

T5.5 Case study Problem- Based Learning (PBL)

Title of Case Study / Problem-based learning case

Wire Arc Additive Manufacturing (DED-arc) Using Pure Copper Wires for Heat Dissipation: A Feasibility Study

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Background:

- **Material:** Pure Copper (Cu-1% Sn) and heterogeneous alloys (Cu-30% Ni, Fe-18% Cr-10% Ni, Fe-18% Cr-10% Ni-Mn, Fe-Mn-Si).
- **Equipment:** 6-axis robotic arm, industrial MIG welding machine, Ar-He (50-50) shielding gas
- **Software:** Parametric toolpath generation software and standard robotic simulation programs

Context & Objective:

Copper is highly desirable for critical applications like heat exchangers and electronics cooling systems due to its excellent thermal and electrical conductivity. However, processing copper via traditional additive manufacturing methods like Powder Bed Fusion (PBF) is extremely challenging. Copper's high reflectivity and thermal conductivity prevent it from absorbing sufficient laser energy, leading to incomplete melting and internal porosity.

Wire Arc Additive Manufacturing (WAAM) overcomes these limitations by utilizing an electric arc, which provides the high heat input necessary to fully melt the copper wire and form dense, pore-free structures. The objective of this case study is to explore the parameter optimization for pure copper deposition and to demonstrate WAAM's capability in manufacturing complex heterogeneous (multi-alloy) walls when faced with equipment limitations.



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Illustration of the case study

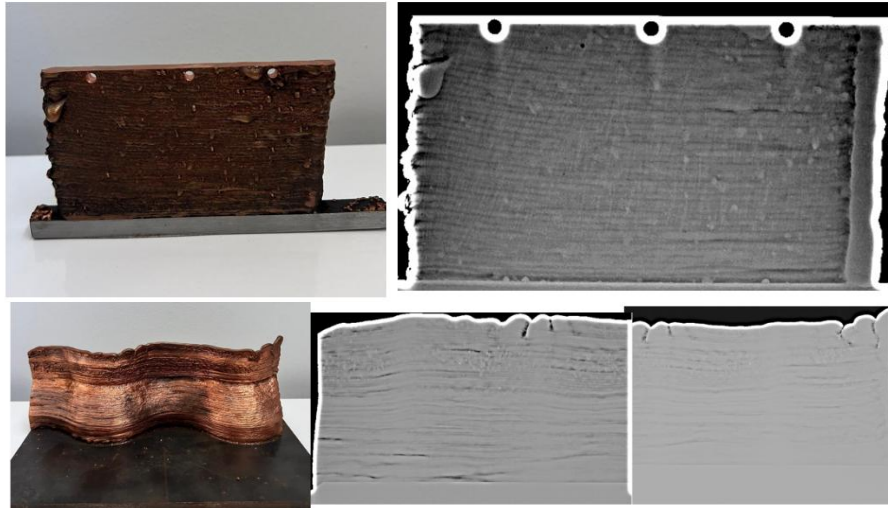


Figure 1. X-ray imaging of the copper WAAM walls, utilized to inspect the internal structural integrity and detect lack of fusion or microporosity

Additional pictures/information



Figure 2. Close-up view of the integrated robotic WAAM system during the deposition of a circular component. The background monitor shows the Mach3 controller interface, which is used to precisely regulate the process parameters

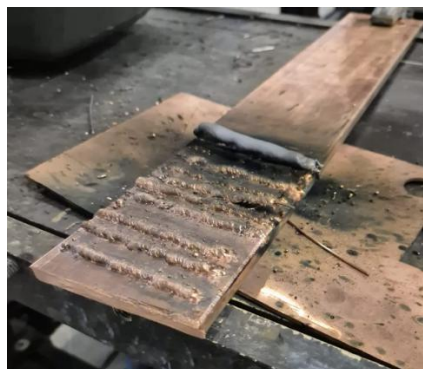


Figure 3. Irregular welding beads



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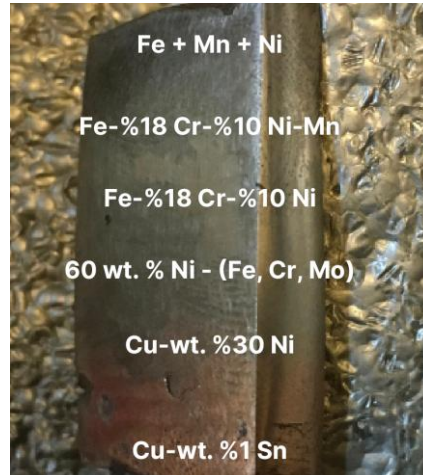


Figure 4. The custom-built dual-wire feeder assembly utilized in the WAAM system to dynamically adjust material composition during the deposition process.

Technical challenge

- **Thermal Management:** Rapid heat dissipation during copper arc welding leads to high thermal gradients and residual stresses. How can operators mitigate this without causing coarse-grained, anisotropic microstructures that degrade mechanical properties?
- **Software Flexibility:** Traditional robotic software (like RobotStudio) lacks the flexibility required for complex or irregular AM geometries. How can parametric algorithms (e.g., Rhino Grasshopper) be integrated to dynamically generate and control the robotic toolpath?
- **Equipment Limitations:** During experimental trials, fixed voltage settings on the robot control panel hindered the optimization of smooth pure copper lines. How can the WAAM process be adapted to successfully build a multi-alloy heterogeneous structure under these hardware constraints?

Detailed solution/ process

1. Parametric Toolpath Generation (Grasshopper Integration)

To overcome the limitations of standard robotic software for irregular geometries, parametric modeling software is utilized to create an adaptive toolpath.

Reasoning: A custom slicer algorithm processes the base mesh, divides surface curves into equal segments, and generates oriented planes. A plugin then translates this directly into executable code for the robotic arm, defining precise translation, rotation, and speed targets. This ensures the robotic system can dynamically adjust to design constraints before any physical deposition occurs.

2. Managing Copper's Thermal Behavior

The high thermal conductivity of copper causes rapid heat loss during the WAAM process.

Reasoning: To counteract this, the process requires preheating and significantly reduced welding speeds. Although slower speeds impact overall production efficiency, they are absolutely essential to prevent the formation of coarse-grained microstructures, which would otherwise result in poor and anisotropic mechanical properties in the final part.



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3. Heterogeneous Wall Fabrication (Strategy Pivot)

During the initial trials with Cu-1% Sn wire, it was discovered that voltage adjustments could not be made dynamically through the robot control panel, preventing the formation of smooth, stable pure copper lines.

Reasoning: Instead of halting production, the strategy shifted to leverage WAAM's unique capability for multi-material deposition. The system successfully deposited a continuous heterogeneous wall, sequentially transitioning through different alloy wires: Cu-1% Sn, Cu-30% Ni, Fe-18% Cr-10% Ni, Fe-18% Cr-10% Ni-Mn, and finally Fe-Mn-Si. This demonstrates that even when single-material optimization is hardware-limited, WAAM can be utilized to produce complex functionally graded structures.

4. Quality Control (Future Next Steps)

To validate these structures for industrial applications, rigorous post-process inspection is required. Students/Engineers should apply metallographic examinations to assess porosity and grain structure, followed by mechanical testing to verify the strength of the heterogeneous joints.

The Purpose of the elaborated Case Studies

Case studies are structured examinations of real-world situations or challenges designed to bridge theory and practice. They are developed both as a research method and as a learning tool to strengthen analytical and problem-solving skills. By engaging with authentic industrial scenarios, students gain practical insight into complex professional environments.

The purpose of this case studies is to encourage active, learner-centred engagement. They support approaches such as problem-based learning by enabling students to work independently or collaboratively, with or without instructor guidance. Through analysing theoretical concepts within realistic contexts, students learn to interpret data and test results, evaluate alternative courses of action, and develop well-reasoned, creative solutions.

This approach is particularly valuable in sectors such as aerospace, defence, and advanced manufacturing, where challenges are multifaceted and solutions are rarely singular. Because multiple valid solutions often exist, guided facilitation is frequently beneficial to help students structure their reasoning, assess trade-offs, and justify their decisions effectively.



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Competence unit coverage:

AILEEN competence units		Covered CU
AW_01	Welding: Advanced Metallic Materials in Aerospace and Defence Sectors	X
AW_02	Welding: Advanced Welding Processes and Equipment in Aerospace and Defence Sectors	X
AW_03	Welding: Advanced Welding Applications in Aerospace and Defence Sectors	X
AW_04	Welding: Introduction to brazing technology Knowledge for quality brazed joints	
AW_05	Welding: Fundamentals of Industrial Brazing: Main Processes, Quality Standards & Applications	
AI_01	Inspection: Non-Destructive Testing (NDT) in Additive Manufacturing for metals and polymers	X
AI_02	Inspection: Metrology in Additive Manufacturing for metals and polymers	X
AI_03	Inspection: Inspection of AM parts. Material Quality	X
AAM_01	AM: Qualification, Certification and Standards for AM in A&D	X
AAM_02	AM: Quality Assurance & Quality Control for AM in Aerospace & Defence	X
AAM_02/3	AM: Design of AM parts for A&D (2 courses - for DED & PBF)	X
AD_01	Digital: Introduction to Digital Technologies in Advanced Manufacturing	
AD_02	Digital: Data Acquisition and Analysis	
AD_03	Digital: Industrial Internet of Things (IIoT) and Advantages in Advanced	
AD_04	Digital: Artificial Intelligence and Advantages in Advanced	
AD_05	Digital: Automation and Advantages in Advanced Manufacturing	
AD_06	Digital: Potentials of Advanced Simulation and Modelling in Advanced	
AD_07	Digital: Potentials of Digital Twins and Smart Factory Automation in Advanced Manufacturing	
AD_08	Digital: Unlocking the Potential of 3D Models Beyond Technical Drawings in the Aerospace and Defence Sector	
AG_02	Green: Sustainable Design and Environmental Compliance in Aerospace and Defence	

