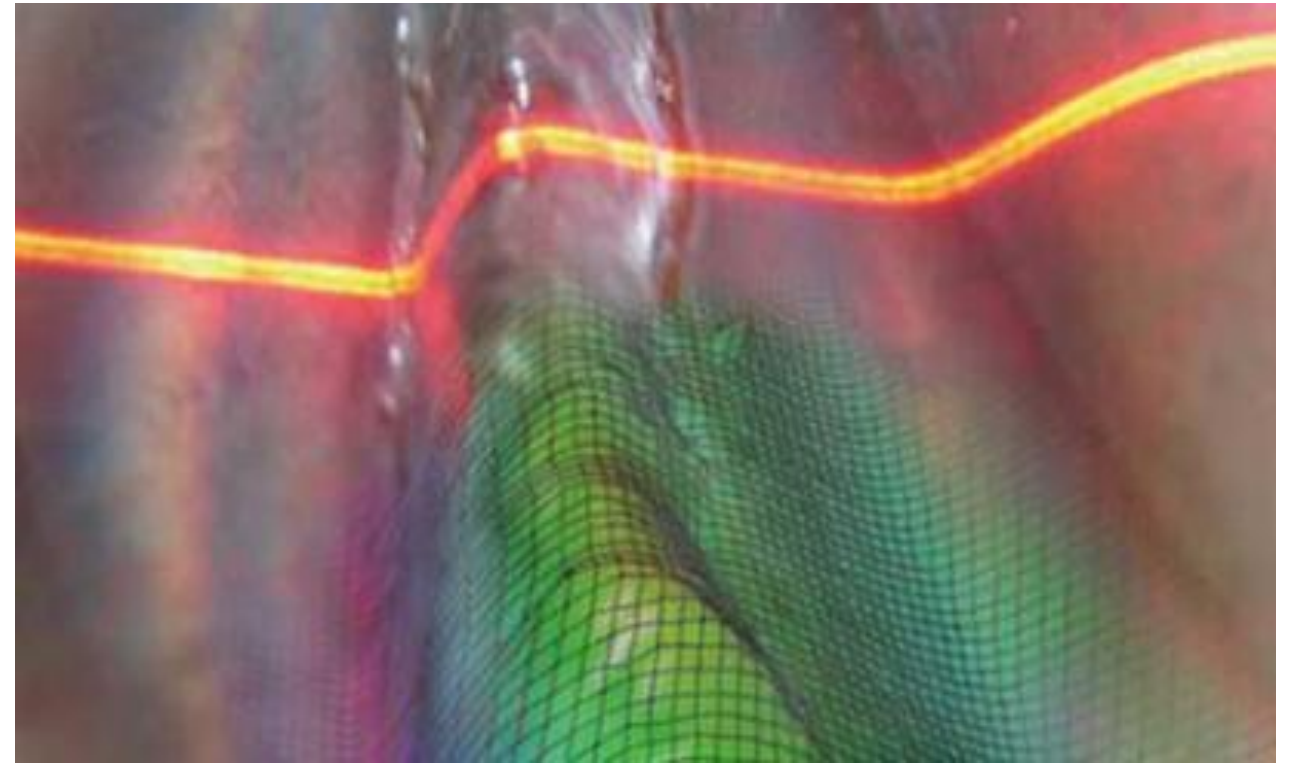
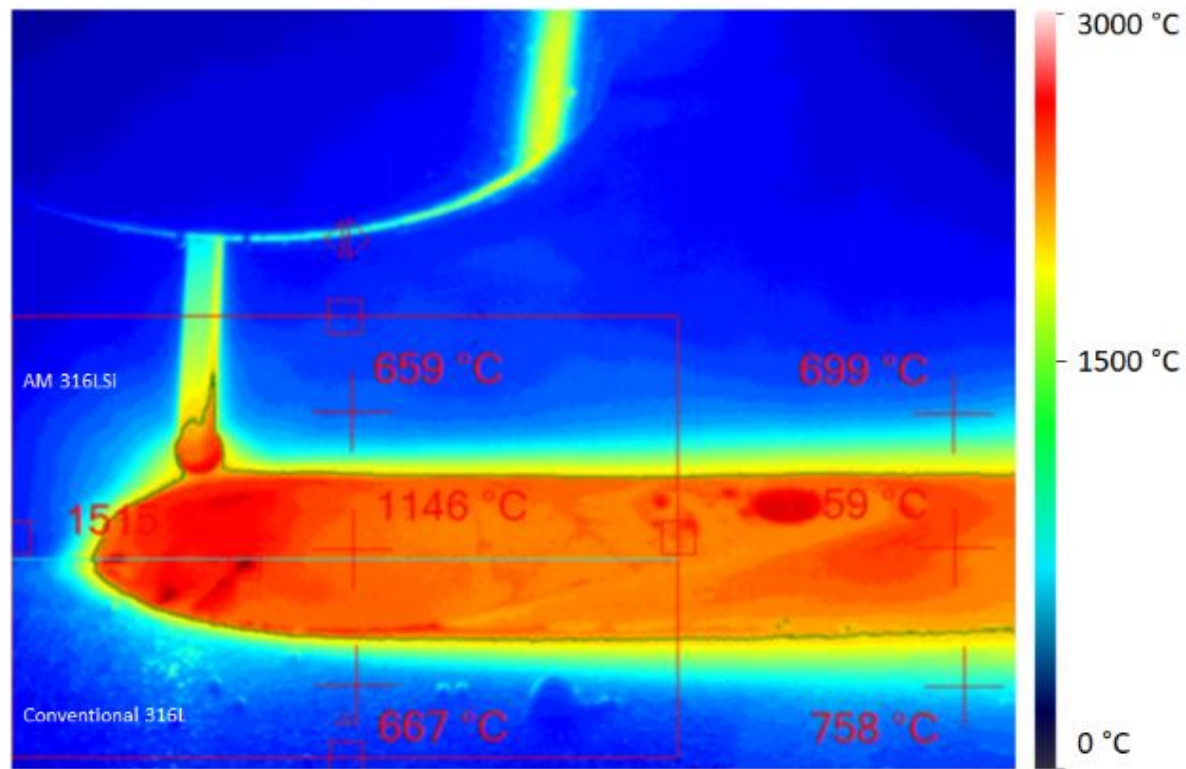




Real-time quality monitoring of welding processes

- Koen Faes (Belgian Welding Institute)
- Mathieu Vandecasteele (imec-IPI, Ghent University)



Joining your future.

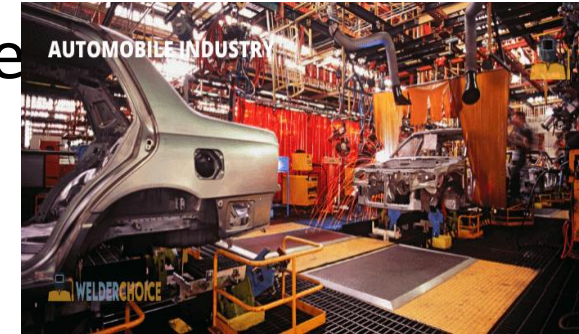
BIL/VCL LASDAGEN

19, 20 & 21 mei 2026 - Antwerp Expo



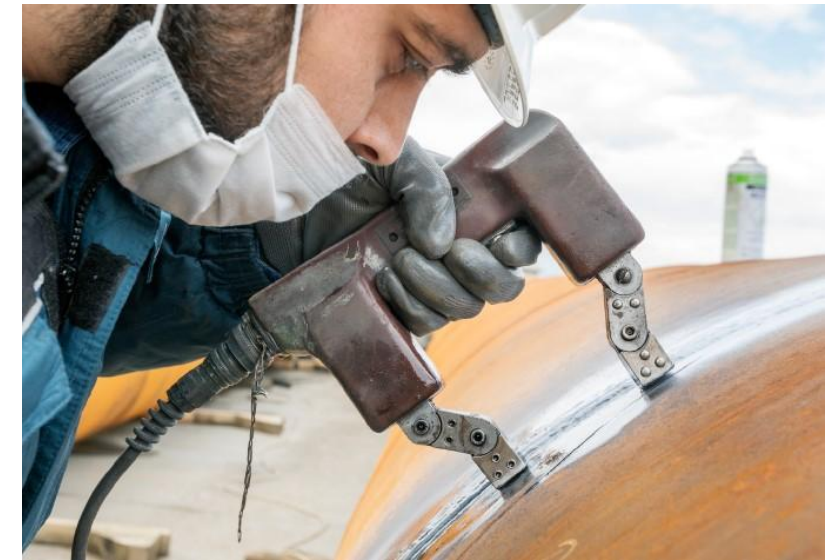
Context

- ▶ Welding : most important fabrication technique
 - ▶ Inherently generate defects due to the process complexity
 - ▶ Detected after fabrication
- ▶ Presence of defects :
 - ▶ Wasted production time, energy or raw materials (scrap, or need for repair)
 - ▶ Increased production costs
 - ▶ Delivery delays
 - ▶ Safety consequences
- ▶ Vital to detect defects as soon as possible :
 - ▶ During the production process
 - ▶ To intervene quickly and avoid further defective products



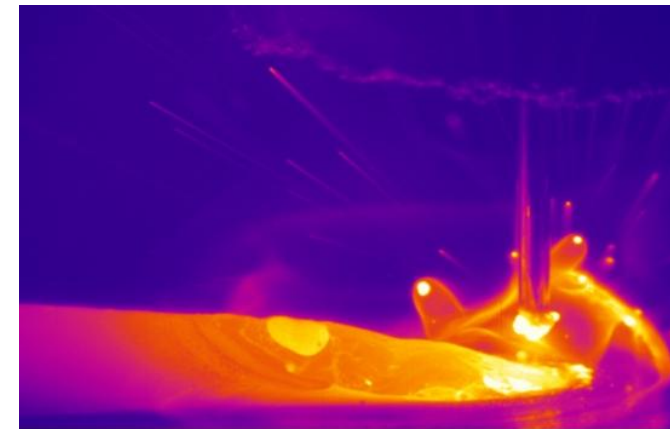
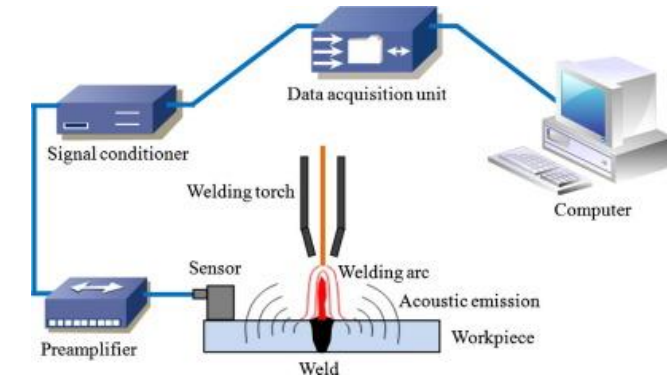
Context

- ▶ Weld quality : becoming increasingly important
 - ▶ Customer expectations increase
 - ▶ New materials
 - ▶ Smaller production series
- ▶ Quality inspection :
 - ▶ Offline
 - ▶ Time-consuming
 - ▶ Selective
 - ▶ Subjective
 - ▶ Conventional non-destructive methods : limits regarding the technological use as well as their economic feasibility :
 - ▶ Sometimes inspection is technically not possible
- ▶ Yielding an increase of the cost of products



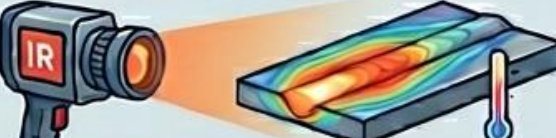
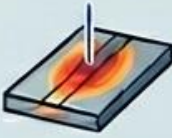
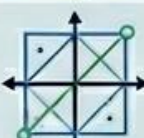
Context

- ▶ Solution : real-time quality monitoring :
 - ▶ Defect detection during the production
- ▶ Advantages :
 - ▶ Early defect detection
 - ▶ Reduction of production cost, loss of production time, energy or materials, delivery delays and safety implications
 - ▶ Possibility to test 100% of the welds → Complete product traceability
 - ▶ Reduction of the amount of destructive and non-destructive off-line tests
 - ▶ Higher reliability of manufactured products
- ▶ Step towards closed-loop quality control systems
 - ▶ Adjustment of process parameters in real time
 - ▶ Zero-defect manufacturing



Monitoring technologies

COMPREHENSIVE WELDING MONITORING TECHNIQUES SUMMARY

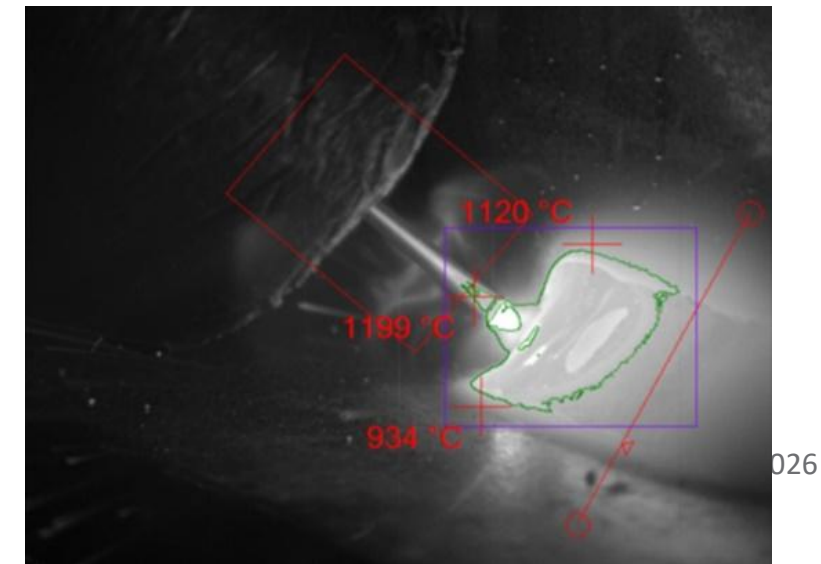
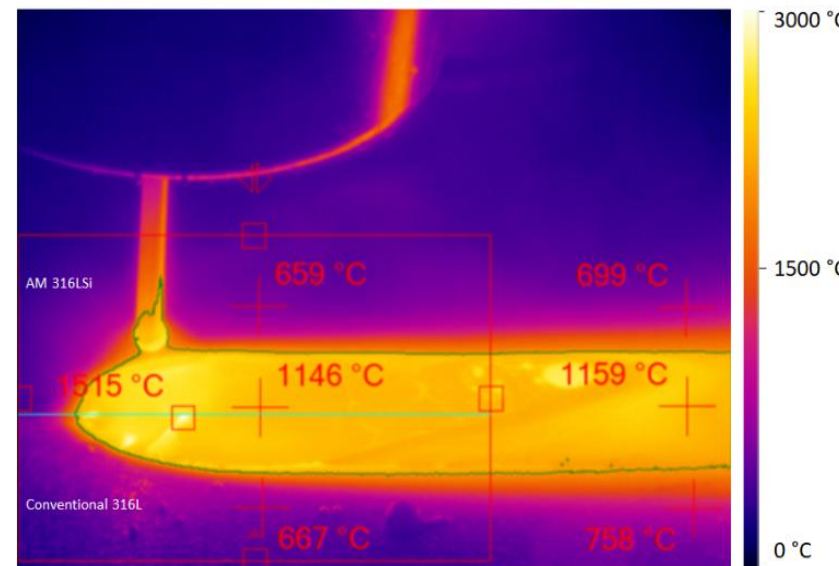
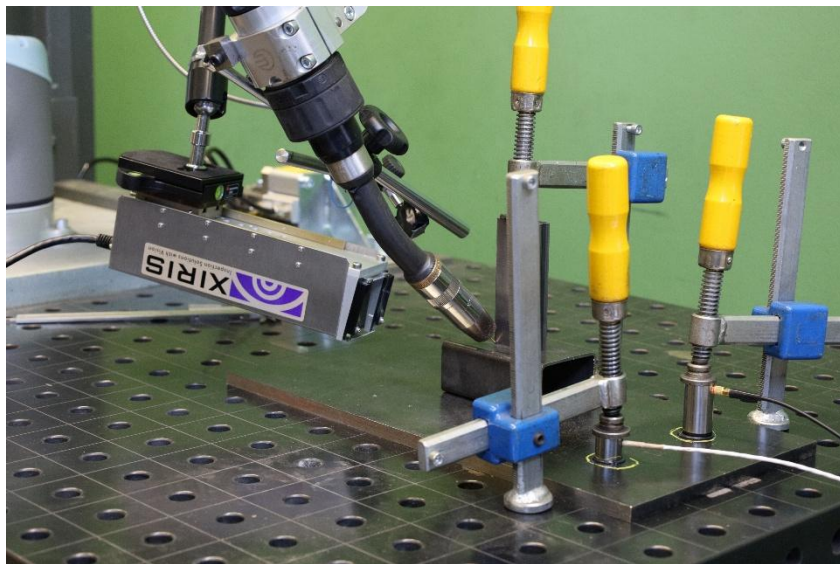
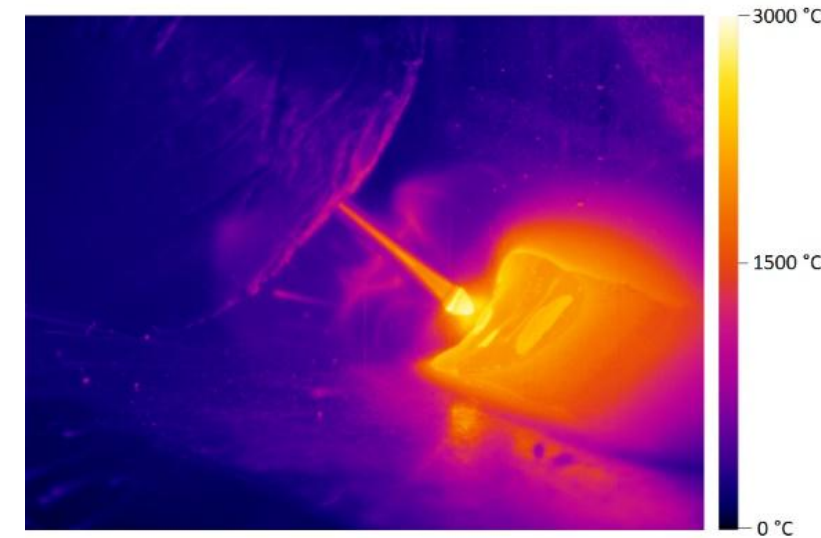
MONITORING TECHNIQUE & KEY PRINCIPLE	SIGNALS & MEASURED DATA	PRIMARY ADVANTAGE & IDEAL APPLICATION
 Process Parameters: (Arc V, I, WFS)	 Electrical Voltage, Current, & Wire Feed Speed	 Immediate Arc Stability Assessment & Closed-Loop Control
 Thermography: (Thermal Imaging)	 Surface Temperature Field & Cooling Rate	 Contactless, Real-Time Heat Distribution & HAZ Quality Control
 Visual Cameras: (Weld Pool Imaging)	 Pool Geometry, Dynamic Flow, Spatter & Seam Tracking	 Rich Visuo-Spatial Detail for Surface & Defect Detection
 Laser Triangulometry: (Profile Measurement)	 Cross-Sectional Joint Profile, Bead Geometry & Height	 High-Speed, Non-Contact Geometry Profiling for Seam Tracking
 Spectroscopy: (Plasma Analysis)	 High-Frequency Ultrasonic Sound from Solidification & Defects	 In-Situ, Non-Destructive Defect Detection for Critical Welds
 Multi-Sensor Fusion & AI: (State of the Art)	 Correlated Data from Multiple Sensors	 Robust Defect Classification & Adaptive Process Control (Industry 4.0)

● STATE OF THE ART (ML-ENHANCED)

● MAIN LIMITATIONS (e.g., FUMES, REFLECTIONS)

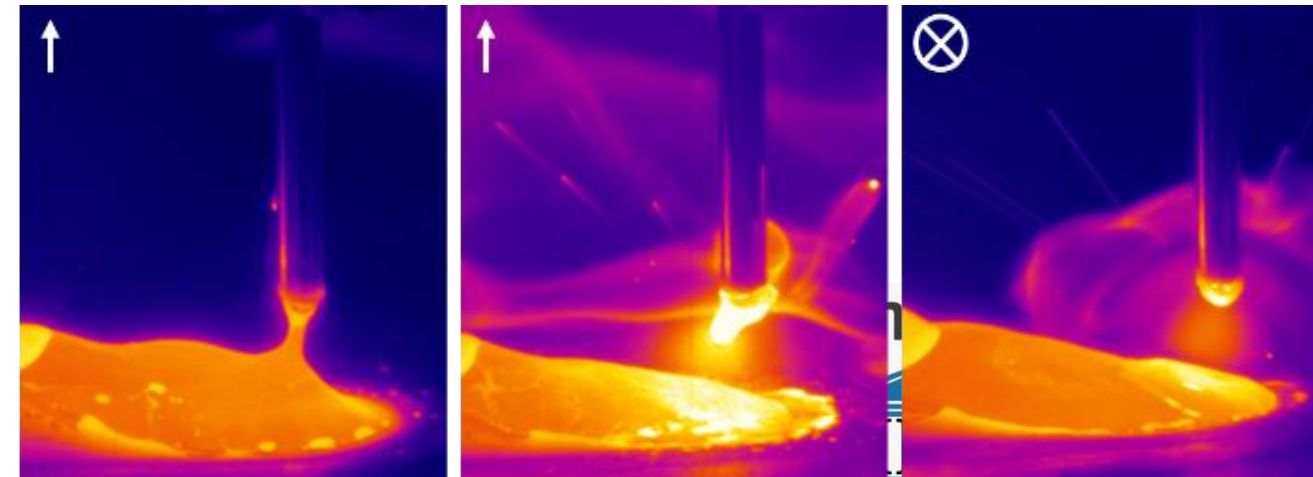
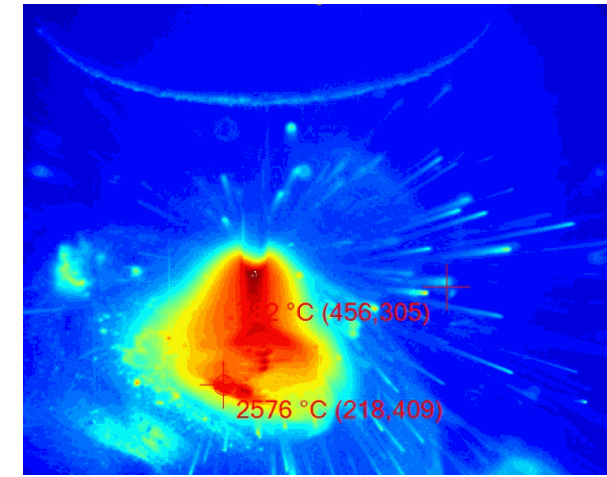
Thermography

- ▶ Equipment : XIR-1800 thermal camera
- ▶ Short-Wave InfraRed (SWIR) spectrum camera
- ▶ Enhanced imaging of joining processes beyond what is visible using standard thermal or visible-light cameras
- ▶ Clear view of the weld pool
- ▶ Software tools for analysis



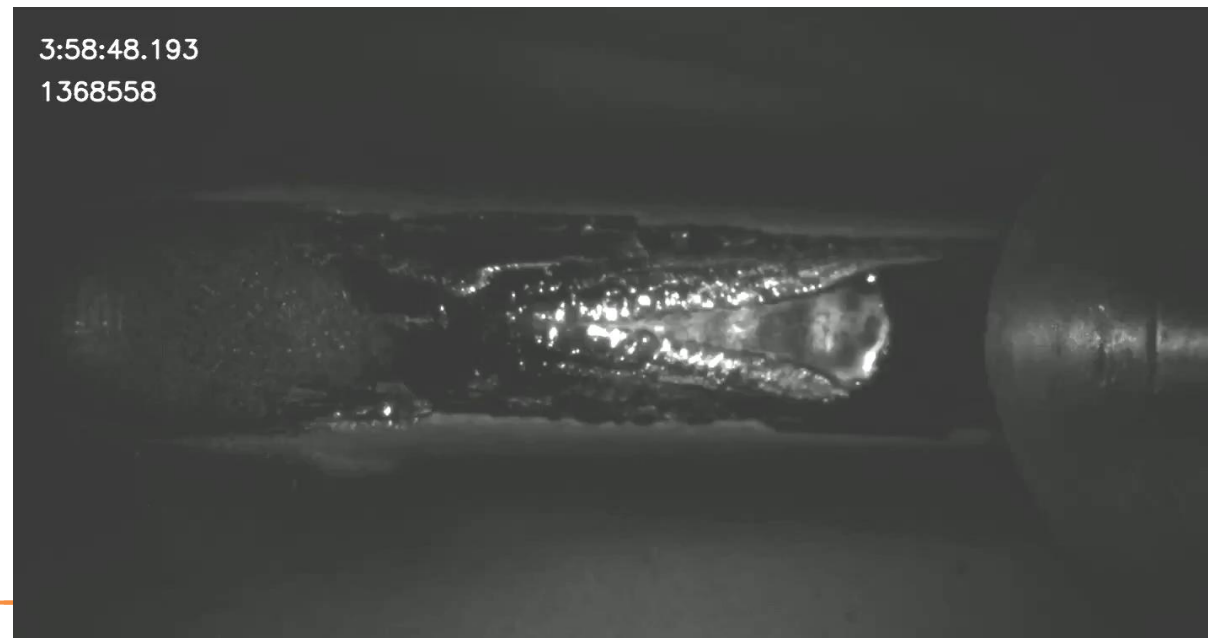
Thermography

- ▶ Established for monitoring temperature fields, cooling rate, bead width, seam tracking and penetration depth.
- ▶ Applied across arc welding, friction welding, friction stir welding and additive manufacturing.
- ▶ Also used for detecting defects such as cracks, porosity, lack of fusion and inclusions.
- ▶ Main trend: from simple thermal imaging to quantitative thermal process monitoring and defect classification using Machine Learning



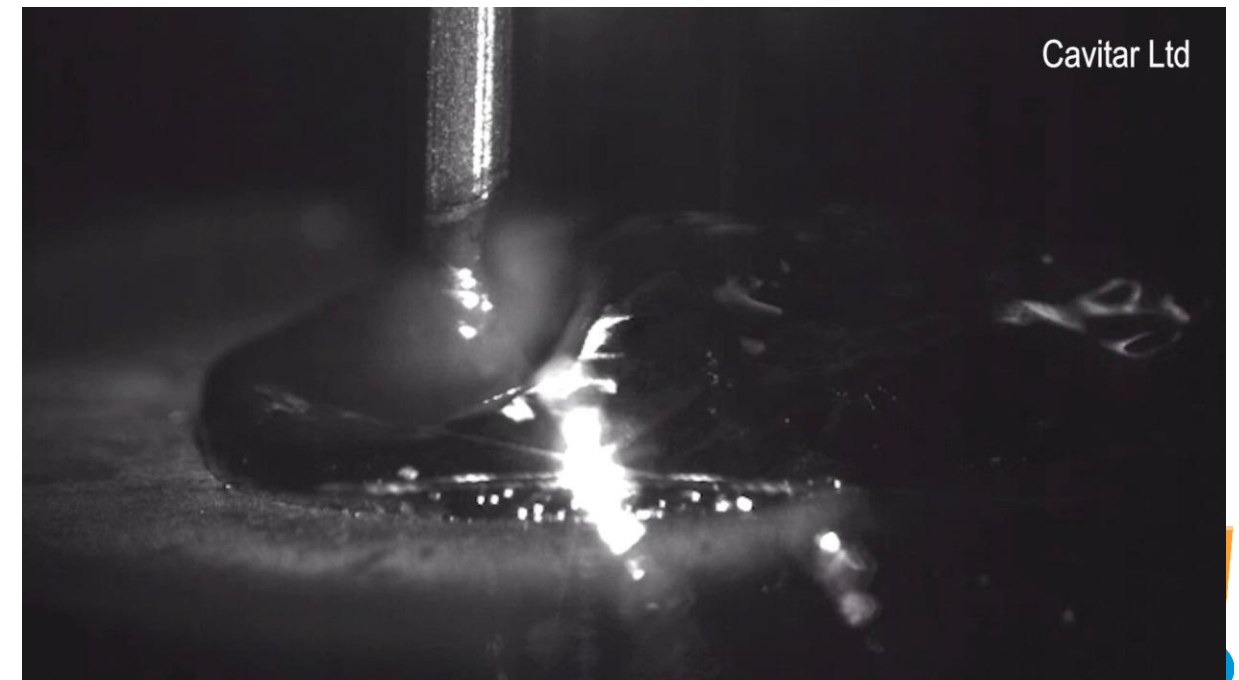
Optical monitoring

- ▶ Equipment : Cavitar C350
- ▶ Welding optical camera equipped with laser illumination
- ▶ Enhanced imaging of metal joining and additive manufacturing processes by suppressing arc-light oversaturation, enabling observation of critical aspects of weld pool behaviour and torch movement
- ▶ Clear view of the deposition path and weld joint alignment



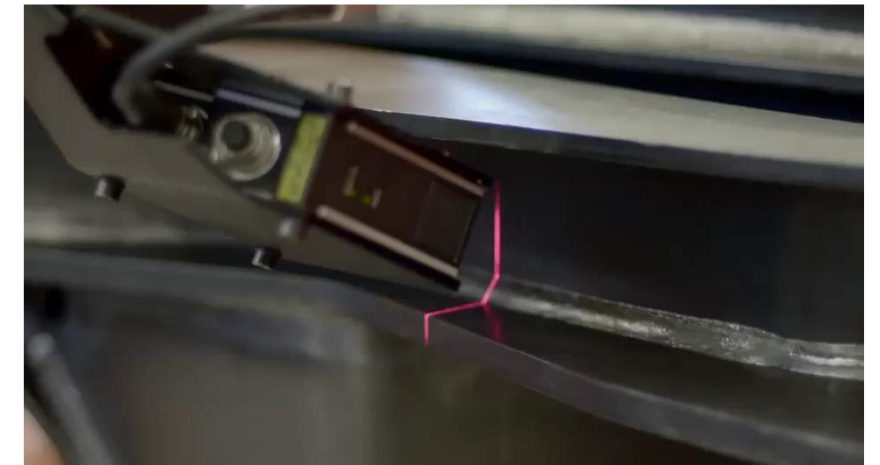
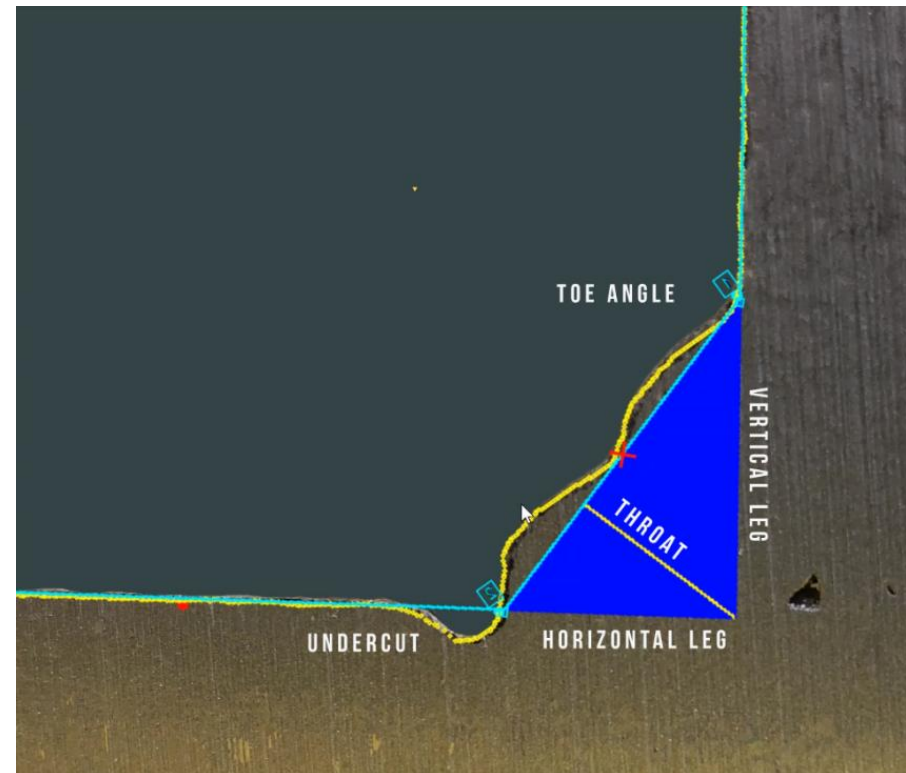
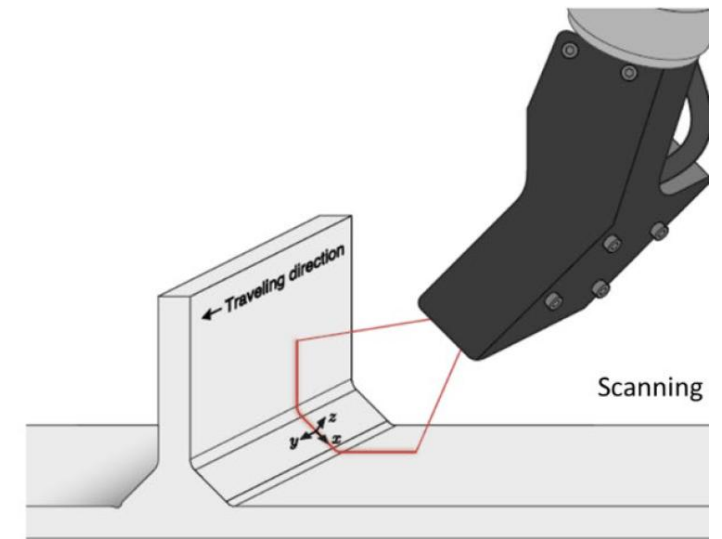
Optical monitoring

- ▶ Used for real-time weld pool observation, arc length detection, seam tracking, and bead geometry measurement.
- ▶ Newer systems increasingly aim to directly visualize molten metal and joint phenomena.
- ▶ Strong for external defect detection and process observation, especially when combined with image processing or AI.
- ▶ Main trend: moving from simple camera inspection to inline, high-speed, data-driven monitoring.



Laser triangulometry

- ▶ Equipment : Keyence LJ-X8000
- ▶ Laser measurement of the weld geometry
- ▶ Digitalisation of visual testing of welds (e.g. according to ISO 5817)

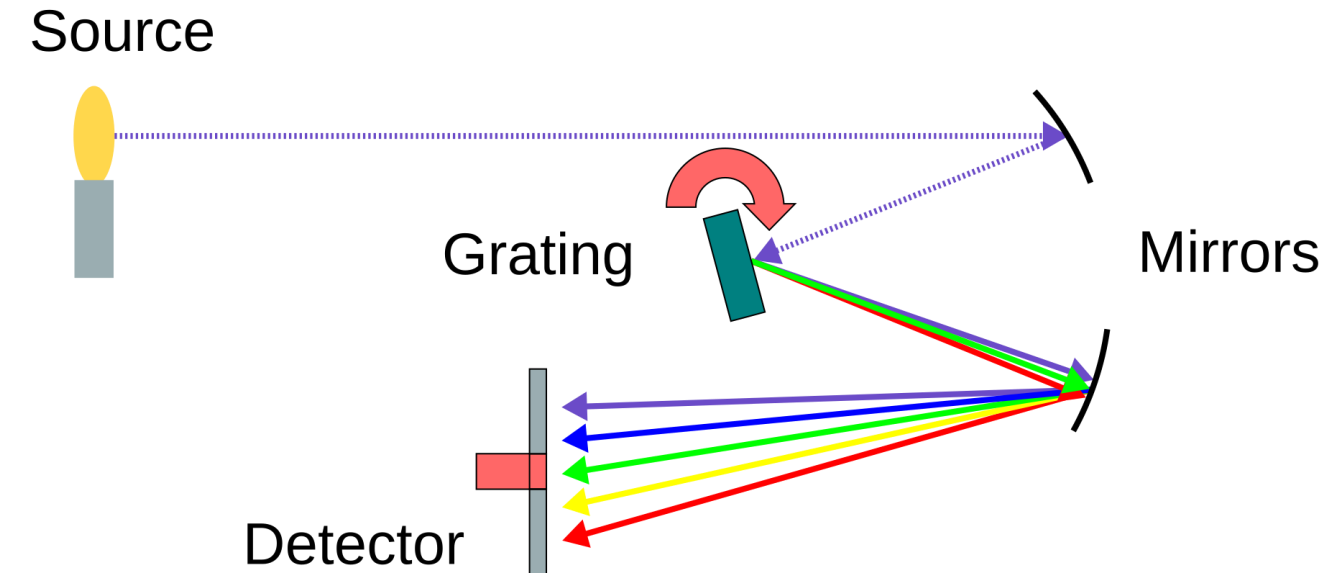


Process parameters

- ▶ Based on changes in arc voltage and/or current as torch-to-workpiece distance changes.
- ▶ Commonly used for seam tracking in MAG welding.
- ▶ It is simple, low-cost, and directly integrated into the welding power source.
- ▶ State of the art remains focused on robust tracking and adaptation, rather than full defect characterization.

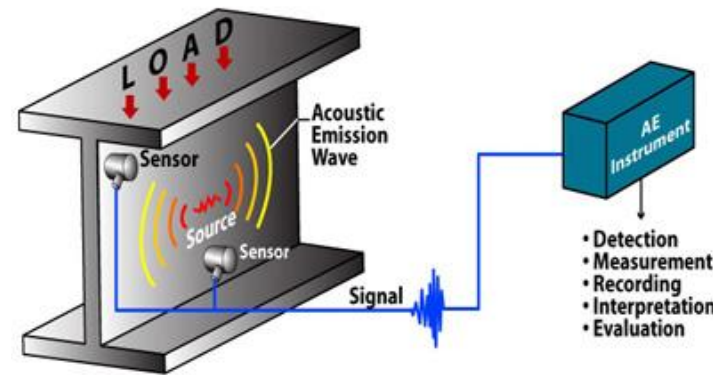
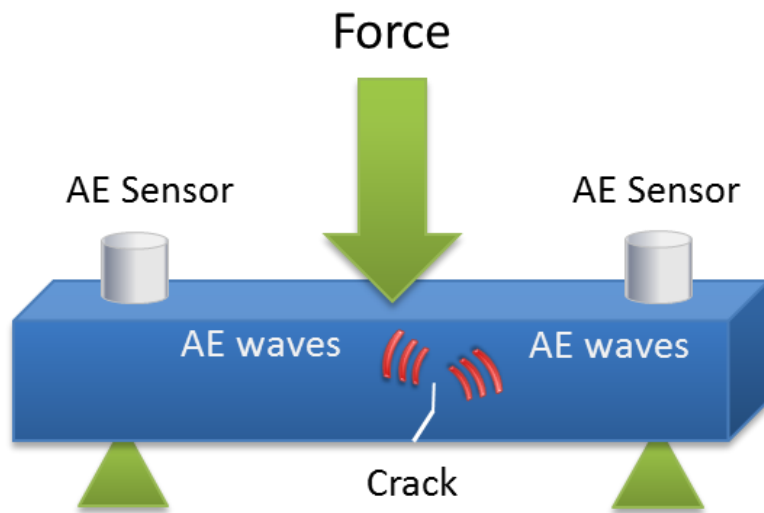
Spectroscopy

- ▶ Uses spectral content of arc light to estimate arc stability and process conditions.
- ▶ Variations in spectral intensity and peak shape can be correlated with disturbances and weld quality changes.
- ▶ Applied to TIG, MIG/MAG and laser welding.
- ▶ Current state of the art combines spectral features with statistical methods, feature extraction and neural networks for defect detection.



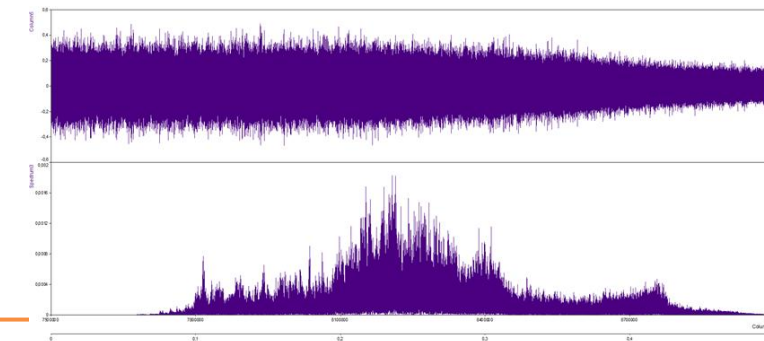
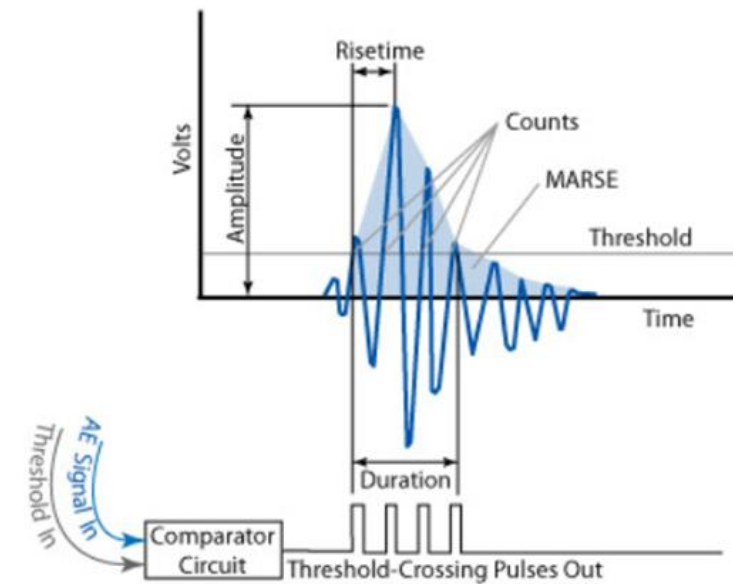
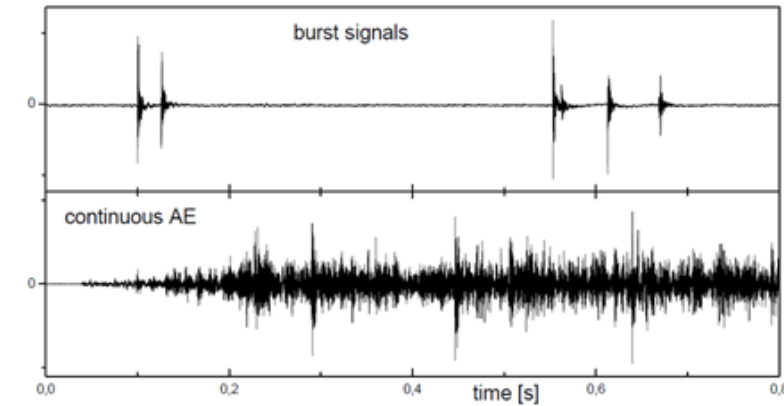
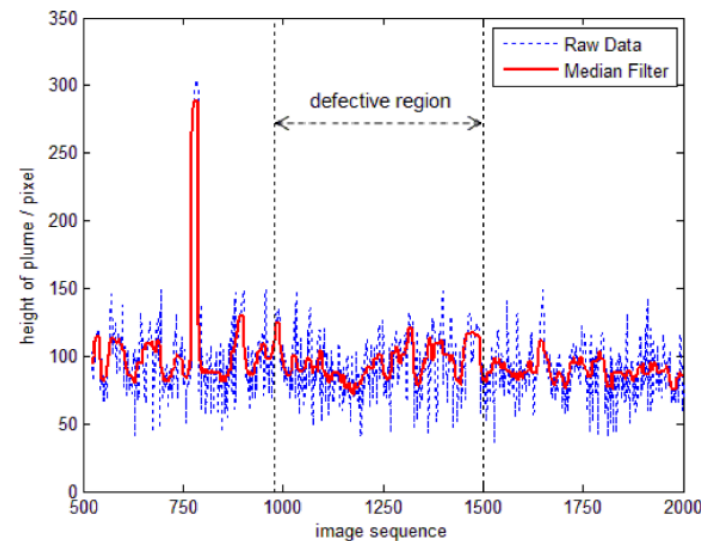
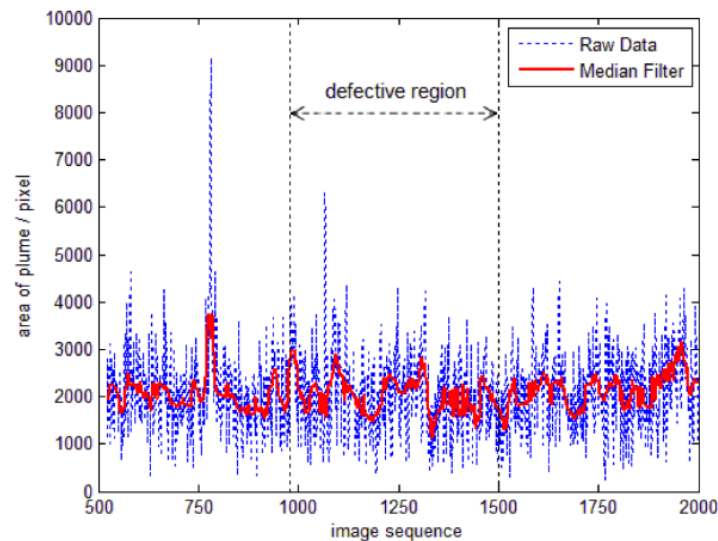
Acoustic emission monitoring

- ▶ Detection and conversion of high-frequency waves into electrical signals
- ▶ Emission of low-level sound waves when a metal is stressed, for example during plastic deformation
- ▶ Can be detected at the surface using piezo-electric sensors
- ▶ AE sources : cracks, processes related to plastic deformation, fracturing and debonding of inclusions



Acoustic emission monitoring

- ▶ Can provide information on process stability, metal transfer mode, bead appearance, penetration depth, and internal defects.
- ▶ Studied in MIG/MAG, TIG, plasma welding, resistance welding, friction spot welding, and magnetic pulse welding.
- ▶ State of the art is increasingly based on machine learning, neural networks, and statistical feature extraction.



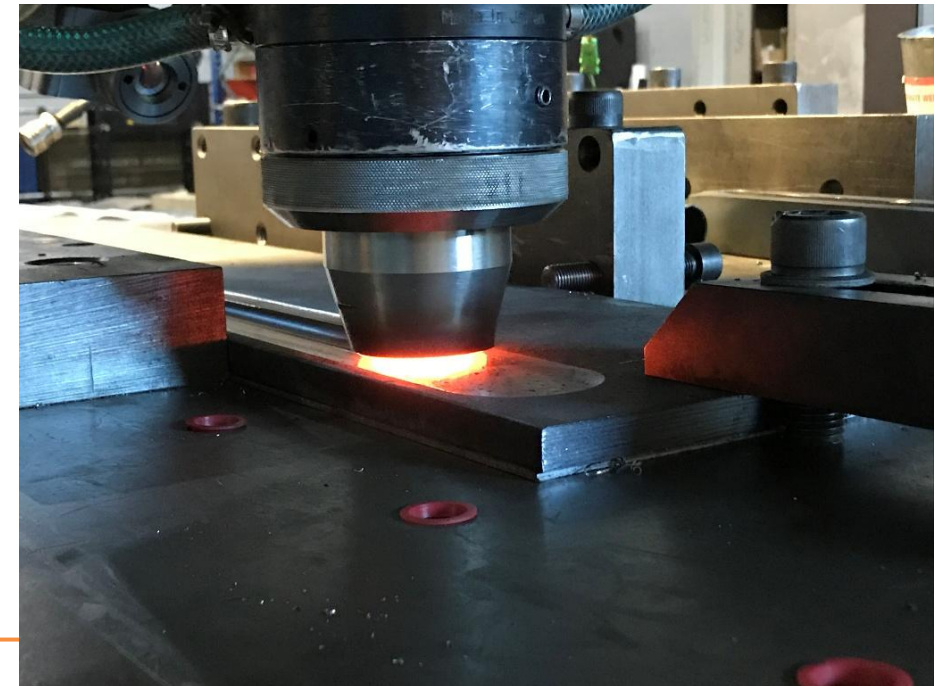
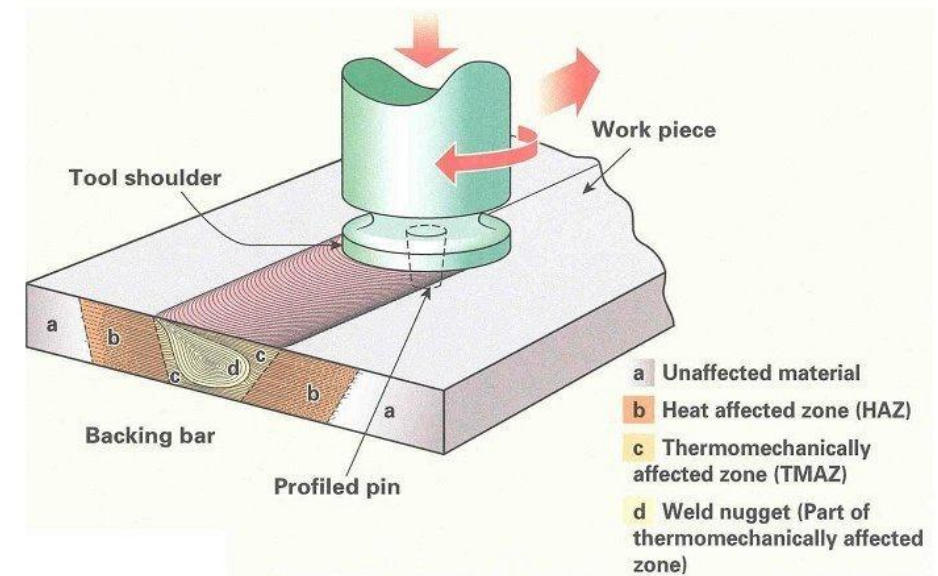
Monitoring systems

- ▶ **Process parameters** are mature and easy to implement, but only provide indirect quality information.
- ▶ **Thermography, vision, spectroscopy, and acoustic emission** are the main real-time methods for defect detection and process monitoring.
- ▶ **Laser triangulometry** is especially useful for weld geometry measurement and seam tracking.
- ▶ The main trend is toward **multi-sensor fusion with AI/ML**, because no single sensor can capture all defects reliably.
- ▶ A key challenge remains **transferability**: models often work well only for the specific material, joint, or process they were trained on.

STWIN : General objectives



- ▶ FSW process innovation:
 - ▶ Develop new Friction Stir Welding (FSW) methods for various steel grades and thicknesses.
 - ▶ Optimise parameters for joining high-strength steels and dissimilar materials like steel-aluminum.
- ▶ AI & Digital Twin integration:
 - ▶ Predict weld quality by correlating real-time measurement data with physical defects.
- ▶ Industrial validation:
 - ▶ Demonstrate techno-economic advantages through innovative industrial use cases.



STWIN : Project partners



Belgian Welding Institute

Independent non-profit specialising in welding research, education and solid-state processes.



CIDAUT

A private non-profit research institution serving the transport and energy sectors.



ISEND

High-tech company providing non-destructive testing solutions



STIRWELD

French start-up providing low-cost Friction Stir Welding (FSW) solutions



STIRTEC

Austrian high-tech company that provides full-line solutions for Friction Stir Welding



SSAB

Specialized global steel company and leading producer of Advanced High-Strength Steels



ELEMENT6

Global leader in synthetic diamond supermaterials, including specialized tools for FSW.



GRANALU

Leading semi-trailer manufacturer



HIAB

A Swedish manufacturer of loader cranes



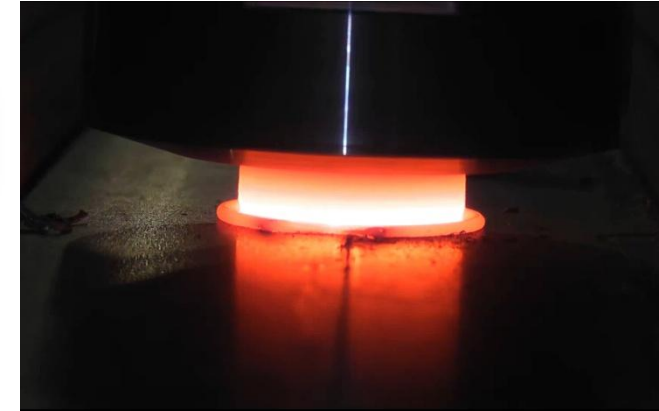
HORSE

Producer of high-efficiency, low-emission internal combustion and hybrid powertrain technologies

STWIN : Weldability investigations

Friction stir welding of steel

- ▶ High strength steels S700 / S960
- ▶ Thicknesses : 3 – 6 – 8 – 10 mm
- ▶ New tool geometries to optimise joint properties and tool life
- ▶ Welding of dissimilar steel joints
- ▶ Double sided FSW for welding of larger thicknesses (up to a thickness of 25 mm)



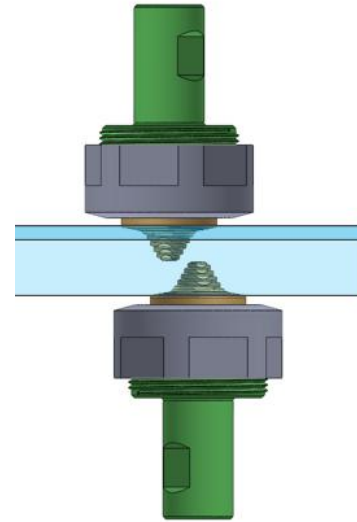
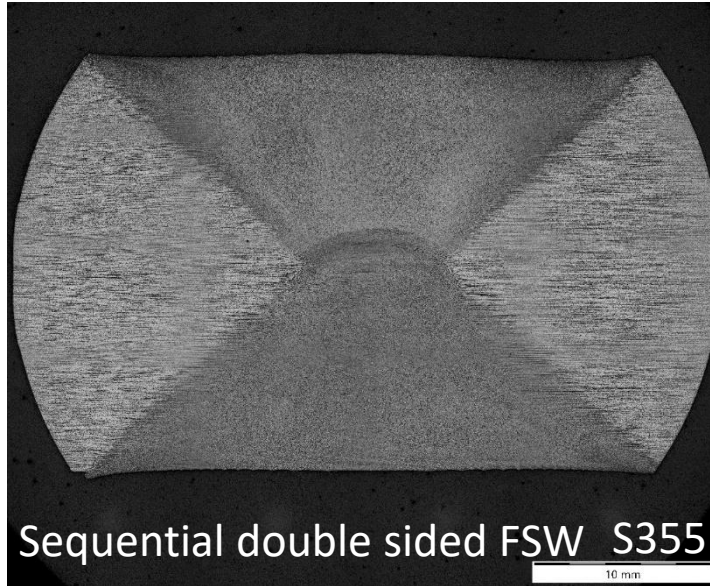
Friction stir welding of dissimilar materials

- ▶ Joining of aluminium to steel & cast iron - steel
- ▶ Investigation of the influence of the process parameters on the weld properties



STWIN : Weldability investigations

Friction stir welding of steel



STWIN demonstrators

Loader cranes components

- ▶ HIAB
- ▶ Joining of high strength steels (S700 – S960),
- ▶ Sheets with dissimilar thicknesses.



Trailer manufacturing

- ▶ GRANALU
- ▶ Joining of aluminium to stainless steel



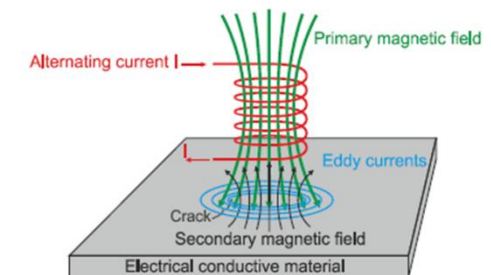
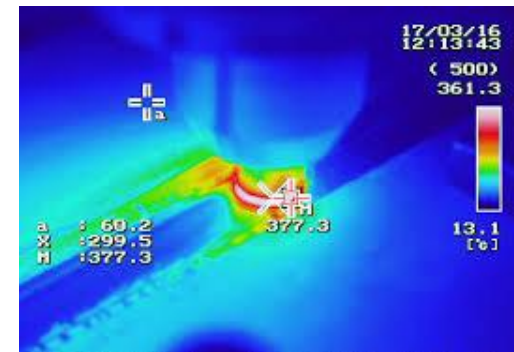
Automotive parts (differential)

- ▶ HORSE
- ▶ Joining of high strength steel and cast iron
- ▶ Weight saving



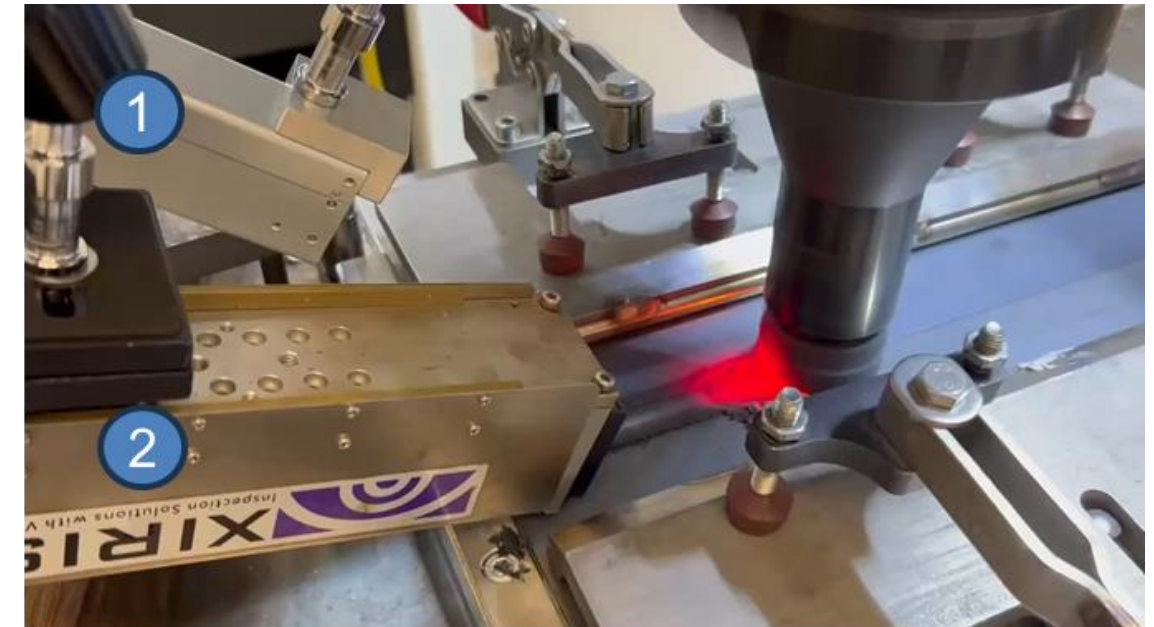
STWIN : Quality monitoring for friction stir welding

- ▶ In depth research of fast integrated measurement systems for real-time quality monitoring for FSW,
- ▶ Evaluate the detection capabilities of the measurement methods:
 - ▶ Acoustic emission monitoring
 - ▶ Thermography
 - ▶ Visual camera
 - ▶ Eddy current testing
 - ▶ Parameter monitoring



STWIN : Quality monitoring for friction stir welding

- ▶ Material : S700 high strength steel – 3 mm
- ▶ Portal FSW equipment of UCLouvain
- ▶ Measurements :
 - ▶ Visual camera (1)
 - ▶ Thermal camera (2)
 - ▶ Acoustic emission – Contactless
 - ▶ Acoustic emission – Contact



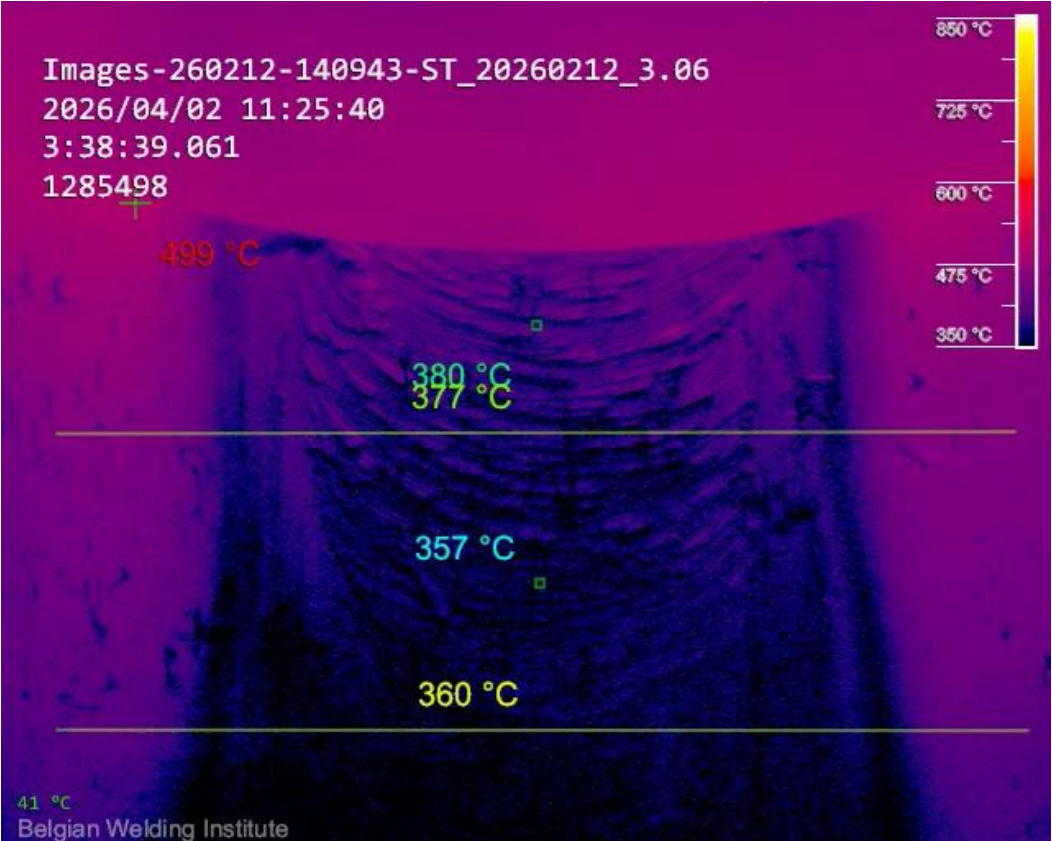
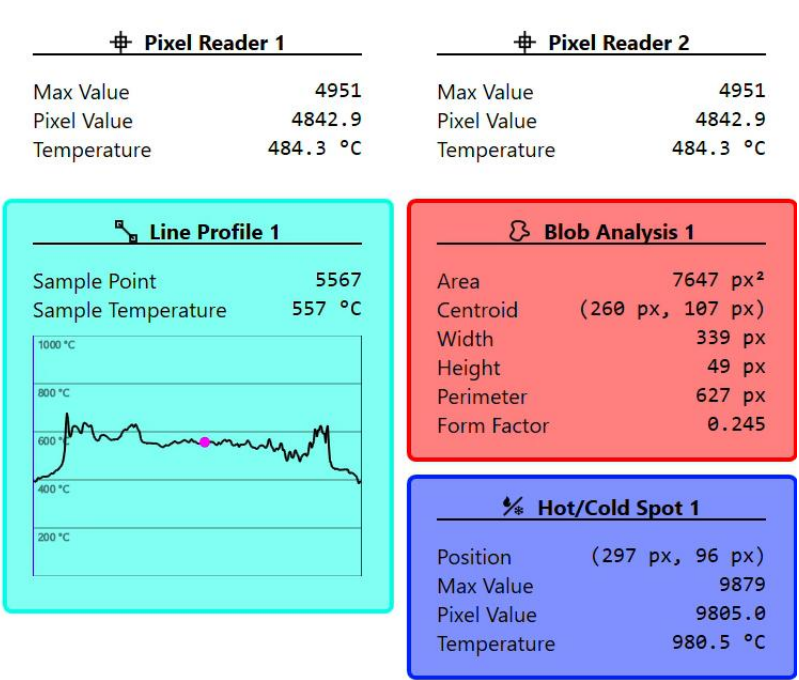
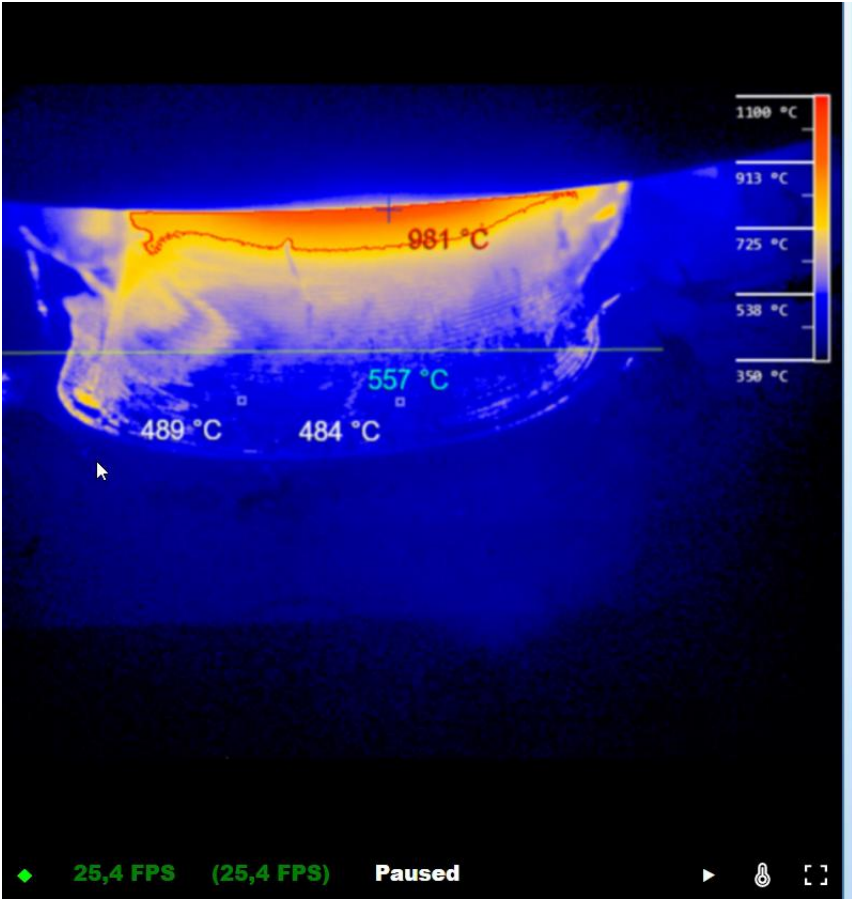
STWIN : Quality monitoring for friction stir welding

Visual camera



STWIN : Quality monitoring for friction stir welding

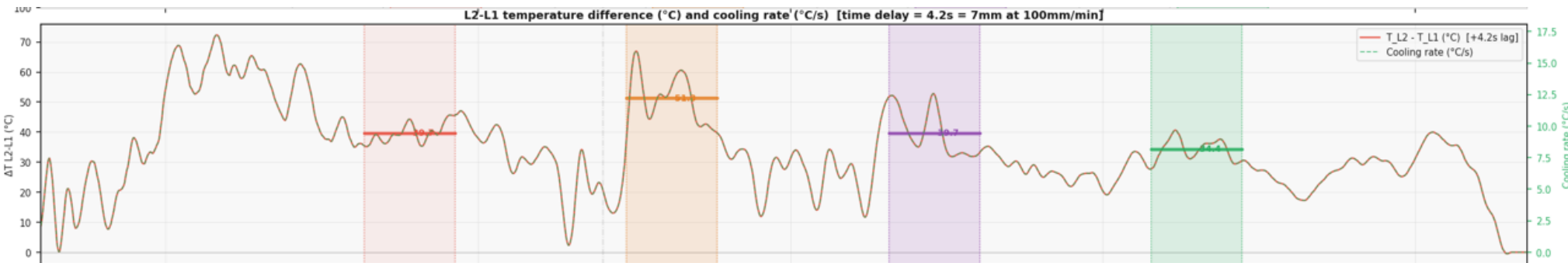
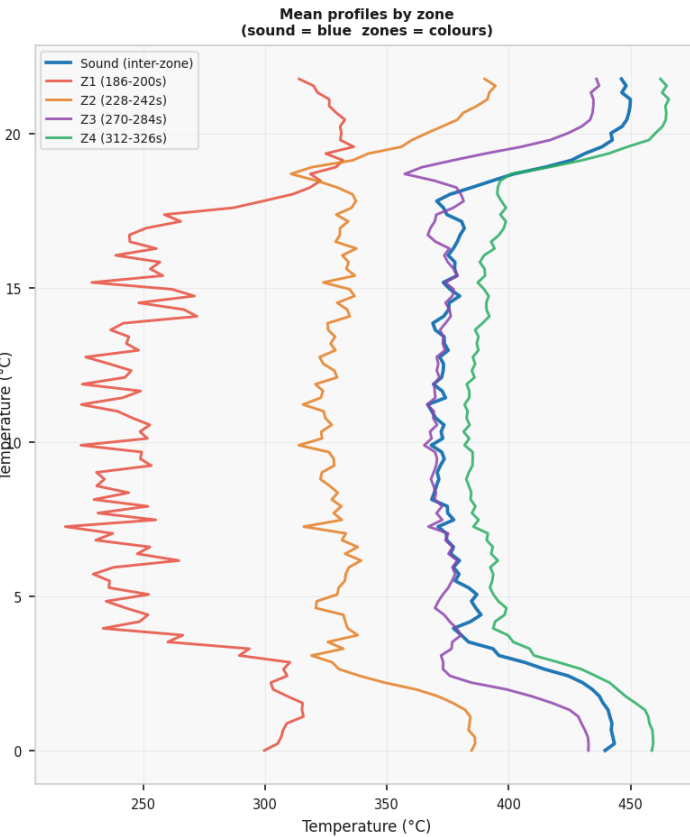
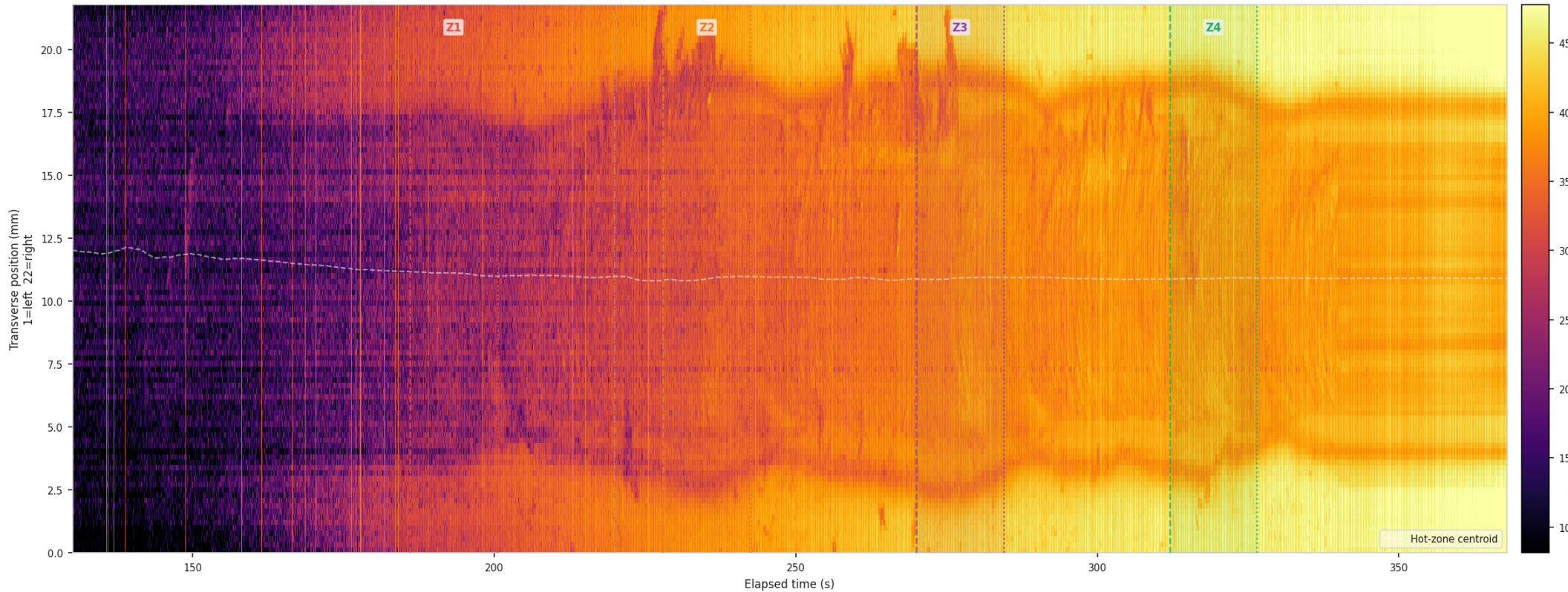
Thermal camera



STWIN : Quality monitoring for friction stir welding

► Thermographs

Full-weld thermal heatmap | SW-S7-3.6 | Type5_chamfer_1.6mm | L1
Colour = temperature (°C) Vertical bands = defect zones [rev_55]



AID-WELD : General objectives



- ▶ Multi-sensor systems for real-time quality monitoring for arc welding
- ▶ Small form factor sensing platform (< 25 k€)
- ▶ Performant data-driven predictive modelling (AI)
- ▶ Efficient transfer from lab environment to production environment

AID-WELD : Project partners



Belgian Welding Institute

Independent expert center specialized in welding technologies and materials weldability research and testing.



imec-UGent IPI Lab

Advanced Image Processing & Interpretation Lab focused on innovative visual data analysis and interpretation.

SANHA

Sanha Fittings

Global leader in the manufacturing and distribution of multi-material piping systems and specialized fittings.

bosal

Bosal

Tier 1 automotive supplier and leading manufacturer in the strategic fields of mobility and energy systems.

dekiMo

Dekimo Group

Comprehensive design house providing end-to-end services for electronics, PCB layout, mechanics, and certification.



IBA Benelux

Innovative provider of high-precision real-time and offline analysis tools for industrial and medical applications.

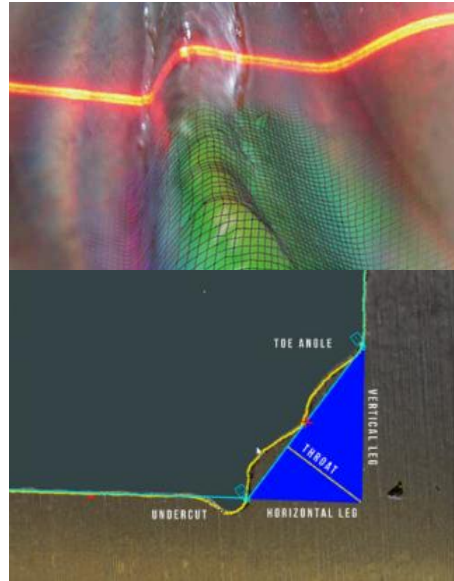
imec



VLAIO



AID-WELD : Generic investigations

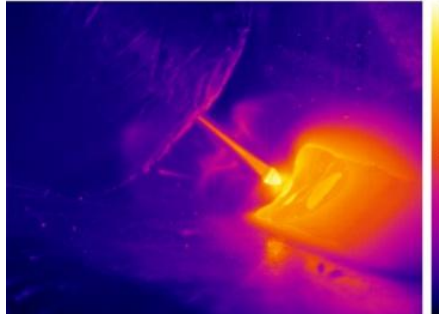
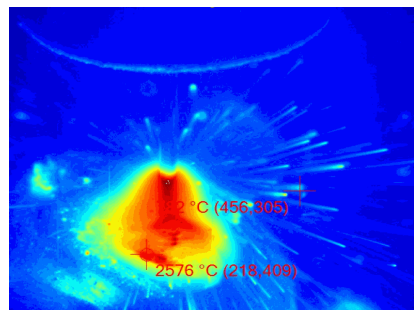
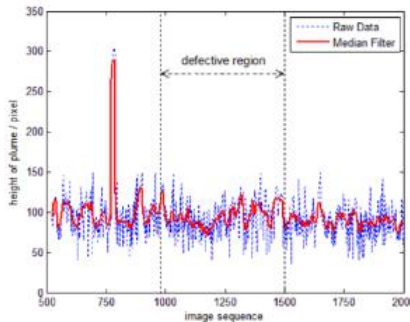
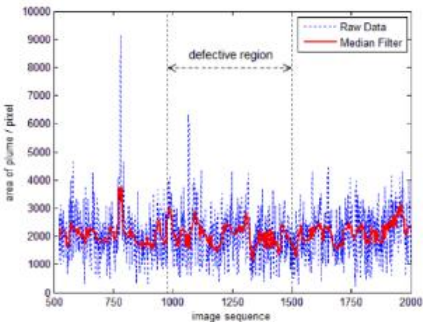


► Goals :

- Research the relationship between welding parameters, defects, and sensor measurements
- Optimize the choice of sensors for weld quality monitoring, trading off accuracy, size, cost, etc.
- Design experiments for the collection of quality AI training data

► Advancements on SotA :

- Multi-sensor fusion hardware platform optimized for weld quality monitoring
- New experiments that induce welding defects in an efficient and realistic way



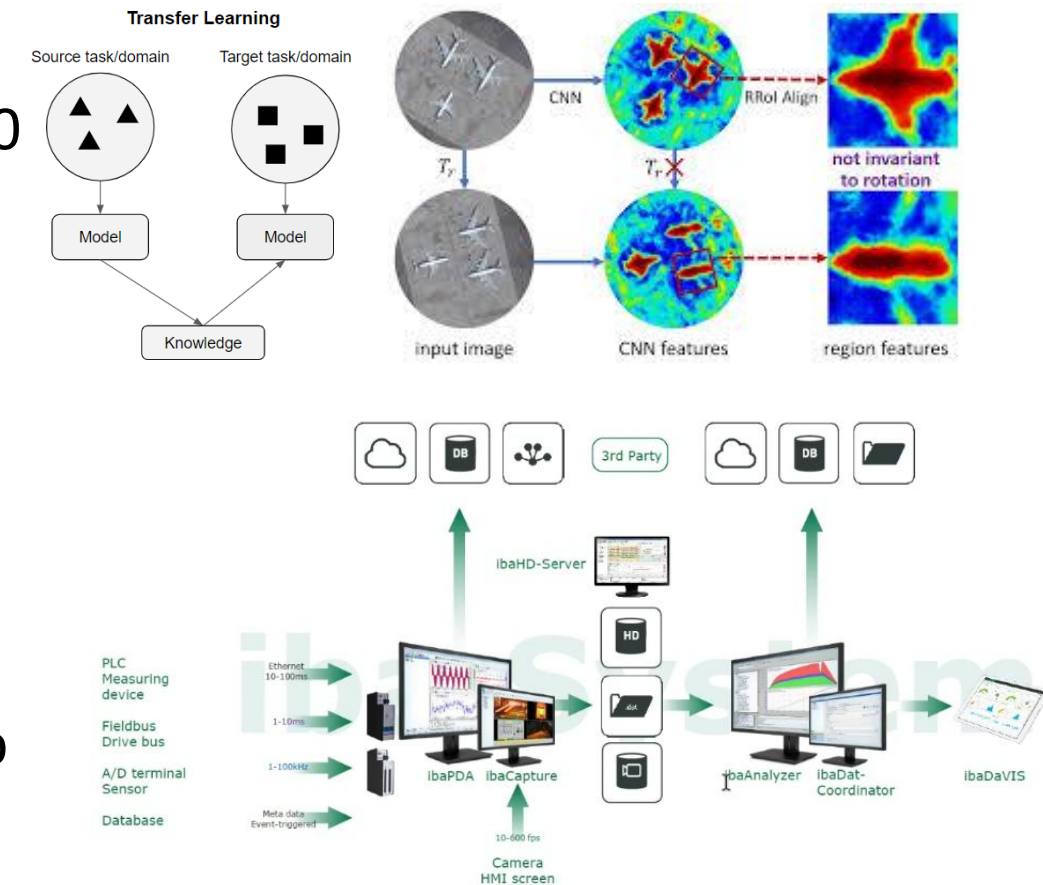
AID-WELD : Data analytics, synthesis and reporting

► Goals :

- Real-time AI for industrial weld defect detection (every 50 ms)
- Automated aggregation & synthesis of results (at weld & part level)
- Automated reporting of weld quality to operators (e.g., email or SMS warnings)

► Advancements on SotA :

- Novel edge AI modelling with invariance to welding setup & transfer learning techniques
- New expert system for data synthesis & reporting



AID-WELD : Industrial process optimisation

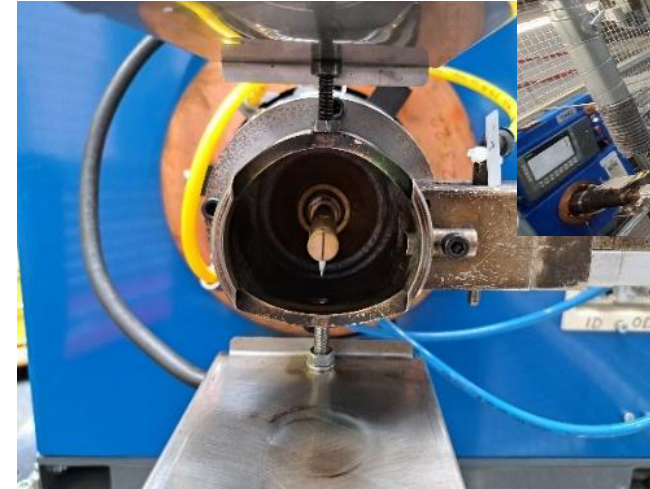
- ▶ TIG-welding
 - ▶ Optimisation of welding parameter windows
 - ▶ Minimised chamber contamination
 - ▶ Upstream task optimization



bosal



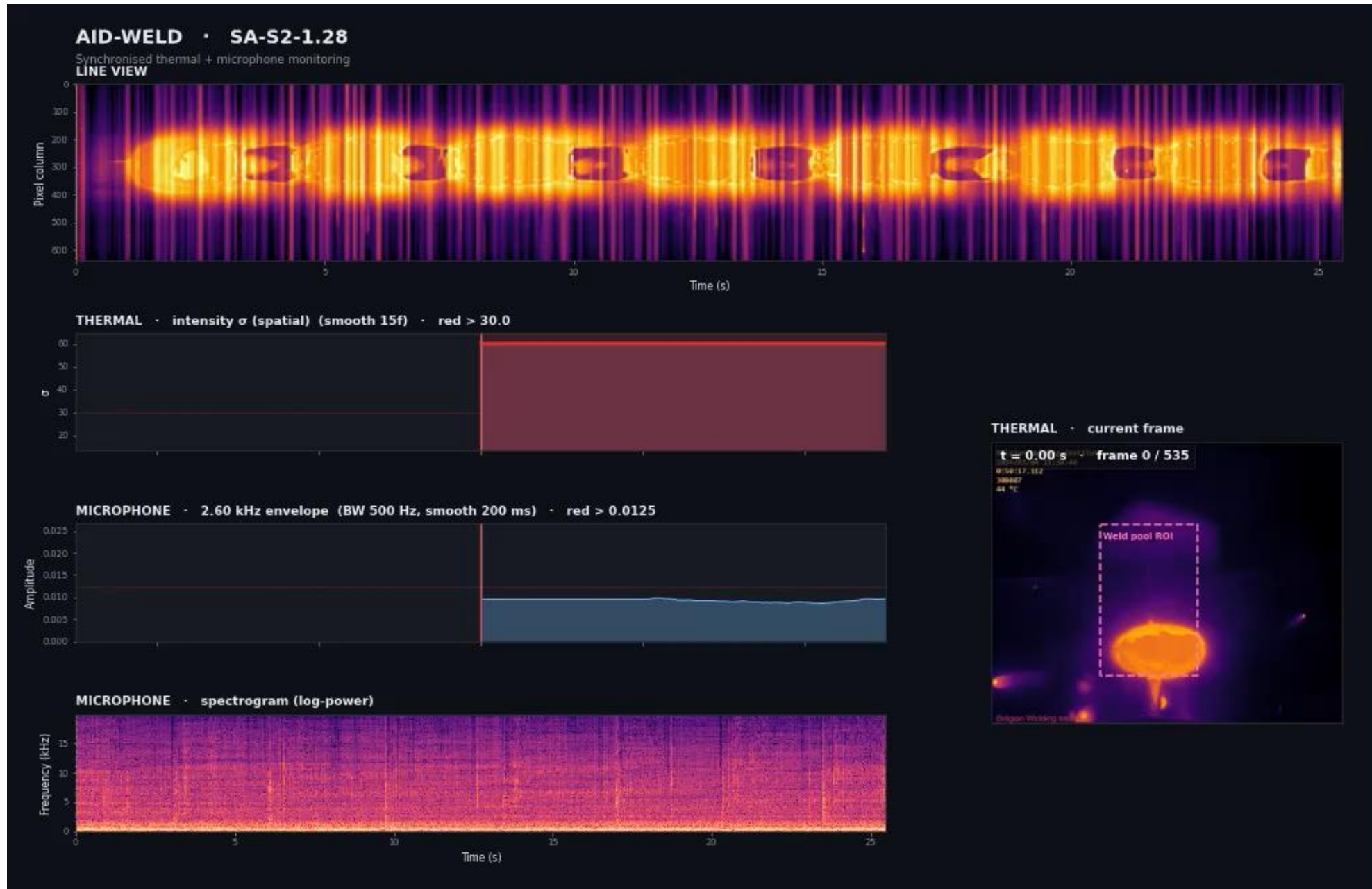
SANHA



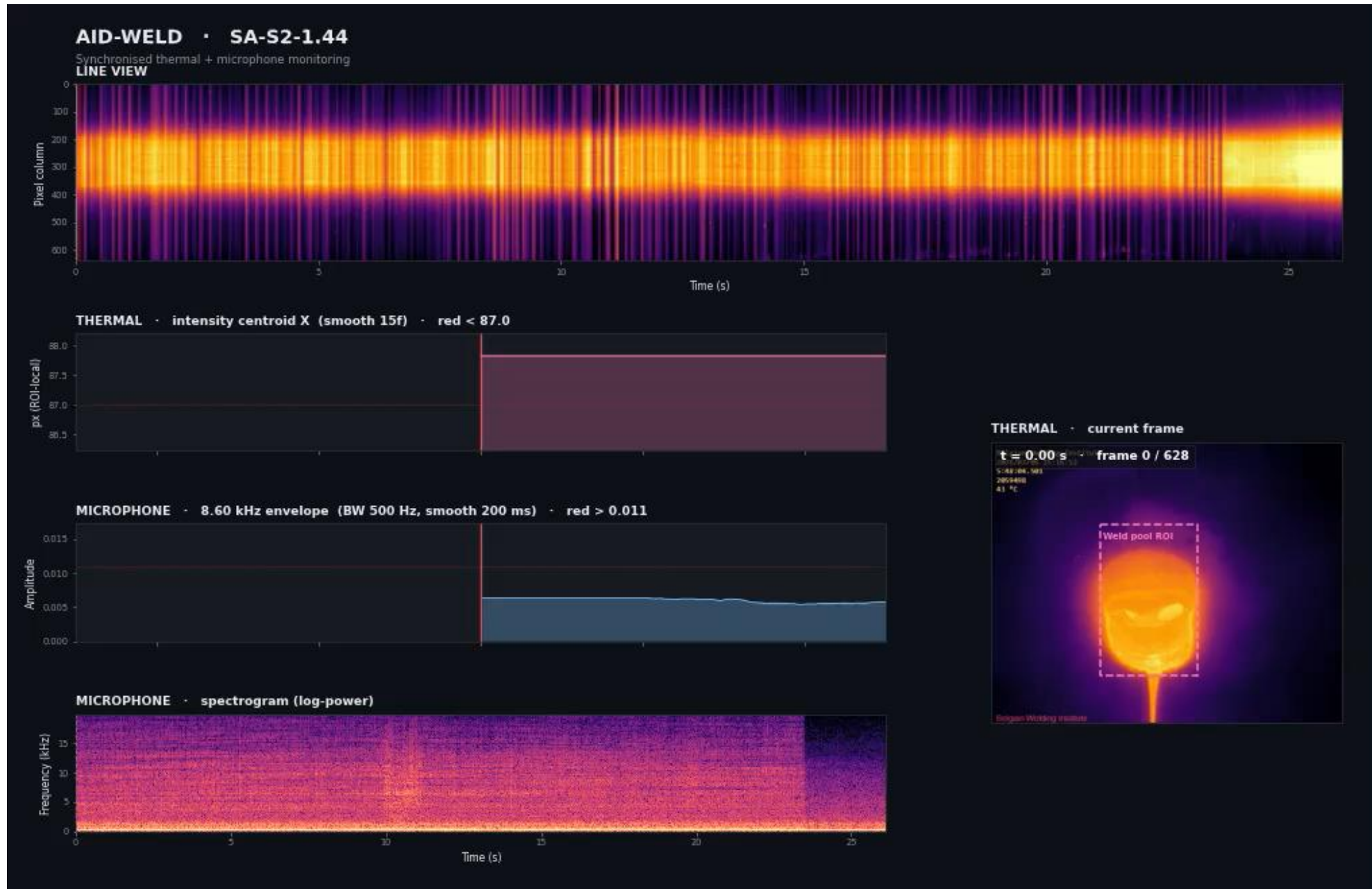
▶ MIG/MAG-welding

- ▶ Optimization of welding parameter windows
- ▶ Predictive maintenance for MIG/MAG equipment replacement
- ▶ Predictive maintenance modeling for contact tip replacement

AID-WELD: example



AID-WELD: example



AID-WELD : Join our advisory group!

- ▶ Get regular updates on the project's progress
- ▶ Offer advice & feedback on our research
- ▶ Contact :
 - ▶ Brian Booth – imec-IPI - UGent
Email: Brian.Booth@ugent.be
 - ▶ Koen Faes – BWI
Email: Koen.Faes@BIL-IBS.be



AID-WELD

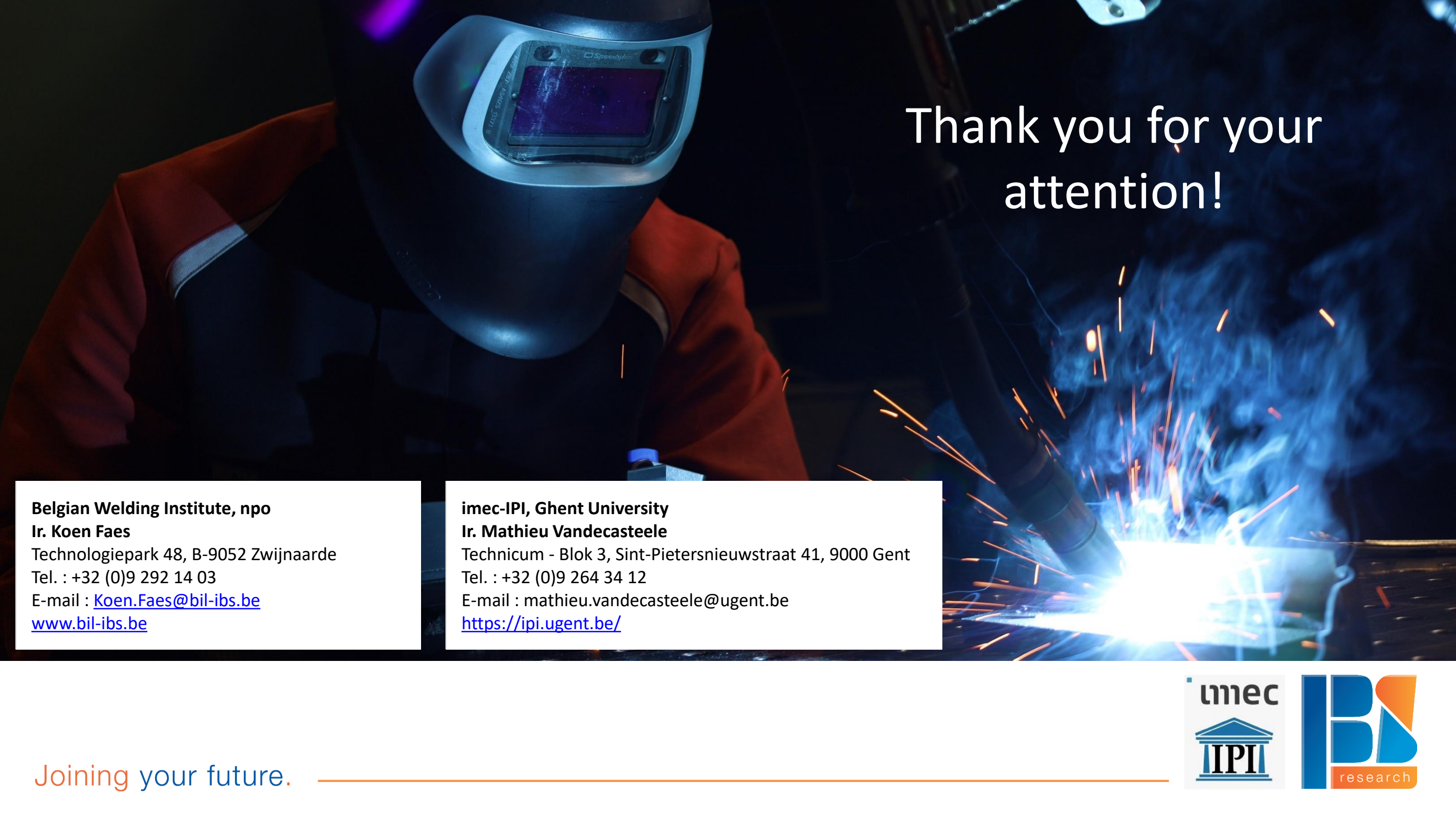
Real-time quality monitoring of
welding processes



bosal

SANHA





Thank you for your
attention!

Belgian Welding Institute, npo

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