

# Understanding and addressing corrosion due to amine solvents in post-combustion carbon capture processes

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UKCCSRC Biannual Meeting  
April 21 2015

# Outline

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Background on corrosion, particularly in amine systems

Testing corrosion

1. Experimental methods and amines of interest
2. Analysis techniques

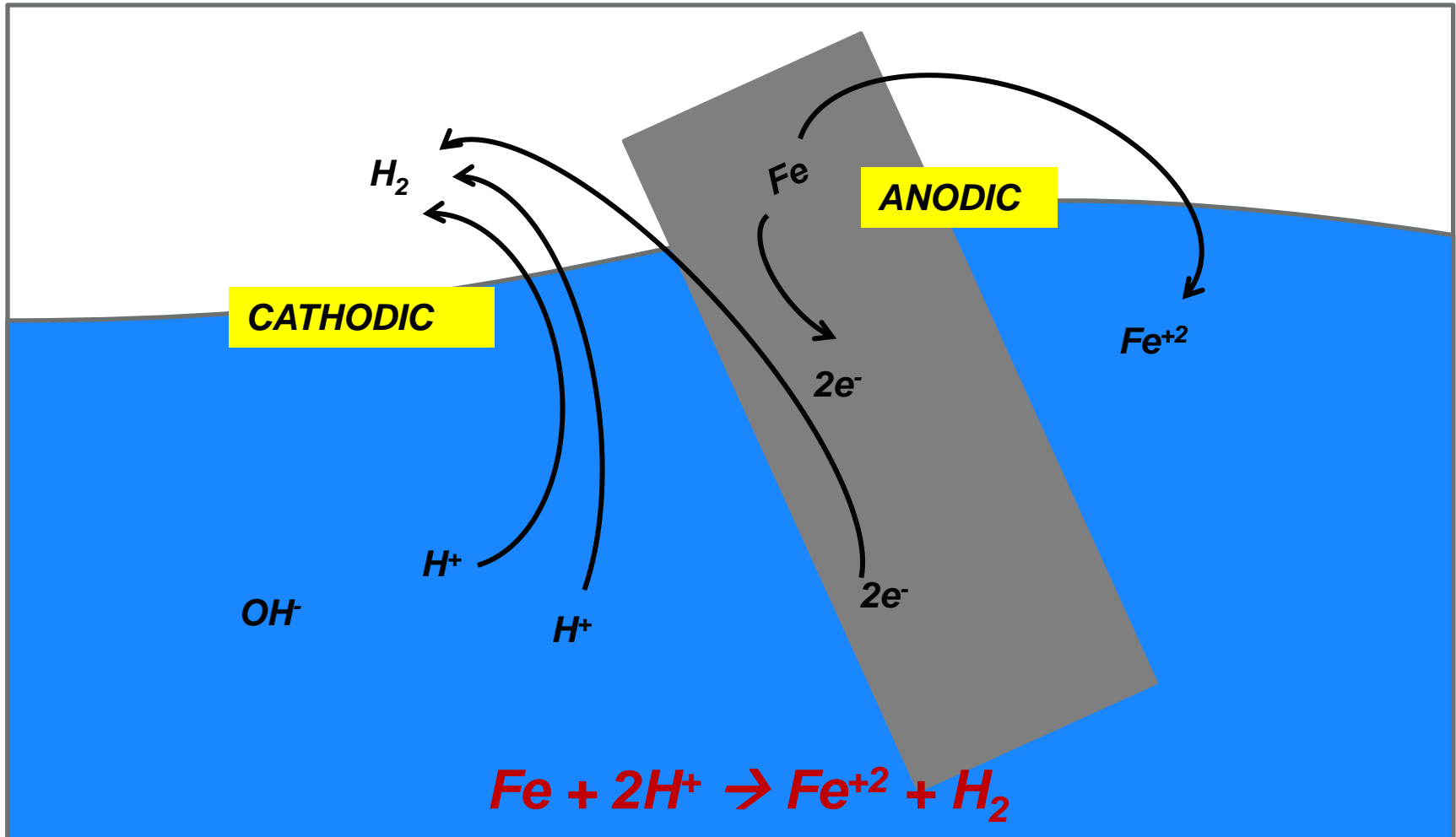
Corrosion observed for aqueous amine (binary) systems

1. Visual inspection and 'hanging film'
2. Elemental analysis of the solution
3. Surface characterization and compositional analysis

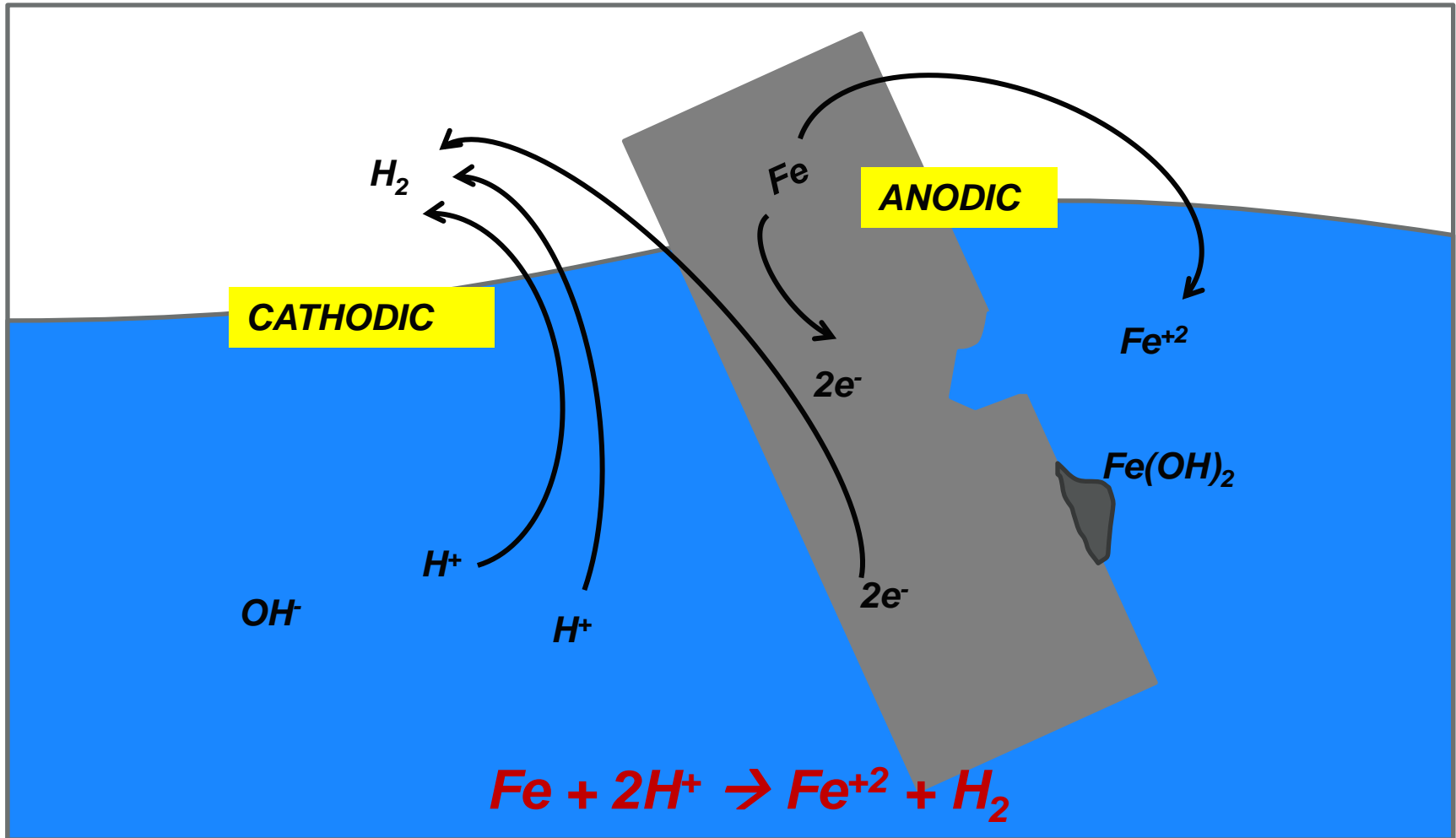
Corrosion observed in aqueous amine (multi-component) systems

Conclusions

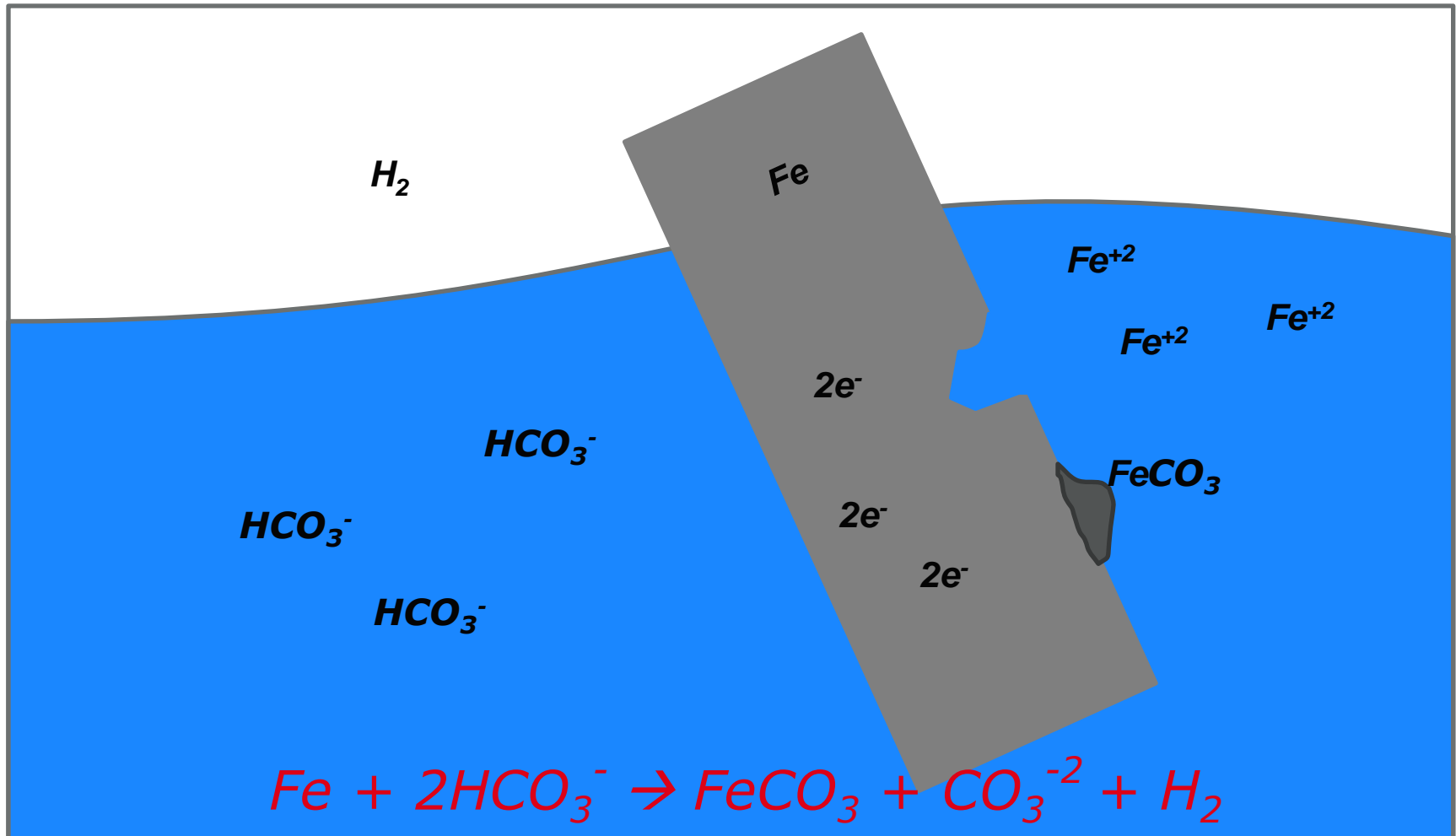
## Background on Corrosion



# Background on Corrosion



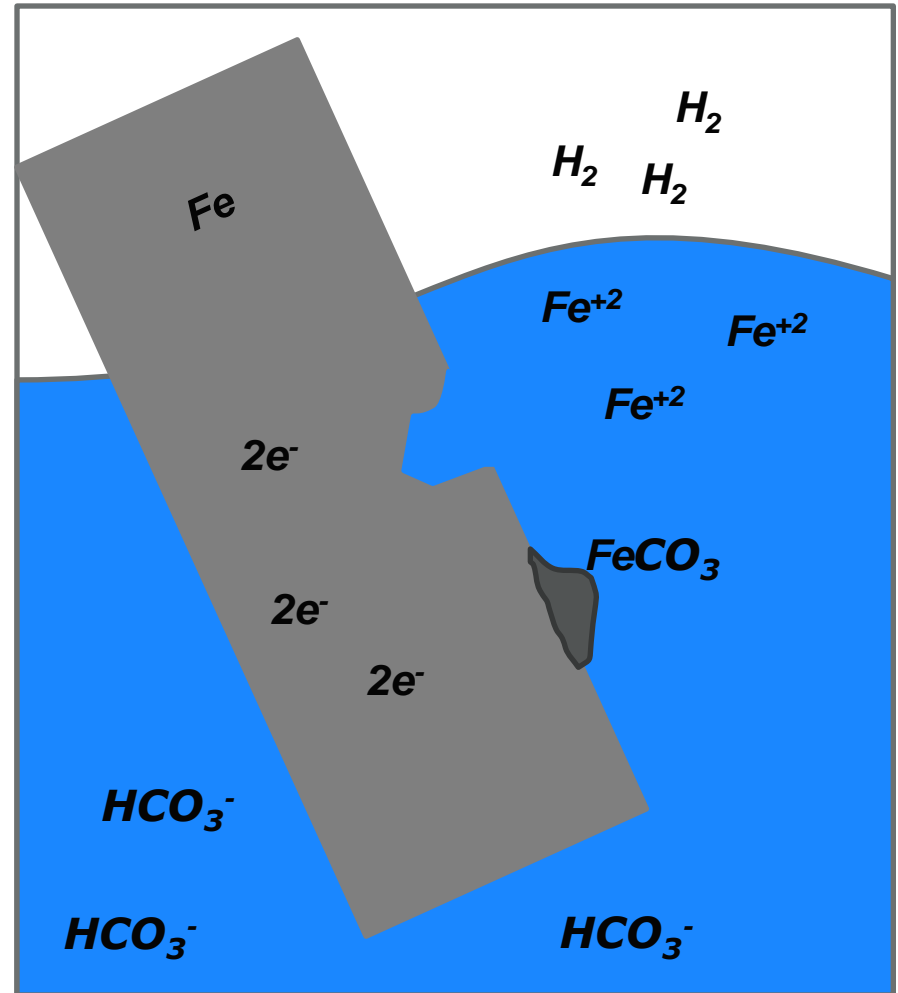
## Background on Corrosion



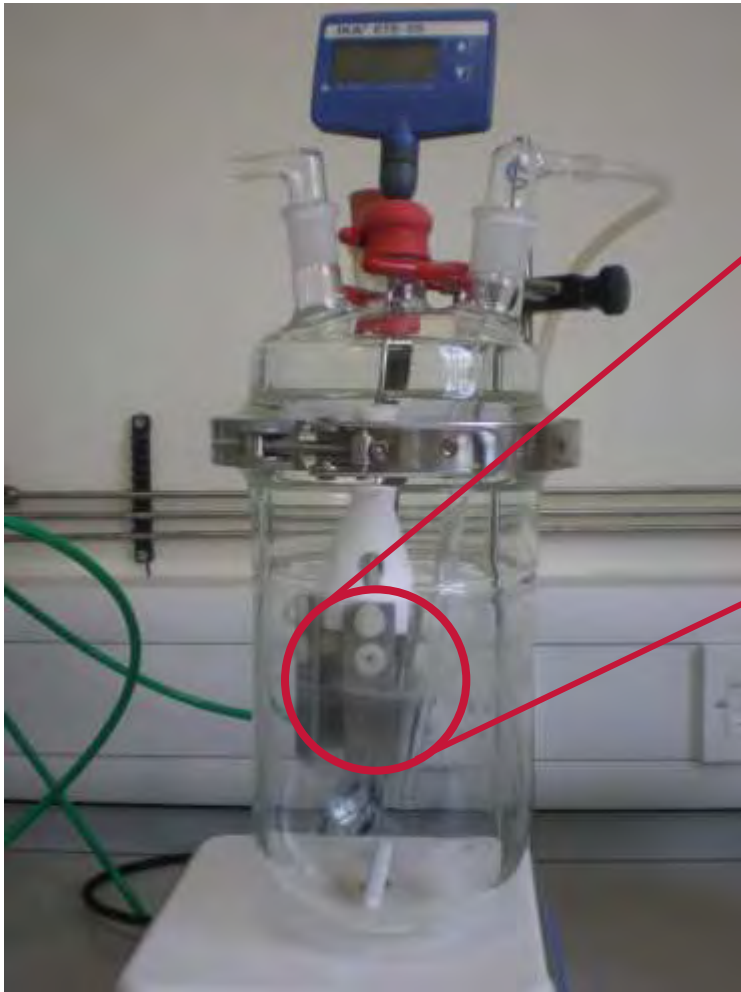
# Testing Corrosion

Experimental Methods:

1. Large scale (direct)
2. Electrochemistry

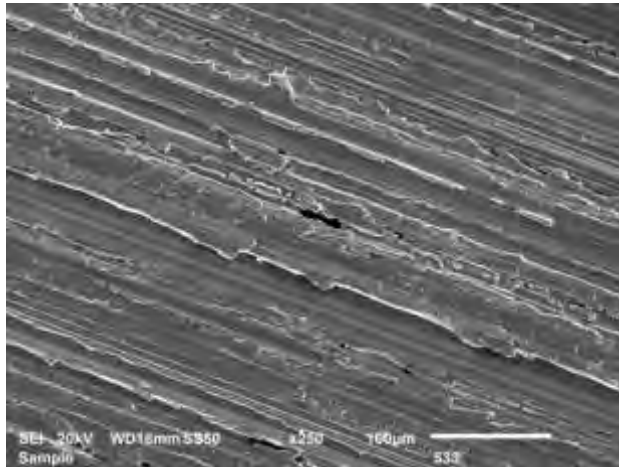


## Testing Corrosion: Experimental Apparatus



Element	Content %
Fe	98.851
C	00.170
Mn	00.800
Cr	00.040
Al	00.042

## Testing Corrosion: Metal Coupons



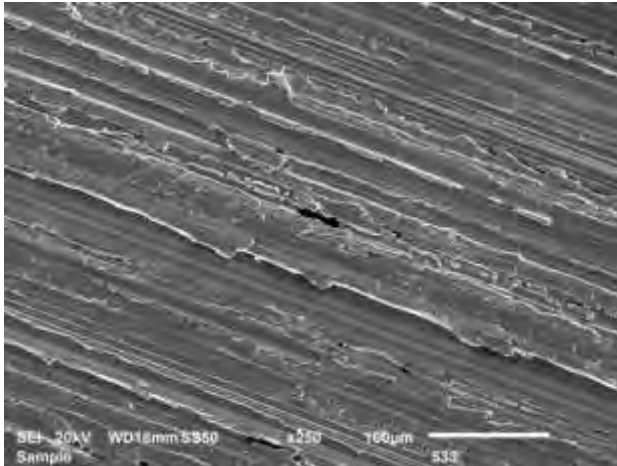
Typical Industrial Machine Finish



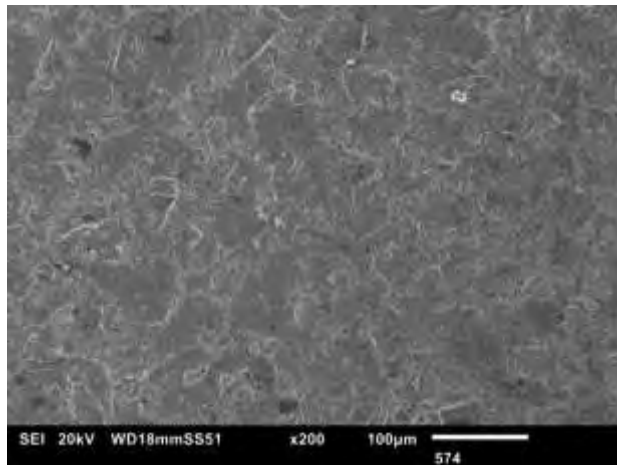
Element	%
Fe	98.851
C	00.170
Mn	00.800
Cr	00.040
Al	00.042



# Testing Corrosion: Metal Coupons



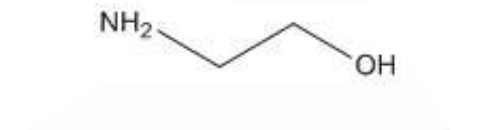

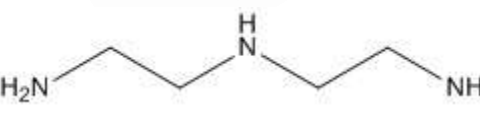
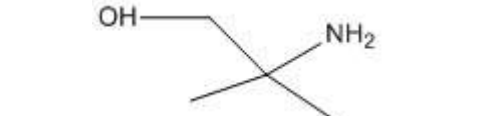
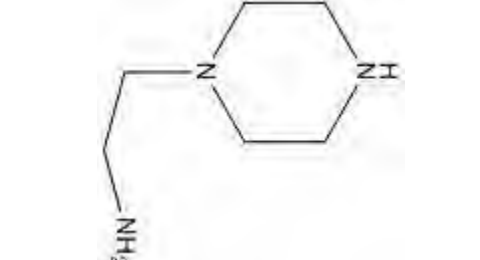
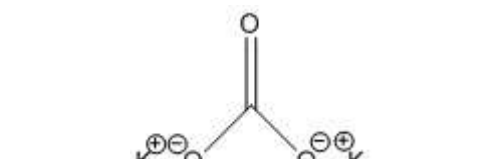
Typical Industrial Machine Finish



120 Grit Testing Finish

Element	%
Fe	98.851
C	00.170
Mn	00.800
Cr	00.040
Al	00.042

# Testing Corrosion: Aqueous Amine Solutions

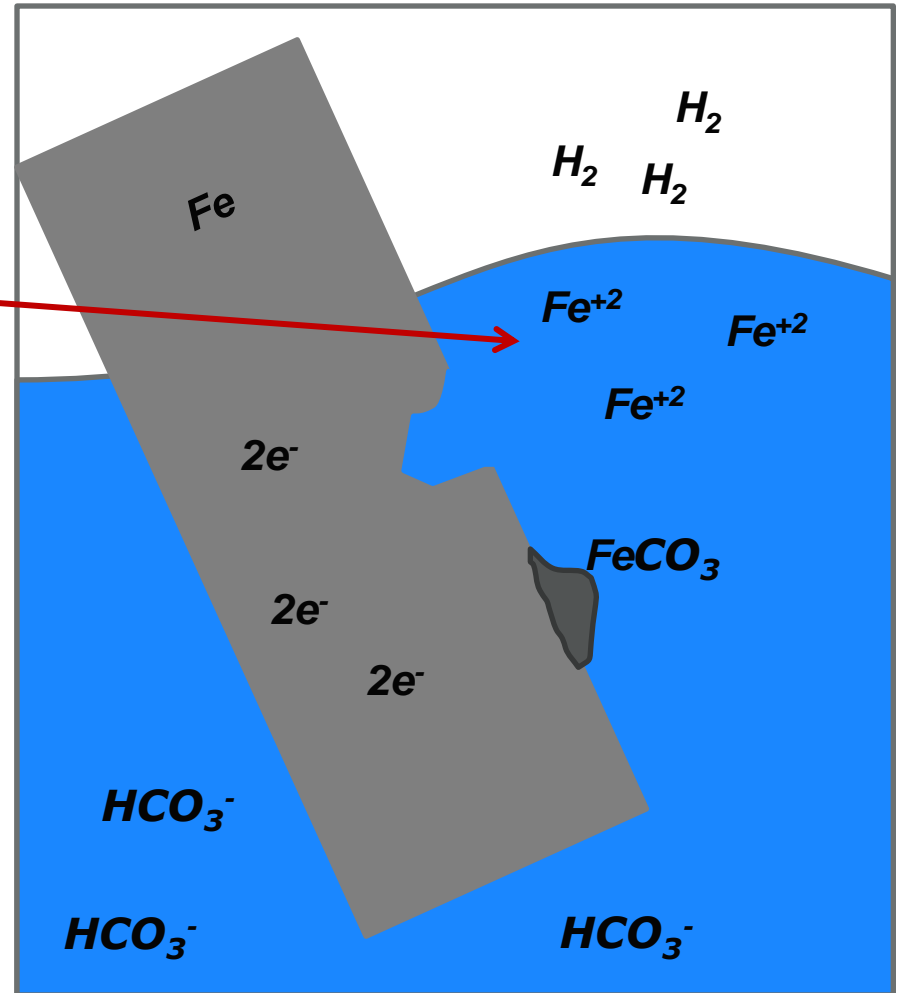
Monoethanolamine (MEA)		#1: Primary
Methyldiethanolamine (MDEA)		#1: Tertiary
Diethylenetriamine (DETA)		#1, #2 Primary, #3 Secondary
2-amino-2-methylpropanol (AMP)		#1: Primary
1-(2-aminoethyl)-piperazine (AEP)		#1: Primary, #2: Secondary, #3 Tertiary
Potassium Carbonate (K <sub>2</sub> CO <sub>3</sub> )		N/A

# Testing Corrosion

Analysis Methods:

1. Traditional: Hanging Film (Weight loss/gain)

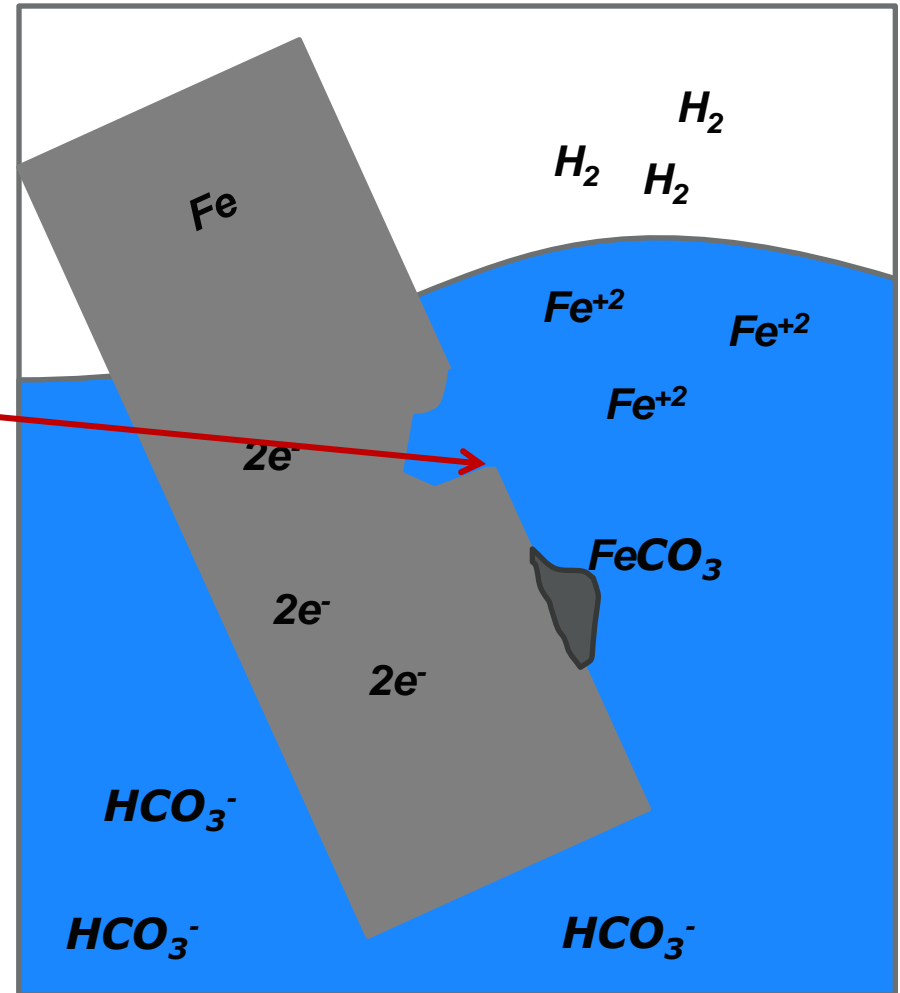
2. Bulk chemical (metal ions) contents:  
ICP – OES



# Testing Corrosion

Analysis Methods:

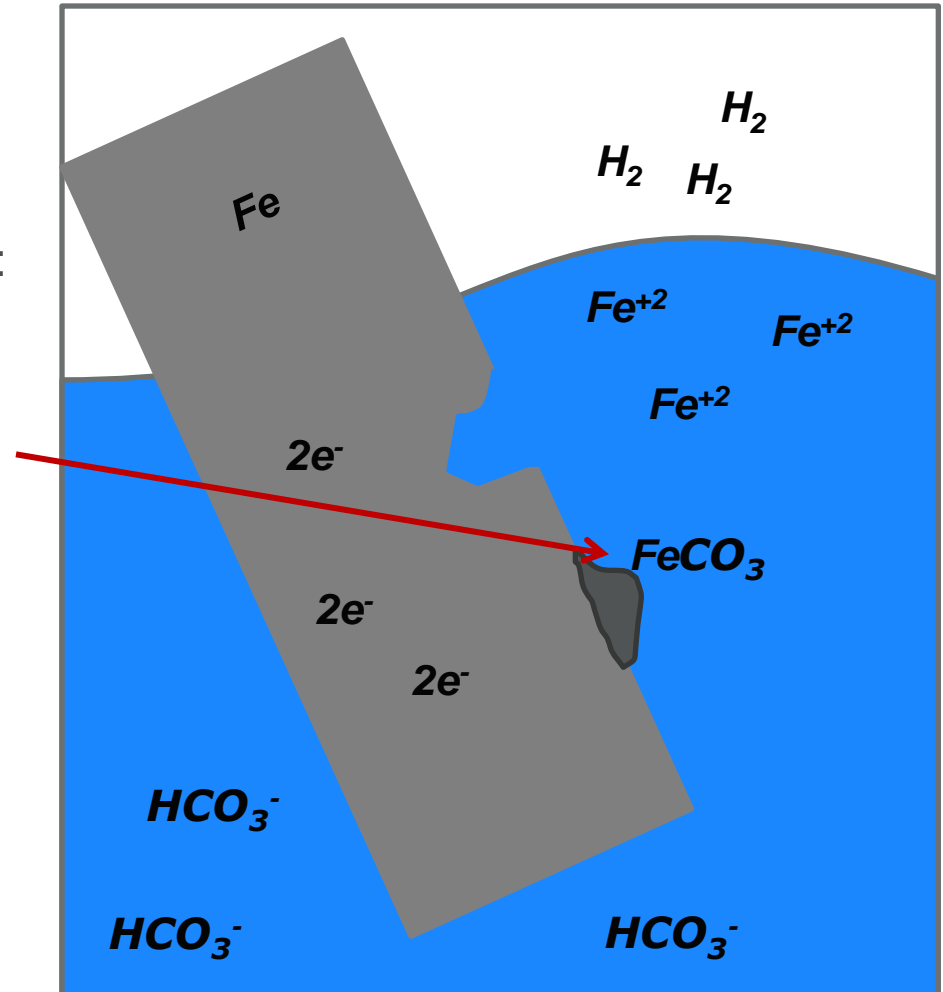
1. Traditional: Hanging Film  
(Weight loss/gain)
2. Bulk chemical (metal ions) contents:  
ICP – OES
3. Surface imaging: SEM, (AFM)



# Testing Corrosion

Analysis Methods:

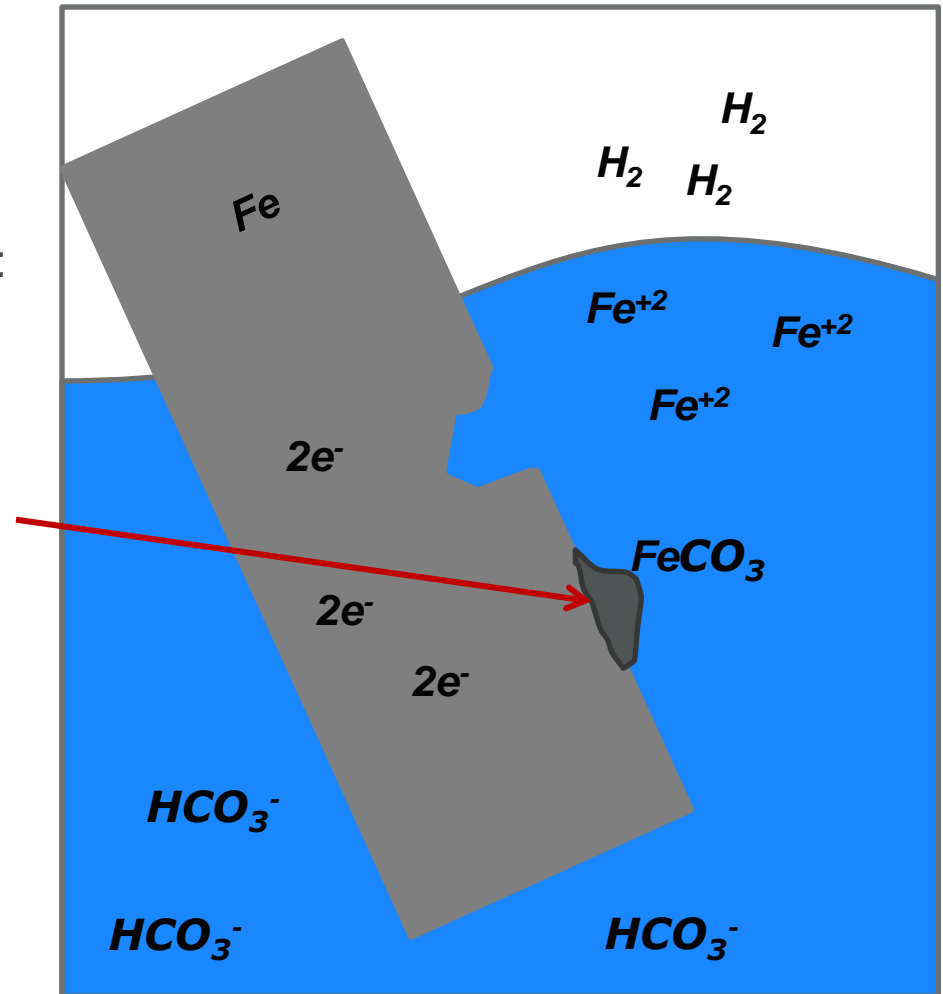
1. Traditional: Hanging Film (Weight loss/gain)
2. Bulk chemical (metal ions) contents: ICP – OES
3. Surface imaging: SEM, (AFM)
4. Surface chemistry: EDX, (Raman)



# Testing Corrosion

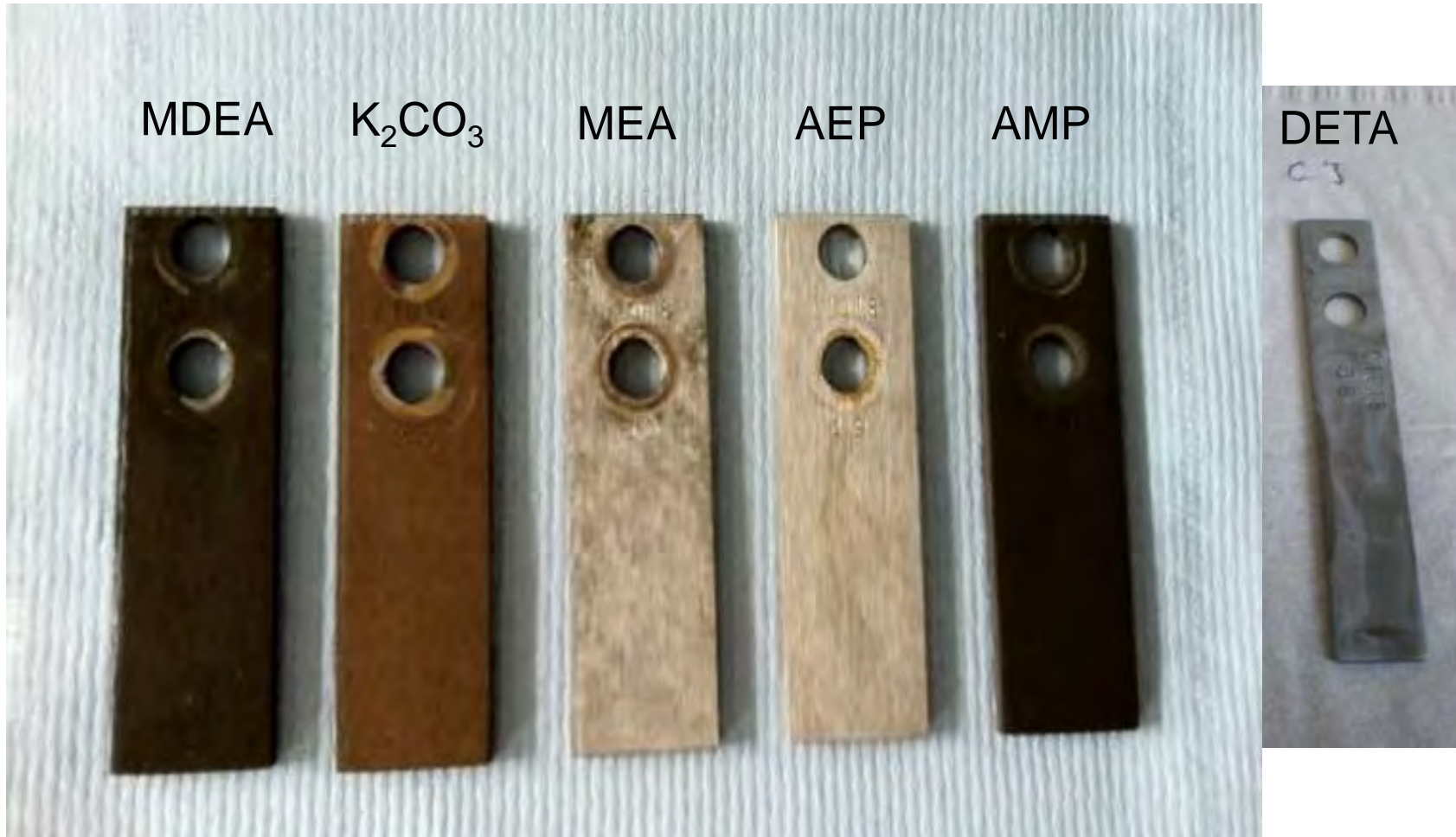
Analysis Methods:

1. Traditional: Hanging Film (Weight loss/gain)
2. Bulk chemical (metal ions) contents: ICP – OES
3. Surface imaging: SEM, (AFM)
4. Surface chemistry: EDX, (Raman)
5. Surface (crystal) structure: Visual, SEM, XRD, (XPS)



# CORROSION OF AMINES ON STEEL

## Aqueous Amine Solutions – Visual Inspection

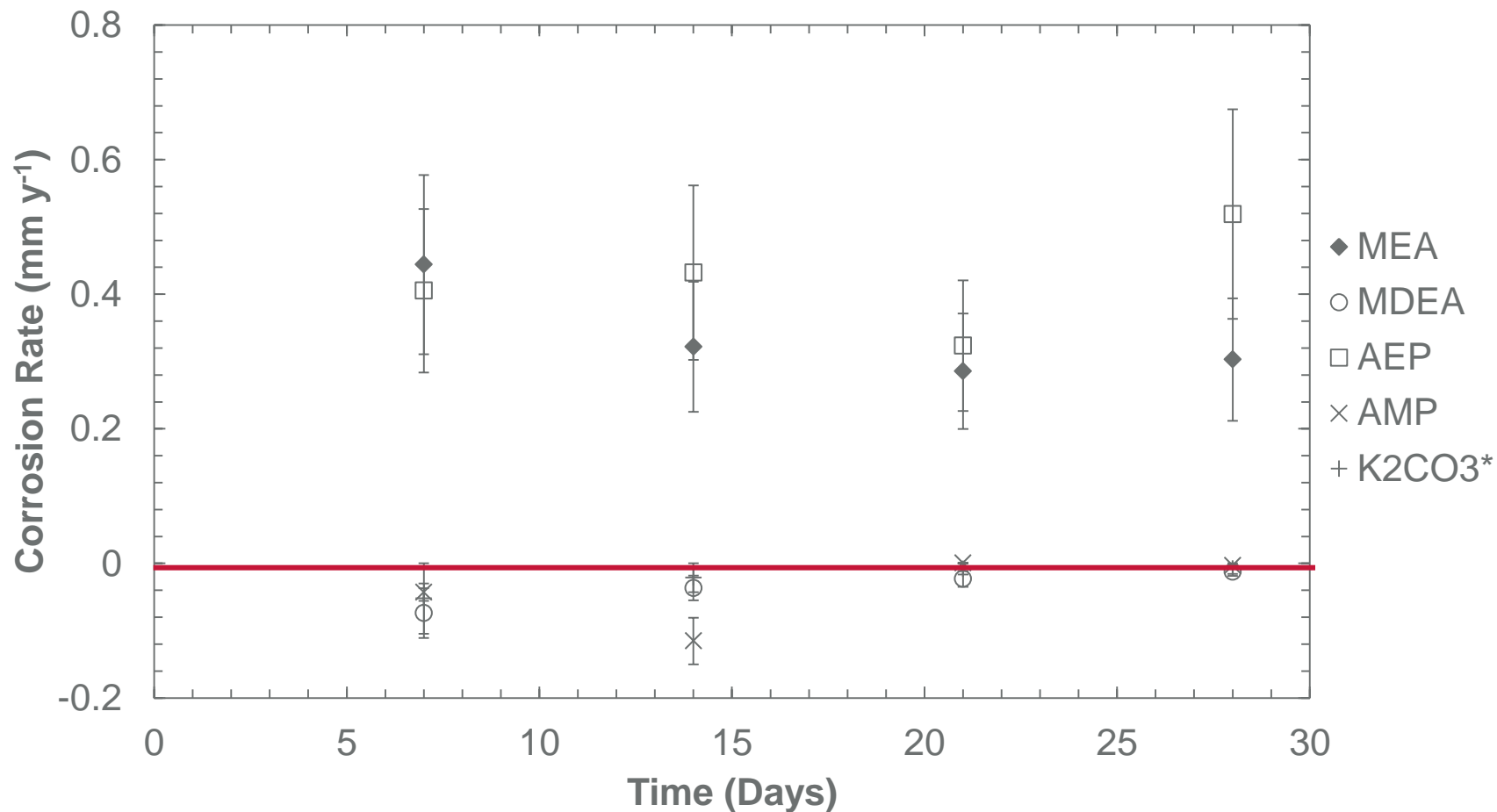


Corrosion: MEA, AEP, DETA

Passivation: MDEA, AMP,  $K_2CO_3$



# Aqueous Amine Solutions – Hanging Film Method

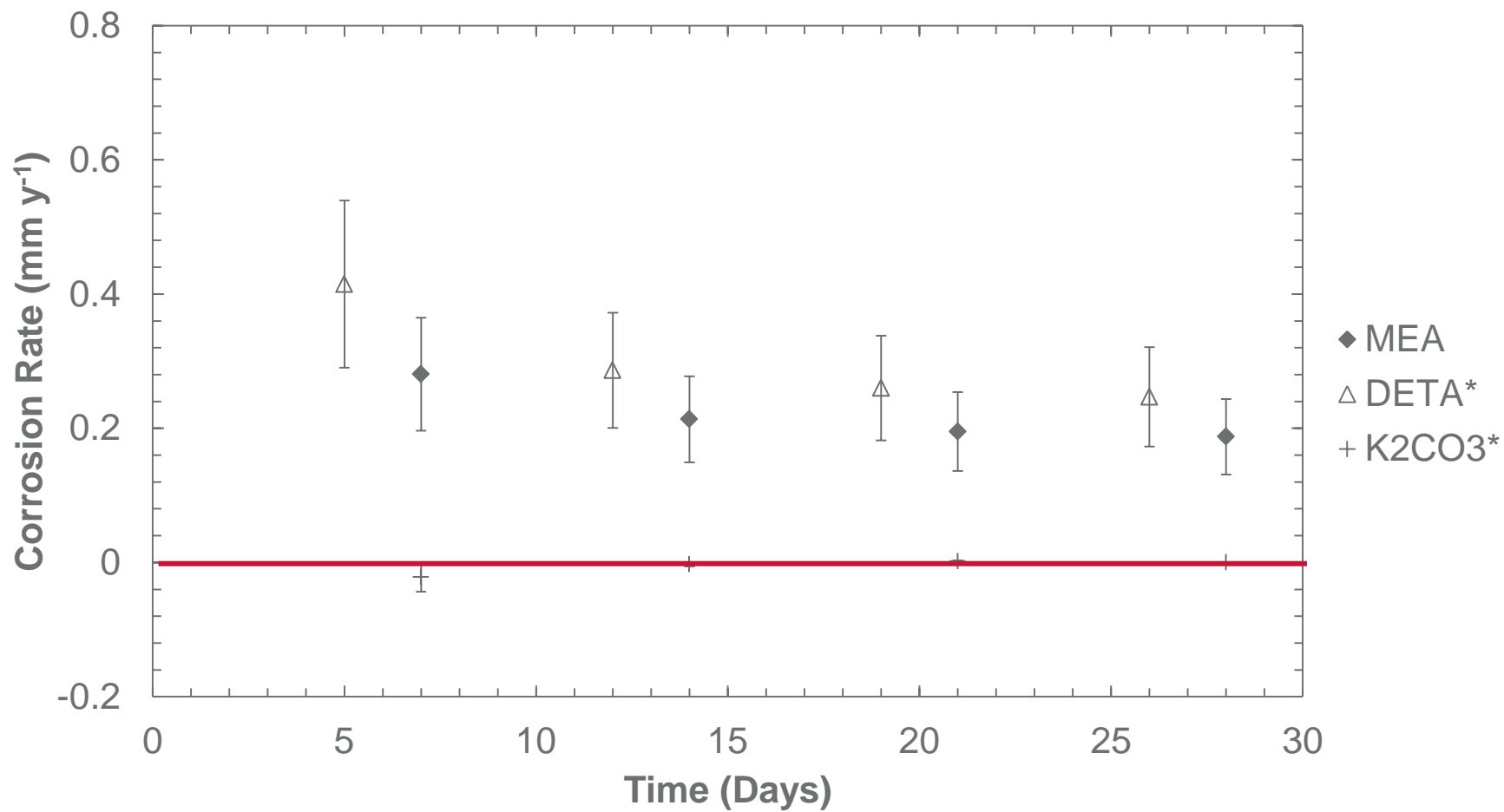


**Corrosion** 
→
 **Passivation**

AEP MEA

AMP MDEA K<sub>2</sub>CO<sub>3</sub>\*

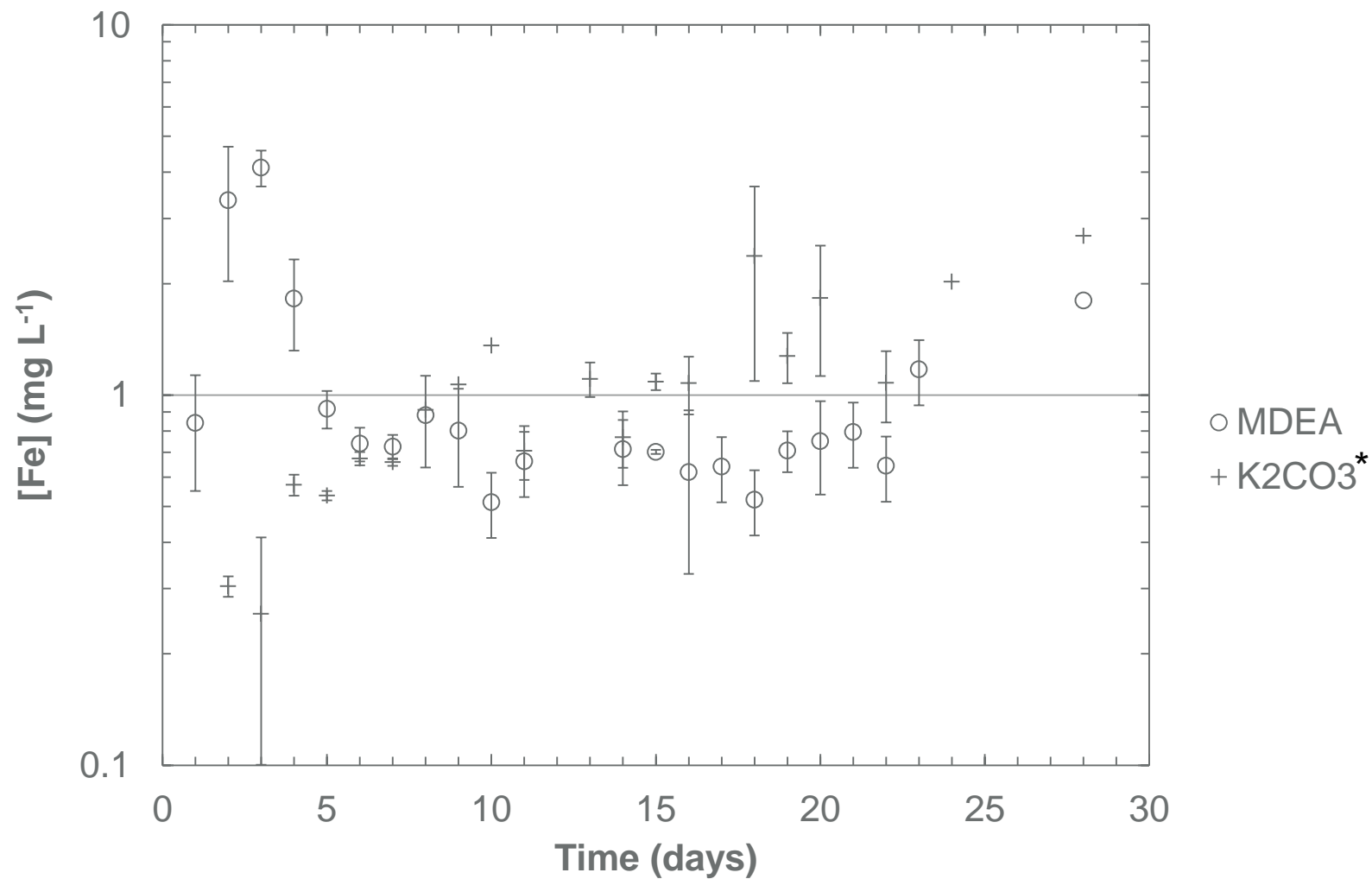
# Aqueous Amine Solutions – Hanging Film Method



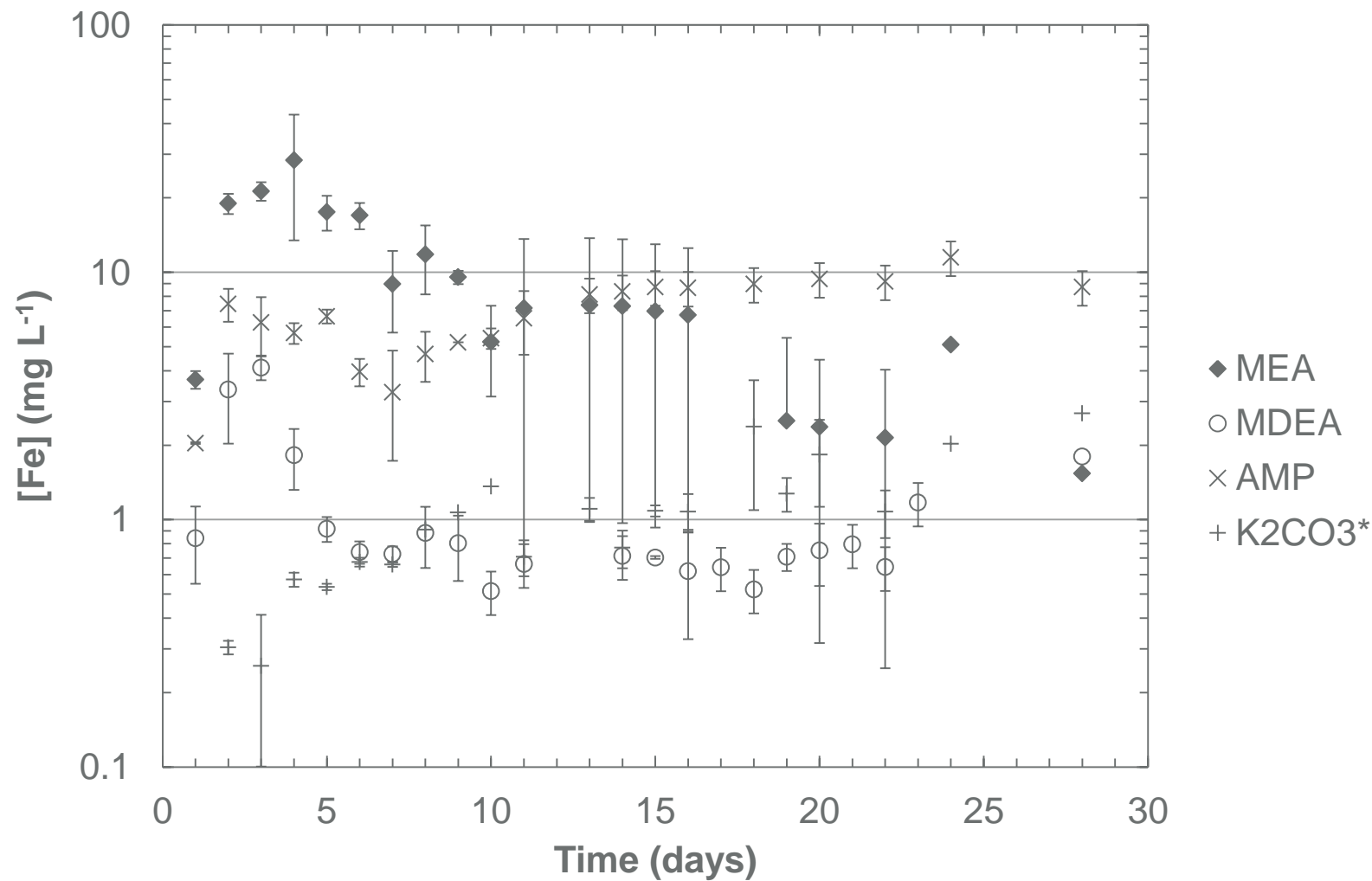
**Corrosion**  $\xrightarrow{\hspace{15em}}$  **Passivation**

AEP MEA DETA\* AMP MDEA K<sub>2</sub>CO<sub>3</sub>\*

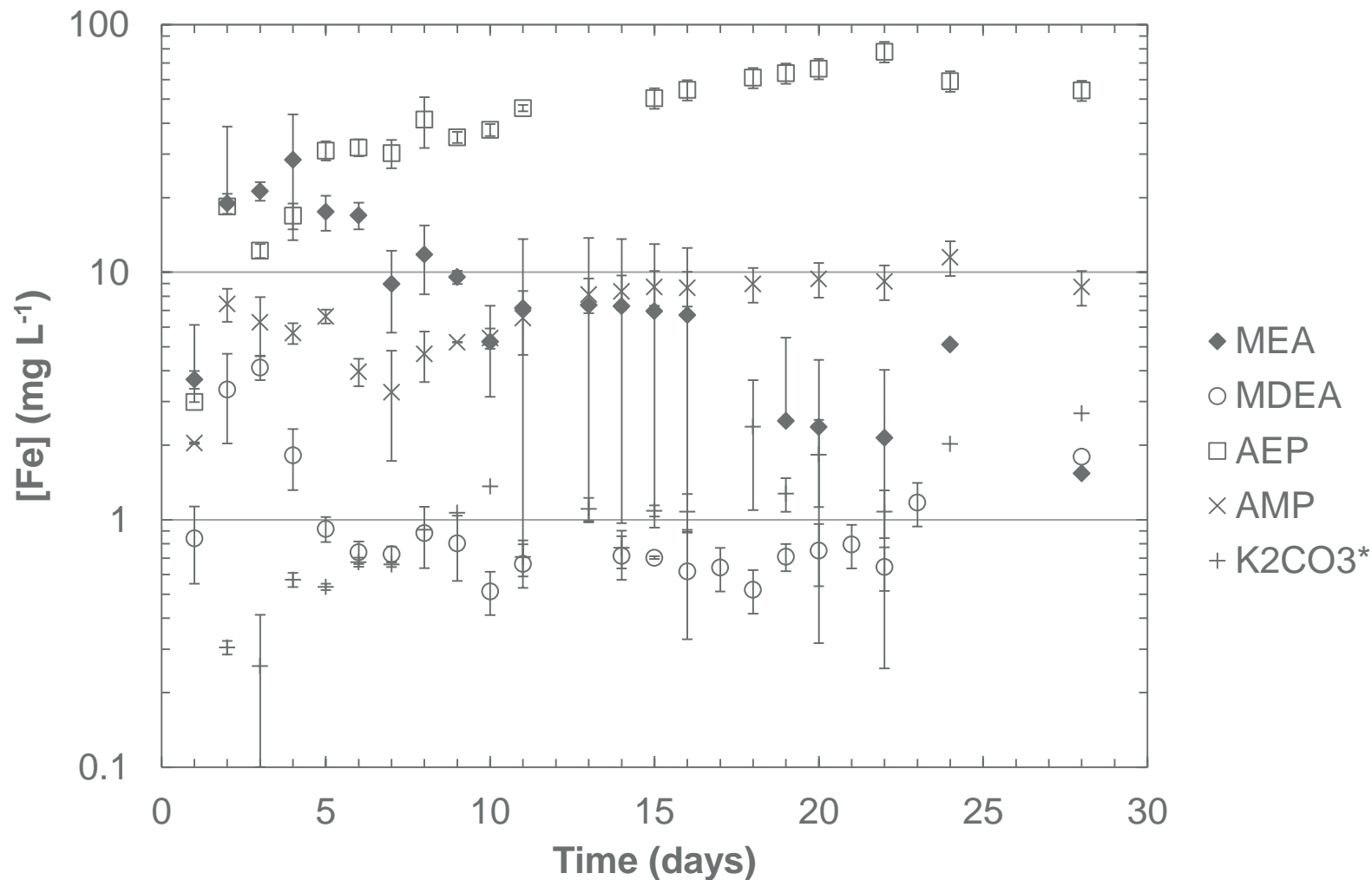
# Aqueous Amine Solutions – ICP - OES



# Aqueous Amine Solutions – ICP - OES



# Aqueous Amine Solutions – ICP - OES



Corrosion

AEP

MEA

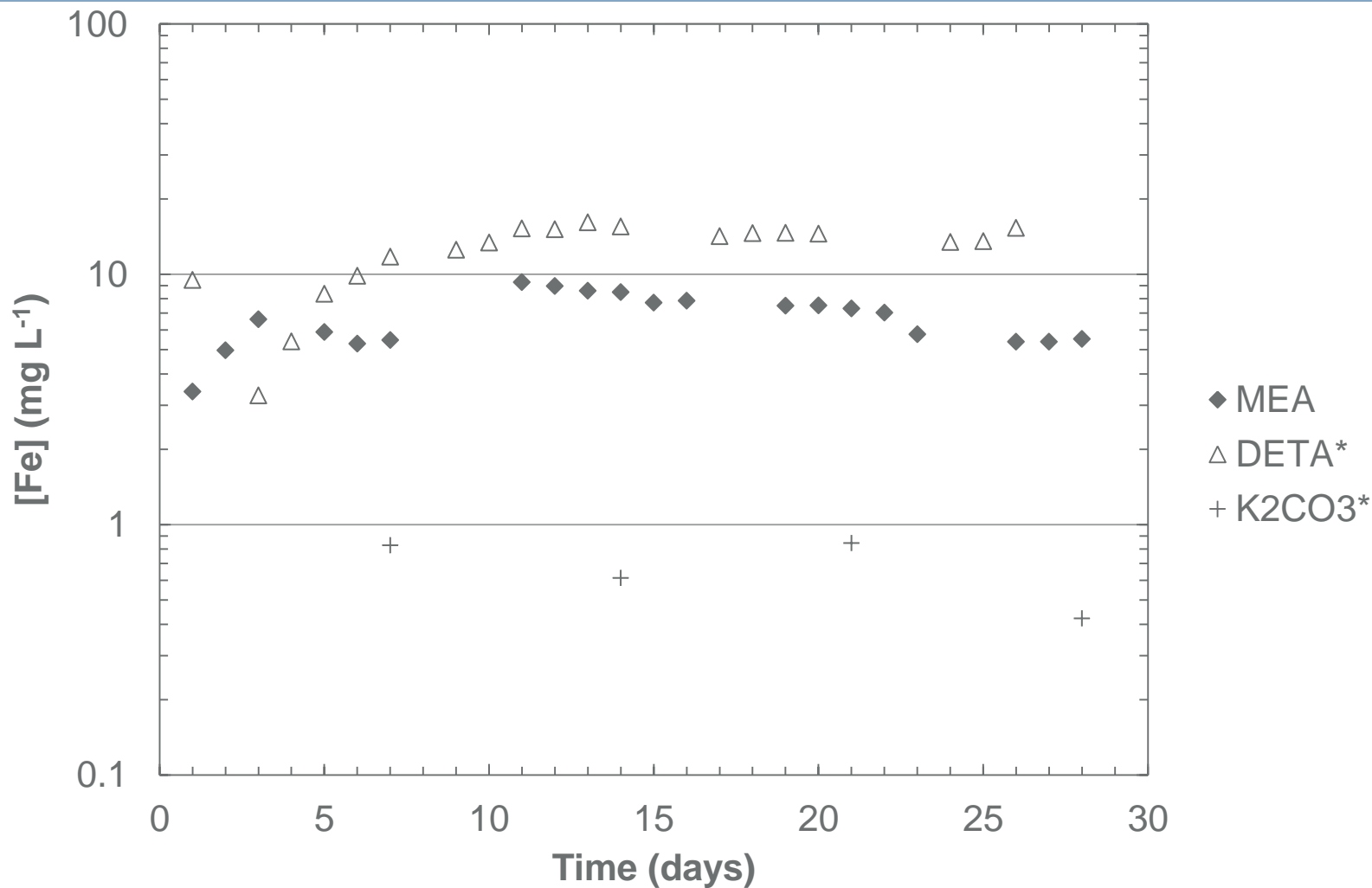
AMP

MDEA

K<sub>2</sub>CO<sub>3</sub>\*

Passivation

# Aqueous Amine Solutions – ICP - OES

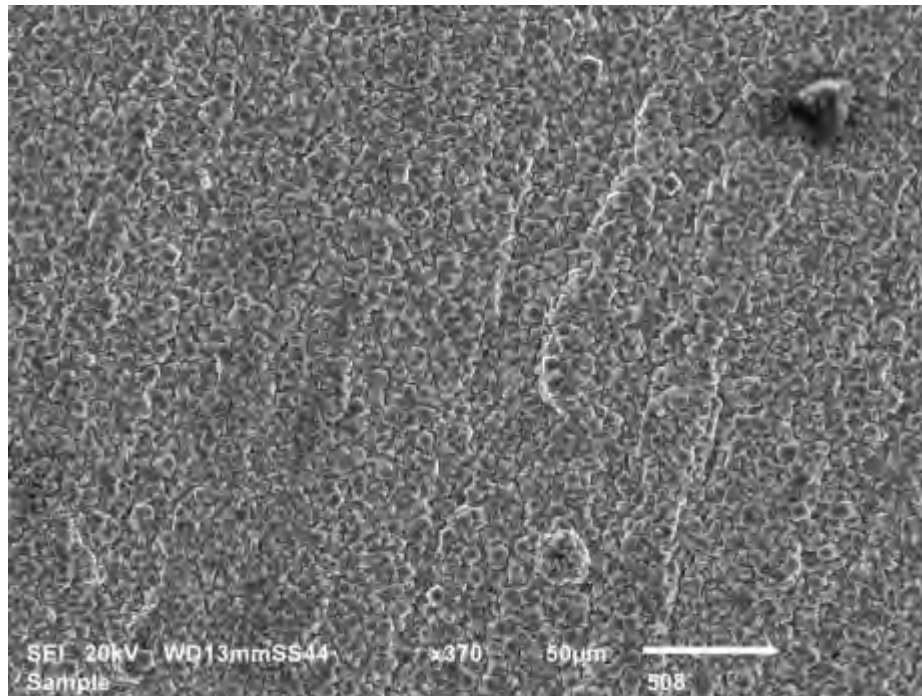


**Corrosion** —————> **Passivation**

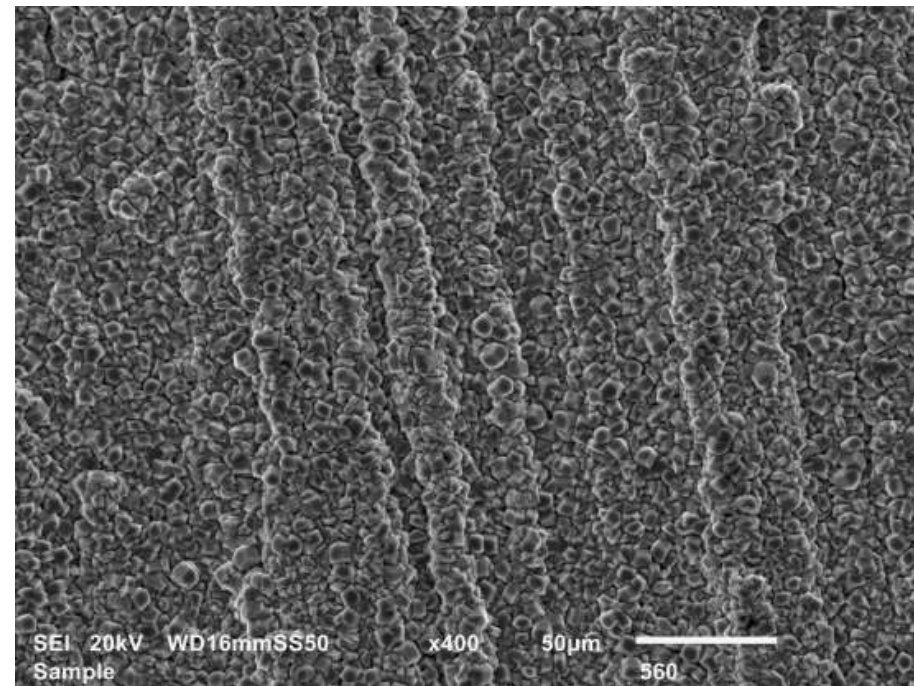
AEP DETA\* MEA AMP MDEA K<sub>2</sub>CO<sub>3</sub>\*

# Aqueous AMP Solutions – SEM / EDX

DAY 7



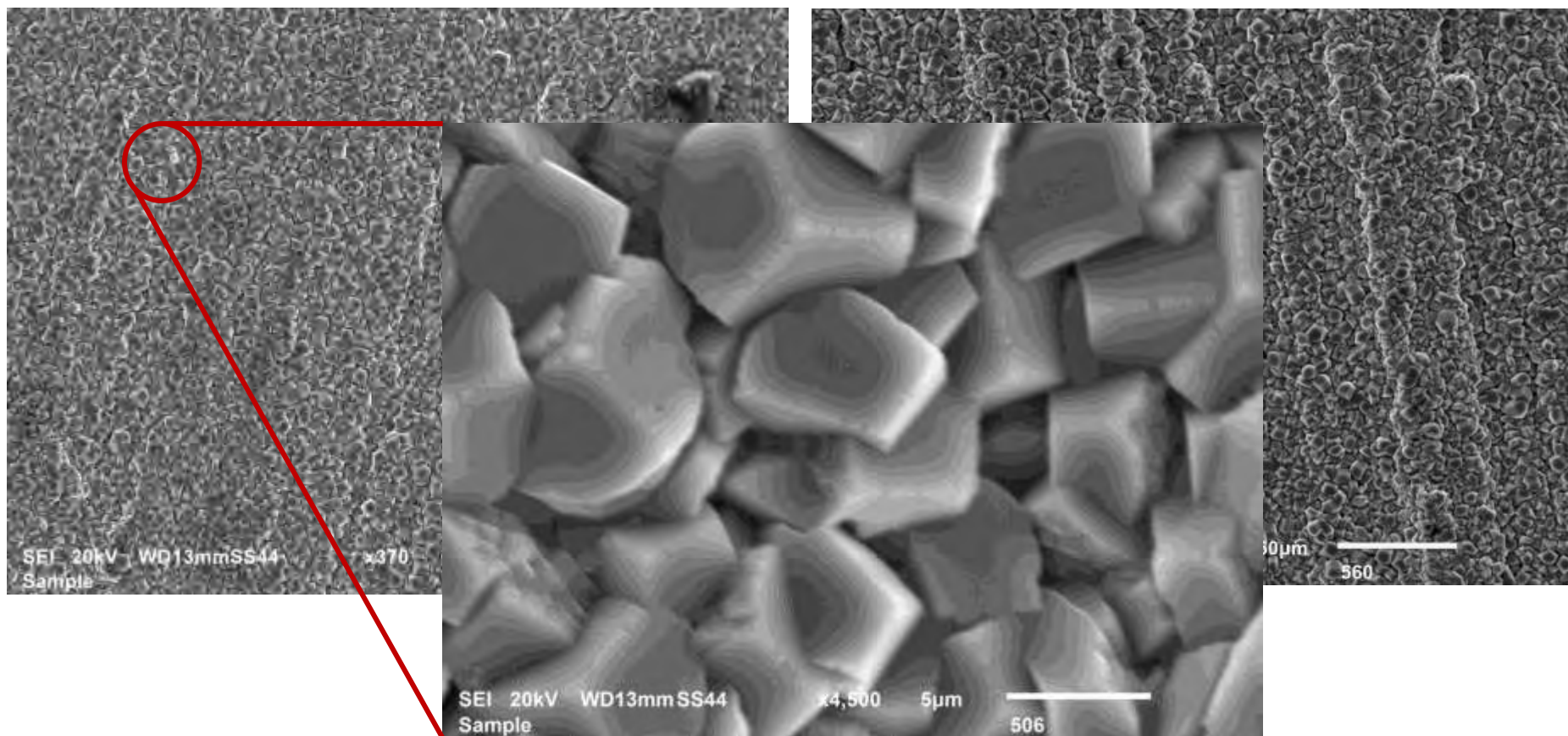
DAY 28



# Aqueous AMP Solutions – SEM / EDX

DAY 7

DAY 28



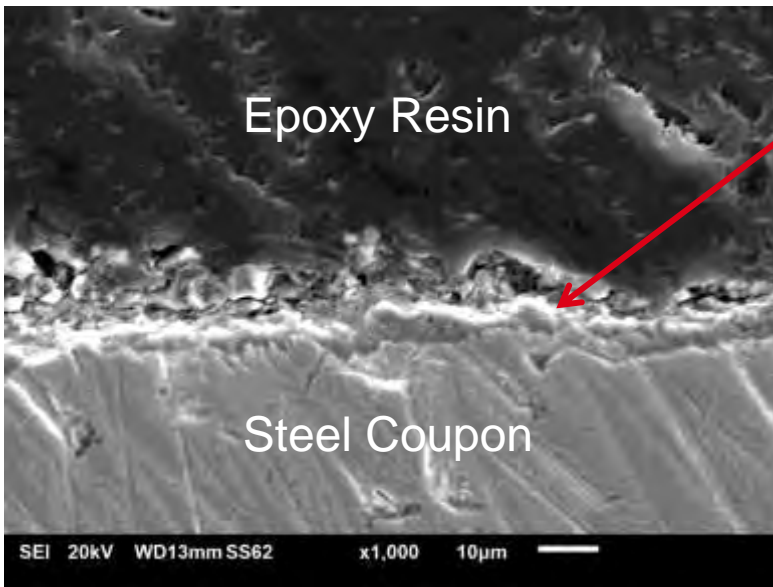
100% Surface Coverage



## Aqueous AMP Solutions – SEM / EDX

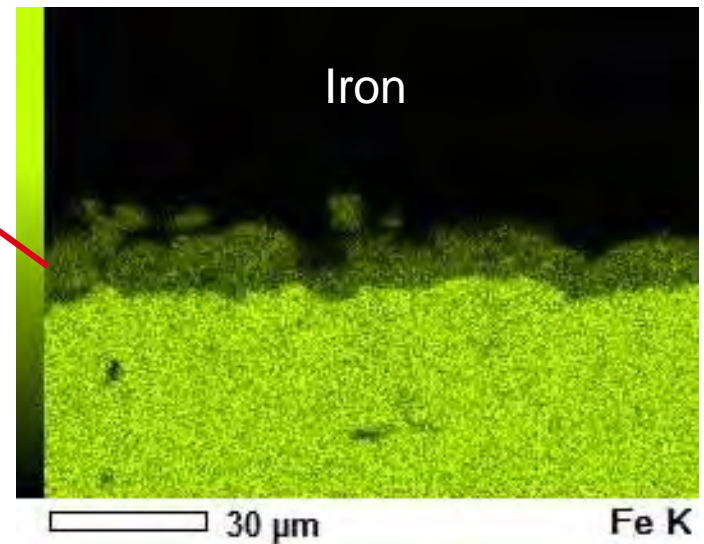
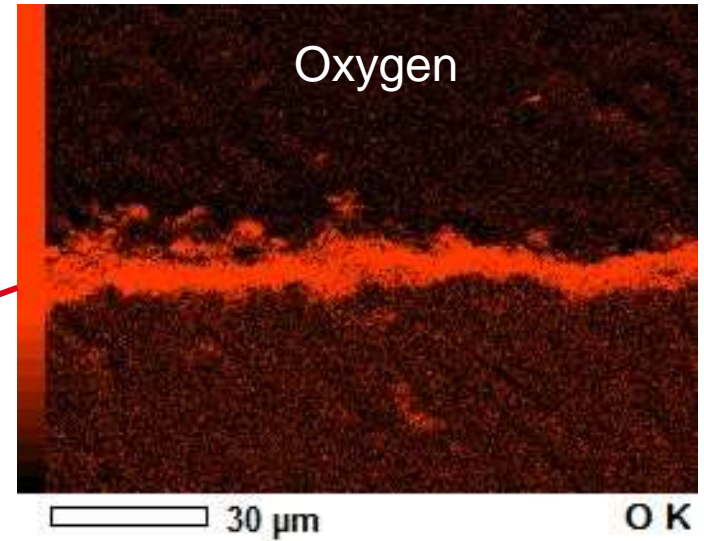
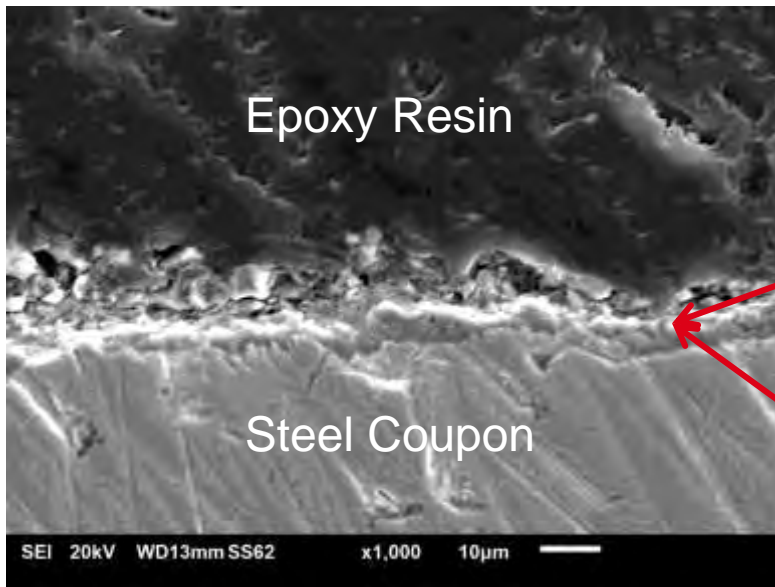
DAY 7

Passivation layer



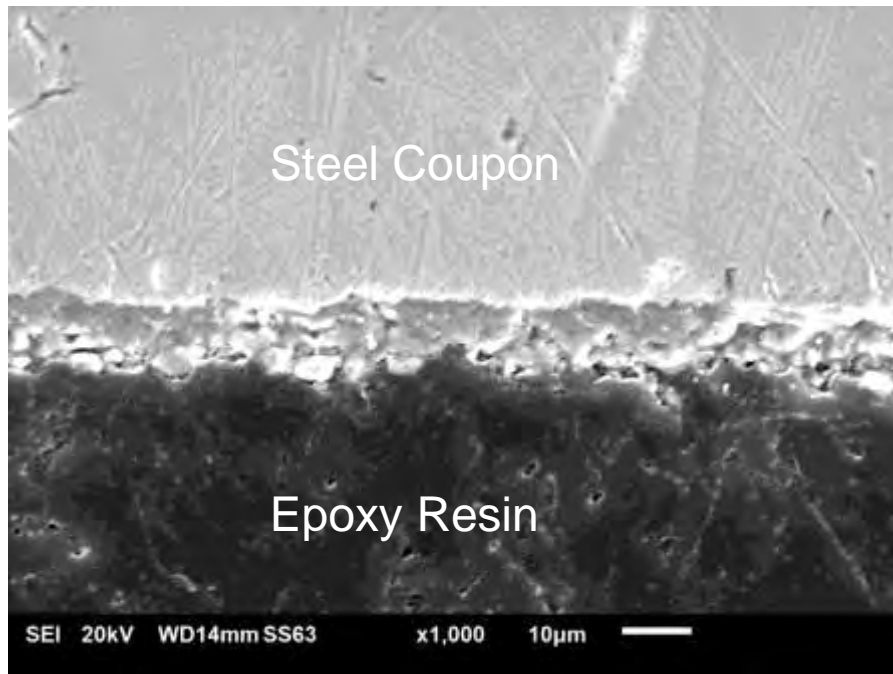
# Aqueous AMP Solutions – SEM / EDX

DAY 7



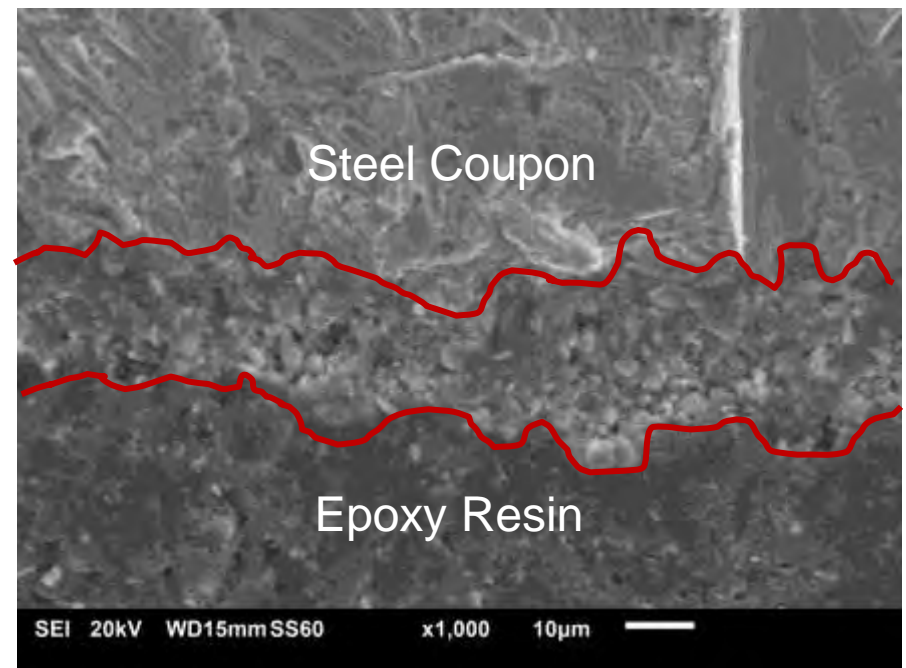
## Aqueous AMP Solutions – SEM / EDX

DAY 14



Passivation Layer ~ 10µm

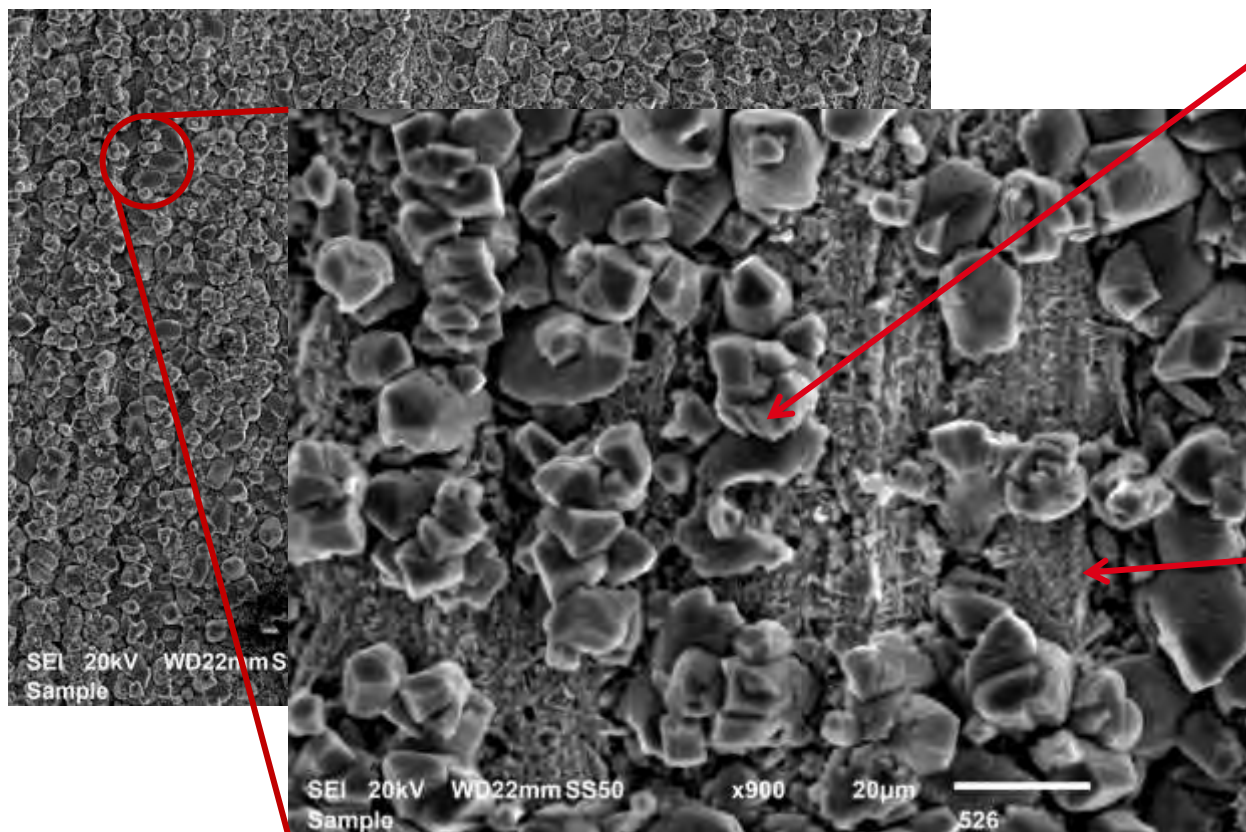
DAY 28



Passivation Layer ~ 20µm

# Aqueous $K_2CO_3$ Solutions – SEM / EDX

DAY 7



Element	Mole Ratio
C	18.12
O	51.36
Fe	30.52

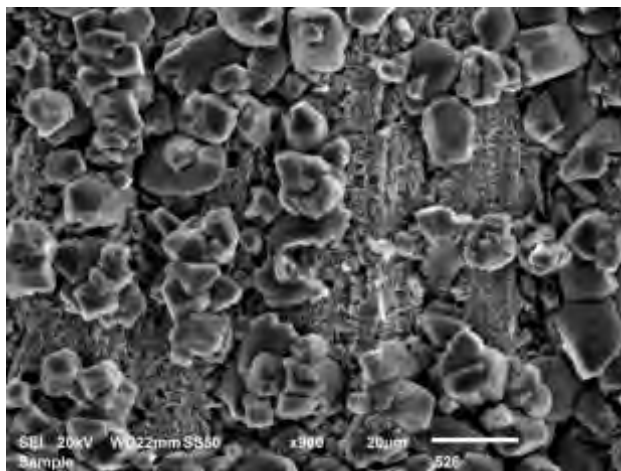
Mixture of products?

Element	Mole Ratio
C	14.86
O	5.15
Fe	79.99

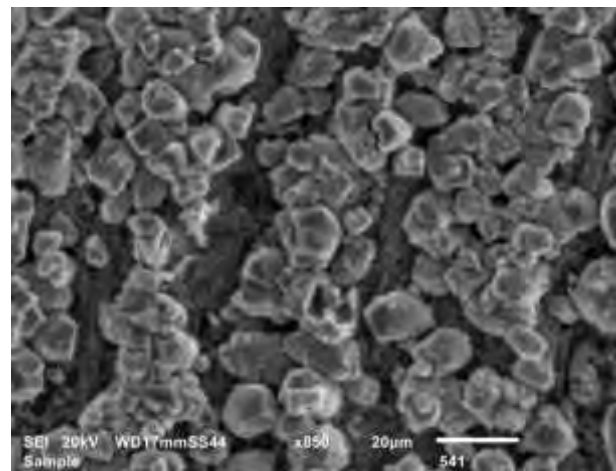
<100% Surface Coverage

# Aqueous $K_2CO_3$ Solutions – SEM / EDX

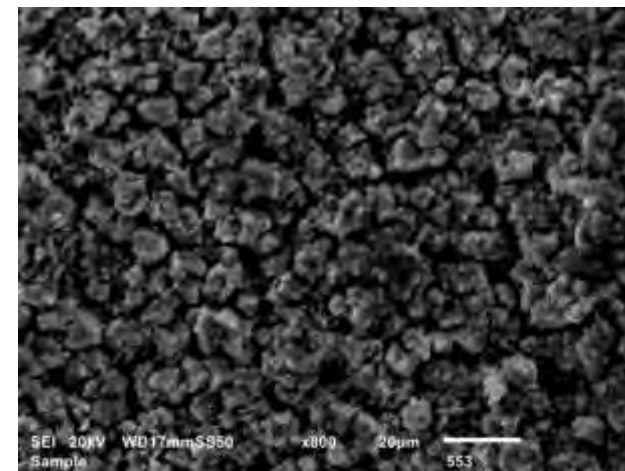
DAY 7



DAY 21



DAY 28

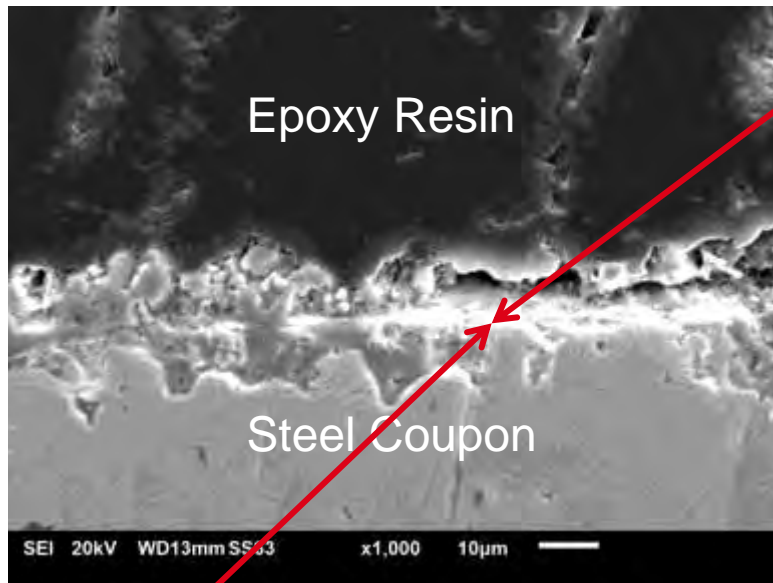


↑ Surface Coverage



# Aqueous $K_2CO_3$ Solutions – SEM / EDX

DAY 7

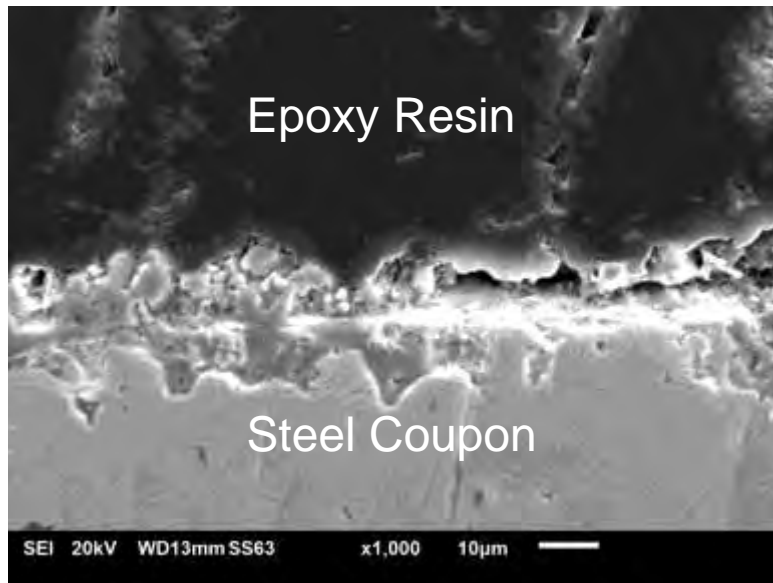


Passivation layer

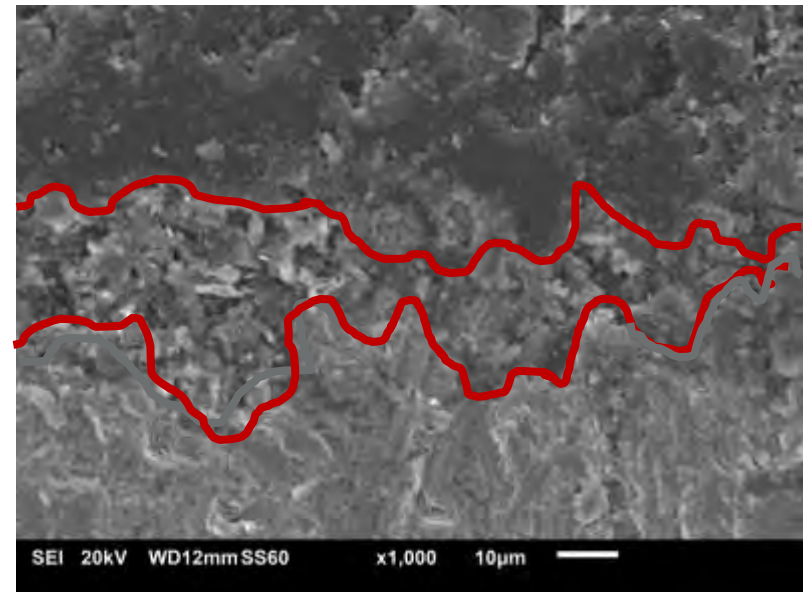
Element	Moles Ratio
C	16.11
O	44.98
Fe	38.91

# Aqueous $K_2CO_3$ Solutions – SEM / EDX

DAY 7



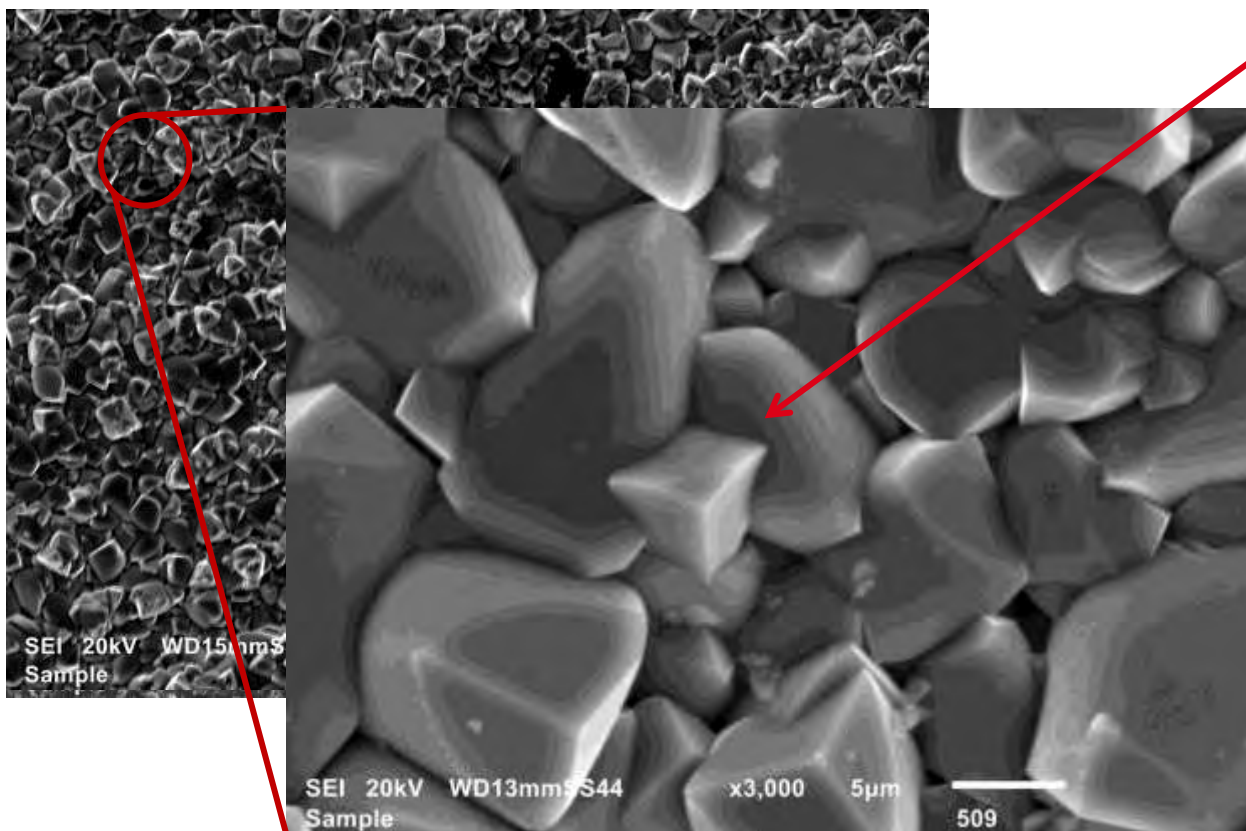
DAY 21



Element	Moles Ratio
C	16.11
O	44.98
Fe	38.91

## Aqueous MDEA Solutions – SEM / EDX

DAY 7



Element	Mole Ratio
C	18.92
O	54.07
Fe	26.52

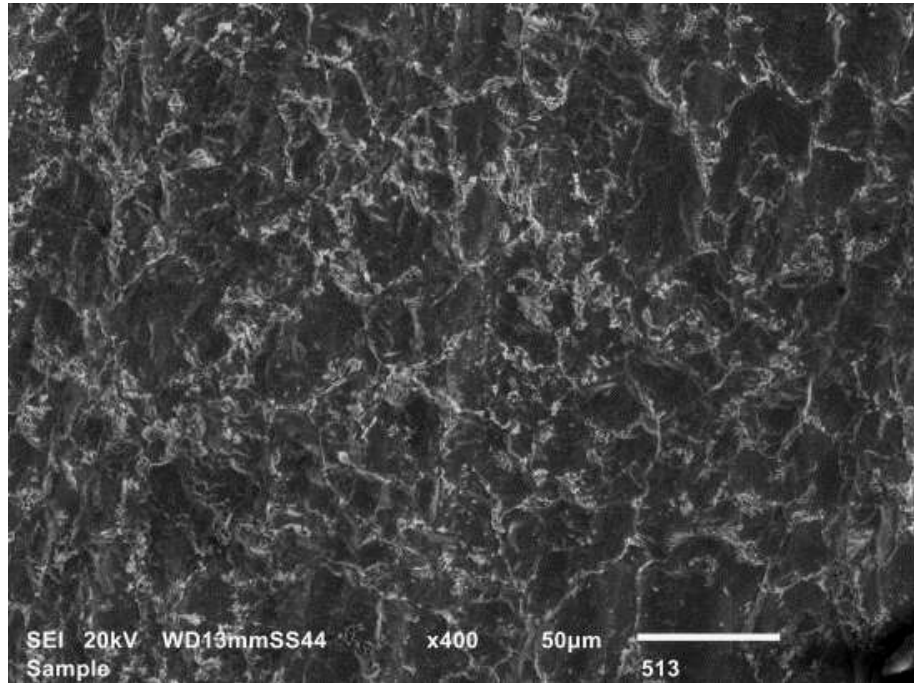
Suggests **FeCO<sub>3</sub>**

100% Surface Coverage

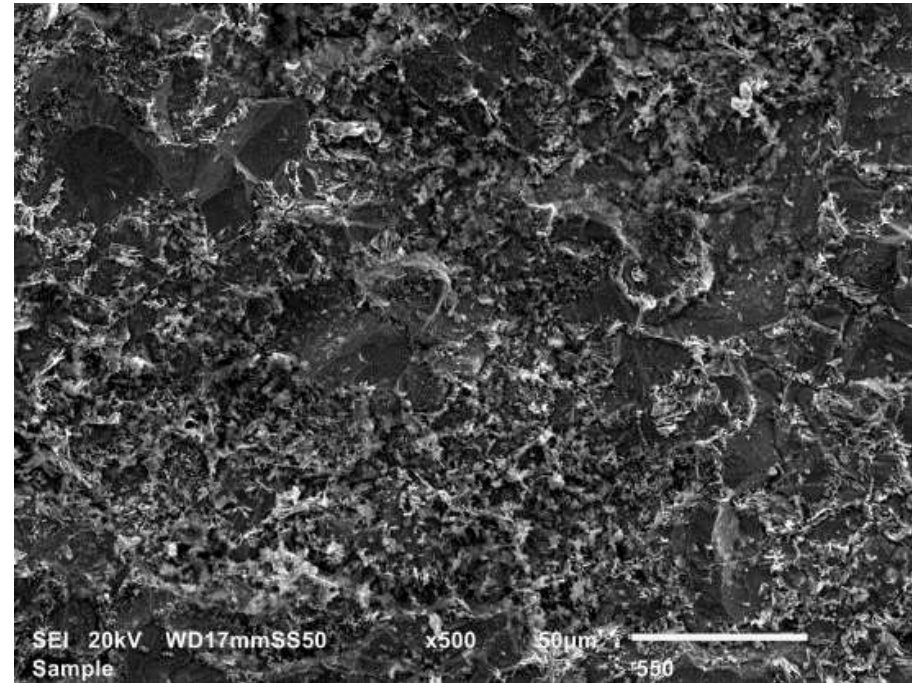


# Aqueous AEP Solutions – SEM / EDX

DAY 7



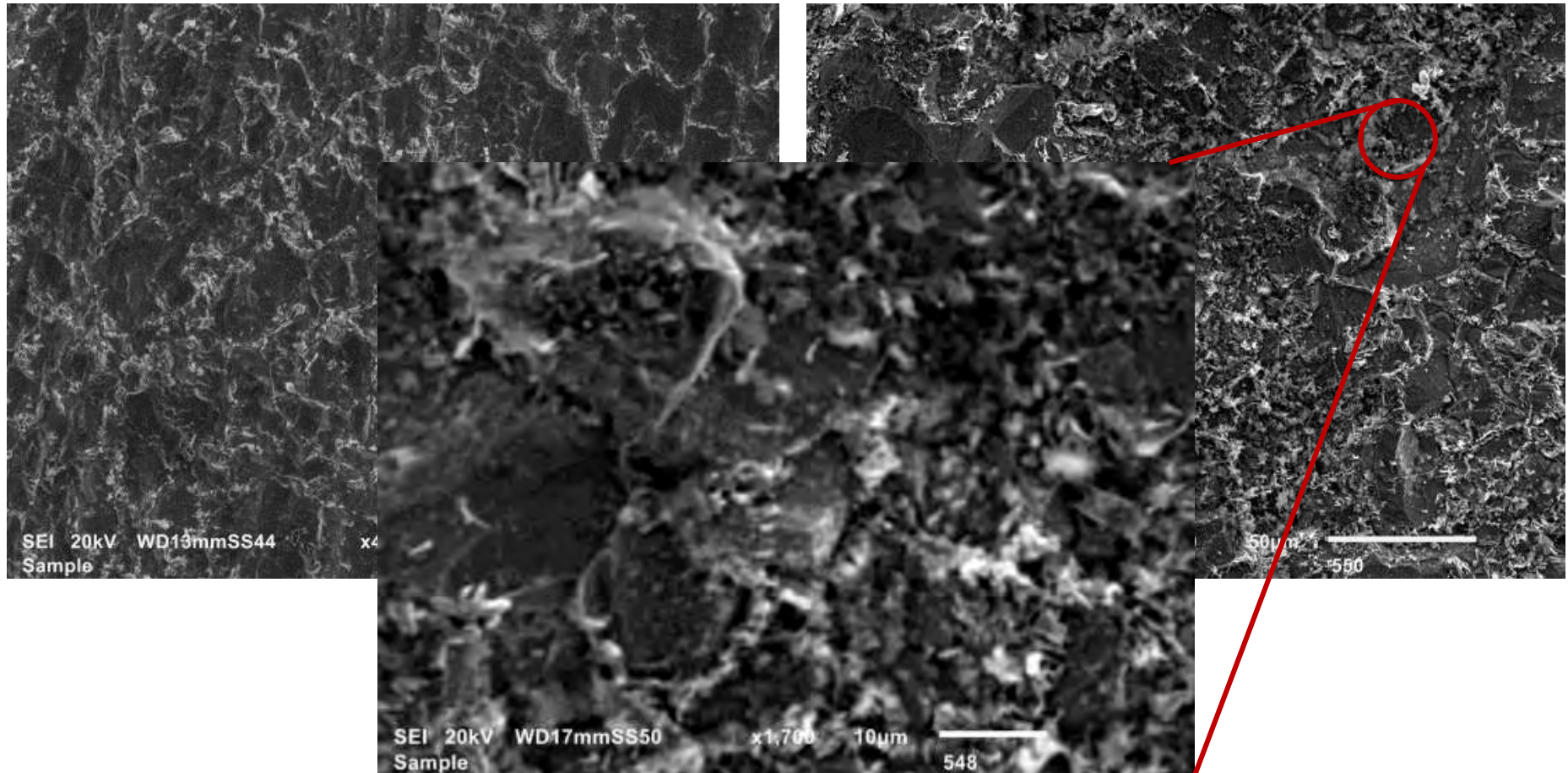
DAY 28



# Aqueous AEP Solutions – SEM / EDX

DAY 7

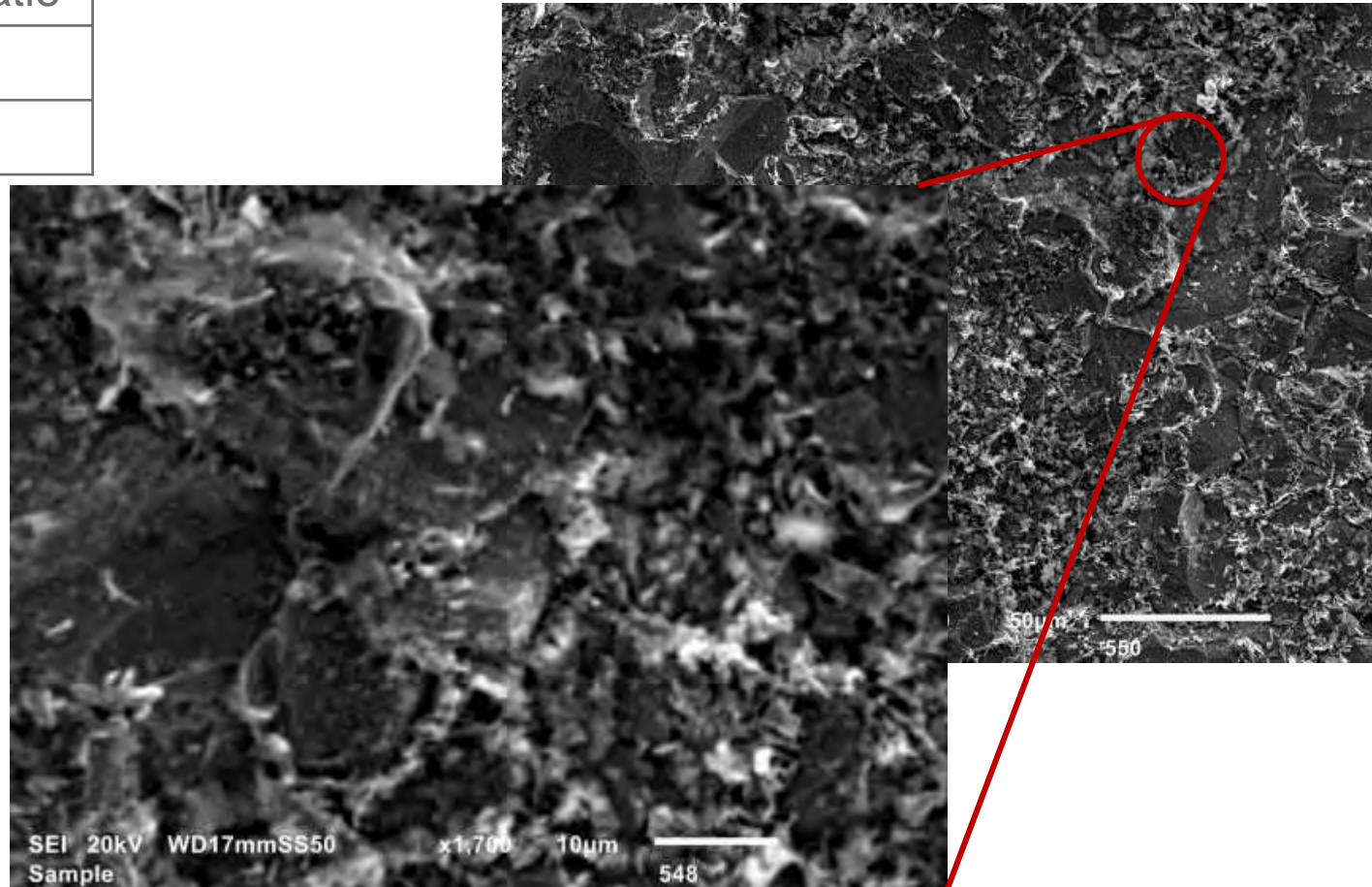
DAY 28



# Aqueous AEP Solutions – SEM / EDX

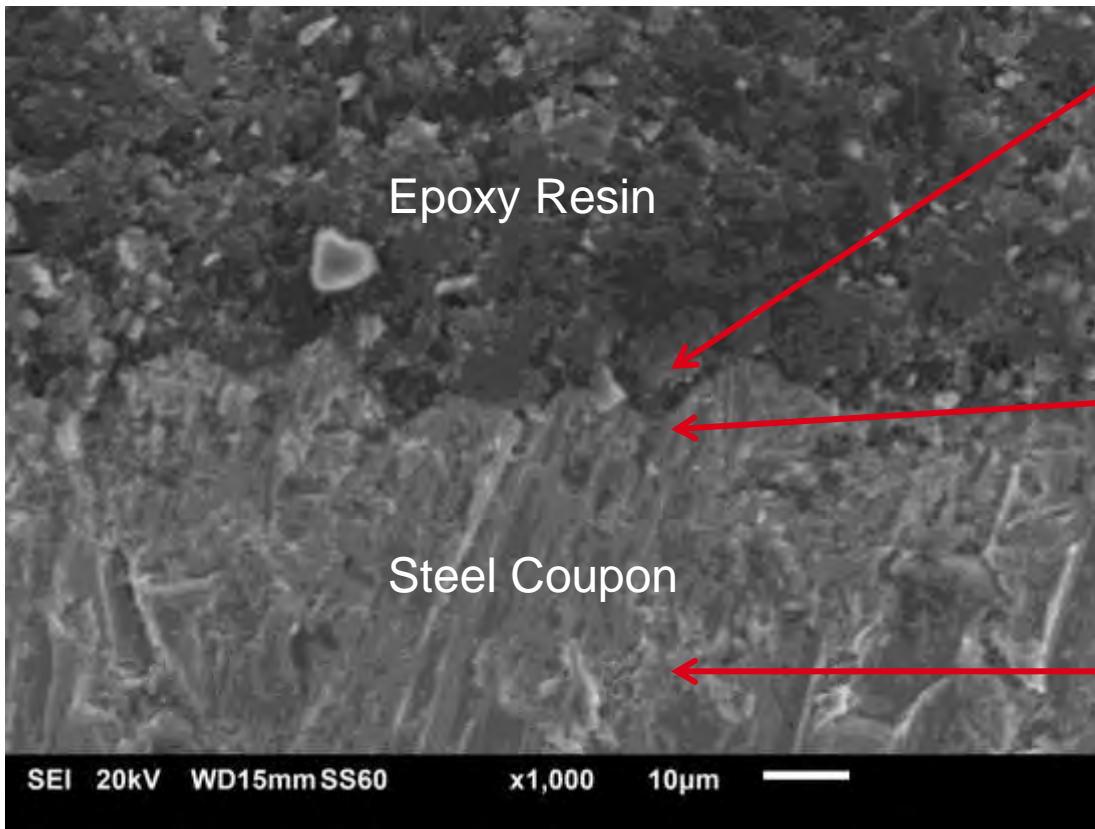
DAY 28

Element	Mole Ratio
Mn	1.05
Fe	98.63



# Aqueous AEP Solutions – SEM / EDX

## Cross-Section at Day 28



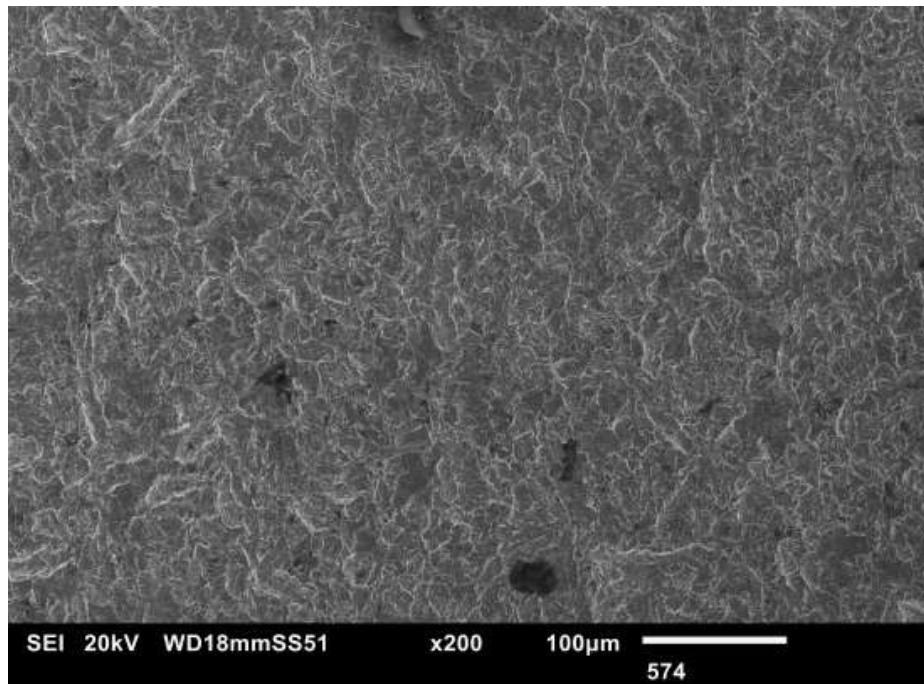
Element	Mole Ratio
C	85.97
O	12.30
Fe	1.72

Element	Mole Ratio
C	28.01
Fe	71.99

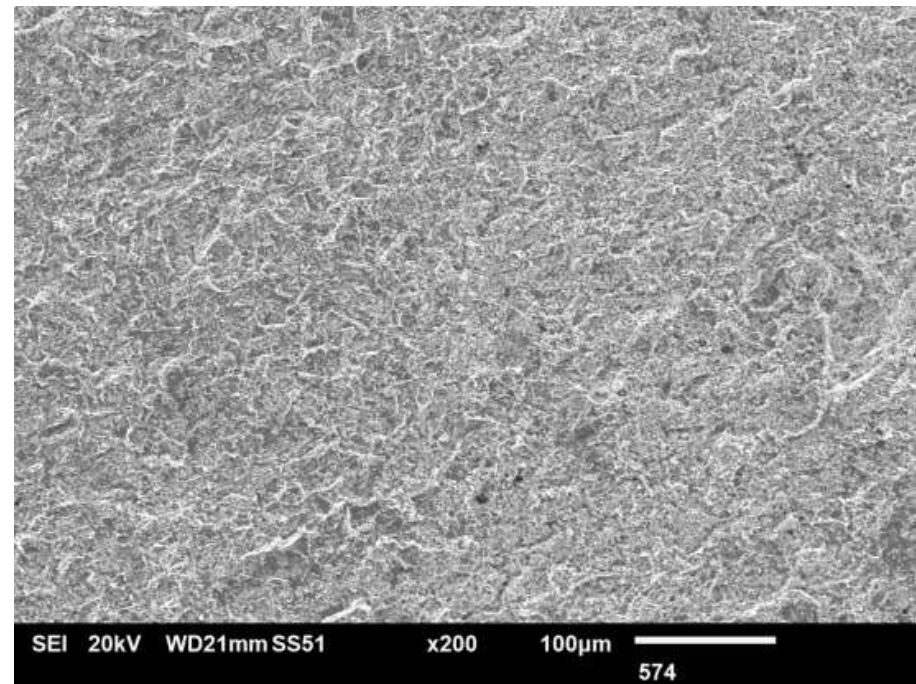
Element	Mole Ratio
Fe	100

# Aqueous DETA Solutions – SEM / EDX

DAY 7

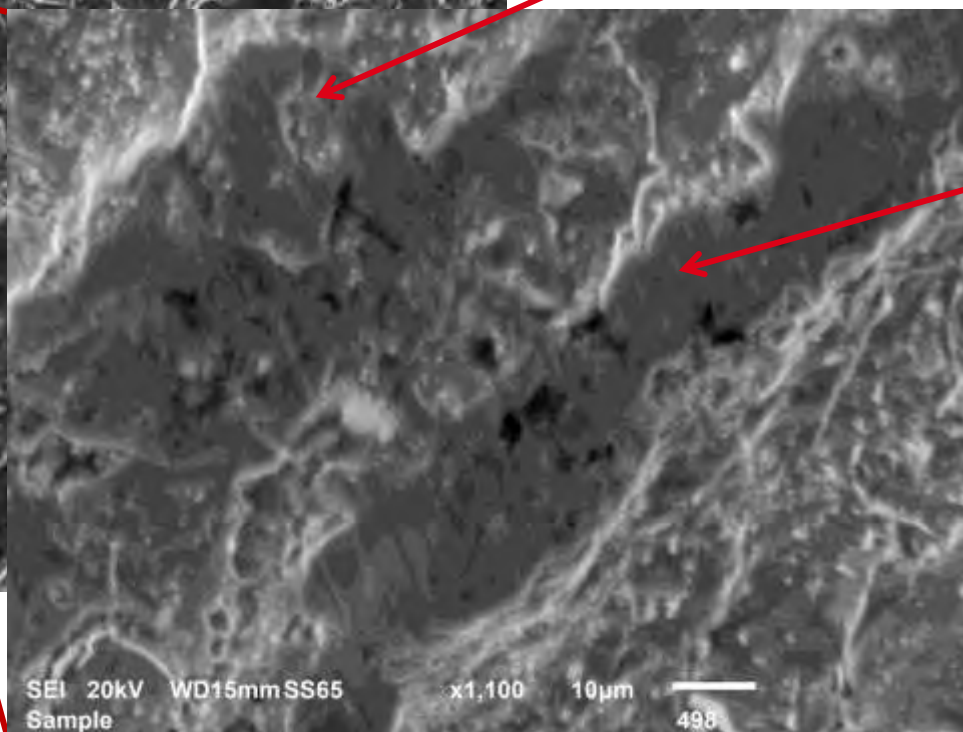
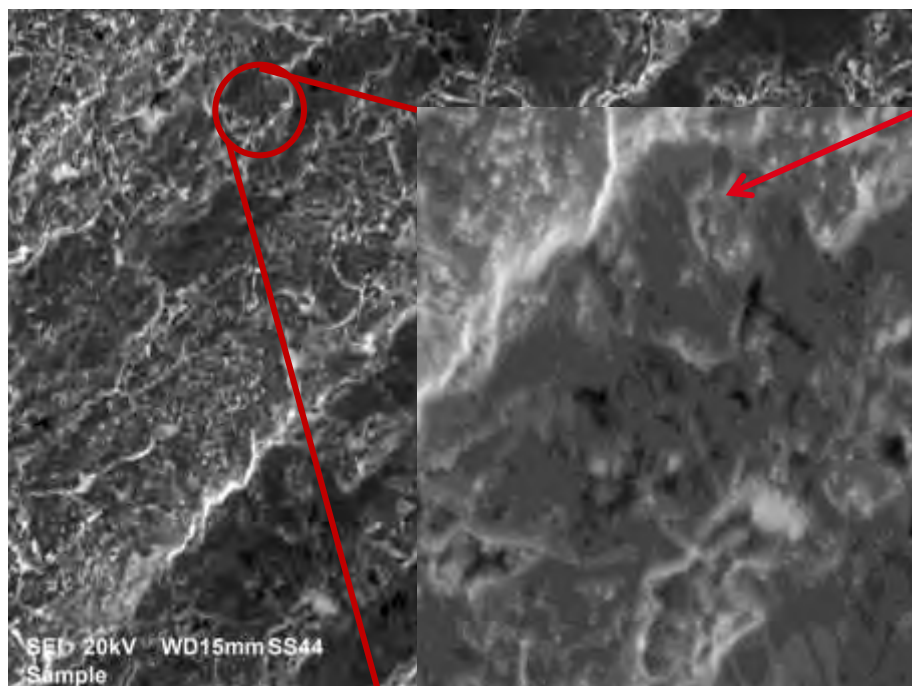


DAY 28



# Aqueous MEA Solutions – SEM / EDX

DAY 7



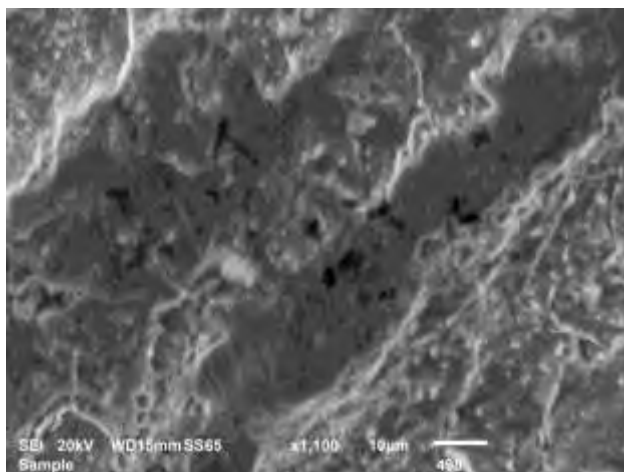
Element	Mole Ratio
C	7.85
Fe	92.15

Element	Mole Ratio
C	59.34
O	10.73
Fe	29.12
Other	0.81

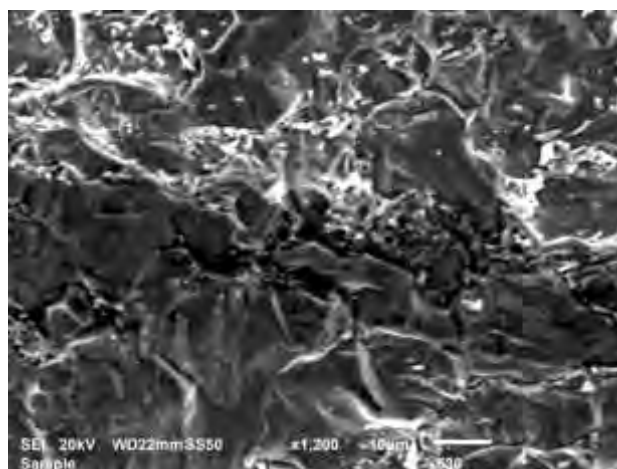
Non-uniformity

# Aqueous MEA Solutions – SEM / EDX

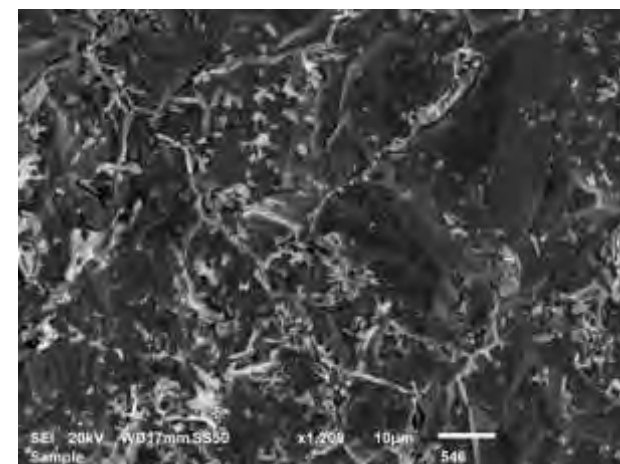
DAY 7



DAY 14



DAY 21



Element	Mole Ratio
C	7.85
Fe	92.15

Element	Mole Ratio
C	11.24
Fe	88.76

Element	Mole Ratio
Mn	1.07
Fe	98.93

## Summary of Binary Aqueous Amine Solutions

	MEA	MDEA	DETA*	AEP	AMP	K <sub>2</sub> CO <sub>3</sub> *
Hanging film	C	P	C	C	P	P
ICP – OES	?	P	C	C	?	P
SEM / EDX	C	P	C	C	P	P
<b>Overall</b>	<b>C</b>	<b>P</b>	<b>C</b>	<b>C</b>	<b>P</b>	<b>P</b>

**Corrosion**  **Passivation**

AEP DETA\* MEA AMP MDEA K<sub>2</sub>CO<sub>3</sub>\*



## Conclusions

Traditional 'hanging film' method is an imprecise method for distinguishing corrosion from passivation and determining the rate of change

Elemental analysis of both the solution and substrate provide strong indicators of the corrosion and passivation occurring

**Corrosion**

**Passivation**

AEP DETA\*

MEA

//

AMP

MDEA

K<sub>2</sub>CO<sub>3</sub>\*



Aqueous amine multi-component solutions can overcome the presence of highly corrosive species

Rate of change observed on the substrate requires additional analysis

## Acknowledgements

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This work is funded in part by the Department of Energy and Climate Change and Carbon Clean Solutions.

Contributions to this work were made by: Miss Y. Zhao and Dr. J. Hall.

# Understanding and addressing corrosion due to amine solvents in post-combustion carbon capture processes

KL Sedransk Campbell, DR Williams  
Department of Chemical Engineering, Imperial College

UKCCSRC Biannual Meeting  
April 21 2015