Inspection of Additive manufacturing parts, study of NDT solutions for WAAM

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Abstract: As manufacturer of tubular solutions for the Oil & Gas market, Vallourec is investigating opportunities offered by additive manufacturing. This production mode may come on top of conventional processes of the group to overcome a certain amount of customer challenges. The targeted products being large parts, developments are mainly focused on WAAM technology.

In the production routes definition, NDT inspection of the parts is considered as key to ensure quality of the products to our customers. Vallourec Research Center France is then working on potential solutions to cope with the challenges of additive manufacturing parts inspection. Indeed, parts manufactured are most of the time with complex shapes, can present heterogeneities in their volume or surface that can require specific NDT solutions. On top of this, NDT techniques developed need to be compatible with an industrial use.

The paper will present the investigations performed by Vallourec Research Center France to determine the best NDT solutions for WAAM parts inspection, evaluate their performances and confirm their compatibility with the products constraints. Concerned NDT methods are mainly ultrasonic and magnetic particles analyses. The paper will develop a used case of part manufactured with WAAM process and its inspection. It will illustrate solutions in place and the conclusion will focus on remaining challenges for additive manufacturing parts inspection.
Inspection of additive manufacturing parts, study of NDT solutions for WAAM

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\textsuperscript{2}SAIPEM
\textsuperscript{3}EDF Hydro
Growing activity within Vallourec group

- Oil & Gas, PowerGen, Maritime, etc.
- 3 existing production sites: 1 in Germany, 1 in Singapore and 1 in France

Motivations

- Reduce lead time
- Reduce total cost of ownership
- Limit environmental impact

On-demand parts manufacturing

WAAM

Add functions

Wire Arc Additive Manufacturing
Design optimization for WAAM

CAD modelling + 3D slicing + Path generation

Weld setting & robot code generation

Printing (Germany)

Pre-machining (blanking)

NDT on blanking (UT)

Heat treatment

Base plate removal + Final machining

Final NDT (PT or MPI or RT)

Preparation for delivery
WAAM LINE
CONSIDERATION OF NDT CONSTRAINTS

Design optimization for WAAM
CAD modelling + 3D slicing + Path generation
Weld setting & robot code generation
Printing (Germany)
Pre-machining (blanking)
NDT on blanking (UT)
Heat treatment
Base plate removal + Final machining
Final NDT (PT or MPI or RT)
Preparation for delivery

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NDT FOR WAAM
CHALLENGES & OVERVIEW OF SOLUTIONS

Main challenges

- Raw surface state
- Part geometry / Various materials / large catalogue of products
- New manufacturing process = new expected defectology
- No existing standards for WAAM

Vallourec proposals

- Full body-machining after heat treatment (UT + RT)
- Intermediate machining (blanking) (UT only)
- Volume inspection = manual UT / coded UT / conventional RT
- Surface inspection = wet MPI / wet LPI
- Study of welding defectology
- Study of equivalent product / process standards
- Definition of internal standards

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USE CASE N°1
SEAL RING FOR EDF HYDRO
USE CASE N°1

3D printing of a « seal ring » for EDF Hydro
- Delivery of a full-scale first article
- Made in martensitic stainless steel (13Cr4Ni)

Bigger OD = 890mm
OPERATING CONDITIONS FOR UT
EQUIPMENT

Inspection done at One R&D in coded mode (Aulnoye-Aymeries)

10MHz phased array probe, 64 elements, in contact mode (flat wedge)

Skoot scanner from Jireh

Panther 128/128 PR from M2M

Computer to drive electronic system for UT

Print to be inspected

Use of TFM imaging after blanking

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OPERATING CONDITIONS FOR UT SCAN PLAN

- Inspection from side face, full circumference: TFM only
- Inspection from side face, full circumference: TFM only
- Inspection from top face, full length: TFM + PA
- Inspection from top face, full length: TFM + PA

2 directions of inspection
TFM RESULTS FOR THE TWO PRINTS
RESULTS ARE CUMULATED AND DISPLAYED ON CROSS-SECTIONAL VIEWS

Gain is here set to « REF gain »
Ø3mm side drilled holes are used as reference defects

Some few indications detected on print n°1 (poor signal amplitude) / Nothing detected on print n°2
RESULTS ON PRINT N°2
FINAL GEOMETRY 0,7MM ON SURFACES – LIQUID PENETRANT TESTING

Some rounded indications were detected and sized (size ranging from 2 to 14mm)

Maximum diameter of observed porosities = 1mm

No linear indications detected

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USE CASE N°2
WAAM ADD-ON FOR SUBSEA COMPONENT (WASC) FOR SAIPEM
USE-CASE N°2

► WASC study (Waam Add-on for Subsea Component)

► Proof-of-Concept for SAIPEM
  • Delivery of a demonstrator
    » 1 sacrificial part
    » 1 actual part
  • Made in carbon steel

On-demand parts manufacturing

Add functions

WAAM

Wire Arc Additive Manufacturing
Use of Phased array UT after blanking

5MHz phased array probe, 64 elements, in contact mode (flat wedge)

Lathe

Panther 128/128 PR from Eddyfi

Computer to drive electronic system for UT

Inspection done at One R&D in automatic mode (Aulnoye-Aymeries)
OPERATING CONDITIONS FOR UT
SCAN PLAN

2 directions of inspection

Straight beam inspection / Cylindrical surface = Volume + Interface (longitudinal waves)

Angle beam inspection / Conical surface = Volume + Interface (shear waves)

Angle beam inspection / Conical surface= Volume (longitudinal waves)
UT RESULTS
STRAIGHT BEAM INSPECTION / CYLINDRICAL SURFACE

Sacrificial part

Actual part

TCG at 80% FSH on Ø6mm FBH
Good SNR / Some indications over 40% FSH detected on both parts

Max. amplitude = 89% FSH

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INVESTIGATIONS ON THE DETECTED INDICATIONS
ON SACRIFICIAL PART ONLY

NDT (UT)
Max. amplitude = 89% FSH

Accurate positionning using UT TFM

Destructive investigations (saw cutting)

Micrographic examinations (before Nital 3% etching)

Micrographic examinations (after Nital 3% etching)

Lack of fusion associated with inclusion particles

Defect localized in a start & stop region

« Easy to avoid in production »
LPI RESULTS
LIQUID PENETRANT TESTING ON ACTUAL PART AFTER FINAL MACHINING

No indication to be noticed.
Part compliant with class 2X of NF EN ISO 23277
CONCLUSIONS
**CONCLUSIONS**

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<th><strong>Use case n°1</strong></th>
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<td><strong>EDF</strong></td>
<td><strong>SAIPEM</strong></td>
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<td>Liquid penetrant testing after final machining</td>
<td>Best quality level achieved</td>
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<td>Ultrasonic testing after blanking</td>
<td>Best quality level achieved</td>
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Parts delivered with high quality standards!
CONCLUSIONS

► **First articles** printed with **success**

► Some indications detected in both cases
  - Macro-porosities (Ø < 1mm)
  - Lack of fusion

► **Lessons learnt**
  - NDT = very good **quality barrier**
  - Very good improvement of the WAAM process
    » 2\textsuperscript{nd} print was better than the first one in both cases
    » NDT = useful for efficient quality loop (**continuous improvement**)
  - **Overall quality** of the produced parts was considered as **good** although not always reaching the maximum level
  - Quality levels **requirements** need to be set in regards to what is necessary for **usage** of the part

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Thank you for your attention!

Any questions?

Next-level customer experience with our new additive manufacturing mobile app
Some rounded indications were detected and sized (size ranging from 2 to 9mm)

5 linear indications were also detected (size ranging from 4 to 12mm)
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TCG at 80% FSH on Ø6mm SDH
Good SNR / No indication above 40% FSH