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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
- Numerical simulation of manufacturing process
- Controlling the manufacturing process in real time
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 builds 3D objects by adding layer-upon-layer of material
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

Product complexity

L-PBF
- Laser Powder Bed
- Complex designs
- Small size

LMD
- Laser Powder projection
- Complex designs
- Medium size

WAAM
- Arc Wire
- Simple design
- Large size

Size
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.

Illustration of the conception rules
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
Thank You!

[Image of Framatome logo and industrial buildings]
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