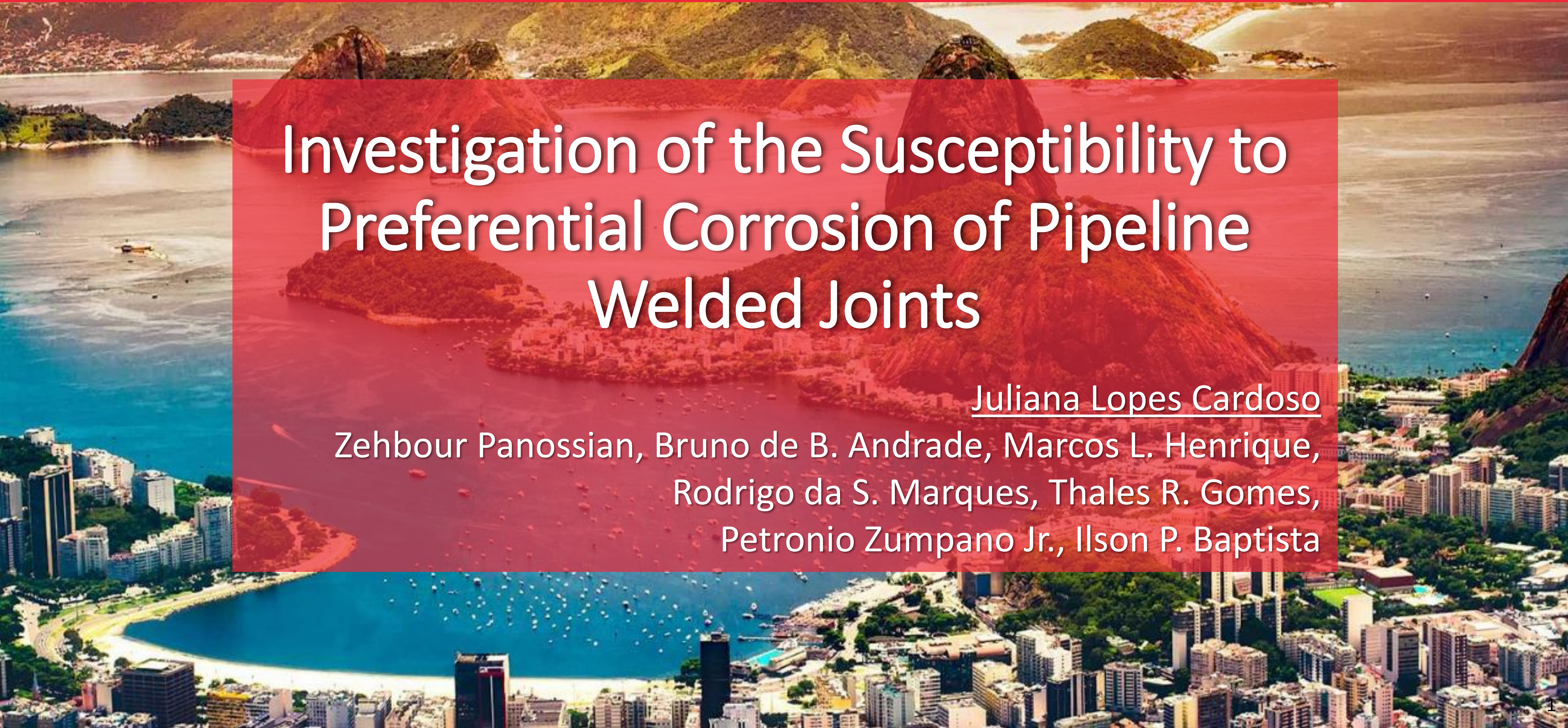
Nº 178794

Investigation of the susceptibility to preferencial corrosion of pipeline welded joints

Juliana Lopes Cardoso
Zehbour Panossian
Bruno de B. Andrade
Marcos L. Henrique
Rodrigo da S. Marques
Thales R. Gomes
Petronio Zumpano Junior
Ilson P. Baptista

Palestra apresentada no LATINCORR & INTERCORR 2023, Rio de Janeiro . 25 slides.

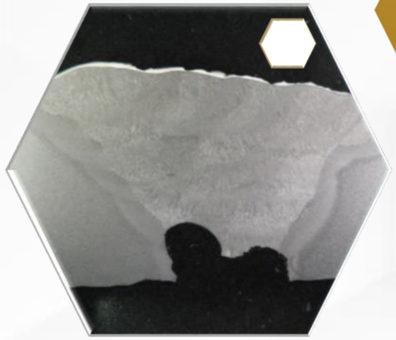


Investigation of the Susceptibility to Preferential Corrosion of Pipeline Welded Joints

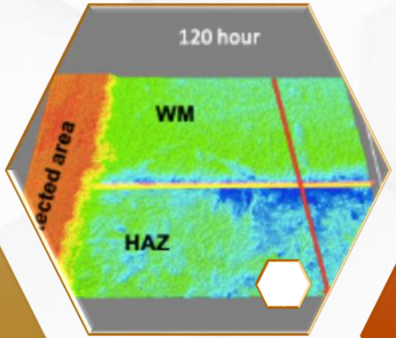
Juliana Lopes Cardoso
Zehbour Panossian, Bruno de B. Andrade, Marcos L. Henrique,
Rodrigo da S. Marques, Thales R. Gomes,
Petronio Zumpano Jr., Ilson P. Baptista

Summary

INTRODUCTION – Historical background

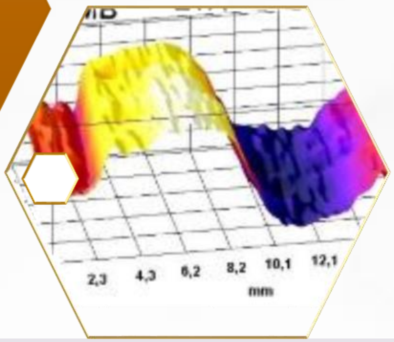


METHODOLOGY
- Materials
- Techniques and tests

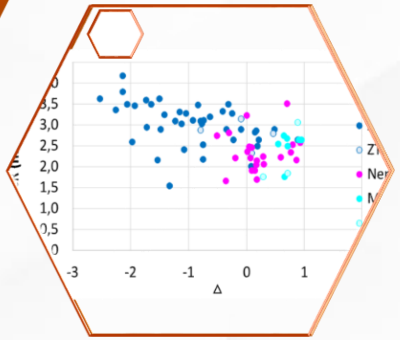


RESULTS

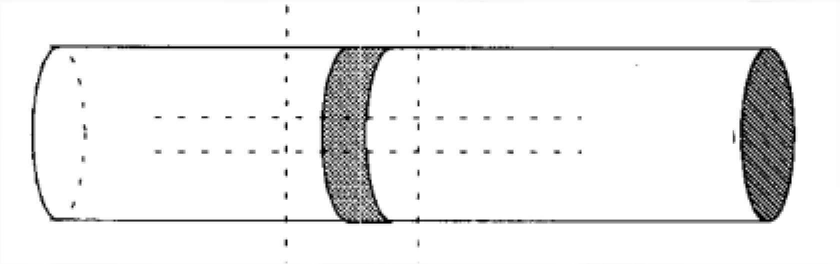
STATISTICAL ANALYSES
- Suggested equations

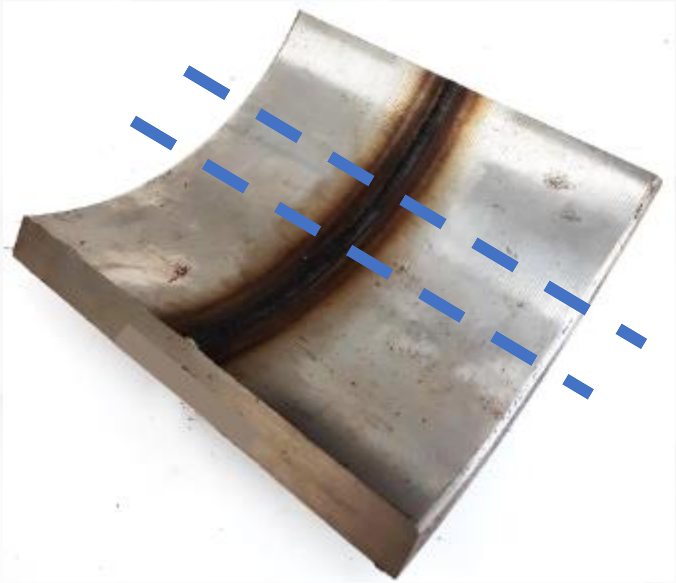


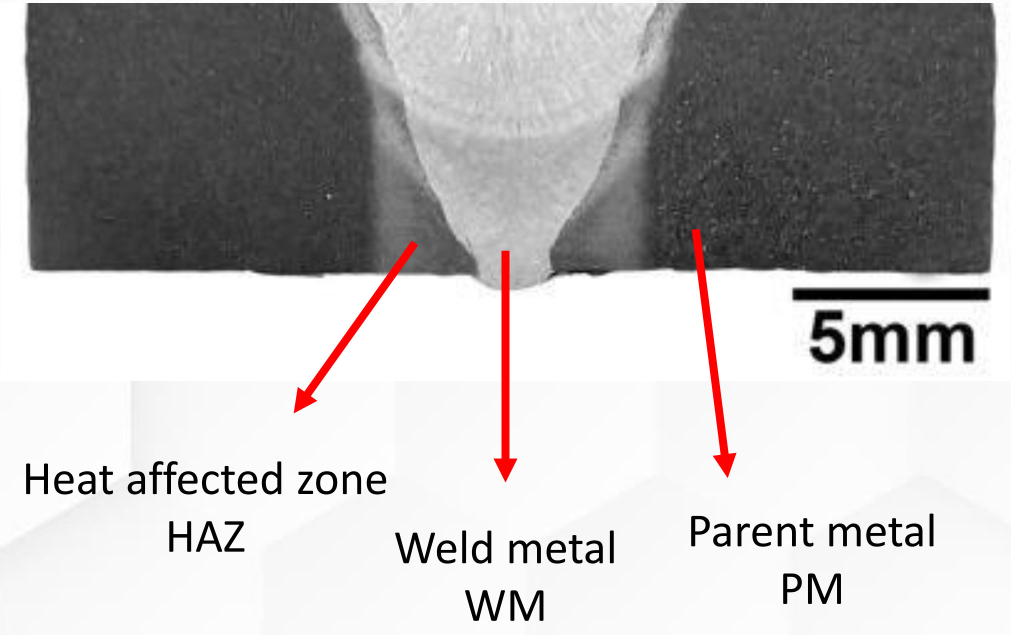
CONCLUSIONS



What is a welded joint and PWC?

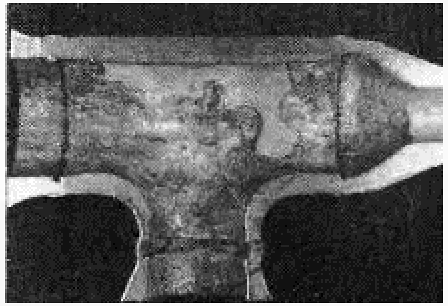






Historical background

PWC in sea water.
WM anodic to the PM (1)

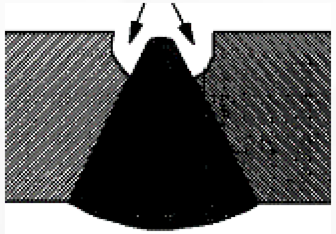


1910

Similar failures were verified in O&G, in sea water injection pipes.
Use of cathodic WM to prevent PWC (Ni and Cu alloyed) (2)

1997

Corrosion of HAZ of pipelines WM ~0,65 % Ni. Protective carbonate film may play an important role of PWC (3)



1999

Some studies pointed out that the rule of using a cathodic WM to avoid PWC does not apply for low conductivity media (4)

2010

Some criteria were proposed for the PWC mitigation. One of them is:

$$\Delta = 3.8(Cu_{PM} - Cu_{WM}) + 1.1(Ni_{PM} - Ni_{WM}) + 0.3$$

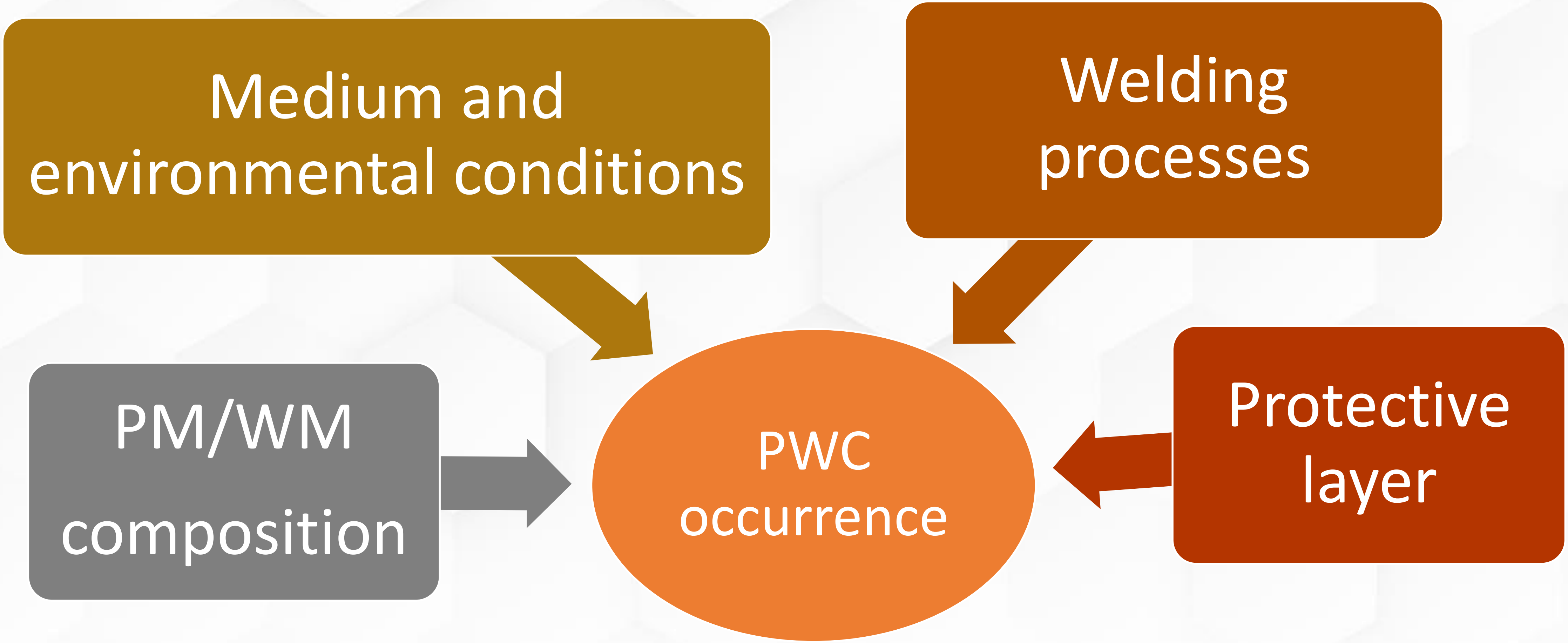
$\Delta < 0$: WM is cathode
$\Delta > 0$: PM is cathode
$\Delta > 0.3$ high probability for WM/HAZ corrosion (5)

2016

Criteria of Δ is suitable for sea water but not for low conductivity media (6)

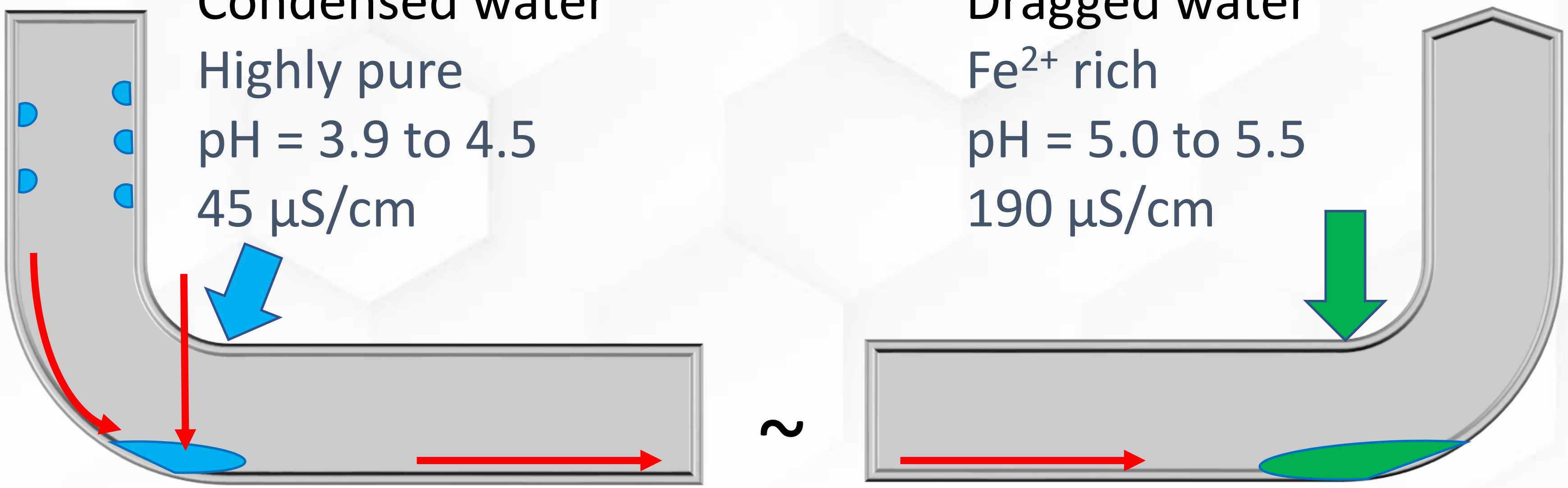
(1) Rothwell; Neil; Mervyn,1990 (2) Joosten; Payne,1988 (3) Olsen; Sundfaer; Enerhaug, 1997 (4) Dawson et al., 1999 (5) Mahajanam; Joosten , 2010 (6) MCintyre; ACHOUR (2016)

Literature Review Highlights



The problem: gas-exportation pipe corrosion

- PWC was observed in gas-exportation in contact with low conductivity CO_2 condensed water

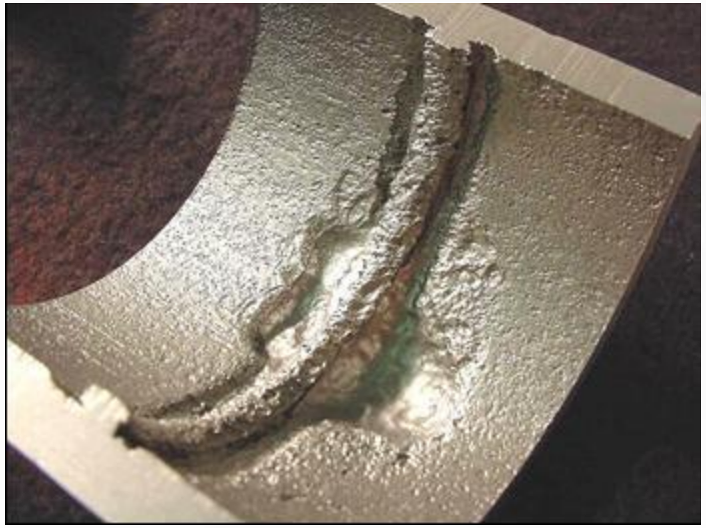


Goal

- To find out a criterium for selection of the parent metal and welding consumables for gas-transportation pipelines (condensed water and dragged water, which are low conductivity media)

- To establish laboratory facilities to test 79 different circumferential joints with different △ values

- To choose the best techniques to identify the PWC phenomenon in low conductivity media aiming at understanding the overall processes:
  - immersion test;
  - galvanic current measurement;
  - SVET technique test.



Source: Raman. T. J. Dissertation Universiti Teknologi PETRONAS. 2016.

Materials / Parent metals

- Seven different parent metals

Parent Metal	Welding process	Most abundant relevant alloy element, in descending order
8” DNVGL SMLS 450	GTAW / GMAW	Si
10” DNVGL SMLS 450	GTAW / GMAW	Cr + Si
12” DNVGL SMLS 450	GTAW / GMAW	Ni + Si + Cu
20” DNVGL SAW 450	GTAW / GMAW / SAW	Ni + Si + Cr + Cu
24” DNVGL SAW 450	GTAW / GMAW / SAW	Si + Cr
8” Forged	GTAW / GMAW	Ni + Cr + Si
20” Forged	GTAW / GMAW / SAW	Ni + Si + Cr + Cu

Materials / Welding processes and consumables

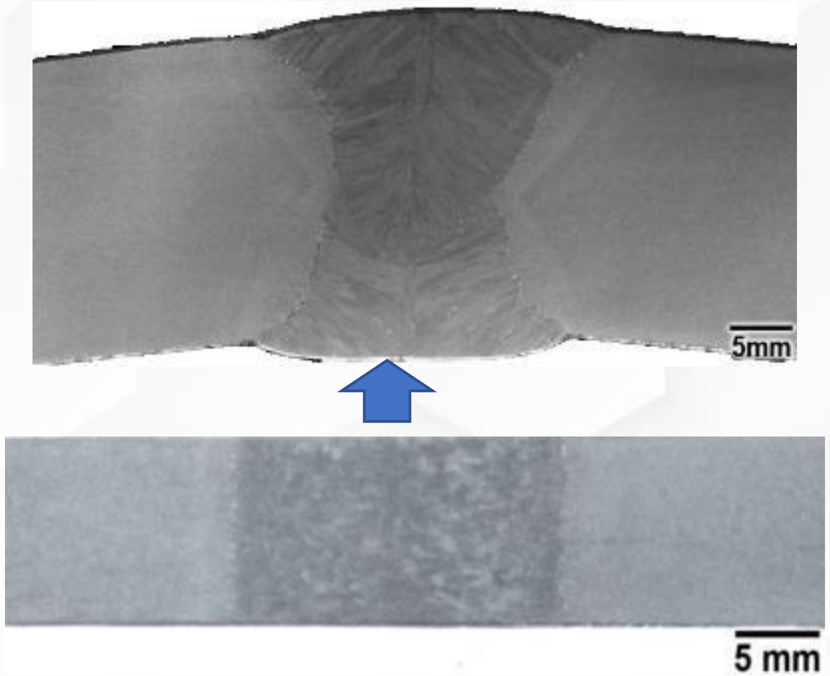
- Most abundant relevant element of the consumable for each welding process

GTAW	GMAW	SAW
↓ Si	↓ Si	Si
↑ Si	↑ Si	Ni + Si
Ni + Si	Ni + Si	Ni + Cr + Si + Cu
Si + Cr + Ni	Ni + Si + Cu	-x-
Ni + Si + Cu + Cr	Si + Cu + Cr + Ni	-x-

Total of 79 welded joints

Materials / Specimens

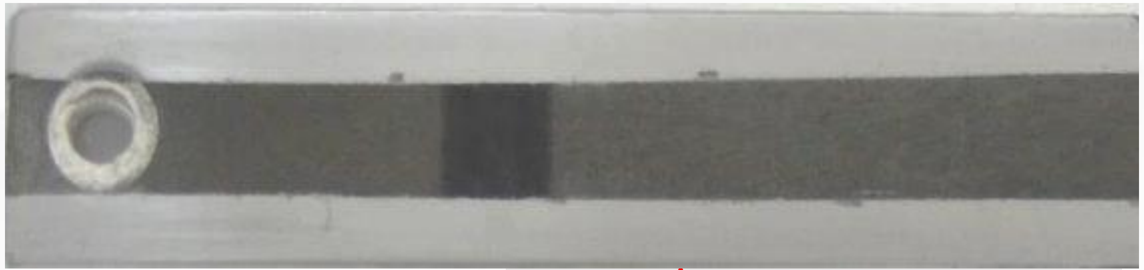
- Immersion-test samples:
- Girth welds =
  SAW (wider)/ GTAW / GMAW (narrower)



Sample ready to be tested

470 Scotch tape to protect the surface
This area was used as a reference for thickness-loss measurement

Sample after the test



Non-corroded area (reference)

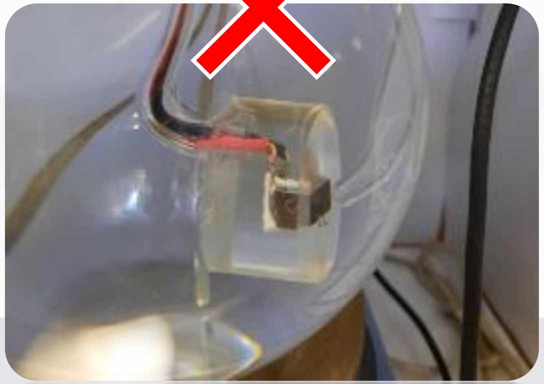
Materials / Specimens

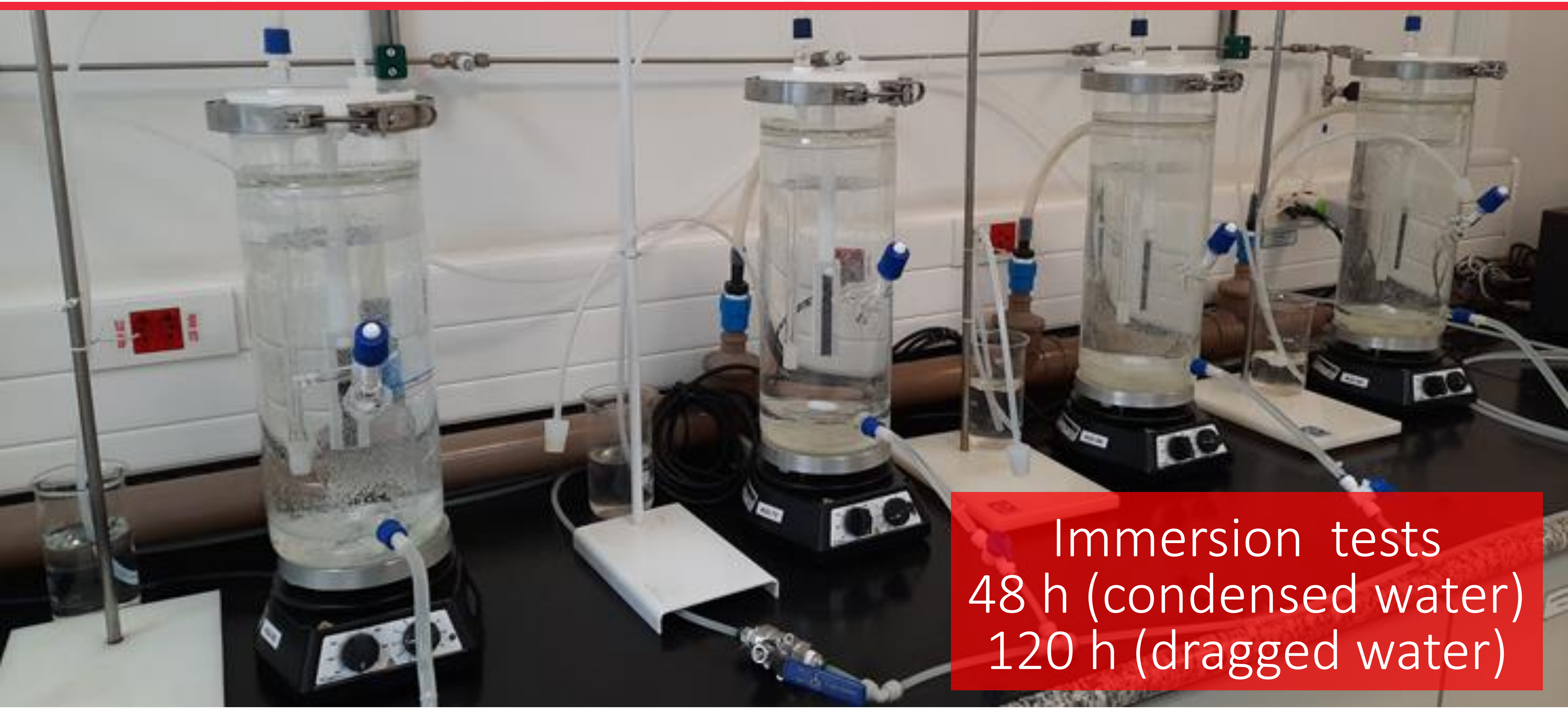
GCM TEST

SVET

Preliminary tests

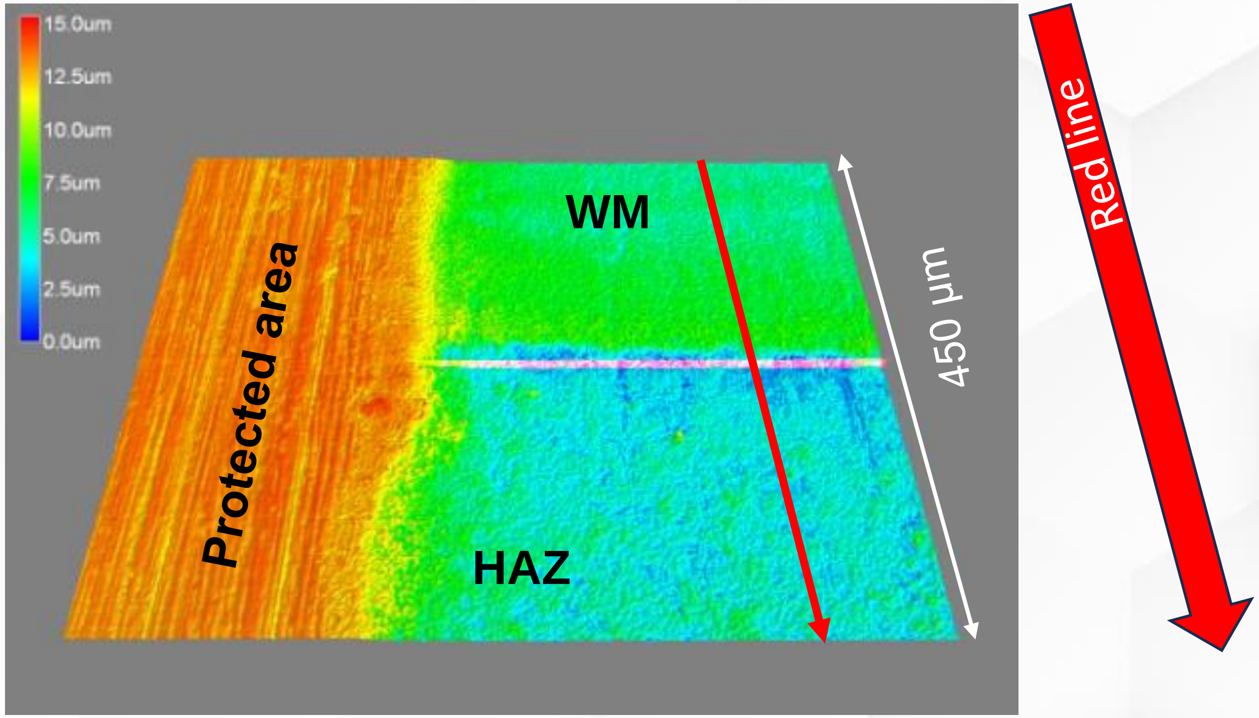
- Several preliminary tests were conducted for the selection of methodologies for low conductivity media.
- Galvanic current measurement: anodic and cathodic regions of the galvanic couple MS/MB+ZTA alternate over time.
  No clear indication of PWC occurrence.
- **Immersion test** and **SVET technique** using the **entire joint** were selected.

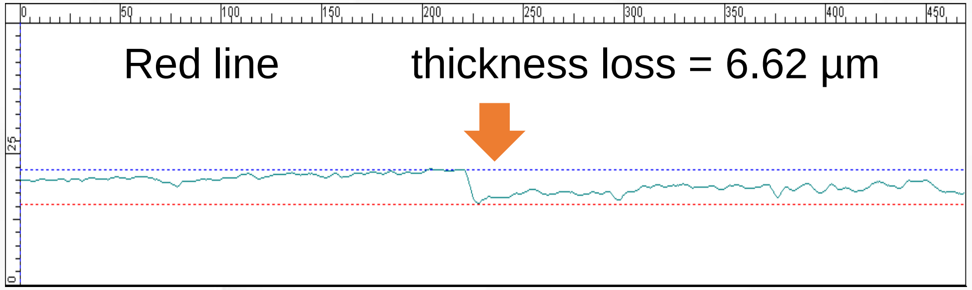




Immersion tests
48 h (condensed water)
120 h (dragged water)

Identification of PWC occurrence by confocal microscope



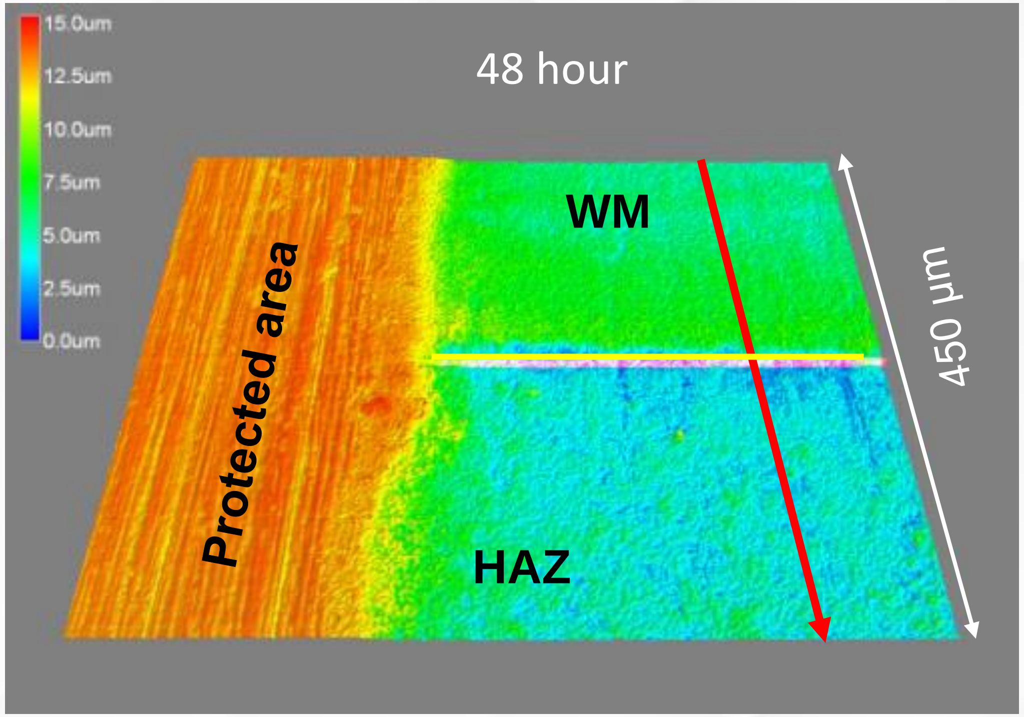


The maximum groove heights (MGH)

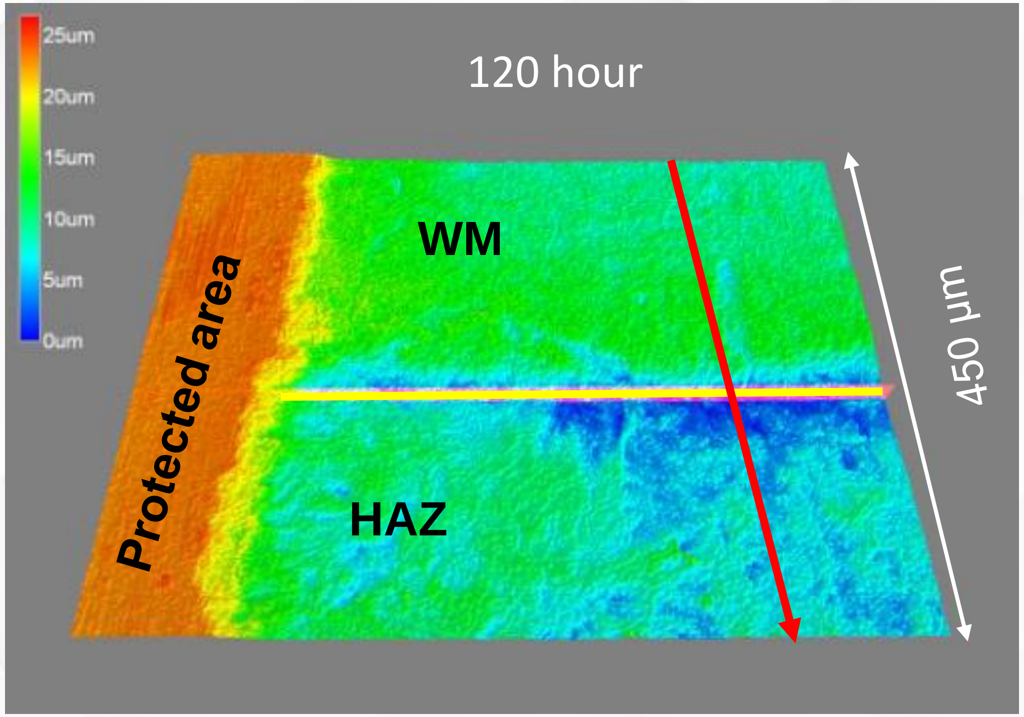
Light HAZ preferential attack close to HAZ/WM fusion line: the galvanic action is restricted to the distance less than 100 µm from fused line (FL) because of the low conductivity of the condensed water (**45 µS/cm**)

Identification of PWC occurrence by confocal microscope

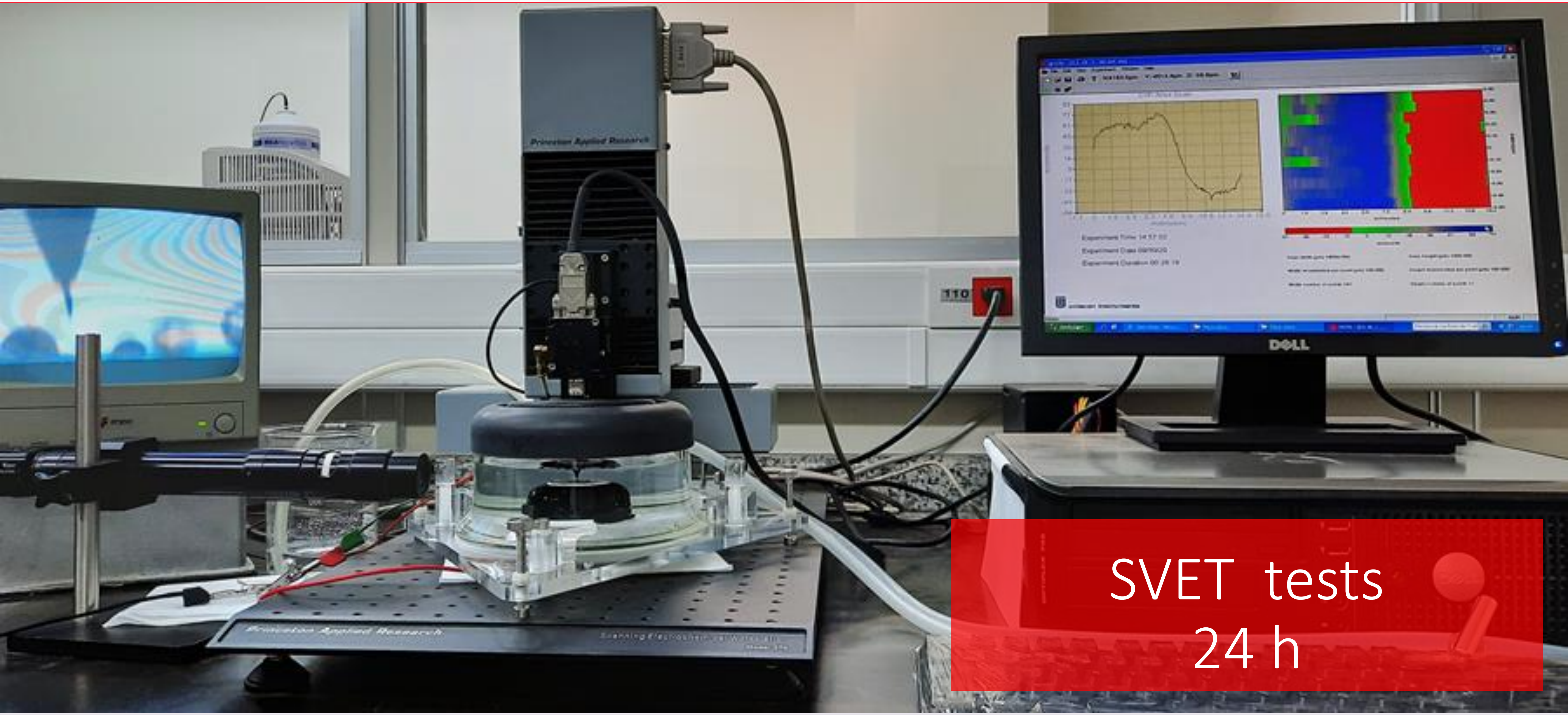
CO_2 condensed water - **WJ-1**



CO_2 dragged water - **WJ-1**



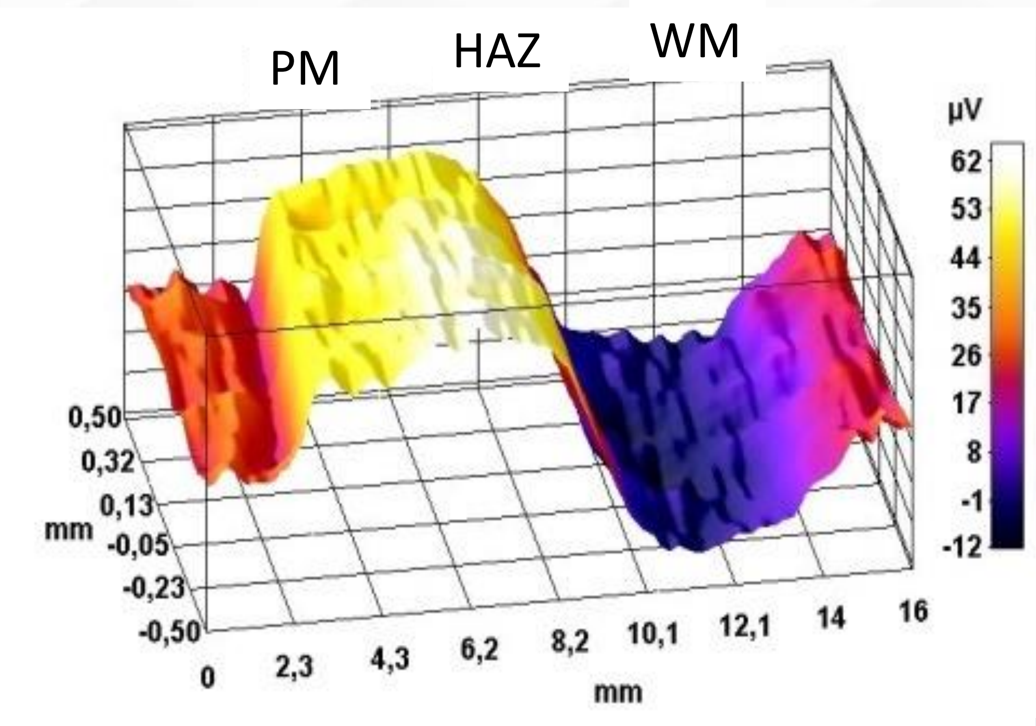
Light HAZ preferential attack close to HAZ/WM fusion line: the galvanic action is restricted to the distance less than 100 µm from fused line (FL) for the condensed water (**45 µS/cm**) and less than 200 µm for the dragged water (**190 µS/cm**) .

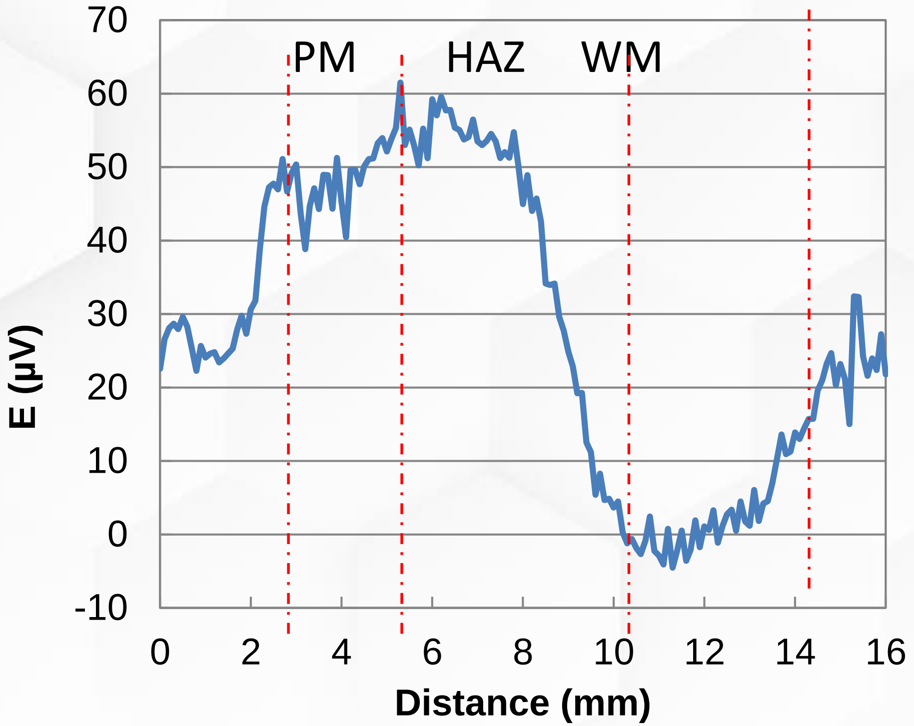


SVET tests
24 h

SVET Results

- Condensed water - WJ1
- WM is the cathode in the vicinity of the fused line (in agreement with the immersion tests)





Statistical analyses

- For the condensed water:
  - The ANOVA and regression analyses indicated that only the maximum corrosion rates (MCR) and maximum gouge heights (MGH) were affected by the composition of the WM or PM;
  - There is no dependence of the corrosion rates and the welding processes.

Statistical analyses

- For the condensed water:
  - The equation obtained for **the maximum groove heights** (MGH) was:

$$MGH = 1.71 - 0.58(Ni_{PM} - Ni_{WM}) - 1.49(Cu_{PM} - Cu_{WM}) - 1.36(Cr_{PM} - Cr_{WM})$$

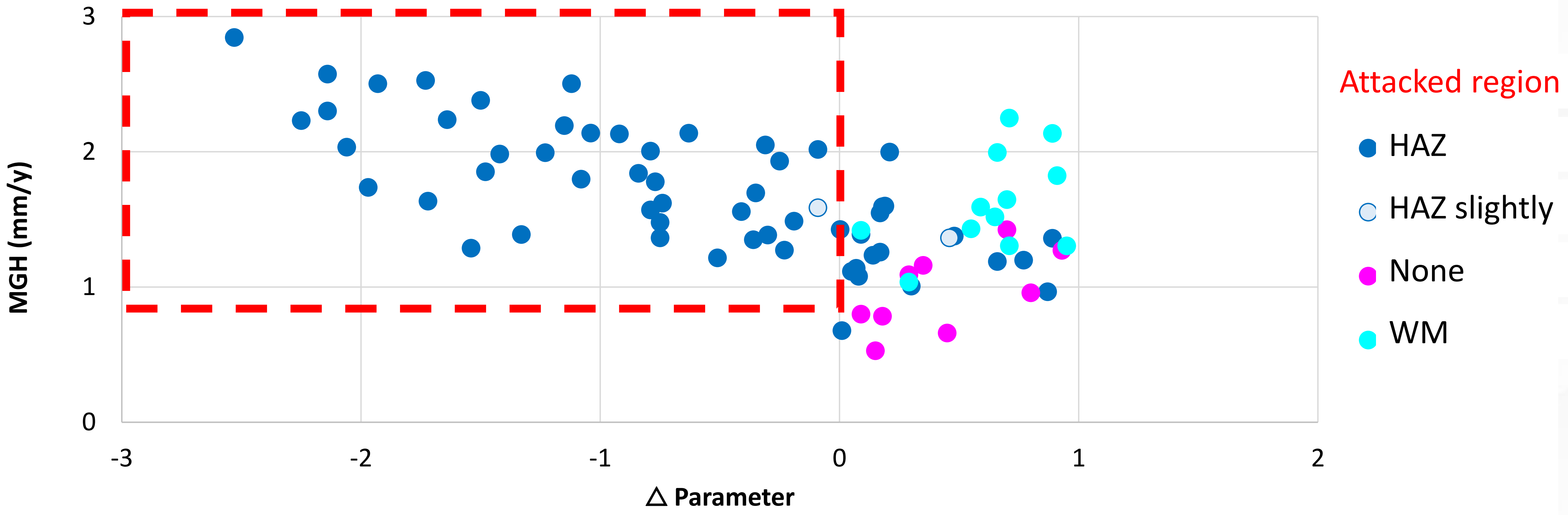
  - With correlation coefficient of 84 % and considering 22 welded joints excluded from the regression

PM and WM difference	Chemical composition valid range
ΔNi	-2.172 a 0.243
ΔCu	-0.517 a 0.127
ΔCr	-0.443 a 0.442

Overall results

For condensed water

Δ < 0 : WM is cathode
Δ > 0: PM is cathode
Δ> 0.3 high probability for WM/HAZ corrosion

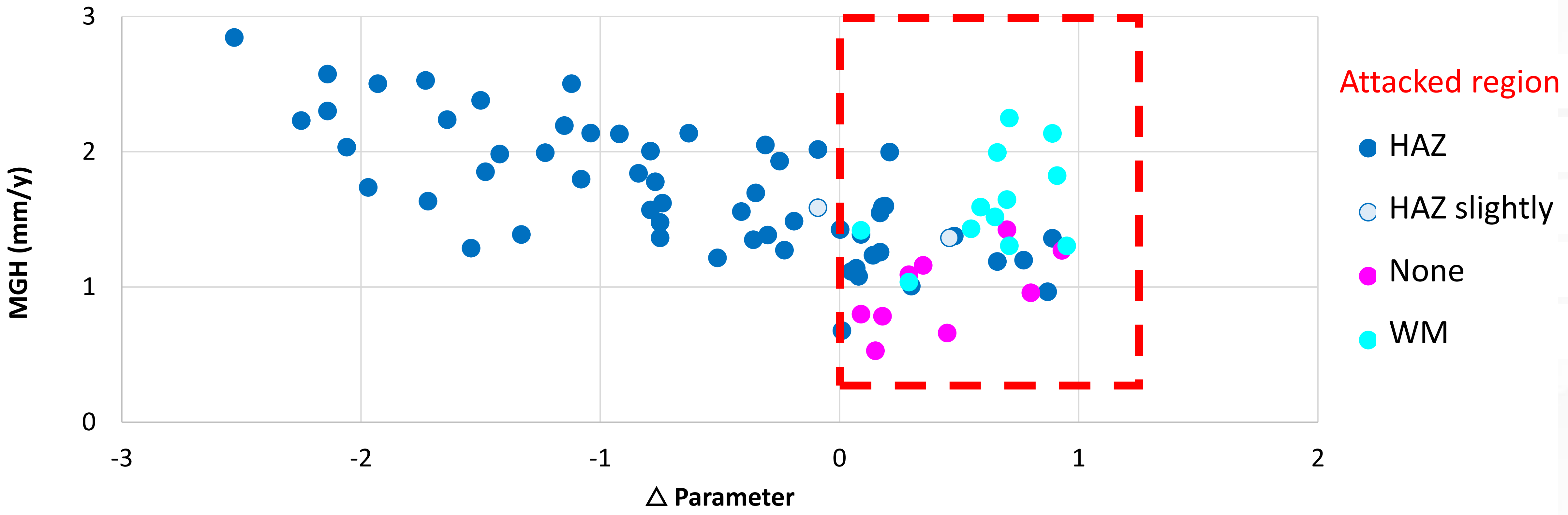


The negative delta-parameter criterium, within the values considered in this study (-2.53≤Δ<0), is capable of reliably predicting the cathodic nature of the WM of a welded joint

Overall results

For condensed water

Δ < 0 : WM is cathode
Δ > 0: PM is cathode
Δ> 0.3 high probability for WM/HAZ corrosion

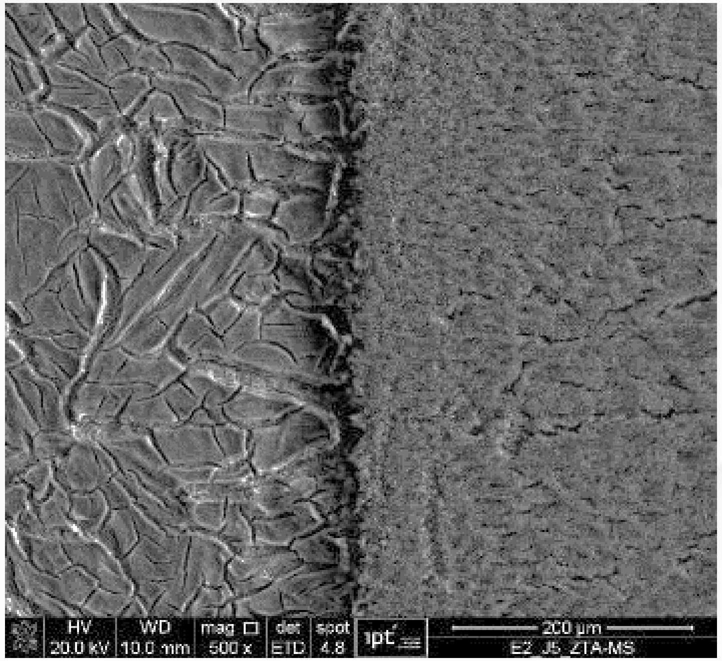


The positive values considered within the test matrix of this study (0<Δ≤0.95) are not able to predict precisely whether preferential corrosion will occur in the WM/HAZ or not, and the division into two blocks, before and after the value of 0.3, is not valid

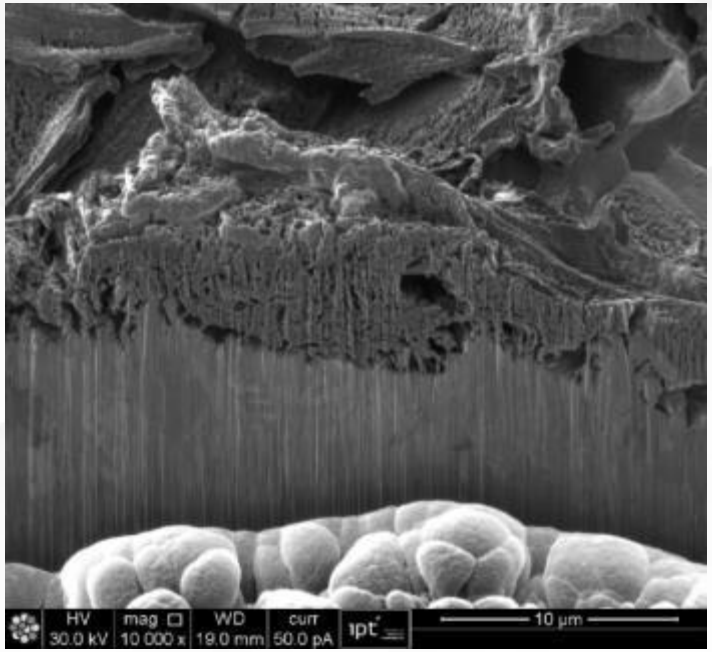
Overall results

- The dragged water is a favorable medium for the formation of a protective layer of iron carbonate, but the test duration did not allow the layer to consolidate.

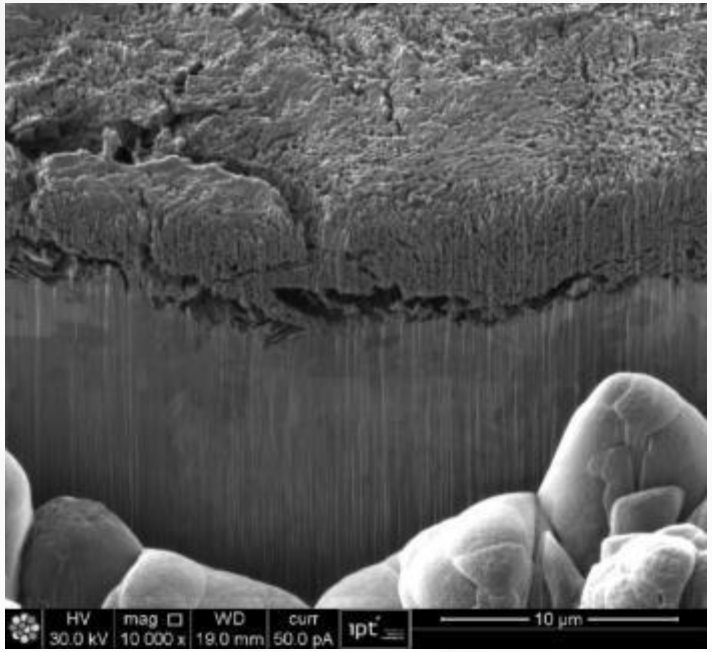
HAZ WM



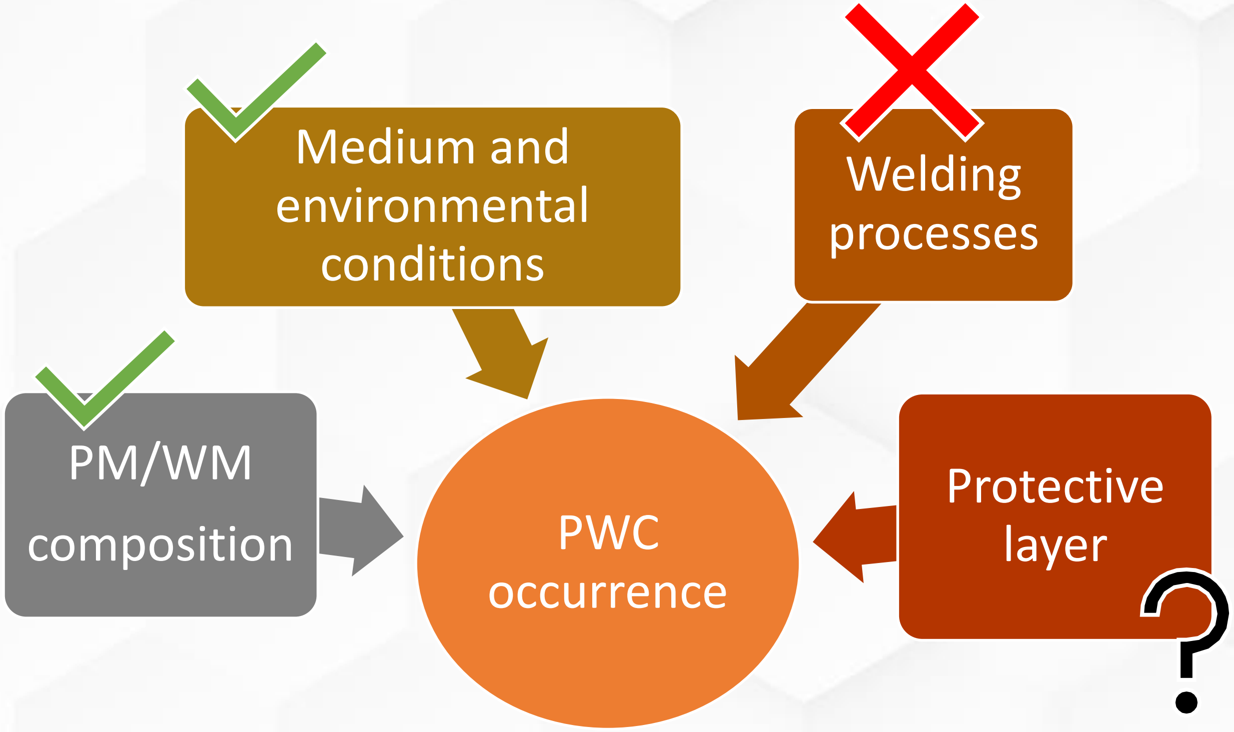
HAZ



WM



Conclusions



- For low conductivity media with CO_2 (condensed water):
  - the △ parameter accurately indicates only the cathodic behavior of the weld metal.

Conclusion

- The immersion tests showed the preferential corrosion was restricted in the fusion line, reaching 100 µm to the condensed water and 200 µm to the dragged water
- For the condensed water, the △ parameter was valid only for $-2.53 \leq \Delta < 0$, which indicates the cathodic behavior of the WM
  - For positive values, $0 < \Delta \leq 0.95$, it was not observed the cathodic behavior of the parent metal (or HAZ) or the occurrence of PWV in the WM/HAZ region, above or below 0.3
- For the dragged water, 120 h of immersion was not enough to consolidate the iron carbonate layer
- Statistical analysis was useful for identifying the parameters influencing corrosion

ipt INSTITUTO DE PESQUISAS TECNOLÓGICAS

SÃO PAULO GOVERNO DO ESTADO SÃO PAULO SÃO TODOS

fipt fundação de apoio ao instituto de pesquisas tecnológicas

BR PETROBRAS

Thank you for your attention!

Dra. Juliana Lopes Cardoso
jcardoso@ipt.br
+55 11 3767-4805
Laboratory for Corrosion and Protection