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Sebelas Maret University (UNS-Solo)
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Rehabilitation of Corrosion of Reinforcement for Sustainable Construction

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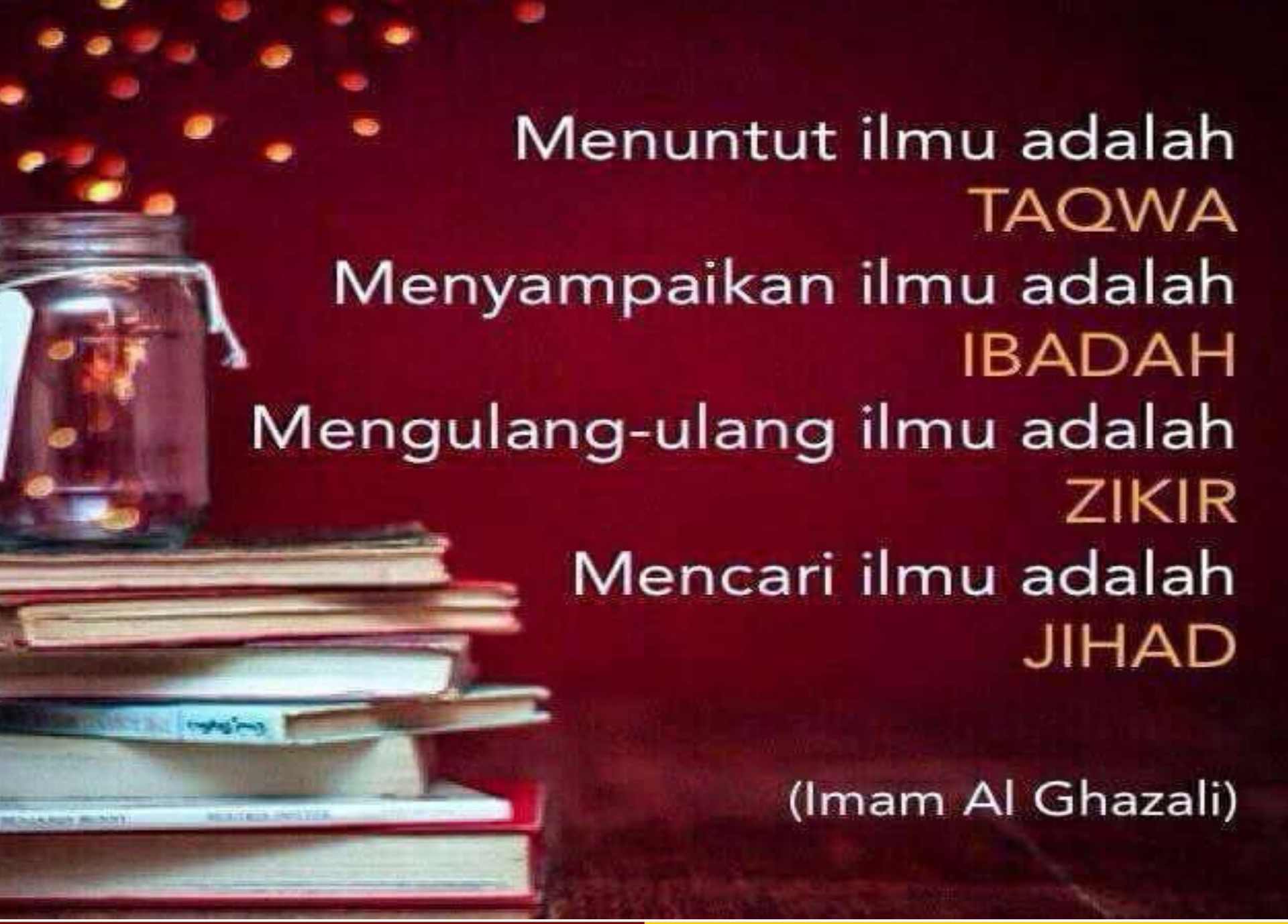
PRESENTATION OUTLINE

- **Aluan** *(Ucapan salam dan selawat, Bersyukur ke hadrat Allah, Terima kasih, UTM in Brief)*
- **Introduction**
- **Reality of Construction**
- **Mechanism and Causes of Corrosion**
- **Effect of Corrosion**
- **Corrosion Prevention and Control**
- **The way forward**
- **Conclusions**
- **Acknowledgement**


Menuntut ilmu adalah
TAQWA
Menyampaikan ilmu adalah
IBADAH
Mengulang-ulang ilmu adalah
ZIKIR
Mencari ilmu adalah
JIHAD
(Imam Al Ghazali)

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DEPARTMENTS

Structures & Materials

Geotechnics & Transportations

Water & Environmental Engineering

- **Post Graduate**
- **External Programme**

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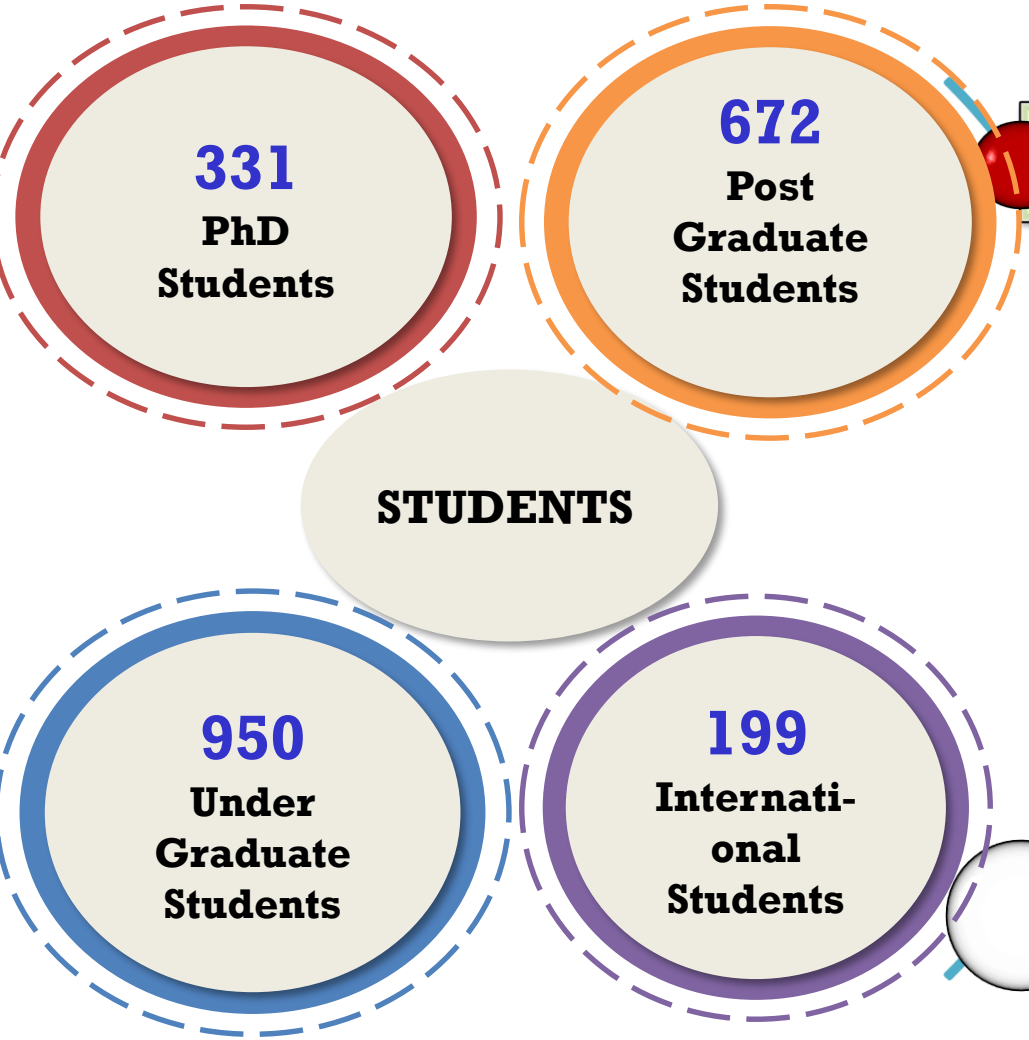
Facts & Figures



125 Academic Staff

42 Admin Staff

42 Technical Staff

59 students won awards at national and international level

85 % graduates employability (59th UTM Convocation)

Ratio Staff Student

1:8

Shanghai Ranking – Global Ranking of Academic Subject

ACADEMIC RANKING OF WORLD UNIVERSITIES SINCE 2003

University	Subjects	World Ranking
UTM	Civil Engineering	76-100
	Energy Science & Engineering	151-200
	Mechanical Engineering	201-300
	Material Science & Engineering	401-600
UM	Energy Science & Engineering	101-150
	Mechanical Engineering	201-300
	Chemical Engineering	201-300
	Electrical Engineering	301-400
	Material Science & Engineering	401-600
USM	Chemical Engineering	101-150
	Environmental Science & Engineering	201-300
	Material Science & Engineering	401-600

UTM Global Rankings 2017

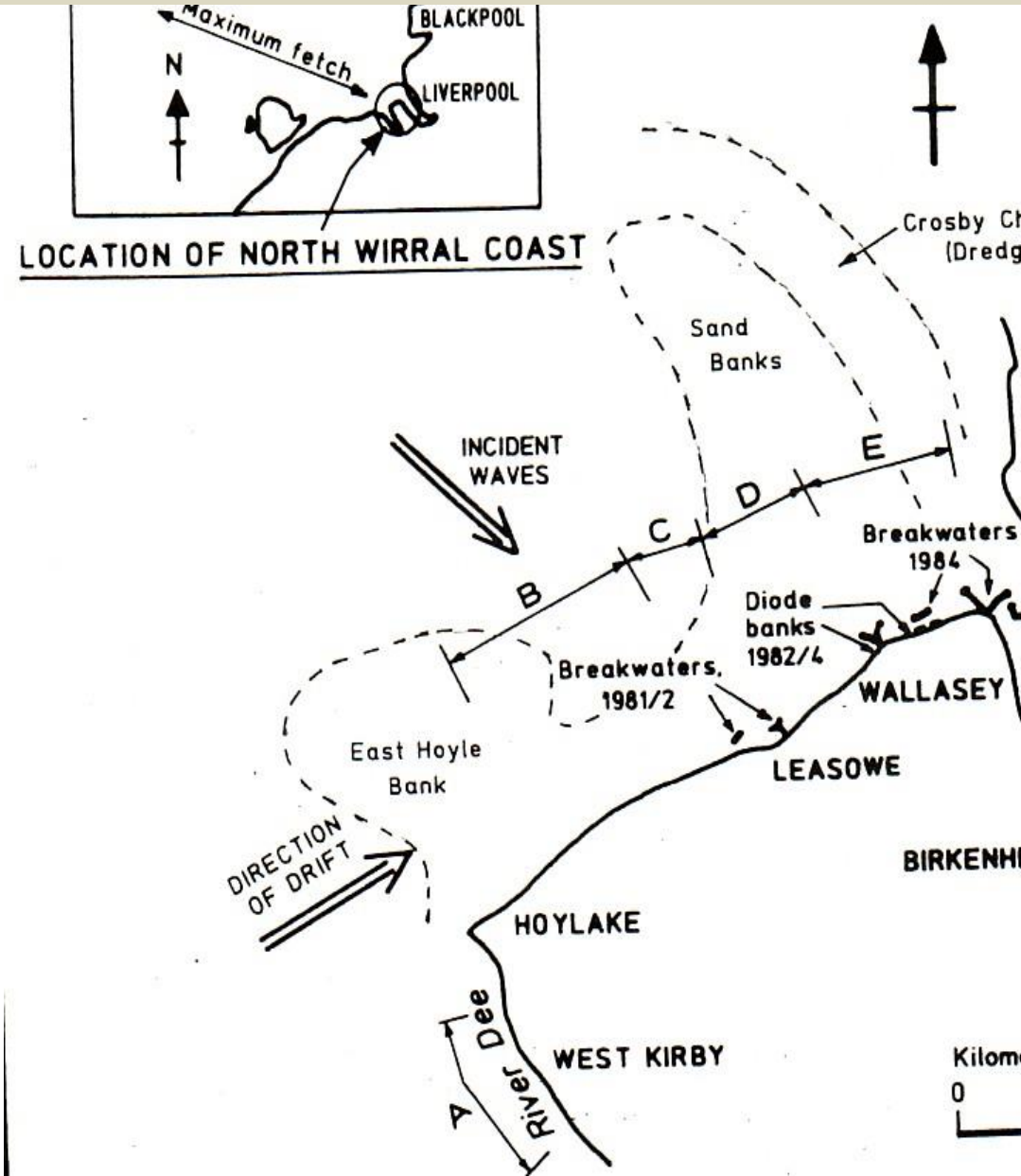
QS WORLD UNIVERSITY RANKINGS by subject

6 subjects in Top 100

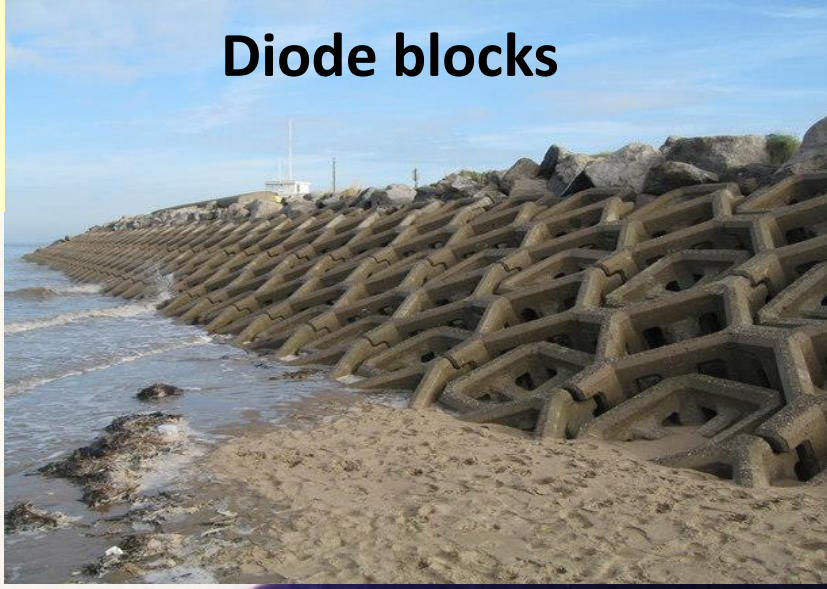
QS Ranking	Subjects
Top 100	Built Environment/Architecture Chemical Engineering; Electrical & Electronics Engineering, Mechanical Engineering (up) Civil & Structural Engineering (up) Computer Sciences & Information System (up)
Top 150	Environmental Sciences; (up) Material Sciences; (up) Agriculture & Forestry (new addition)
Top 200	Education (up)
Top 250	Mathematics, Chemistry (up)
Top 300	Linguistics (new addition) Modern Languages (new addition)
Top 350	Physics & Astronomy
Top 400	Biological Sciences (new addition)

INTRODUCTION

University of Liverpool 1989-90



CORROSION Monitoring



Reef blocks

Mermaid unit

INTRODUCTION (cont.)

- ✓ Corrosion is commonly defined as the **deterioration of a substance (usually a metal) or its properties** because of a reaction with its environment.
- ✓ Like other natural hazards, corrosion can cause dangerous and expensive damage to everything such as:

Automobiles

Home appliances

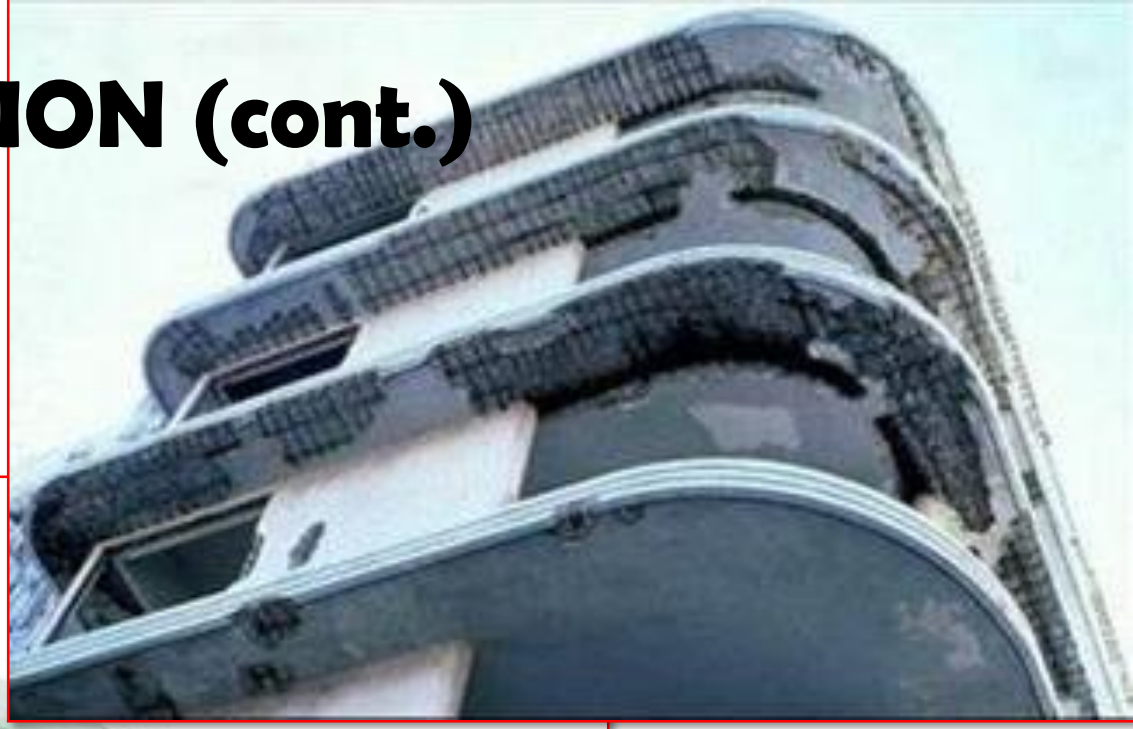
INTRODUCTION (cont.)

Drinking water systems

Pipelines

INTRODUCTION (cont.)

Public buildings

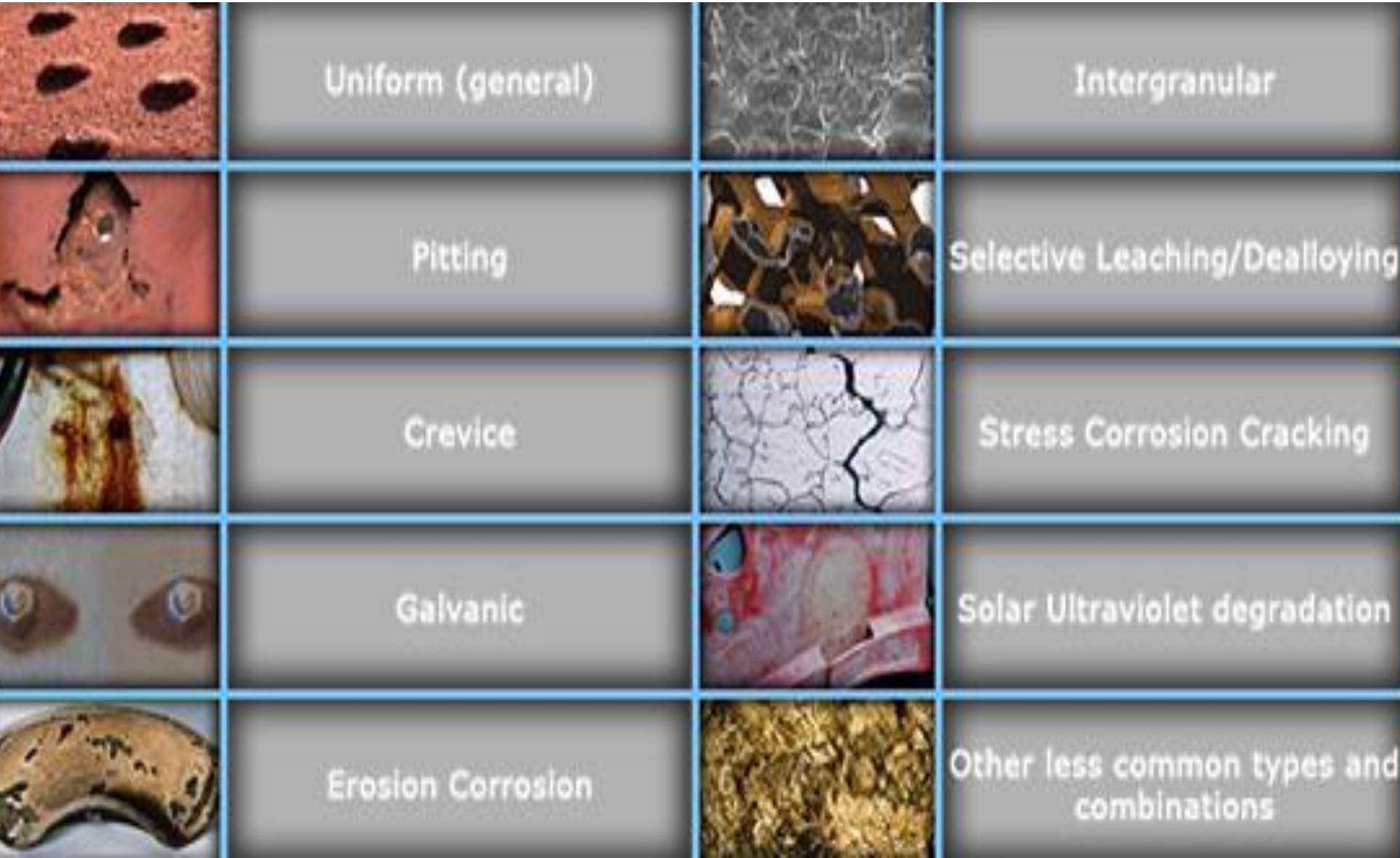


Bridges

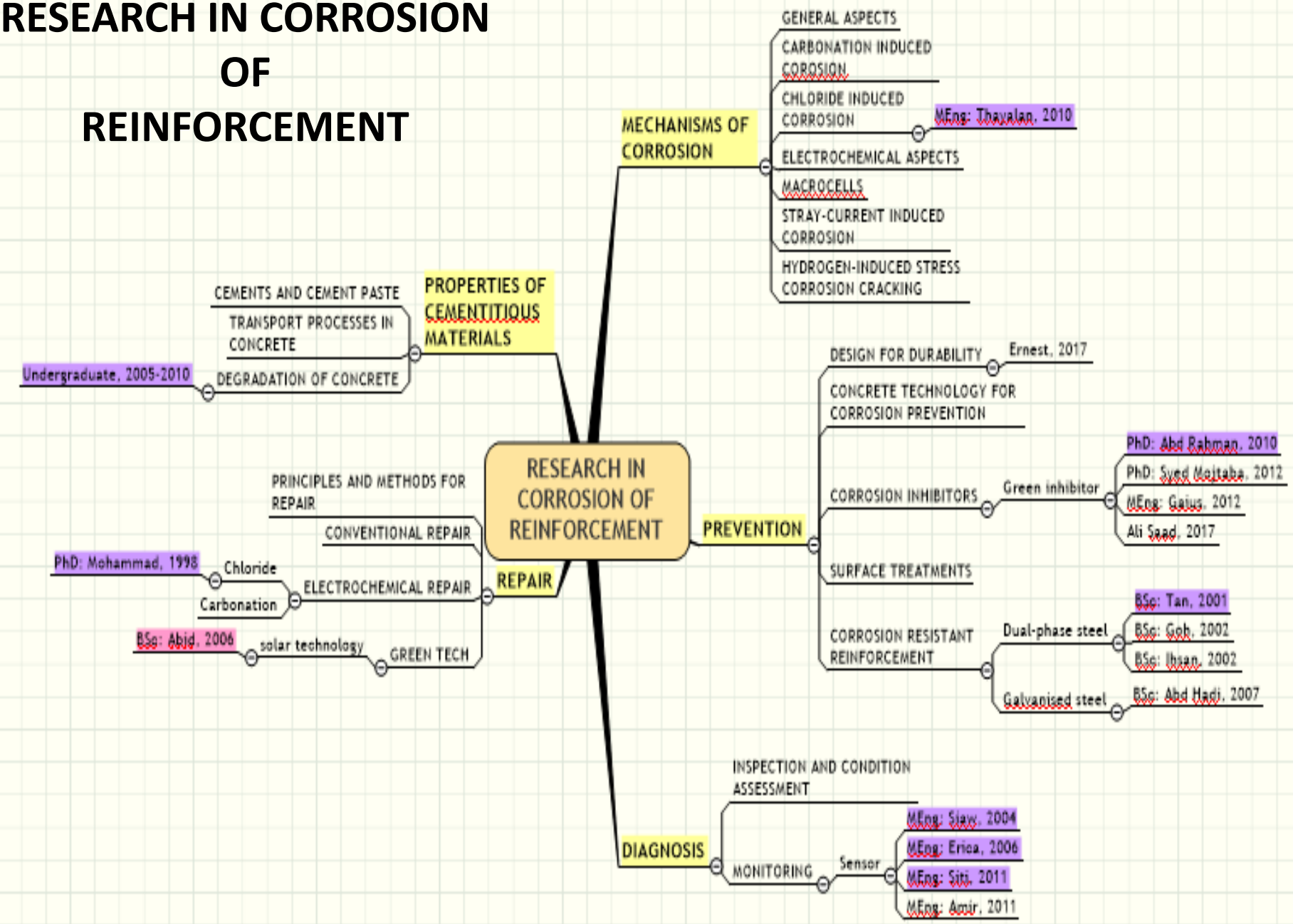
INTRODUCTION (cont.)

The dilapidation of concrete structures caused by corrosion of embedded steel

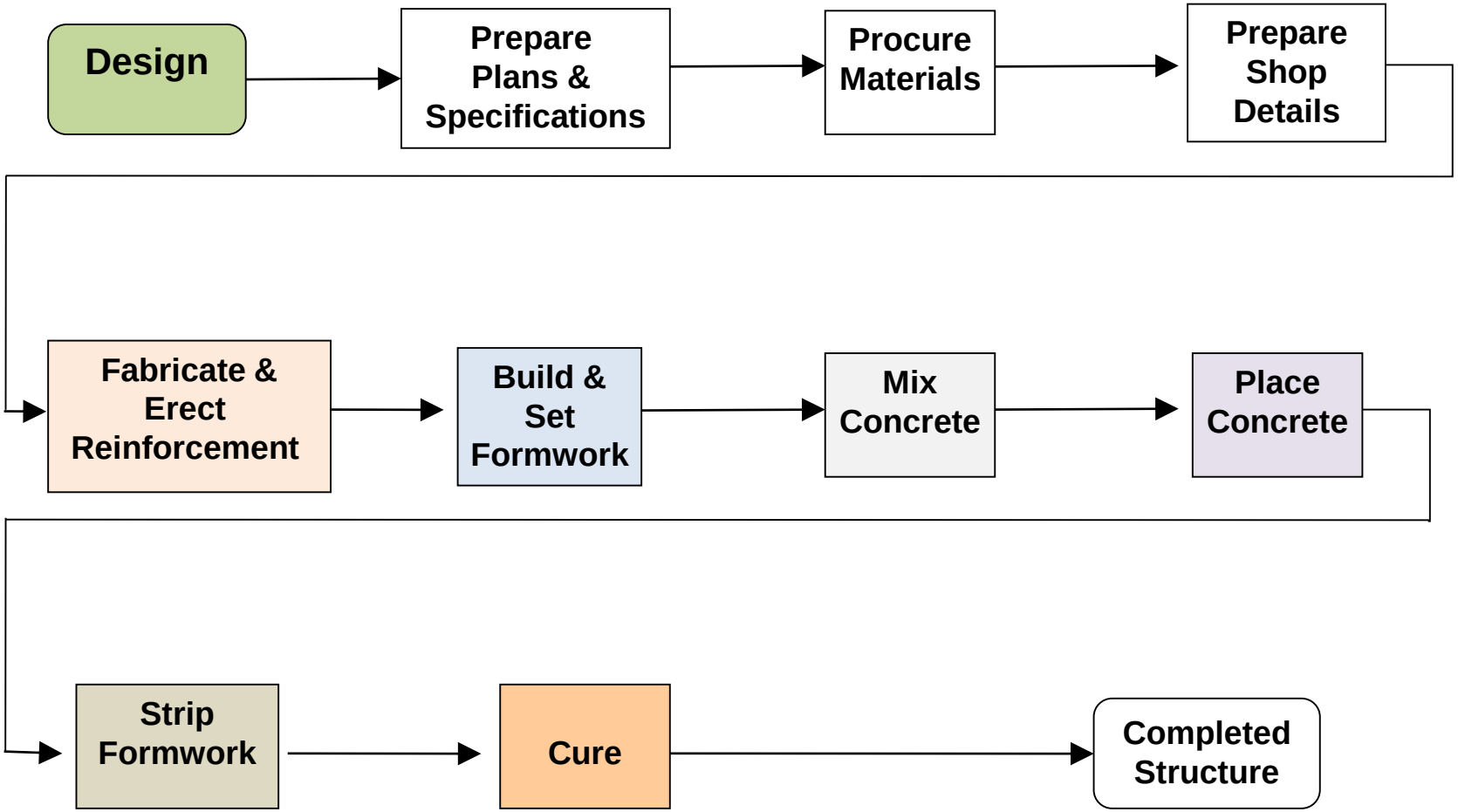
TYPES OF CORROSION



RESEARCH IN CORROSION OF REINFORCEMENT



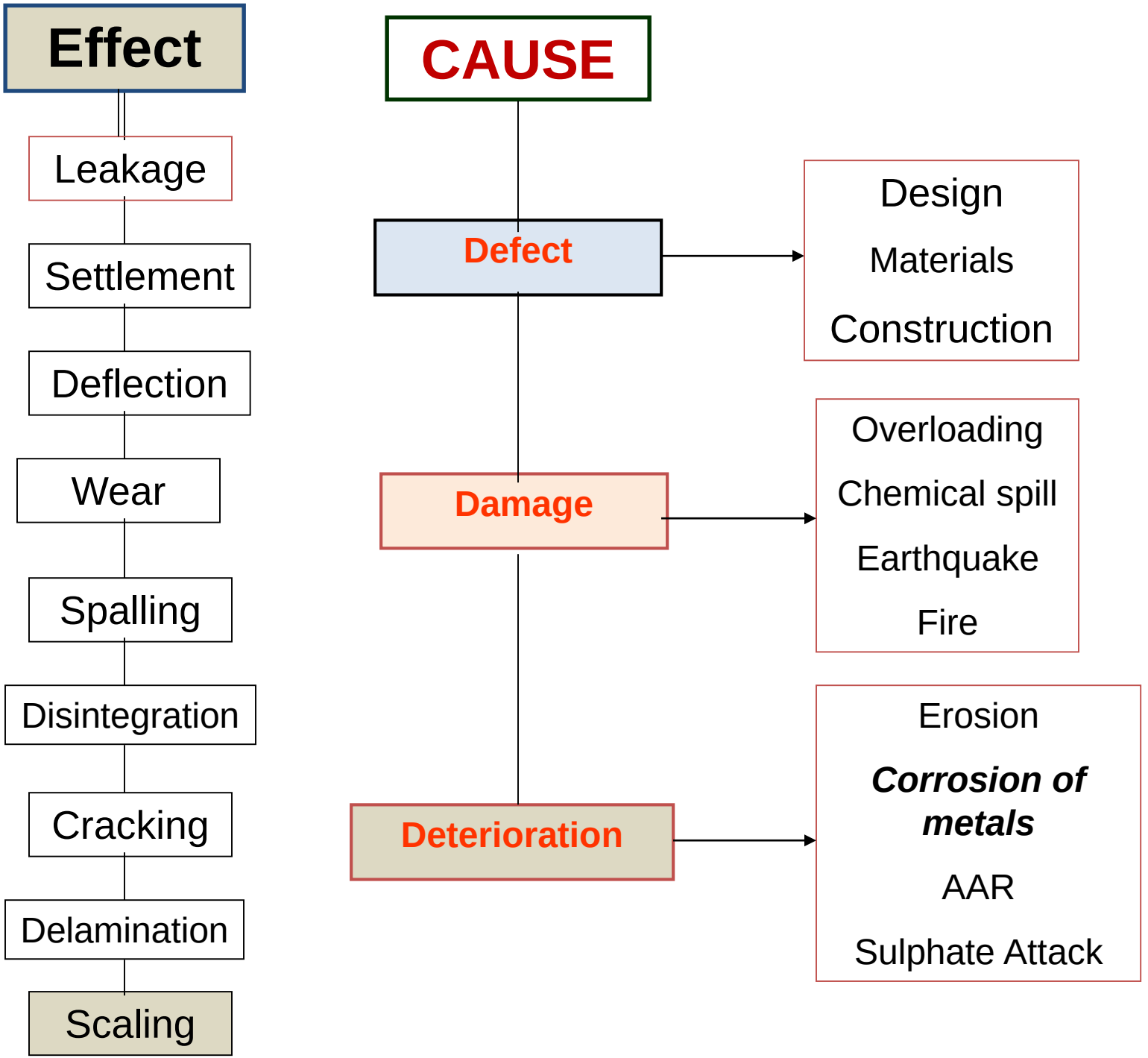
STAGES IN CONSTRUCTION



True improved performance of structures is hard to achieve by improving the material characteristic alone because of complex nature of environment.

Other factors that considered necessary are:

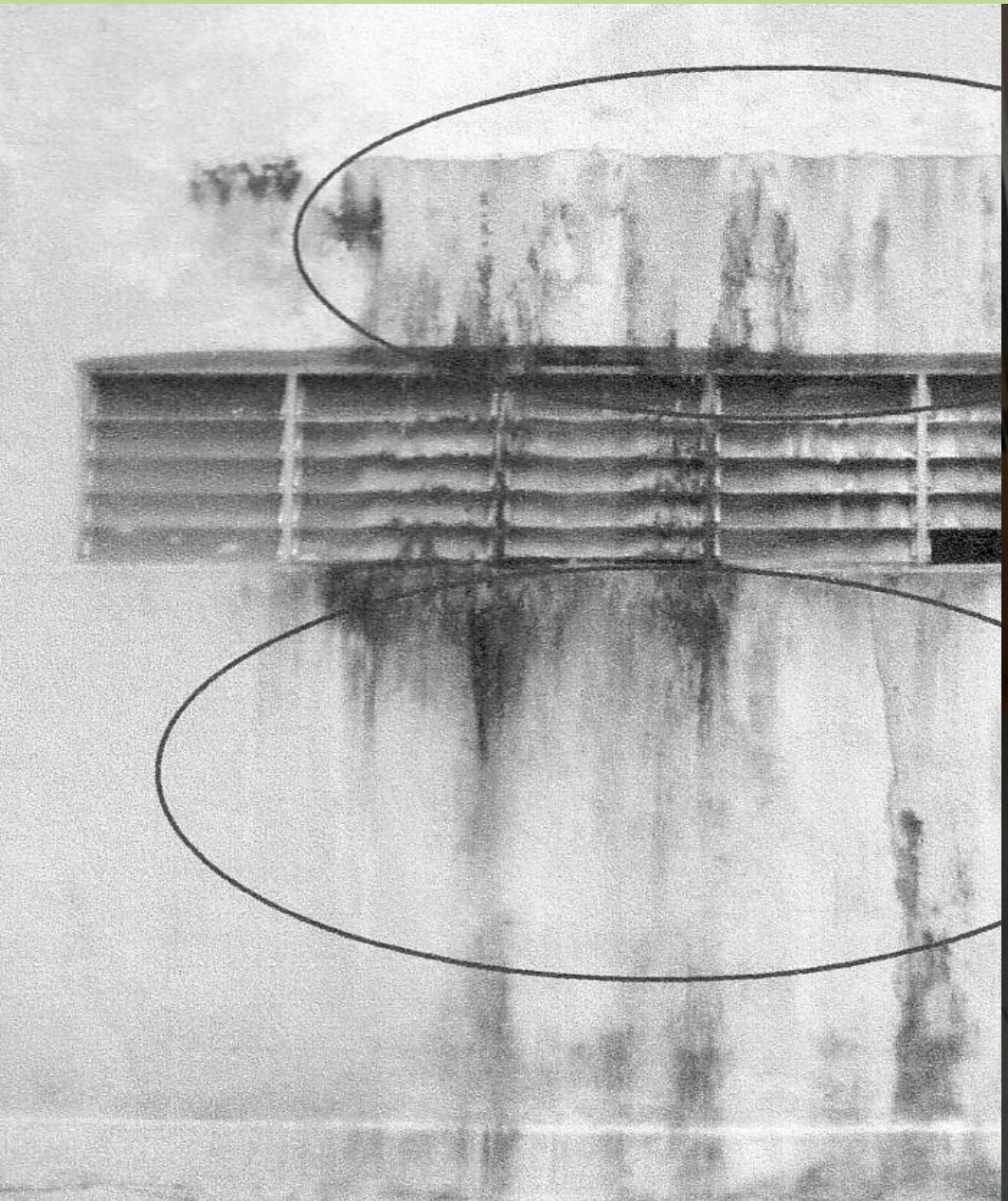
- the elements of architectural and structural design,
- process of execution, and inspection and
- maintenance procedure, including preventive maintenance.


Effect
Leakage
Settlement
Deflection
Wear
Spalling
Disintegration
Cracking
Delamination
Scaling
CAUSE
Defect
Design
Materials
Construction
Damage
Overloading
Chemical spill
Earthquake
Fire
Deterioration
Erosion
Corrosion of metals
AAR
Sulphate Attack

Design and Detailing – Flat roof

Workmanship - Water Ponding

Quality - Humidity and Water Leakage



Lack of Maintenance

Soil movement

Construction defect/weakness

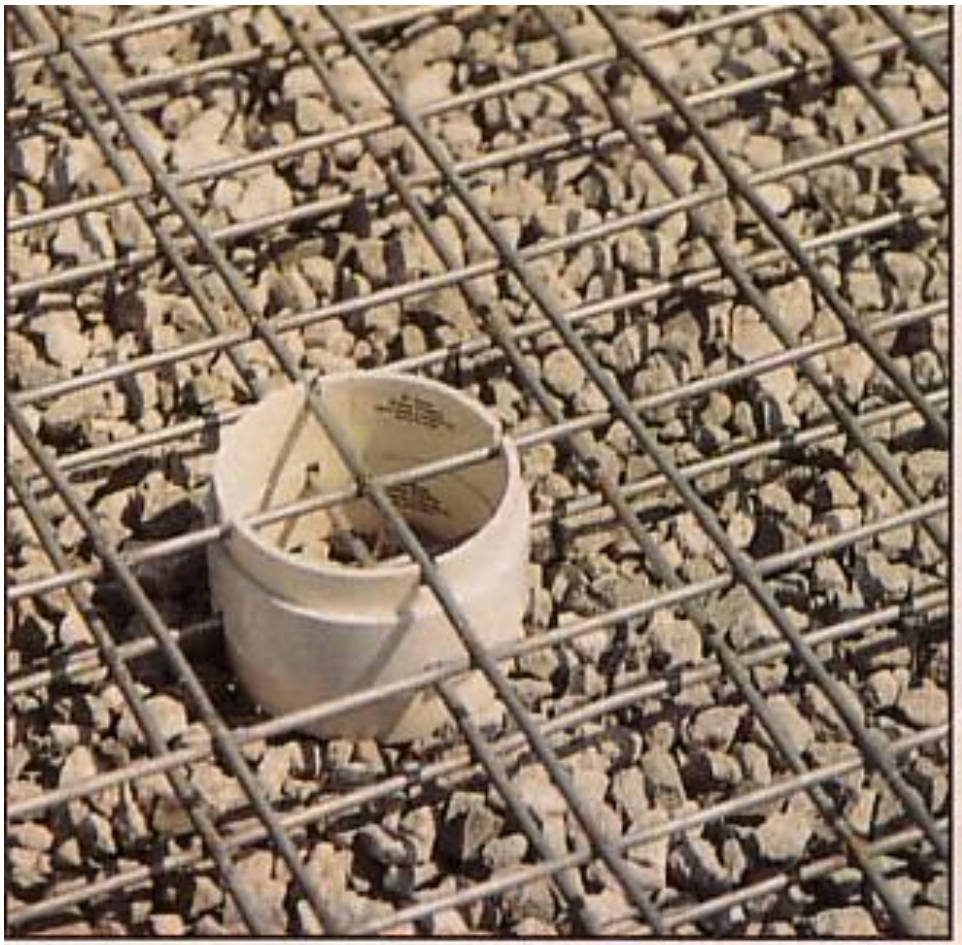
Construction defect/weakness

Highly Congested Reinforcement

Improper Bar Placement

Cover Thickness

Concrete block (used to support bottom layer)
Wire chairs (used to support top layer)



Plastic support designed for two layers of WWR

Honeycomb

Deterioration
Corrosion of Reinforcement

1. CLIMATE IMPACT ON REINFORCED CONCRETE

- The effects of climate on concrete durability are propelled by the concrete **micro-environment parameters.**
- In 2007, Haque et al. proclaimed the need for characterization of climate parameters in the natural climate and their responses in concrete based on climate zones for adequate design of durable concrete structures.

ERNEST ITUMA EGBA

Year	Authors	Area of study	Climate	Climate Parameter (CP)		Response of CP in concrete		Corrosion behaviour	Concrete behaviour	
				T	RH	T	RH		BS	FS
			Tropical							
1997	Castro *et al.*	Yucatan, Mexico	Savanna	√	√			√		
1998	Veleva *et al.*	Yucatan, Mexico	Savanna	√	√	√	√	√		
2002	Pech-Canul & Castro	Yucatan, Mexico	Savanna	√	√			√		
2007	Trocónis de Rincón *et al.*	Venezuela	Monsoon	√	√			√		
2010	Meira *et al.*	Pessoa, Brazil	Savanna	√	√			√		
2013a	Castañeda *et al.*	Havana, Cuba	Savanna	√	√			√		
2013b	Castañeda *et al.*	Havana, Cuba	Savanna	√	√			√		
2014	Muthulingam & Rao	Chennai, India	Savanna	√	√			√		
2015	Muthulingam & Rao	Chennai, India	Savanna	√	√			√		
2016	Ismail *et al.*	Malaysia	Rainforest	√	√			√		

he tropical climate

Records show that:

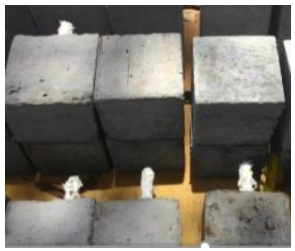
- 12.5 % of the research in the tropical savanna evaluated the responses of T and RH in concrete.
- 0 % of research in the monsoon and rainforest measured the responses of T and RH in concrete.
- There is no study on effects of corrosion on BS and FS of concrete exposed to the tropical climate.

Research Methodology

Concrete mix design proportion

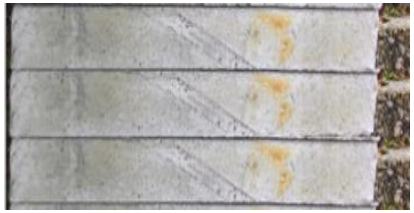
Material	Quantity (Kgm^{-3})
Cement	350.00
Fine aggregate	717.60
Coarse aggregate	1122.40
Water	210.00
Sodium chloride	17.50

EPRA



CBT

DTPT



MPR

SEM/EDX/XRD

Concrete Specimens

Exposure conditions

Notation	Description
L	Lab environ condition at ambient T of 24 ± 2 °C, and RH of 55 ± 5 %.
Ps	7 days W&D alternate cycle process in 3.5 % NaCl solution by wt of H_2O, and sheltered natural environment.
Pu	7 days W&D alternate cycle process in 3.5 % NaCl solution by wt of H_2O, and unsheltered natural environment.
S	Sheltered natural environment.
U	Unsheltered natural environment.
W	Continuous immersion in 3.5 % NaCl solution by wt of H_2O.

FSDT

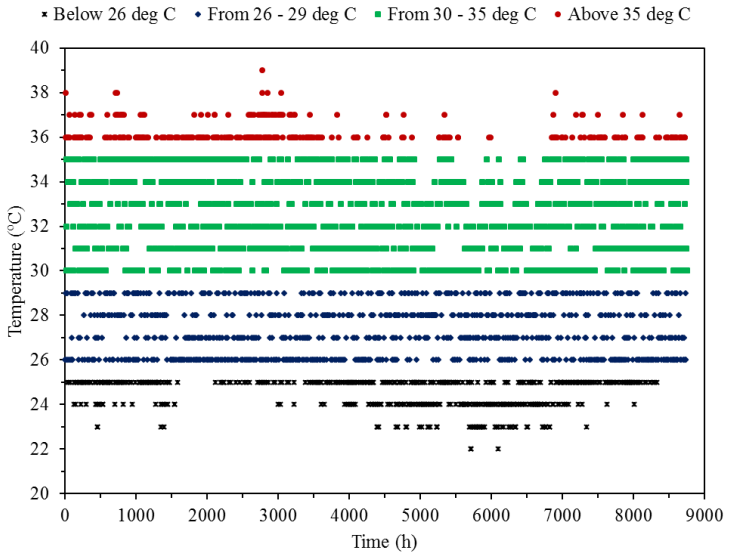
Results on Environmental Parameters Analysis

Basic properties of concrete used for the study

Compressive Strength (MPa)	Tensile Strength (MPa)	Flexural Strength (MPa)	Modulus of Elasticity (GPa)	UPV (km/s)	Water Absorption (%)	Thermal Conductivity (W/mK)
31.5	3.78	4.73	25.45	4.54	3.90	1.74

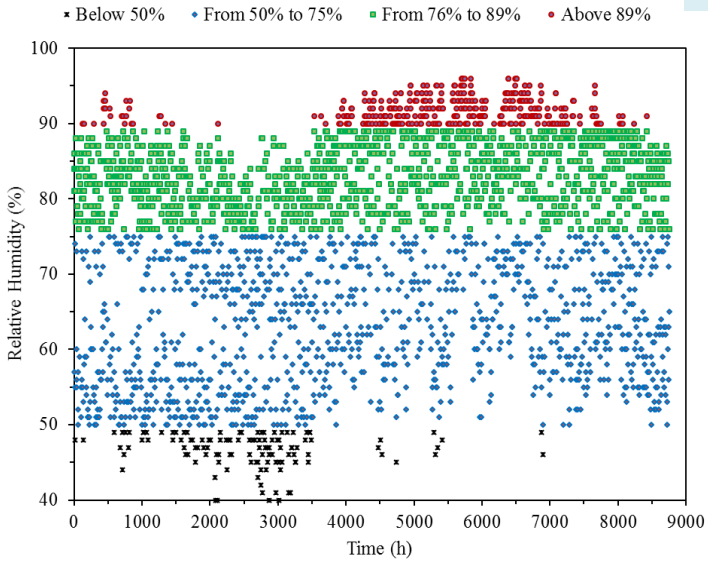
Pg. 113

Pg. 122



Analysis of 1 year natural climate temperature

Below 26 °C	--	18.29 %
From 26 – 29 °C	--	29.59 %
From 30 – 35 °C	--	42.29 %
Above 35 °C	--	09.83 %

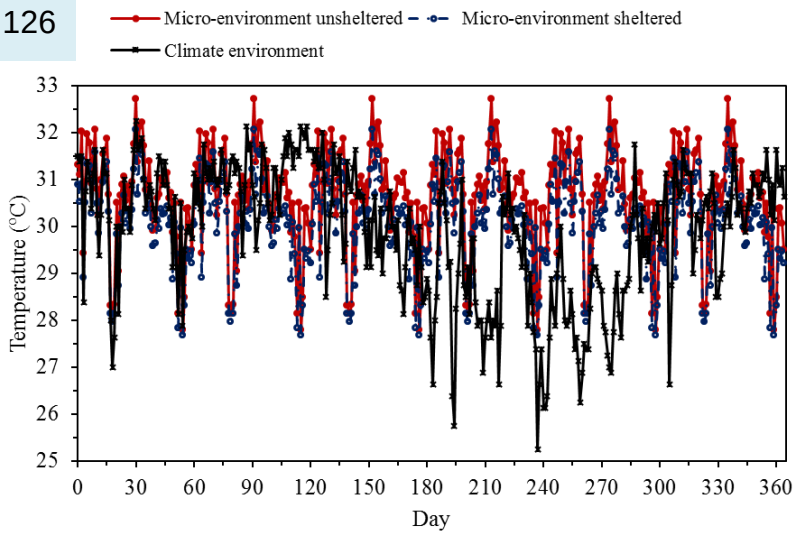


Analysis of 1 year natural climate relative humidity

RH below 50 %	--	04.14 %
RH from 50 % to 75 %	--	39.41 %
RH above 75 %	--	56.47 %

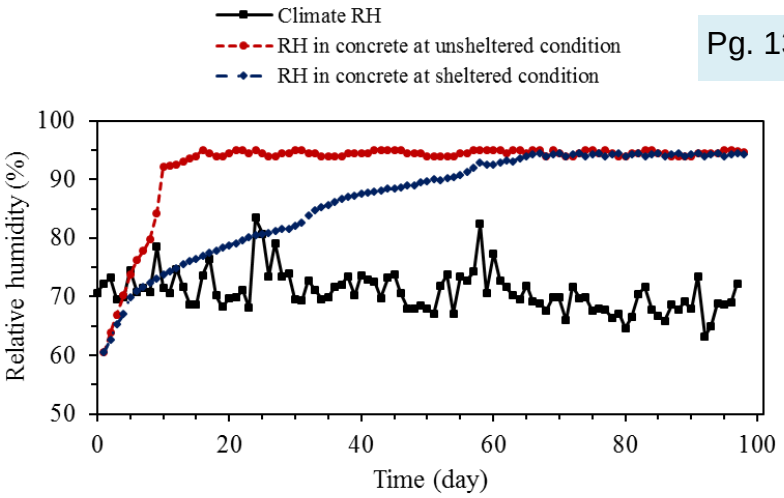
Results on Environmental Parameters Response in Concrete

Pg. 126



Response of climate temperature in concrete

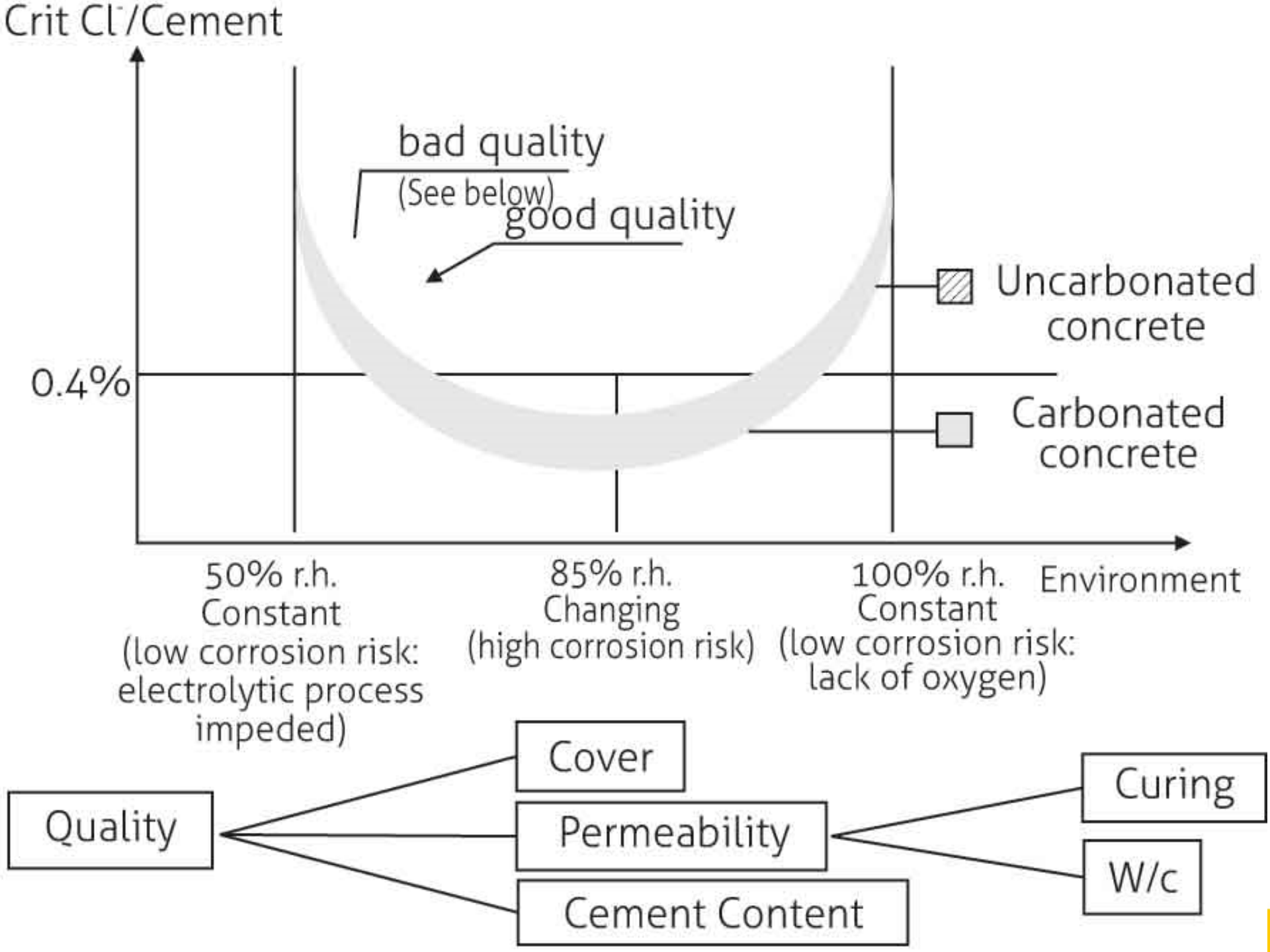
Pg. 138



Response of climate relative humidity in concrete

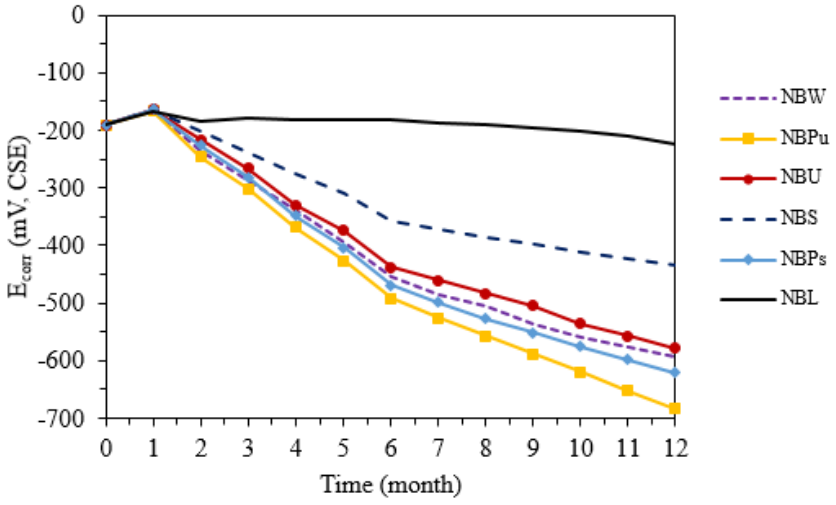
- Climate temperature is greater than **30 °C for 52.12 %** of time per annum.
- Concrete micro-environment temperature at unsheltered and sheltered environments is greater than **30 °C for 80.33 %** and **62.00 %** respectively, of time per annum.

- It takes **9 days** and **60 days for RH** to reach equilibrium level in concrete exposed to unsheltered and sheltered natural environments respectively.
- After attaining equilibrium level, RH in concrete exposed to the unsheltered and sheltered natural environment is **above 90 %.**


Crit Cl⁻/Cement
bad quality
(See below)
good quality
Uncarbonated concrete
0.4%
Carbonated concrete
50% r.h.
Constant
(low corrosion risk:
electrolytic process
impeded)
85% r.h.
Changing
(high corrosion risk)
100% r.h.
Constant
(low corrosion risk:
lack of oxygen)
Environment
Quality
Cover
Permeability
Cement Content
Curing
W/c

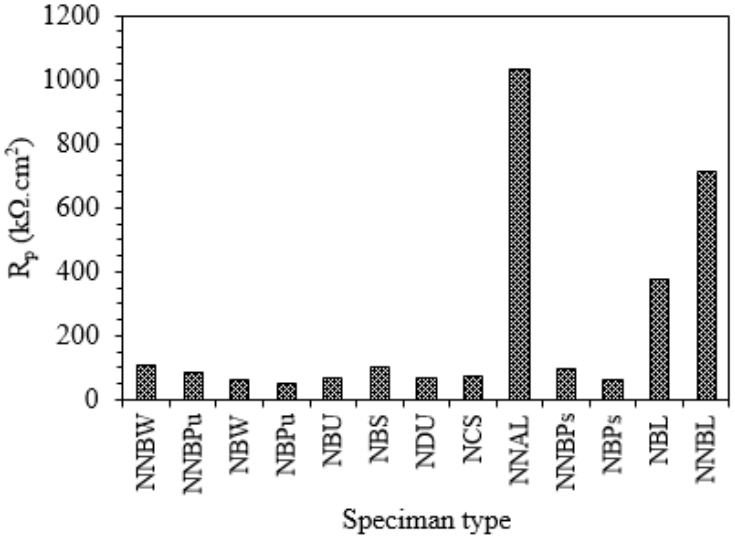
Results on Corrosion Behaviour in Concrete Under Natural Climate (E_{corr} & R_p)

Pg. 150



Corrosion potential as a function of time

Pg. 159



Polarization resistance as a function of time

The ratio of increase of corrosion potential E_{corr} for NBU specimen is 2.57 relative to the NBL specimen.

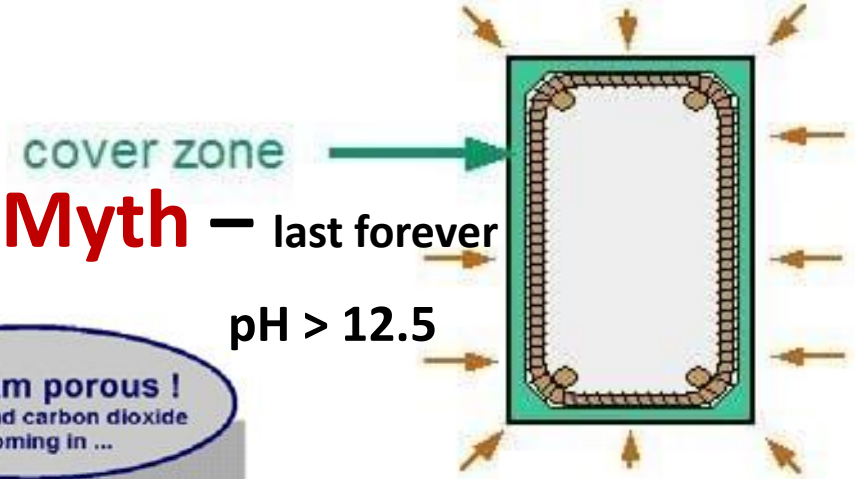
The change of polarization resistance R_p for NBU specimen has a close relationship to the NBPu specimen with a factor of 1.042.

Research output

1	Ernest Ituma Egba, Norhisham Bakhary, Mohammad Ismail, 'Influence of Natural Climate Curing Treatment on Corrosion Activity of Reinforced Concrete', *Indian Journal of Science and Technology,* Vol 9, (46), pp 1-6, Dis. 2016 DOI: 10.17485/ijst/2016/vxxx/81691, I ISSN (Print) : 0974-6846 ISSN (Online) : 0974-5645.
2	Ernest Ituma Egba, Norhisham Bakhary, Mohammad Ismail*, 'Configuration of Electrochemical Impedance Spectoscopy for Reinforced Concrete Exposed to Tropical Rainforest Natural Environment', *Jurnal Teknologi (Sciences & Engineering)* xx:x(2016) X-X, eISSN 2180-3722 (In Press).

MYTH, MYSTERY AND REALITY

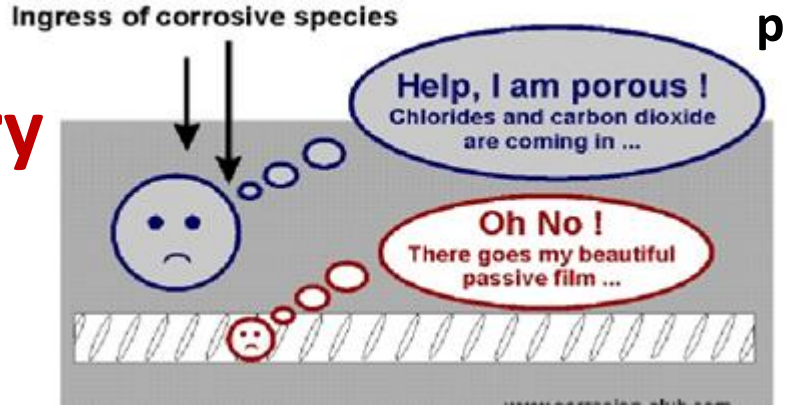
Reinforced Concrete

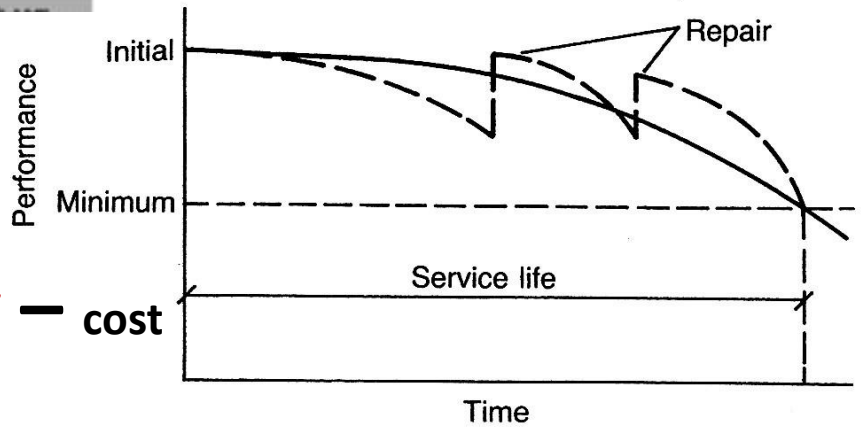


Myth – last forever

pH > 12.5

Mystery



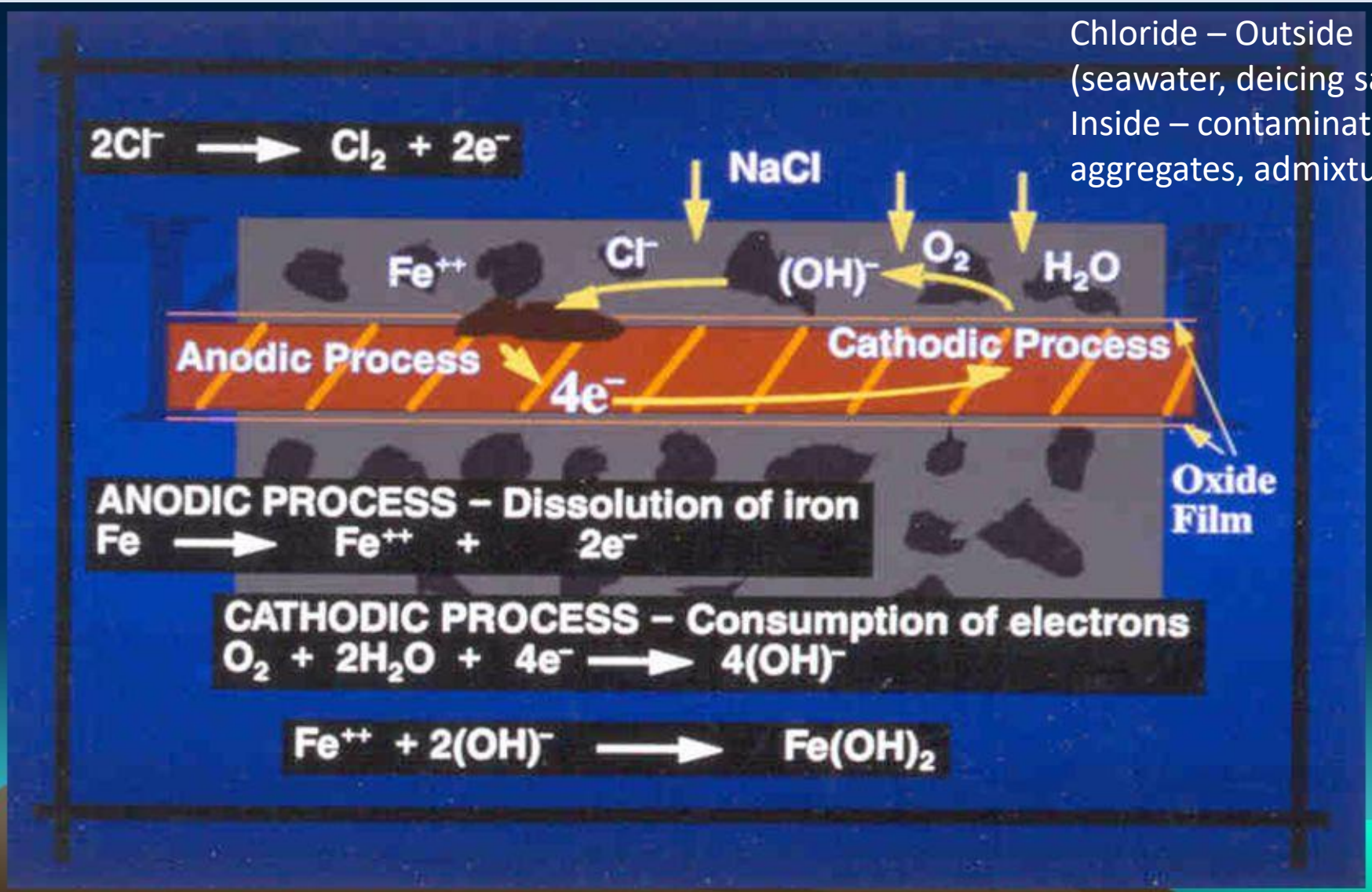


Reality – cost

Factors Influencing Corrosion of Reinforcement

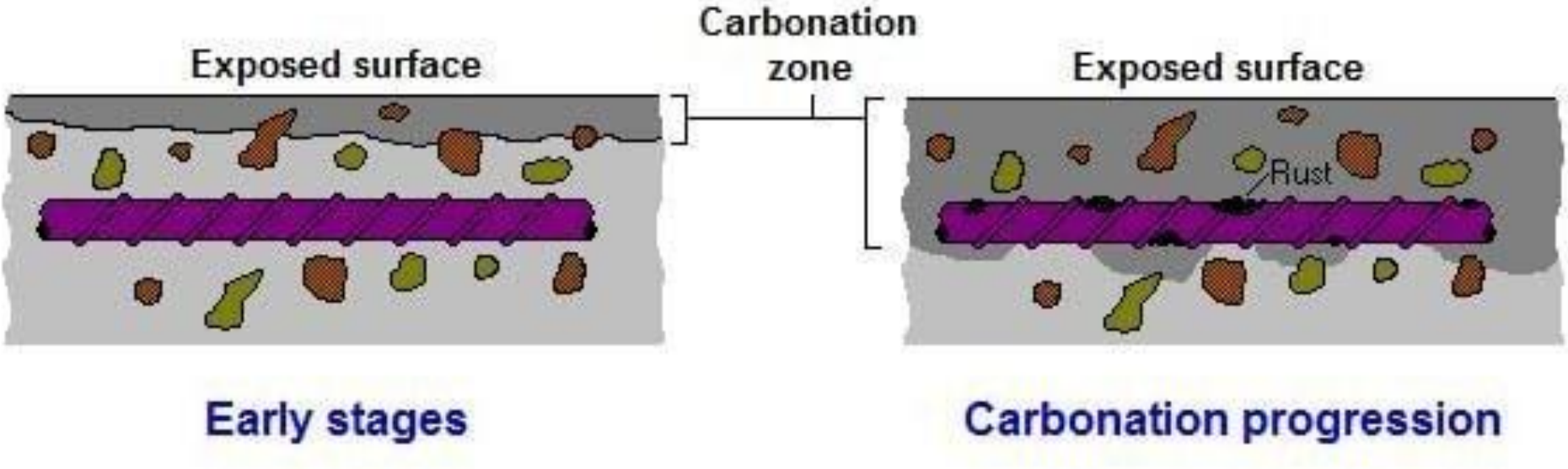
- **Chlorides**
- **Carbonation**
- Moisture
- Oxygen diffusion
- Concrete mix variables
- Construction variables
- **Temperature**
- **Humidity**

MECHANISMS OF CORROSION OF REINFORCEMENT - Chloride



Chloride – Outside (seawater, deicing salt)
Inside – contaminated aggregates, admixture

MECHANISMS OF CORROSION OF REINFORCEMENT - Carbonation



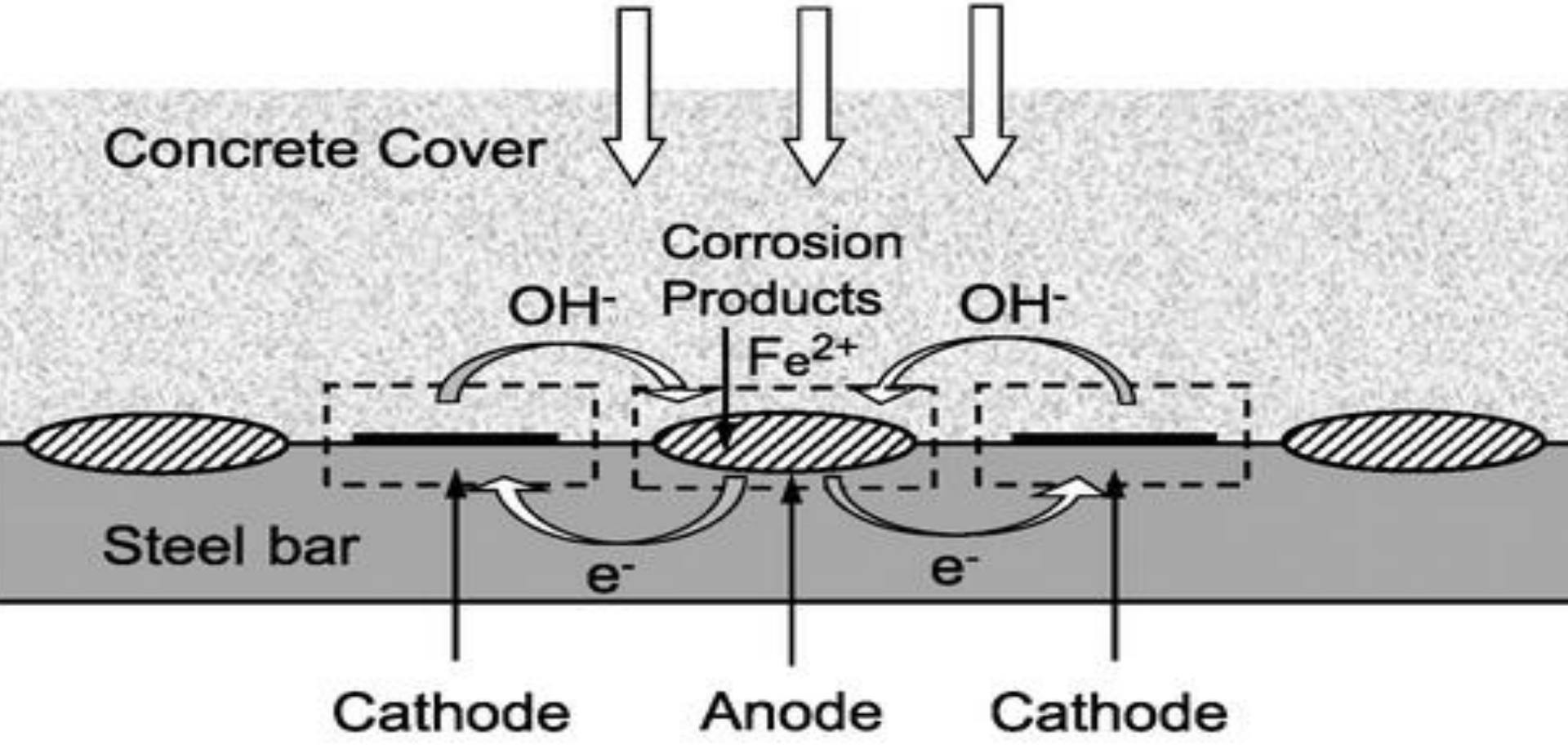
Carbonation is a reaction between acidic gases in the atmosphere and the products of cement hydration

$$CO_2 + H_2O \longrightarrow H_2CO_3$$

$$H_2CO_3 + Ca(OH)_2 \longrightarrow CaCO_3 + 2H_2O$$

Carbon dioxide diffuse in concrete react with calcium hydroxide and reduce pH value (pH < 10)

Acid Anions (Cl^-,SO_4^{2-} , HCO_3^-,etc.),O_2,H_2O



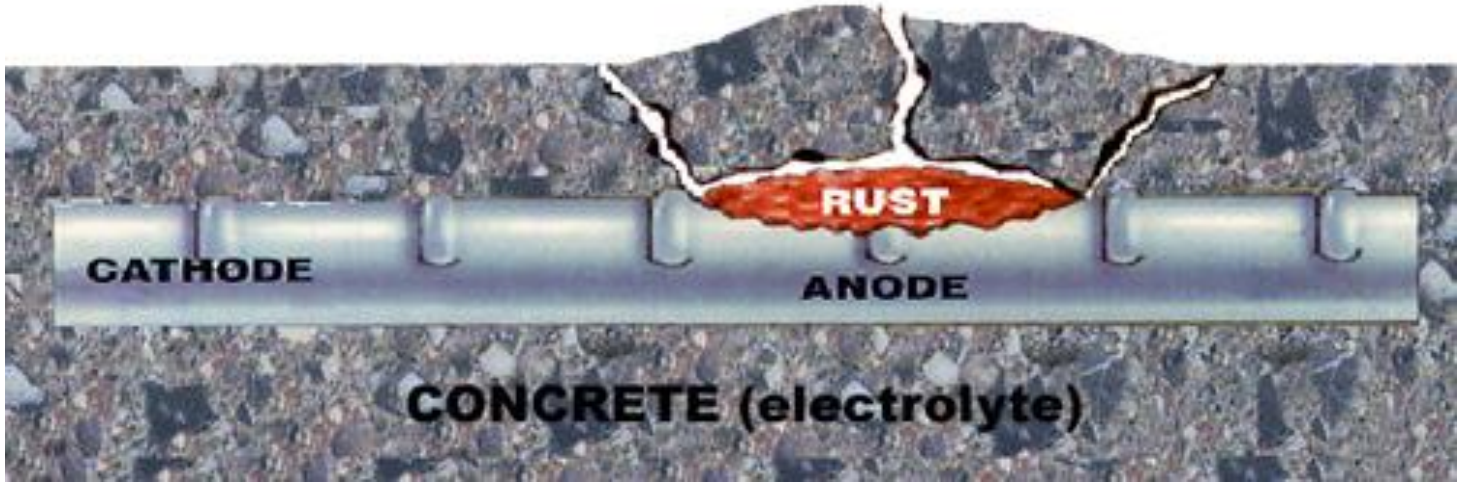
Anode Reaction: $Fe \rightarrow Fe^{2+}+2e^-$

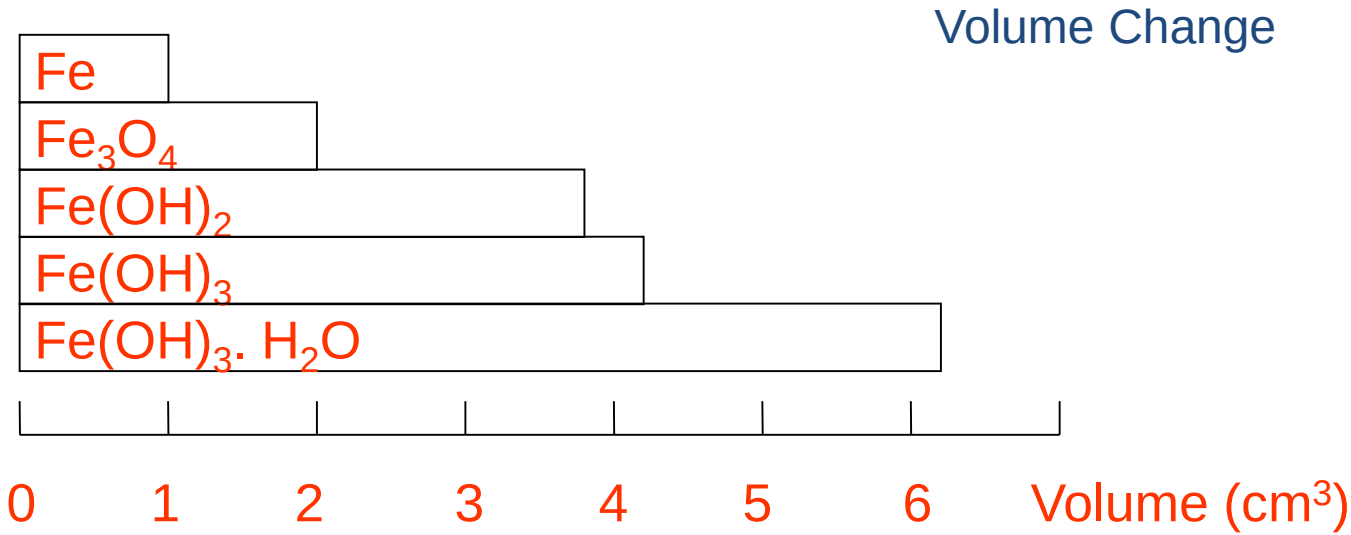
$Fe^{2+}+2OH^- \rightarrow Fe(OH)_2$

$4Fe(OH)_2+O_2+2H_2O \rightarrow 4Fe(OH)_3$

Cathode Reaction: $O_2+2H_2O+4e^- \rightarrow 4OH^-$

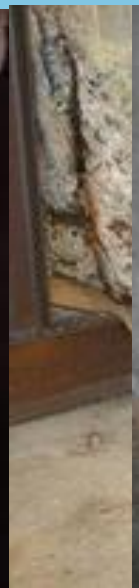
EFFECT OF CORROSION





Corroded steel increased in volume and exert pressure to concrete cover, hence crack, later spall off.


3E
3E
DE-LAM



Penang Jetty tragedy, July 1988

On the 31st July, 1988, the Sultan Abdul Halim Ferry Terminal(Penang Ferry Jetty) in Butterworth, suddenly collapsed due to severe overcrowding and weak steel bars structure of the jetty. The collapse caused 32 deaths and at least 1674 people were injured,

PREVENTION AND CONTROL OF CORROSION

CORROSION PREVENTION - 1

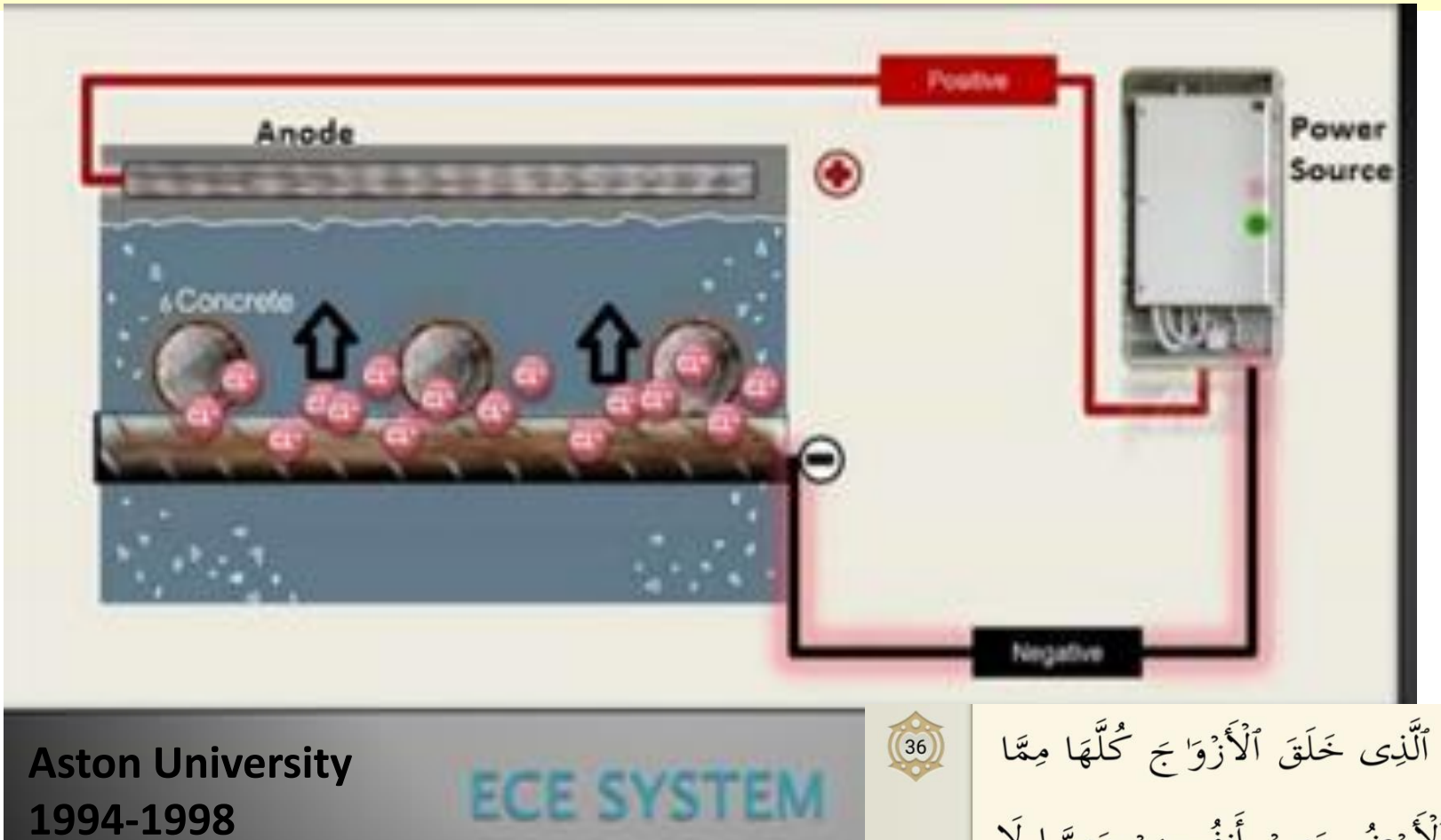
- **Reversing the effect of corrosion** by cathodic protection (CP)

- It works based on the principles of ***eliminating the anodic sites*** (corrosion sites) by progressing the steel to a cathodic state
  - **Sacrificial anodes CP**
  - **Impressed current (CP)**

CORROSION PREVENTION - 2

- **Preserving or restoring passivity** (reserving the effect carbonation and chloride attack by electrochemical processes)
  - **Realkalization : Introduce alkaline solution into concrete to prevent further deterioration due to carbonation. Produce hydroxyl ions & restoring pH levels**
  - **Chloride extraction (Desalination) : Technique to remove ingressed or cast in chlorides in order to arrest deterioration due to chloride**

1&2. RESTORING PASSIVITY



Direct current forced to circulate between an anode, place on an external surface of the structure, and the reinforcement.

36

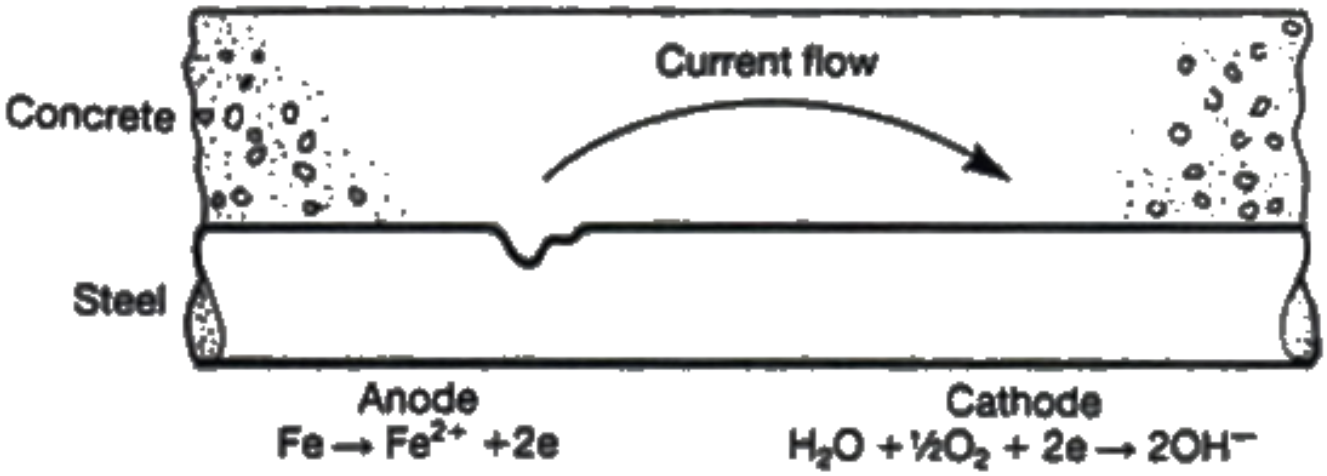
سُبْحَـٰنَ ٱلَّذِى خَلَقَ ٱلْأَزْوَٰجَ كُلَّهَا مِمَّا

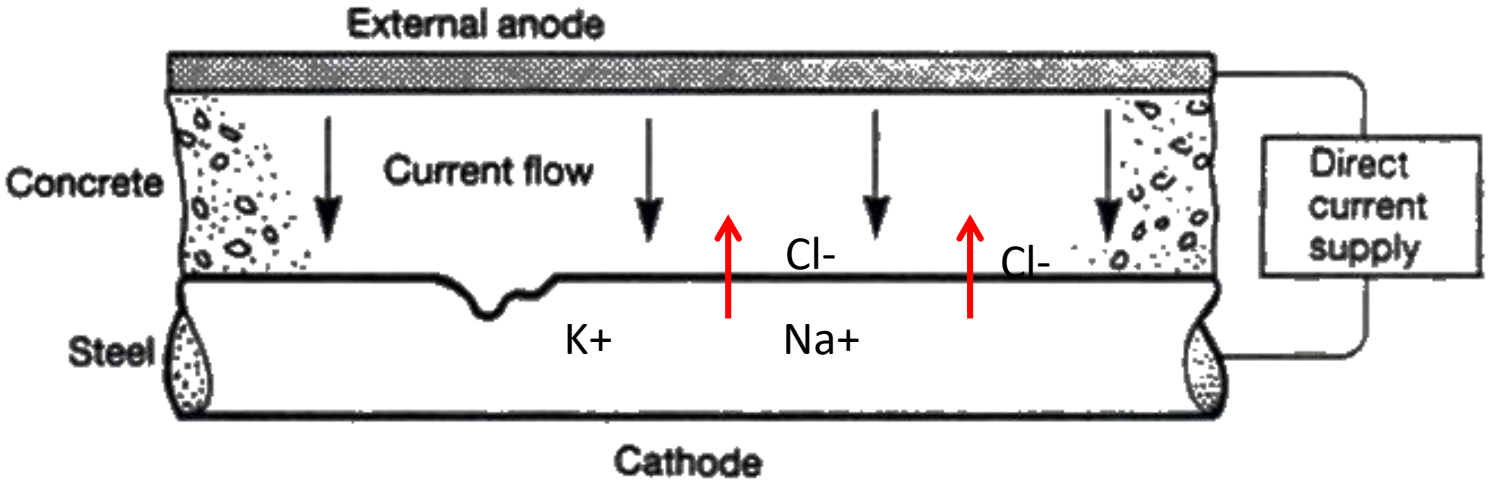
تُنۢبِتُ ٱلْأَرْضُ وَمِنْ أَنفُسِهِمْ وَمِمَّا لَا

يَعْلَمُونَ

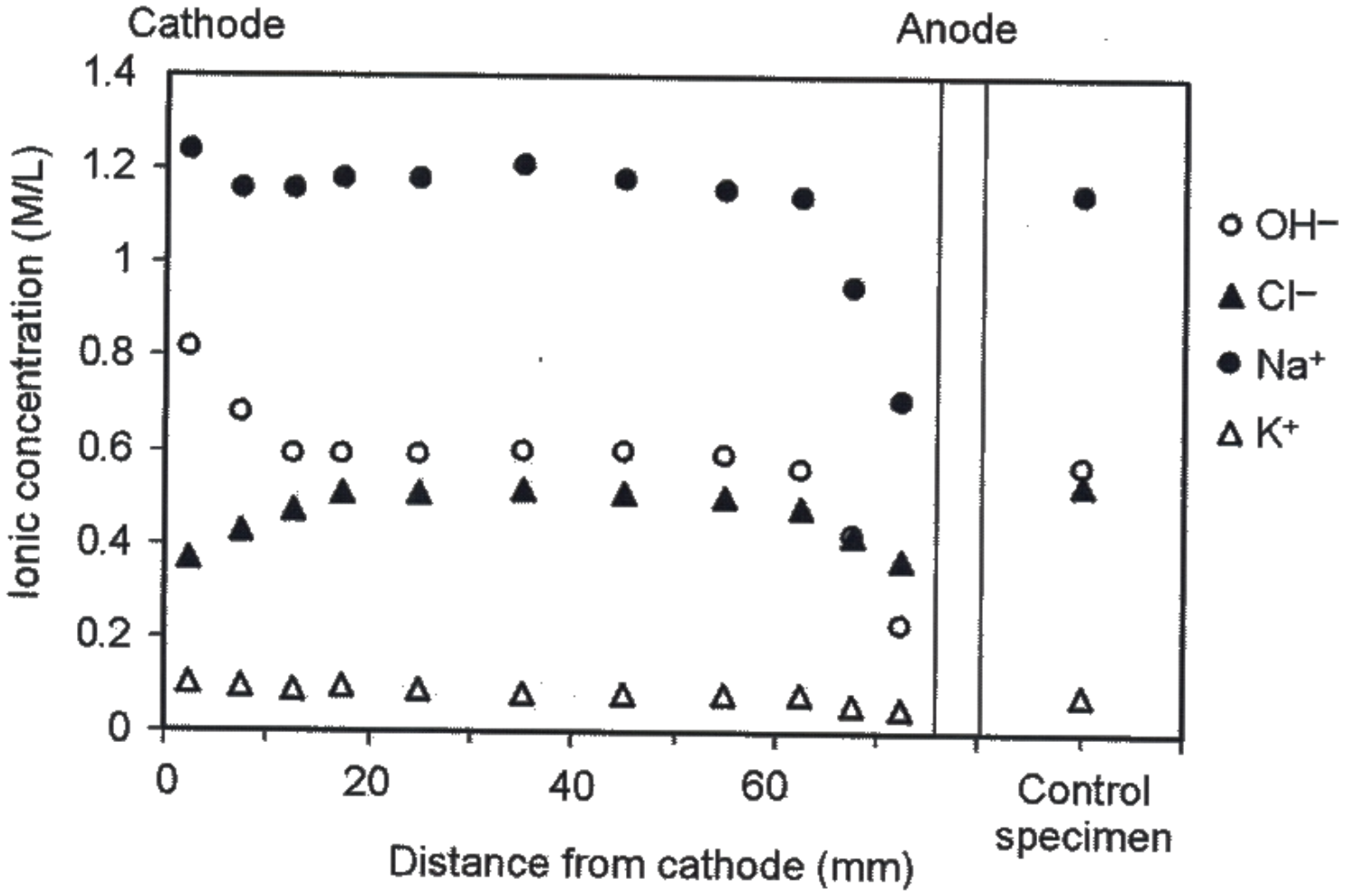
Yaasin

Glory be to Him Who created pairs of all things, of what the earth grows, and of their kind and of what they do not know.

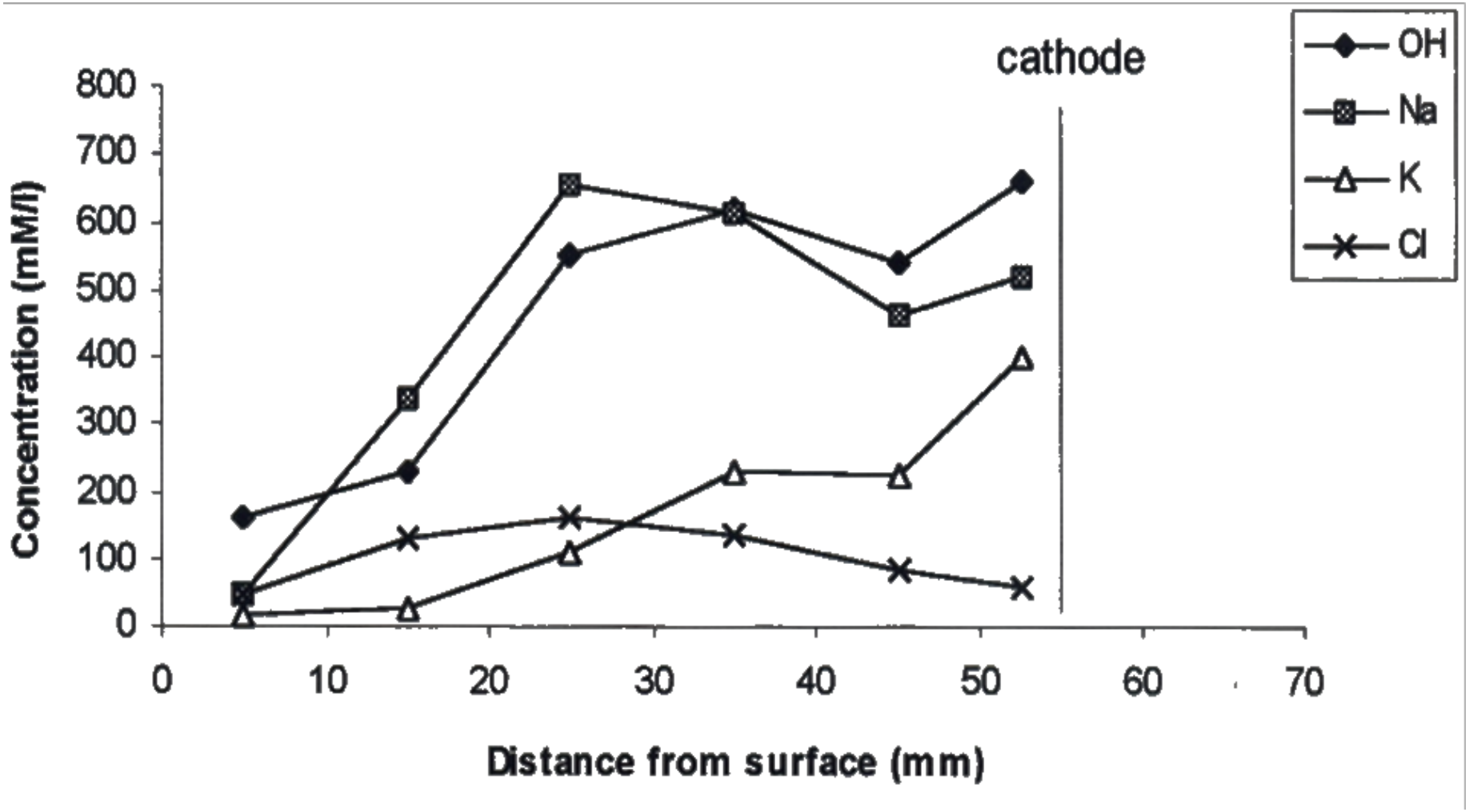

Current flow
Concrete
Steel
Anode
$Fe \rightarrow Fe^{2+} + 2e$
Cathode
$H_2O + \frac{1}{2}O_2 + 2e \rightarrow 2OH^-$


External anode
Concrete
Current flow
Cl-
Cl-
Direct current supply
Steel
K+
Na+
Cathode

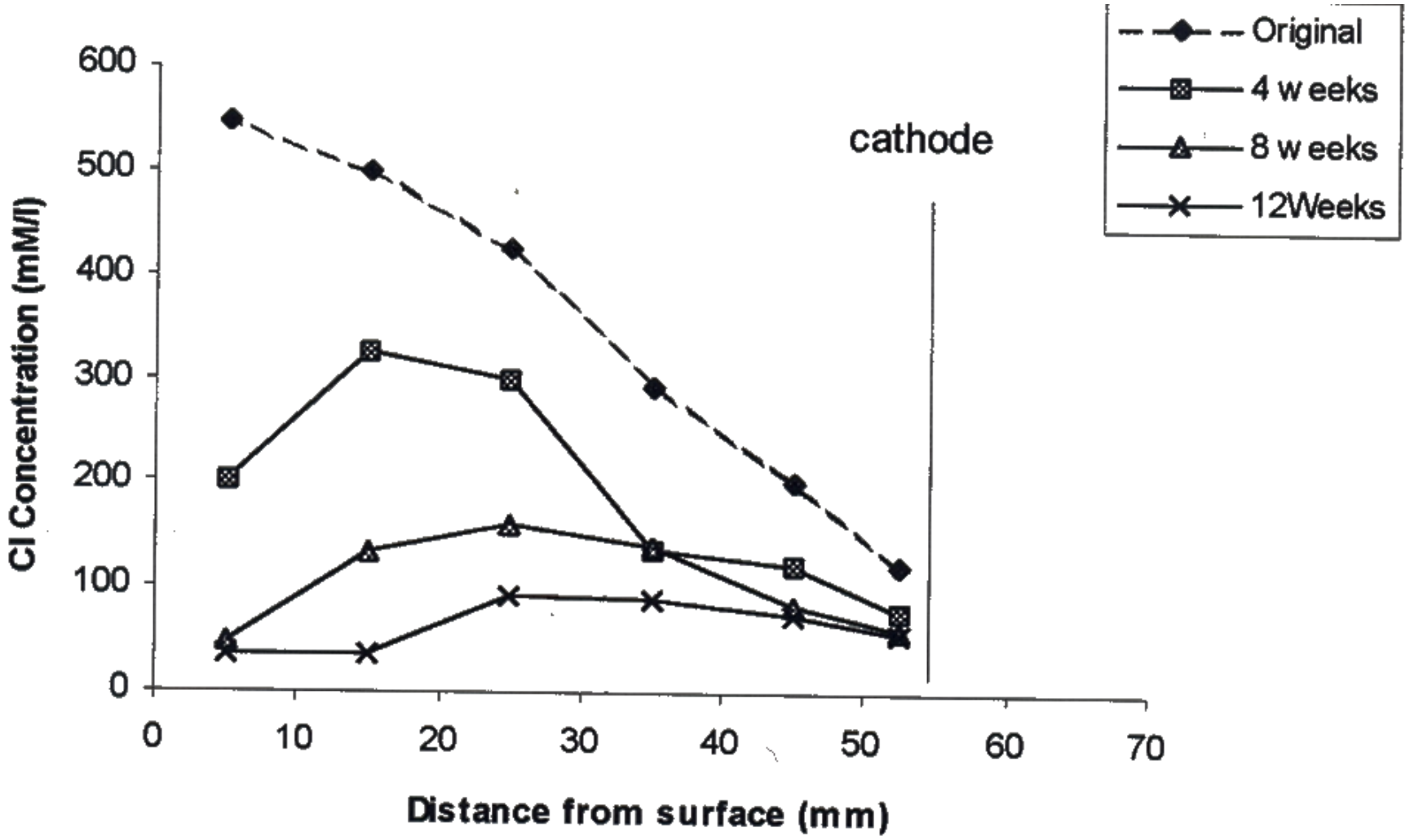
Profile of Ionic Concentration Measured Between Anode And Cathode



Ionic Concentration Profile in Pore Solution After Treatment



Chloride Concentrations Profile



Research output

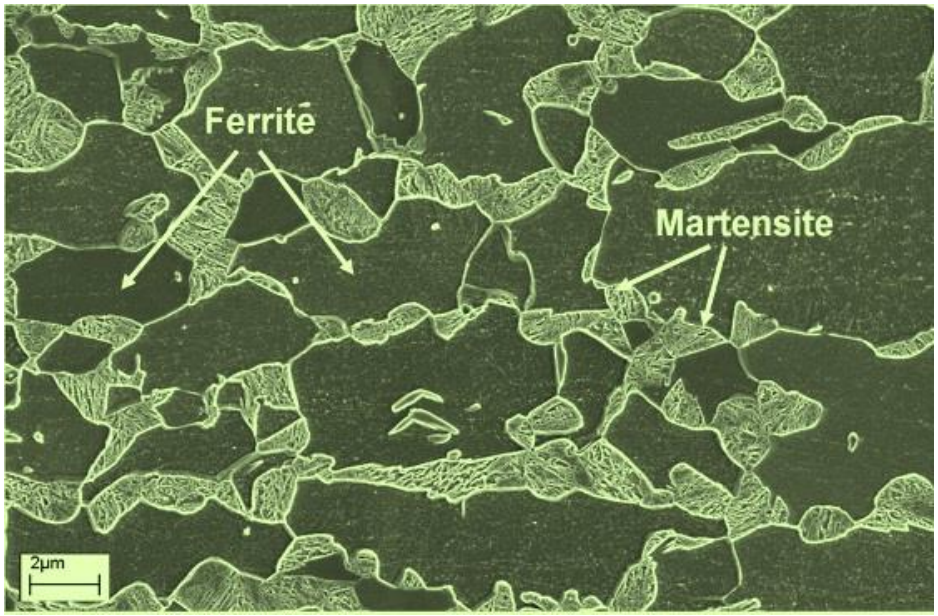
1	Mohammad Ismail and George S Sergi, "Electrochemical Chloride Extraction Treatment on Chloride Contaminated Concrete", *Jurnal Teknologi*, No. 33(B), pp41-68, Dis.2000
2	Mohammad Ismail and Bala Muhammad, *'Electrochemical Chloride Extraction Effect on Blended Cements'*, Doi: 10.1680/adcr.2011.23.1.1. *Advances in Cement Research,* 23 (5), pp. 241-248, 15 Sept. 2011. (IF 1.080),

CORROSION PREVENTION - 3

- **Isolation of reinforcement** from the chemical effect of corrosion by means of physical barrier or chemical inhibition
  - Use of epoxy coated reinforcement
  - Use of galvanized reinforcement
  - **Use of dual-phase steel**
  - Use of stainless steel reinforcement
  - Use of bar primer
  - Use of zinc rich paint

3. ISOLATION OF REINFORCEMENT -

DUAL – PHASE STEEL



Dual-phase steel consists of soft ferrite and hard martensite. Dual-phase steel as a new kind of material that evolved in the course of developing high strength low alloy (HSLA) steels.

'dual-phase' refer to the presence of two phase: ferrite and martensite although small amount of bainite, pearlite, and retained austenite may also be present in the microstructure unit

Dual – Phase Steel

1	Comparison between Dual-phase steel and galvanised steel Rebar Corrosion Behaviour in Concrete	Tan Wui Keong (2001)
2	Corrosion Rate Measurement of Steel Rebar Embedded in Concrete	Goh Chun Guan (2003)
3	Corrosion Behaviour of Steel Rebars Embedded in Concrete	Ihsan Abdul Rahman (2003)

Dual – phase steel

It can be seen that the corrosion potential (Ecorr) and corrosion current density (Icorr) of dual-phase steel is lower than the conventional steel in ordinary water and 3.5% Cl solution.

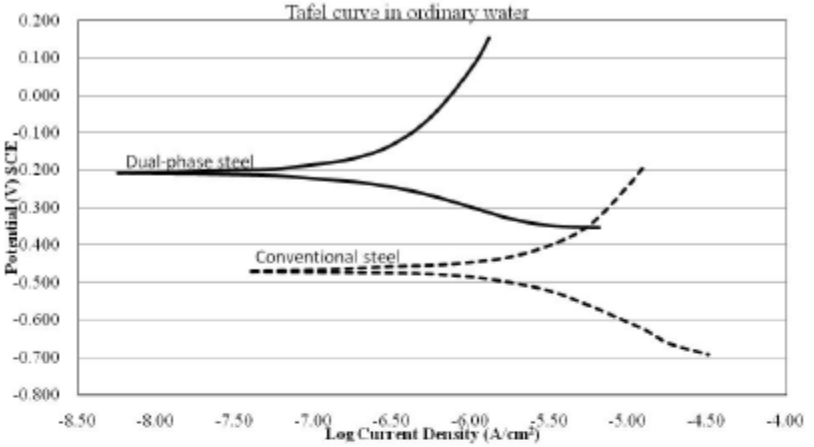


Figure 8: Tafel extrapolation curve of dual-phase steel and conventional steel in ordinary water

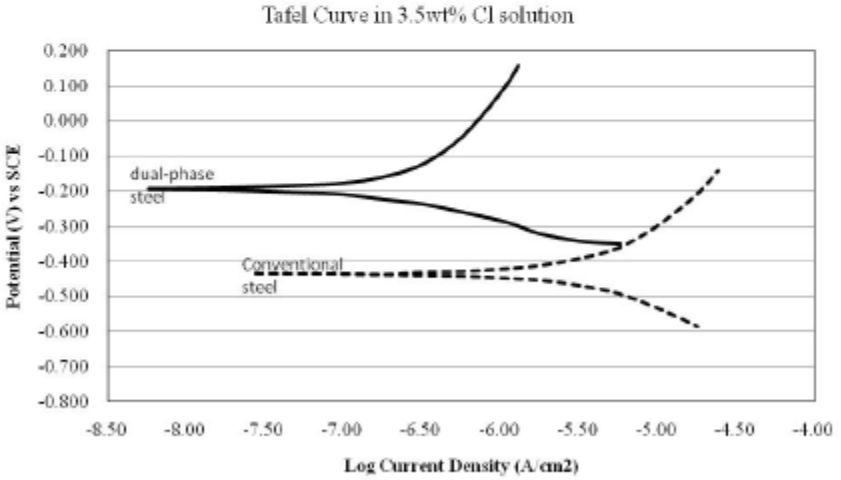


Figure 9: Tafel extrapolation curve of dual-phase steel and conventional steel in 3.5% wt in Cacl

Research output

1	Mohammad Ismail and Esah Hamzah, 'Corrosion Performance of Dual-Phase Steel Embedded in Concrete', *Arabian Journal for Science and Engineering* Vol 35, 2B, pp81-90, Oct 2010. (IF 0.106).
2	Mohammad Ismail, Bala Muhammad, Esah Hamzah, TanWui Keong, 'Corrosion behaviour of dual-phase and galvanized steels in concrete', *Anti-Corrosion Methods and Materials* 59(3), 132-138, 15 Mei 2012. (IF 0.414)

CORROSION PREVENTION - 4

- Use of sufficient cover (thickness)
- Use of **impermeable good quality** concrete
  - Lower water binder ratio
  - **Use of mineral admixtures / (INHIBITOR)**
  - Use of optimum cement content
  - Optimum compaction
  - Early and comprehensive curing
  - Apply surface treatments
  - Use of durability related tests for compliance (gas & water permeability, chloride permeability, chloride diffusion)

4. CORROSION INHIBITOR

1	Comparative Study of Green Corrosion Inhibitors of Steel Reinforcement in Concrete	ABDULRAHMAN SALAWU ASIPITA (2012)
2	Effect of Inhibitors on the Corrosion Behaviour of Carbon Steel in Concrete	EYU GAIUS DEBI (2013)
3	Corrosion Inhibitor effect on corrosion and durability of Structure	SEYED MOJTABA GHURAISHI (2016)
4	Synthesis green nano particles using plant extract and its application on corrosive media	MOHAMMAD ALI ASAAD ZEKI ALSAAD (2018)

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ELAEIS GUINEENSIS AND SILVER NANOPARTICLES AS GREEN INHIBITOR FOR CORROSION OF REINFORCEMENT

Green inhibitor

Green nanotechnology for the synthesis of metal nanoparticles from plant extract attract people from various fields including physics, chemistry, biology, medicine, engineering and material science due to:

Methodology

Phase I, Objective 1

Extraction of green inhibitors from plants (*Elaies guineensis & Rhizophora apiculata)*

Green inhibitors screening in 1 M HCl

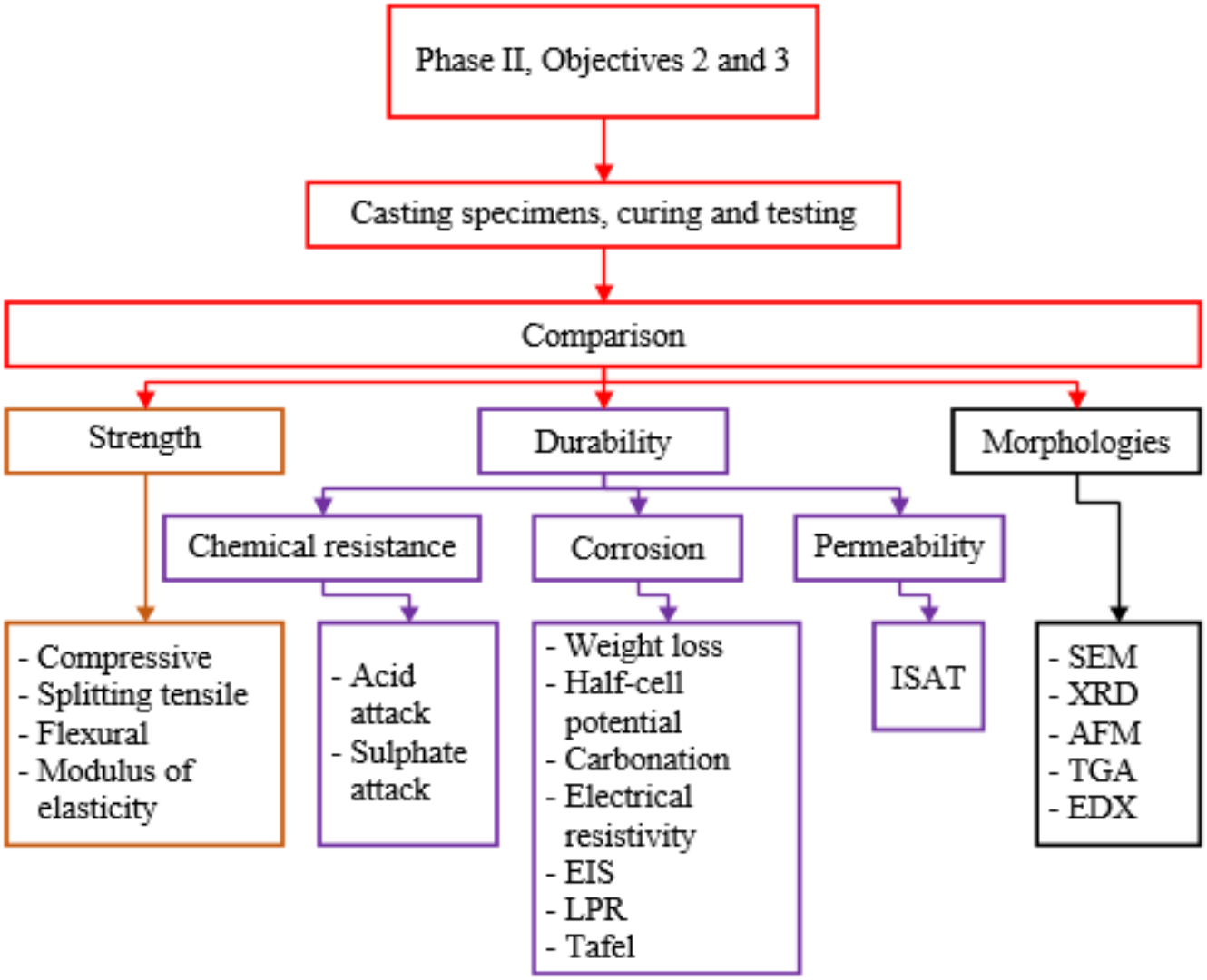
Selection of the best inhibitor based on the highest efficiency

Synthesis of green nanoparticles inhibitor (*Elaies guineensis*/Silver nanoparticles)

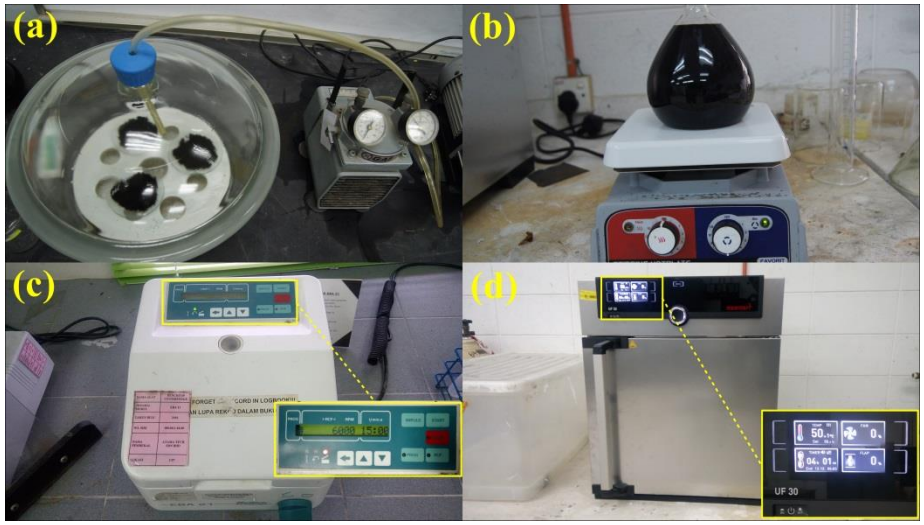
Characterisation of green nanoparticles inhibitor by means of XRD, TEM and EDX

Screening of green nanoparticles inhibitor in 1 M HCl

Methodology



Methodology



Phase III, Objectives 4

Development of self-healing coating

Preparation of smart nanocontainers

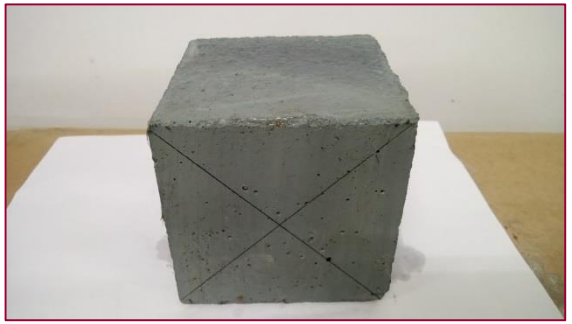
Characterization of smart nanocontainers/ FESEM, EDX and TGA

Preparation of self-healing coating

Screening of self-healing coating by SEM & AFM

Application of self-healing coating for reinforced concrete

- Corrosion
- Permeability
- Sulphate attack
- Morphologies



Results and Discussions

Chemical Compositions

The chemical compositions of EG and EG/AgNPs inhibitors by XRF analysis		
Parameter	Chemical Compositions (PPM), mg/cm^2	
	EG Inhibitor	EG/AgNPs Inhibitor
Magnesium - Mg	15900	10800
Potassium - K	140000	489000
Calcium - Ca	38000	31600
Chromium - Cr	780	6100
Iron - Fe	12000	3280
Nickel - Ni	-	29.7
Copper - Cu	5700	175
Zinc - Zn	12670	5147
Silver - Ag	5480	42000
Tin - Sn	9210	27300
Hafnium - Hf	6010	-
Tantalum – Ta	13690	17109
Rhenium - Re	16770	31430
Zirconium - Zr	140000	137000
Samarium - Sm	4800	-

Results and Discussions

Examination and Characterisation

Inhibitor Concentration % (v/v)		Weight Loss (g)			Efficiency (%)		
		24 h	48 h	72 h	24 h	48 h	72 h
Control	0.0	0.2231	0.2879	0.3872	0.0	0.0	0.0
Rhizophora apiculata bark Inhibitor (A)	2.5	0.1094	0.1256	0.1634	50.9	56.4	57.8
	5.0	0.1069	0.1252	0.1599	52.1	56.5	58.7
	7.5	0.0979	0.1110	0.1348	56.1	61.5	65.2
	10	0.0881	0.1019	0.1245	60.5	64.6	67.8
Elaeis guineensis (EG) Inhibitor (B)	2.5	0.0997	0.1165	0.1435	55.3	59.5	**62.9**
	5.0	0.0912	0.1078	0.1314	59.1	62.6	**66.1**
	7.5	0.0881	0.0938	0.1137	60.5	67.4	**70.6**
	10	0.0764	0.0896	0.1014	65.8	68.9	**73.8**
Rhizophora apiculata leaf Inhibitor (C)	2.5	0.1230	0.1433	0.1863	44.8	50.2	51.9
	5.0	0.1192	0.1396	0.1821	46.6	51.5	53
	7.5	0.1096	0.1382	0.1792	50.9	52	53.7
	10	0.1109	0.1323	0.1591	50.3	54.1	58.9

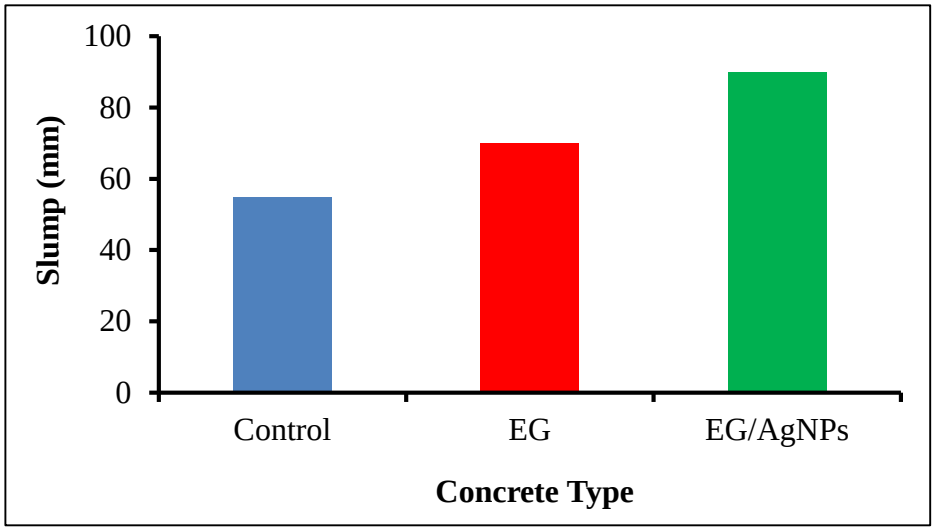
Results and Discussions

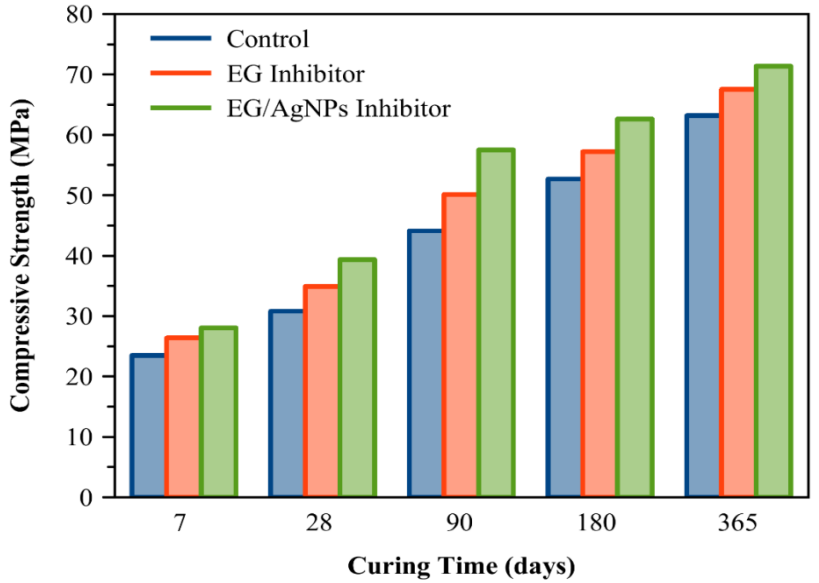
Examination and Characterisation

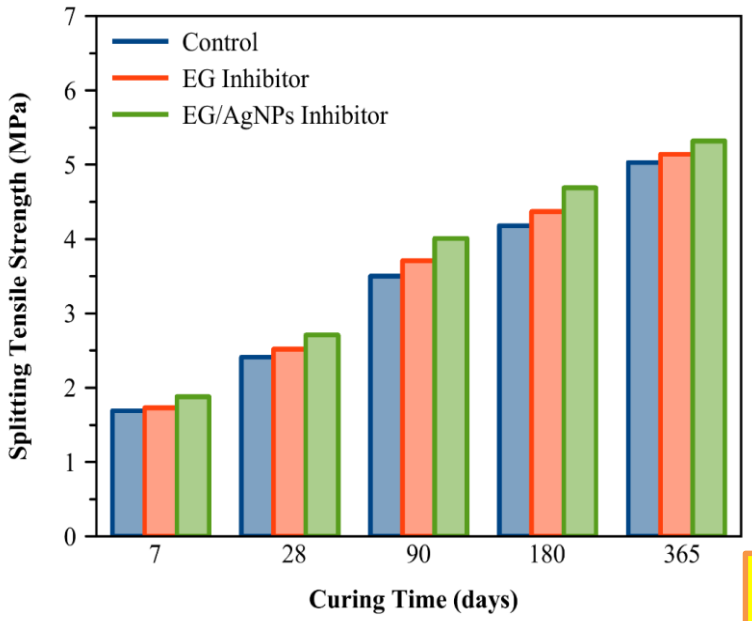
Inhibitor Concentration % (v/v)		Weight Loss (g)			Efficiency (%)		
		24 h	48 h	72 h	24 h	48 h	72 h
Control	0.0	0.2231	0.2879	0.3872	0.0	0.0	0.0
EG/AgNPs Inhibitor	2.5	0.0423	0.0436	0.0533	81.0	84.9	86.4
	5.0	0.0411	0.0423	0.0470	81.6	85.3	87.7
	7.5	0.0363	0.0318	0.0412	83.4	89.0	89.4
	10	**0.0307**	**0.0283**	**0.0269**	**86.2**	**90.2**	**93.1**

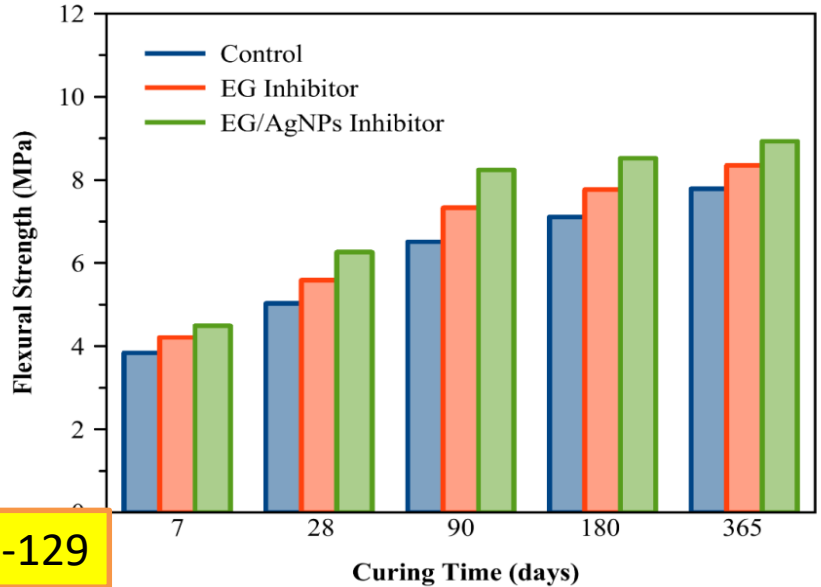
Results and Discussions

Fresh and Hardened Properties





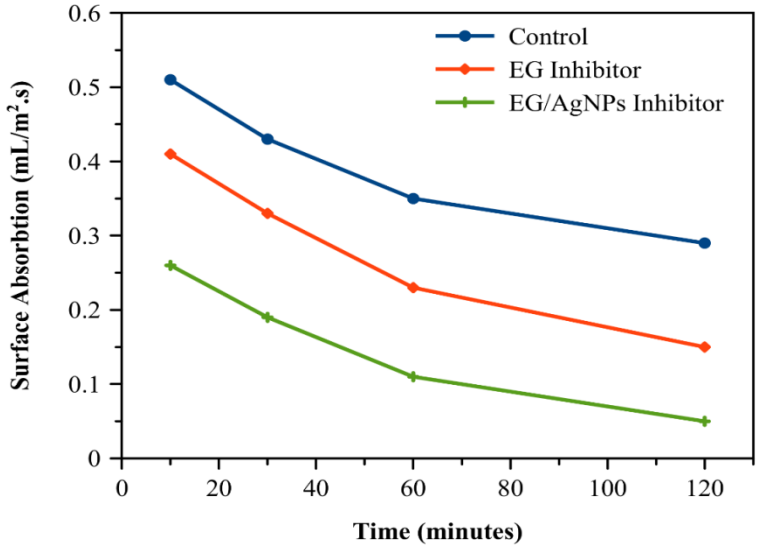


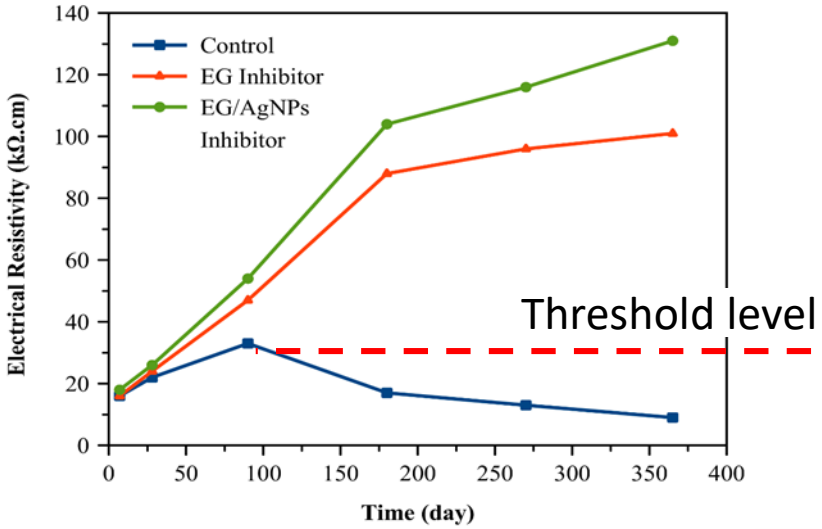


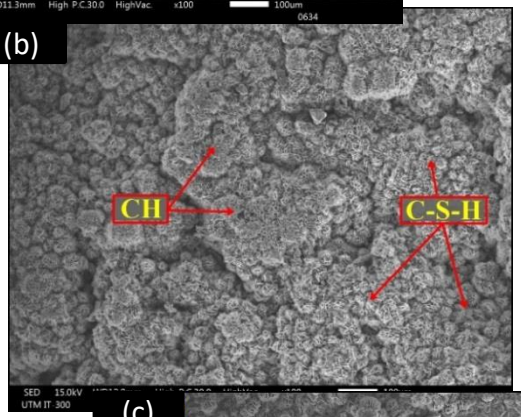
CH5/125-129

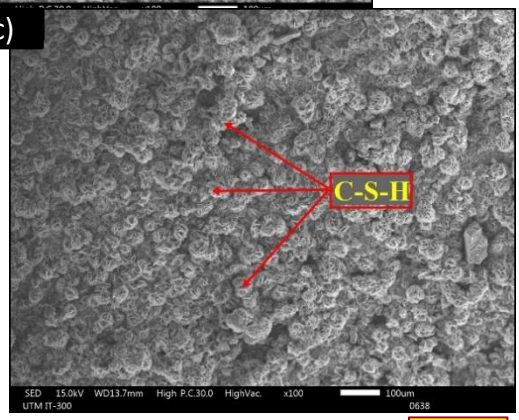
Results and Discussions

Durability – Water Absorption and Resistivity





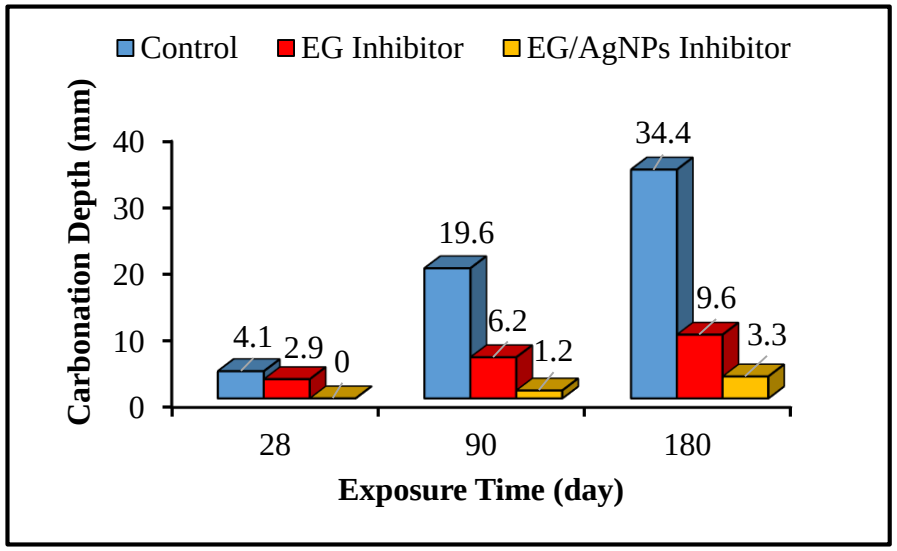


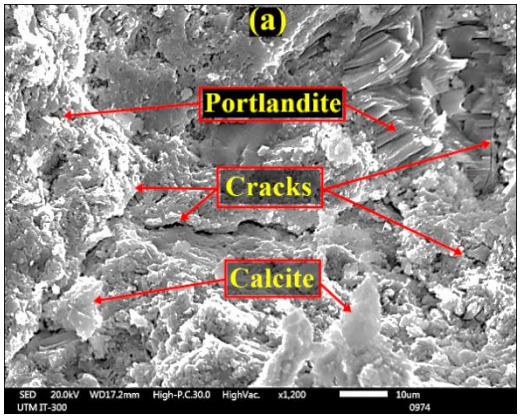


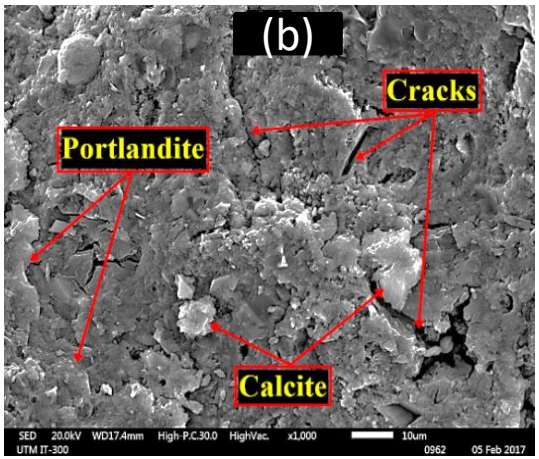
Seawater exposure

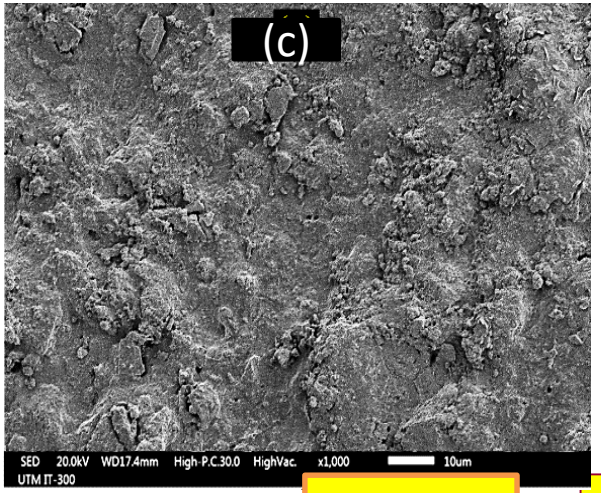
Results and Discussions

Durability - Carbonation



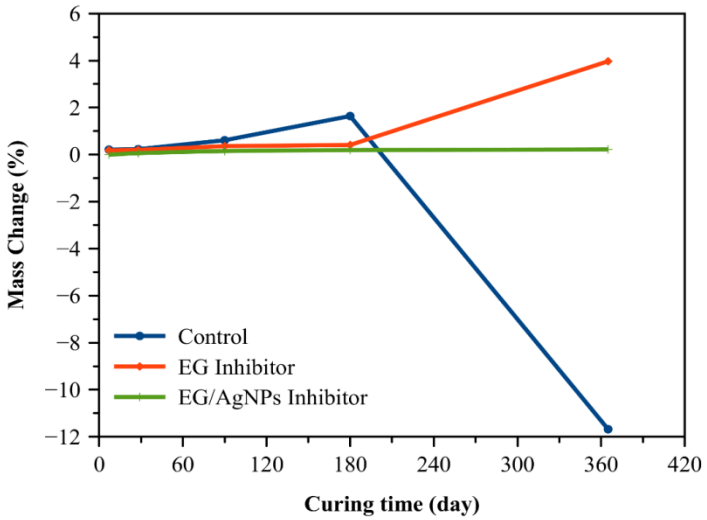


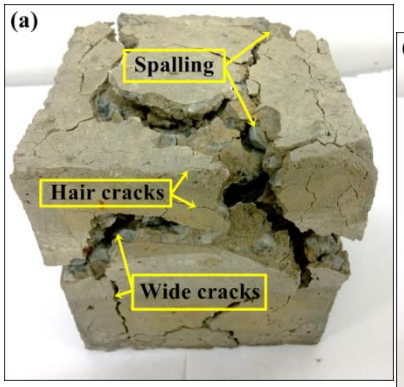


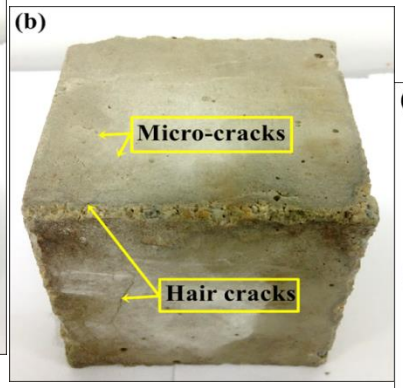


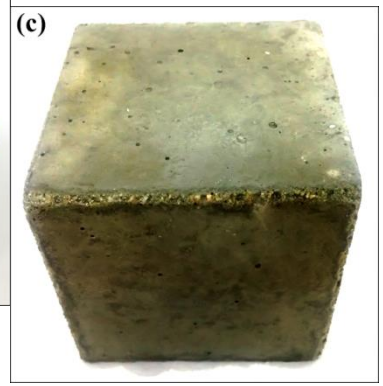
Results and Discussions

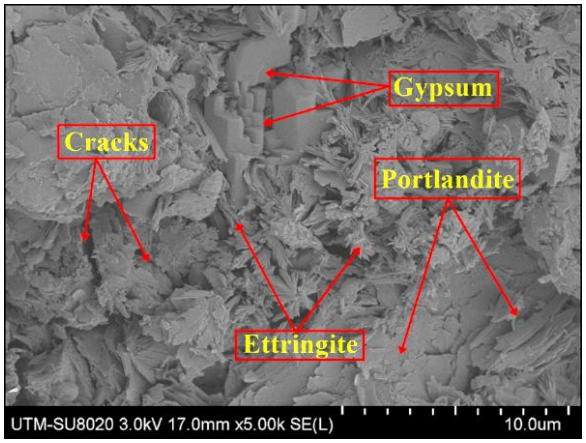
Durability - Sodium sulphate

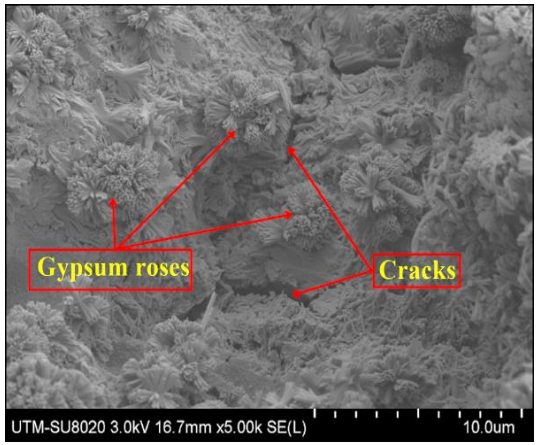


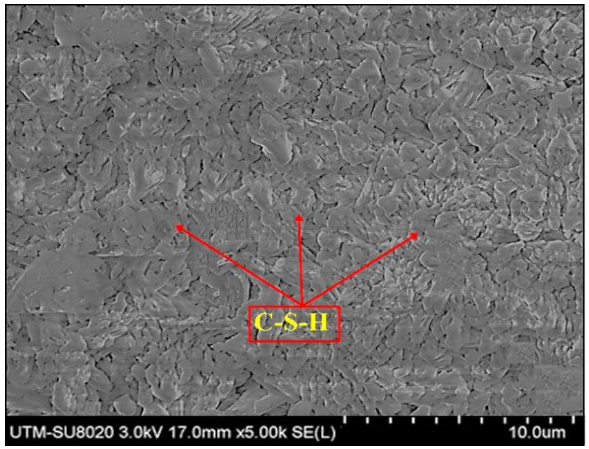






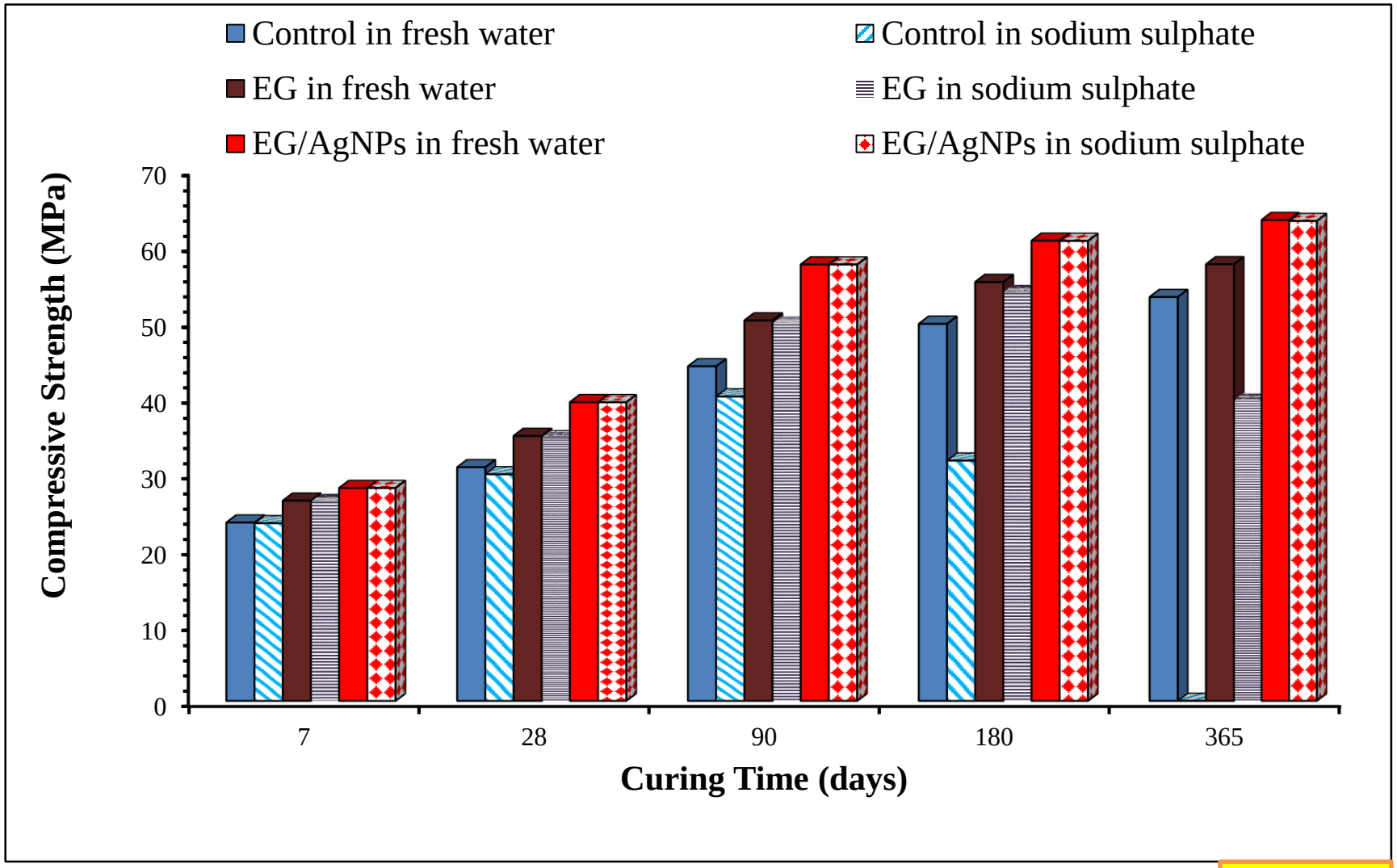






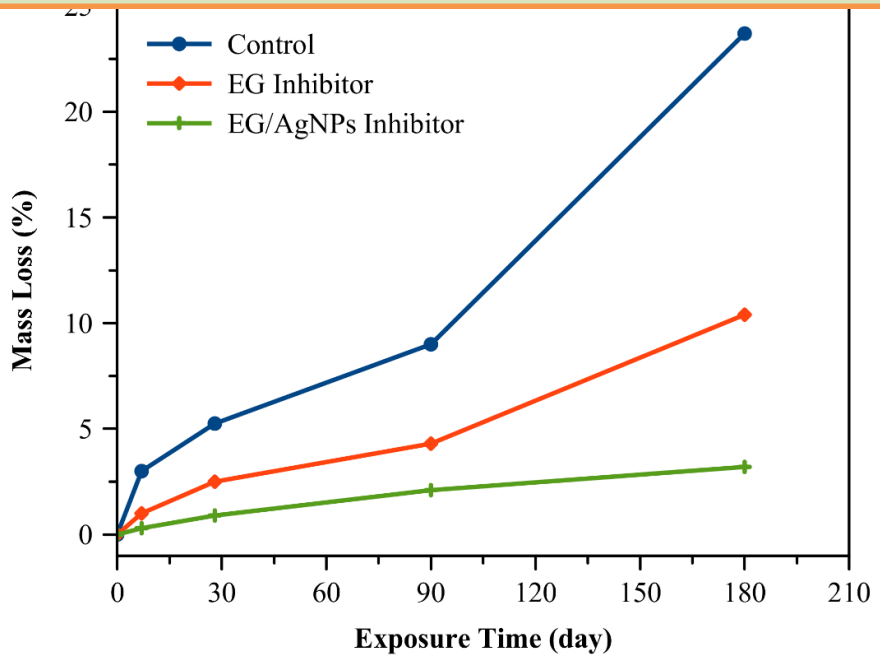
Results and Discussions

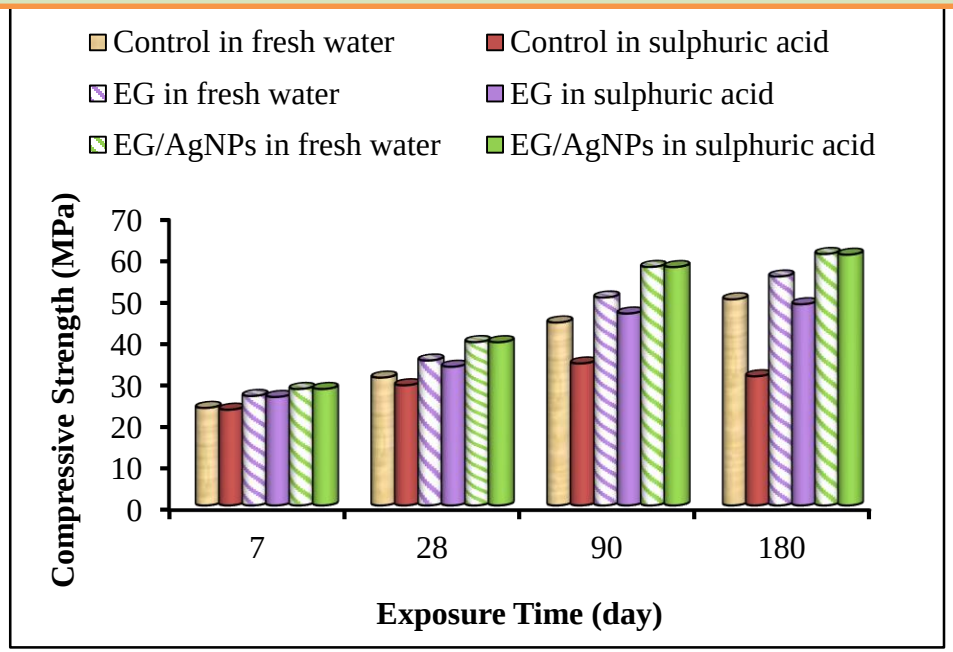
Hardened Properties – Sodium sulphate

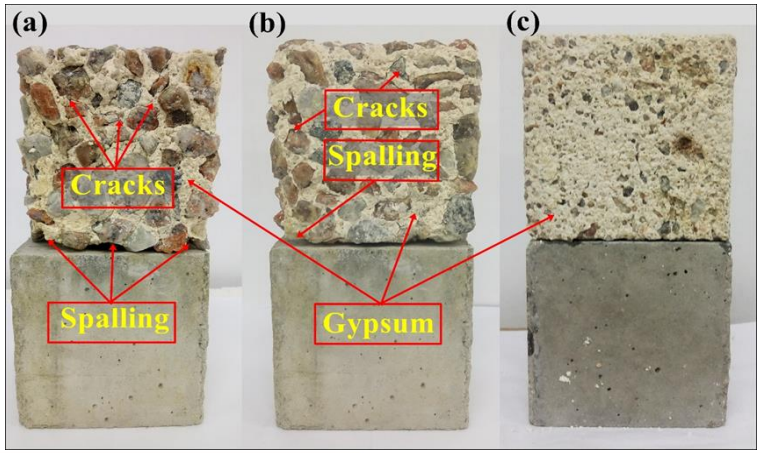


Results and Discussions

Durability – Suphuric acid

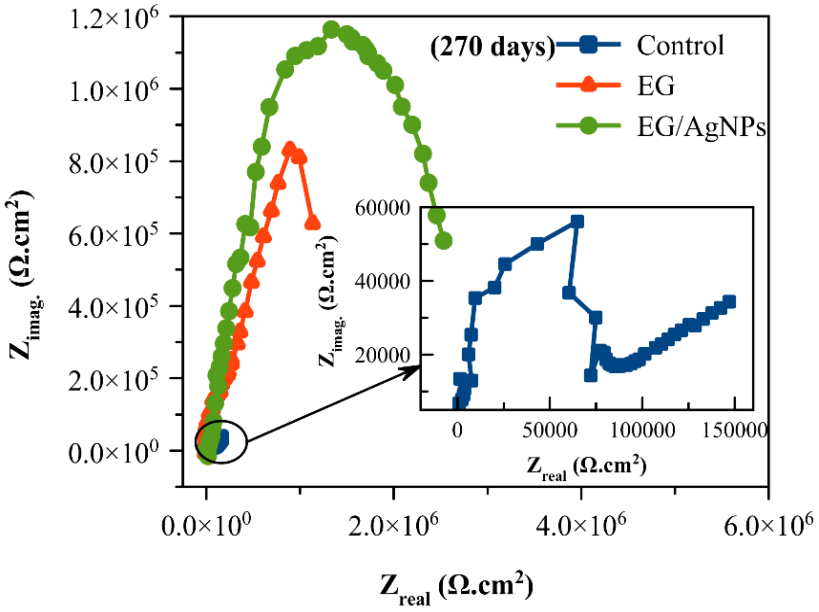


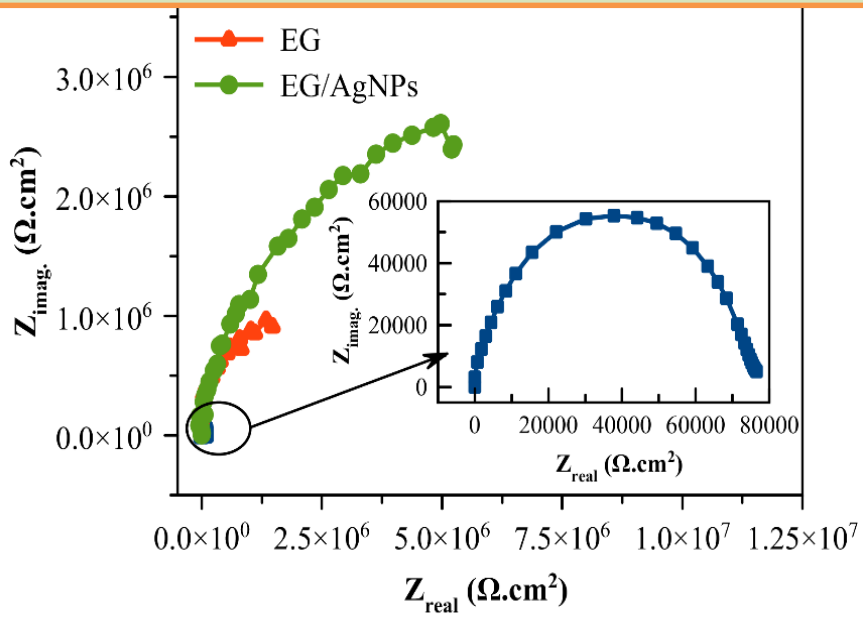




Results and Discussions

EIS

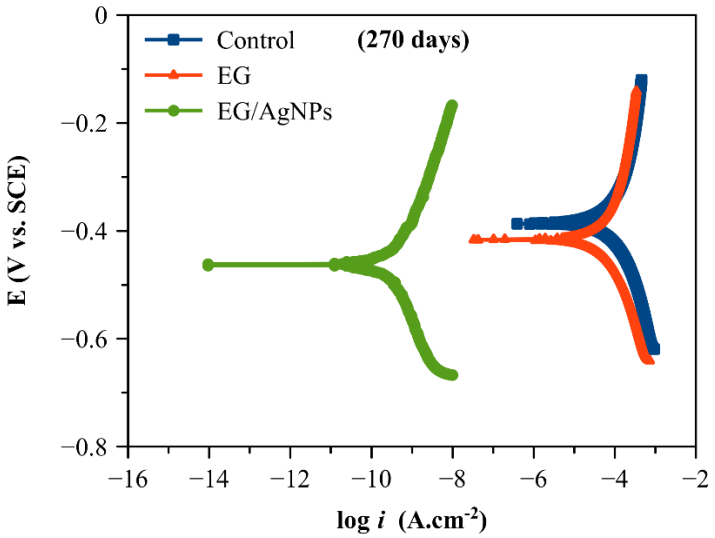


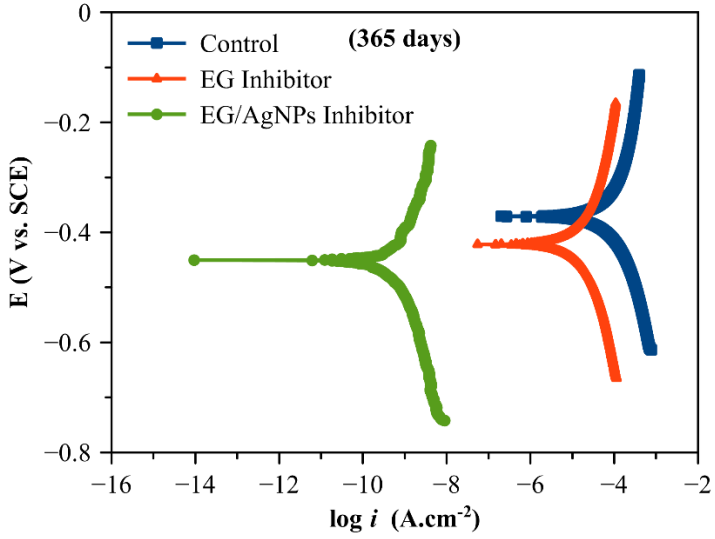


Time (day)	Specimen	EIS Parameters			
		R_s ($\Omega.cm^2$)	R_{ct} ($\Omega.cm^2$) $\times 10^2$	C_{dl} ($\mu F.cm^{-2}$) $\times 10^{-5}$	*IE* (%)
270	Control	10.9	29.15	4.35	-
	EG	12.1	118.40	0.173	75.4
	EG/AgNPs	12.2	411.90	0.0176	92.9
365	Control	11.7	27.12	7.68	-
	EG	12.7	102.80	0.21	73.6
	EG/AgNPs	12.8	496.00	0.0138	94.5

Results and Discussions

Tafel plot – potential dynamic

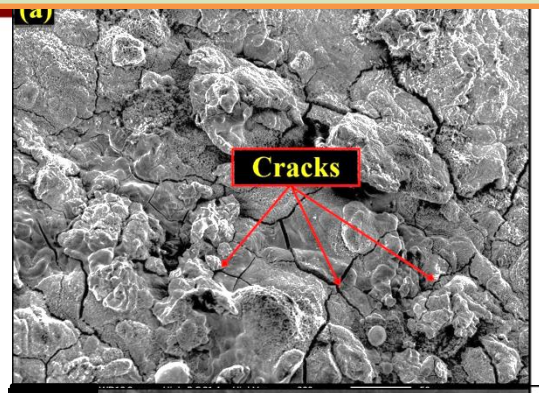


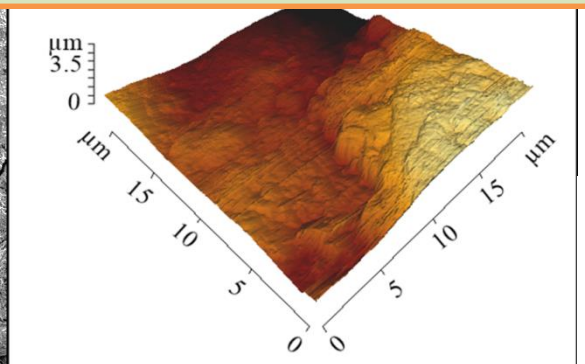


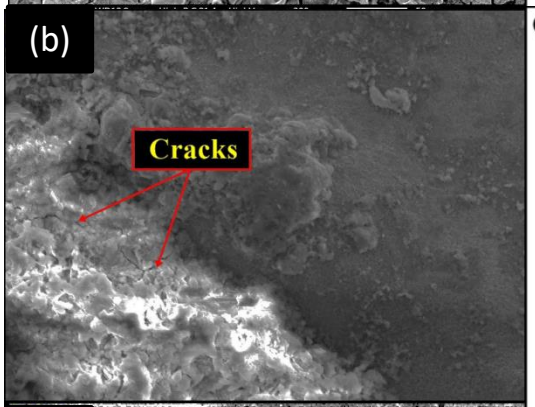
Time (day)	Specimen	Potentiodynamic Polarisation Parameters					
		$-E_{corr}$ (V)	i_{corr} (μA/cm^2)	b_a (V/dec)	$-b_c$ (V/dec)	*CR* mm/year ×10^{-3}	*IE* (%)
270	Control	0.384	443.8	0.3844	0.1119	6.18	-
	EG	0.427	107.6	0.511	0.223	1.48	75.75
	EG/AgNPs	0.462	29.1	0.363	0.362	0.41	93.44
365	Control	0.371	501.5	0.3409	0.688	7.53	-
	EG	0.422	132.4	0.827	0.775	2.11	73.60
	EG/AgNPs	0.450	26.5	0.382	0.402	0.39	94.72

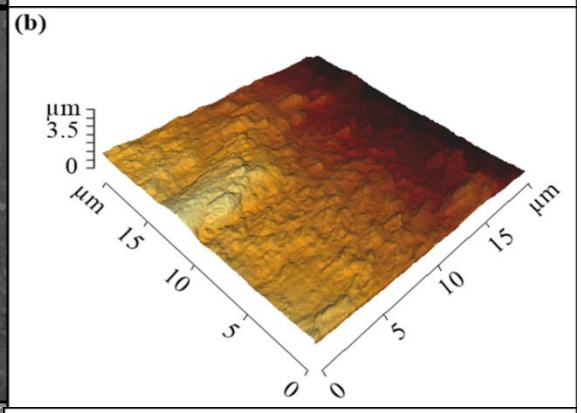
Results and Discussions

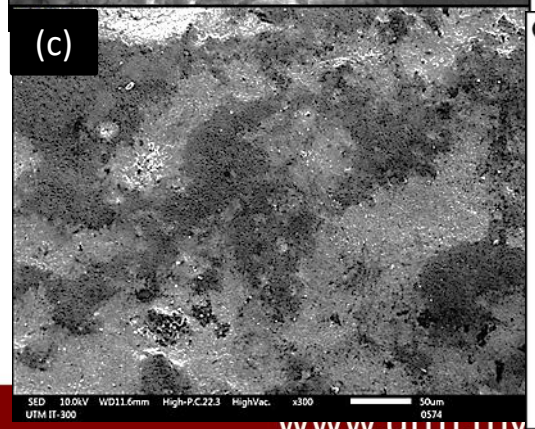
SEM and AFM

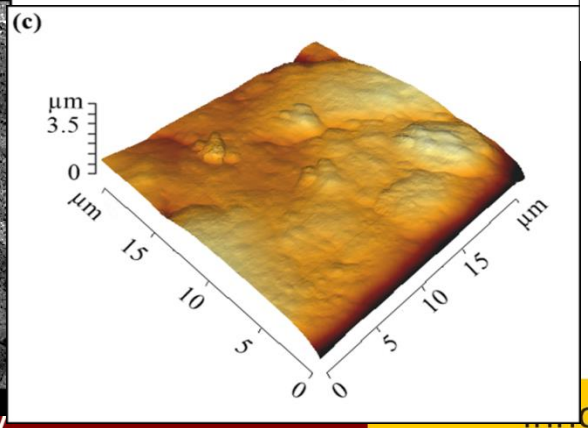


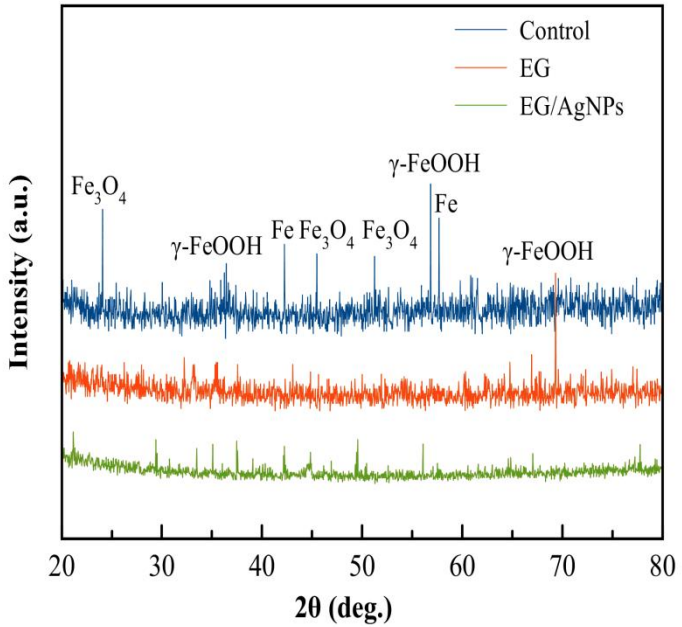












Research Output

1	Abdulrahman, A.S., Ismail, M., Hussain, M.S. 'Corrosion inhibitors for steel reinforcement in concrete: A review', Scientific Research and Essays, 6 (20), pp. 4152-4162, 2011. (IF 0.442)
2	Salawu Abdulrahman Asipita, Mohammad Ismail*, Muhd Zaimi Abd Majid, Zaiton Abdul Majid, CheSobry Abdullah, Jahangir Mirza, 'Green Bambusa Arundinacea leaves extract as a sustainable corrosion inhibitor in steel reinforced concrete'. Journal of Cleaner Production 67 139-146, 15 Mar. 2014, ISSN 0959 6256., ENGINEERING, ENVIRONMENTAL = Q1/ GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY = Q1, (IF 3.398).
3	Pandian Bothi Raja, Seyedmojtaba Ghoreishiamiri and Mohammad Ismail, 'Natural Corrosion Inhibitors for Steel Reinforcement in Concrete—A Review'. Surface Review and Letters, Vol. 22, No. 3 (2015) 1550040 (8 pages). World Scientic Publishing Company. Print

Research Output

4	Pandian Bothi Raja, Mohammad Ismail, Seyedmojtaba Ghoreishiamiri, Jahangir Mirza, Mokthar Che Ismail, Saeid Kakooei & Afidah Abdul Rahim, 'Reviews on Corrosion Inhibitors – A Short View', Chemical Engineering Communications, (2016), 203: 1145-1156, ISSN: 0098-6445 (Print) 1563-5201 (Online), DOI: 10.1080/00986445.2016.1172485 (IF 1.433)
5	Asaad, M. A., Ismail, M., Raja, P.B., Khalid, N.H.A. 'Rhizophora Apiculata as Eco-Friendly Inhibitor Against Mild Steel Corrosion in 1 M Hcl', (2017), Surface Review and Letters November 2017, Vol. 24, No. Supp01, World Scientific. Q4
6	Eyu D. G., Esah H., Chukwuekezie C., Idris J. and Mohammad I.. 'Effect of Green Inhibitor on The Corrosion Behaviour of Reinforced Carbon Steel in Concrete'. ARPN Journal of Engineering and Applied Sciences, Vol. 8, No. 5, pp 326-332, May 2013 ISSN 1819-6608
7	Abdulrahman, A. S. and Mohammad Ismail. 'Electrochemical assessment of concrete ternary inhibitors used in retarding corrosion of steel reinforcement', ARPN Journal of Engineering and Applied Sciences, Vol. 9, No. 5, May 2014 ISSN 1819-6608

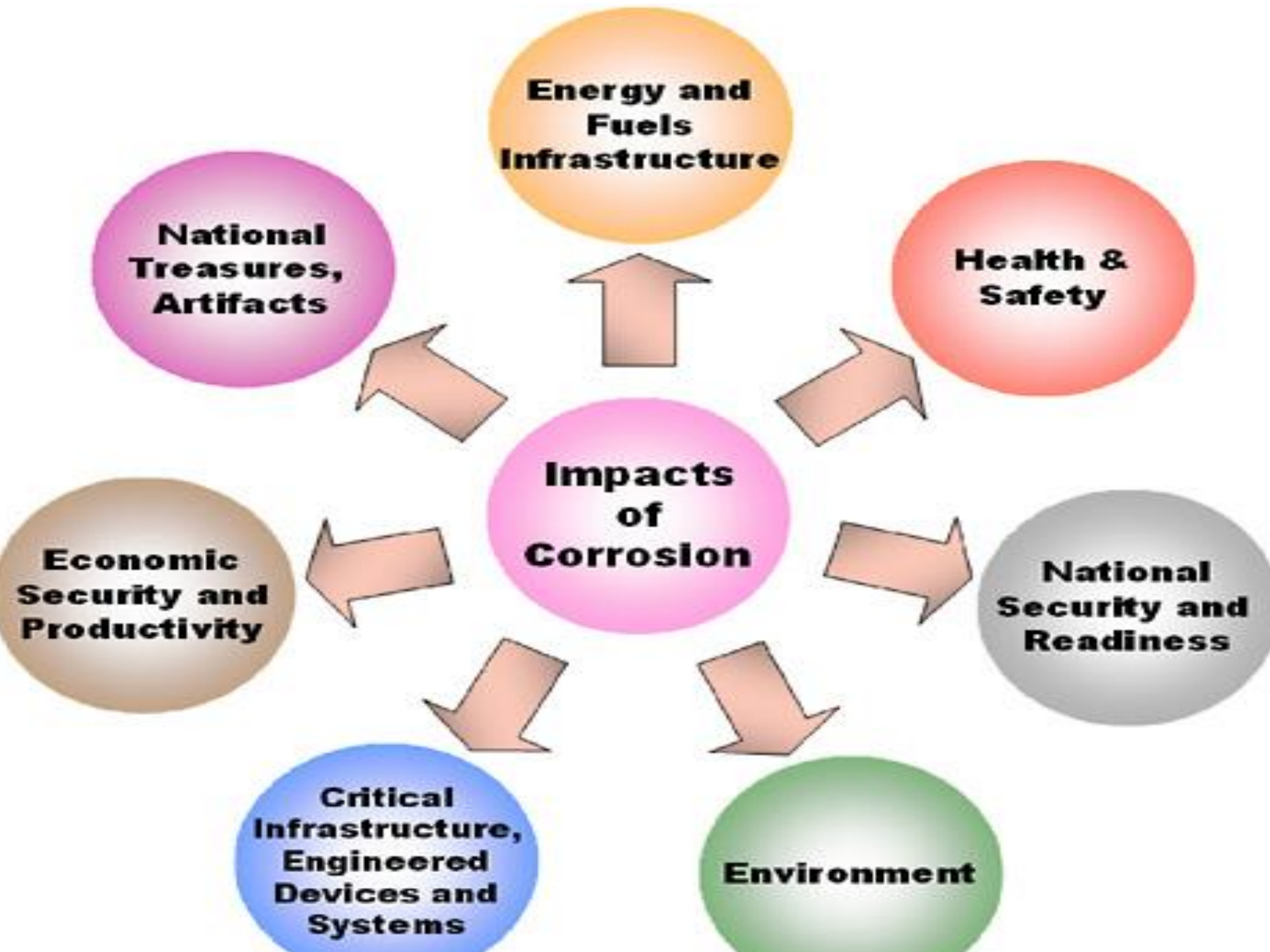
Research Output (cont.)

1	Patent Application Number: PI 2017300005, A Method for Synthesizing Corrosion Inhibitor Utilising Nanoparticle. 11 April 2017.
2	Patent Application Number: PI 2017300006, A Nanoparticles Corrosion Inhibitor as Concrete Admixture for Protecting Steel Reinforcement. 11 April 2017
3	Patent Application Number: PI 2017300007, A Method for Anticorrosion Self-Healing Coating. 11 April 2017
4	Patent Application Number: PI 2017300008, A Self-Healing Coating for Corrosion Inhibition. 11 April 2017

Impact on Economy

According to NACE (2016):

Country	Corrosion cost ($ billion)	Corrosion cost (GDP %)
Thailand	3.9	1.45%
Malaysia	6.7	3.23%
UK	70.6	3.09%
Australia	70.6	7.67%
China	310	3.34%
USA	451.3	2.7%


Energy and Fuels Infrastructure
Health & Safety
National Security and Readiness
Environment
Critical Infrastructure, Engineered Devices and Systems
Economic Security and Productivity
National Treasures, Artifacts
Impacts of Corrosion

THE WAY FORWARD

- **STANDARDIZATION** of green corrosion inhibitors (stability in concrete / electrolytes / atmospheric conditions / different temperatures and pressure) - Usage of biocides to increase the stability of inhibitors
- Usage of green solvents / recovery of solvents after extraction

THE WAY FORWARD

- Corrosion monitoring over prototype setup before used in industry / field. Structural Health Monitoring.
- More research should be explored on area such as **CORROSION RESISTANCE STEEL, CORROSION REHABILITATION**
- **MODELLING OF CORROSION** – Mechanism, behaviour
- Encouragement on the use of **PRE-CAST TECHNOLOGY** for construction work.

THE WAY FORWARD

- **NANOTECHNOLOGY:** Application of nanotechnology material in cement and concrete composite is getting much attention, such as addition of Nano-binders cement based material with nano-sized cementitious components. Silicon dioxide nano-particles (nano-silica) added as admixture to produce ultra-high performance concrete.

THE WAY FORWARD

- **GREEN CONCRETE:** Concrete of tomorrow will be green. Concrete of low water/binder ratio will be stronger and durable and no longer considered as low commodity product.

THE WAY FORWARD

- **USAGE OF WASTE AND AGRICULTURE WASTES** as corrosion inhibitors (example: paddy fibers after harvesting, mango seeds, sugar cane waste from field and industry)

THE WAY FORWARD

- Use of **RECYCLED MATERIALS** as well as any other suitable by-product should be encouraged and support with necessary (standard) document.

Akram

CONCLUSIONS

- **Understand the environmental** condition and all related treat from the surrounding.
- **Design** – should follow and complied to the standards and specification, including the materials chosen (Good quality materials).
- **Construction practices** – Understand the drawing and carefully translate the drawing to site.
- **Close and continuous monitoring** throughout the on-going project.
- **Maintenance**

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Thank you

If you cannot endure learning, then you will endure the sting of ignorance

BILA KAMU TAK TAHAN LELAHNYA BELAJAR,
MAKA KAMU AKAN MENANGGUNG PERITNYA KEBODOHAN

-Imam Syafie-

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Al-Kahfi

قُل لَّوْ كَانَ ٱلْبَحْرُ مِدَادًا لِّكَلِمَٰتِ رَبِّى
لَنَفِدَ ٱلْبَحْرُ قَبْلَ أَن تَنفَدَ كَلِمَٰتُ رَبِّى
وَلَوْ جِئْنَا بِمِثْلِهِۦ مَدَدًا

Say: If the sea were ink for the words of my Lord, the sea would surely be consumed before the words of my Lord are exhausted, though We were to bring the like of that (sea) to add