Activités en Fabrication Additive au CEA LITEN - POUDRINNOV

FROM RESEARCH TO INDUSTRY

POUDRINNOV Technological Platform of Advanced Powder Metallurgy and Plastics Processing

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#1 LOW-CARBON POWER GENERATION

#2 MANAGEMENT OF ENERGY GRIDS

#3 IMPROVE ENERGY EFFICIENCY

Finding the Economic and Environmental Optimum of the Energy Transition

CIRCULAR ECONOMY

Resource Efficiency & Environmental Sustainability

Material & Energy Efficiency

- Additive Manufacturing
- Structural Electronics

Closing the Carbon Cycle

- Value out of fossil waste (gas, liquid or solid) by thermochemical processes

Reducing the Environmental Footprint

- Life-cycle analysis & Tech-eco
- Recycling

POSITIONING & FIELDS OF APPLICATION

- **Materials Engineering and Processes for Sustainable Development**
  - Elaborating and converting materials by innovating technologies
  - Development of new and more performing (multi)-materials
  - Set up of new architectures at different scales
  - Comprehensive understanding of interactions between process parameters and mechanisms of materials' transformation
  - Development of energy-frugal processes

Control of the continuum Materials - Processes - Products

Metals

Ceramics

Thermoplastics

- **Broad fields of applications**
  - Energy & Environment
  - Mobility & Transport
  - Medical
  - Electronics & Microelectronics
  - Luxury …

KEY FIGURES AND ACTIVITIES OF SA3D

- Total staff 36 permanent and 18 non permanent researchers, of which 10 postgraduates
- 3 laboratories

	LMCM Laboratory of Magnetic Components and Materials C. Delafosse	LFM Laboratory of Formulation of Materials J. Maisonneuve	L3M Laboratory of Modelling and Materials for Metallurgy V. Bonnefoy
Materials	• Hard permanent magnets (NdFeB, SmCo) • Soft Ferrite (MFe2O4) • Plasto-magnet	• Sintered materials (oxides, main alloy classes out of Al, composites) • Thermoplastic materials with low env. Impact (bio-sourced and secondary)	• Metals (main alloy classes) • Composites (MMC) • Thermoelectric materials
Processes	• Injection moulding • Powder Injection Moulding (PIM)	• Formulation (powder and feedstock) • Injection moulding and PIM • **Additive manufacturing (FFF, DLP, MJF, BJ)** • Spark Plasma Sintering	• **Metal additive manufacturing (Laser powder bed Fusion - LBM)**
Topics	• Electrical Generators (EV) • Power Electronics (LETI) • Recycling and reduction of critical metals in permanent magnets • Mould design under field and magnetic systems	• Protection coatings	• Functionalisation of powders • Development of new materials/microstructures • Advanced design • Digital Simulation • Thermoelectric devices

POUDRINNOV and Additive Manufacturing Value chain

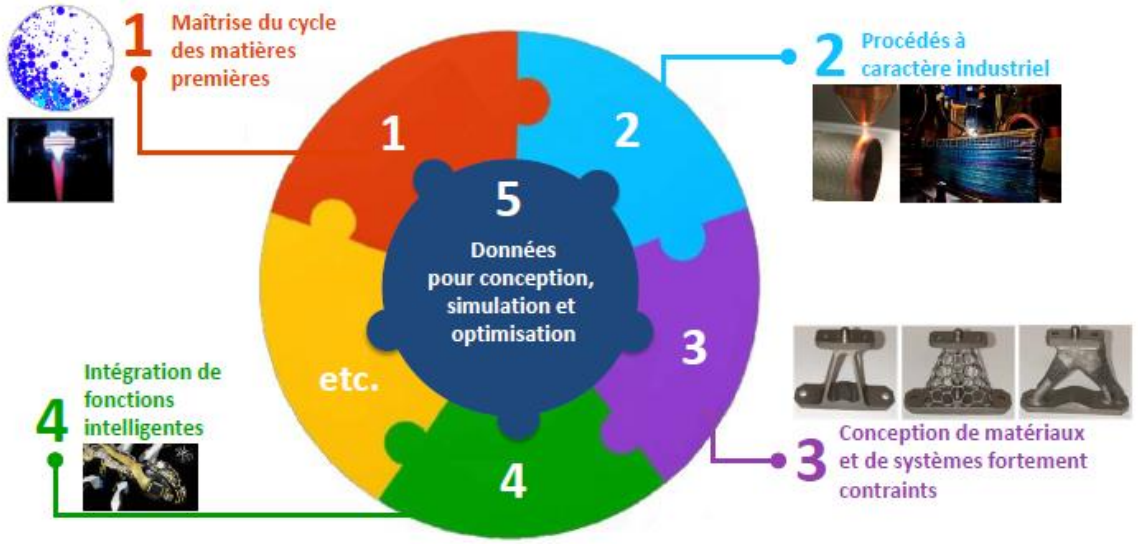
OBJECTIVES

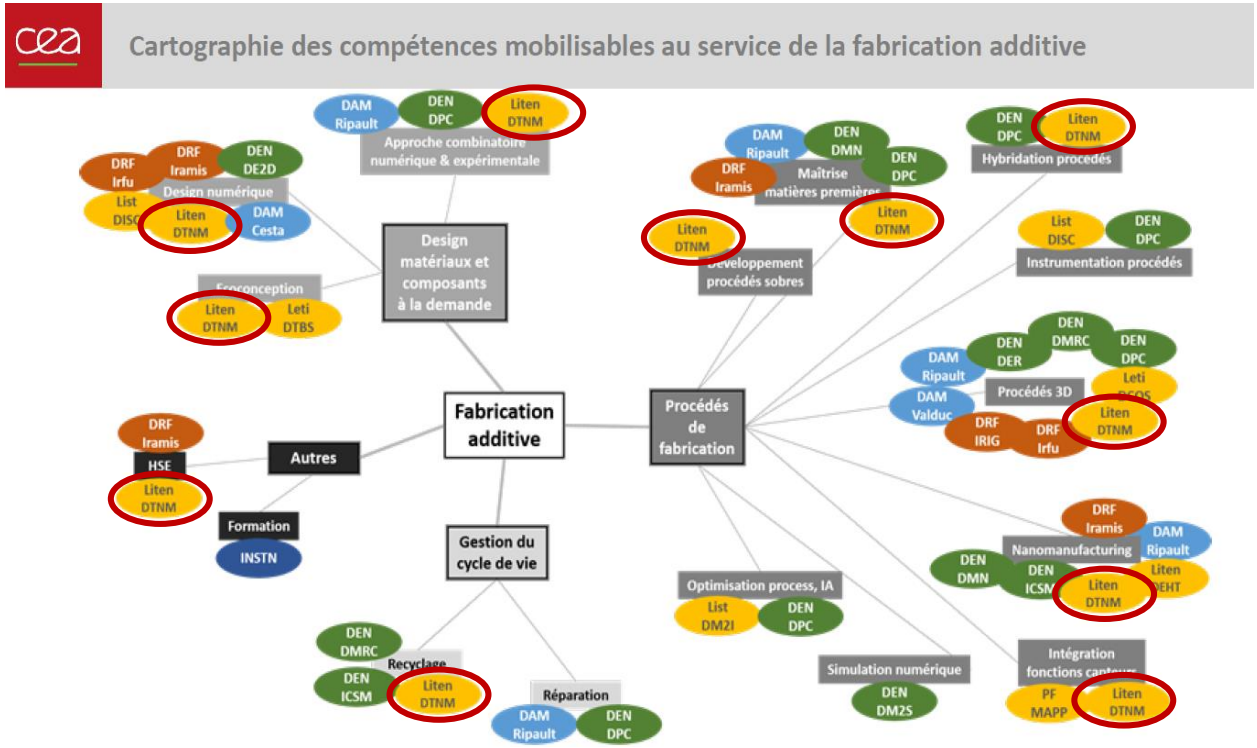
- Durability
- Performances
- Environmental impact
- Cost
- Added value
- Development time

Techno-economical model, Life-cycle analysis, HSE

POUDRINNOV and LITEN in the AM-ecosystem

- **CEA/LITEN and POUDRINNOV in the core of key topics and eco-system :**





clefs CEA — Cet article est extrait du dernier numéro de Clefs consacré à « l'impression 3D au cœur des grandes transitions ».

source = F.Schuster-
In : Presentation-GT-Fab-Add-Seminaire-janvier 2020
and CEA - Comment la fabrication additive peut-elle accompagner nos grandes transitions ?

Many technologies in Additive and Netshape manufacturing

50 engineers and technicians

12M€ investment

1500 m² space

2012

2014

2016

2018

2020

PIM : Powder Injection Molding

SPS : Spark Plasma Sintering

SC : Strip Casting

SLA : Stereolithography Apparatus

LBM : Laser Beam Melting

3D Systems ProX200 (300W)

Farsoon FS271M (400W)

MJF : Multi Jet Fusion

FDM : Fused Deposition Modeling

SLM 125HL (400W)

ADDUP FormUp350 (2x500W)

BJ: Binder Jetting

LBM/LPBF equipments

Equipment	ProX200	FS271M	FormUp 350	SLM 125 HL
				
Manufacturer	3D Systems	Farsoon	AddUp	SLM Solutions
Powder feeder	Feed tray	Feed tray	Gravity dispenser + vibrating conveyor + Vol. screw feeder	Gravity dispenser
Recoating system	Roller	Blade	Roller	Blade
Laser power	270 W	480 W	2 x 500 W	370 W
Spot size	70 µm	130 µm	60 µm	70 µm
Construction size	120*120*100 mm **Connection to glove box*	225*225*320 mm	350*350*350 mm	125*125*125 mm
Plate volume	4 L	22 L	~40 L	~2 L
Heated plate	No	170 °C	200 °C	200 °C
Atmosphere	Ar or N_2	Ar or N_2	Ar or N_2	Ar or N_2

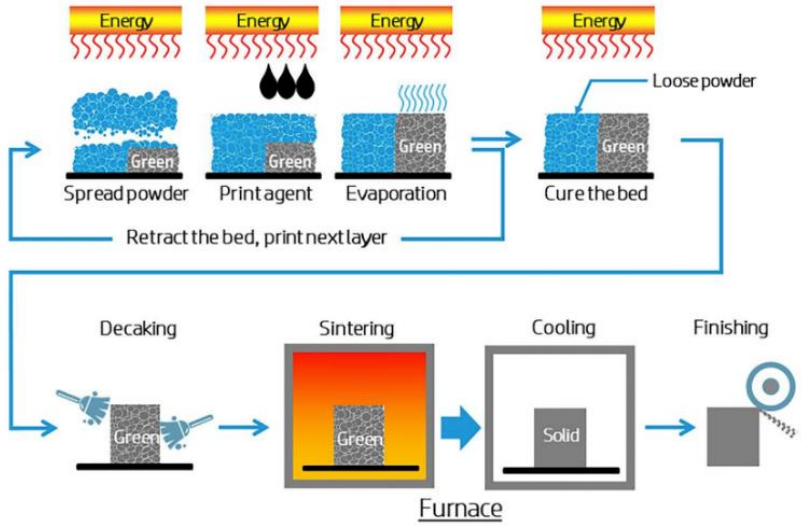
BJ equipments

Binder Jetting HP in POUDRINNOV Platform

Main characteristics of equipment (HP data)

- Manufacturing volume
  - 430X310X150mm – 20L
- Tolerance achieved
  - +/-0.5% to 1.5% (as a function of component mass and volume)
- Resolution
  - 21 µm
- Materials available
  - 316L, 17-4PH , copper in dev.
- Printing productivity
  - Up to 1400cm^3/h

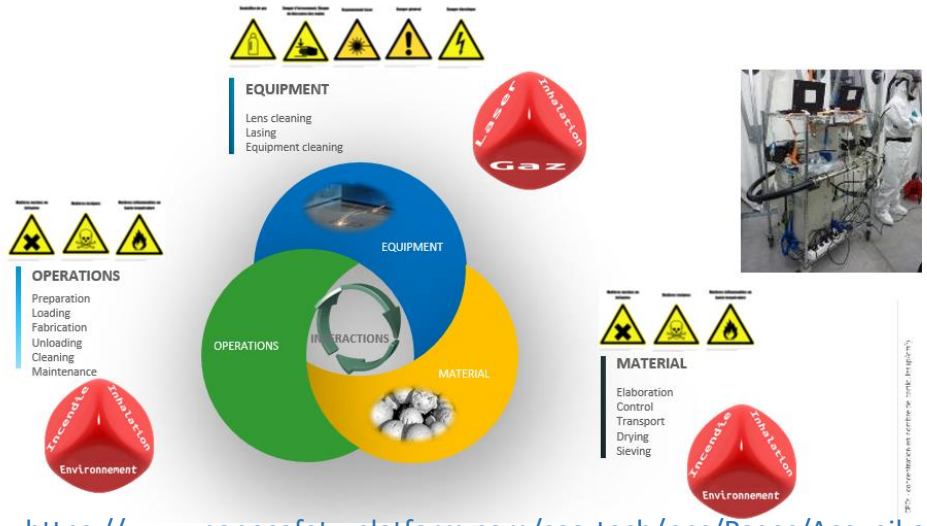
Process principles of BJ



SUPPORTING RESSOURCES

NANOSAFETY platform

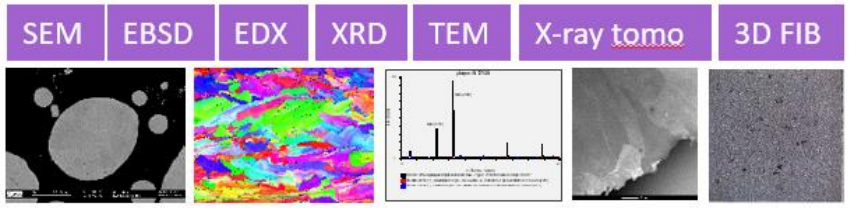
- Health and safety related to powders and nanomaterials handling



https://www.nanosafety-platform.com/cea-tech/pns/Pages/Accueil.aspx

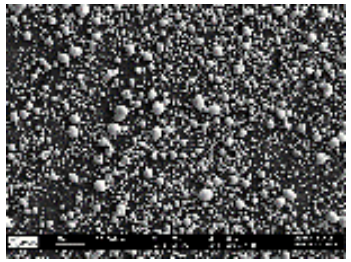
NANOCHARACTERISATION platform

- Expertises and means for materials and surfaces characterisation



https://liten.cea.fr/cea-tech/liten/english/Pages/Work-with-us/Technology-platforms/Nanocharacterisation.aspx

METAL AM : from powder to components (ex:LPBF)



POWDER
- Powder characterization (PSD, morphology, flowability, density, chemical composition, moisture, etc.)
- Powder bed characteristics
- Powder management : impact of powder re-using in LBM machine, storage, transportation, powder recycling, etc.

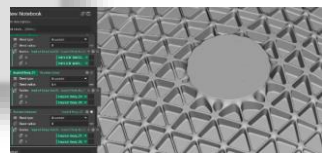
PROCESS
Process parameters development

SAMPLES CARACTERISATION
- Mechanical characterization
- Microstructural analysis
- Others properties : density, chemical composition
- 3D Scanning : deformations, dimensional conformity, etc.
- Other features : roughness, surface finish

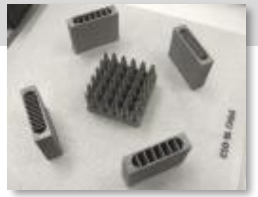
POST-TREATMENTS
- Heat treatments
- HIP
- Surface treatments

POC

DESIGN / MODELING
- Re-design for AM
- Topological optimization
- Process Modelling



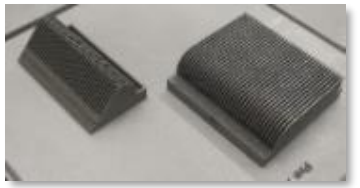
MATERIALS
- Stainless steel (316L, 304L, 17-4PH, etc.)
- Nickel based alloys (IN718, IN625, IN600, Hastelloy C22, HastelloyX)
- Standard Aluminium Alloys (AlSi10Mg, AlSi7Mg, AlSi12, etc.)
- Structural Aluminium Alloys (6xxx, 2xxx, 7xxx)
- High Entropy Alloys (Al0,3CoCrFeNi)
- Iron based-alloys (FeSi, FeCo, FeC, etc)
- Magnetics alloys
- Copper Cu and copper-based alloys CuCrZr

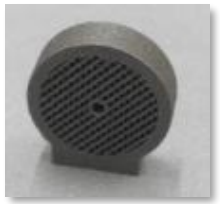


Al - heat exchanger

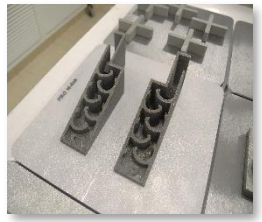
316L - valve

Inco625 - turbine





Al - exchanger/reactor



Al - Fuel cell H_2O separator

CuCrZr component

CuCrZr Inductor

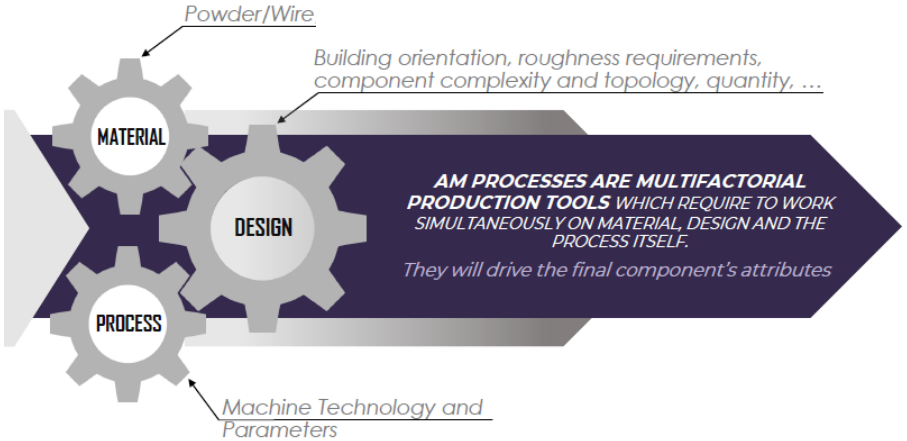
316L - turbine

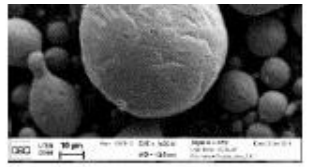
HEA - Jet engine bracket and lattice structure

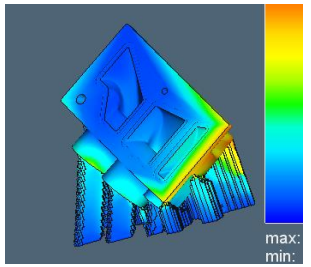
316L – Heat sink

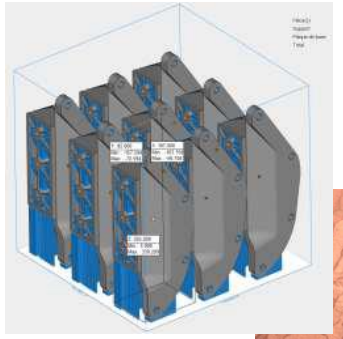
METAL AM : scope of activities … for LPBF – BJ processes

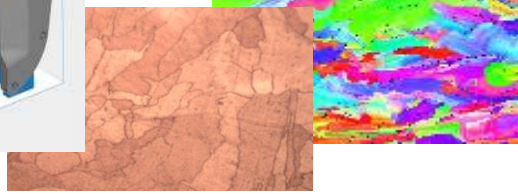
- **Advanced design and conception acc.to customer specifications**:
  - Functional analysis, functional integration of component into system
  - Design for X, topological optimisation, generative and parametric design
    - cellular structures, lattices, auxetic structures, compliant structures
  - Multi-physics modelling and validation of components
  - Process simulation
    - dimensional changes, distorsion and defects, residual stresses,..
- **Materials**
  - Innovation in material selection, material formulation and functionalization
  - Sourcing of materials, validation and certification
  - Re-use, recycling of materials
  - Advanced characterisation, including dynamic behaviour of powder beds
- **Processes** :
  - DOE and material qualification, parameter setups
  - Process parameters influence on material characteristics
    - impact on µstructures, fatigue performance, heat treatment settings, …)
  - Benchmark of processes and equipment qualification , scale-up ..
- **Prototypes / components / POC :**
  - Full characterisation
    - Micro-structures, physical + mechanical properties, geometry and dimensions
  - In-use testing characterization on specific bench
- **Technical-economical assessment, technological transfers and scale-up**



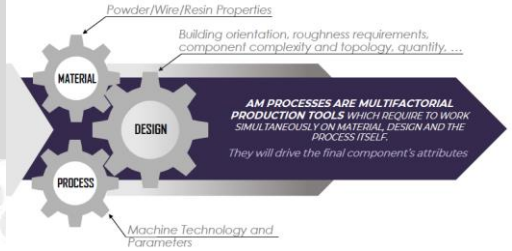






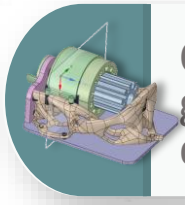


DESIGN AND SIMULATION FOR ADDITIVE MANUFACTURING

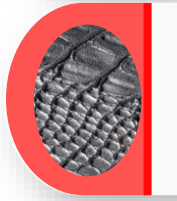


- **Skills:**

DESIGN for AM


Organic / generative design

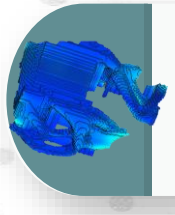

Cellular, lattices structures


Surfaces texturing

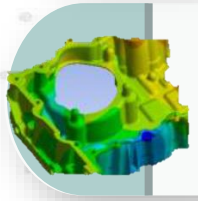

Auxetic structures

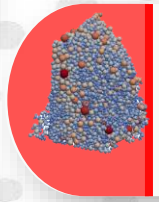

Compliant and flexible structures

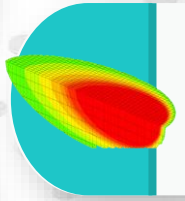
MODELLING AND SIMULATION


Process simulation (strains)


Topological Optimisation


FEM analysis (multiphysics)

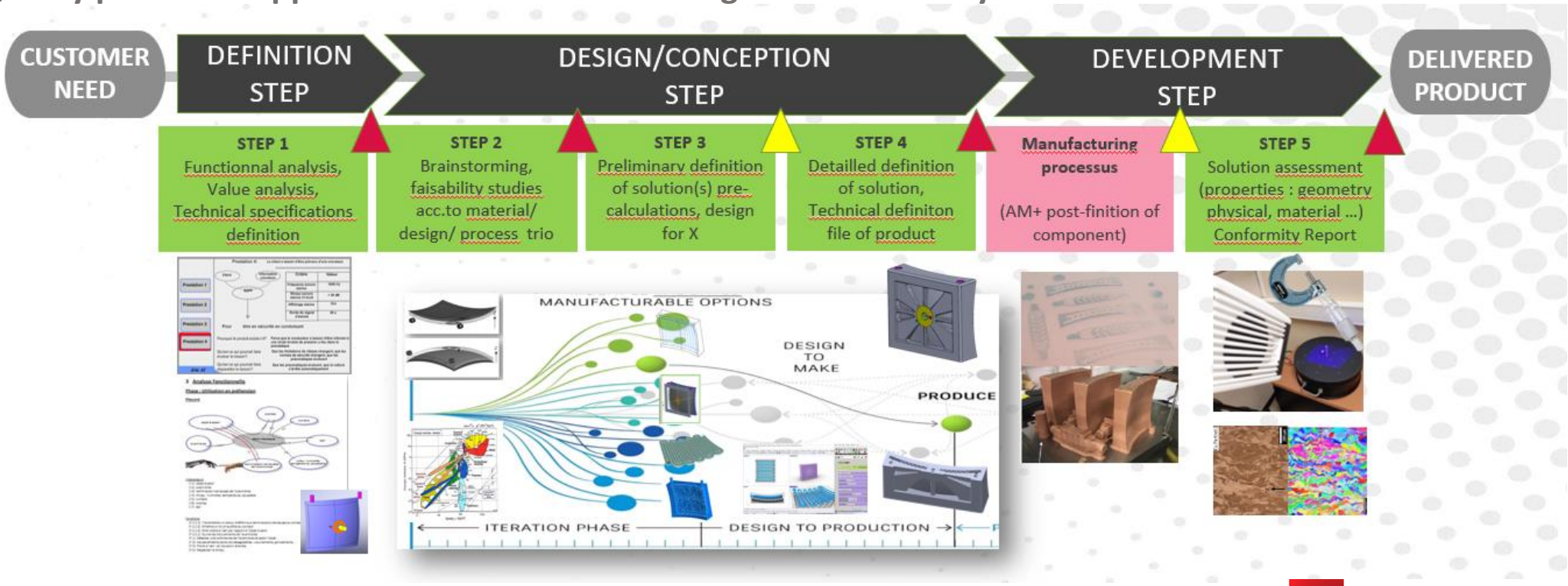

DEM, powder bed simulation


Local thermo-mechanics

- **Tools and software:**

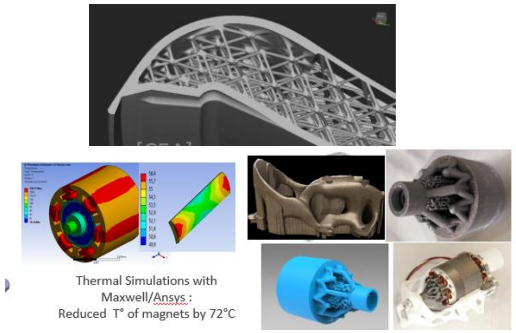
COMSOL MULTIPHYSICS
ANSYS DISCOVERY
Altair HyperWorks OptiStruct
MSC Software
SIEMENS NX
Materialise Magics
AddUp
CATIA
SOLIDWORKS
Rhinoceros modeling tools for designers
grasshopper
nTopology

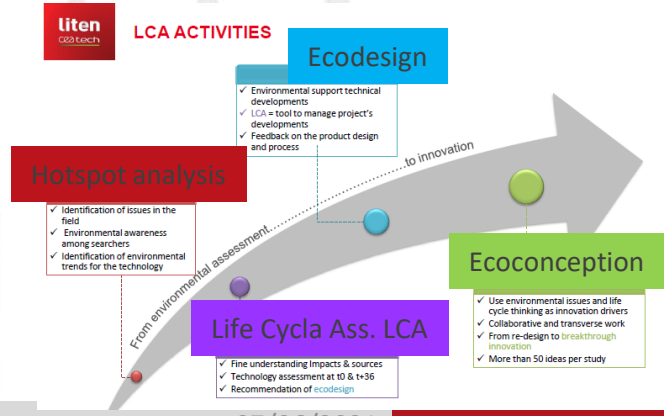
Quality processus approach of our advanced design for AM activity



Lastest developments:

- Generative parametric design and algorithmic modelling
- Coupling with multiphysics calculations
- Eco-circularity and Sustainable Development standards / LCA
- Control by 3D scanning (ZEISS COMET + GOMInspect)





- **All scales concerned**

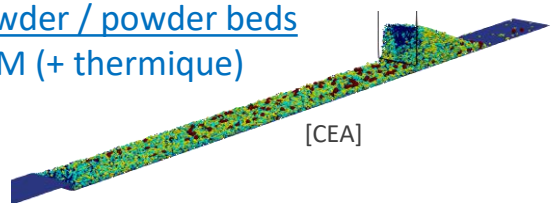
µm

mm

cm

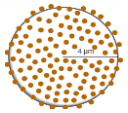
dm

Powder / powder beds
DEM (+ thermique)



[CEA]

Laser / particle Interaction
FE or analytical simulation of Maxwell equations (+thermique)



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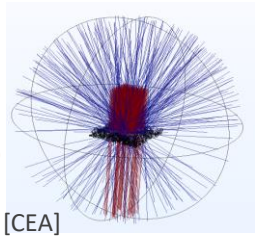

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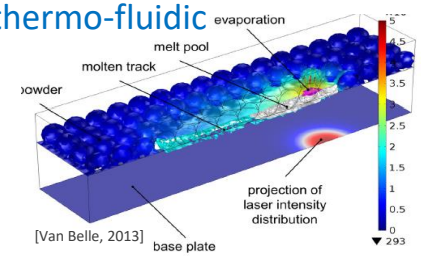
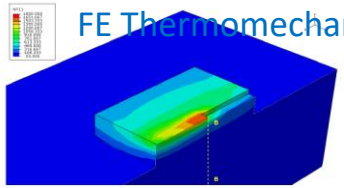
Melt pool prediction
FE thermo-fluidic



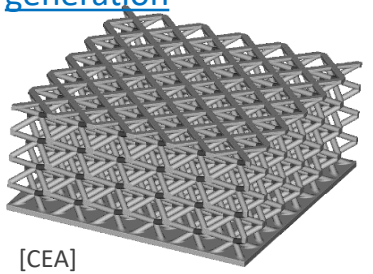
[Van Belle, 2013]

Mesoscopic simulation
FE Thermomechanical Simulation (+metallurgy)



[Leitz et al., 2016]

Cellular structures generation



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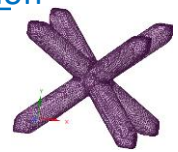
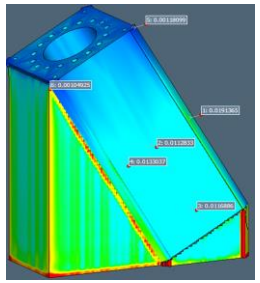
Periodic / cellular strutures homogeneisation

$$\begin{pmatrix}\sigma_x\\ \sigma_y\\ \sigma_z\\ \sigma_{xy}\\ \sigma_{yz}\\ \sigma_{xz}\end{pmatrix} = \begin{bmatrix} D_{11} & D_{12} & D_{13} & & & \\ D_{21} & D_{22} & D_{23} & & & \\ D_{31} & D_{32} & D_{33} & & & \\ & & & D_{44} & & \\ & & & & D_{55} & \\ & & & & & D_{66} \end{bmatrix} \begin{pmatrix}\epsilon_x\\ \epsilon_y\\ \epsilon_z\\ \gamma_{xy}\\ \gamma_{yz}\\ \gamma_{xz}\end{pmatrix}$$



Macroscopic simulation
FE thermomechanical simulation (deformation, sintering, ..)



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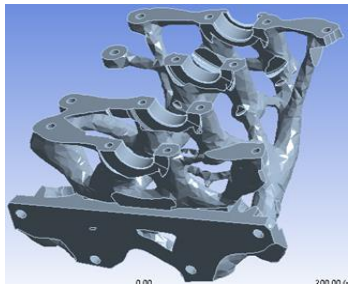
Topological optimisation



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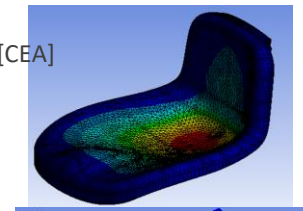

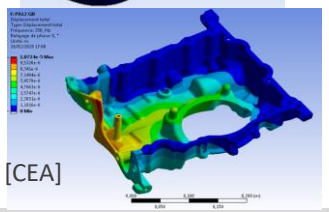

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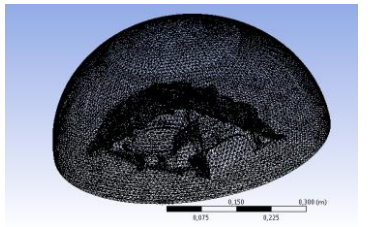
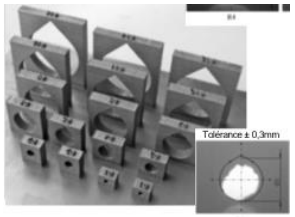
Calculations : mechanical , thermal, magnetic, vibratory, acoustic, …

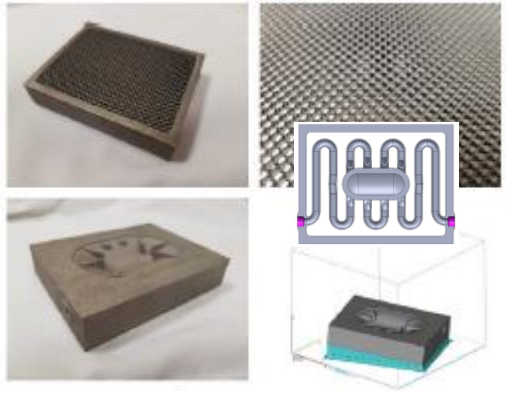


DESIGN FOR AM : Application to heat exchangers

Illustration of components in the field of heat exchangers / reacting heat exchangers

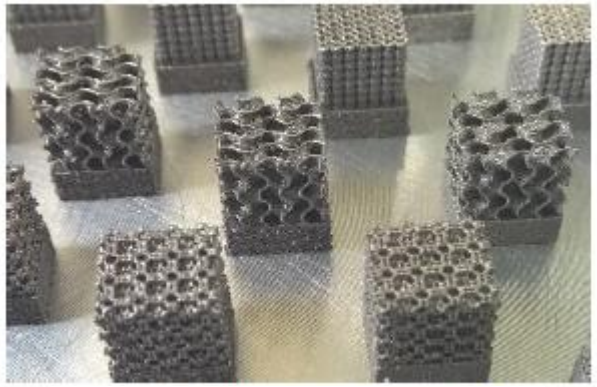


Also : rules for design



COMPLEX EXCHANGER MOULD

CONCEPTS FOR CATALYST SUPPORTS

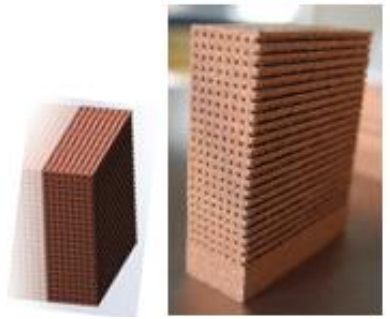


CONCEPTS FOR CATALYST SUPPORTS

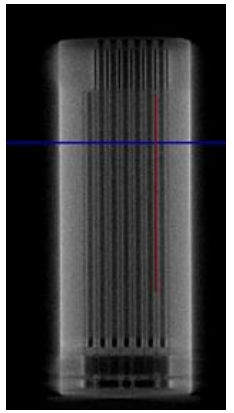
NH_3/H_2O ABSORPTION REACTING HEX

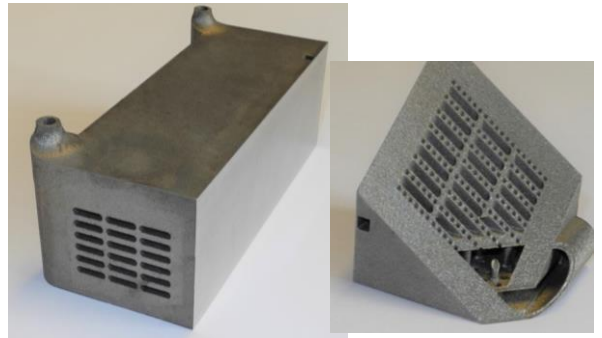
FUEL CELL HEAD PLATES

PHASE SEPARATOR (H_2/H_2O), 316L STEEL



CuCrZr CATALYST SUPPORT





METHANATION REACTING HEAT EXCHANGER

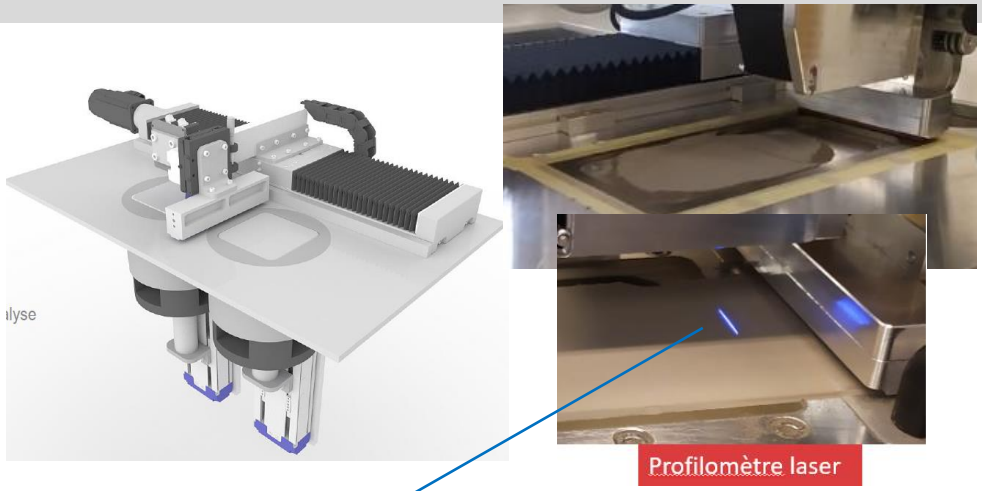
ROADMAP on PROCESSES : FOCUS on POWDER BEHAVIOUR

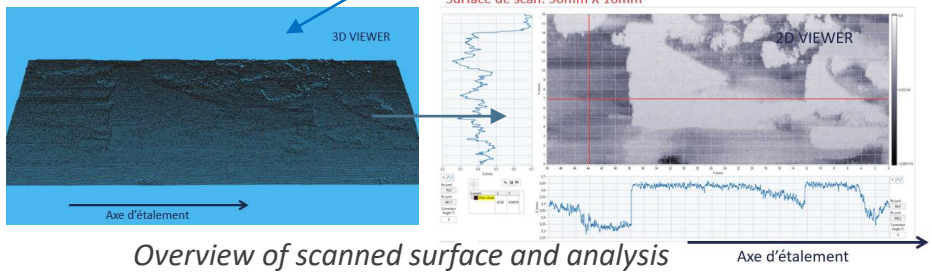
Powders and powder beds behaviour characterisation :

- characterisation of powders acc.to standards ISO/ASTM
- BUT also need to simulate powder bed generation in AM machine

→ **NEW : INSTRUMENTED BENCH FOR POWDER BEDDING**

- All powder type for AM, flexible configuration and setups
- Base powders, functionnalized powders, recycled powders, etc..
- Surface monitoring + powder weighting for density assessment
- Dispense up to 275mm/s – Profilometer resolution 0,5µm in Z-direction)

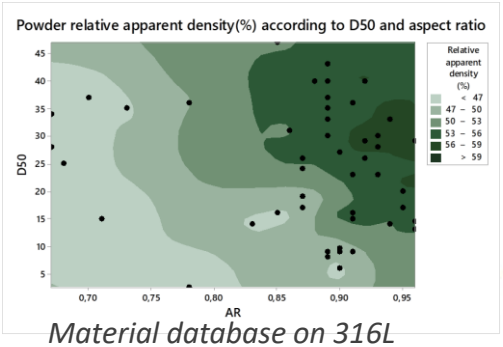




Overview of scanned surface and analysis

Powder database and statistical models

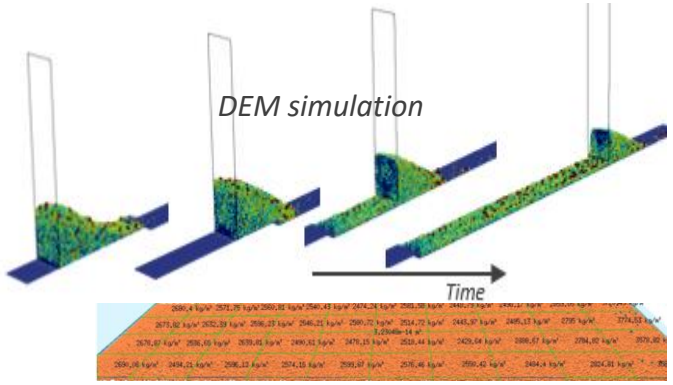
- Entry data : aspect ratio, SPAN, D50
- Property evaluated : density or roughness ou rugosité.
- Powder behaviour anticipation with standard properties



Material database on 316L

Simulation by DEM of powder bed constitution

- Parametric study of influencing parameters
- Opportunities for Process optimisation
- Numerical twin of process step 1 = powder bed



PhD Thesis – Internal projects – Industrial projet

MATERIAL DEVELOPMENT : SOME KEY DEVELOPMENTS

▶ Structural Aluminium alloys for LPBF without hot cracking issues

- Cost-effective solution of nano-functionalised powder (dry mixing)
- Effective for 6061, in progress for 7075 alloy.
- In parallel, development of optimized heat treatments

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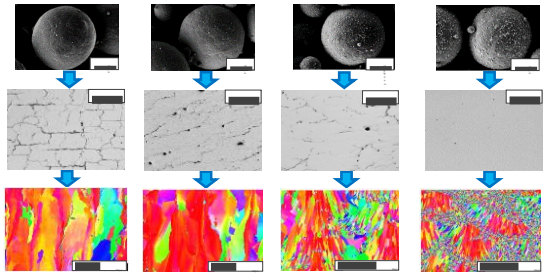

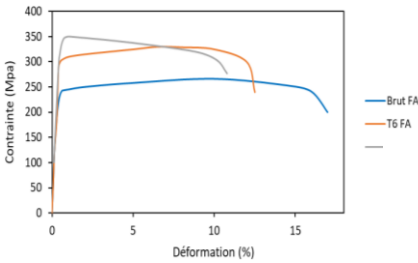

▶ Highlight on Cu & Cu alloys by LPBF = Pure Cu and CuCr1Zr

- Characterisation of powders + Functionnalizing powders for enhanced process ability
- Process parameters for dense parts >99%, links between microstructure and properties (LPBF + HT parameters on mechanical and electrical properties)
- Properties of CuCrZr as function of composition and post-processing operations
- Benchmark of technologies (LPBF, EBM, BJ, etc..)
- Rules for designing components depending on selected process

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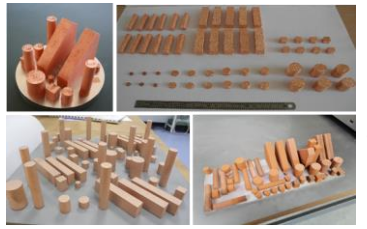
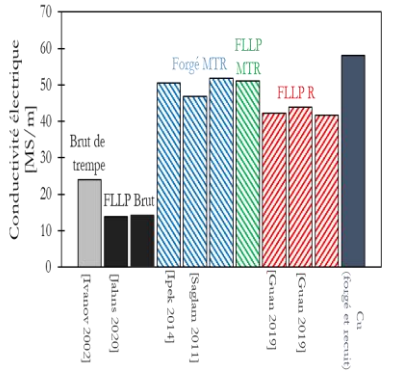
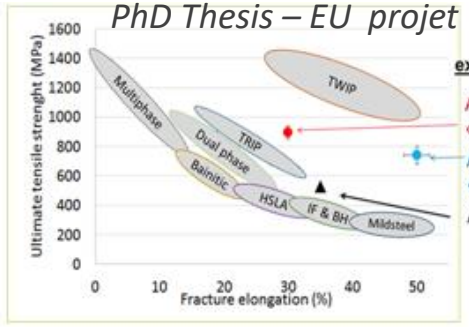


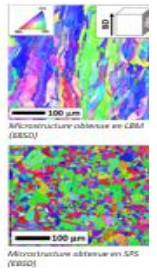


▶ HEA alloys with specific properties and associated process (LPBF vs SPS)

- Example of a Al0,3CoCrFeNi alloy : process influence is studied : cast vs. LPBF vs SPS process routes, Using LPBF, µ-structure is controlled by process parameters
- High density of dislocations leads to improve yield and ultimate tensile strength
- Study of nitrogen effects on mechanical properties

PhD Thesis – EU projet





▶ Other items :

- Controled porosity components – Materials with magnetic / thermoelectric properties -Fatigue-corrosion of SLMed materials

ROADMAP on PROCESSES : MONITORING, CONTROL, DATA

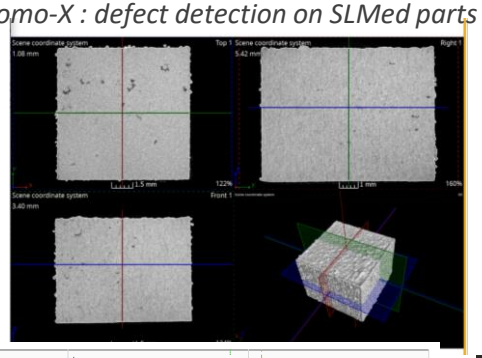
Actions in the frame of « INFLEXION POSITIVE » with CEA/LIST

- **Development of ex-situ + in-situ NCD techniques :**
  - Many techniques are being tested and applied to LPBF / BJ
  - Eddy current (powder beds /
  - Ultrasound resonance
  - X-Rays radiography and tomography for database collection and defects detection + characterisation

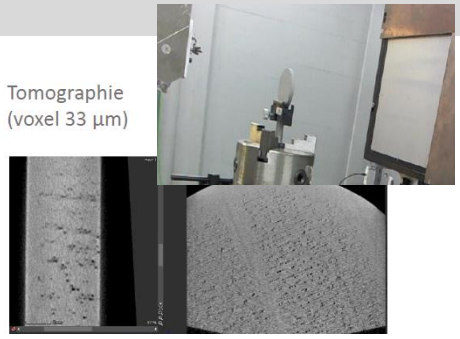
On both techniques, CEA/LIST can handle machine learning or IA for analysis and model definition

- **In-situ thermal monitoring - management**
  - Management of thermal history of the built volume to give realistic data for simulation
  - Base on IR camera + specific US thermometer-system
  - Numerical integration in CAst3m code + Experimental validation
  - Opportunity for in-situ / real time corrective and adaptive actions

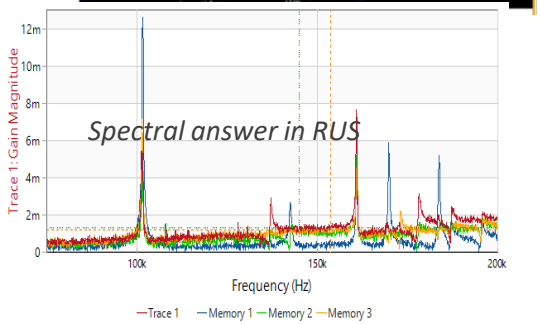
Tomo-X : defect detection on SLMed parts



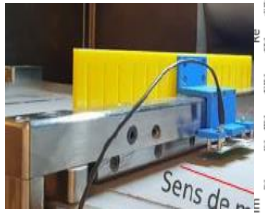
Tomographie (voxel 33 µm)

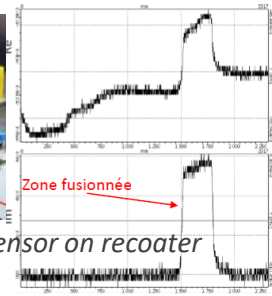


Tomo-X : defect detection on green part

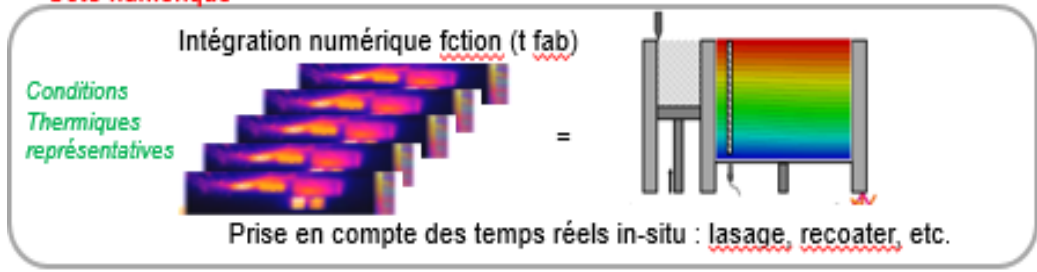


Spectral answer in RUS





Eddy current sensor on recoater



→ CEA INTERNAL DATABASE

3D Manufacturing Database Key benefits:

- Ensure traceability and future-proof AM projects;
- Capture the full picture: any test type for powders, materials, and parts.
- Consolidate, control, and share AM data across your organization.
- Manage key AM workflows.
- Understand process parameters and impact on performance.

MERCI DE VOTRE ATTENTION

pour completer, ne manquez pas :

Thierry BAFFIE - 15h20

Hervé GLEYZES – 14h00

Laboratoire d'innovation pour les technologies des énergies nouvelles et les nanomatériaux – www.liten.cea.fr