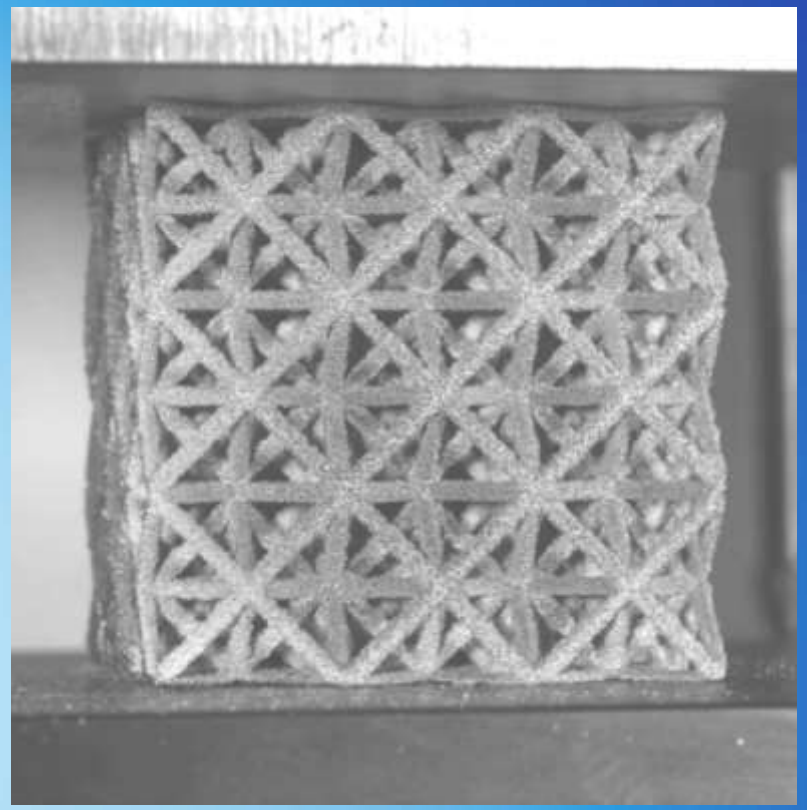
4. New processes 2/2

Additive: beyond Ti64

- TWIP alloys
- Low modulus
- SMA
- Lattice
- Composites



Schaal, Castany, Gloriant (Rennes) MSEA 2023

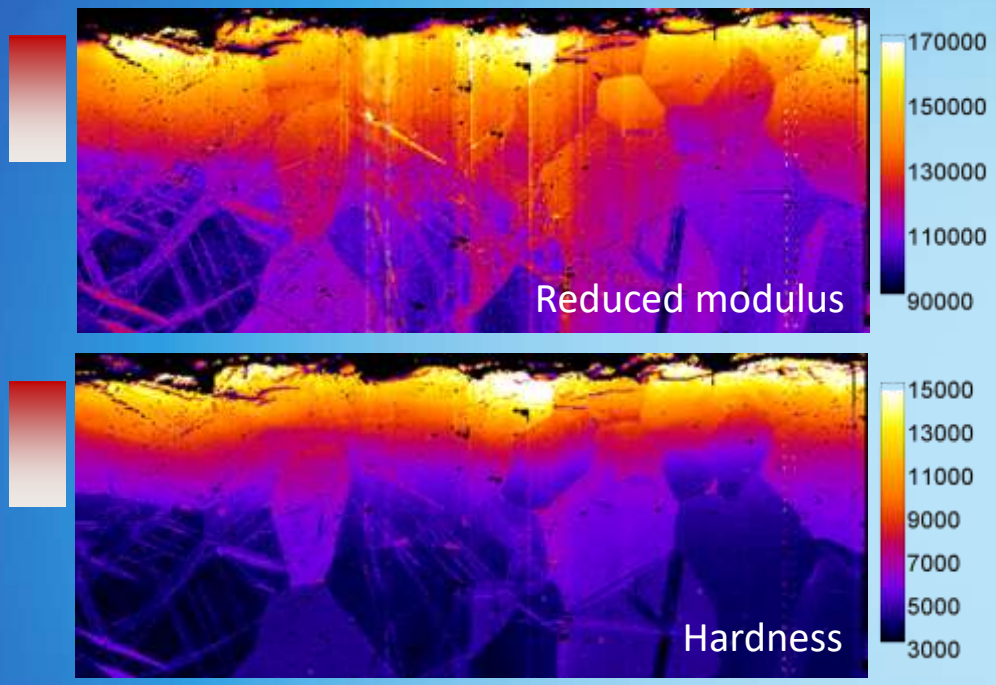


Duport et al. Scripta Materialia 2022
group of Rémi Dendeviel (Grenoble)

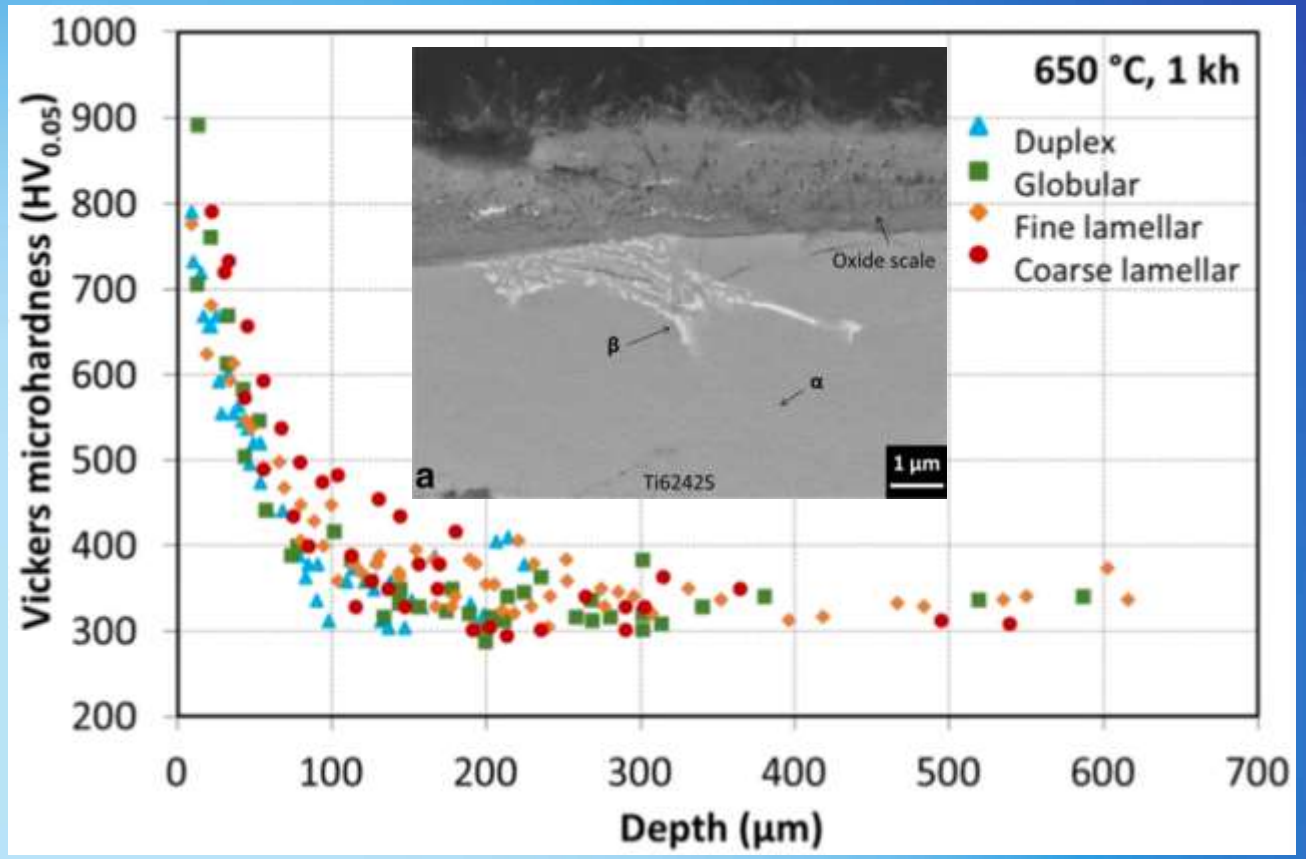
- Paul Lohmuller (Metz) Processing of NiTi shape memory alloy by laser powder bed fusion: influence of substrate temperature on manufacturability *Friday morning*
- Guillaume Abrivard (airbus)
  - Toward a circular economy for titanium additive manufacturing parts, *Wednesday morning*
  - Upcycling of titanium machining swarfs for manufacturing wire feedstock used in additive manufacturing for aerospace industry, *Wednesday morning*

5. Environment 1/2

Oxidation



Texier, Sirvin, Dziri (Albi)



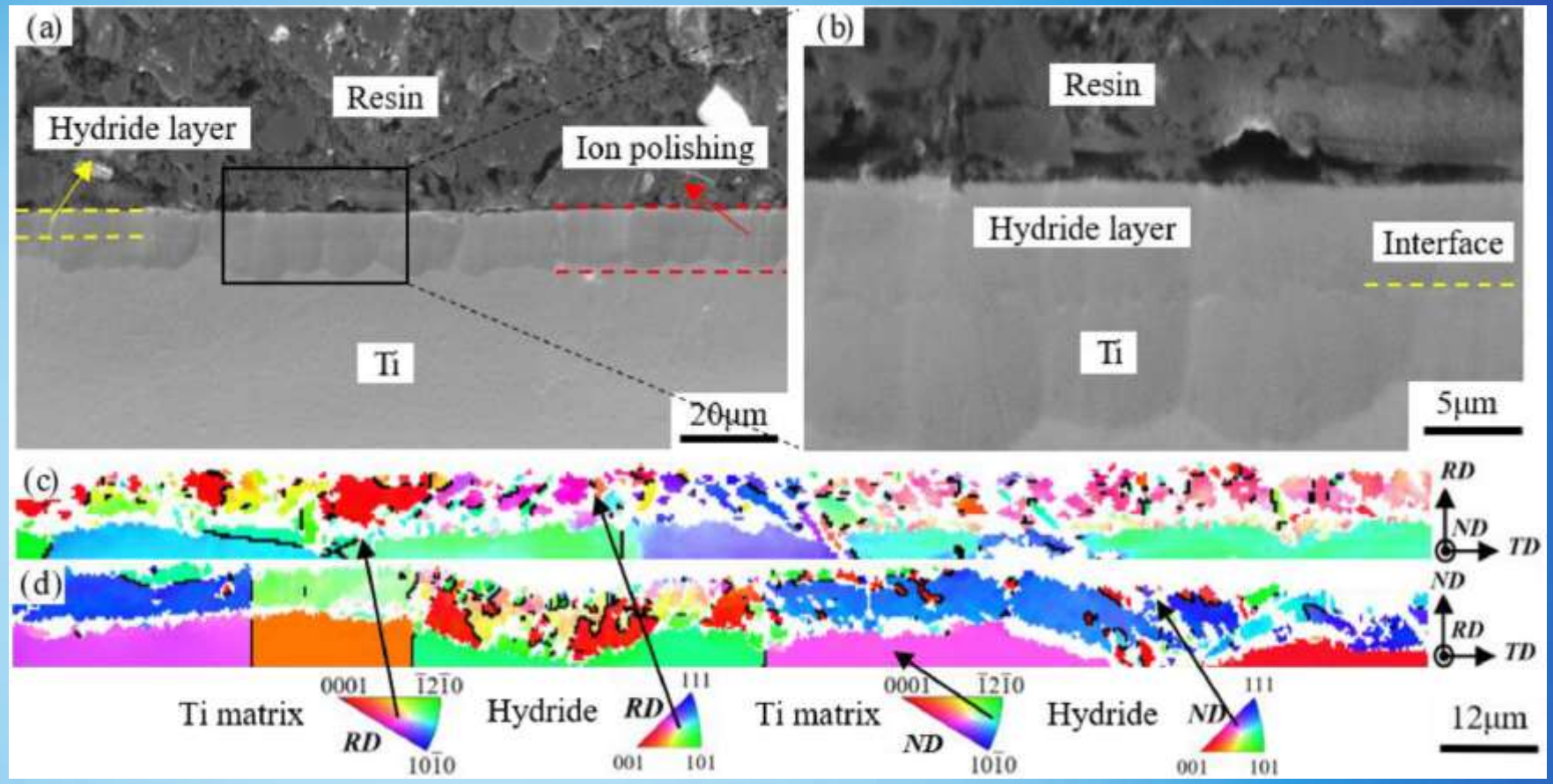
Vande Put, Dupressoire, Thouron, Emile, Peraldi, Dod, Monceau (Toulouse), Oxidation of Metals 2021

- Kevin Gautier (Toulouse) Theoretical and experimental studies of alloying elements on oxygen diffusion and solubility in titanium alloys, *Wednesday morning*
- Damien Texier (Albi) Effect of the oxygen content on the sub-grain nanoindentation response in titanium affected by high-temperature oxidation, *Wednesday before lunch*
- Quentin Sirvin (Albi) Oxygen content effect on mechanical behavior of CP titanium exposed at elevated temperature, *tomorrow morning*

5. Environment 2/2

Hydrogen

- La Chance Lepemangoye (Dijon) Consequences of cold rolling on the hydriding of commercially pure titanium T40, *tomorrow morning*



Wang, Xu, Zhao, Lecomte, Schuman (Metz), J. Materials Science & Technology 2022

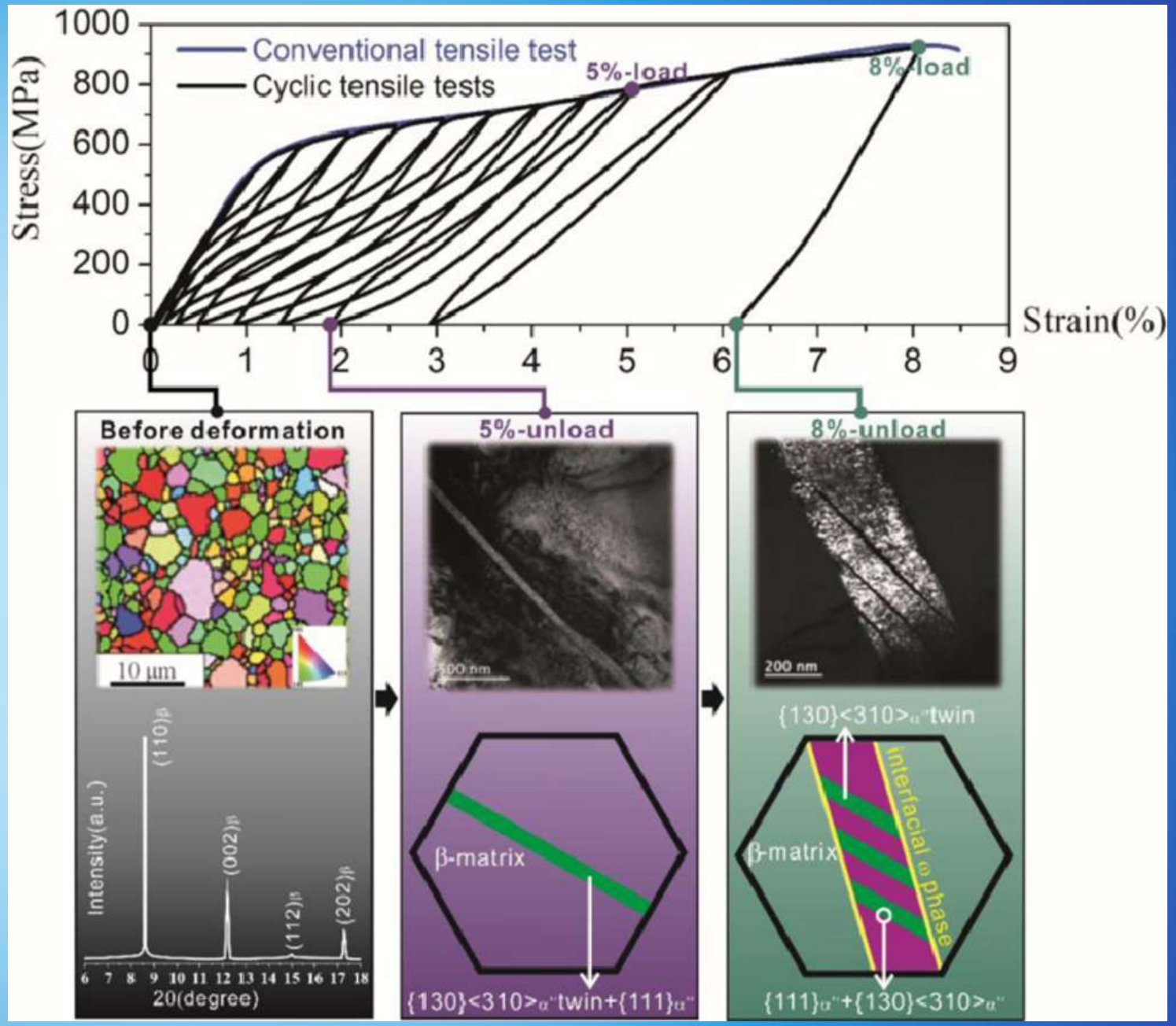
Nitriding

- Renaud Génin (Poitiers) Coupling Superficial Mechanical Attrition Treatment with plasma nitriding on a metastable β-Ti alloy, *this morning*
- Cyriac Christophe (CEA Saclay) Effect of surface nitriding on the durability of a Ti-6Al-4V alloy in high temperature pressurized liquid water, *tomorrow morning*

6. Biomedical

- Philippe Castany (Rennes) Evidence of an intermediate phase during the β to α" stress-induced martensitic transformation in Ti-based superelastic alloys *Thursday morning*

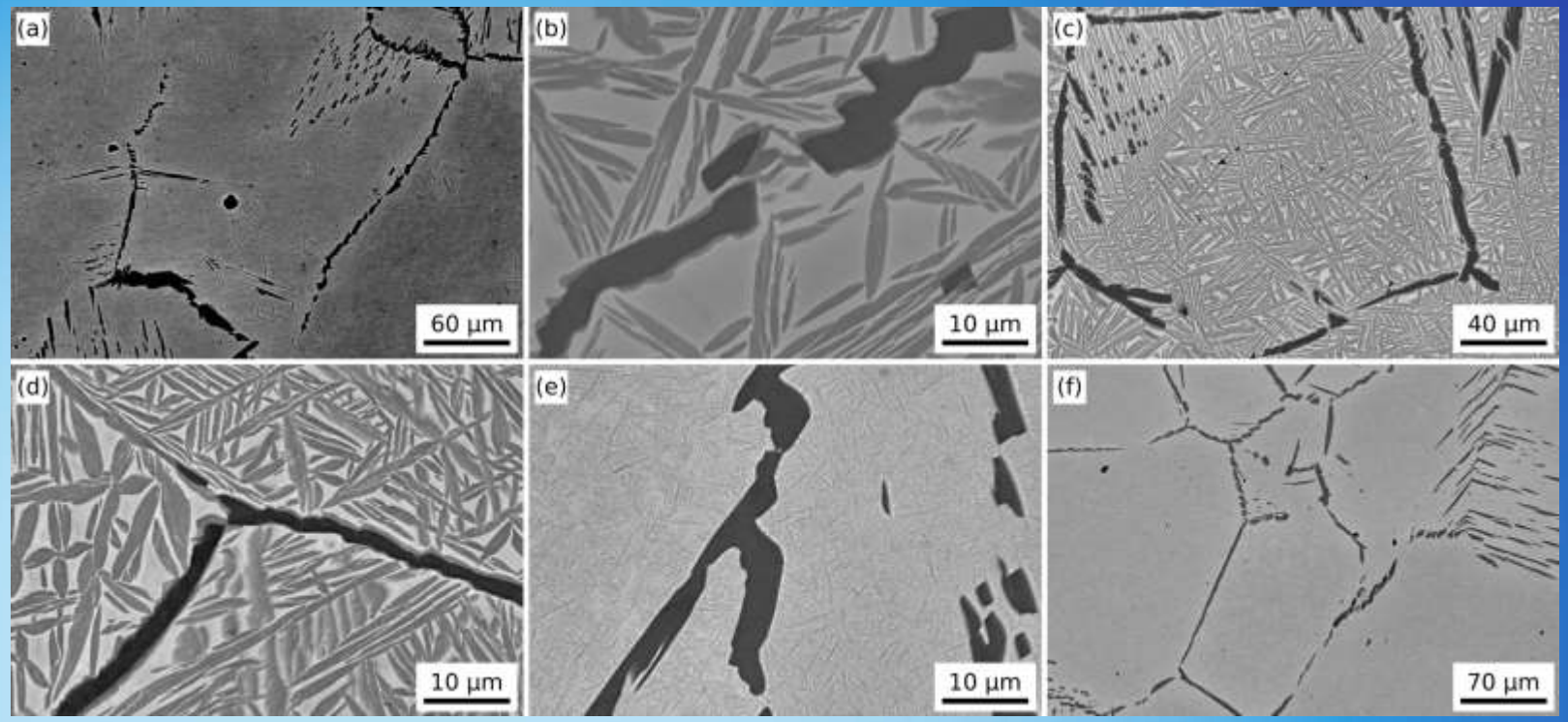
- Julie Deya (Paris) Towards antibacterial implants: Influence of the microstructure on the properties of Ti-7Ag alloy, *Tomorrow morning*
- Stéphanie Delannoy (Paris) Achieving high strength-to-elastic modulus ratio by microstructural fine-tuning in the Ti-13Nb-13Zr (w.%) alloy, *Thursday afternoon*



Gao, Castany, Gloriant, Acta Materialia 2022

7. Intermetallics

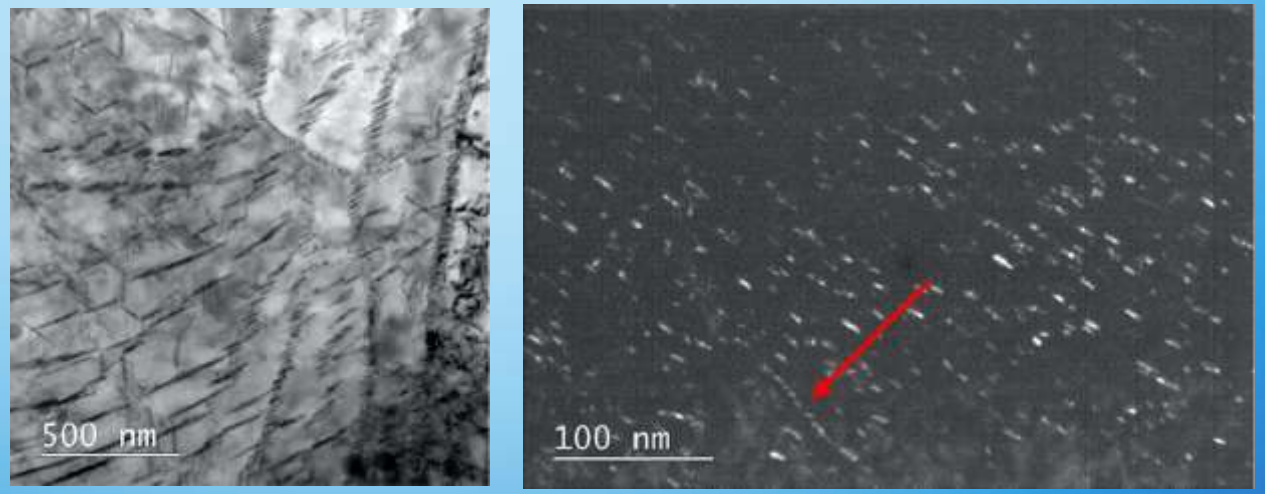
- Vladimir Esin (Évry)
  Effect of prior α_2 phase on precipitation kinetics of O-phase in advanced Ti_2AlNb alloy, *tomorrow morning*



Ayadh et al., Acta Materialia 2023

8. Irradiation

- Sylvie Doriot (CEA Saclay)
  Transmission Electron Microscopy analysis of irradiation defects in a Ti6-4 alloy. Comparison between Ti^{2+} ion irradiation and neutron irradiation, *Wednesday morning*



Doriot et al., Journal of Nuclear Materials 2023

Thank you