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

Title of Case Study / Problem-based learning case

Hybrid Additive Repair for Worn Moulding Cavity Castles – Reconditioning and Repurposing of High-Performance Tooling.

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Based on / adapted from: Moliporex/CENTIMFE - ISQ hybrid mould repair case study.

- Moliporex – Moldes Portugueses, Importação e Exportação, now integrated directly under the unified brand name Vangest grew to become the flagship company of the Vangest Group (https://vangest.com/), specializing in high-complexity molds, particularly for the automotive lighting and industrial sectors.
- CENTIMFE (https://www.centimfe.com/en-home.html) is the Technological Center for the Mouldmaking, Special Tooling and Plastic Industries in Portugal.

Background:

A high-performance injection mould used in polymer processing has worn, damaged or dimensionally degraded moulding cavity castles and side flanges. Instead of replacing the entire tool, the industrial team decides to evaluate a hybrid additive repair strategy:

The existing H11 tool-steel base is re-machined by CNC milling down to the plane corresponding to the base of the castles. Above this plane, M300 maraging steel (DIN 1.2709) is deposited by PBF-LB (Powder Bed Fusion – Laser Beam) to rebuild the castles and side flanges. The repaired tool is then age-hardened and finish-machined to functional tolerances. The repaired mould is validated dimensionally, metallurgically and functionally by injection trials.

The case is therefore not simply “additive manufacturing of a new mould.” It is a hybrid repair and repurposing problem: combining subtractive machining, additive deposition, heat treatment, metrology, metallurgy and functional testing.

Key materials and geometry

Item	Detail
Substrate	H11 tool steel, ≈5 wt.% Cr
Additive material	M300 / DIN 1.2709 maraging steel, PBF-LB
M300 age-hardened properties	YS ≈ 1854 MPa, UTS ≈ 1916 MPa, hardness ≈ HRC 55
Deposition strategies	Case 1: castles only, 2 mm deposited height; Case 2: total deposition, 2.5 mm deposited height
Side allowance	0.3–0.5 mm over-thickness for final machining
Functional tolerances	Micrometre order on cavity/ castle surfaces after machining
Original tool availability	Original mould no longer available; similar geometry used for repair study

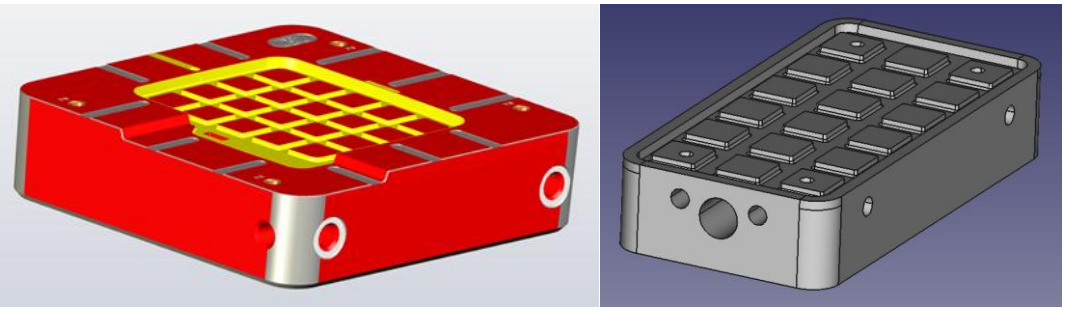
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A first deposition trial showed good material deposition but visible deformation of the base plate, highlighting that thermal distortion control is a critical issue in hybrid repair.

Illustration of the case study



CAD models of the original Moliporex mould and the CENTIMFE alternative geometry.

Technical challenge

The problem-based learning challenge is:

- What tests can you perform to determine the nature and cause of wear/damage?
- Perform a root-cause analysis (RCA) of the worn cavity castles and interface region.
- Check the compatibility, weldability/printability, interface metallurgy and known problems of M300 deposited on H11.
- After the RCA, determine what tests could be performed to pass functional/injection validation successfully.
- How can this be tested on small samples?
- Select either castles-only or total deposition, then compare both repair approaches with conventional machining and full replacement.

Detailed solution/ process

1. Root-cause analysis of worn/damaged cavity castles
A systematic RCA should include:

- Visual and stereoscopic inspection of the worn castles, side flanges and interface.
- Dimensional inspection by CMM to quantify material loss, distortion and deviation from nominal geometry.
- Hardness mapping on the worn H11 substrate and remaining functional surfaces.
- Microstructural investigation using optical microscopy and SEM-EDS to identify wear mechanisms, oxidation, corrosion pits, heat checking or microcracks.
- Chemical analysis to check whether the H11 substrate has degraded or been contaminated.
- Literature search

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2. Hybrid manufacturing strategy
The selected route is:

- Reverse engineering / CAD adaptation
- Base preparation by CNC milling (the H11 base down to the plane corresponding to the bottom of the castles)
- Side flanges receive 0.3–0.5 mm over-thickness for final machining.
- Calibration and fixation (the mould base is rigidly fixed. A PBF-LB webcam calibration procedure aligns the existing substrate with the deposition coordinate system)
- PBF-LB deposition of M300
- Two strategies are compared: Castles-only deposition: rebuilds only the upper functional region (2 mm) and Total deposition: more extensive reconstruction (2.5 mm).
- Post-processing: Stress relief / age hardening, finish machining of over-thickness, polishing of functional surfaces
- Validation: CMM dimensional verification, metallurgical characterization by SEM-EDS, tensile testing of hybrid coupons, corrosion testing
- Injection trials.

3. Testing

- Non-destructive testing (NDT): CMM / optical scanning for distortion and geometry, dye penetrant for surface defects, radiography or CT for internal porosity/defects, hardness mapping where geometry permits.
- Destructive testing: Macro-sectioning to evaluate joining quality, SEM-EDS at the M300/H11 interface, tensile tests.
- Corrosion tests: cyclic potentiodynamic polarization (CPP) and electrochemical impedance spectroscopy (EIS) in 0.6 M NaCl.
- Thermal shock / short thermal cycling to approximate injection conditions.

Because extended fatigue tests are not possible, the team should use short proxy tests:

- Tensile strength and elongation as indicators of ductility and fatigue resistance.
- Interface hardness and SEM-EDS to detect brittle phases.
- CMM distortion before/after deposition.
- Injection trials as final functional validation.

4. Results from the case
Geometric distortion:

- Before printing:
  Case 1: max–min height difference = 13.5 µm.
  Case 2: max–min height difference = 9 µm.
- After PBF-LB:
  Case 1: distortion increased to 0.105 mm.
  Case 2: distortion increased to 0.135 mm, with central concavity.
- Conclusion: distortion remains in the tenths-of-a-millimetre range, relatively small for the process, but must be considered for functional performance.

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Metallurgical interface:

- SEM-EDS showed interdiffusion of Ni, Co and Mo from M300 and Cr from H11.
- The interface is a critical zone and may be prone to preferential attack or brittle phase formation if not controlled.

Corrosion behaviour:

- H11: corrosion potential ≈ −0.28 V vs. SCE, about 200 mV nobler than M300.
- M300: ≈ −0.48 V vs. SCE, active dissolution, high pitting susceptibility in chloride media.
- Hybrid M300+H11: electrochemically dominated by M300; galvanic coupling concentrates attack on the deposited side.
- Interface revealed preferential attack.
- Recommendation: post-deposition treatments such as HIP, solution treatment and aging to mitigate corrosion.

Economic and functional benefits:

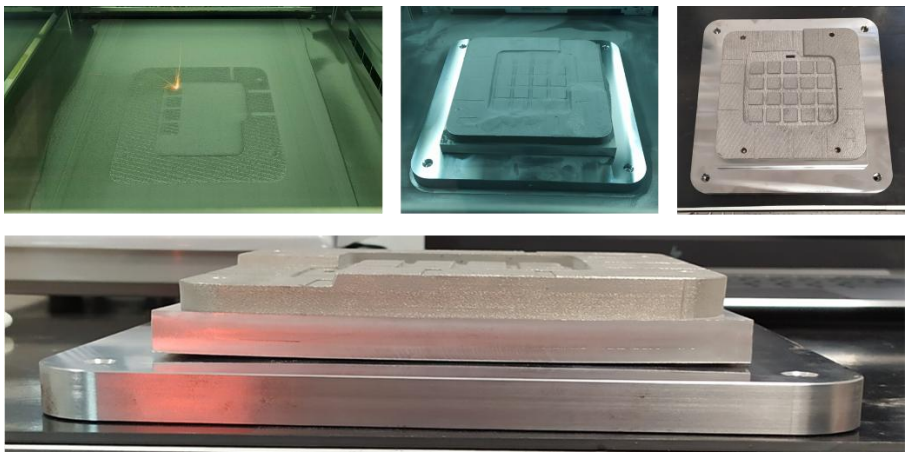
- Reduced material waste compared with machining a solid H11 block.
- Reduced lead time.
- Possibility of local repair instead of full mould replacement.
- Estimated cost reduction of 20–40%, depending on geometry and batch size.

5. Conclusion of the technical challenge

Hybrid additive repair is technically viable for worn moulding cavity castles, but success depends on:

- Correct base preparation and alignment.
- Selection of deposition strategy.
- Control of thermal distortion.
- Metallurgical compatibility of M300 and H11.
- Corrosion protection and post-treatment.
- Metrological and functional validation.

Additional pictures/information

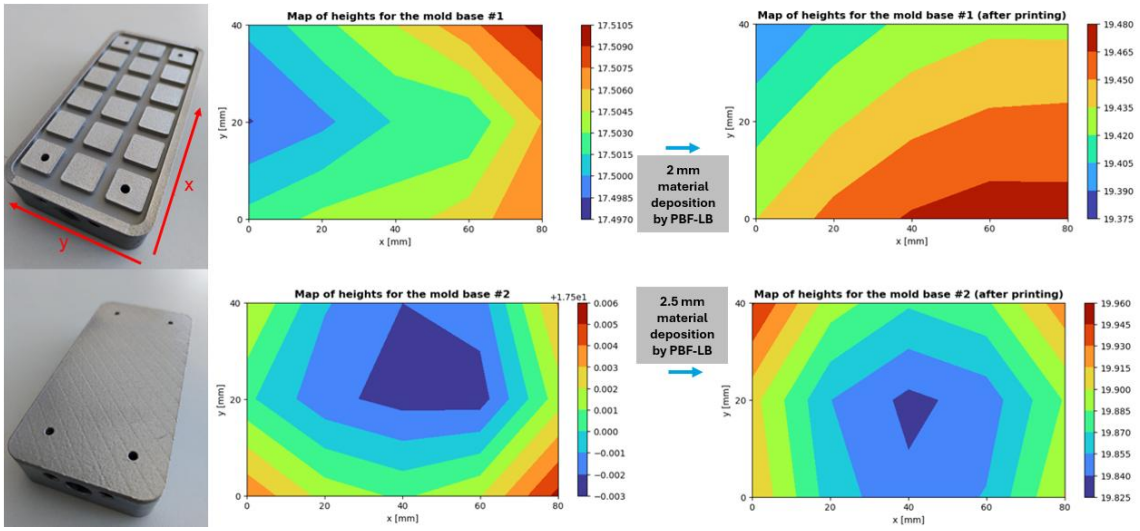


First PBF-LB deposition of castles on the H11 mould base, showing good deposition but base deformation.

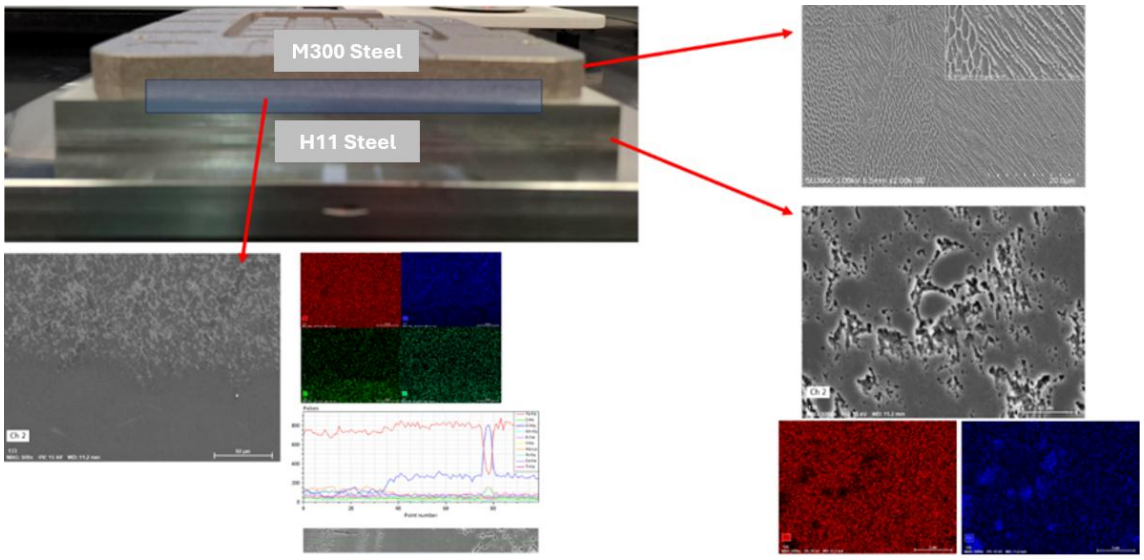
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CENTIMFE moulds variants with two deposition strategies - castles-only and total deposition, M300 steel, PBF-LB (left). CMM distortion measurement setup and results (right).

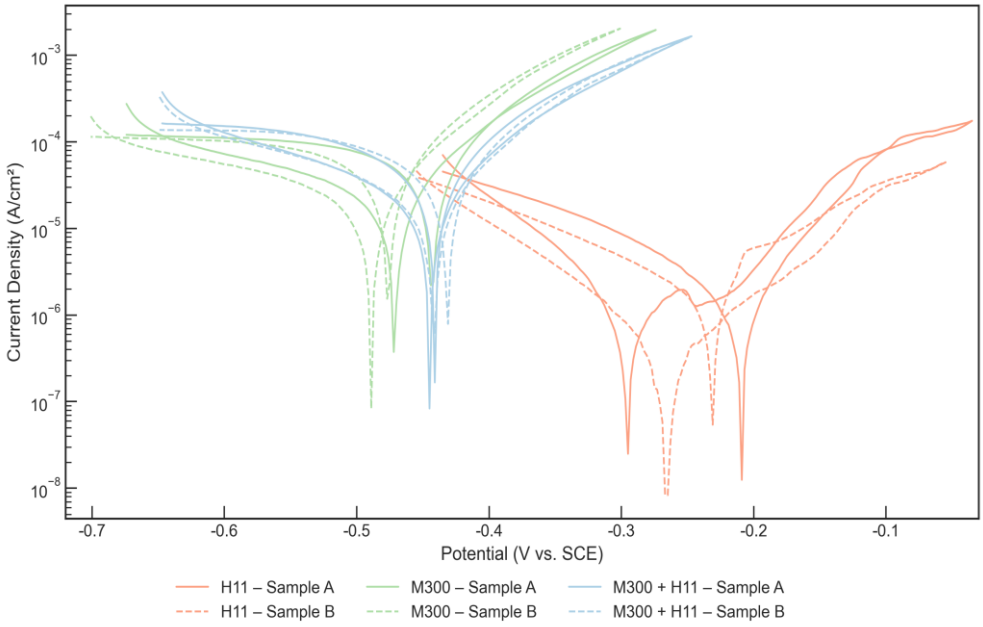


SEM-EDS characterization of the M300/H11 interface

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Corrosion test results - polarization curves for M300, H11 and M300+H11.

Purpose of the Elaborated Case Study

This case study bridges theory and industrial practice in hybrid additive repair. It encourages learners to:

- Analyse a real repair problem where additive manufacturing does not replace conventional processing but complements it.
- Perform root-cause analysis of worn tooling.
- Select and justify hybrid manufacturing strategies.
- Interpret CMM, SEM-EDS, tensile and corrosion results.
- Evaluate trade-offs between repair and replacement.
- Develop short, practical validation tests when extended fatigue testing is not possible.
- Communicate a well-reasoned, creative solution in a sector where multiple valid solutions exist.

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Competence unit coverage:

	AILEEN competence units	Covered CU
AW_01	Welding: Advanced Metallic Materials in Aerospace and Defence Sectors	
AW_02	Welding: Advanced Welding Processes and Equipment in Aersopace and Defence Sectors	
AW_03	Welding: Advanced Welding Applications in Aerospace and Defence Sectors	
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	
AAM_02	AM: Quality Assurance & Quality Control for AM in Aerospace & Defence	
AAM_02/3	AM: Design of AM parts for A&D (2 courses - for DED & PBF)	
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	x
AG_02	Green: Sustainable Design and Environmental Compliance in Aerospace and Defence	
AAM_04	AM for Aerospace & Defence	x

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