



Application Of Functionally Graded Materials to Extra-Large Structures (Grade2XL):

The European Ambition to Industrialise the Multi-Metal WAAM Process

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Conventional Manufacturing vs WAAM

| Traditional processes (forging, casting, machining) | Wire Arc Additive Manufacturing (WAAM) |
|--|---|
| Limited range of design options | Design freedom |
| Material properties globally controlled by process (casting/rolling) | Local control of chemical composition and thermal cycle during deposition |
| High « buy-to-fly » ratios | Near-net shape deposition |
| Long lead times, storing necessary | Short production times, produce on-demand |



The Proposed Solution

- **Multi-material** Wire + Arc Additive Manufacturing (WAAM) for **Large-Scale structures**.
- **Gas Metal Arc Welding** based system integrated with industrial robotic arm.
- **Flexible** Manufacturing system, full data logging & NDT post-processing, *specific* for the end-user application.
- Integrated **cryogenic (LNG) cooling** system.



Grade2XL objectives

- Functionally graded Materials
- WAAM process development
- Life cycle assessment
- Topology optimisation

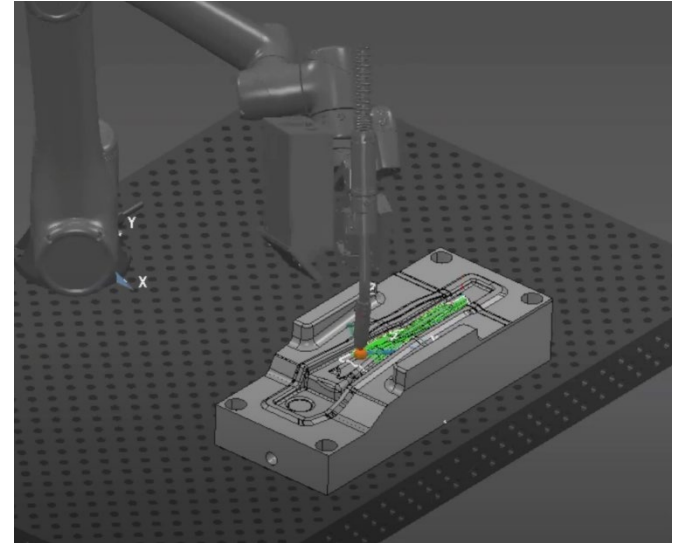
Process development

- Dual robotic setup developed by Autodesk and Valk Welding.

- 2 Panasonic Welding Robots
- S-AWP torches
- 1-axis external manipulator
- a plasma cutter
- A cryogenic cooling setup
- Sensors for process monitoring
- Sensors for geometrical control
- RAMLAB Max-Q

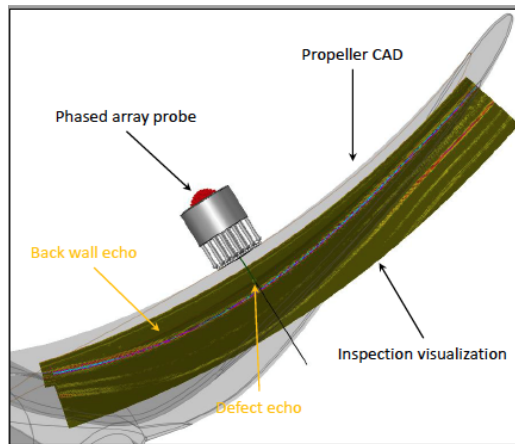


Flexible manufacturing system - Repair



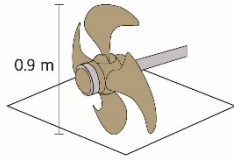
In line non-destructive testing and control

- Methods of NDT used:
 - Advanced Phased Array Ultrasonic Imaging
 - Scanning Laser doppler Vibrometer(SLDV)
 - XRF
 - Eddy current
 - Acoustic Emission



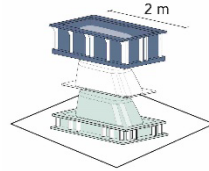
*Preliminary result test
on WAAMPeller, by
CEA list for Bureau
Veritas and RAMLAB.*

8 Demonstrators

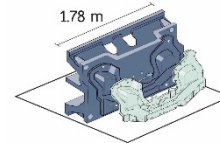


A-1 Propeller

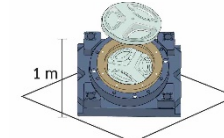
MAN-ES
/RAMLAB



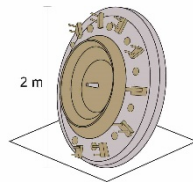
**B-1 Mould for
Bathtub
Showface**
Villeroy&Boch
/RAMLAB



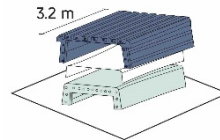
**B-3 Injection
Mould for Plastic
Parts**
Shapers
/Naval Group



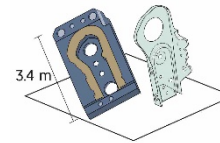
**B-5 Forming die for
Stainless Steel
Parts**
Gorenje
/RAMLAB



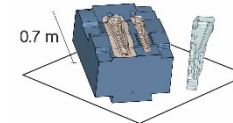
**A-2-Mobile Ring for
Hydroelectric Plant**
EDF
/Naval Group



**B-2 Mould for
Composites**
GKN
/RAMLAB



**B-4 Forming die for
steel parts**
Gorenje
/RAMLAB



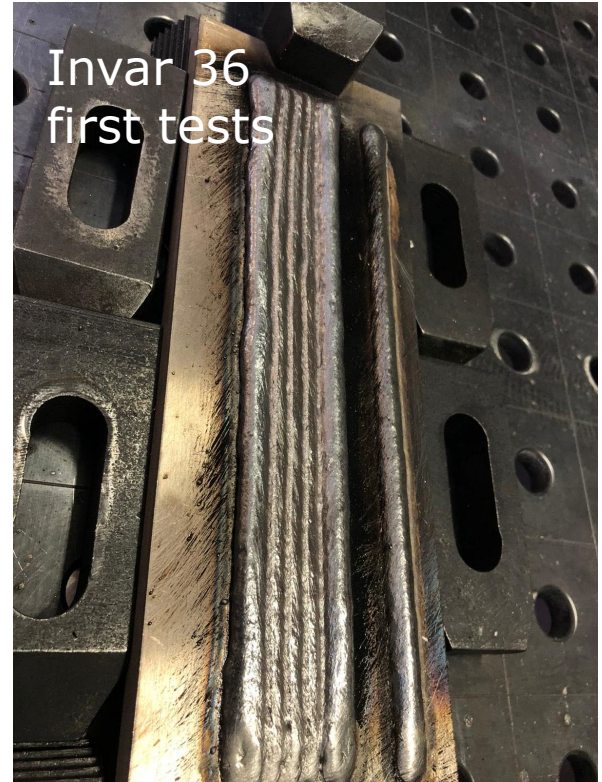
**B-6 Hot Forging die
(repair)**
Kuznia Jawor
/RAMLAB

Materials



Wide variety of consumables

- Low alloy steel ER70
- Aust. Stainless steel AISI316L
- Mart. Stainless steel AISI410
- Inconel 625
- Invar 36 and in-situ alloyed Invar 42
- CuAl8, CuSi3
- Metal cored custom high alloy steels



Coupon testing -> Demonstrator

- Microstructural evaluation, OM, SEM, TEM
- Chemical analysis: EDS, EPMA
- Mechanical testing
 - micro-hardness
 - tensile testing (elevated temperatures)
 - charpy-V impact testing
 - fatigue testing
 - wear testing
- End user case requirements: Roughness, corrosion, Post deposition heat treatments (optional)

Building strategy development

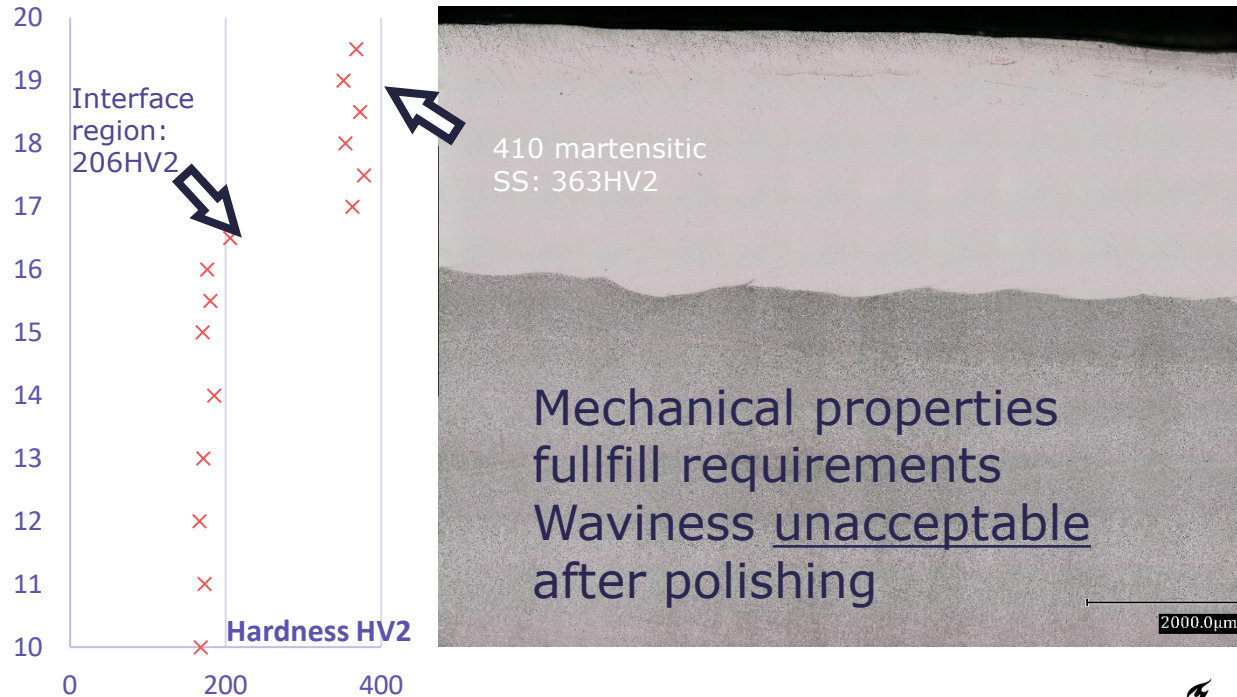
- Building strategies tailored per demonstrator
- General guidelines will be formulated.
- Samples with geometry of representative complexity.
- Integration of cooling channels/hollow sections is common feature in many demonstrators.



Pathfinder part printing

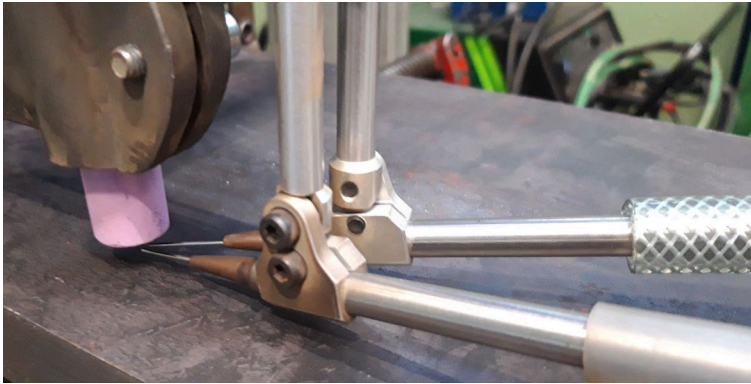


Pre-production studies- coupons



Pre-production studies- coupons

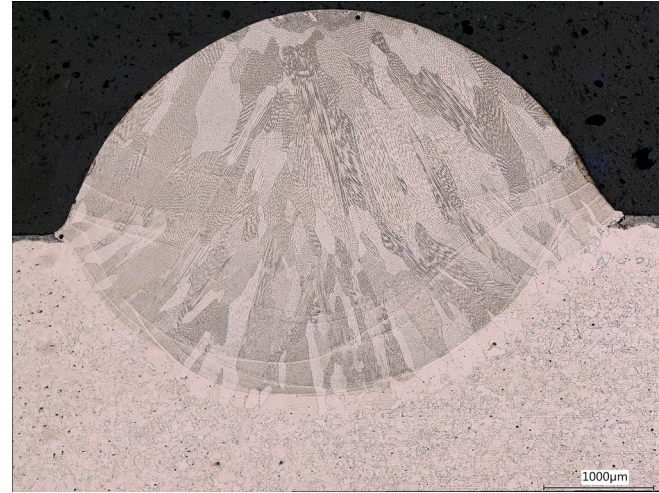
Grading of invar Invar 36 to invar 42



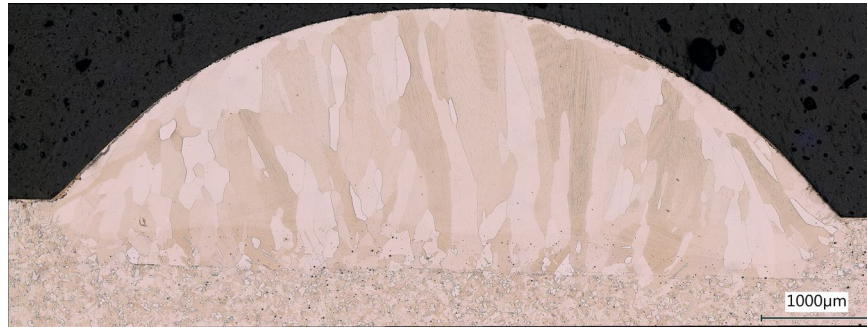
Pre-production studies- coupons

Invar 36 - GTAW

Single beads for
Parameter selection

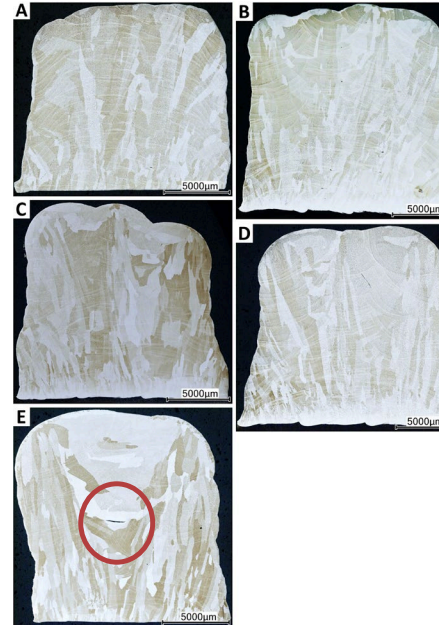
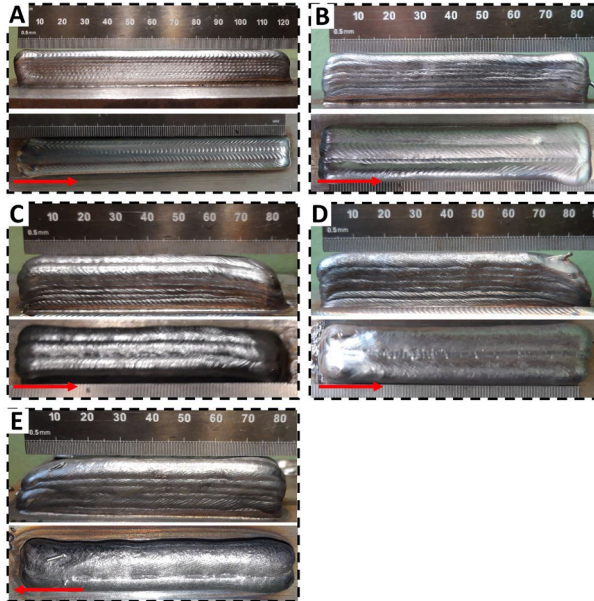


I: 56-150 A
 V_t : 3, 6 mm/s
WFR: 16-56 mm/s

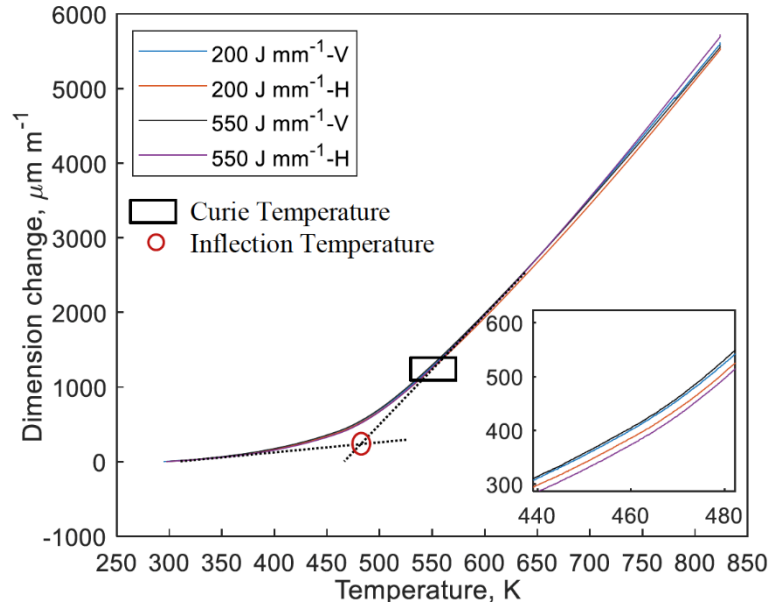


Pre-production studies- coupons: Invar

Variation of heat input in uni-material blocks, cracks are observed



Thermal expansion of WAAMed Invar



- Thermal expansion of WAAM invar shows consistent behaviour within the processing window.
- Not significant difference in different directions.

Key findings of the project so far



- Stable Deposition parameters at >4.0 Kg/hr
- MaxQ monitoring and control system to control geometry, temperature and log data which can be cross-correlated with NDT data.
- Invar deposition is possible for crack-free deposition, but slow. Alloy modification may be required for volumetric part production.
- Cryogenic cooling was successfully implemented with prototype nozzle. Optimisation of the design is necessary for maximising the cooling effect.
- Pathfinder parts are being produced (~ 0.5 m) in to validate deposition strategies for all demonstrators.

Join an « Experience Day »

Free and public industrial demos:

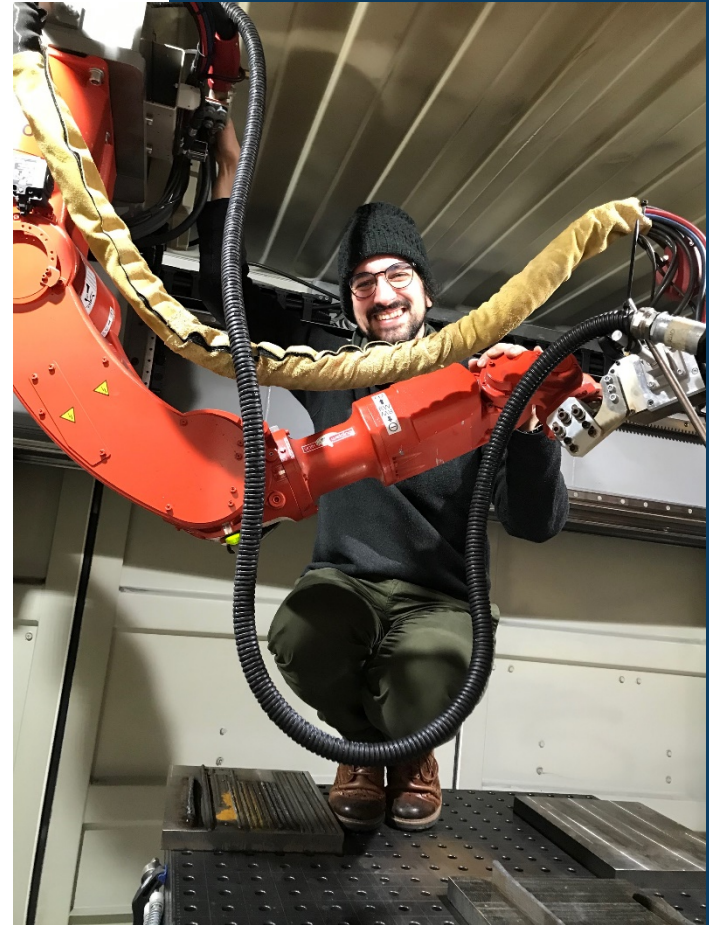
- Technical description of WAAM
- Live prototyping of a part
- Business model definition
- Individual coaching on financing

Started in June 2022

Join us for a one-day sessions at our facilities:

In Czech Republic, Denmark, France, Germany or in the Netherlands.

Or apply for a **demo coming at your site** after having enrolled your colleagues and partners.



 **Thank you for your attention!**

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Visit our website grade2xl.eu

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Project partners



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