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SAM
SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING

2023-02-14

CU 01: DED-arc Build platform, atmosphere, feedstock and other consumables

Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

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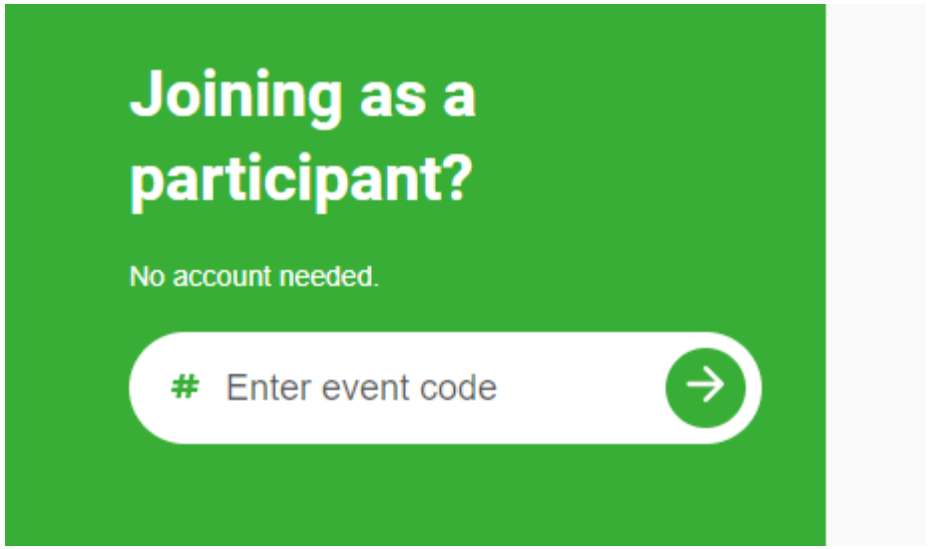

Question. Word cloud pool

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Outline

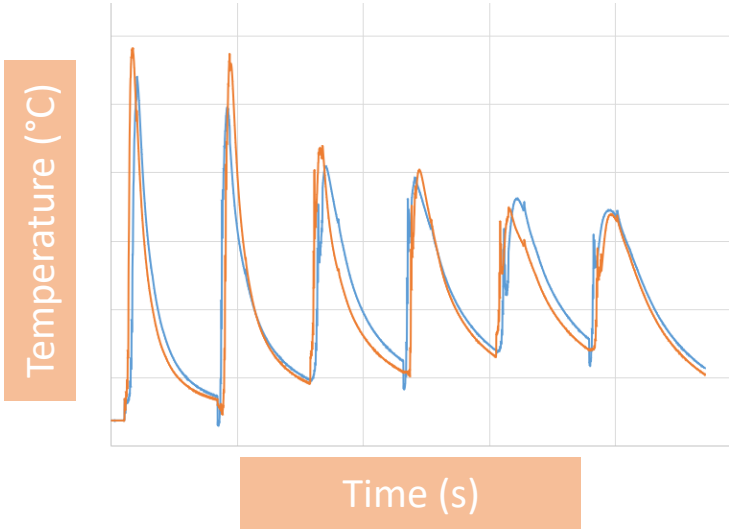
- Processable materials with DED-arc
- Build platform materials and condition
- Build platform, feedstock and other consumables handling and storage
- Shield gases

Processable materials with DED-arc

- All material than can be processed in wire format
- Non weldable typical materials
- Steel coils are usually coated by a nanometric film of Cu to help the ignition of arc (not appropriate for LMD due to its reflection)
- Premium quality wires are recommended.
- Generally DED-arc systems are wire based but powder can be also used
- Powder has risk to adhere to the electrode and contaminating it (TIG). Higher material waste. Highly used for EHLA (extra high-speed laser deposition) for cladding
- Arc based systems also often use MIG, where the wire is the electrode – therefore incompatible with powder

Processable materials with DED-arc

- The material need to be tolerant to:
  - High heat input
  - Low cooling rate
  - Successive cycles of heating/cooling and hardening/annealing that implies the superimposing of multiple layers and the possible heat treatment as post-processing.
- The material experiences constant phase changes due to mentioned successive cycles of heating/cooling. This has an effect in the obtained microstructure and mechanical properties.



Processable materials with DED-arc

- The selection of the wire must consider the desired mechanical and physical properties.
- Some manufacturers implemented specific adaptations in chemical composition and manufacturing in their welding wire for WAAM purposes.

Metallurgical benefits	Process benefits
Made for low cooling rates and high heat input	High process stability for Robotic MIG or other mechanised processes
Accepts multiple hardening/tempering cycles by multiple layers	Drum and spool weights can widely be adopted to the weight of parts
Optimised for post print heat treatment	Extended quality control to ensure consistent arc and feeding behavior
Tailor-made metallurgy for complex materials	Optimised surface technology for long arc cycles, Liners stay clean, contact tips last longe

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Processable materials with DED-arc

The chemical composition of the wire has an effect in:

- Arc stability
- Melt pool fluidity
- Impurities that form films in the surface

Surface quality of the wire has an effect in:

- Contamination
- Durability of dragging system consumables
- Welding tip durability
- Wire feed rhythm

Processable materials with DED-arc

- Material has to be validated and properly qualified ensuring:
  - Alloy chemistry within specification (ideally more adjusted than welding purposes)
  - Interstitial chemistry
  - Morphological properties
- All should be included in the material specification given by supplier.
- Important to check the variation of chemical composition between providers and between batches.

化学成分 Chemical Composition(%)													
Ti	Al	V	Fe	C	O	N	H	Y	/	/	/	/	其它元素（Other）
Balance	6.26	4.17	0.15	0.024	0.14	0.006	0.003	0.002	/	/	/	/	单个（Each）<0.05
	/	/	/	/	/	/	/	/	/	/	/	/	总和（Total）< 0.20
	/	/	/	/	/	/	/	/	/	/	/	/	/

Processable materials with DED-arc

- Each material has specific needs and hence it has to be optimised regarding:
  - Electric parameters
  - Shielding gases
  - Shielding systems
  - Deposition strategies
  - Cooling strategies

Processable materials with DED-arc

Materials

- Steels
  - 316L
  - 308L
  - ER60
  - ER70S-6
  - ER80S-Ni1
  - ER90-B3
  - ER120
  - Maraging 250 y 350 grades
  - …
- Aluminum alloys
  - 5356
  - 2319
  - 5183
  - 4043
  - 5087
  - …

  } 2024
- Others
  - Invar 36
  - IN718
  - IN625
  - Ti-6Al-4V
  - Tungsten
  - CuNi8Al6
  - Stellite 6
  - …

Processable materials with DED-arc

General properties of materials

- Aluminium alloys
  - ✓ Good mechanical and thermal properties
  - ✓ Low density
  - ✓ Good electrical conductivity
  - ○ Low hardness
- Titanium alloys
  - ✓ Corrosion resistance
  - ✓ Excellent strength-to-weight ratio
  - ✓ Low thermal expansion
  - ✓ Biocompatible
- Stainless Steel and tool steels
  - ✓ High wear resistance
  - ✓ Great hardness
  - ✓ Good ductility and weldability
- Cobalt-Chrome superalloys
  - ✓ Excellent wear and corrosion resistance
  - ✓ Great properties at elevated temperatures
  - ✓ Very high hardness
  - ✓ Biocompatible

Processable materials with DED-arc

General properties of materials

- Niquel superalloys (Inconel)
  - ✓ Excellent mechanical properties
  - ✓ High corrosion resistance
  - ✓ Temperature resistance up to 1200 ºC
  - ✓ Used in extreme environments
- Precious metals
  - ✓ Used in jewellery making
  - ○ Not widely available

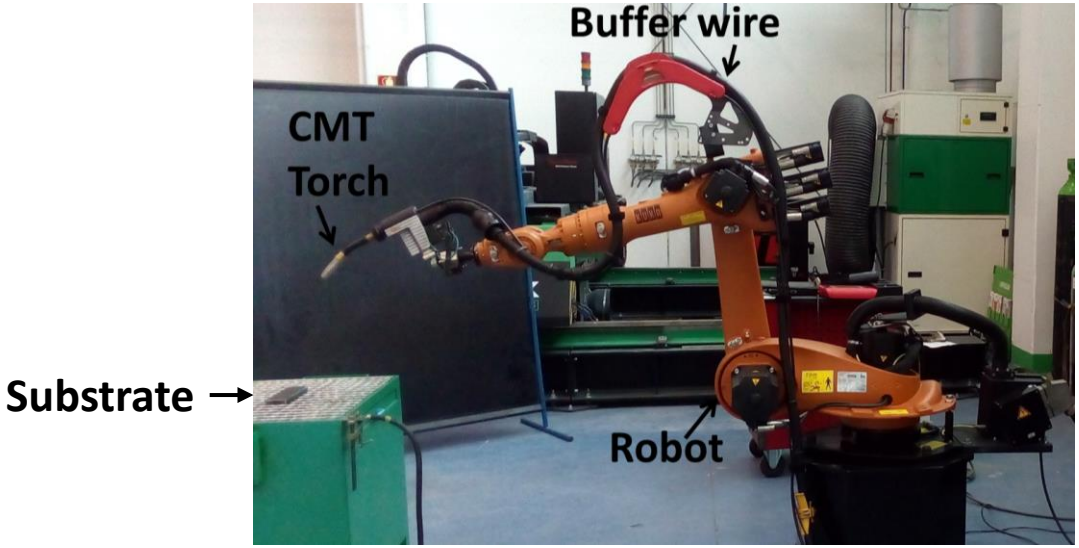
Processable materials with DED-arc

Wire providers:

- Lincoln Electric
- Miller
- Vbc Group
- ESAB
- OERLIKON
- SelectArc
- SAFRA
- HOBART
- FSH WELDING Group
- ALCOTEC
- …

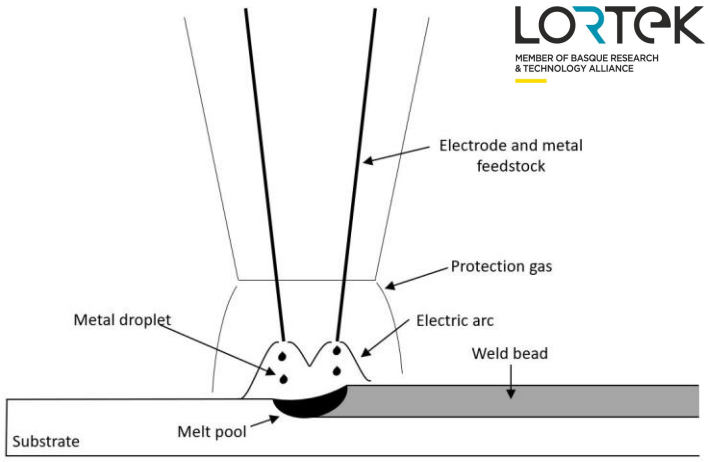
Build platform materials and condition

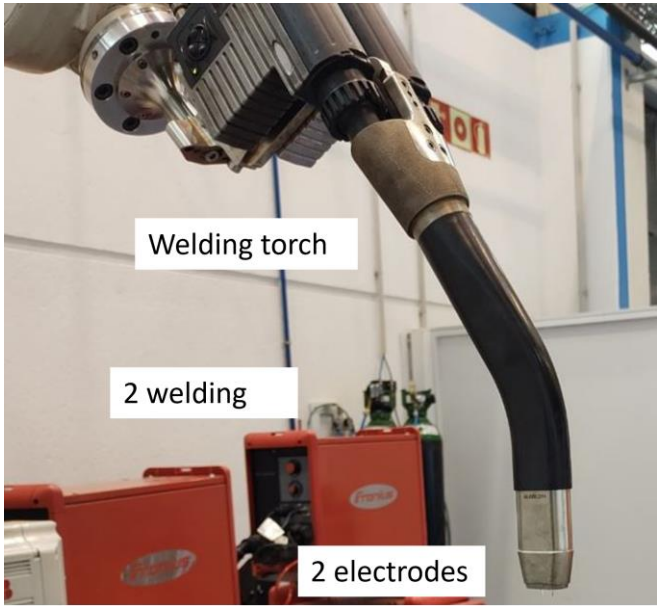
- Main build platform consists of torch, wire feeder, substrate and robot.
- It can be designed as an open architecture with interchangeable or adaptable components



Build platform materials and condition

- Torches:
  - Dependent of the technology
  - Unitary or double wire
  - Coaxial (MIG/MAG)





Build platform materials and condition

Welding torches can be attached to:

- CNCs
- Robotic arms (6 axis)

With different dimensions of spatial range for different part dimensions.

Hybrid machines in the market combining WAAM and machining for light metals. (Links: https://www.zayer.com/actualidad/es/xios-addimill-innovacion-en-fabricacion-aditiva/ and https://metrom.com/waam/)

Build platform materials and condition

- Specific requirements of parts, such us tilted walls, symmetric manufacturing, extremely long parts, etc.
  - 2 additional external axis.
  - Tilting table.
  - Linear rail for robot.

Build platform materials and condition

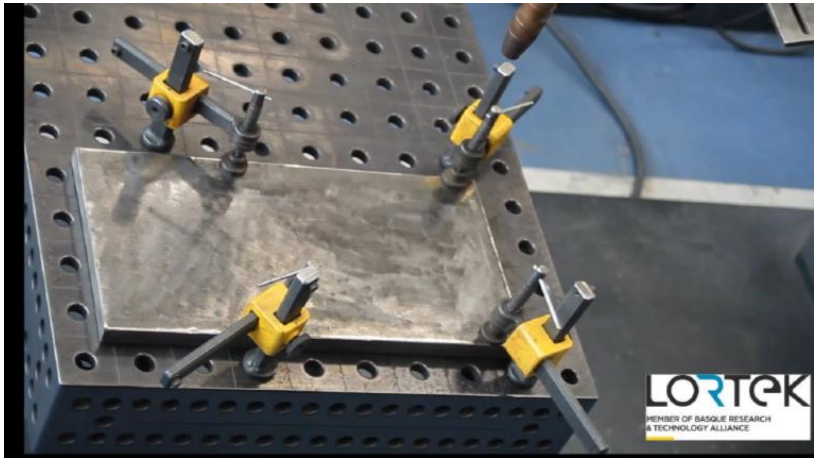
Wire feeder:

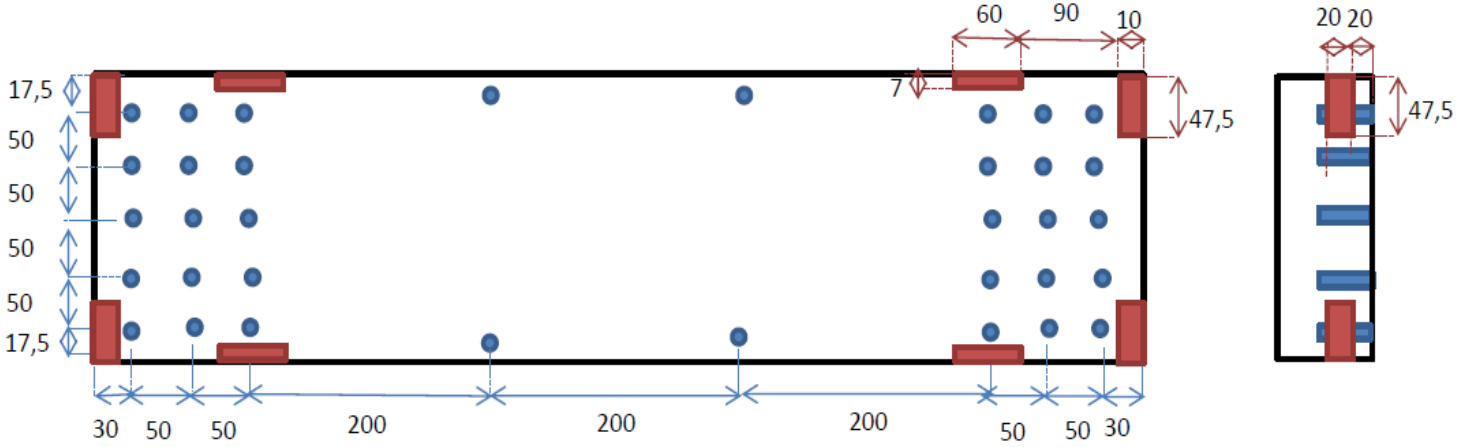
- Objective: to feed the arc with at a constant rate
- Wire feed systems are fundamentally very simple and easily controlled
- They can easily be added to any pre-existing system
- TIG Hot Wire:
  - Increases the deposition rate
  - Minimim risk of lack of fusion
  - High quality weld bead
- A sensor of wire feed speed can be included to control

Build platform materials and condition

Substrate:

- Chemical composition
- Dimensions (oversize)
- Clamping system:
  - Fixed tooling
  - Compliant tooling to avoid distortions



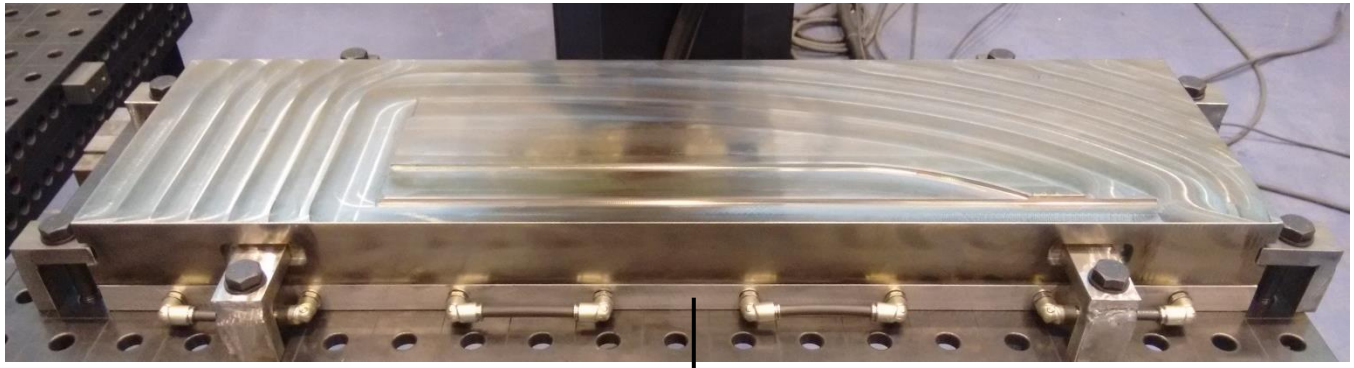


Build platform materials and condition

Interpass cooling conditions is a key factor to control manufacturing time and heat accumulation during manufacturing. **Heat accumulation** is related to the loss in part accuracy and distortions. There are **different tools** to control these interpass conditions:

- Dwell time control: Automated control of dwell time between the deposition of overlapped layers.
- Active cooling systems: local gas application, cold plate and water pool, among others.

Changes in these cooling conditions affect to the resulting microstructures and mechanical properties. By selecting the optimum interpass time a good balance of as built mechanical properties can be achieved.



Cooling plate connected to a water cooling system

Build platform materials and condition

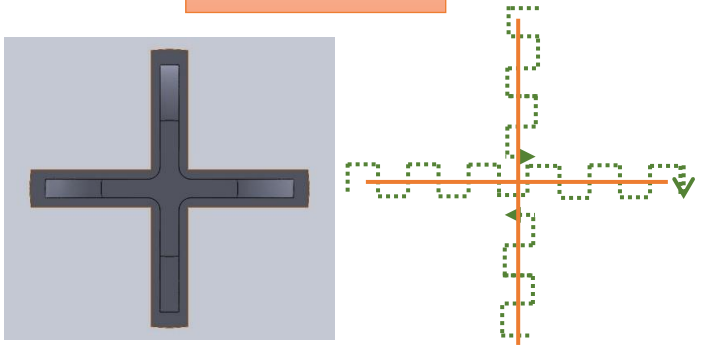
- Design. CAD SW

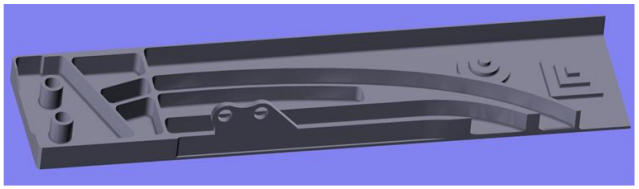
The design of the final part need to be processed. For that purpose, generally an **overthickness** is required in each surface taking into account a post machining process to remove the surface waviness which is normally more than 1 mm from each side. For the redesign, 2 different options can be used:

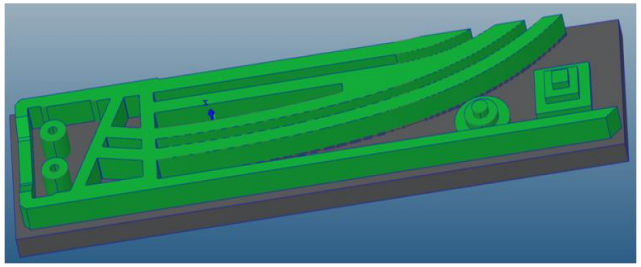
- A **preform**: it includes the overthickness that the robot needs to manufacture.
- **Central line** of the part walls: the robot will follow the lines and the amplitude is defined in order to obtain the overthickness required.

The optimisation of the overthickness is important to reduce the BTF ratio.

2 options



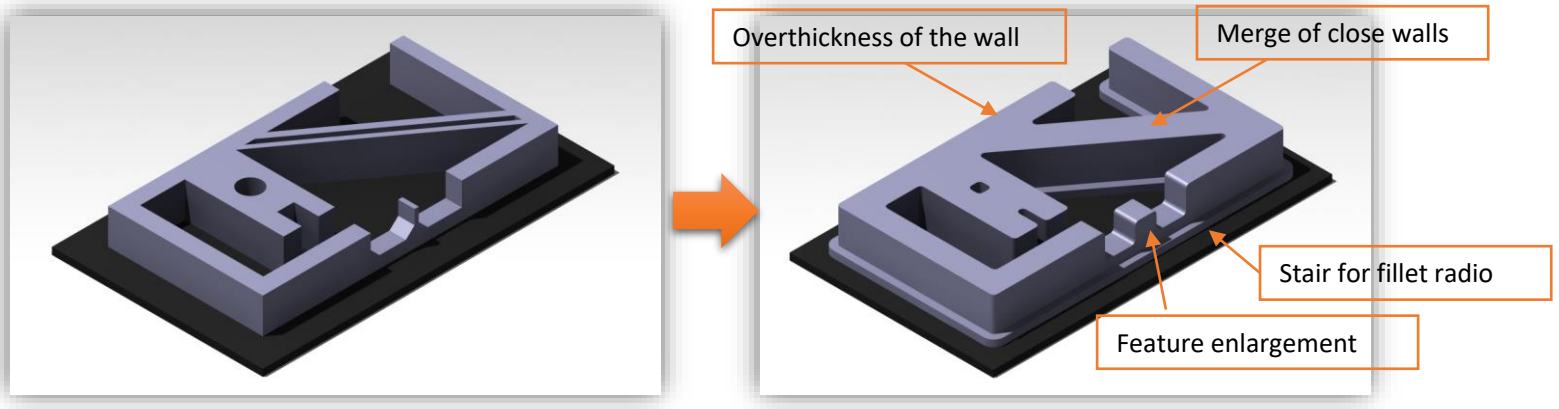




Build platform materials and condition

- Design. CAD SW

Redesign to reduce complexity during manufacturing. Basic design rules:



Build platform materials and condition

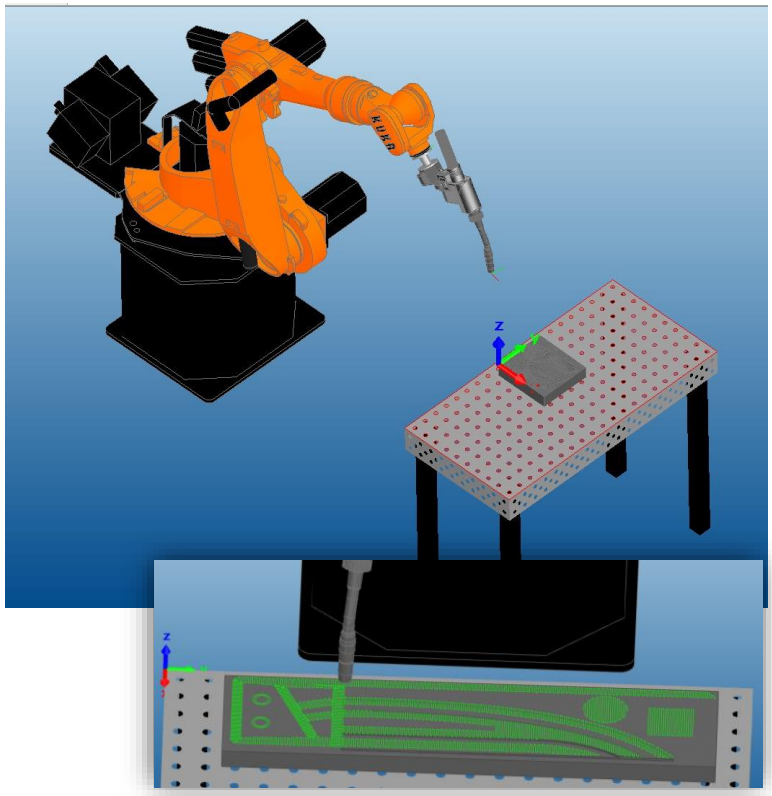
- CAD/CAM SW. Main functions:
  - CAD file import
  - CAD functionality (e.g.: surface modeler)
  - Powerful slicer
  - CAM functions (toolpath generation)
  - Simulation of multiple axis systems, of CNC machines and robots
  - Post-processing

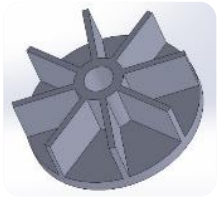
Build platform materials and condition

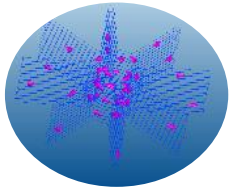
CAM

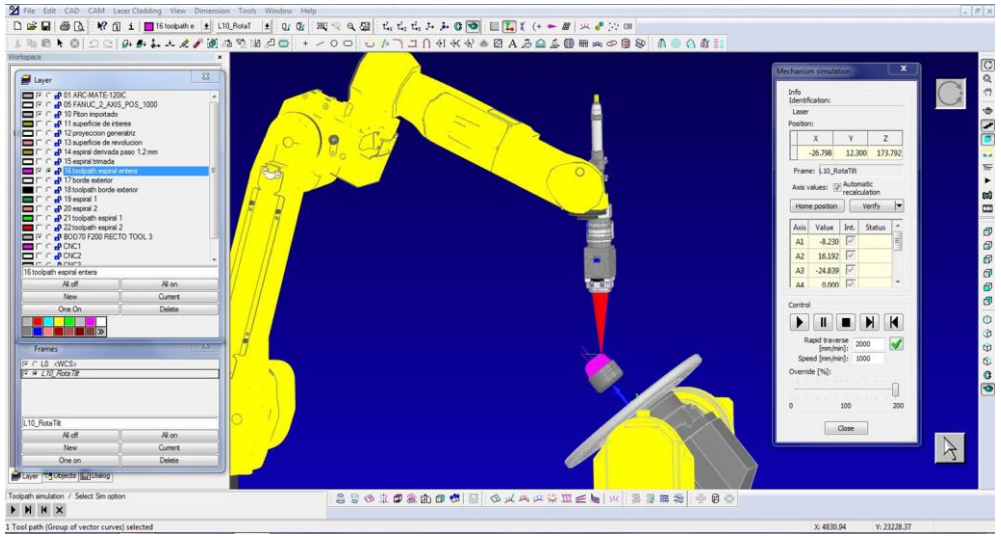
- CAD/CAM

- Tebis
- SKM
- PowerMILL
- WAAMPlanner
- Almacam WAAM









Build platform materials and condition

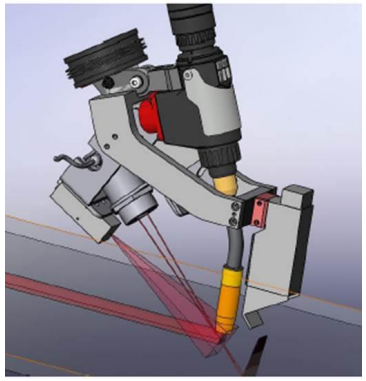
- Monitoring systems

In order to assure the quality and reduce scraps, in-line monitoring is highly recommended.

Captured data like melt pool temperature and dimensions, geometrical features of deposited material, electrical variables, wire feeding rate, shielding conditions and robot displacement data can be correlated with defects.

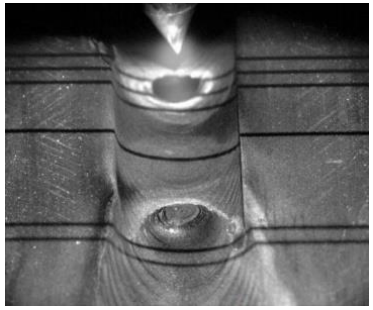
In REDAMP project, 3 solutions have been developed for real time monitoring of WAAM process:

- Laser profilometer for **interlayer height measurements**
- The multisensor approach provides merged information
- Dynamic shielding system with temperature monitoring



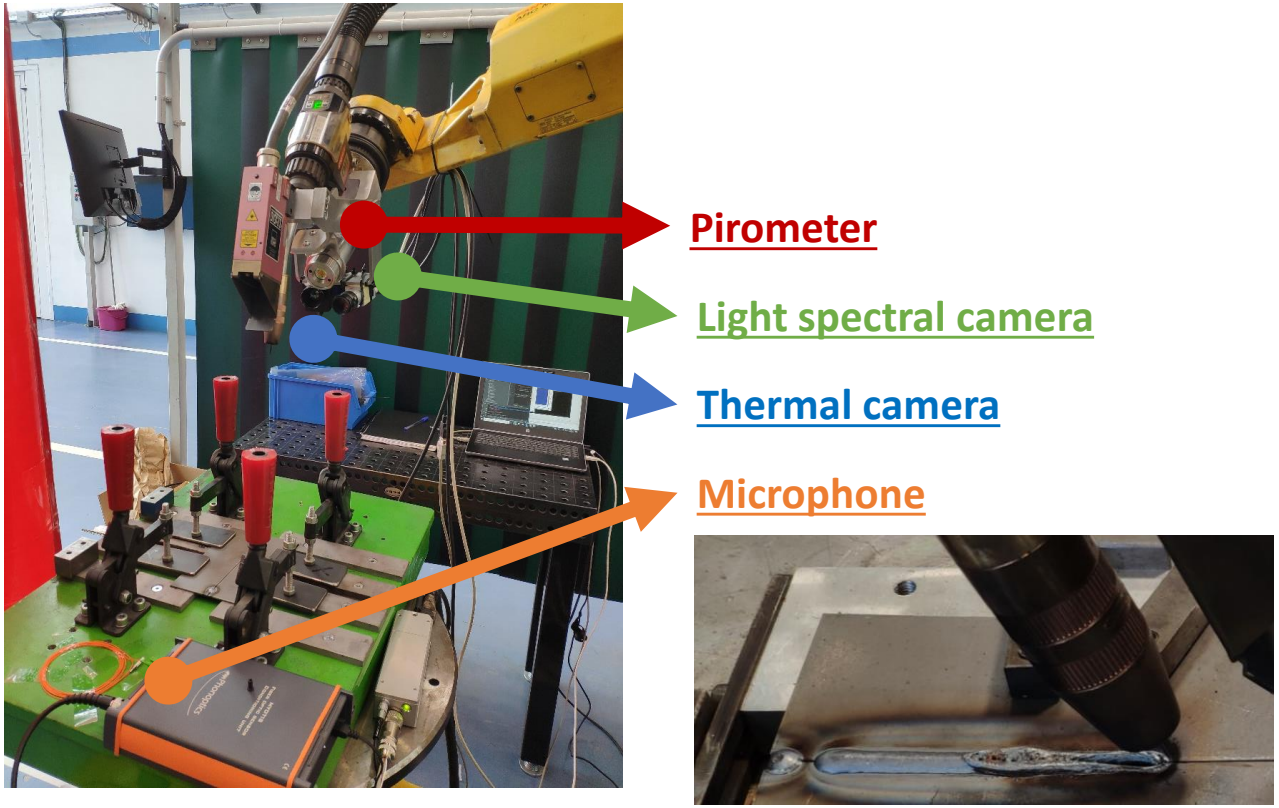
The objective of laser profilometer is to obtain:

- Geometry of single weld bead
- Minimum effective thickness
- Optimum robot Z-offset



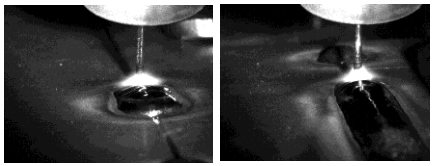
Build platform materials and condition

- Monitoring systems

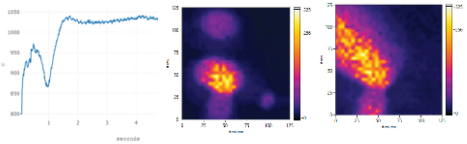


Build platform materials and condition

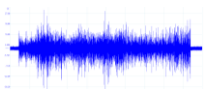
- Monitoring systems



- Visible: defects related with the behaviour of the melted metal

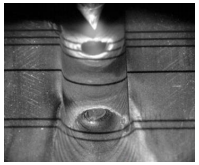


- Thermal: defects related with the temperature distribution



- Acoustic: defects related with anomalies in the metal transference

- Weld bead geometry

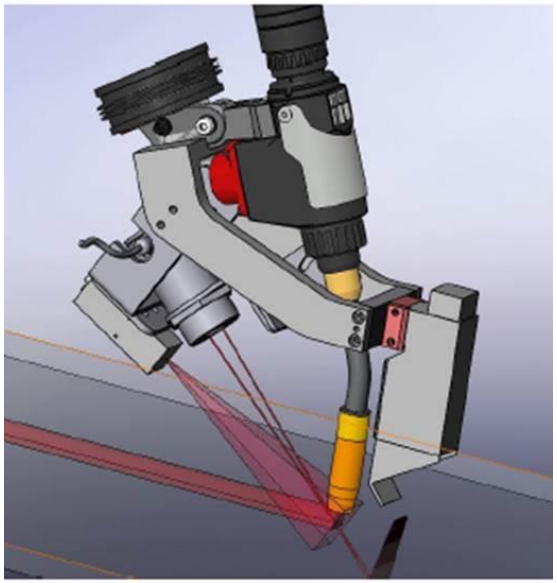


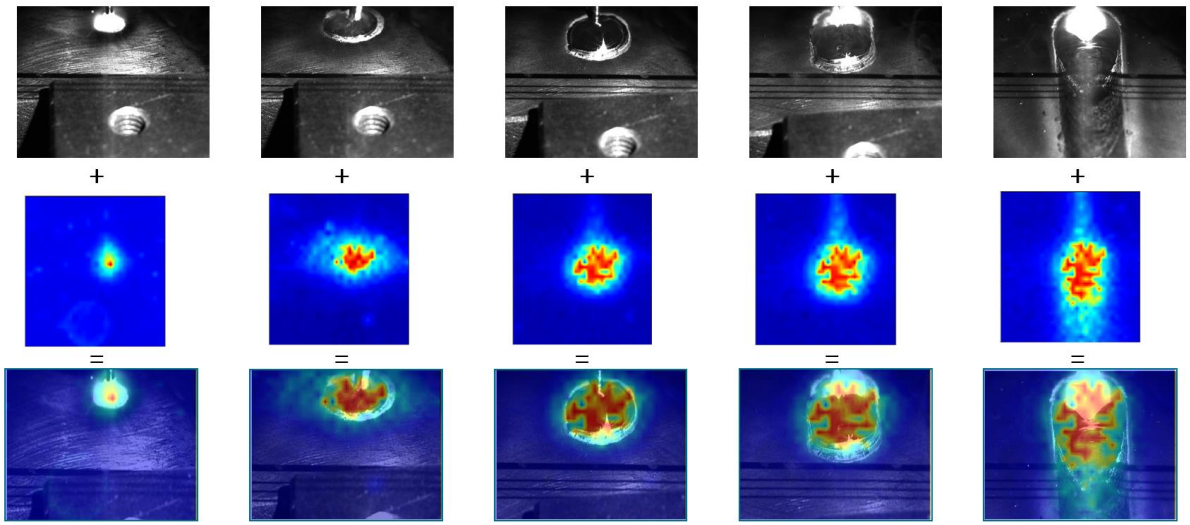
- Generally these techniques are used separately → loose of information
- **Objective: sensor and data fusion**

Build platform materials and condition

- Monitoring systems

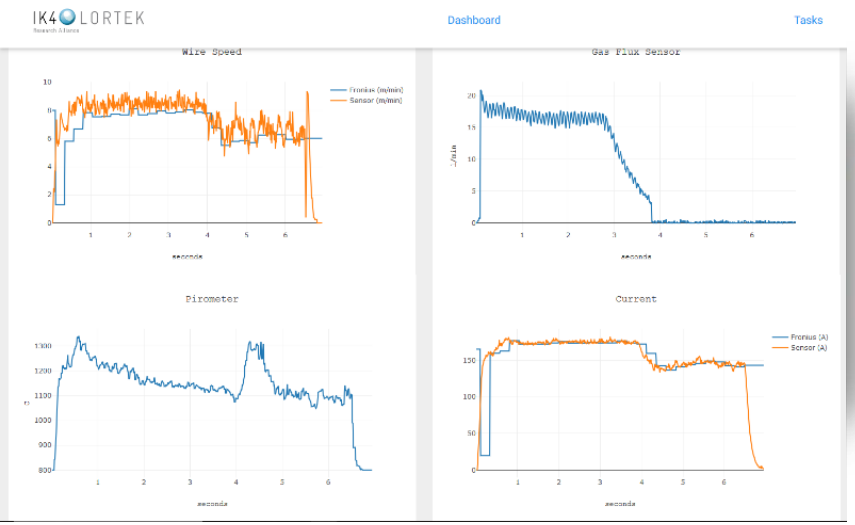
Signal combination

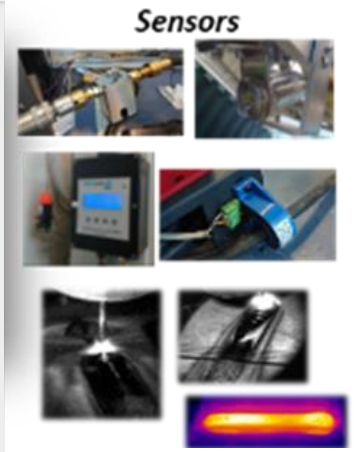


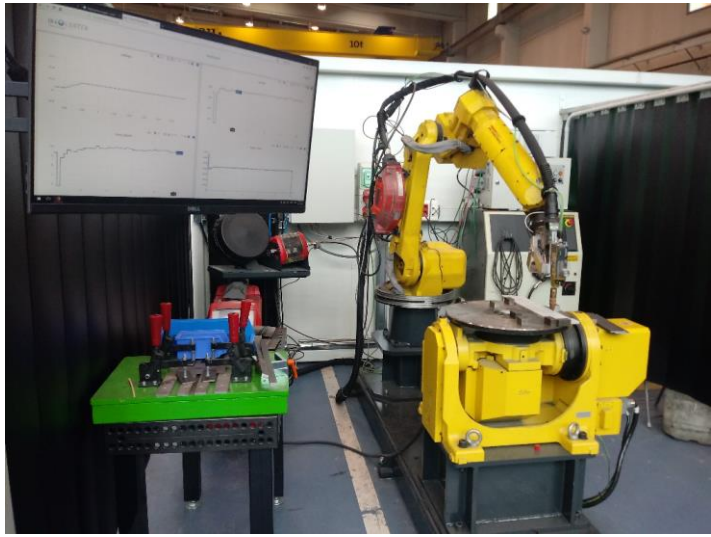


Build platform materials and condition

- Monitoring systems







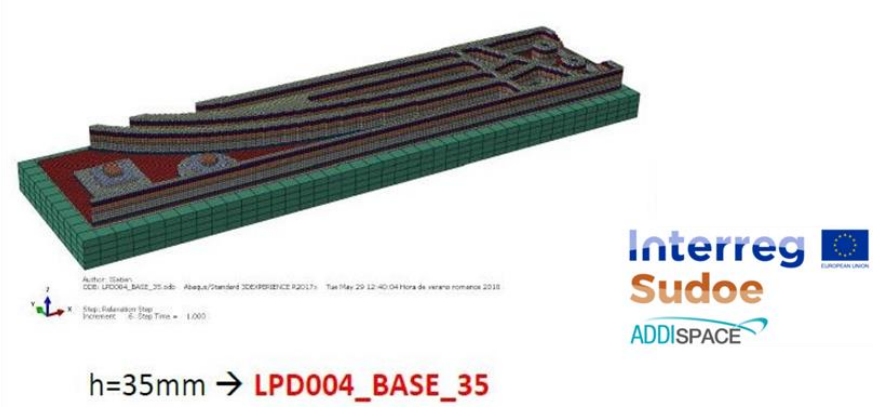
Build platform materials and condition

- Distortion simulation SW

Due to:

- high heat input inherent to electric arc
- heat accumulation during WAAM manufacturing

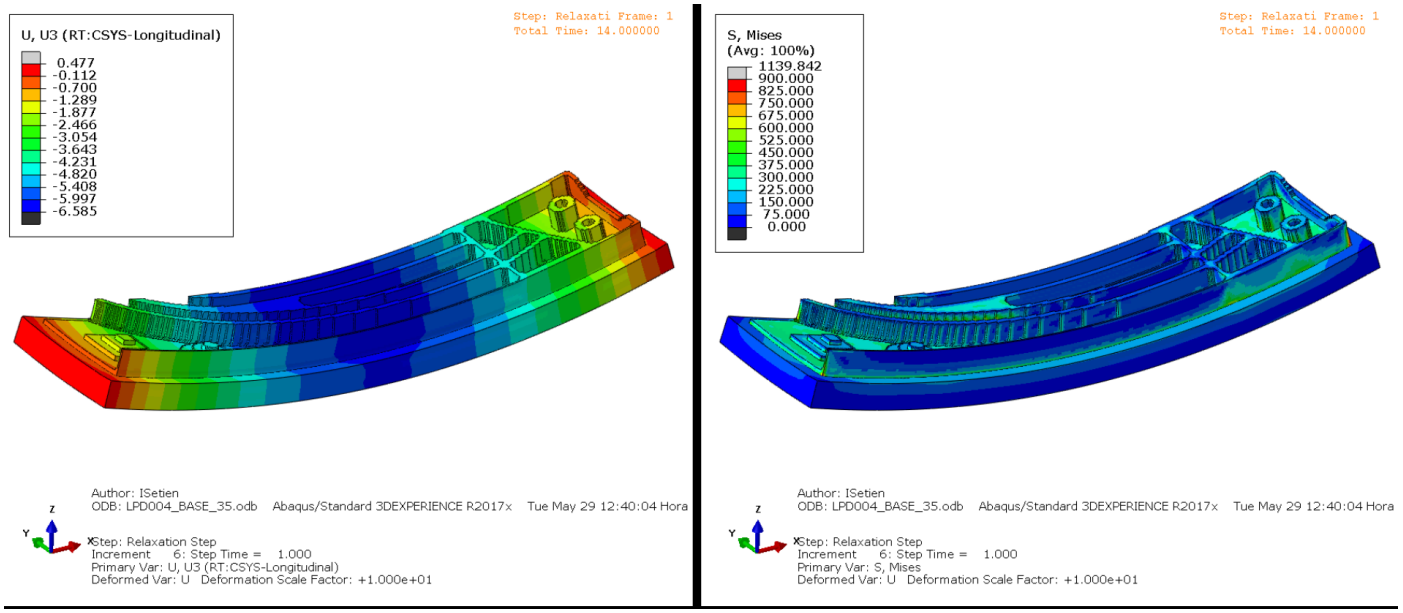
residual stresses are generated commonly during the solidification of the melt pool. These residual stresses can turn into **distortions** of the part after heat treatments due to stress relief. In order to avoid or minimise this effect, fine selection of parameters has to be done. Modelling can be a helpful tool to predict and minimise distortions. It is also helpful for the selection of most appropriate clamping.



Build platform materials and condition

- Distortion simulation SW

Watch the simulation video

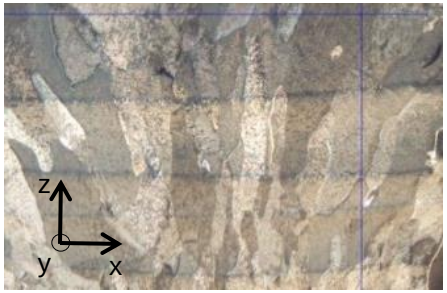


Build platform materials and condition

- Microstructure refining systems:

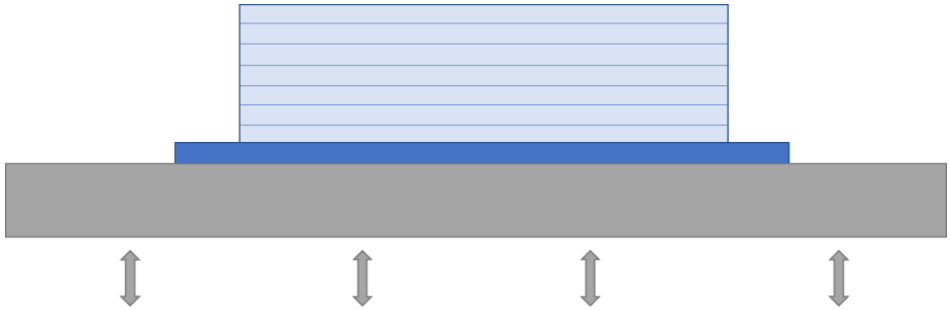
Typical structures show **preferential grain growth** in the building direction due to the heat dissipation conditions. Prior β grains are elongated in the Z axis. This is linked with **anisotropic behavior in mechanical properties**.
Normally, in the vertical orientation the strength is lower than in the horizontal one.

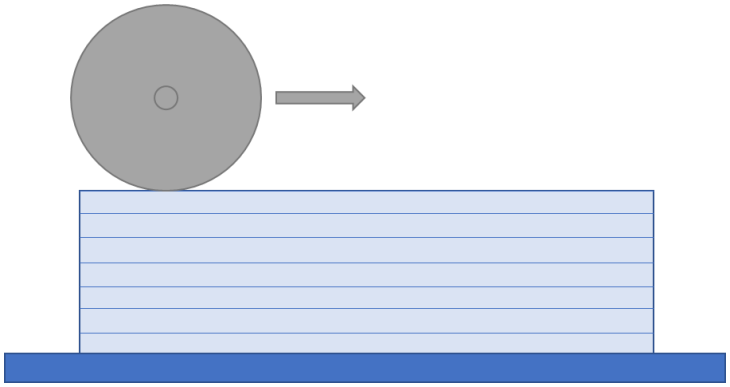
Cold work can be applied between layer deposition or at the end of the manufacturing. There are several devices: rolling, hammer peening. They improve the microstructure by recrystallizing the grains in order to obtain equiaxed grains. In contraposition, the process becomes complicated.

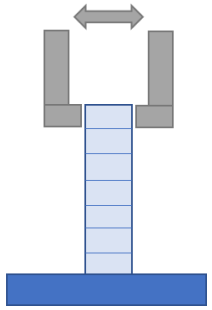


Build platform materials and condition

- Microstructure refining systems:
  - Cold work:
    - Rolling
    - Peening
  - Platform vibration
  - High intensity ultrasounds

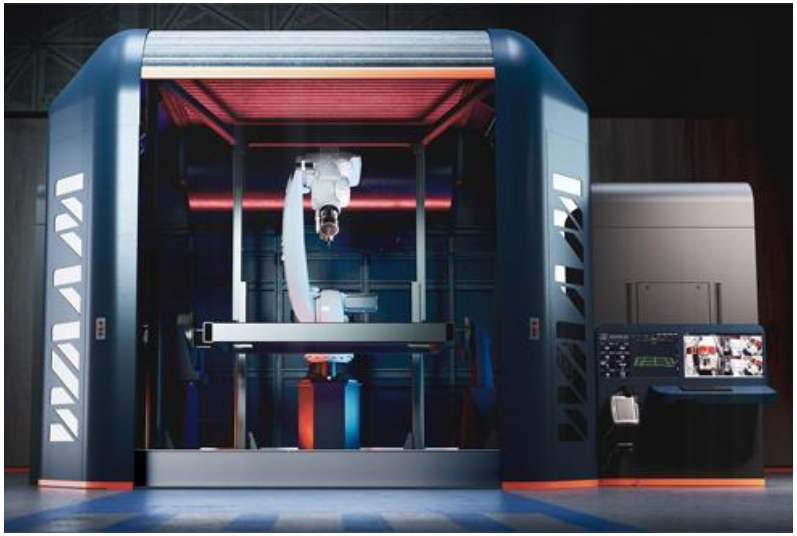






Build platform materials and condition

- Commercial equipment
  - ADDILAN (PAW)
  - GEFERTEC (CMT)
  - NORSK Titanium
  - MX3D
  - Prodways
  - Mazak
  - Mutoh Industries
  - VLM Robotics
  - WAAM3D (PAW and CMT)
    - Fume extraction
    - Robotic arm
    - Closed chamber
    - CAD/CAM
    - Cold work
    - Monitoring
    - …



https://www.waam3d.com/

Build platform, feedstock and other consumables handling and storage

- Format: Coils of 5 to 15 kg or drums of 250 kg.
- Different wire diameters (0.6 – 3.2 mm). Most used one is 1.2 mm.
- Other consumables must be adapted for the selected wire diameter
- Appropriate storage of wire to avoid oxidation or moisture
- Cleanness is of high importance to avoid defects.
- Feedstock is normally classified attending to:
  - Chemical composition
  - Welding process
- The standard naming is given by:
  - UNE-EN ISO
  - AWS:AMERICAN WELDING SOCIETY

Build platform, feedstock and other consumables handling and storage

Substrates:

- Compatible substrate need to be used for a proper bond
- Cleanness
- Sometimes freshly machined surface or other treatments to enhance the bond.

Question. Multiple choice

Shield gases

- Right selection of shielding gas helps on:
  - Preventing porosity
  - Getting proper penetration
  - Obtaining desired mechanical properties
- It has to be considered:
  - Alloy of filler metal
  - Material thickness
  - Mode of GMAW (spray, short-arc, etc.)
  - Welding position
  - Desired penetration profile
  - Cost
- Groups:
  - Reactive gases: Carbon Dioxide, Oxygen, Nitrogen and Hydrogen
  - Inert gases: Argon and Helium (no chemical reaction)
  - Hundreds of shielding gas mixtures

Shield gases

- The properties of gas that has most impact:
  - Ionisation potential. Helps on arc ignition.
  - Thermal conductivity
  - Chemical reactivity
- In general for:
  - Non ferrous materials: Ar, He, Ar-He mixtures
  - Ferrous materials: additions of O_2 and pure CO_2.

Shield gases

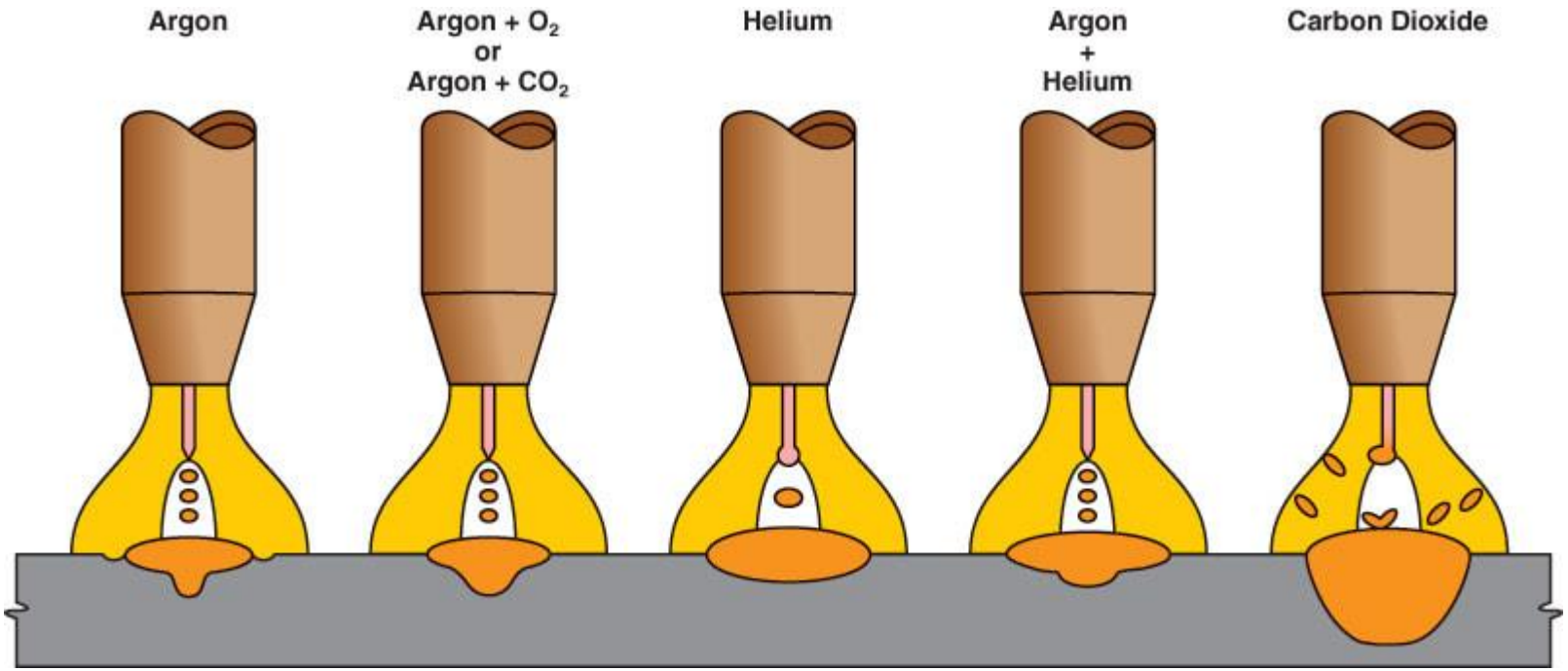
http://www.halversoncts.com/711-gmawfcaw-shielding-gases.html

GMAW Shielding Gases		
Shielding gas or mixture	**Chemical behavior**	**Metals and applications**
Argon	Inert	Virtually all metals except steels.
Helium	Inert	Aluminum, magnesium, and copper alloys for greater heat input and to minimize porosity.
Ar + He (20–80% to 50–50%)	Inert	Aluminum, magnesium, and copper alloys for greater heat input and to minimize porosity (better arc action than 100% helium).
Nitrogen		Greater heat input on copper (Europe).
Ar + 25–30% N_2		Greater heat input on copper (Europe); better arc action than 100% nitrogen.
Ar + 1–2% O_2	Slightly oxidizing	Stainless and alloy steels; some deoxidized copper alloys.
Ar + 3–5% O_2	Oxidizing	Carbon and some low-alloy steels.
CO_2	Oxidizing	Carbon and some low-alloy steels.
Ar + 20–50% CO_2	Oxidizing	Various steels, chiefly short circuiting arc.
Ar + 10% CO_2 + 5% O_2	Oxidizing	Various steels (Europe).
CO_2 + 20% O_2	Oxidizing	Various steels (Japan).
90% He + 7.5% Ar + 2.5% CO_2	Slightly oxidizing	Stainless steels for good corrosion resistance, short circuiting arc.
60–70% He + 25–35% Ar + 4–5% CO_2	Oxidizing	Low-alloy steels for toughness, short circuiting arc.

Co-funded by the Erasmus+ Programme of the European Union

Shield gases

- Selected gas affects to the mode of metal transference



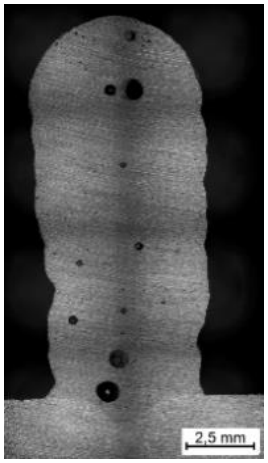
http://www.halversoncts.com/711-gmawfcaw-shielding-gases.html

Shield gases

- Defects:
  - Spatters
  - Pores

Ar ~ 100 %

90



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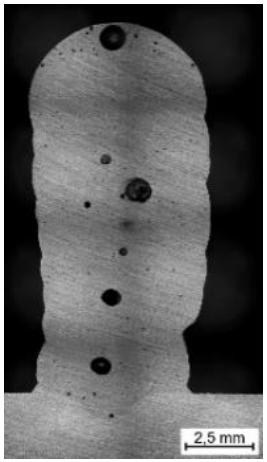
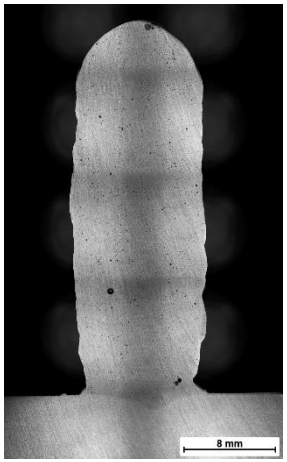


Ar 10 / He 90

45

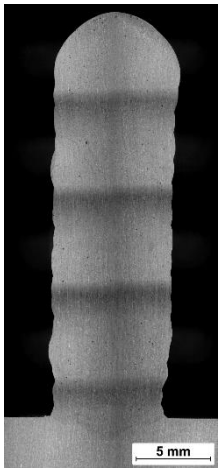


0.67 %

He ~ 100 %

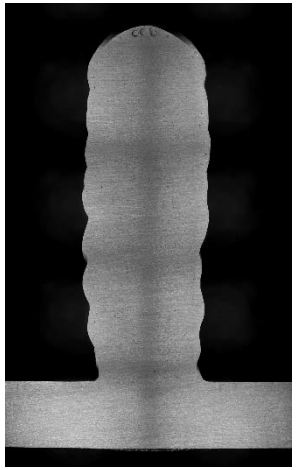
Spatters

90



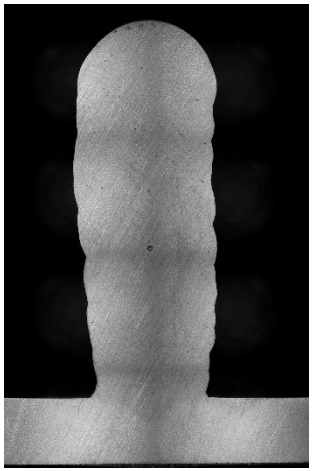
2.64 %

45



1.49 %

30



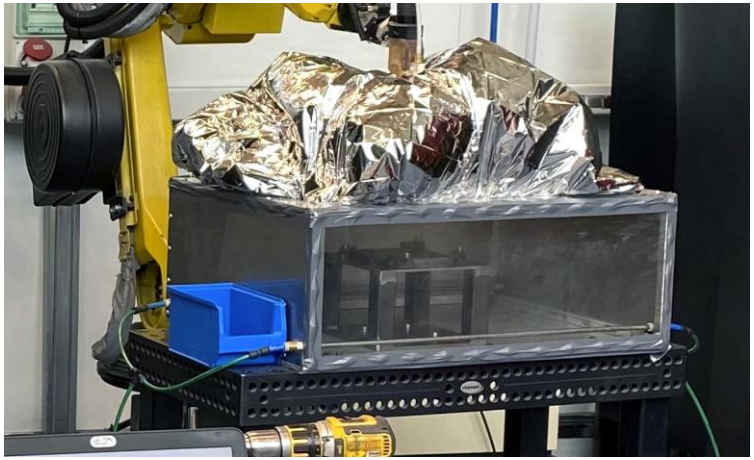
2.97 %

Shield gases

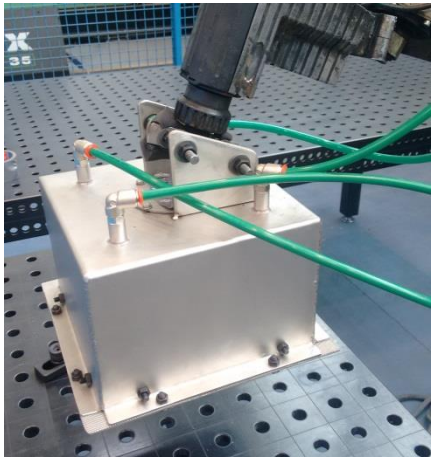
Extra protection with inert gas for highly reactive materials: Ti alloys, some Al alloys, etc.

	Close chamber	Local shielding
Advantages	Easy to use	Non restricted dimensions
	Low gas consumption	Gas flow can be optimised
		Good accesibility
Disadvantages	Restricted dimensions of part	High gas consumption
	Reduced accessibility	

Closed chamber + Oxygen sensor



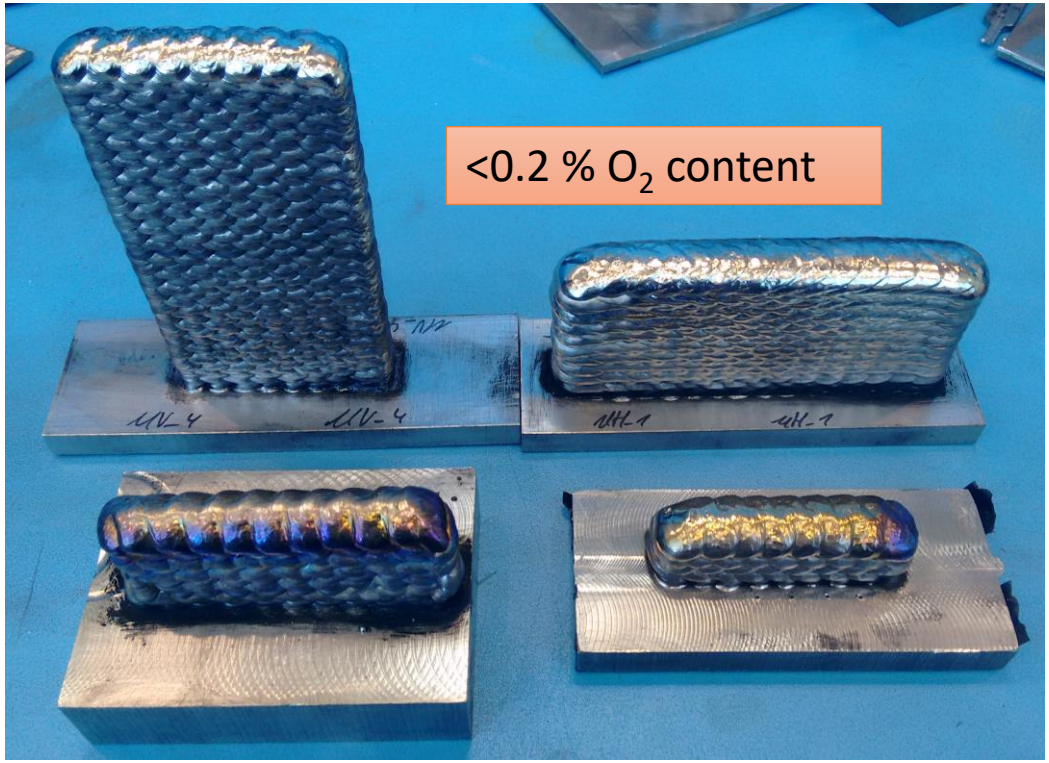
Local protection



* Some commercial machines has a closed chamber of big dimensions (~mm) but assuring good elimination of oxygen and a proper inert atmosphere is difficult and expensive.

Shield gases

- Trailing for highly reactive materials. Example: Ti6Al4V



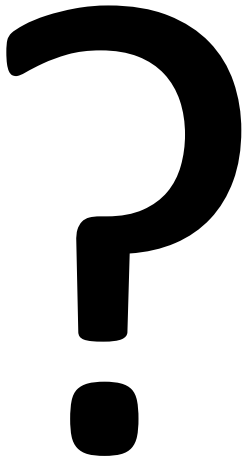
Discolorations ranging from metallic silver, blue-violet, light blue to matt gray

Question. Quizz

Summary

- Premium wire quality is recommended due to consecutive cycling during layer deposition. Proper storage of wire is also important.
- Design rules for WAAM enhances the advantages of the process.
- Forced cooling strategies reduce production time and might be helpful to control the final microstructure and mechanical properties.
- Online monitoring helps on reducing defects or saving energy and material.
- Simulation helps on selecting the best strategies to reduce distortions.
- A proper selection of gas is essential to obtain the desired properties of manufactured parts.
- Additional protection for reactive materials is necessary.

Questions from the audience



Co-funded by the
Erasmus+ Programme
of the European Union

This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.