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Evaluation of corrosion inhibitors to mitigate preferential weld corrosion in low-conductivity medium

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Evaluation of corrosion inhibitors to mitigate preferential weld corrosion in low-conductivity medium

Juliana Lopes Cardoso - FIPT/IPT

Avaliação de inibidores de corrosão para mitigar a corrosão preferencial em soldas em meio com baixa condutividade

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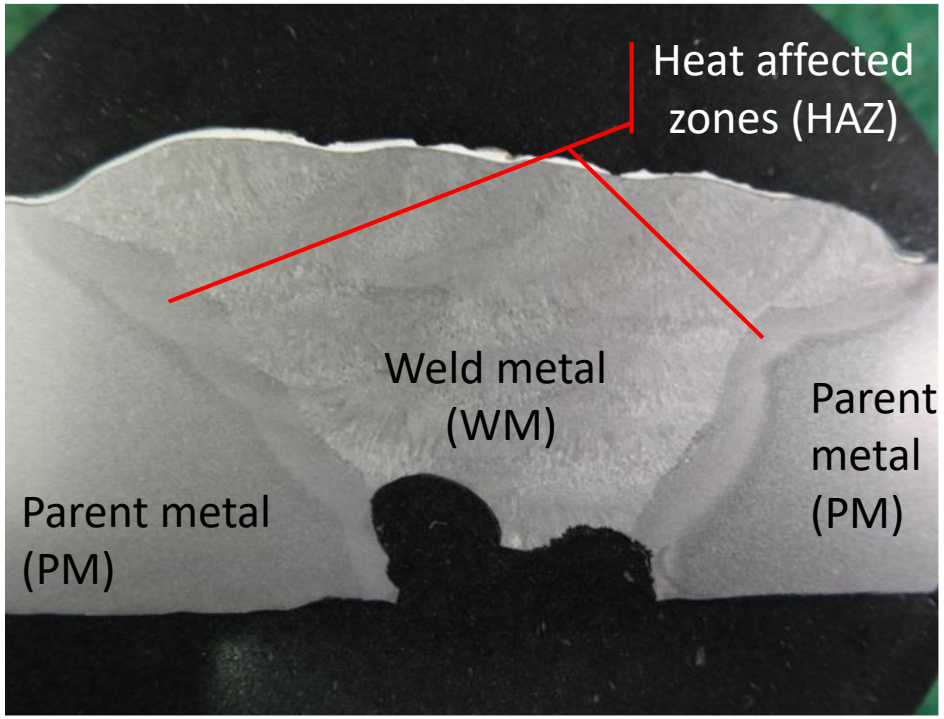
Agenda

- **Introduction and historical background**
- **Test methodology / Results**
  - Materials
  - Galvanic-current measurements
  - Immersion test
- **Conclusions**

MAHAJANAM. S. P. V.; JOOSTEN. M. W. **Selection of filler materials to minimize preferential weld corrosion in pipeline steels**. Proceedings of SPE International Conference on Oilfield. Aberdeen: SPE International. 2010. p. SPE 130513

Introduction



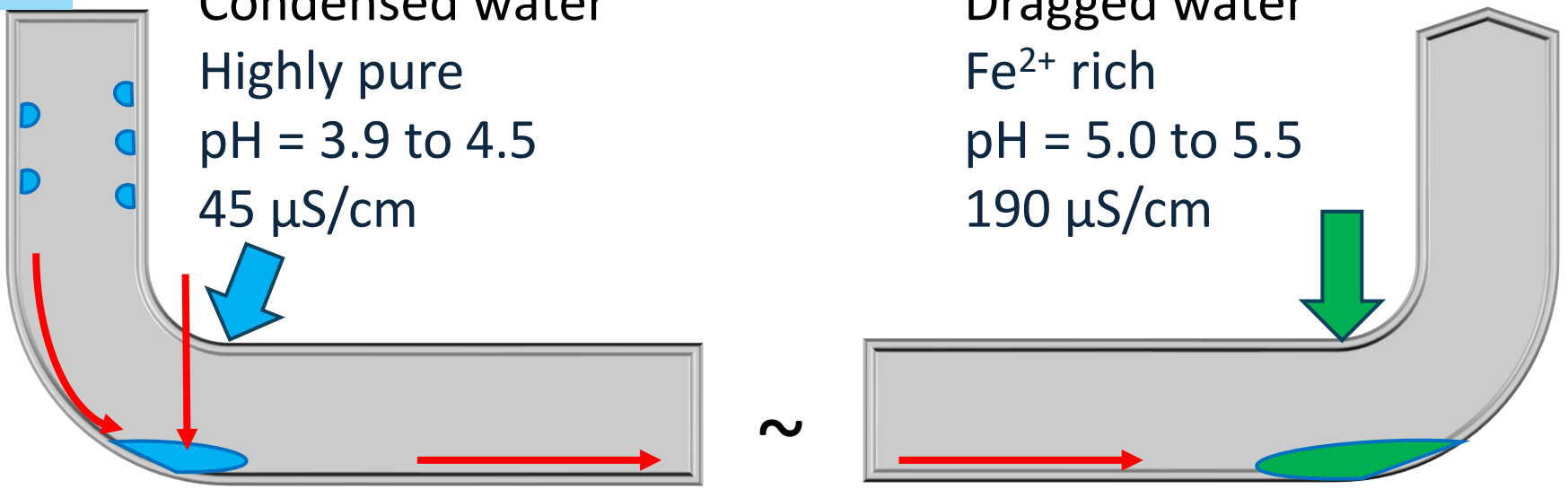
- PWC (preferential weld corrosion)
- Losses of onshore and offshore pipelines
- Development of a method to select welding consumables for a specific PM in low conductive media containing CO_2

The problem: gas-exportation pipe corrosion

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

From production
After treatment

To refinery



Gas-transportation pipeline

Historical background

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

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

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)

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

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

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)

Recommendations

To mitigated the PWC, it was recommended:

- Identify the medium and the conditions where the welded joints are exposed
- Select the appropriate weld metal for the parent metal and exposure medium
- Provide adequate welding process control and surface finish

These recommendations are indicated for the planning and construction of new pipelines.

Mitigation of PWC for existing pipelines

- Corrosion inhibitors can be successfully used to mitigate the occurrence of preferential corrosion of welded joints
- Corrosion inhibitors should be selected through tests that simulate field conditions and
- They should be capable of inhibiting corrosion of all constituents of a welded joint (MS, HAZ and MB)

Objective

- Investigation of the applicability of corrosion inhibitors to mitigate the corrosive process:

- Can the commercial available inhibitors can protect from PWC?
- Which is the dosage necessary to protect from PWC?

- This work is based on the evaluation of longitudinal and circumferential welded joints for submarine systems, presented in previous Intercorr editions (2021 and 2023)

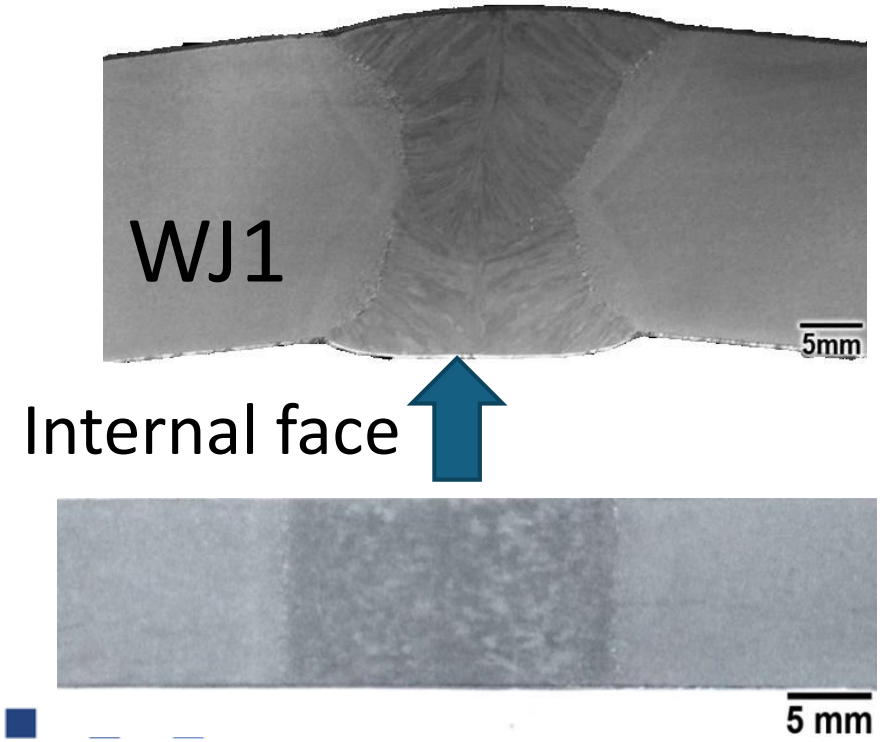
Selected inhibitors

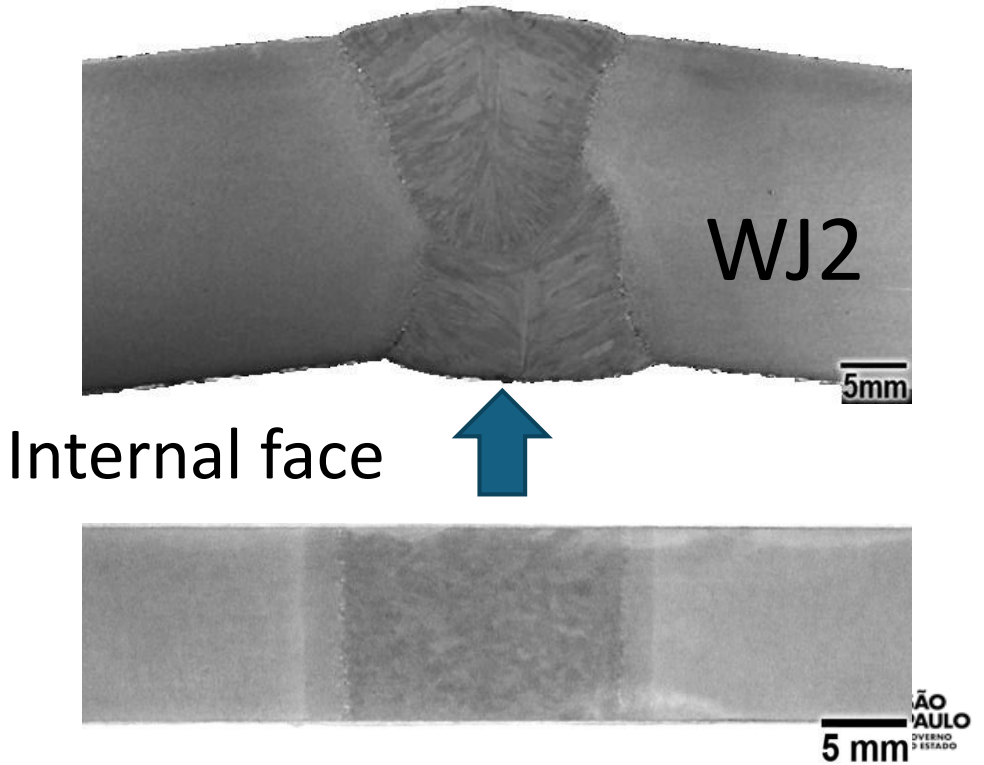
- At the time of this study, there wasn't any commercial inhibitor formulated specifically to mitigate PWC

- Three inhibitors for aqueous media containing chloride ions were selected and evaluated

Specimens

- Two seamed pipe welded joint:
  - Longitudinal welded joints
  - SAW welding process
- Samples were taken from internal-face weld metal





Specimens chemical composition

Chemical composition of the weld joints in wt. % balance Fe

Sample	Region	C	Ni	Cu	Si	Cr	Mn
WJ1	PM	0.039	0.0083	0.0082	0.33	0.165	1.46
	WM	0.04	0.012	0.036	0.40	0.124	1.44
WJ2	PM	0.033	0.24	0.15	0.28	0.036	1.13
	WM	0.04	0.167	0.131	0.35	0.038	1.22

Specimens – Δ

$$\Delta = 3.8\left(\%Cu_{parent} - \%Cu_{weld}\right) + 1.1\left(\%Ni_{parent} - \%Ni_{weld}\right) + 0.3$$

- $\Delta > 0$ *parent metal is cathode*
- $\Delta < 0$ *weld is cathode*
- $\Delta > 0.3\%$ *high possibility of PWC at WM/HAZ*

Chemical composition and Δ calculation

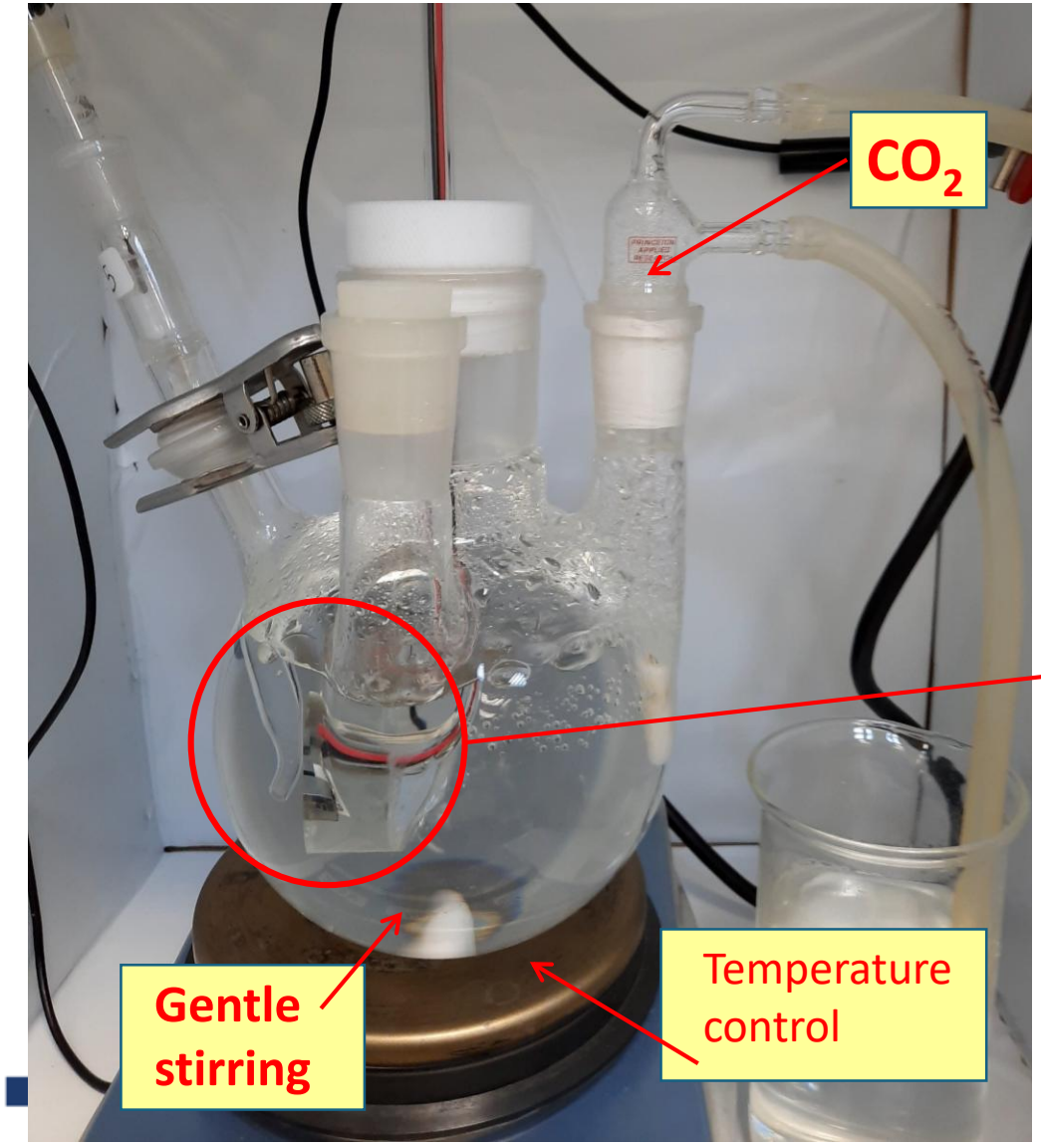
Sample	Cu parent	Cu weld	Ni parent	Ni weld	Δ
WJ1	0.0082	0.036	0.0083	0.012	0.19
WJ2	0.15	0.131	0.24	0.167	0.45

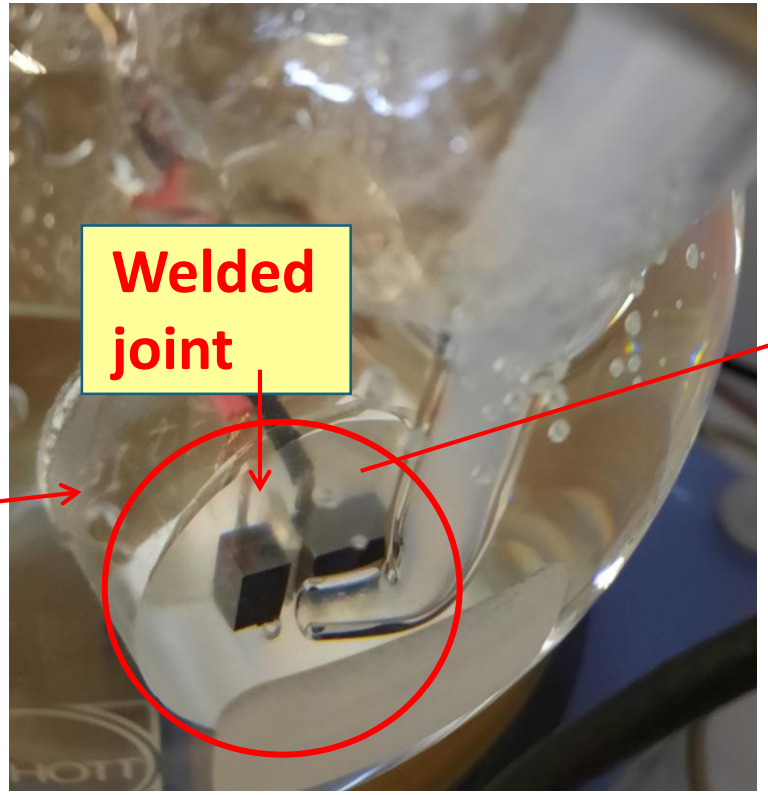
MAHAJANAM, S. P. V.; JOOSTEN, M. W. **Selection of filler materials to minimize preferential weld corrosion in pipeline steels**. Anais da SPE International Conference on Oilfield. Aberdeen: SPE International. 2010. p. SPE 130513

Methodology

- Test media under quasi-static conditions
  - Dragged water (higher conductivity)
- OCP + Galvanic current measurement
  - ASTM G5 electrochemical cell
- Immersion test – 120 h
  - ASTM G31 area ratio

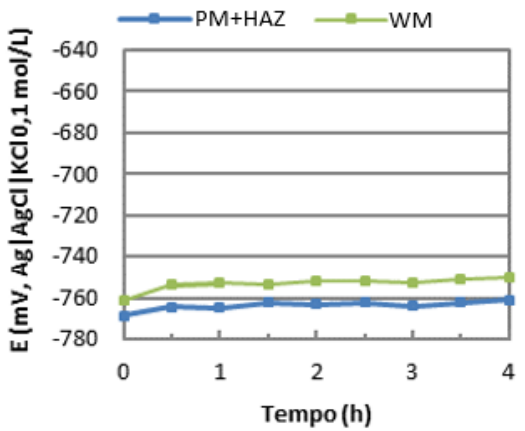
Galvanic current measurement

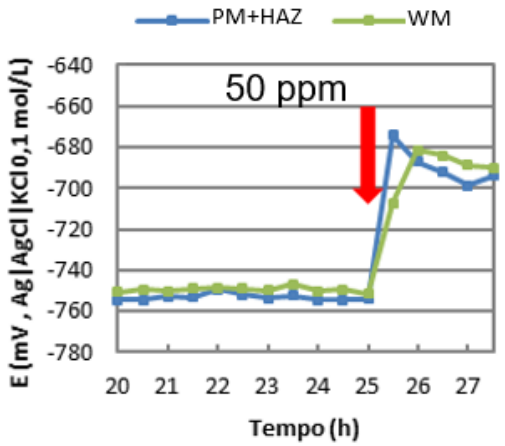


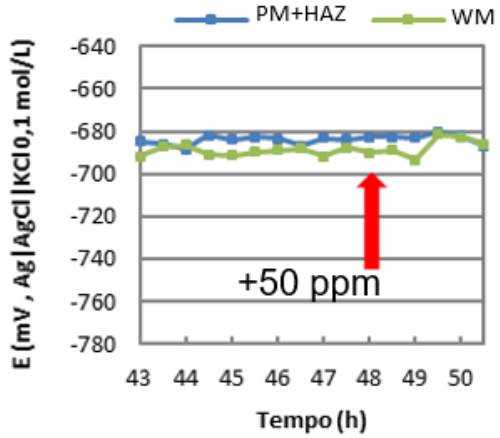


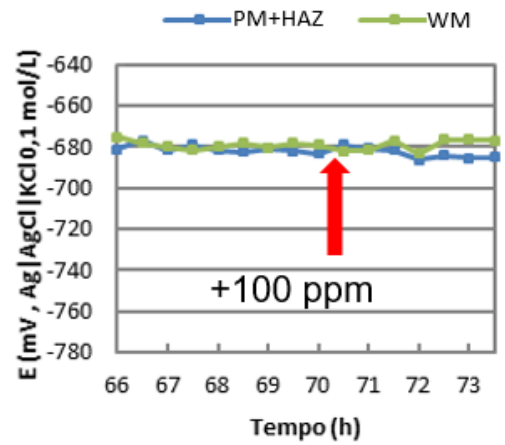
WJ1 - Inhibitor 1

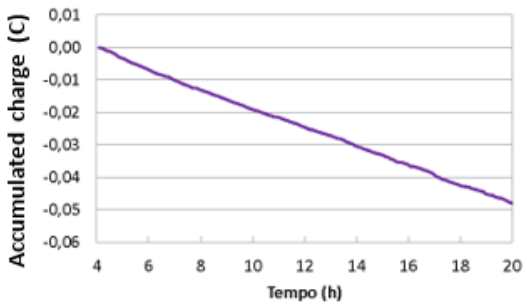
PCA (E) measurement results and the calculated accumulated charge of the WJ1, under the conditions 0 ppm, 50 ppm, 100 ppm and 200 ppm of **Inhibitor 1**. The addition moment is indicated by the red arrow

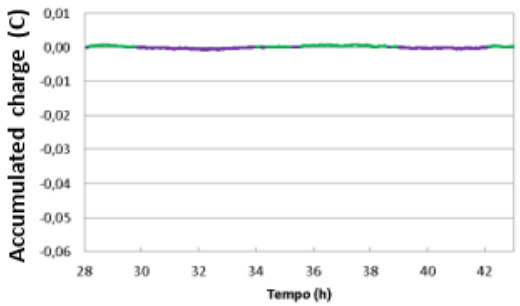


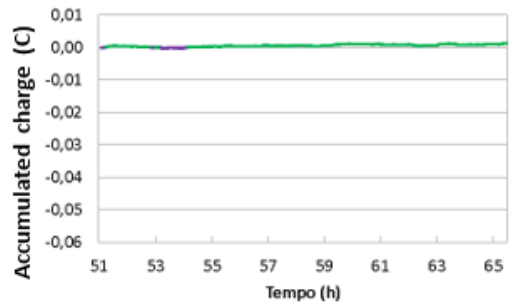


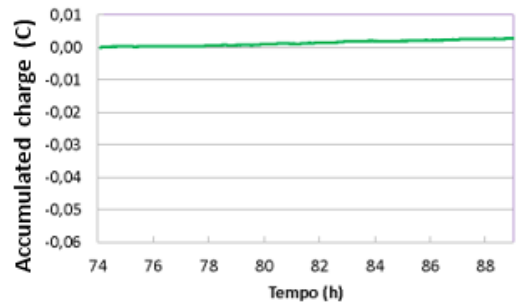








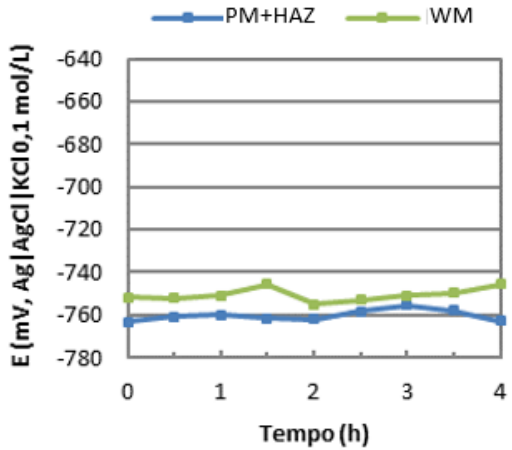


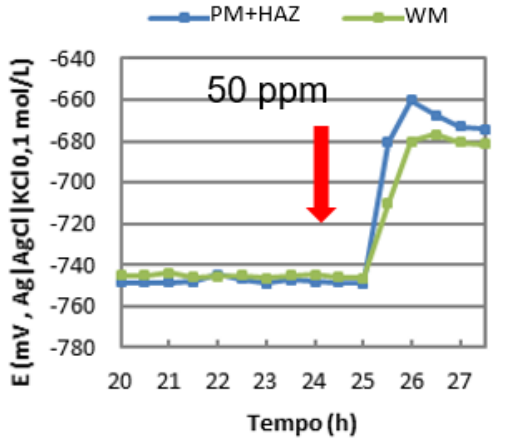


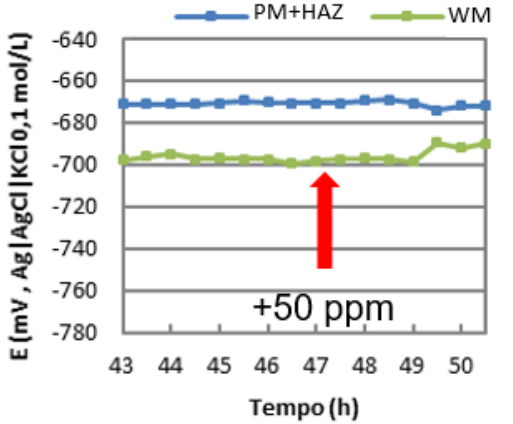
Accumulated charge = -0,0464 C	Accumulated charge = 0,0002 C	Accumulated charge = 0,0010 C	Accumulated charge = -0,0030 C

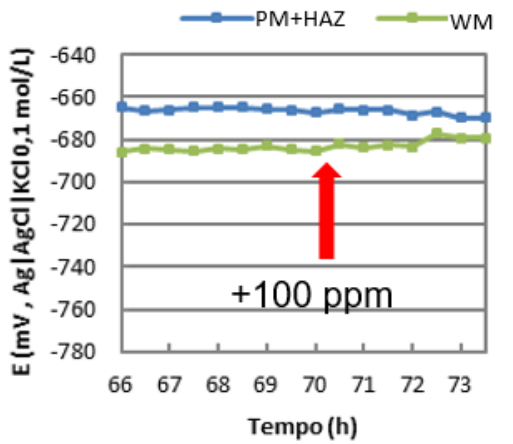
WJ1 - Inhibitor 2

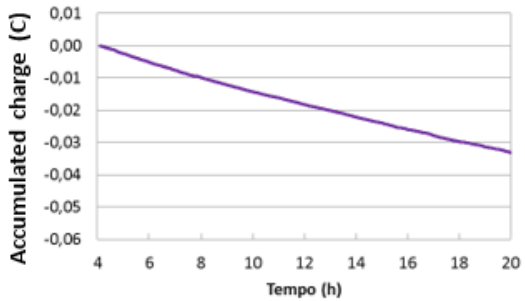
PCA (E) measurements and the calculated accumulated load of the WJ1, under the conditions 0 ppm, 50 ppm, 100 ppm and 200 ppm of **Inhibitor 2**. The addition moment is indicated by the red arrow

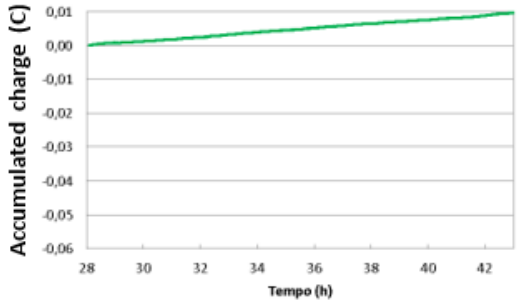


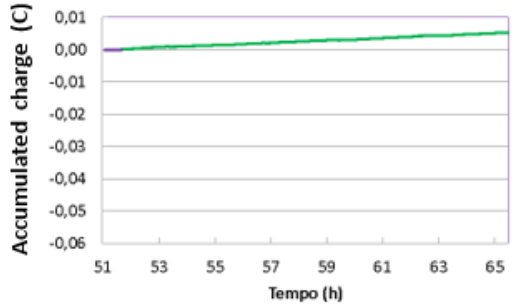


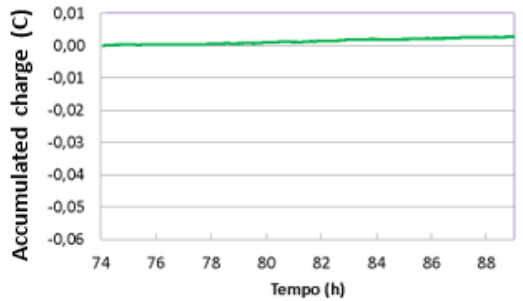








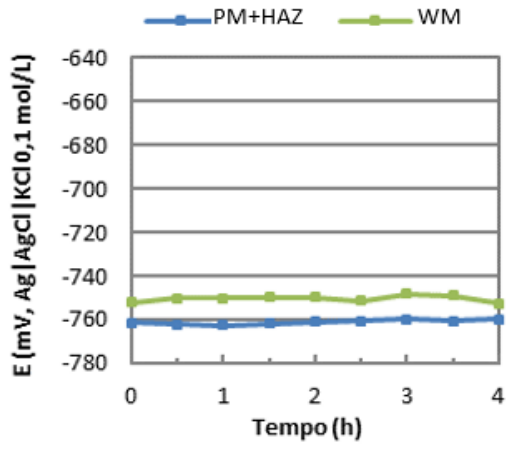
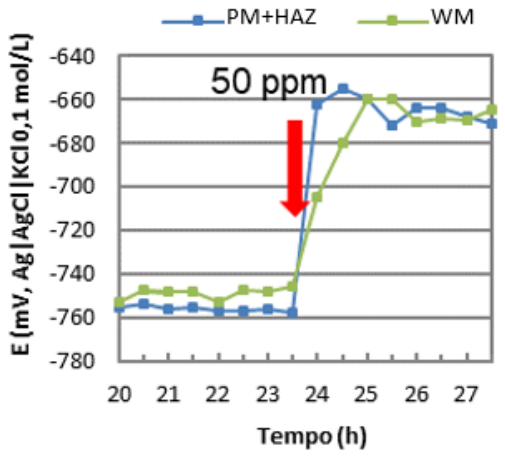
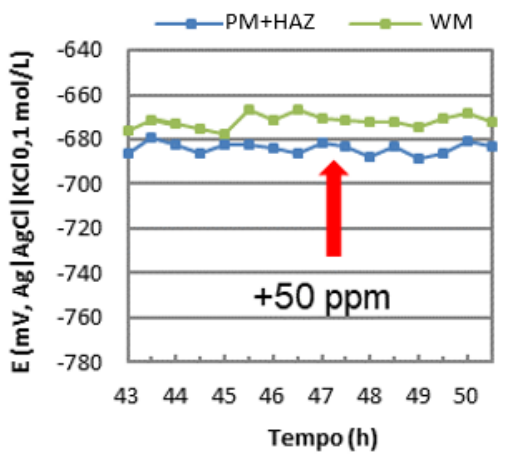
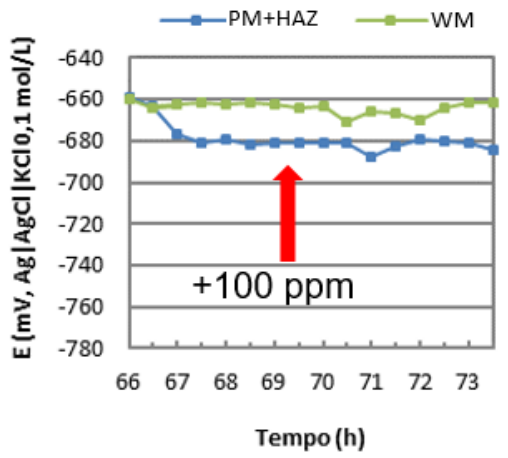
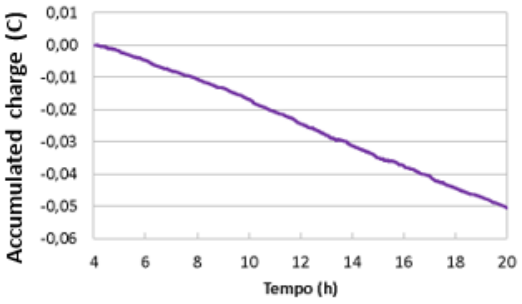
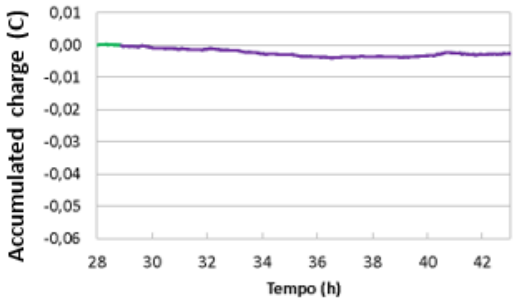
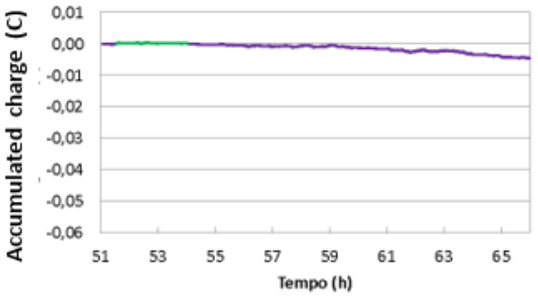
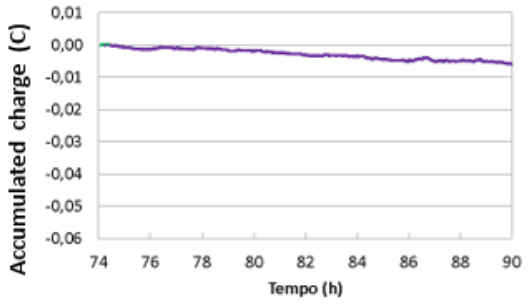




Accumulated charge = -0,0321 C	Accumulated charge = 0,0098 C	Accumulated charge = 0,0055 C	Accumulated charge = 0,0027 C

WJ1 - Inhibitor 3

PCA (E) measurements and the calculated accumulated load of the WJ1, under the conditions 0 ppm, 50 ppm, 100 ppm and 200 ppm of **Inhibitor 3**. The addition moment is indicated by the red arrow

			
			
Accumulated charge = -0,0476 C	Accumulated charge = -0,0027 C	Accumulated charge = -0,0048 C	Accumulated charge = -0,0051 C

WJ1 OCP+ZRA summary

- WM was the cathode without inhibitor
- Inhibitor 1 and 2 – WM became the anode
- Inhibitor 3 – WM maintained as the cathode

- All inhibitors - formation of a protective film on the surface of the welded joint

- Efficiency of galvanic current reduction:

Inhibitor 1 > Inhibitor 3 > Inhibitor 2

WJ2 – OCP+ZRA results

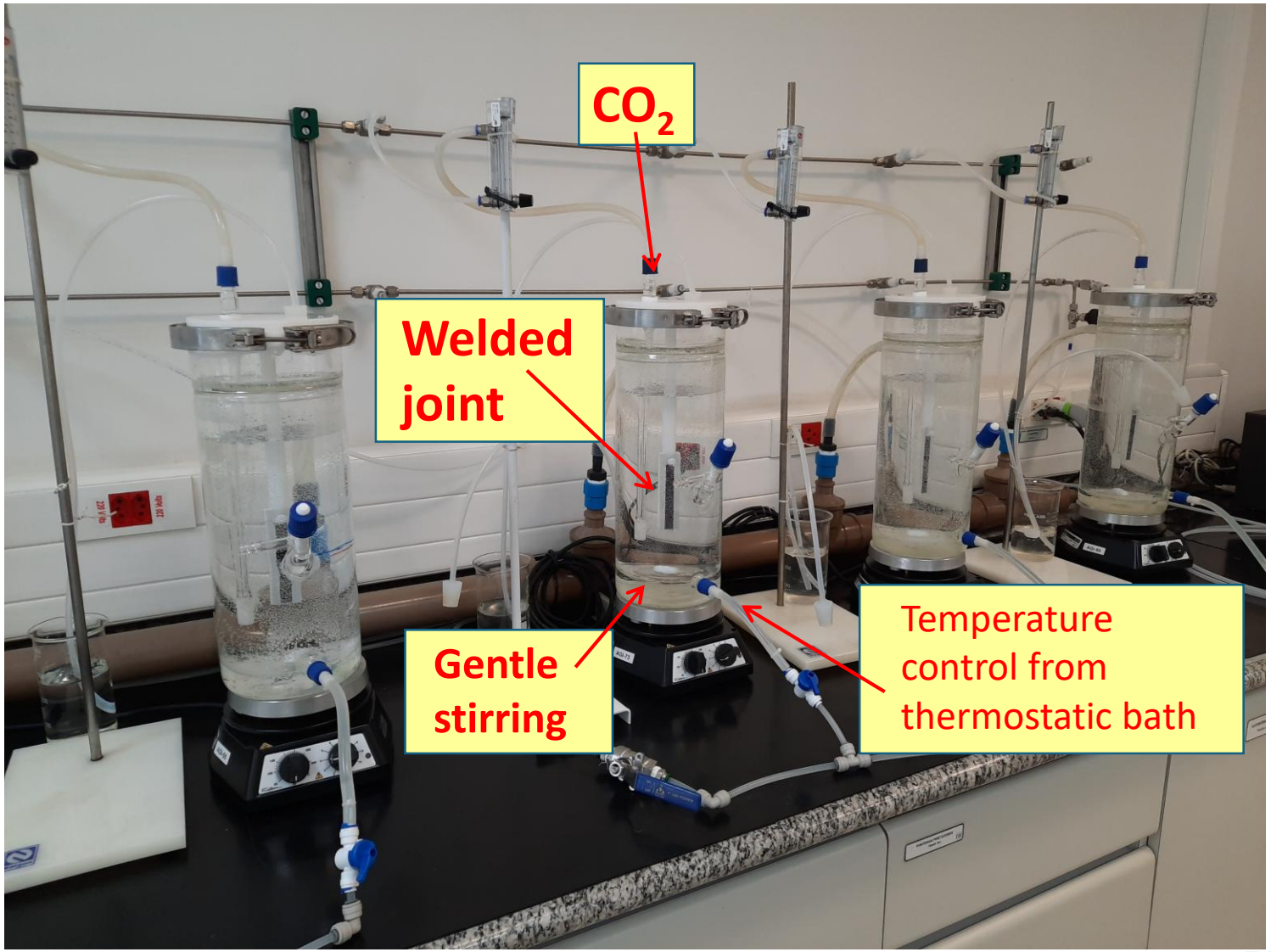
- WM was the anode without inhibitor
- Inhibitor 1– WM became the cathode and change to anode after 200 ppm
- Inhibitor 2 - WM mainteaned as the anode
- Inhibitor 3 – WM became the cathode and change to anode after 100 ppm

- All inhibitors - formation of a protective film on the surface of the welded joint

- Efficiency of galvanic current reduction:

Inhibitor 1 > Inhibitor 3 > Inhibitor 2

Immersion test

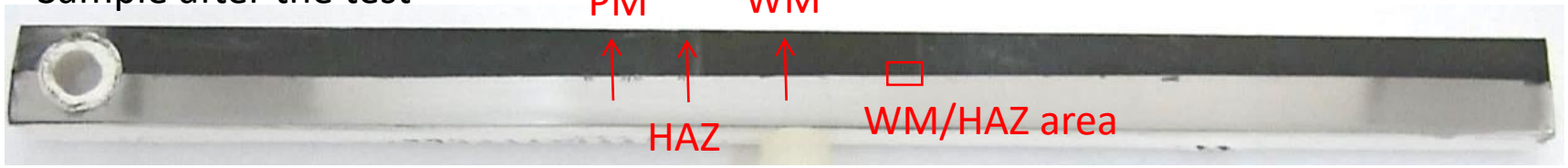


Specimens

Sample ready to test

Scotch tape to protect the surface and later reference for thickness-loss measurement

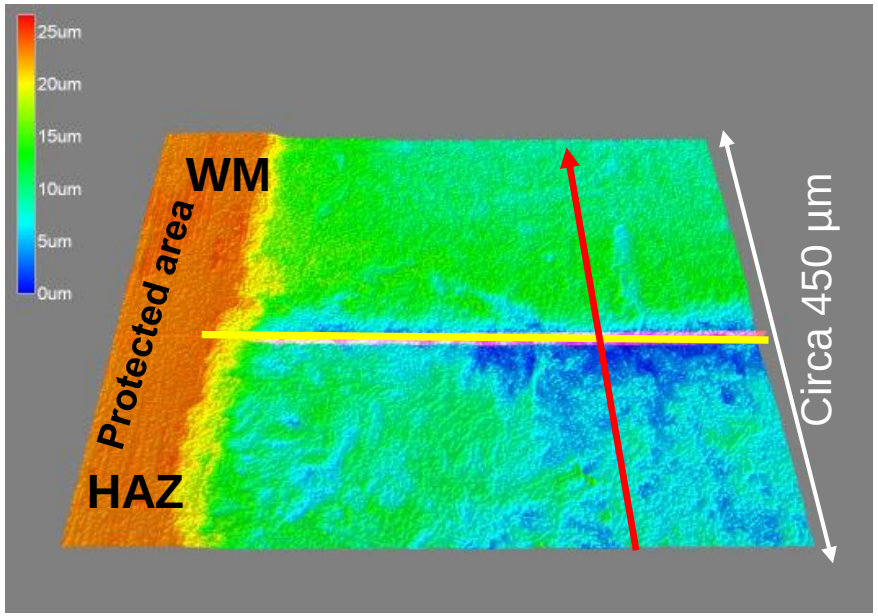
Sample after the test

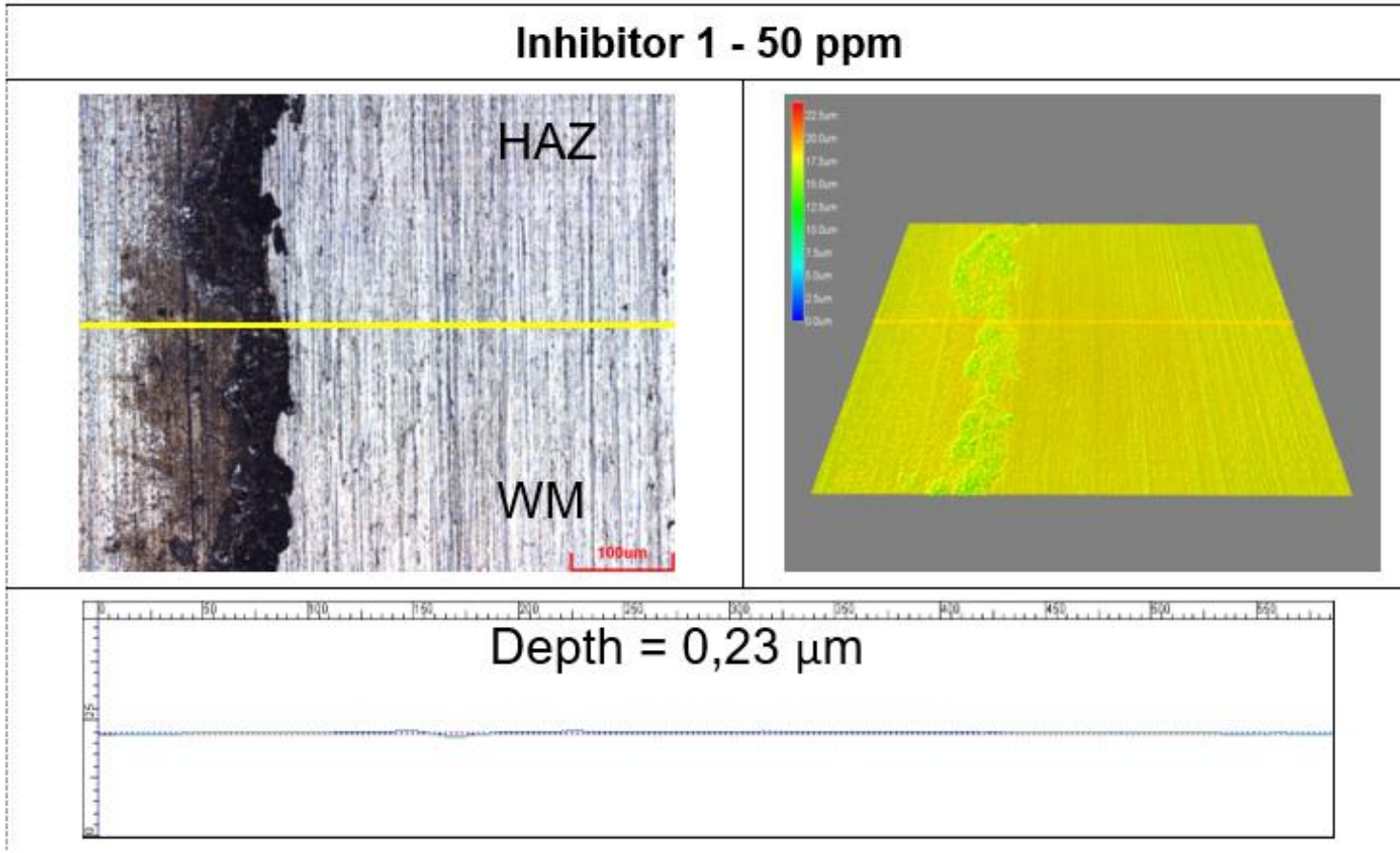


Lines and areas representing the thickness measurements by a confocal microscope

WJ1 – Inhibitor 1

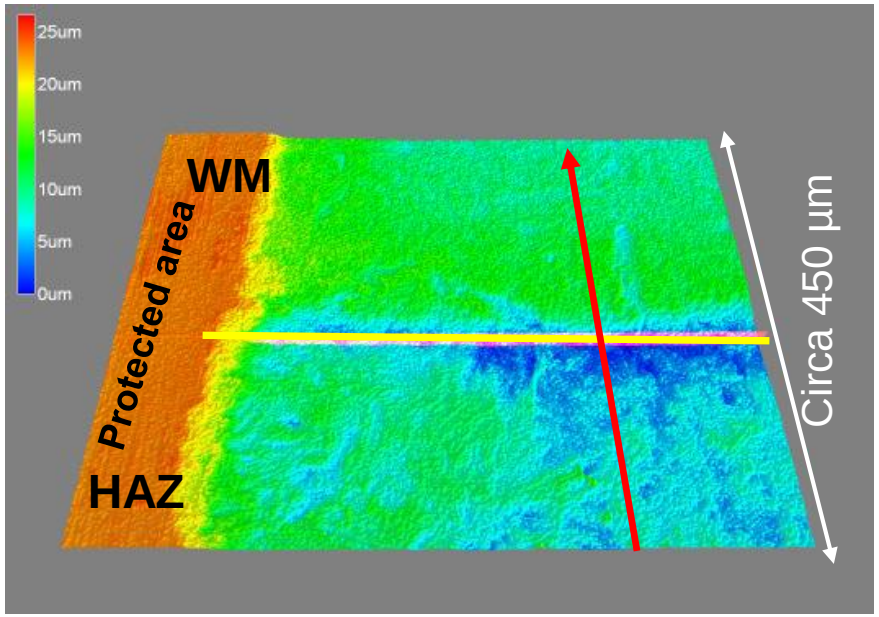
Without inhibitor

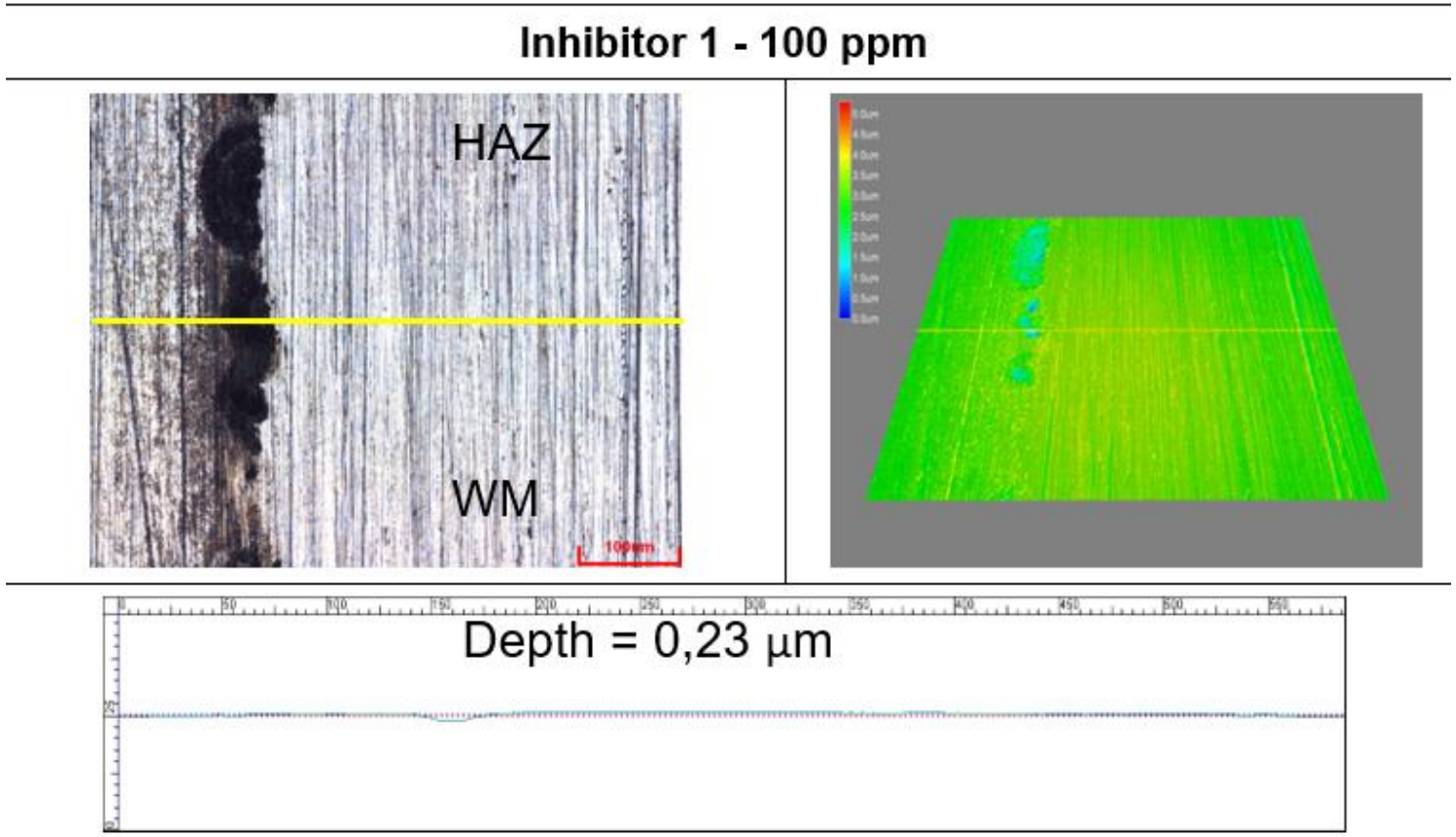




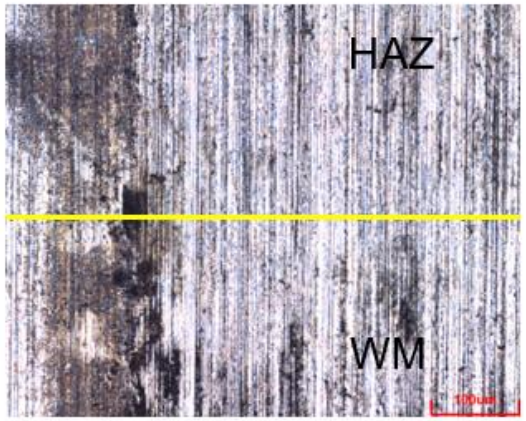
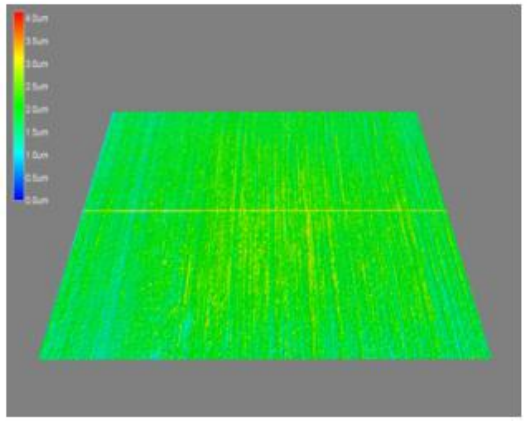
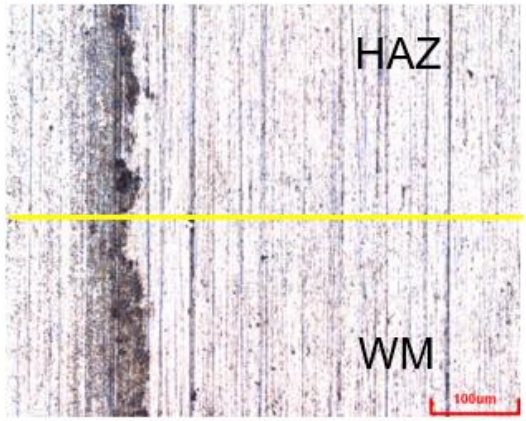
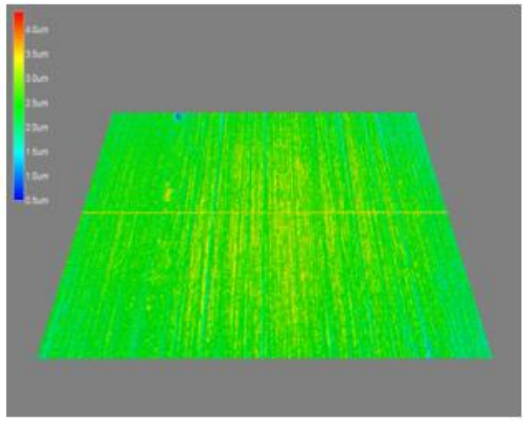
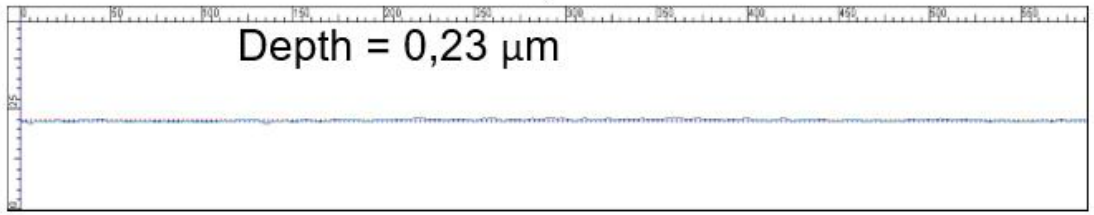
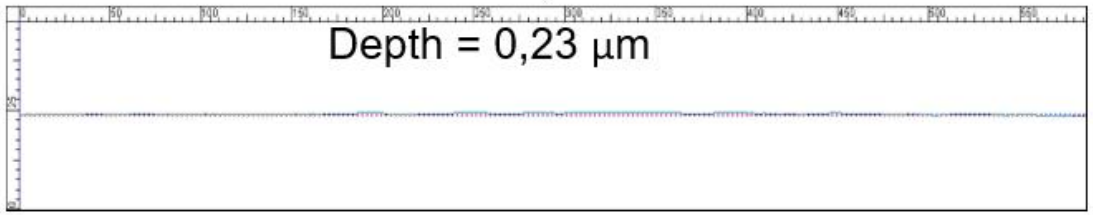
WJ1 – Inhibitor 1

Without inhibitor

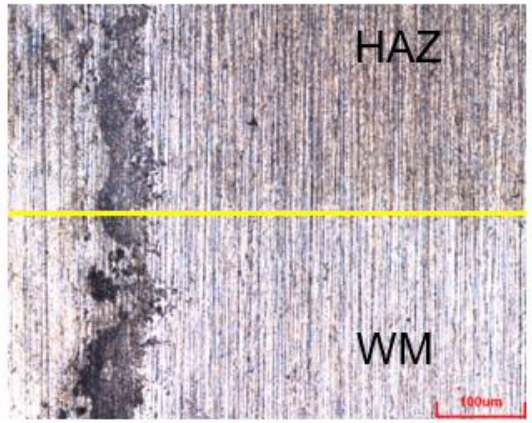
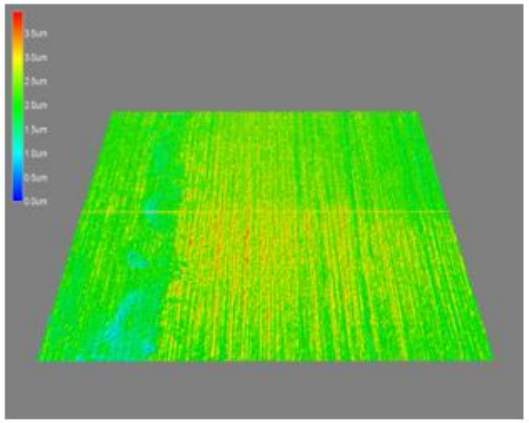
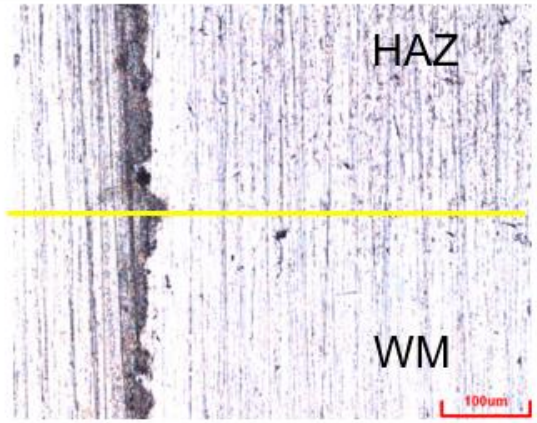
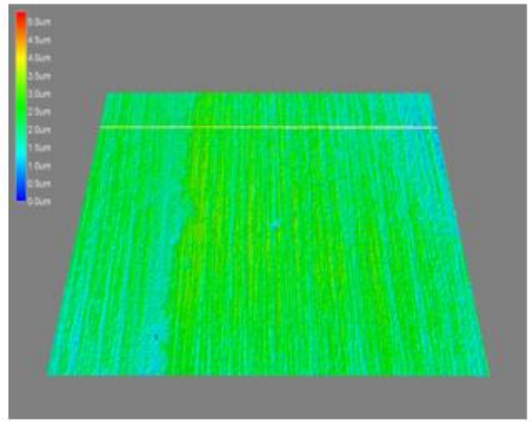
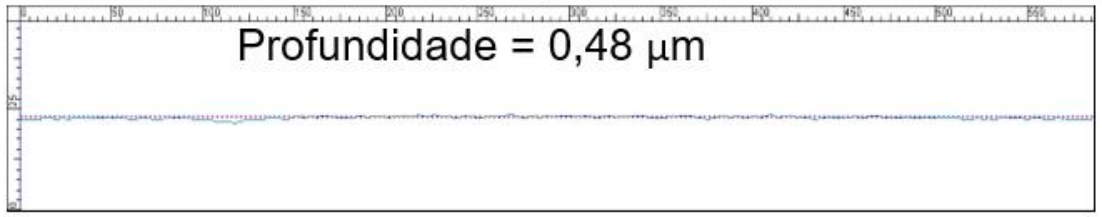
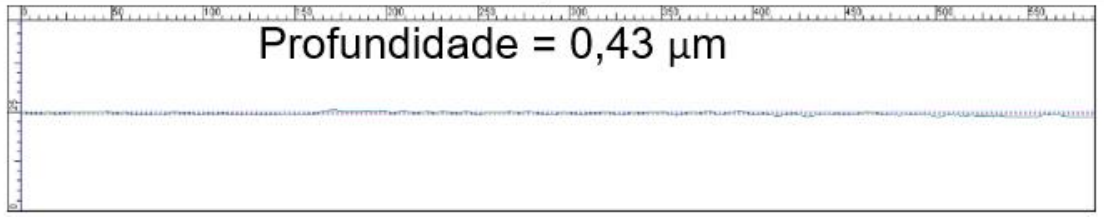




WJ1 – Inhibitor 2

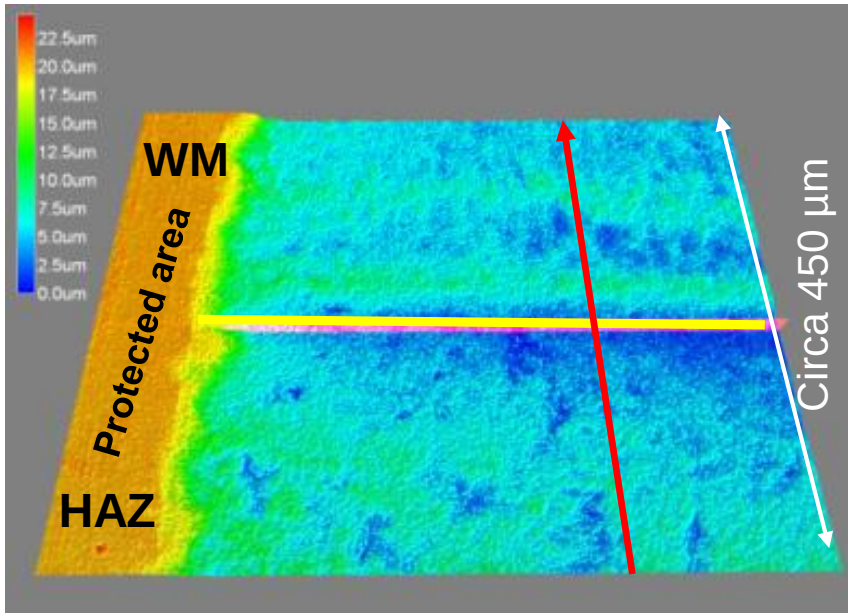
Inhibitor 2 - 50 ppm		Inhibitor 2 - 100 ppm	
			
			

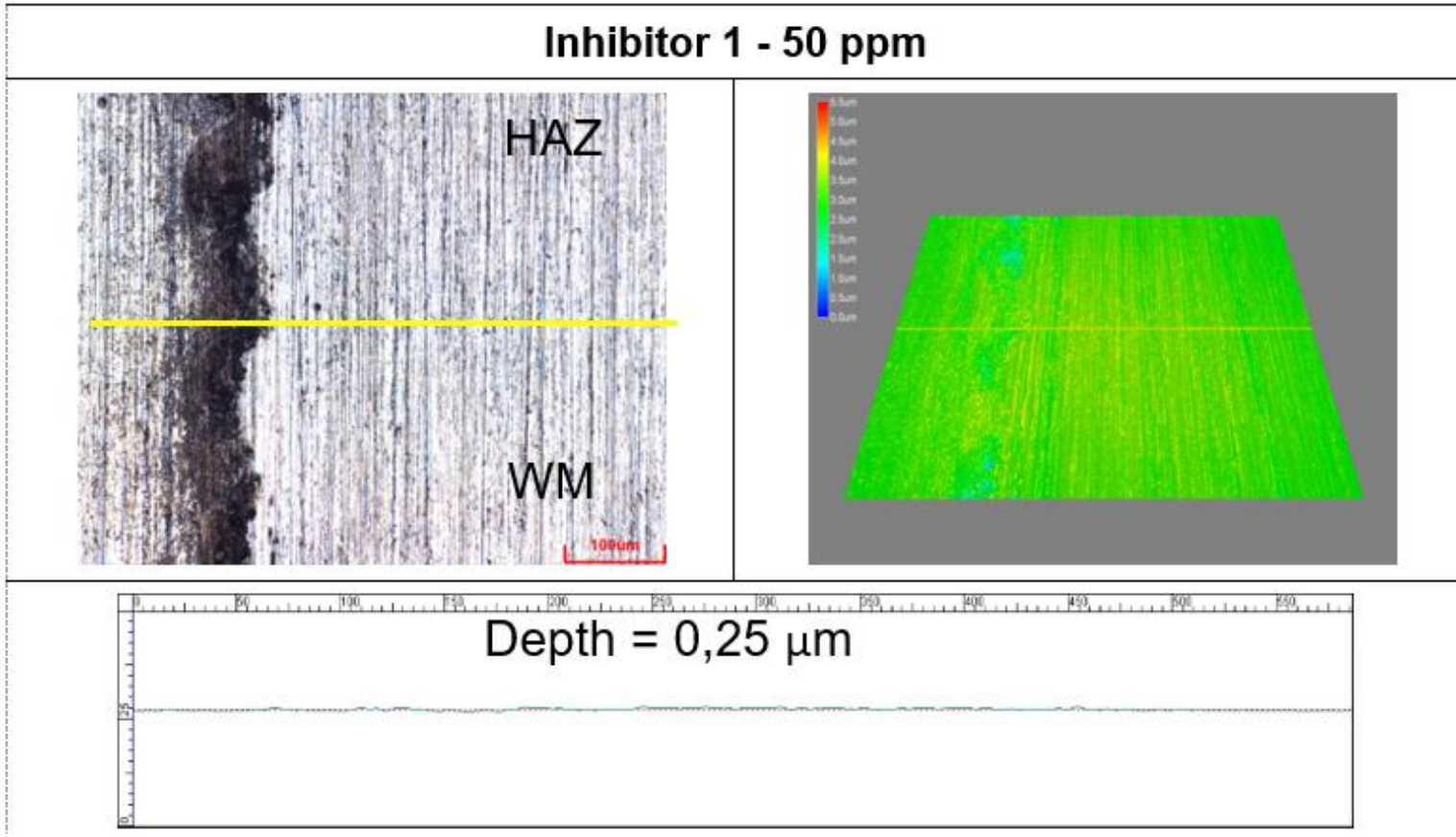
WJ1 – Inhibitor 3

Inhibitor 3 - 50 ppm		Inhibitor 3 - 100 ppm	
			
			

WJ2 – Inhibitor 1

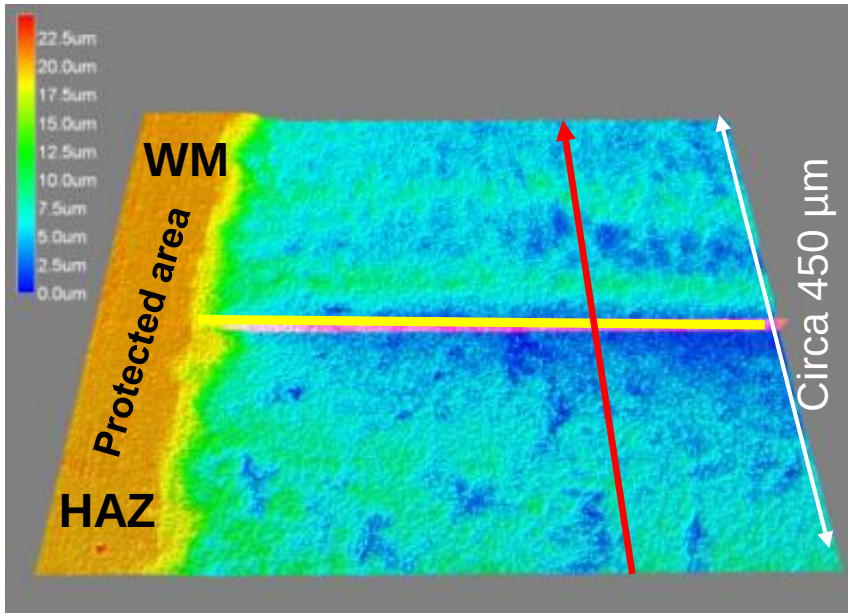
Without inhibitor

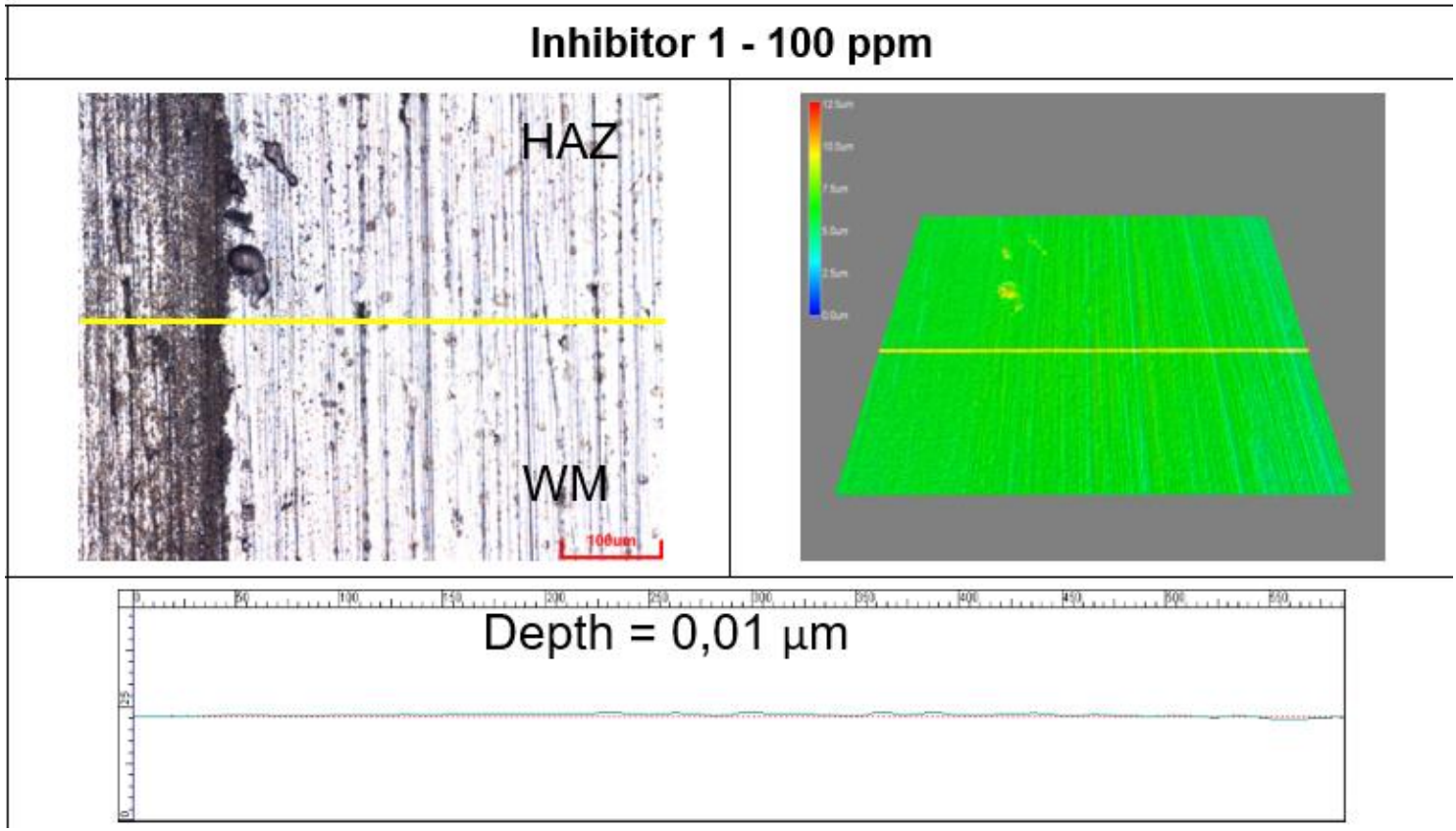




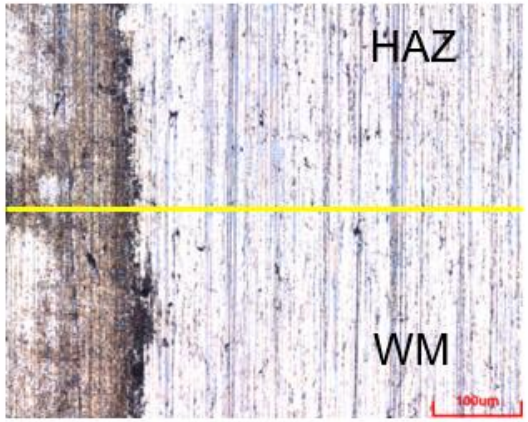
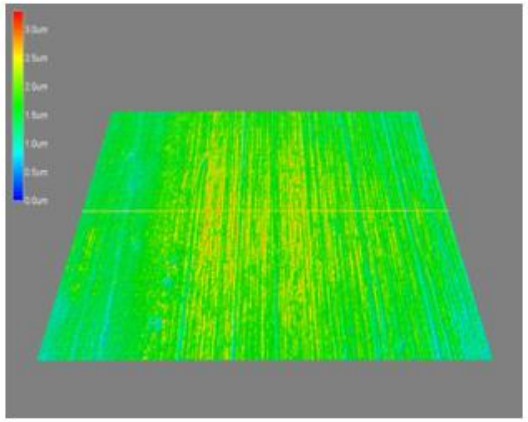
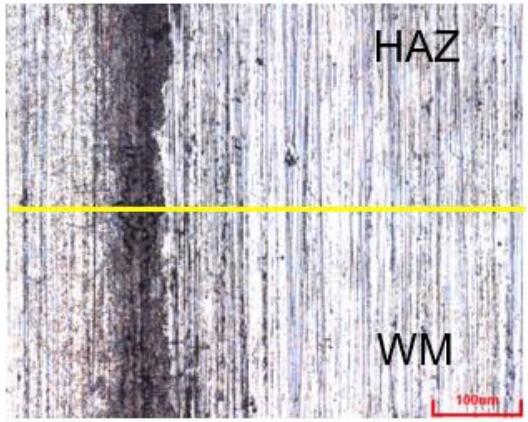
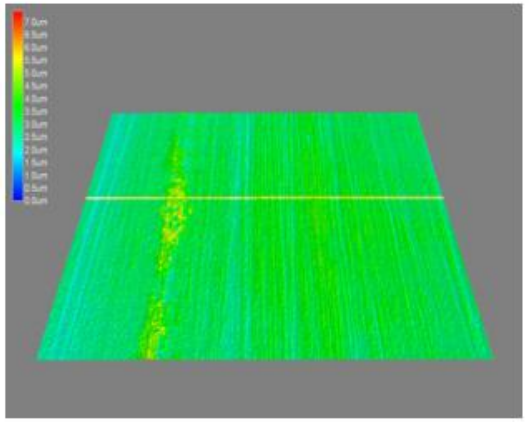
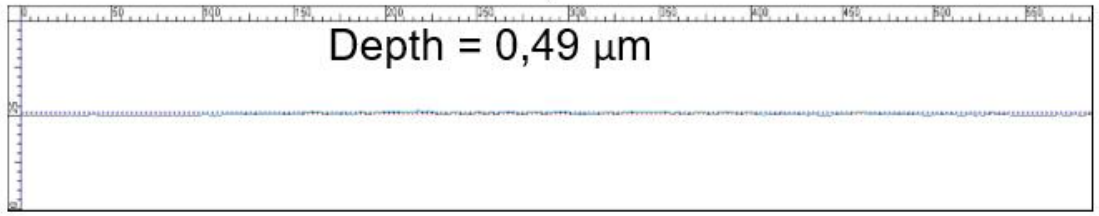
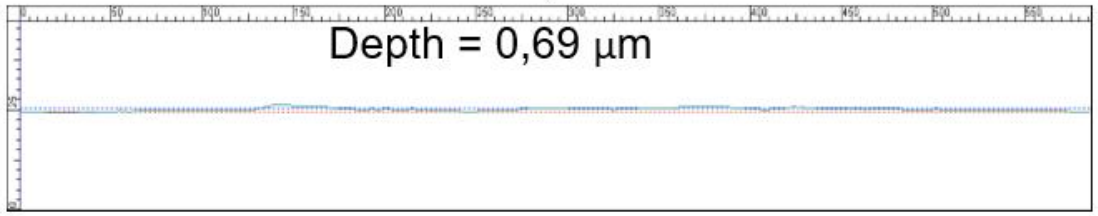
WJ2 – Inhibitor 1

Without inhibitor

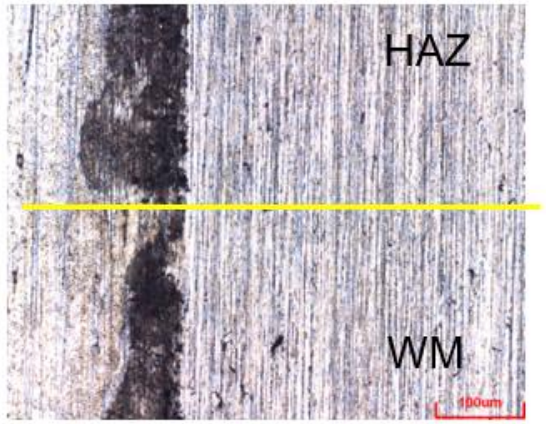
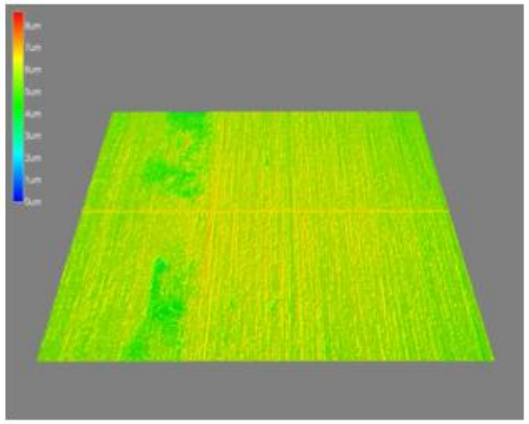
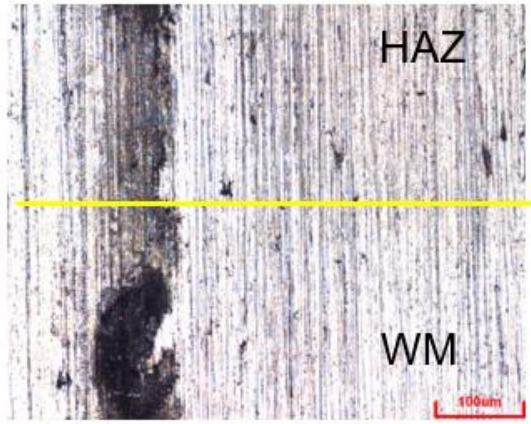
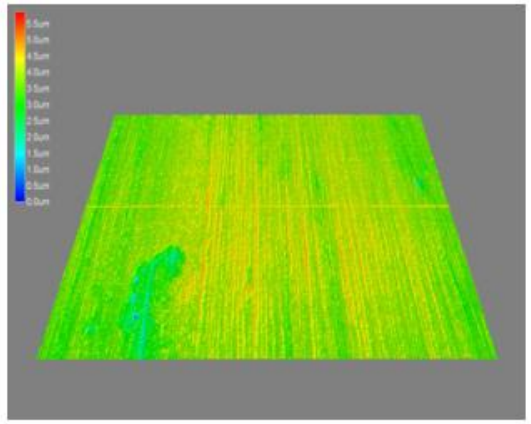
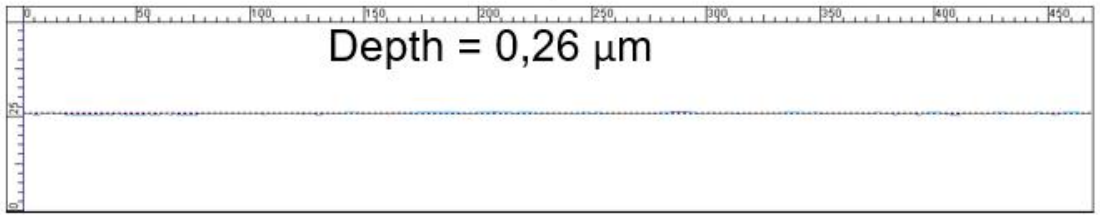
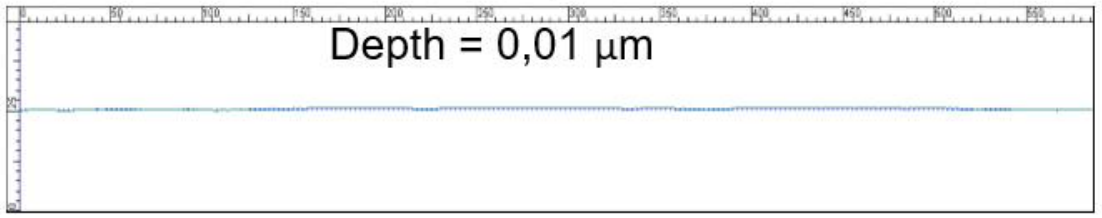




WJ2 – Inhibitor 2

Inhibitor 2 - 50 ppm		Inhibitor 2 - 100 ppm	
			
			

WJ2 – Inhibitor 3

Inhibitor - 50 ppm		Inhibitor 3 - 100 ppm	
			
			

Conclusions

- The inhibitors tested protected both welded joints against PWC
- OCP and galvanic current measurements are a interesting protocol to evaluate galvanic couple of a welded joint
- Longer immersion tests are necessary to evaluate if the behavior of WM as the anode of the galvanic couple is detrimental to the welded joint

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