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INFINITE

Aerospace composites digitally sensorized from manufacturing to end-of-life

D8.5
Final public project report

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1. EXECUTIVE SUMMARY

1.1 CONTEXT AND OVERALL OBJECTIVES

INFINITE Project started in June 2022 with the objective of developing ferromagnetic MW-based sensors embedded in composite structural parts and an analyser for continuous monitoring of manufacturing and structural health throughout the component's life cycle. The wireless monitoring system generates digital signals and extensive data, creating a digital twin that captures the structure's history since manufacturing, including maintenance operations.

The project focuses on incorporating advanced sensing technology into aerospace composite components, contributing to transformative digital technologies for the aircraft lifecycle and enhancing competitiveness. The primary goal was to establish a calibrated system that produces valuable data for Structural Health Monitoring (SHM), enabling accurate, cost-effective quality assurance of aerospace composite components. This approach aligns with circular economic strategies, addressing the challenges faced by the European aircraft industry.

To sustain a competitive edge, the incorporation of smart control systems for in-situ monitoring of high-value manufacturing, in-service Maintenance, Repair, and Overhaul (MRO), and End-of-Life (EoL) processes is essential. Digital twins play a crucial role, serving as a digital representation of real assets with intelligent functions to derive maximum benefits, not just as data stores but also as tools for future development.

Composite materials, known for their lightweight and high-performance properties, are extensively used in aircraft manufacturing. The ability to incorporate wireless sensors within the composite structure is critical for digital transformation. This aligns with the development of "intelligent structures," encompassing reader, sensor, and smart material development, contributing to achieving environmental targets in the aircraft industry.

1.2 WORK PERFORMED AND MAIN ACHIEVEMEMENTS

During the second reporting period, the project achieved a Technology Readiness Level (TRL) of 3–4. The following technical and scientific developments and outcomes were accomplished:

1. Sensor System Development and Validation

A **low-frequency portable reading system** was developed, capable of detecting signals from microwires (MW) embedded both on the surface and within the interior of carbon fibre composites.

A **wireless sensing system** was validated to detect changes in the state of microwires during the manufacturing of carbon fabrics, preforms, and composite structures, confirming the feasibility of **in-situ monitoring**.

The system was verified for its ability to **read microwire signals integrated in composite panels**, supporting its potential for integration in industrial manufacturing environments.

2. Structural Health Monitoring (SHM) and Fault Detection

A **structural health monitoring (SHM) algorithm** was developed to **characterise, quantify, and localise defects** based on the response of embedded microwires to interrogating electromagnetic signals.

The algorithm incorporated **alternative pathways** to adapt to varying data availability, requirements for explainability, and modularity, increasing its flexibility for different use cases and operational environments.

The **capability of microwires to identify composite defects** was confirmed, both during manufacturing and in-service stages, supporting their use in **non-destructive evaluation (NDE)**.

3. Requirements Definition and Material Performance

Requirements were defined for **damage types, environmental conditions**, and **experimental procedures**, which supported the systematic testing and validation of the sensors in relevant scenarios.

The **impact of microwires on composite mechanical properties** was evaluated, ensuring that the integration of sensors does not adversely affect structural performance.

4. Repair and Maintenance Methodologies

A **flow-chart-based methodology** was developed to guide **repair procedures** based on the diagnostic output of the SHM system.

A **repair toolkit for non-crimp fabric (NCF)** structures was created, aiding maintenance actions post-detection of damage.

5. Data Management and System Integration

An **integrated dashboard** was developed to provide **actionable intelligence** based on sensor data, enabling real-time decision support for maintenance and inspection teams.

Material passports were implemented to track historical data from the manufacturing stage through to in-service monitoring, enhancing traceability and lifecycle management.

6. End-of-Life (EoL) Strategy and Recycling

A **reuse strategy** was defined, identifying the possibility of reusing sensorized parts in the aerospace sector or transferring them to sectors with lower technical requirements.

Potential **recycling methods** for sensorized composites were explored, including recovery of **pyrolysis oil, microwires, and carbon fibre**.

A comprehensive **assessment of cost, environmental impact, and material circularity** for the INFINITE sensor technology was conducted using **Life Cycle Assessment (LCA)**, **Life Cycle Costing (LCC)**, and **material circularity assessment tools**.

1.3 RESULTS BEYOND THE STATE OF THE ART

- **Feasibility of Integrating Microwire-Based Sensors**
    - *Result*: Successfully integrated microwire-based sensors into composite structures without compromising structural integrity or mechanical performance.
    - *Potential Impact*: Enables real-time health monitoring of critical components in sectors such as aerospace, automotive, and wind energy. This could extend service life, reduce maintenance costs, and enhance safety.
- **Validation of Structural Health Monitoring (SHM) Techniques**
    - *Result*: SHM methods proved effective for identifying and localising defects both during manufacturing and in service.
    - *Potential Impact*: Improves quality control and reliability of composite structures, contributing to predictive maintenance strategies and reduced downtime.
- **Development of Sensor-Guided Maintenance and Repair Toolkit**
    - *Result*: Initial procedures and tools created to support condition-based maintenance using sensor data.
    - *Potential Impact*: Shifts industry from scheduled to needs-based maintenance, reducing unnecessary interventions and associated costs.
- **Material Passports and System Dashboards**
    - *Result*: Framework established to ensure data continuity across the lifecycle of composite materials.
    - *Potential Impact*: Facilitates traceability, enhances lifecycle management, and supports digital twin implementations, especially for safety-critical applications.
- **Sustainable End-of-Life (EoL) and Circular Economy Insights**
    - *Result*: Data-driven insights provided into recycling and reusability strategies for advanced composites.
    - *Potential Impact*: Contributes to more sustainable materials management and supports policy and industry efforts towards carbon neutrality and resource efficiency.

Key Needs for Further Uptake and Success

- **Further Research and Demonstration**
    - Scaled pilot demonstrations in real-world industrial settings are needed to validate sensor integration and SHM performance over long lifetimes and under diverse operating conditions.
- **Market Access and Commercialisation**

- Engagement with early adopters in aerospace, wind, and transport sectors is crucial. Dedicated market studies, business models, and go-to-market strategies should be developed.

- **IPR Support and Technology Transfer**
  - Clear strategies for intellectual property protection and technology licensing will facilitate industrial adoption and investment.
- **Standardisation and Regulatory Support**
  - Development and alignment of standards for sensor-embedded composite materials and digital lifecycle data (e.g. material passports) are critical for market confidence and certification.
- **Finance and Investment**
  - Access to public and private funding mechanisms, including venture capital and innovation grants, is essential to bridge the gap from prototype to commercial product.
- **Internationalisation**
  - Cross-border collaboration and harmonisation of standards will support global market entry, particularly in aerospace and automotive supply chains.

1.4 POLICY RELEVANT EVIDENCE OF YOUR PROJECT

During the second reporting period, the subsequent steps followed the following objectives:

- Identify the standards that describe the manufacturing process of composite sandwich structures, focusing on the sensors used in infusion, preforming processes, and their relevance to the sensor developed by INFINITE.
- Identify the standards that describe the characterization of composite structures, aiming to use standardized procedures when characterizing the properties of composite structures that include glass-coated metallic wires/sensors.
- Identify standards related to damage in structures, detection methods, and their repair.
- Evaluate the possibility that INFINITE technologies can contribute to or support existing standards or identify areas where INFINITE could establish a roadmap for standardization.
- Define standardized procedures (at the consortium level) for the execution, treatment, and analysis of tests conducted with the Portable Reader.
- Recommendations for Future Directions.

So, as a final result an Standardisation roadmap was defined to engage with standardisation bodies, participate in technical committees, and influence the development of relevant standards. It includes steps such as obtaining a trial membership in national mirror committees, joining Technical Committees (TCs), subcommittees (SCs), and working groups (WGs), and actively participating in ongoing standardisation activities at the European and international levels.

Additionally, the roadmap emphasizes the importance of presenting project findings to standardisation committees, engaging in expert meetings, purchasing and analysing key standards, and proposing new work items where gaps exist. To ensure effective participation, the roadmap also includes training in standardisation processes and procedures, allowing project partners to gain expertise in the development and implementation of standards.