Institute of Fundamental Technological Research
Polish Academy of Sciences

INFLUENCE OF GAMMA IRRADIATION ON THE INITIATION OF STEEL CORROSION IN CONCRETE

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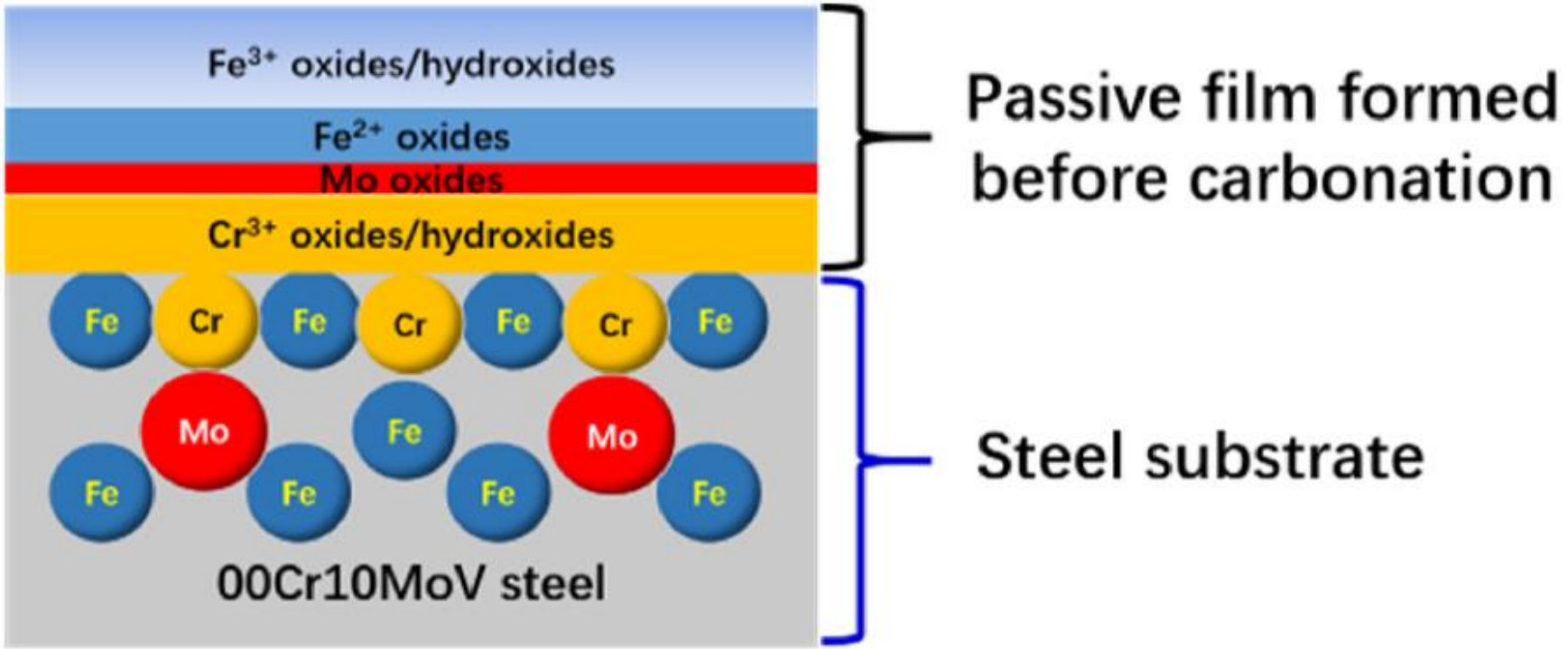
RADCON meeting, 2-3 September, 2021,

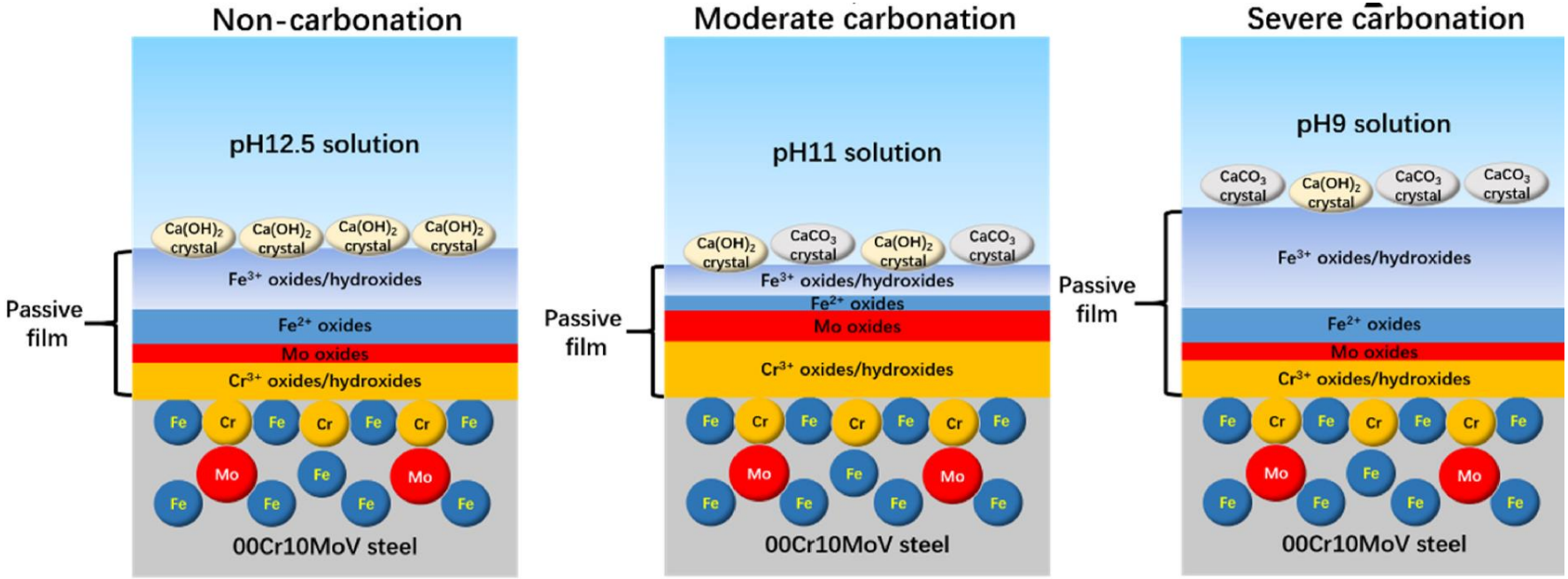
Introduction: passivation

- Perfect protection > 12,5 pH
- Fe^{2+} - protective oxides
- Fe^{3+} - non-protective nature of oxides/hydroxides



I. J. Minga et al., PASSIVE FILM MODIFICATION BY CONCRETE CARBONATION: RE-VISITING A CORROSION-RESISTANT STEEL WITH CR AND MO, CCC 2021

Passivation during carbonation



- Thickness of passivation layer change,
- Dissolution of protective layer of $Ca(OH)_2$,
- Movement of iron ions to non-protective Fe^{3+} oxides/hydroxides layer
- Pitting corrosion (especially with Cl^-)

Objective: effect of gamma radiation

II. T. Nishimura, CORROSION BEHAVIOR OF REINFORCING STEEL IN CONCRETE FOR NUCLEAR FACILITIES EXPOSED IN HIGH CHLORIDE AND LOW PH ENVIRONMENT, JNM 2010

Research program

Decreasing the pH of cement matrix → Dilute of Ca(OH)2 content by SCM

MORTARS

(400 g Portland cement, w/c= 0.6, 1350 g sand 0/2 mm)

cement replacement

20%
40%
SILICEOUS FLY ASH

20%
40%
LIMESTONE

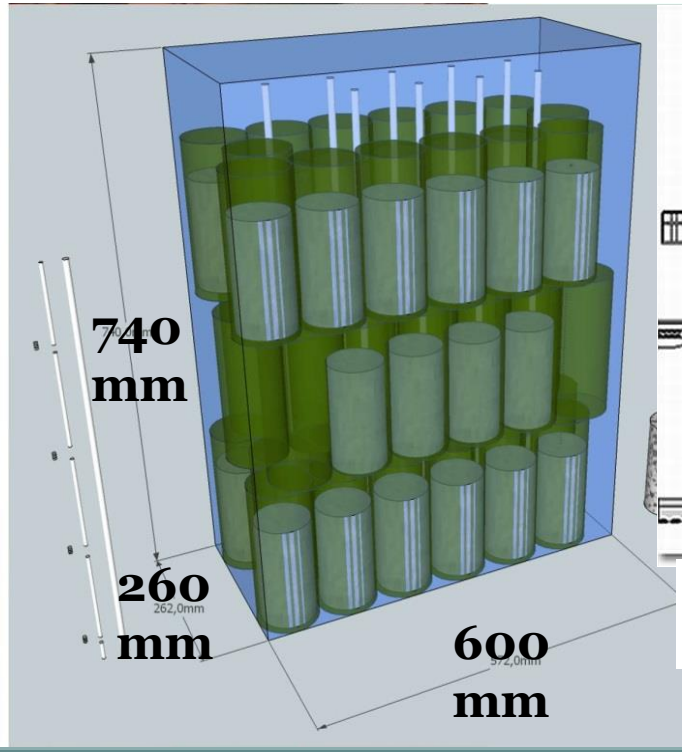
Methods and specimens:

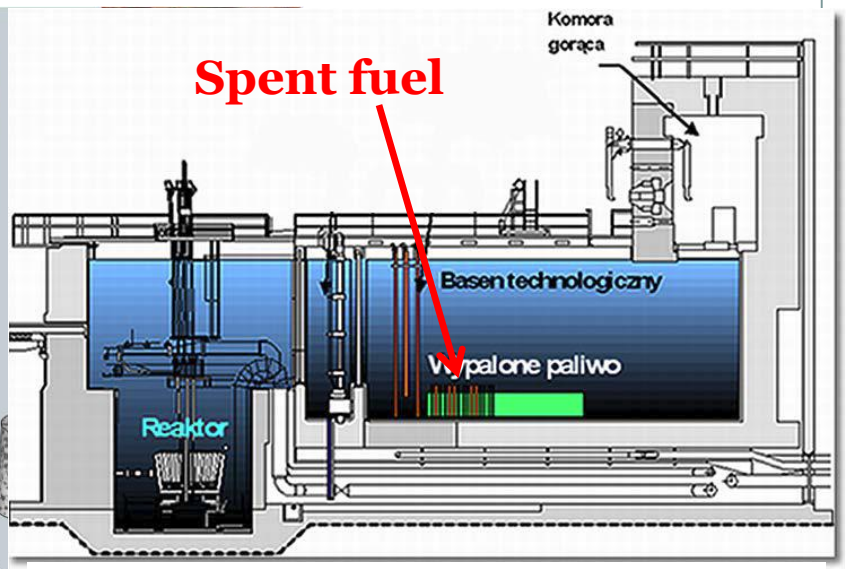
- **Flexural and copressive strength**
  (beems160x40x40 mm)
- **Potentiodynamic measurement - PN-B-01810**
  (cylinders ø=60 mm h=100 mm with steel ø=6 mm rods)
- **Electrochemical impedance spectroscopy (EIS)**
  (cylinders ø=60 mm h=100 mm with steel ø=6 mm rods)
- **XRD, SEM** (cylinders ø=85 mm h=100 mm with steel ø=20 mm rods)

Gamma irradiation

Specimens „lolipops”:

- with steel rod ø=6mm (according to PN-B-01810)
- with steel rod ø=20 mm,





Research reactor „MARIA” at National Center for Nuclear Research

Specimens conditioning

Specimens

(conditions in the sealed can)

SPENT FUEL POOL

- T=38°C (measured),
- CO_2=1%,

I. RH=50%±10%,

II. RH= 100%

LABORATORY CLIMATIC CHAMBER

- T=40°C (set),
- CO_2=1%,

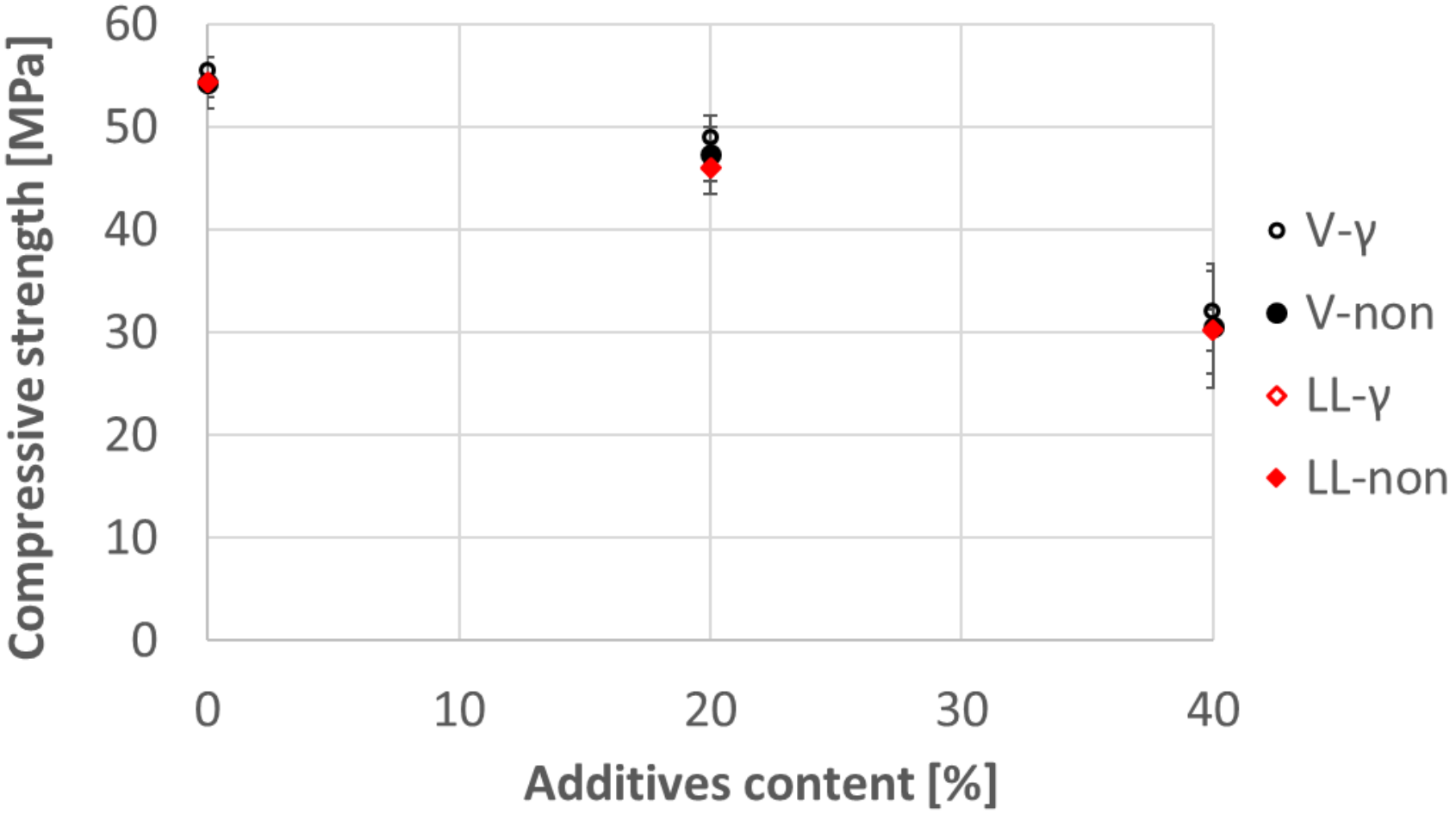
I. RH=50%±10%,

II. RH= 100%

Gamma irradiation:

- Exposure time: 8 months,
- Dose: 0.7-1.0 MGy.

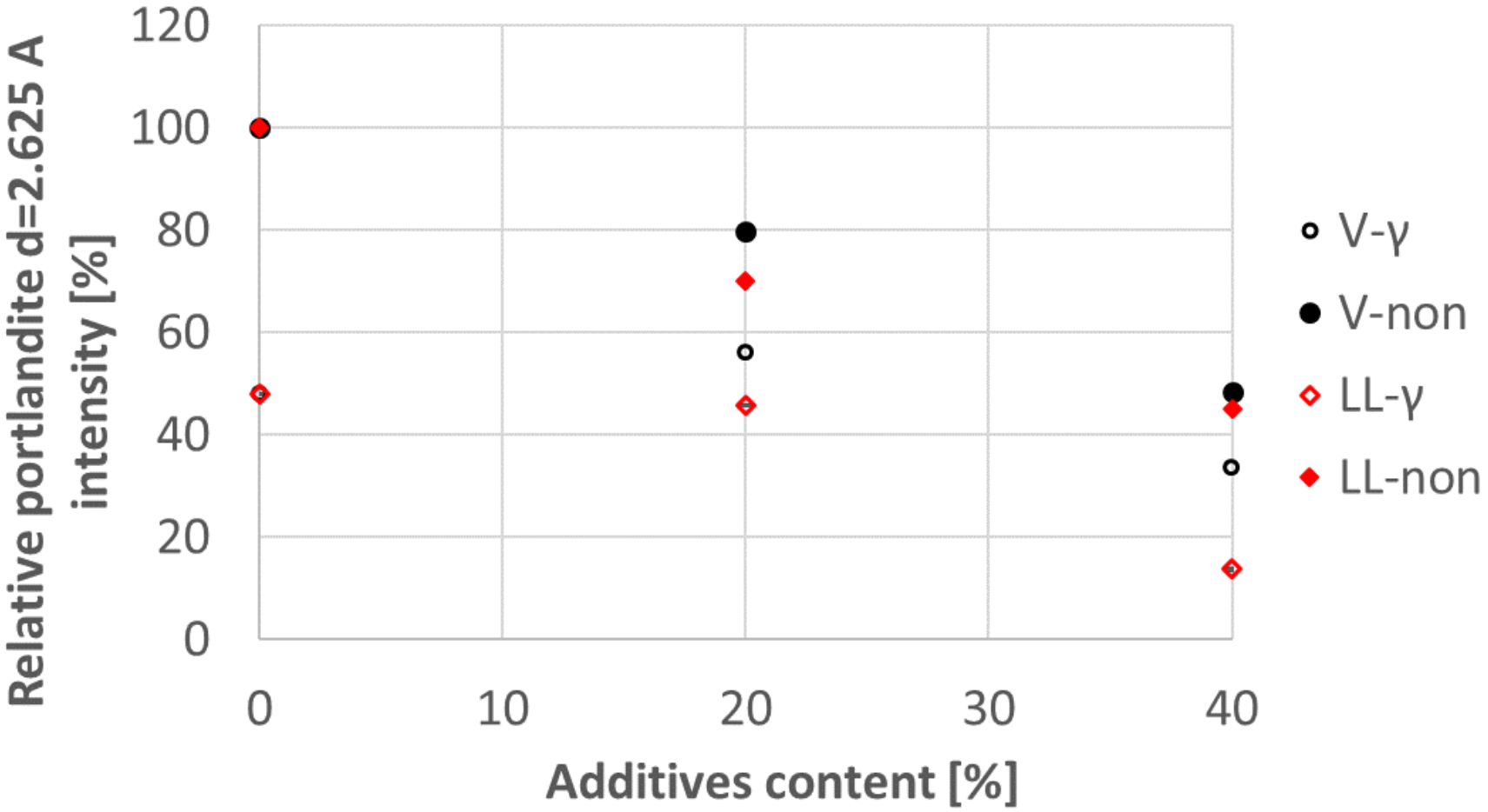
Compressive strength



40x40x40 mm prism after expositon in dedicate conditions (RH=50%)

Portlandite intensity - XRD

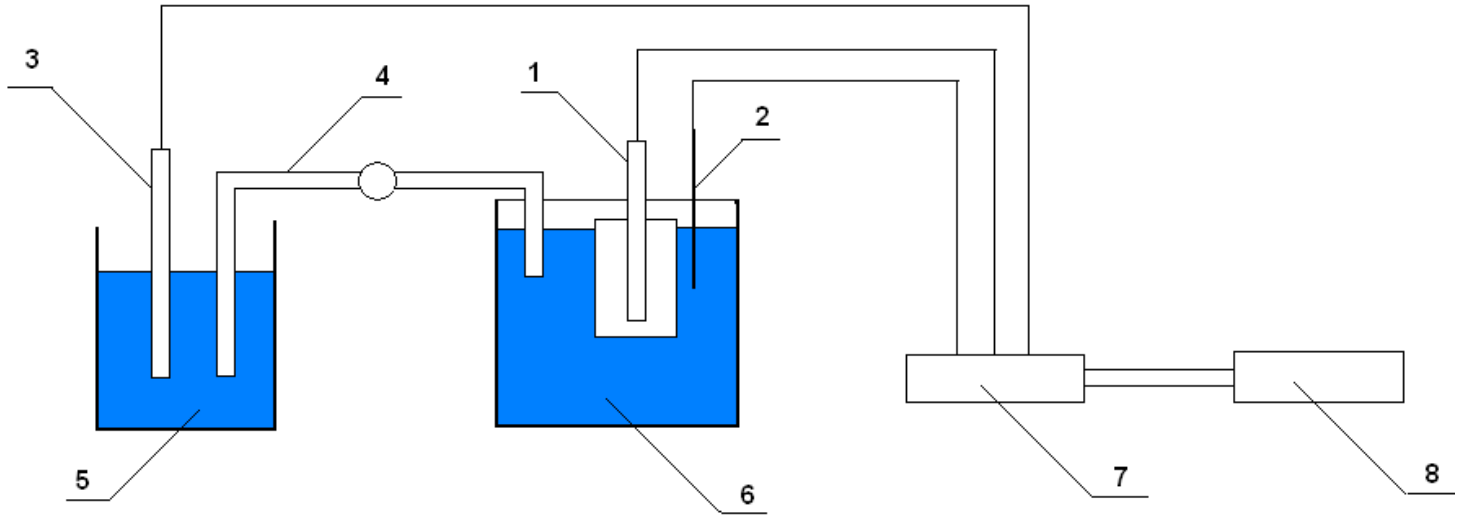
exposition in RH=50%



Portlandite intensity decrease after gamma irradiation → accelerated carbonation

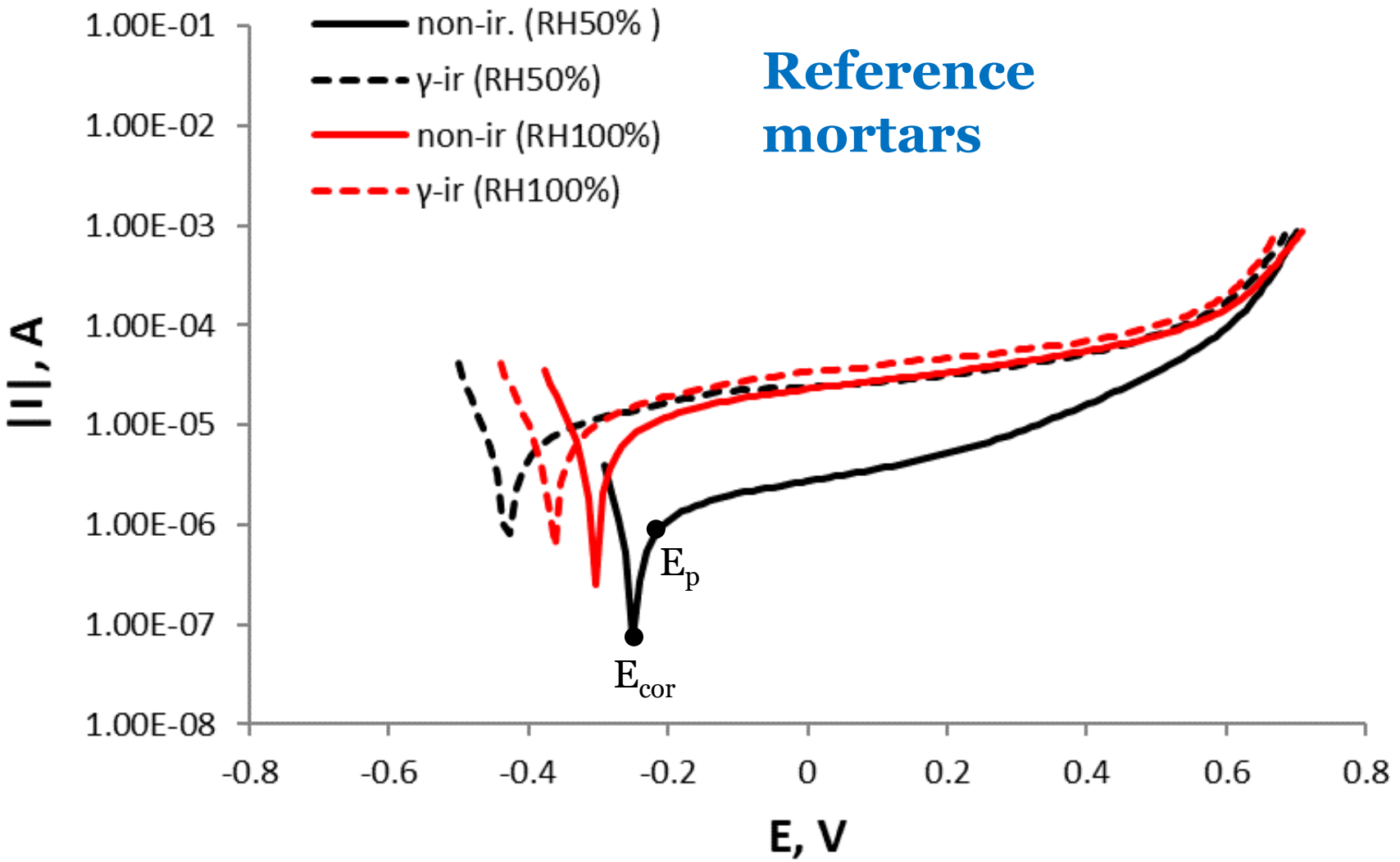
Potentiodynamic electrochemical technique

Equipment: Autolab PGSTAT 302N,
Presaturation: 24h in Ca(OH)2 solution,
The rate of potential change: 1 mV/s,
Reference electrode: the saturated calomel electrode (SCE),

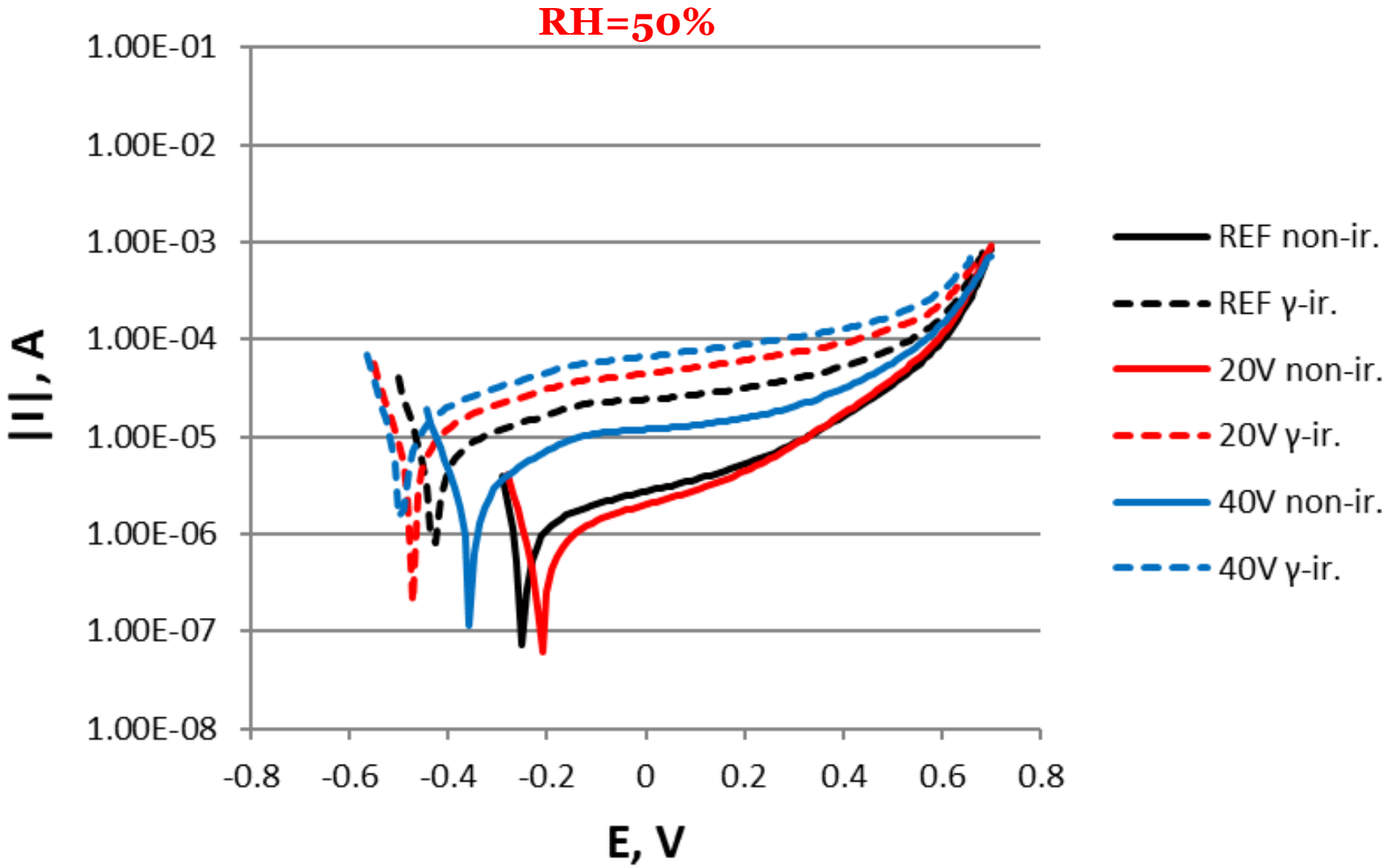


1 - working elctrode, 2 - auxiliary electrode, 3 - reference electrode, 4 - salt bridge, 5 - transition vessel filled with KCl, 6 - water extract from concrete or distilled water, 7 - potentiostat, 8 - acquisition

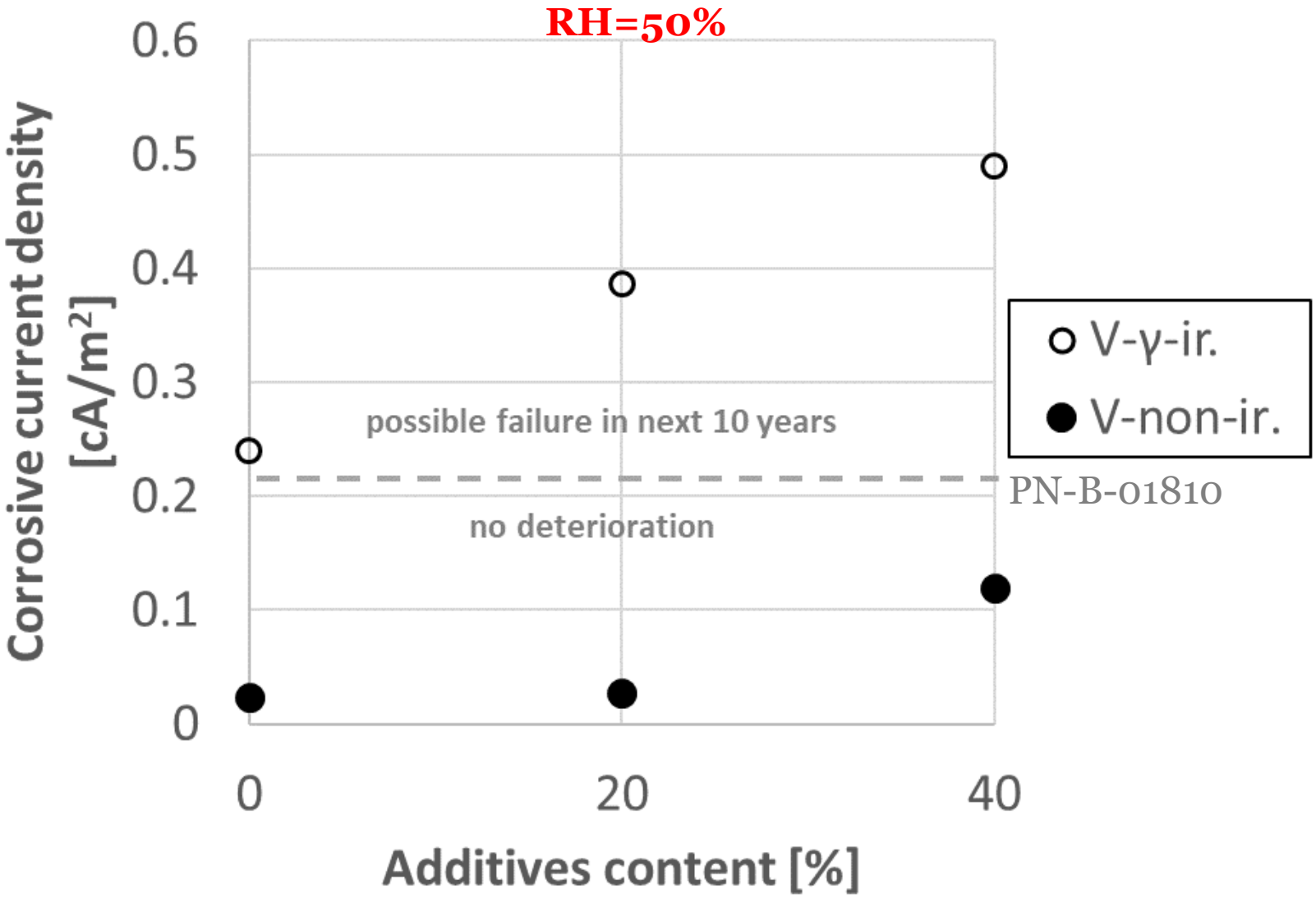
Measurement of passivation characteristic



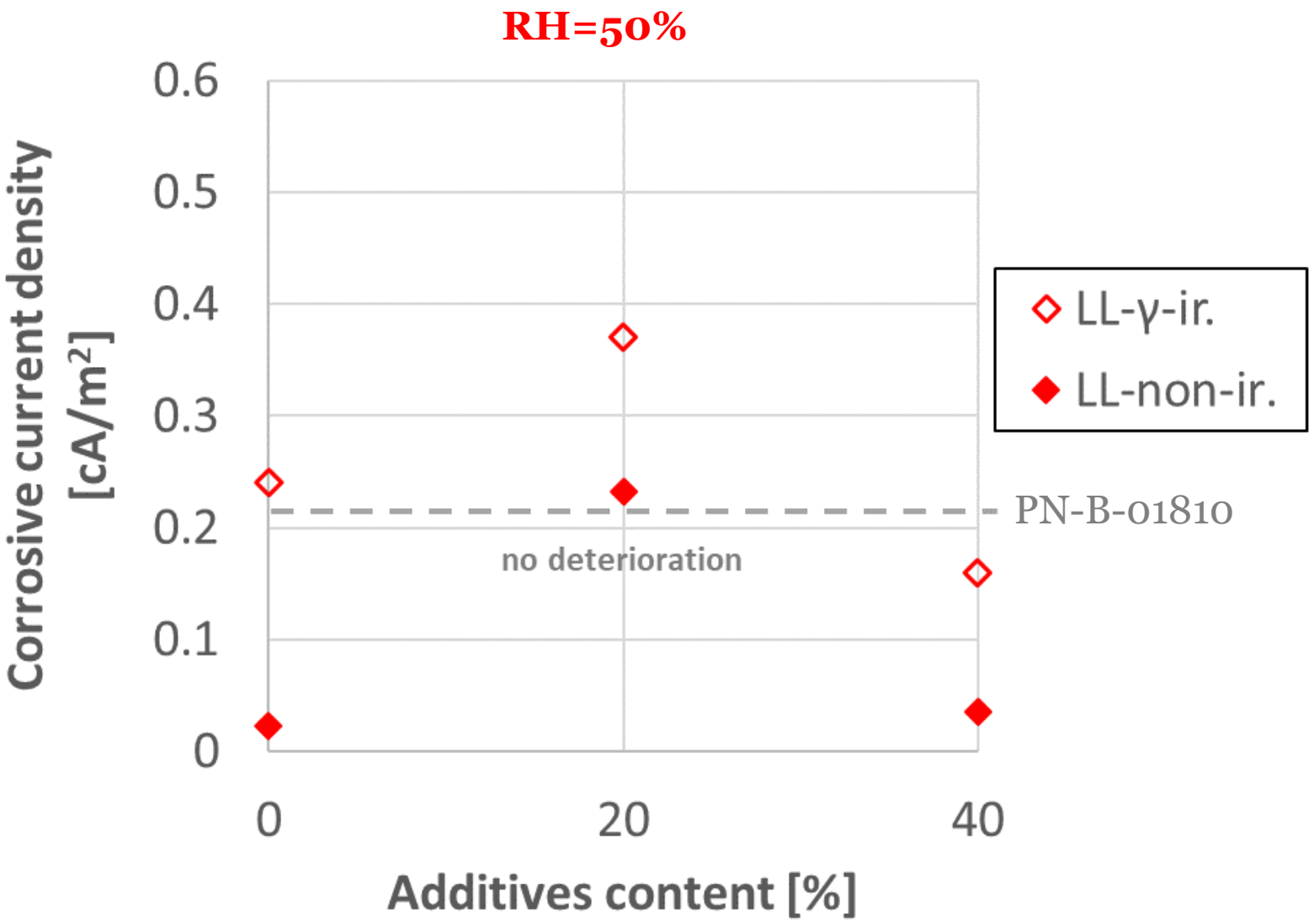
Measurement of passivation characteristic



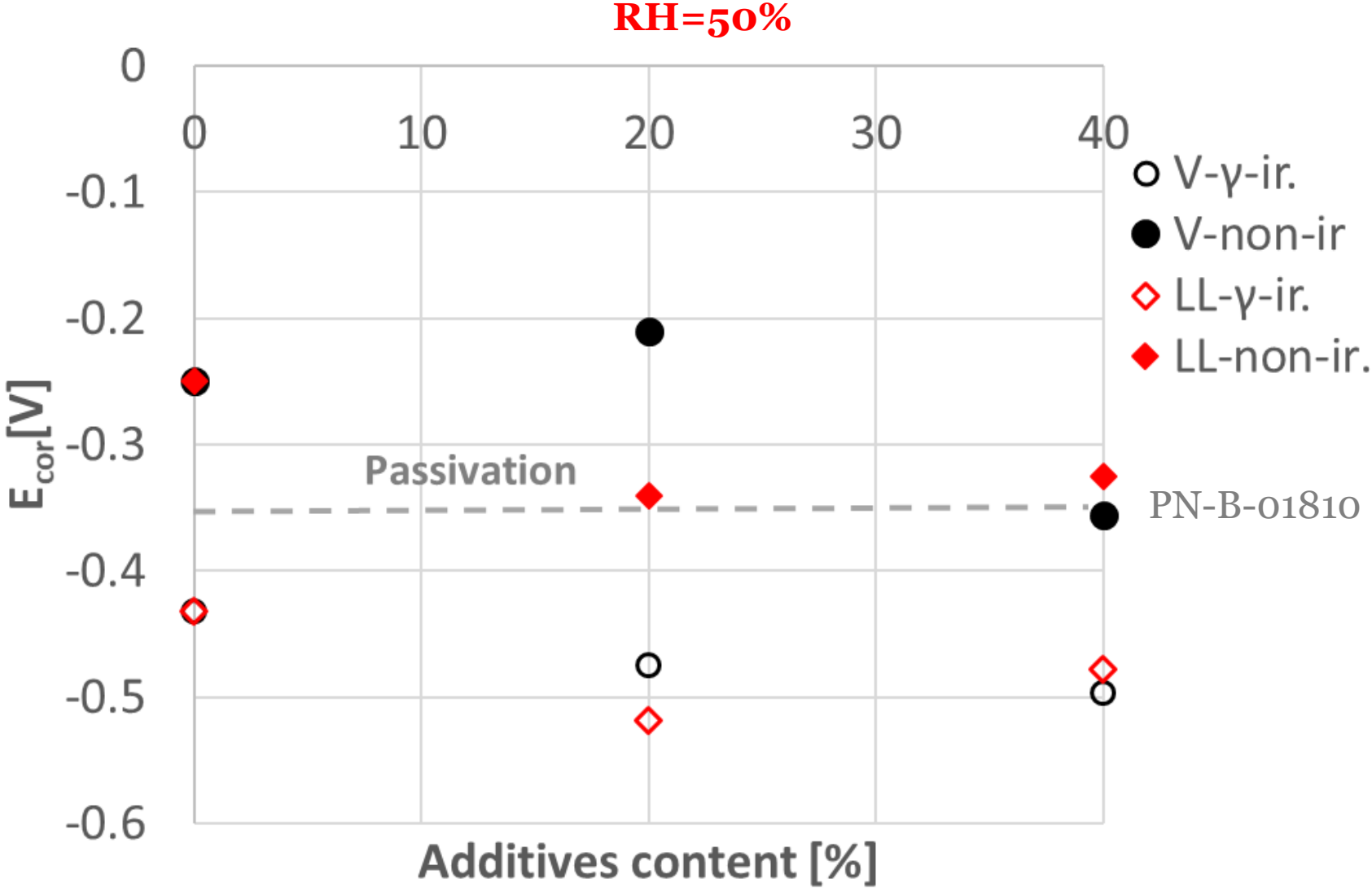
Corrosive current density - j_{cor}



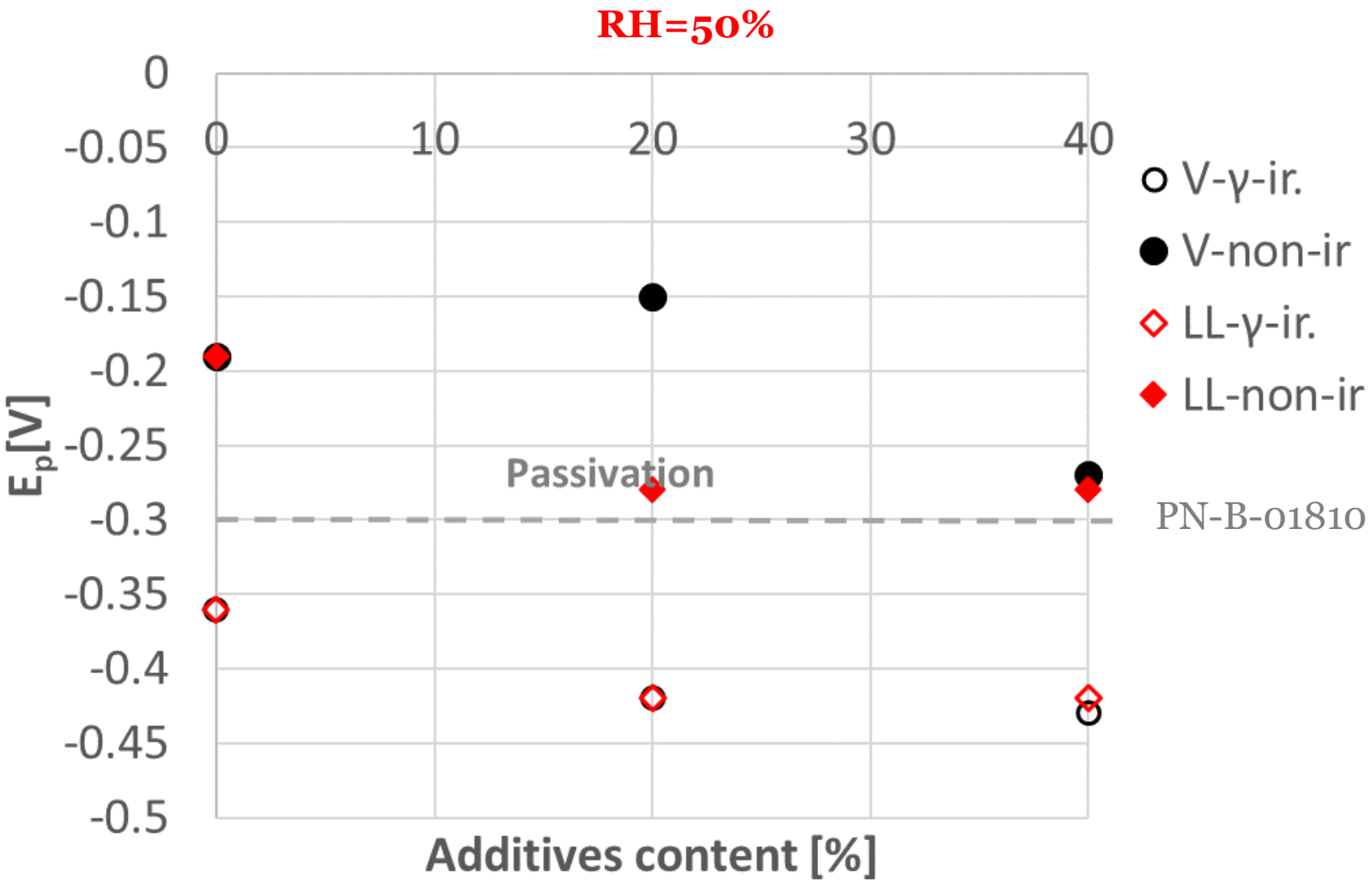
Corrosive current density - j_{cor}



Corrosive potential - E_{cor}



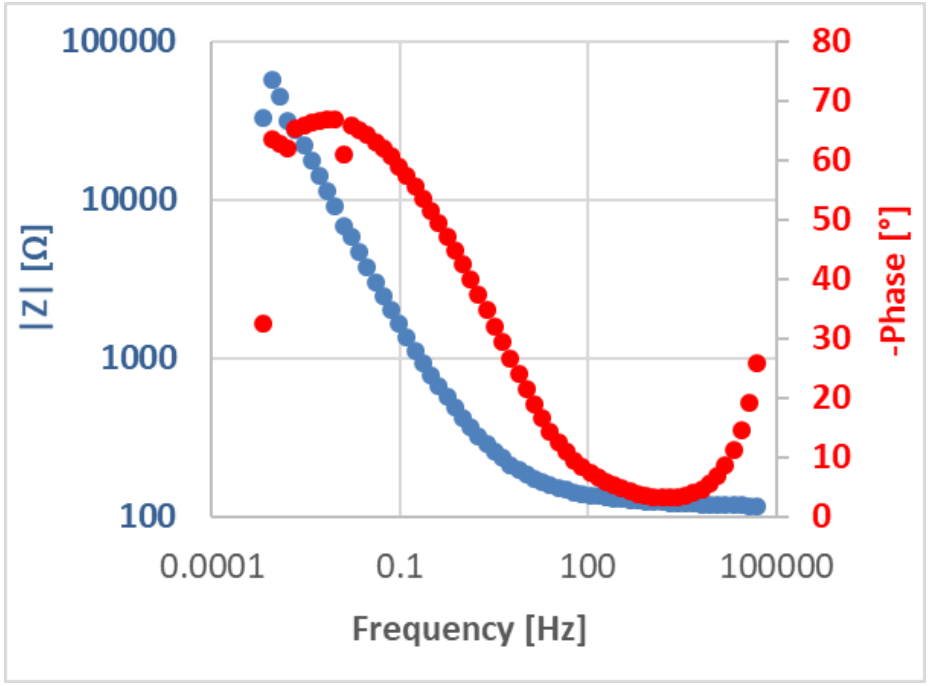
Passivation potential - E_p

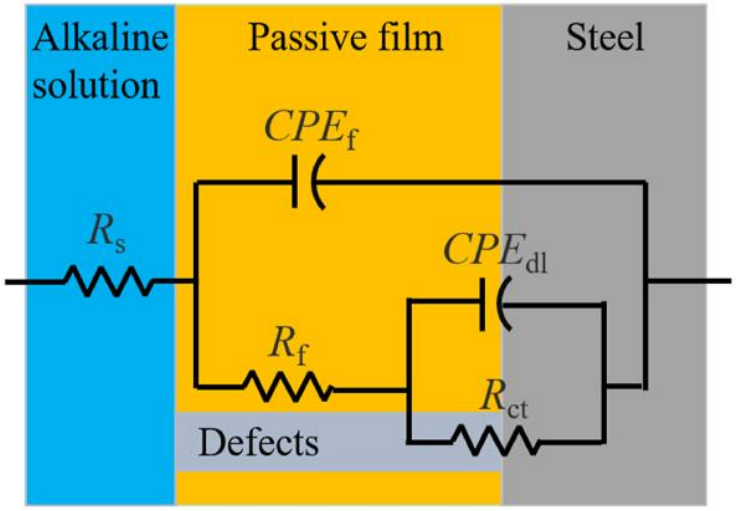


Electrochemical impedance spectroscopy (EIS)

Equipment: Autolab PGSTAT 302N,
Presaturation: 24h in Ca(OH)2 solution,
Frequency range: 50 kHz-0,5 mHz,
Amplitude of the voltage: 10 mV,

Reference mortar – non-ir. RH=50%





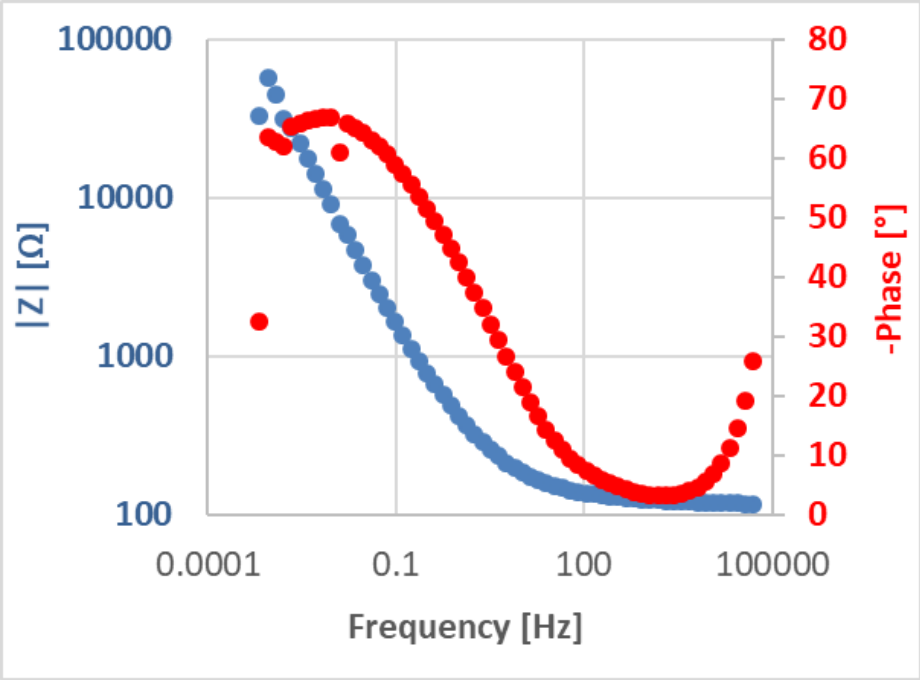
Proposed equivalent electrical circuit

IPPT PAN Institute of Fundamental Technological Research Polish Academy of Sciences

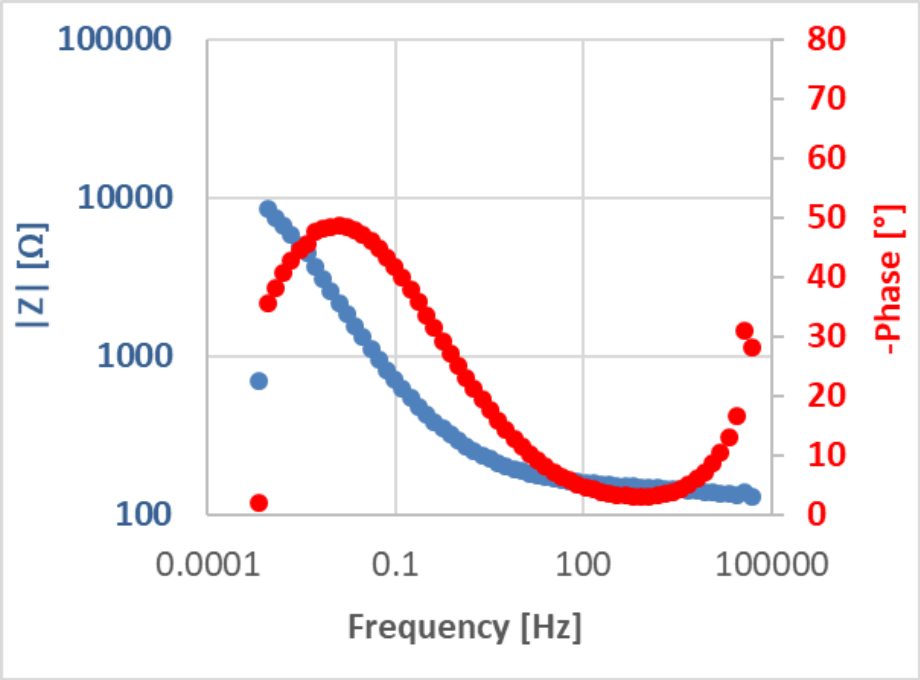
Electrochemical impedance spectroscopy (EIS)

RH=50%

Reference mortar – non-ir.



Reference mortar – γ-ir.



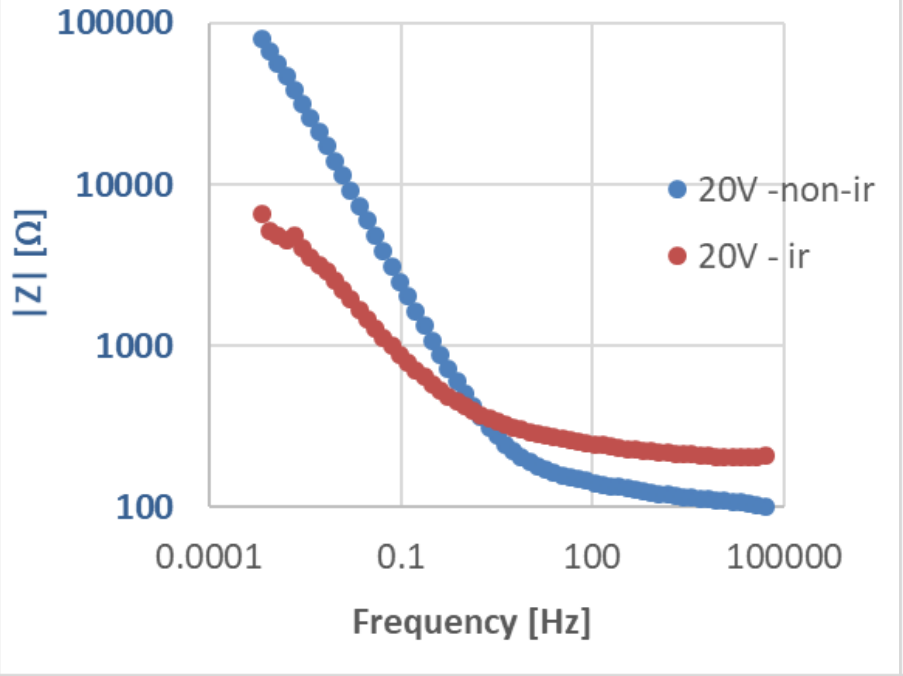
For low frequency:

Higher |Z| → lower corrosion potential
Higher „–Phase” → lower corrosion potential

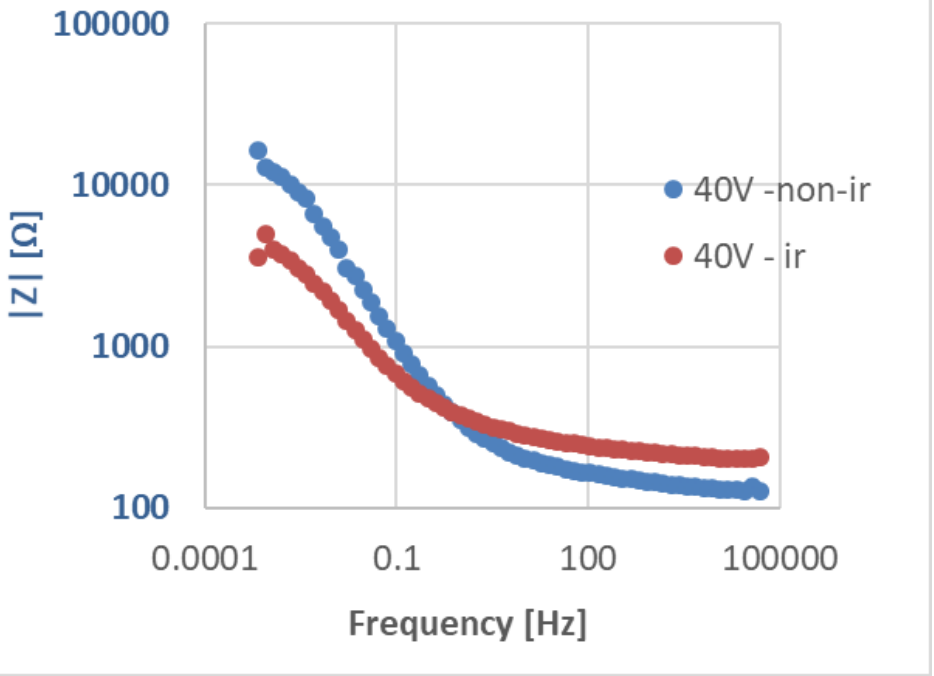
Electrochemical impedance spectroscopy (EIS)

RH=50%

20V



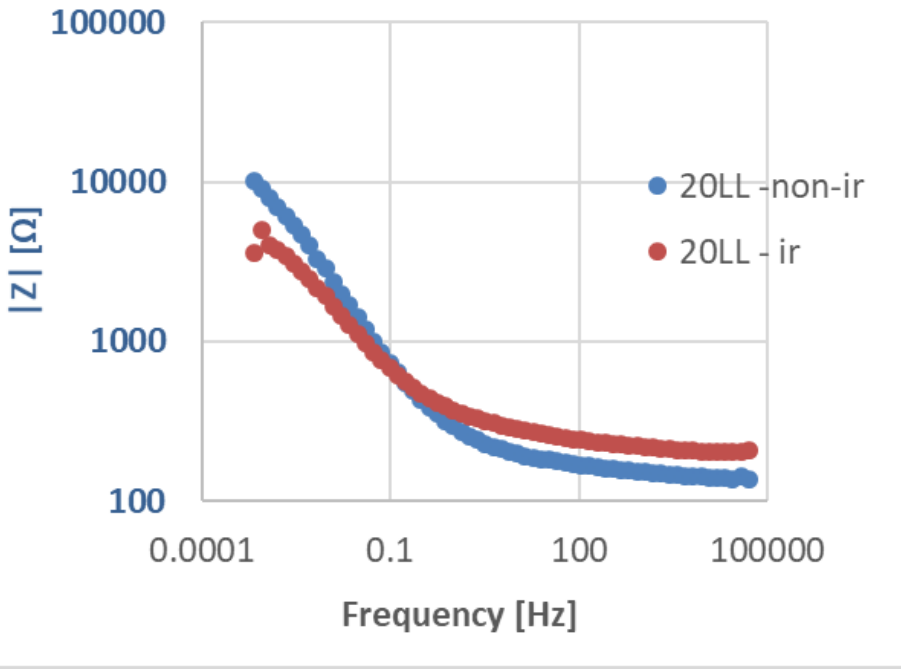
40V



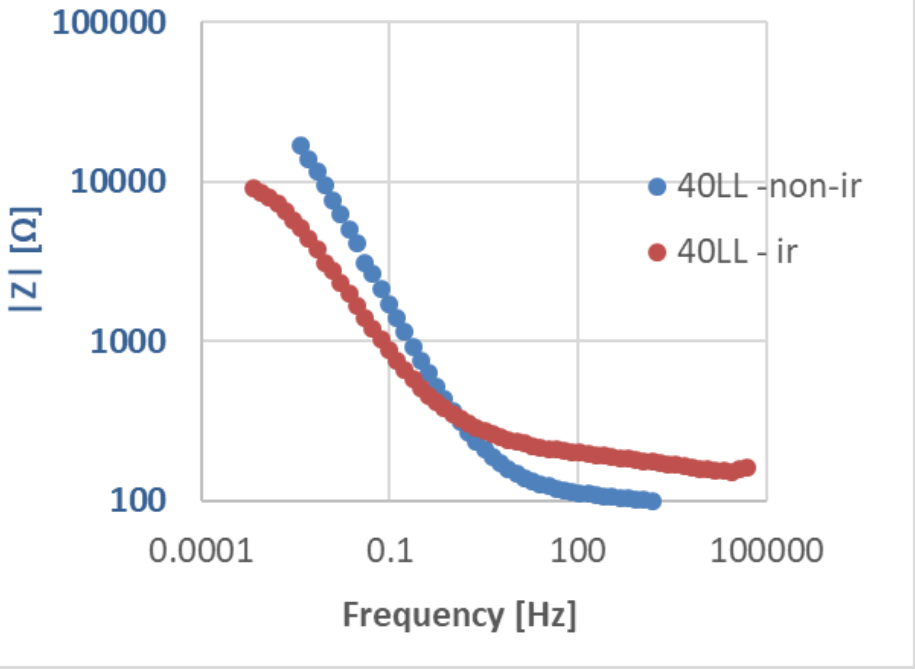
Electrochemical impedance spectroscopy (EIS)

RH=50%

20LL



40LL



Concluding remarks

Electrochemical measurement revealed a significant impact of gamma irradiation with dose up to 1 MGy on the passivation of steel in to cement mortars. Based on results we can draw a following conclusions:

- the decrease of corrosive potential (E_{cor}) and passivation potencial (E_p) of steel in mortars to non-passive region compared to non-irradiated specimens, espesially for conditioning in RH=50±10%,
- the increase of corrosive current density (j_{cor}) of steel in mortars to possible degradation region compared to non-irradiated specimens; tendency is higher when decrease of portlandite in mortars is observed (lower pH),
- Irradiation promote decrease of impedance and phase shift to smaller values for low frequency of current in reinforcement steel, from what is result as higher possibility of corrosion than in case of non-irradiated specimens.

Thank you for your attention!

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