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Department of Mechanical and Aerospace Engineering

ACTIVE THERMOGRAPHY FOR THE INVESTIGATION OF CORROSION IN STEEL SURFACES

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Active thermography for defect detection and analysis

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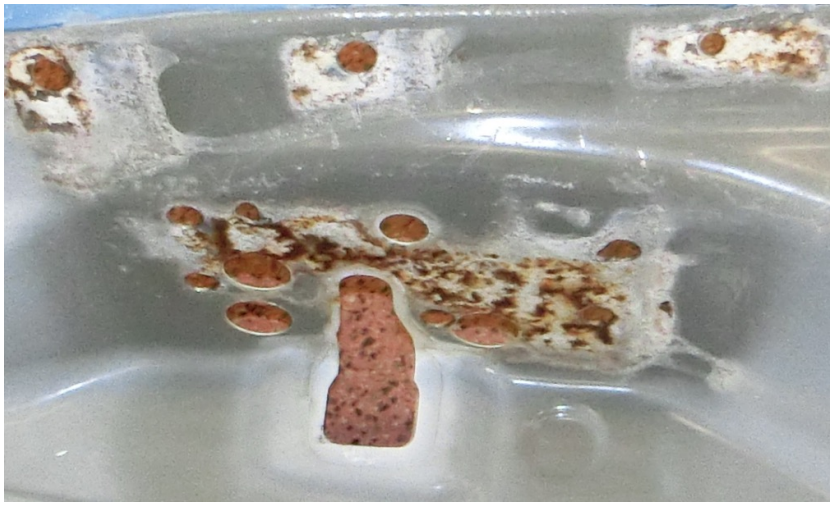
Aim of the research:

- developing an experimental methodology for the analysis of corrosion phenomena of steel surfaces by means of Active Thermography (AT), in reflexion configuration (RC)



IR thermographic techniques

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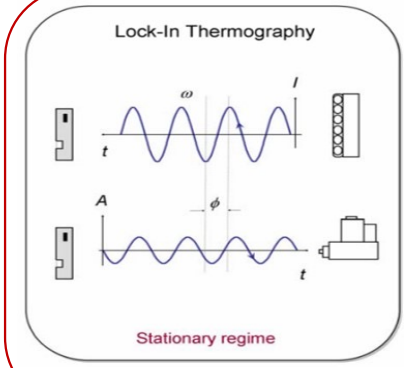
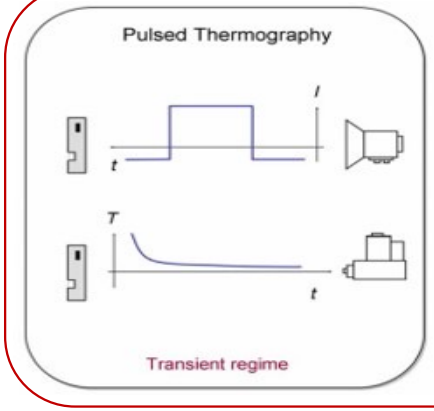
IR thermography

- Passive thermography
- Active thermography



LOCK-IN
- Steady stare regime
- Modulated wave
- Energy concentrated in a frequency value
- Penetration depth related to frequency



PULSED / STEP HEATING
- transient
- Impulse or step loading
- Energy distributed on a frequency range
- Penetration depth related to frequency range

Frequency response provides information on surface and material properties

Active thermography for defect detection and analysis

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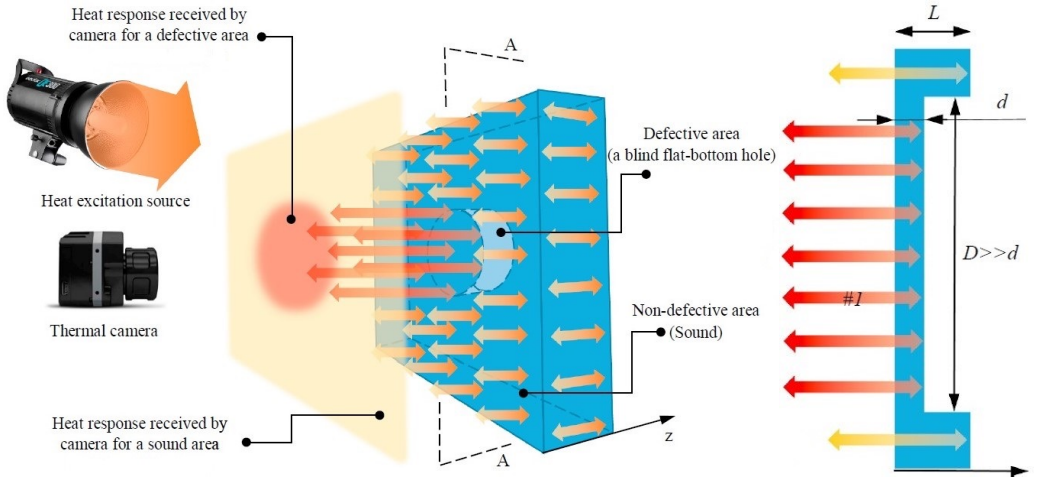
Thermal properties variation

Sub superficial defects and discontinuities are responsible of:

- Lower thermal conductivity
- Thermal energy reflection
- Different thermal contours (from sound region)



CONCENTRATED DEFECTS vs DISTRIBUTED DEFECTS

What is thermal response?

Materials and methods

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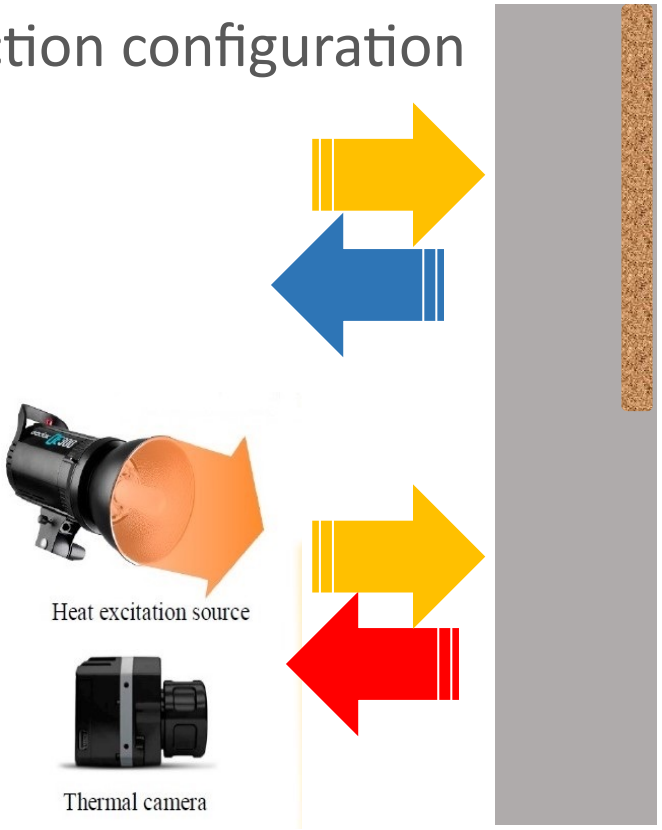
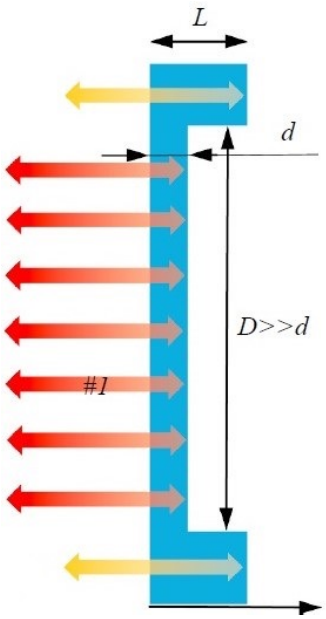
Reflection configuration



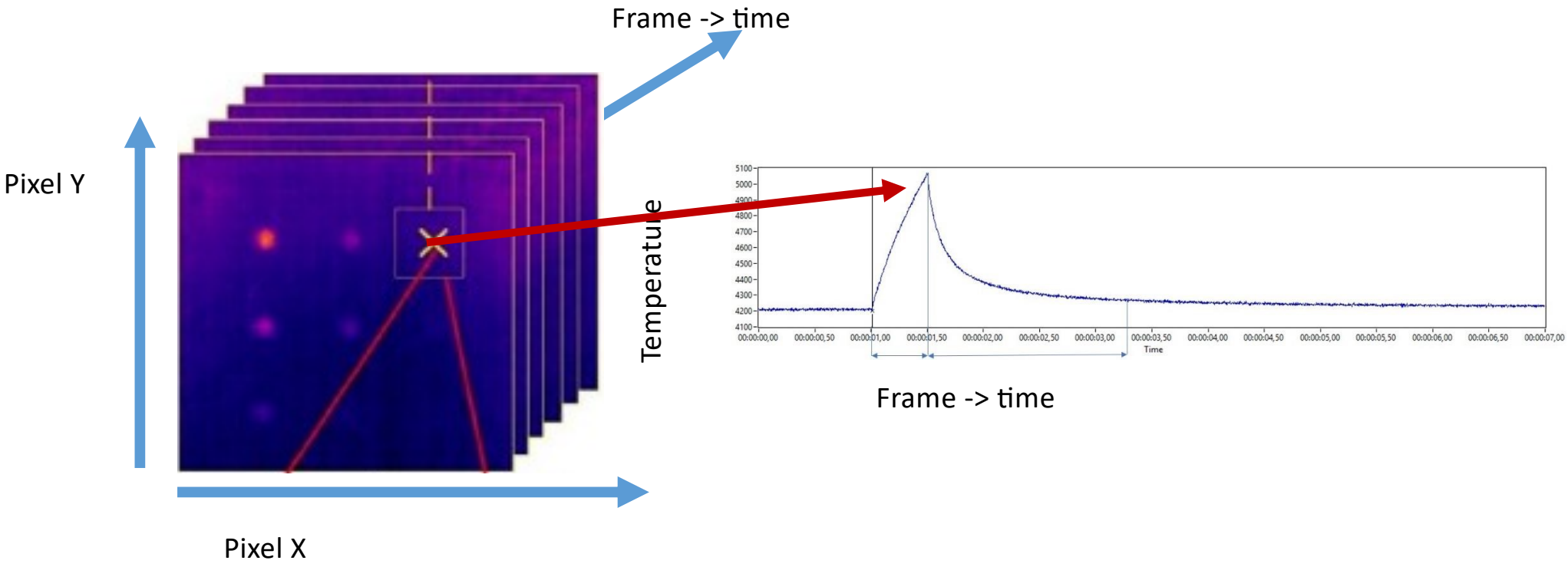
Corroded region

Sound region



$$\frac{\Delta T}{T} \propto -\frac{\Delta L}{L}$$

Algorithm



Algorithm

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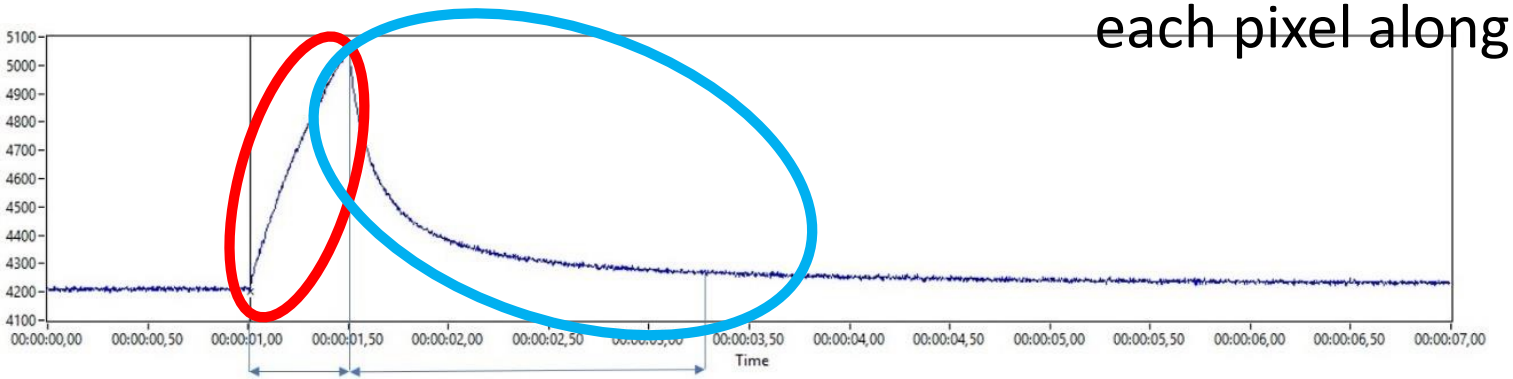
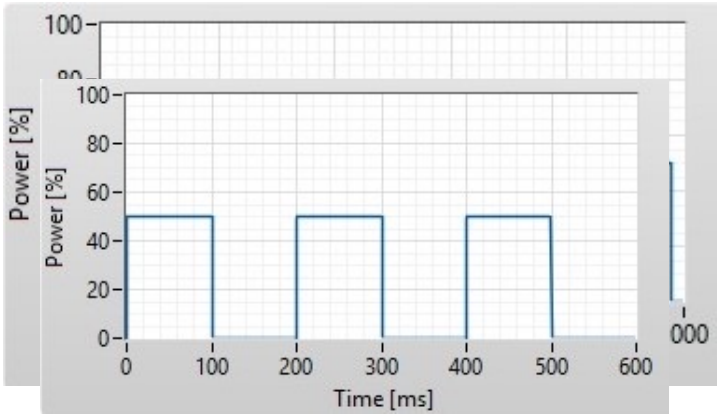
Amplitude and Phase calculation in each pixel along time axis





Excitation frequency
Excitation amplitude
Number of pulses
Acquisition frequency
Acquisition interval

- FFT analysis both for LI and Pulsed
- Amplitude and Phase calculation in each pixel along time axis

Test plan

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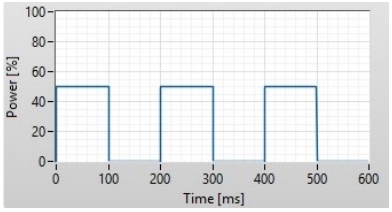
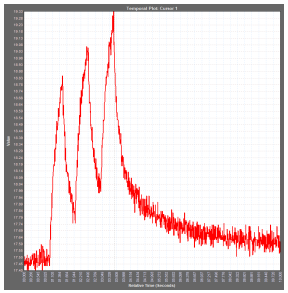
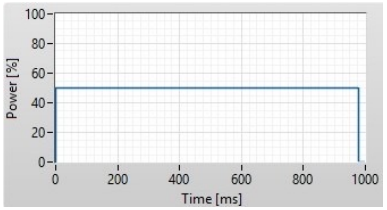
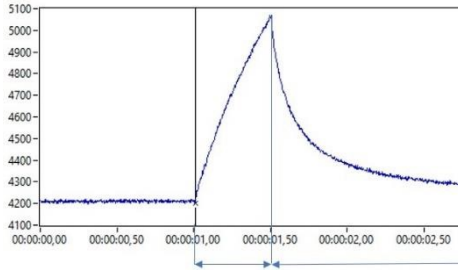
- Lock in and pulsed thermal loading
- Varying excitation parameters (power, time, number of pulses, ….)
- Metallographic optical microscope to measure the thickness variation of the specimens









Specimen preparation

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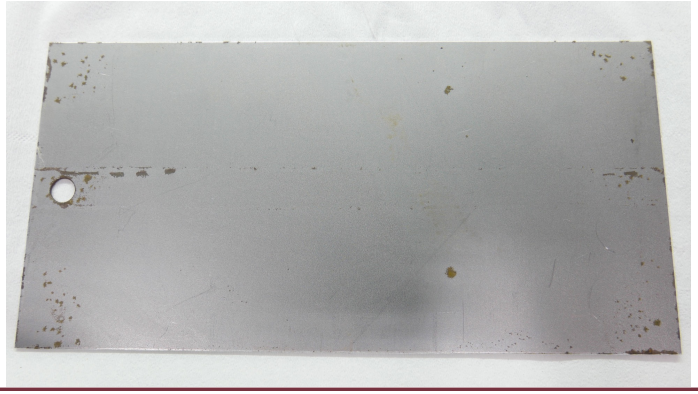
- Non corroded
- 2 weeks corrosion
- 4 weeks corrosion
- Al steel, laminated
- One surface protected with protective film
- Fog of water with 5% di NaCl



Testing equipment

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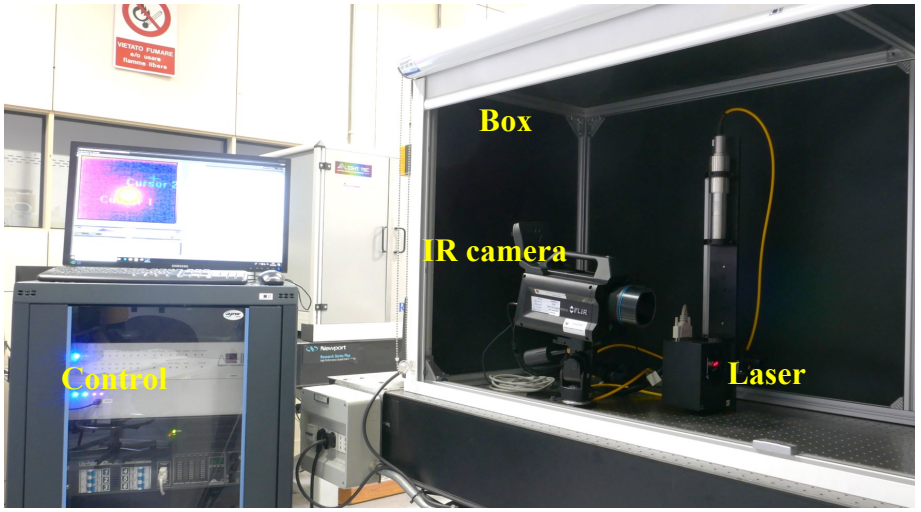
Laser Multides system
Cooled sensor

IR cameraFLIR X6540sc
Cooled sensor
Thermal sensitivity: < 25 mK (18 mK)
Image resolution (full frame): 640×512 pixel
Max frame rate(full frame): 125 Hz
sub-window resolution: 96 × 88 pixel
max frame rate (sub-window): 540.72 Hz

Laser IPG YLP-V2 Series
Fibre laser
Max pulse energy: 1 mJ
PotenMax power: 30 W
Power modulation: 11% ÷ 100%
Laser beam diameter: 6mm ÷ 9mm
Wave shape: pulse / pulse train



Data processing: Lock In tests

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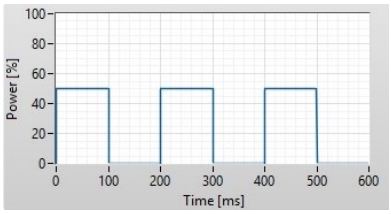
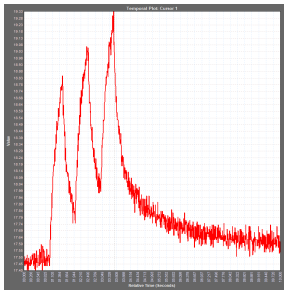
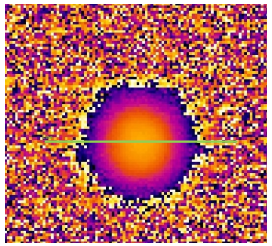


Test name	Corrosion time	Excitation time	Excitation power	Acquisition frame rate
A	0, 2, 4, 6 w.	200 ms	100%	540 Hz
B	0, 2, 4 w.	200 ms	50%	540 Hz
C	0, 2, 4 w.	200 ms	25%	540 Hz
D	0, 2, 4 w.	2000 ms	25%	54 Hz
E	0, 2, 4 w.	1000 ms	25%	108 Hz

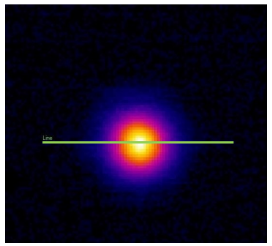
- 3 points investigated:
- 3 impulses per testing configuration
- 3 repetition per point
- Acquisition of thermal contours
- Phase and Amplitude **average** of thermal signal plotted
- Comparison of plots for different corrosion condition and different acquisition configuration

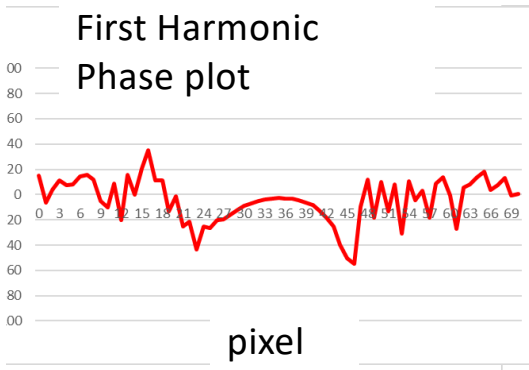


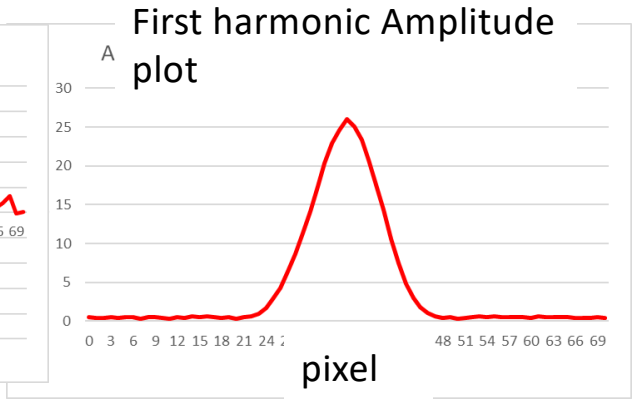
Phase contour



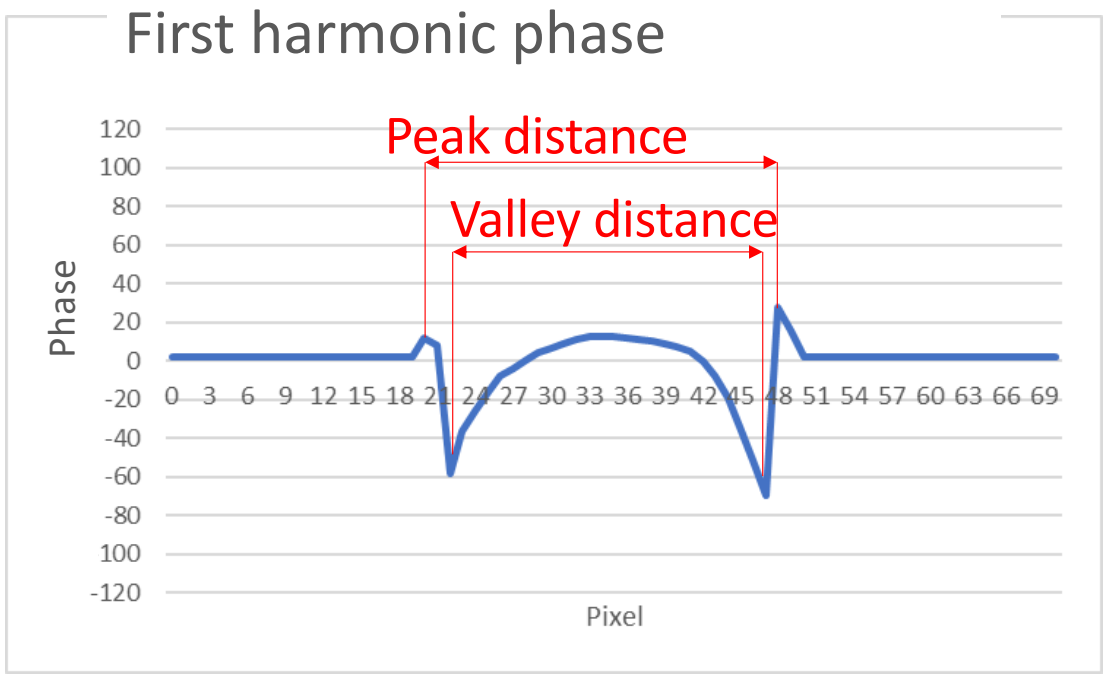
Amplitude contour







Data processing: Lock in tests



Data processing: Pulsed tests

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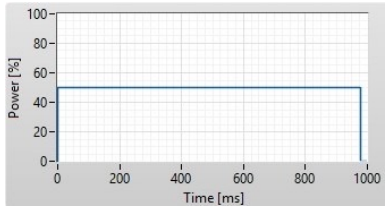
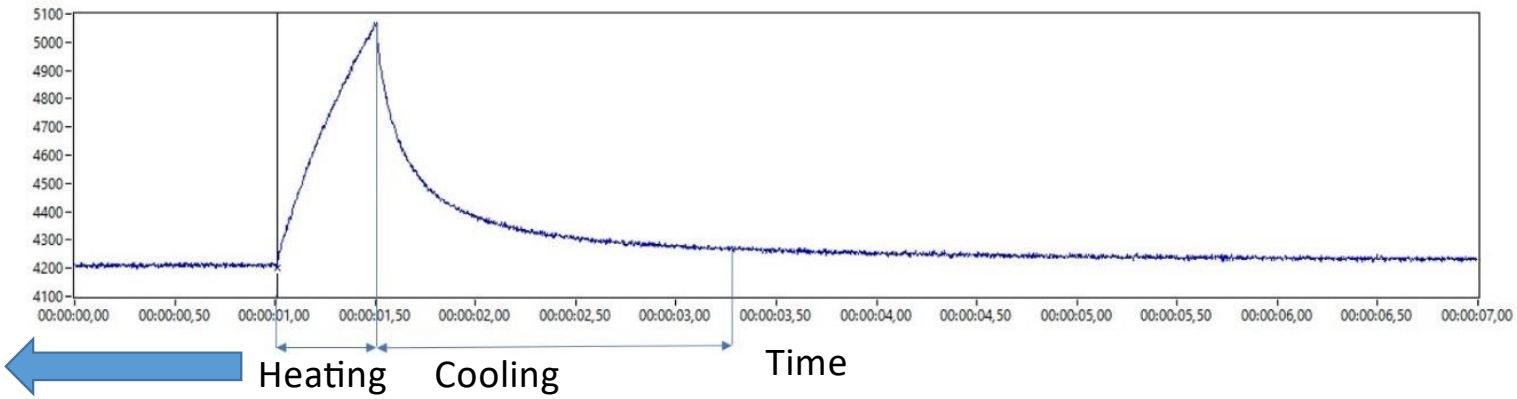
- 3 points investigated:
- 1 impulse per testing configuration
- 3 repetition per point
- Acquisition of thermal contours
- Phase and Amplitude **average** of thermal signal plotted
- Comparison of plots for different corrosion condition and different acquisition configuration



Test name	Corrosion time	Impulse time	Impulse power	Acquisition frame rate
F	0, 2, 4, 6 w.	1000 ms	100%	400 Hz
G	0, 2, 4 w.	1000 ms	50%	400 Hz
H	0, 2, 4 w.	1000 ms	25%	400 Hz
L	0, 2, 4 w.	200 ms	100%	400 Hz
M	0, 2, 4 w.	500 ms	100%	400 Hz



Slope of heating/cooling time curve

R^2 coefficient of the fitting curve

Data processing: Pulsed tests

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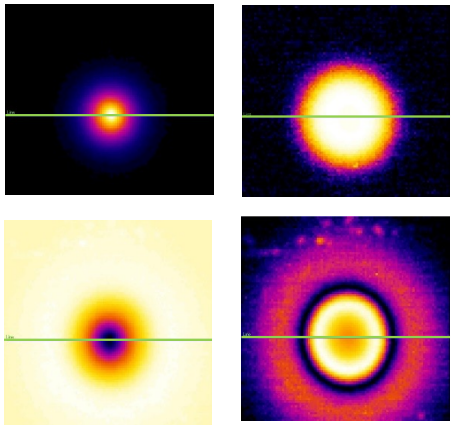
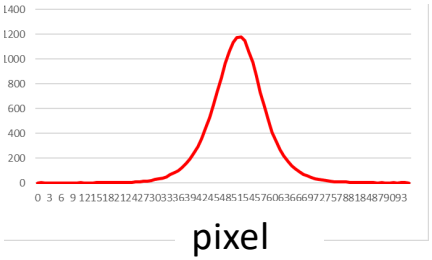
Slope of heating/cooling time curve

R^2 coefficient of the fitting curve

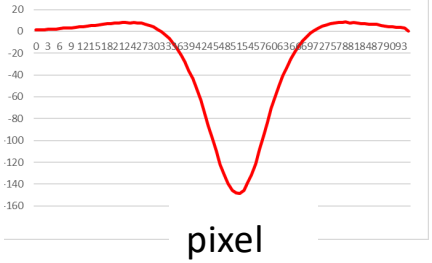
heating cooling



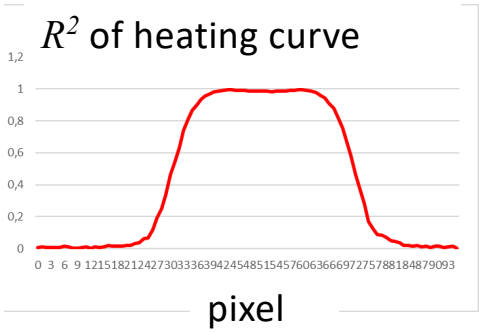
Slope of heating curve



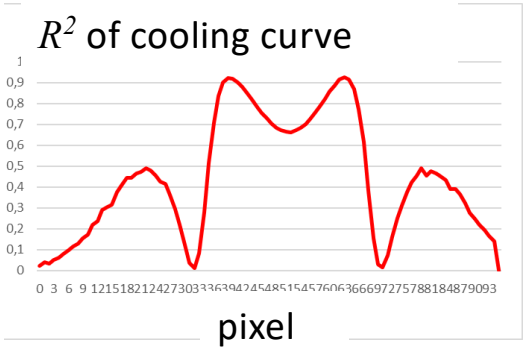
Slope of cooling curve



R^2 of heating curve



R^2 of cooling curve



Data processing: Step heating tests

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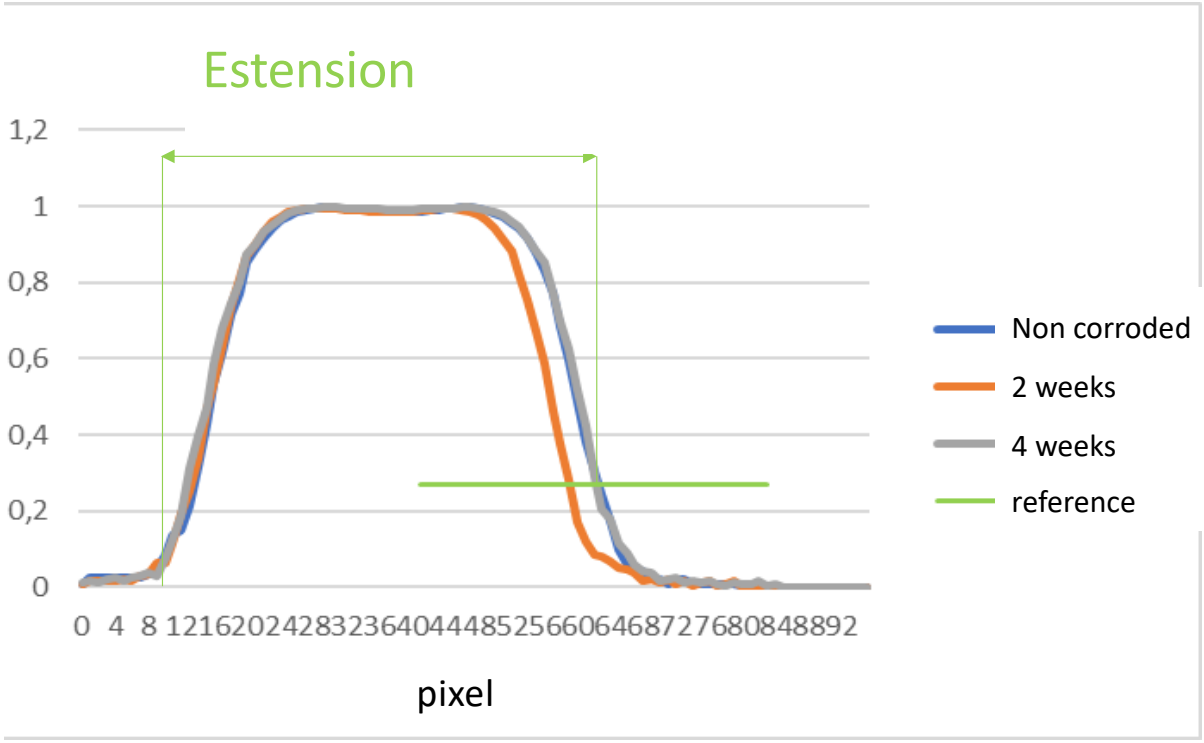
R^2 extension



Results: micrographic analysis

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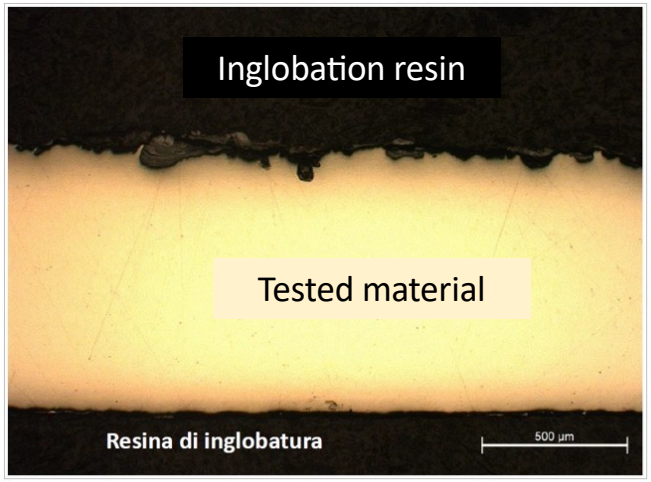
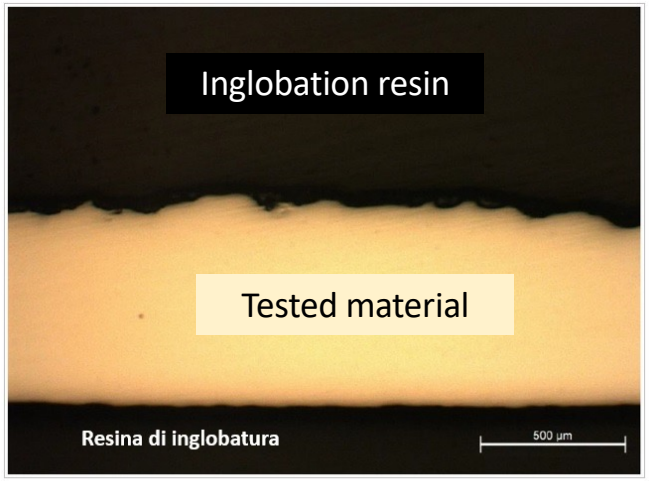
2 weeks corrosion



4 weeks corrosion



Level of corrosion	Material thickness
Non corroded	0,76 ÷ 0,90 mm
2 weeks corrosion	0,72 ÷ 0,95 mm
4 weeks corrosion	0,60 ÷ 0,76 mm

Results: Lock In tests

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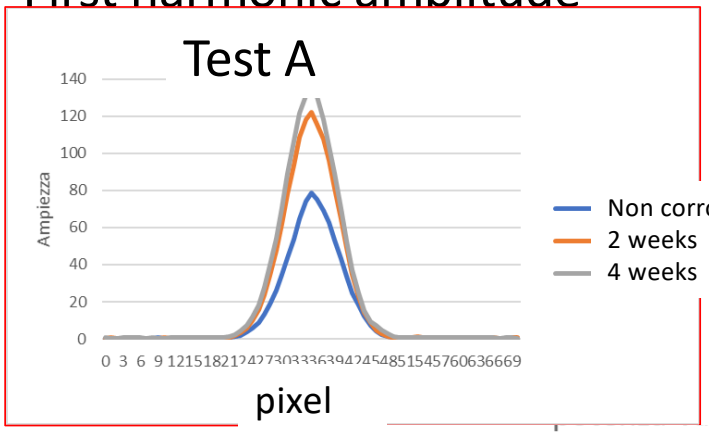
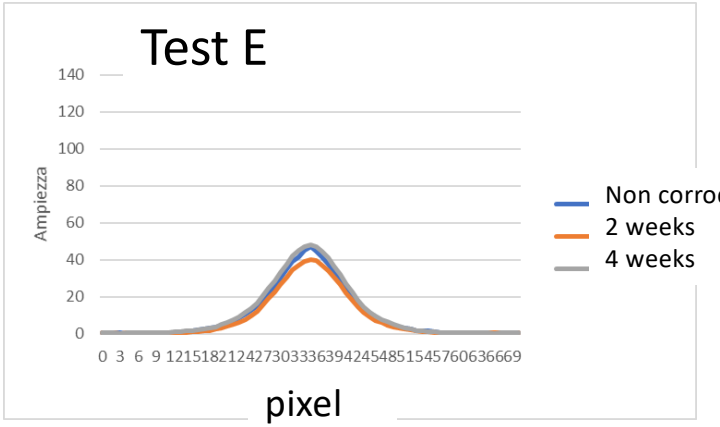
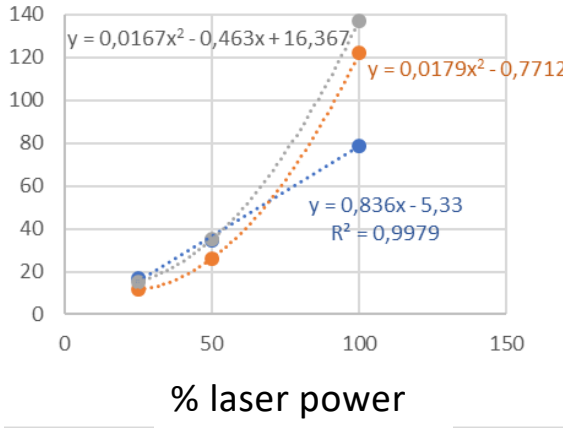
First harmonic amplitude

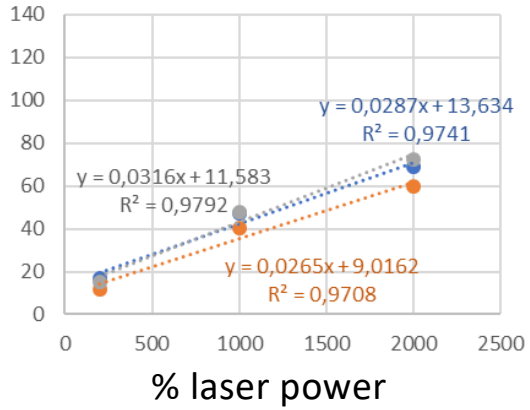




Tests A, B, C



Tests C, D, E



Results: Lock In tests

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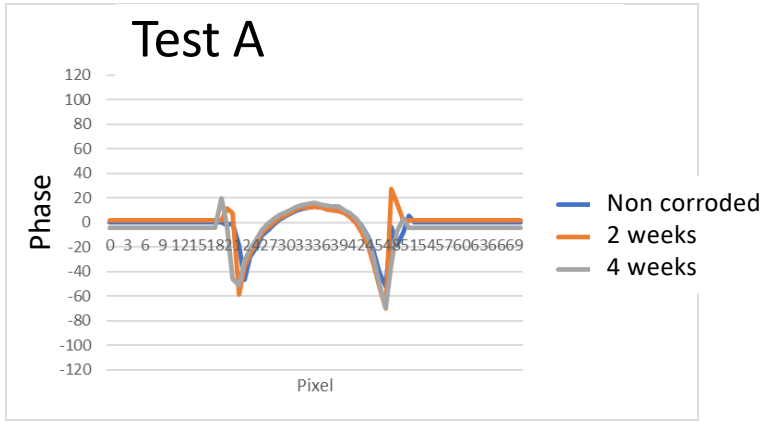
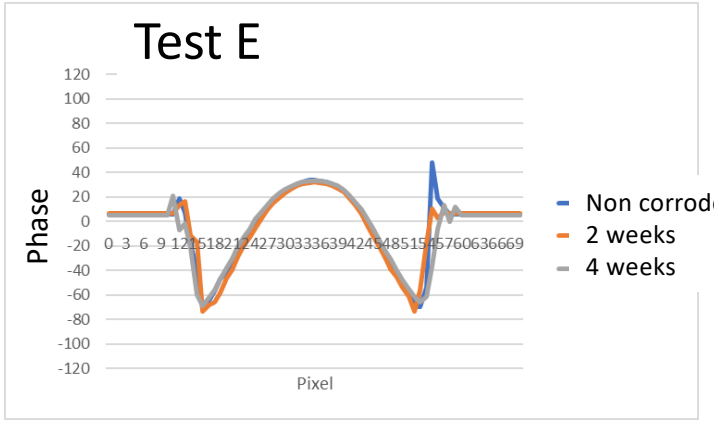
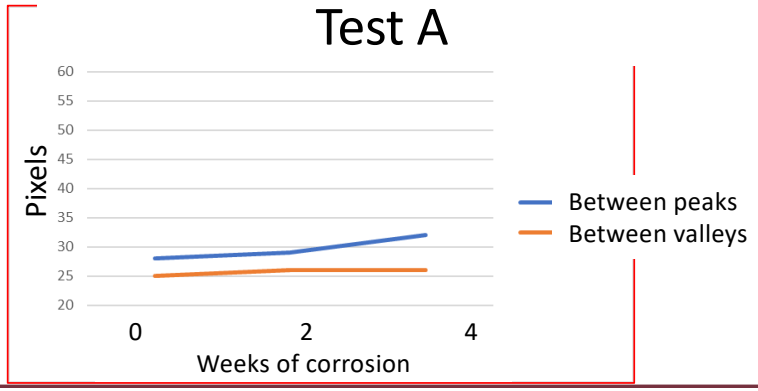
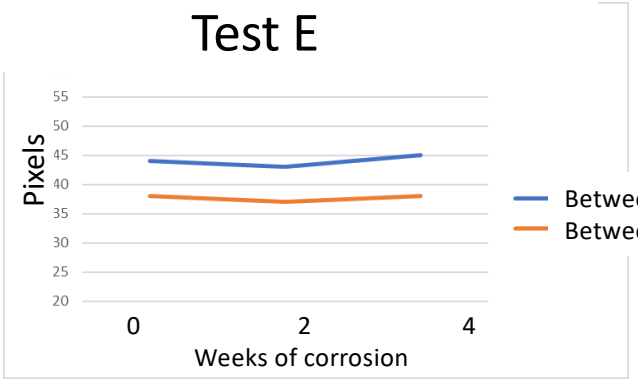
First harmonic phase





First harmonic phase distance





Results: Pulsed

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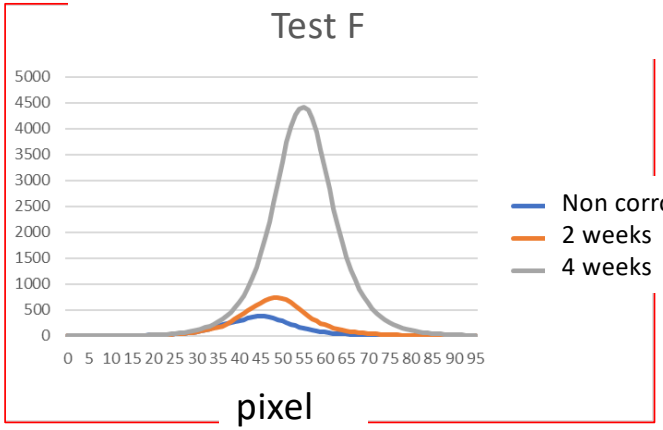
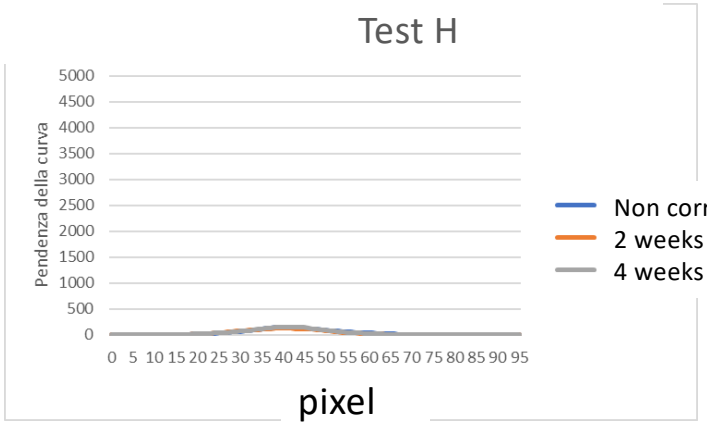
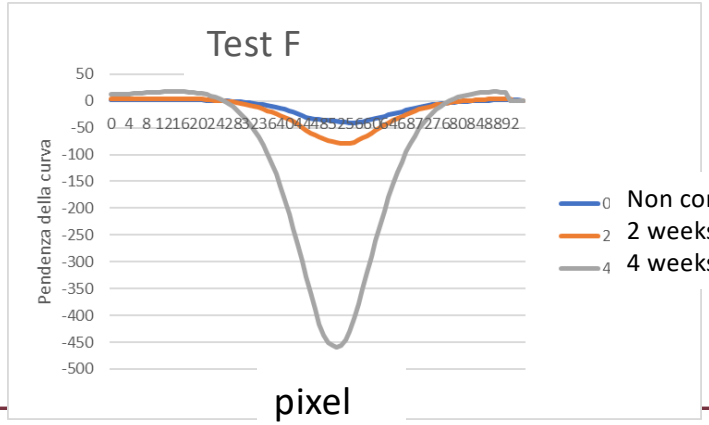
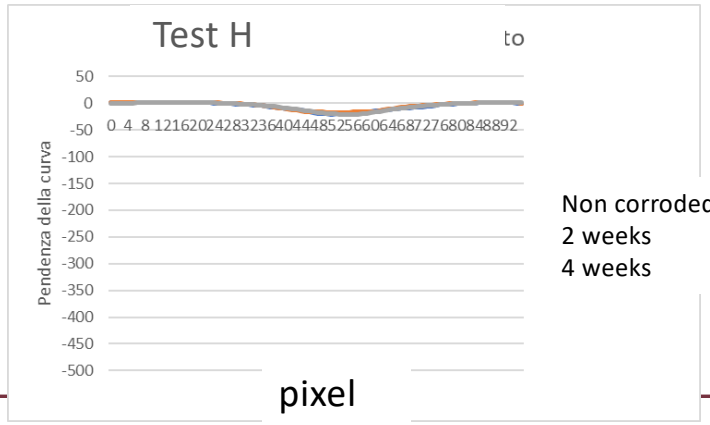
Heating curve slope





Cooling curve slope





Results: Pulsed

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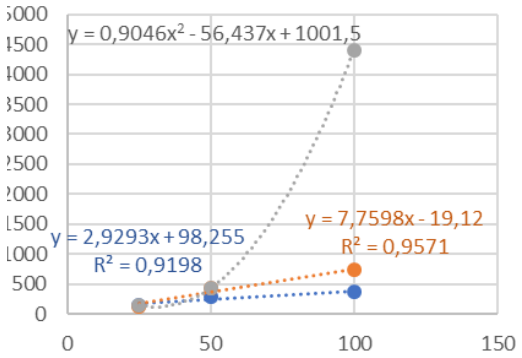
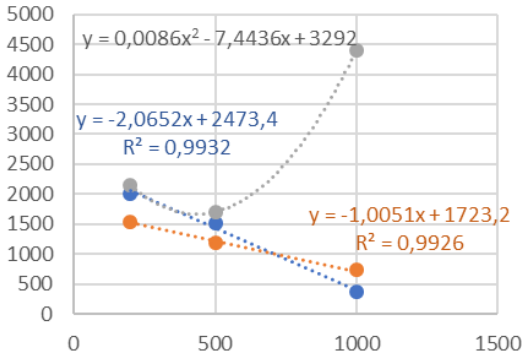
Tests F, G, H

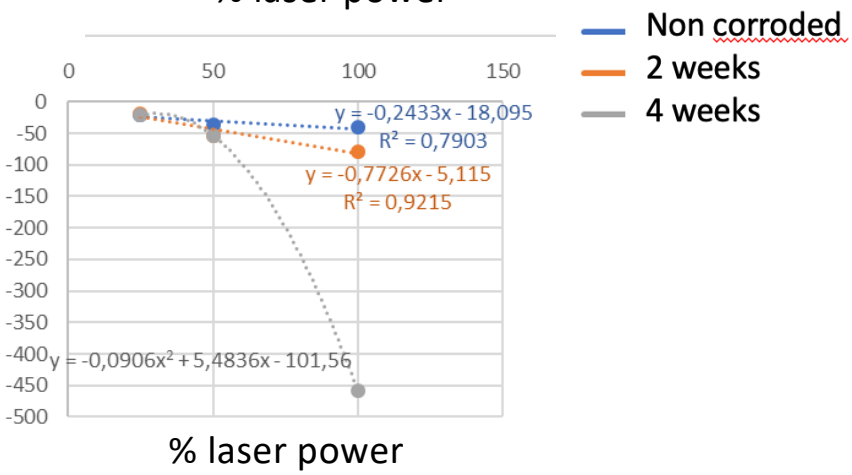
Test F, L, M

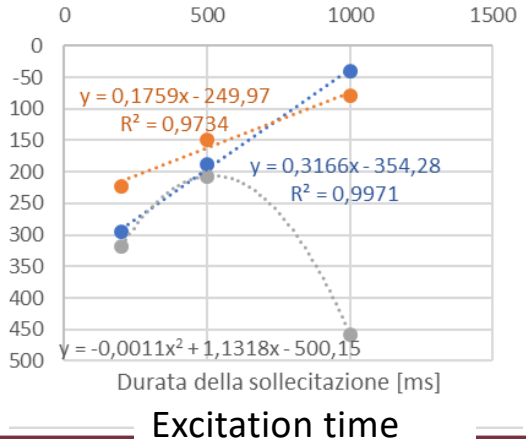
Heating curve slope





Cooling curve slope





Results: Pulsed

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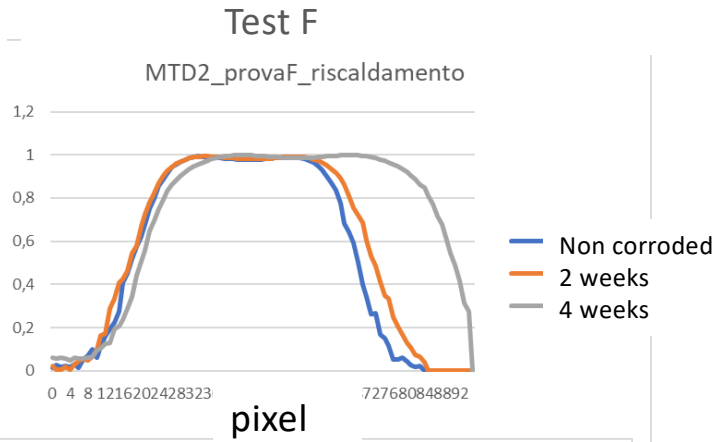
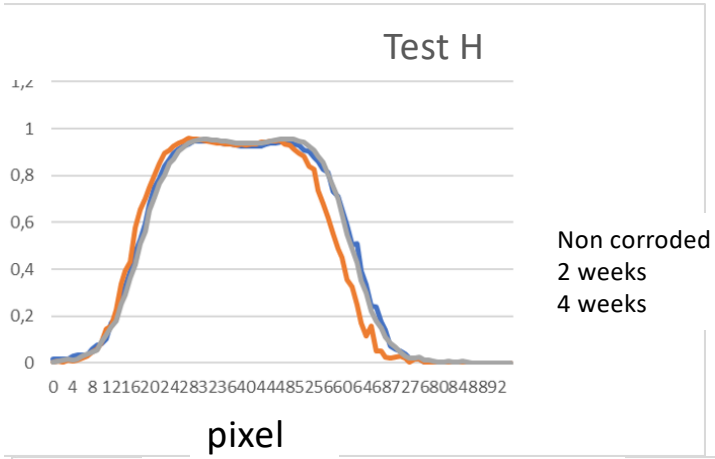
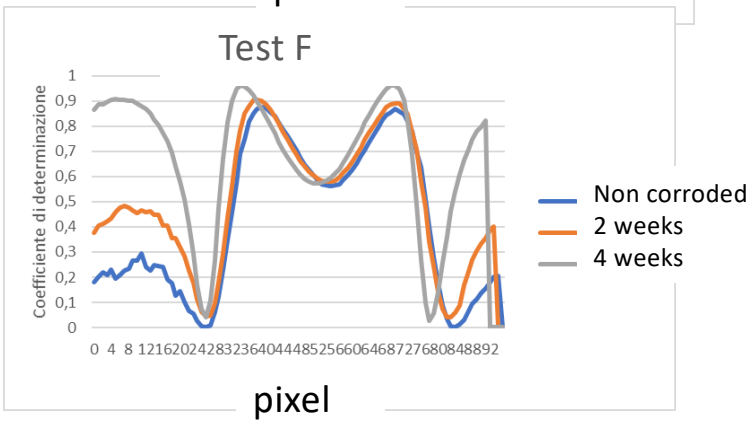
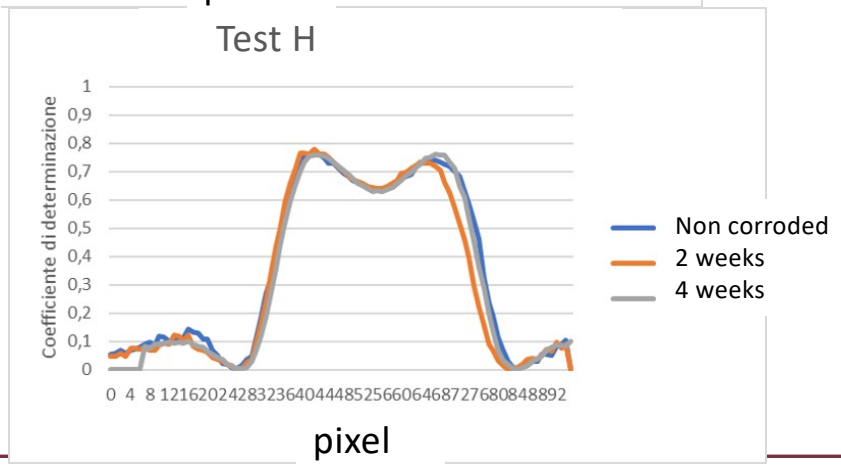
Heating curve R^2





Cooling curve R^2





Results: Pulsed

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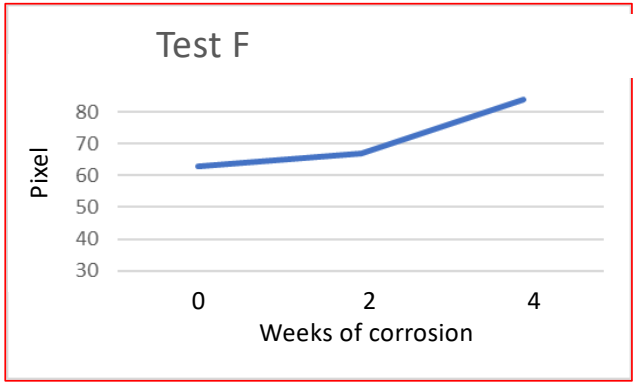
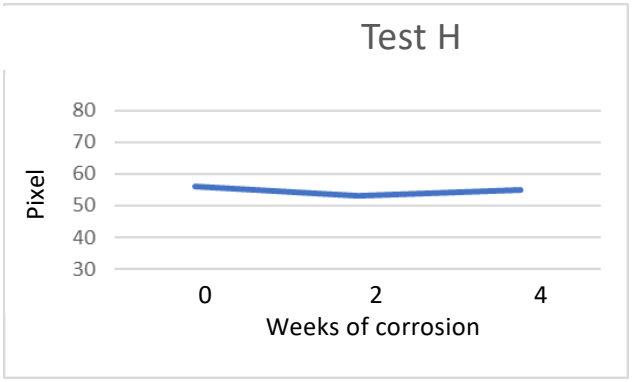
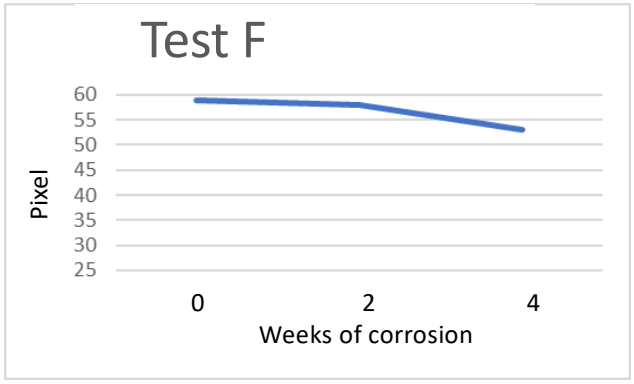
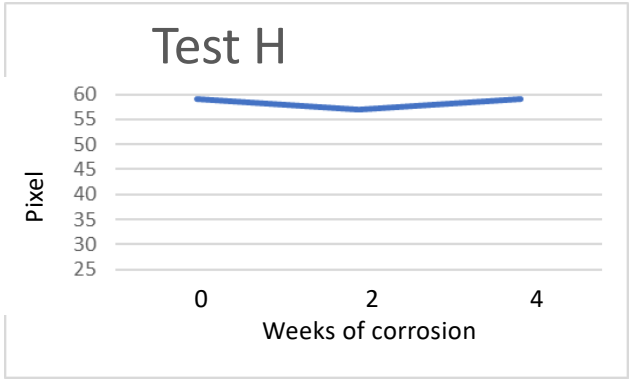
Heating curve R^2 extension





Cooling curve R^2 extension





Conclusions

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- AT technique in reflection configuration, and excitation on the non corroded surface provided good results for what concerns surface distributed defects detection
- The measurements difficulties and uncertainties are related to non uniform corrosion distribution on the specimens and to the signal scattering related to variation of density and of reflecting surfaces
- The optimization of the AT testing parameters allowed to set up the robustness of the technique

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Questions?