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Advanced Manufacturing Techniques

GIF AMME Workshop on Advanced Manufacturing

Virtual, 8th November 2021

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Why Advanced Manufacturing ?

Reliability : To achieve the manufacturing of parts right the first time

Improvement of Design: thanks to advanced manufacturing we can provide new design with improved functionality or higher performance

Cost :to decrease the cost of the part without decrease of quality

Time gain : Allows manufacturing of part in shorter time

Quality: provide better metallurgical quality of components than the former technology,

Improvement of in service properties: in corrosion for example separate the structural material from the coating that gives the corrosion resistance

Use of Advance Manufacturing Technologies (AMTs)

- Framatome is involved in the design, manufacturing and maintenance of nuclear island and main equipment of nuclear power plants.

- Advanced manufacturing techniques offer the possibility to:
  - Diversify our supply-chains (shorter lead-times, secured procurements…),
  - Optimise manufacturing and maintenance (spare parts, specific tools),
  - Improve performance (design optimisation, reduction of development times, relocation of fabrication in the workshop),
  - Improve quality (homogeneity, reduction of the number of workpieces).

- To maintain performance and competitiveness, the development of alternative fabrication processes is a great stake.

Which technologies ?

Powder Metallurgy

Surface treatment

Automation/Digitalisation

Controlling the manufacturing process in real time

Numerical simulation of manufacturing process

Powder Metallurgy

Two technologies in development:

- Hot Isostatic Pressing (HIP)
- Additive Manufacturing (AM)

HIP

- Hot isostatic pressing is a sintering process that exerts an isotropic gas pressure on the powder during the heating process and achieves densification by the combined effects of high temperature and high pressure

Additive Manufacturing

- Additive Manufacturing is a manufacturing technology that build 3D objects by adding layer-upon-layer of material

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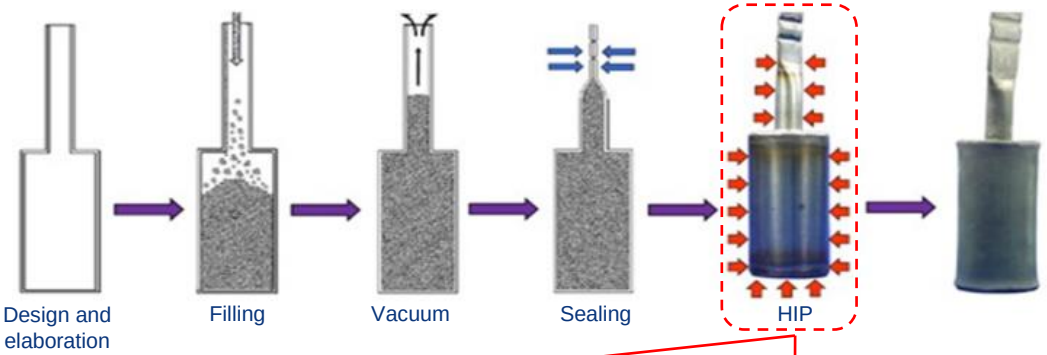
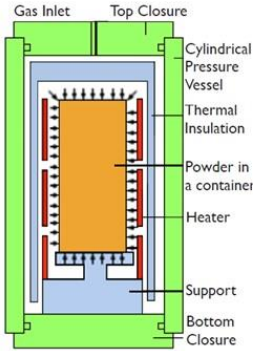
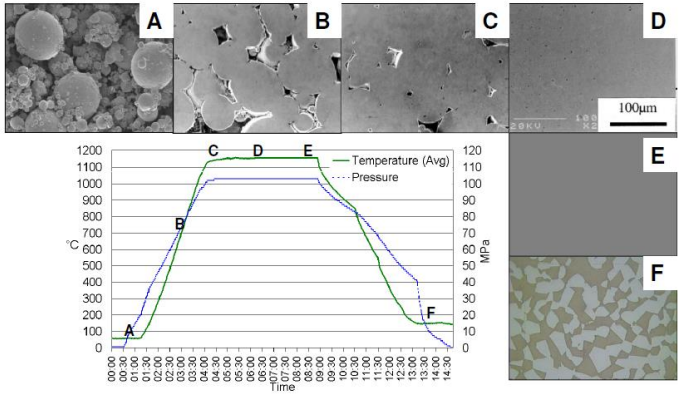
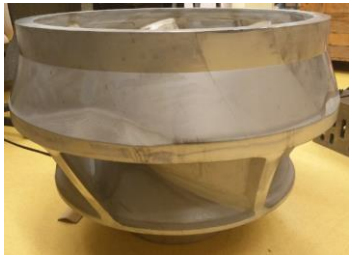
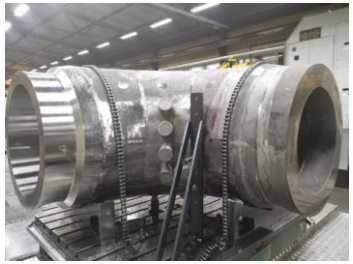
Investigated processes - HIP











Powder Metallurgy HIP

Advantages of HIP:

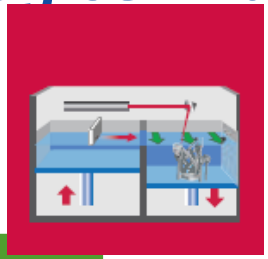
- Quantity of material used far less than with forge technique
- Near Net Shape final part
- Fine and homogeneous metallurgical structure (avoid the large grain CND issue in stainless steel forging)
- As good mechanically as forged steel

Practical Development in Framatome

- Characterization of A 508, 304L and 316L steels processed by HIP and comparison to forged steel
- Manufacturing of scale 1 part of primary pipe in 304L
- Development of a specific HIP software: Simulation of the deformation of the container during HIP cycle (shrinkage) and of the metallurgical state after HIP

Powder Metallurgy. Framatome Additive Manufacturing technologies in development

LPBF: Laser Powder Bed Fusion



WAAM: Wire Arc Additive manufacturing

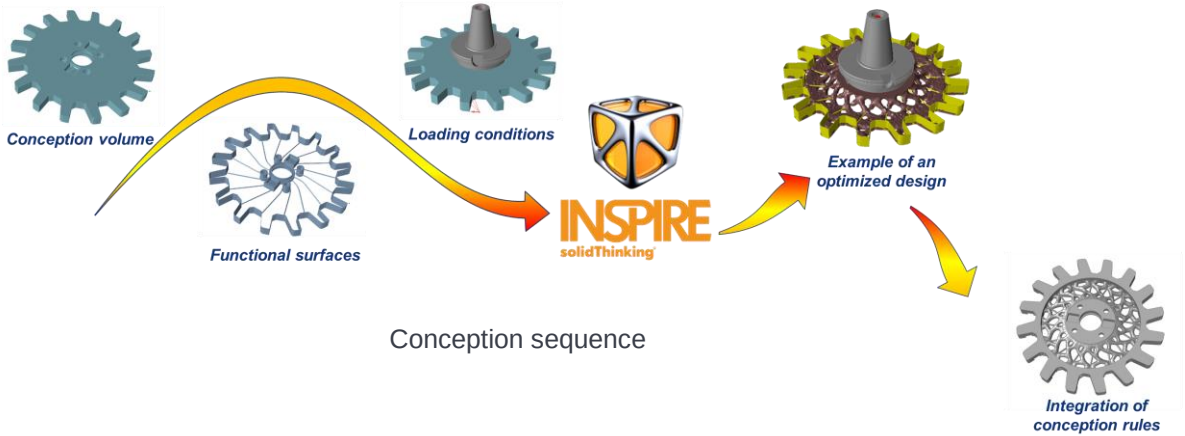
LMD: Laser Metal deposition

Design Optimisation

Investigated processes - AM

On-going projects – Design for AM

- To take advantage of AM techniques, Framatome develops “Design for AM” routes.
- From the functional requirements and a basic CAD model, a finite element based topology optimization is carried out and permits to suggests organic geometries meeting the prescribed performance targets.
- Then, our know-how permits to convert it into a printable design.



Conception sequence

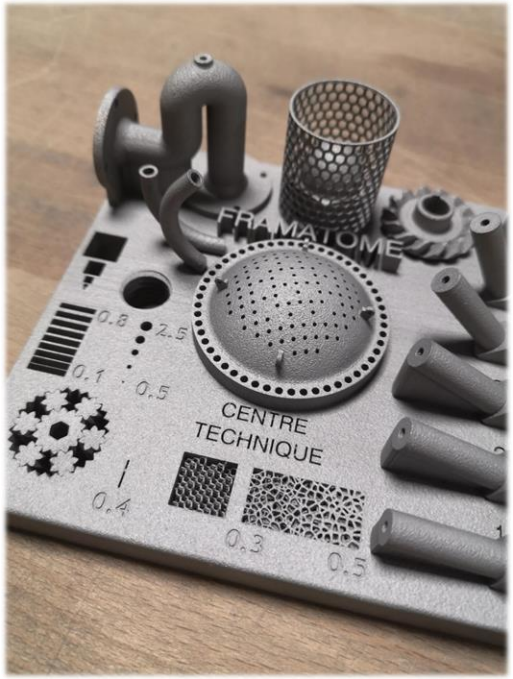
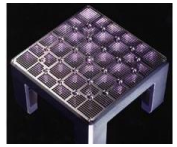
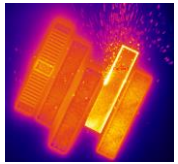


Illustration of the conception rules

On-going projects – L-PBF

- Framatome is engaged in the development of:
  - Process knowledge and breaking of technological barriers linked to fabrication quality,
  - Elaboration of materials folders
  - In-service behaviour evaluation
  - Control means
- Among other projects, this approach relies on:
  - EU funded NUCOBAM project (Nuclear Components Based on Additive Manufacturing)
    - Aims to develop the qualification process and evaluate the in-service behaviour of AM materials (316L stainless steel)
  - Irradiation of stainless steel and nickel base alloy components (Gösgen PWR and Brown Ferry BWR)
  - French consortium Additive Factory Hub
    - Influence of process parameters on materials properties
    - Process monitoring



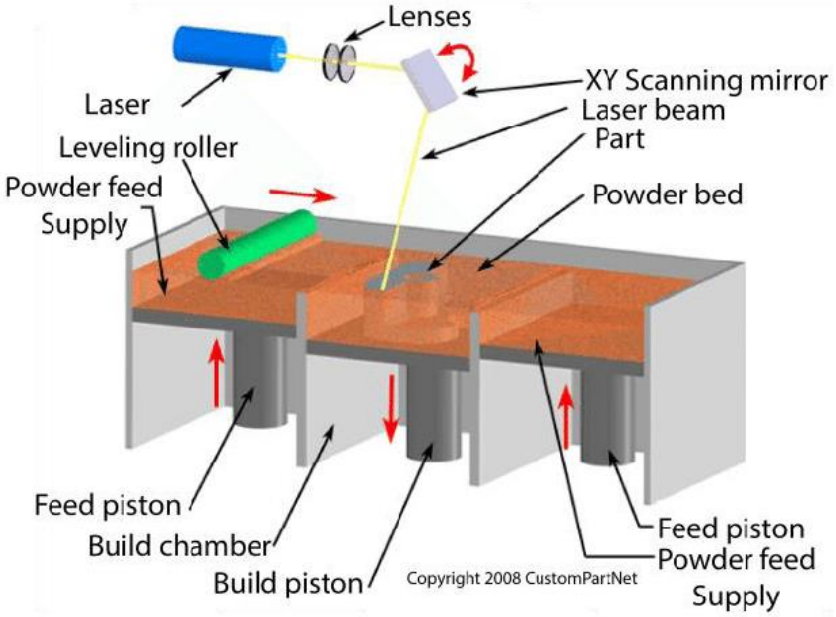


On-going projects – L-PBF

Advantages of LPBF:

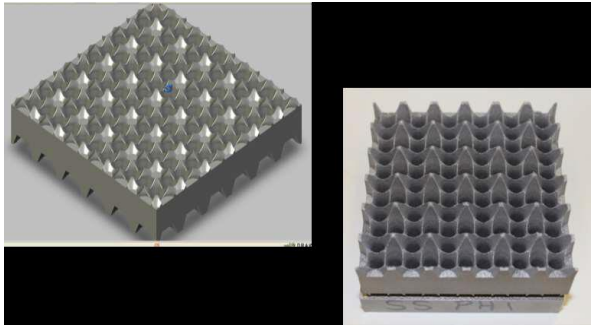
- Complex Parts
- Close to final dimension
- High TRL

Laser process, not in the code

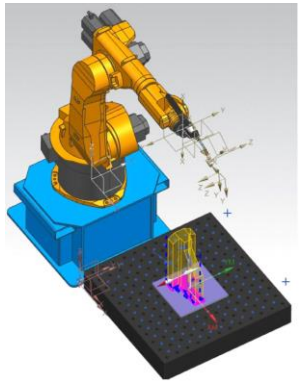


Practical Development in Framatome

- Characterization of 316L and Inconel 718 steels processed by LPBF
- Fuel Assembly Grids
- Tools (for welding Machining…)



On-going projects – WAAM

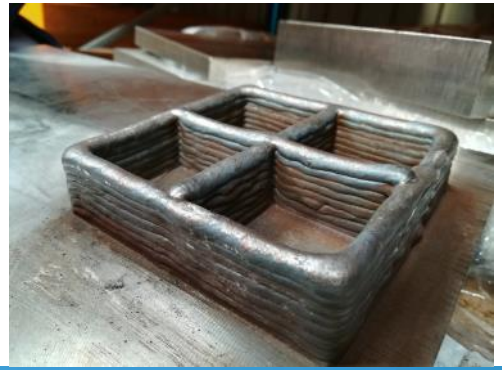


- WAAM is developed in-house, on our welding installations.
- Our development program addresses the main challenges:
  - Design adaptation to WAAM process
  - Elaboration of welding programs using CAM solutions
  - Thermo-mechanical simulations
  - Procurement of wires and definition of operating windows
  - Industrialization
- This approach relies on the elaboration of walls for characterization and of prototypes for feasibility demonstration

On-going projects – WAAM

Advantages of WAAM:

- Large parts
- Technology based on arc welding : easier to codify,
- Reduced investment and material costs
- No specific tools required
- But far from to the final dimensions

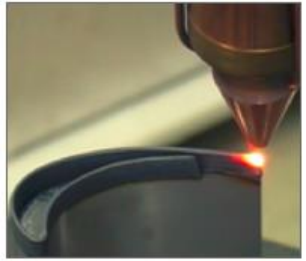


Practical Development in Framatome

- Characterization of 316L A508 steels processed by WAAM
- Master the generation of complex welding paths
- Manage the thermal aspects to improve deposition rates

On-going projects – LMD

- Repair strategies for stainless steel and hardfacing materials
  - Identification of repairable defects
  - Preparation of the defect and stress release
  - Deposition strategy
  - NDE
- Elaboration of components and/or function additions
  - Design adaptation and definition of the deposition strategy
  - Material folders and dimensional control
  - Evaluation of the qualification approach
- Advantages LMD
  - Can be used for repair
  - Coating/cladding
  - Intermediate dimensions
- Laser process, not in the code

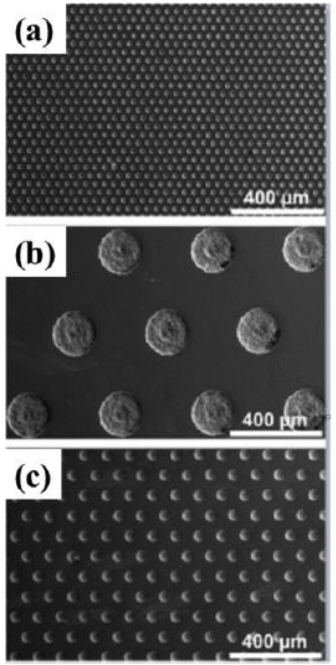


Surface Treatment

Technologies until now not very developed in Nuclear reactors.

Framatome works on some Surface treatment:

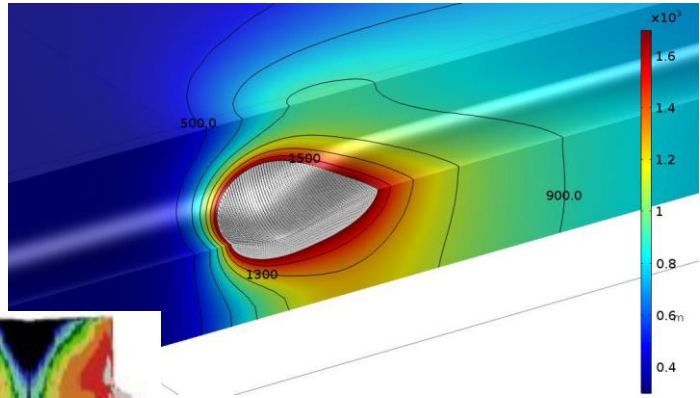
- PVD (Physical Vapour Deposition)
- Graphene or Graphite coating
- Laser texturing
- Cr VI coating replacement (Reach)

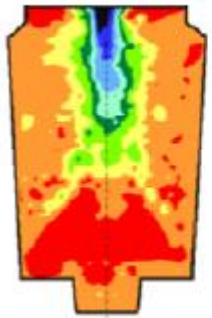


Numerical Simulation of Manufacturing Process

Already some Numerical Simulation software exist. Some are underdevelopment:

- Welding: mechanical simulation, and Multiphysics simulation
- Machining: mechanical simulation
- Metallurgical microstructure simulation
- Heat treatment simulation
- Forge simulation
- Solidification simulation
- HIP simulation





In the future chaining of the software

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Thank You!