

AILEEN

Detecting Hidden Defects: NDT Techniques for Advanced Manufacturing

Prof. Ulaş Yaman

Center for Welding Technology and NDT

Middle East Technical University

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency (EACEA). Neither the European Union nor EACEA can be held responsible for them. PROJECT REFERENCE NO. 101103507

Co-funded by the European Union

Inspection Challenges in Additive Manufacturing



- **Complex Layer Physics**
  - Layer-by-layer deposition introduces non-uniform thermal stress and internal geometry obstacles.
- **Subsurface Invisibility**
  - Critical volumetric flaws remain entirely hidden below component surfaces, defying visual check.
- **Heterogeneous Interfaces**
  - Bimetallic joints exhibit sharp phase transitions requiring multi-property evaluation.

The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Defect Taxonomy

- **Volumetric: Gas Porosity & Voids**
  - Entrapped shielding gas or keyhole collapse leaving spherical interior cavities.
  - Primary Method: **X-Ray** Digital Radiography
- **Interfacial: Lack of Fusion**
  - Insufficient heat input causing unbonded bead boundaries between dissimilar metals.
  - Primary Method: **Eddy Current** Testing
- **Surface: Micro-Cracks & Pores**
  - Thermal gradient tearing and surface-breaking porosity along high-stress fillets.
  - Primary Method: Fluorescent **Penetrant**

The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Case Study – Bimetallic WAAM Interface Inspection

- Evaluating Wire Arc Additive Manufacturing (Steel ER70S-6 to Copper ERCu)
- **Testing Objectives**
  - Verify electromagnetic material transition
  - Detect near-surface planar cracking
  - Validate rapid wire-changeover process



Steel | Fe-Cu Interface | Copper

Ferromagnetic Steel (ER70S-6)

- High magnetic permeability (μr >> 1) dominates impedance response.

Transition Zone (Fe-Cu)

- Heterogeneous globular iron phase embedded in copper matrix.

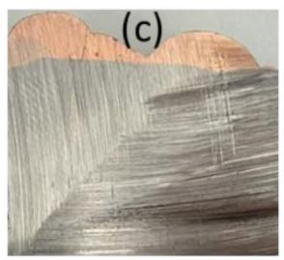
Non-Ferrous Copper (ERCu)

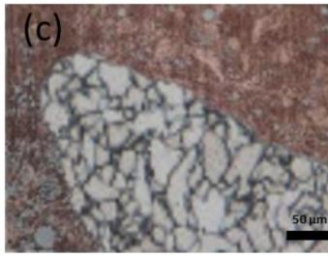
- Non-magnetic (μr ≈ 1), governed by high conductivity (σ).

The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Case Study – Bimetallic WAAM Interface Inspection

- **Steel** Zone: Angled Trajectory
  - Highly linear angled phase vector. Driven by high magnetic permeability of carbon steel substrate.
- **Fe-Cu** Interface: Broadened Loop
  - Multi-directional loop signature reflecting complex localized electromagnetic transition.
- **Copper** Zone: Vertical Response
  - Tightly grouped near-vertical response governed entirely by electrical conductivity.





Nondestructive Proof: Absence of sharp vertical deviations confirms a crack-free metallurgical bond across the bimetallic joint.

The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Case Study – Housing Frames

- **Materials Evaluated**
  - 17-4PH Stainless Steel
  - Ti-6Al-4V Titanium
  - Al 6061-T6 Aluminum
- **Applied NDT Standards**
  - Radiography (RT): ASTM E 1742
  - Liquid Penetrant (PT): ASTM E 1417
  - Acceptance Criteria: TF-DOC-0010870

Components rejected due to subsurface and surface gas porosity.

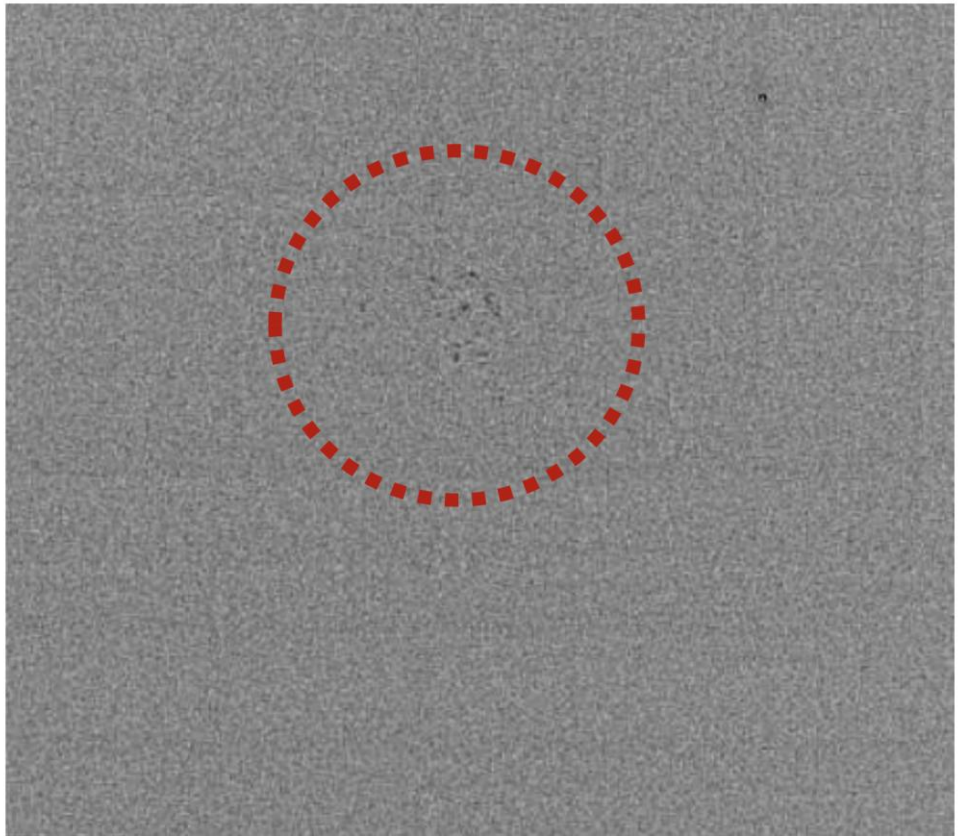
https://www.botingjx.com/aerospace-products/68780733.html



The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Case Study – Housing Frames

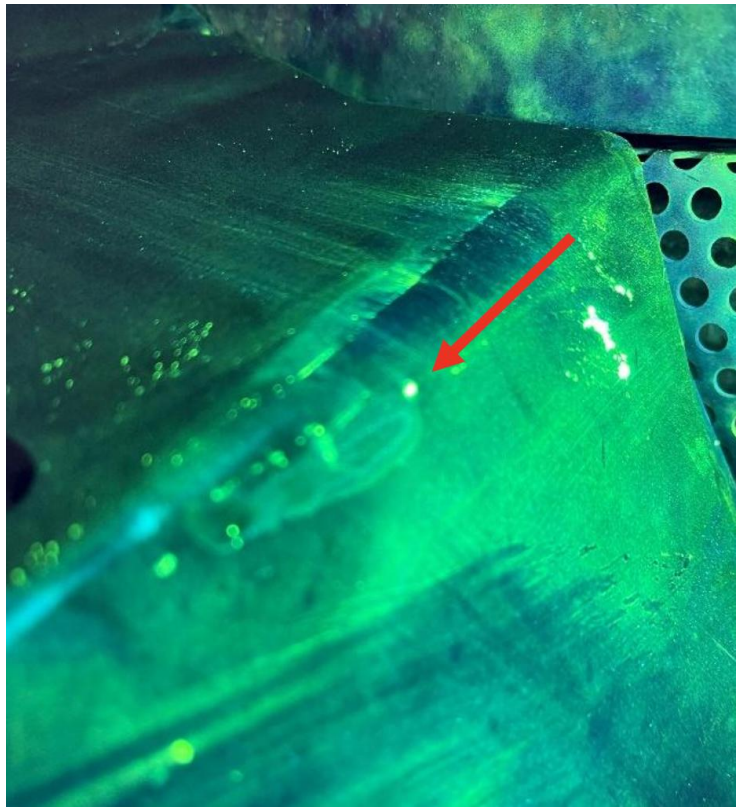
- X-Ray Digital Radiography (RT) Results
  - Subsurface Finding: Internal Gas Holes
    - Digital Radiography revealed trapped subsurface gas porosity within frame wall sections. Internal voids exceeded maximum permitted diameter thresholds defined in TF-DOC-0010870.



The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Case Study – Housing Frames

- Fluorescent Liquid Penetrant (PT) Results
  - High-sensitivity surface discontinuity mapping under UV light
    - Fluorescent inspection illuminated linear porosity clusters along critical corner radii across the components.
    - **Metrological Conclusion:** Surface-connected pores confirm that internal gas entrapment extended through exterior machined walls.



The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Complementary NDT Selection Framework

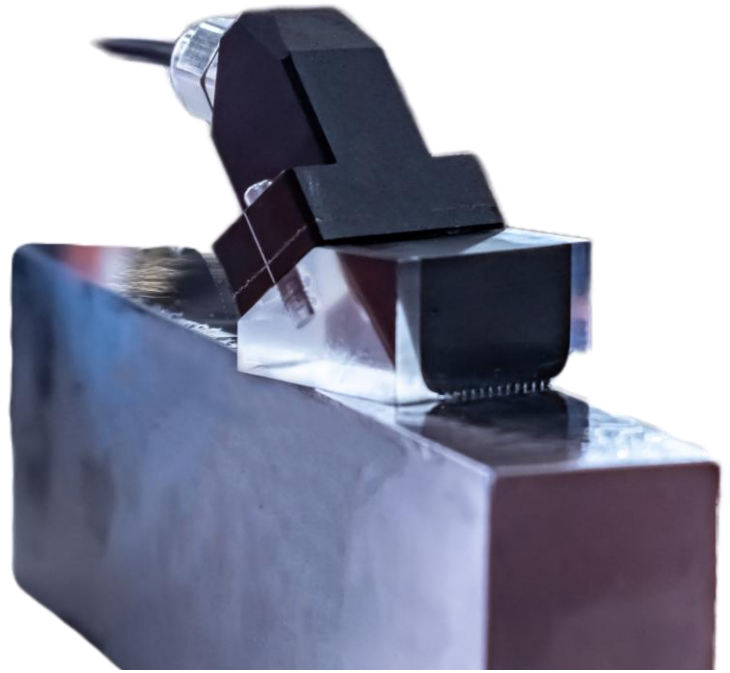
– Matching NDT capabilities to specific defect profiles in advanced manufacturing

NDT Method	Target Defect Profile	Inspection Depth	Key Advantage
Eddy Current (ET)	Planar cracks, material mixing	Near-surface (<3 mm)	Real-time electromagnetic sorting
Radiography (RT)	Gas holes, keyhole voids	Full volumetric body	Internal 2D/3D visual mapping
Liquid Penetrant (PT)	Surface cracks & micro-porosity	Surface-connected only	High sensitivity on complex geometries

The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

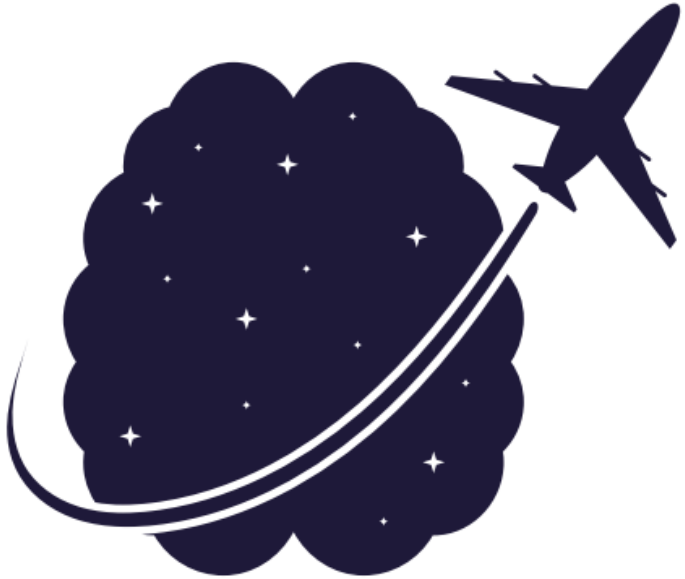
Key Takeaways

- **Multi-Modal Approach**
  - No single method catches all flaws. Surface and volumetric methods must be paired for full assurance.
- **Process-Specific Tuning**
  - Frequencies and energy levels must be calibrated specifically to AM material combinations.
- **CoVE Integration**
  - Embedding real industrial inspection case data into vocational curricula strengthens learner readiness.



The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.





Prof. Ulaş Yaman

uyaman@metu.edu.tr

/ulasyaman

/company/katamer

AILEEN

The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.