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Electrodialytic technology as effluent treatment for reuse in construction materials

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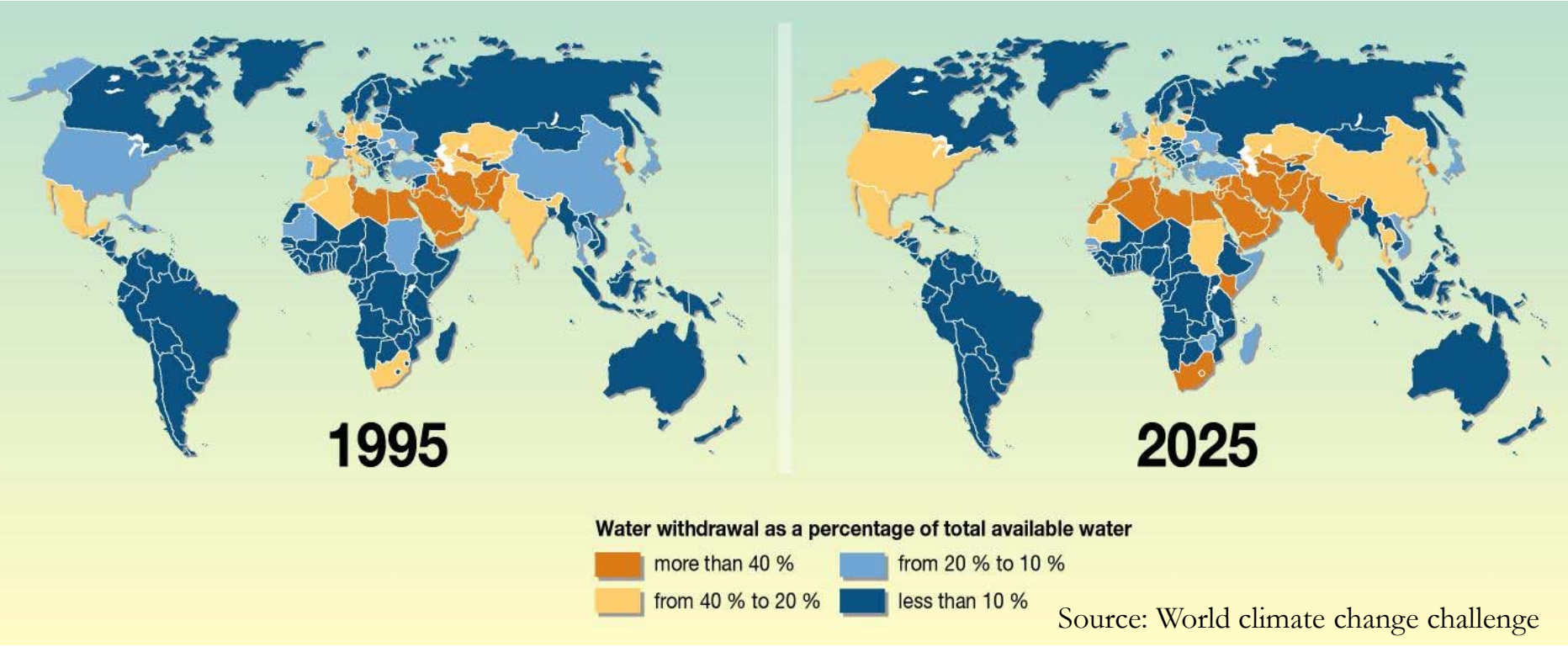
Why? Water Stress

Concrete is the 2nd material most consumed

Water is the 1st



Source: World climate change challenge

water–cement ratio: weight of water to weight of cement used in a concrete mix ≈ 0.45 to 0.60

800 billion liters of water used in 1 year !!!!!

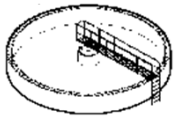
Solution?

Wastewater Pre-treatment with Electrodialytic Process (ED)

WIN-WIN SOLUTION

- ✓ Fresh water safety– Contribute to circular economy
- ✓ Less wastewater volume discharged in water bodies
- ✓ Similar chemical characteristics comparing to tap water

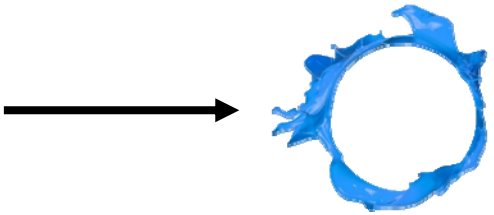
Wastewater with micro-organisms, heavy metals and **salts**



Effluent 2nd clarifier
Before chlorination

+

Building Materials
Mortars specimens



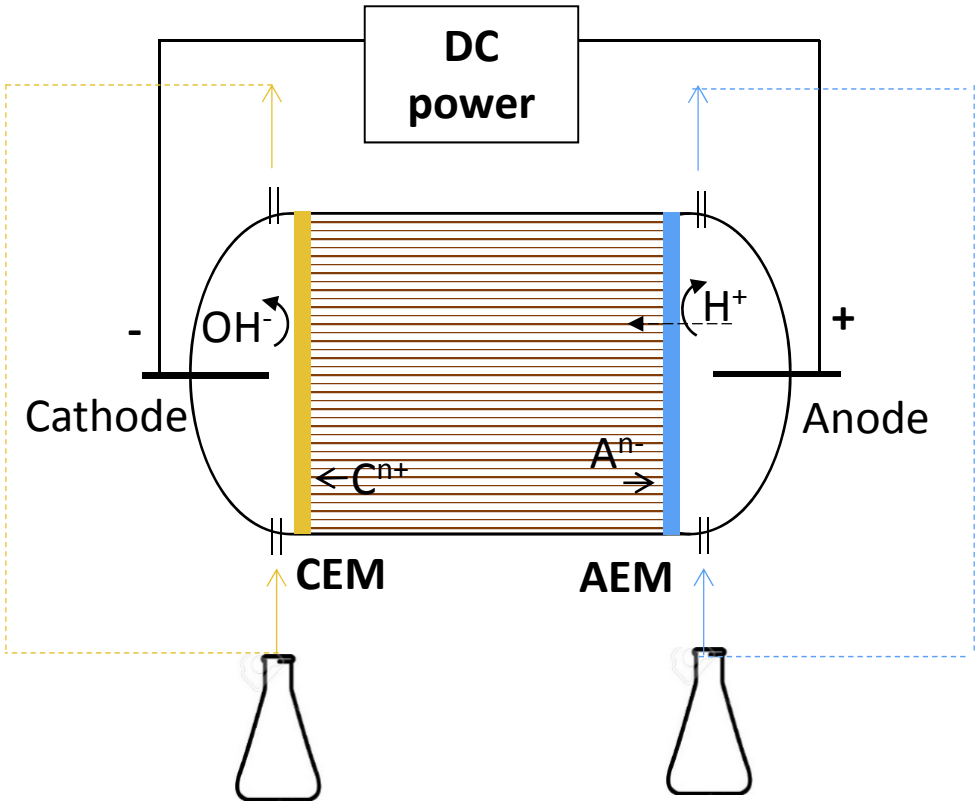
Wastewater Pre-treatment with Electrodialytic Process

?Aim?

- ✓ ED technology optimization:
  - ✓ to remove heavy metals, salts [Cl^- (oxidation of iron), SO^{2-}_4 (crack formation)], macro & micro elements;
  - ✓ to neutralize micro-organisms in effluents
- ✓ Viability to use ED treated effluent in construction materials (mortars) as an alternative to tap water

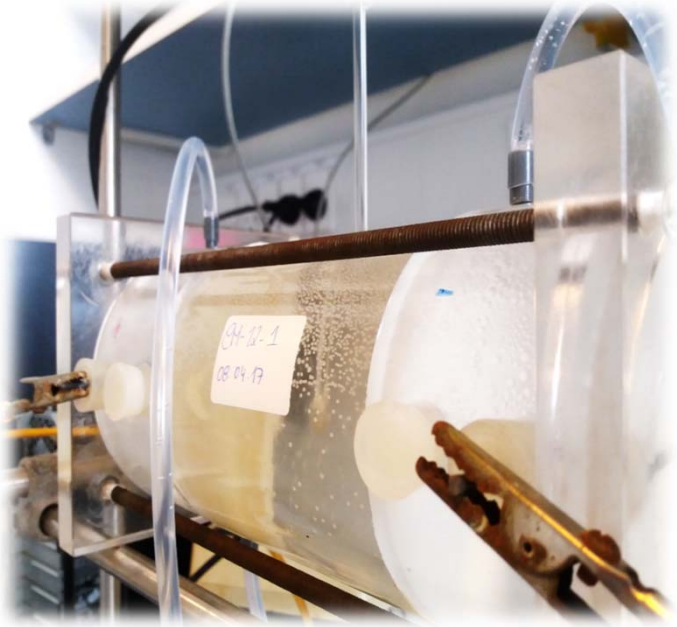
Wastewater Pre-treatment

Electrodialytic Process (ED)



Effluent under treatment

Electrolyte $NaNO_3$



Electrodialytic Pre-treatment

Methodology

Electrodialytic Technology (ED-TEC)

❑Wastewater Source:

➢ **Wastewater treatment plant Mølleåværket A/S, Lyngby, Denmark**

✓ **Effluent 2nd clarifier**

❑Volume treated: 500 mL

Experimental Conditions

✓Membrane type: Ion exchange membranes

✓Time – 24 h, 12 h, 6 h

✓Current: 25 mA

✓ Replicates (n=3/4) and blanks (n=3; no current)

Methodology

Casting of specimens*

- Replacement of Tap Water by Effluent: **50%** and **100%**

(Ordinary Portland Cement – OPC - 0.5 w/c ratio – prisms 40×40×160mm)

- ✓ Raw (effluent without Electrodialytic pre-treatment)
- ✓ ED- T (effluent with ED pre-treatment – 24 h, 12 h, 6 h)
- ✓ Reference

*Casting of specimens – it is the action of making mortars

Methodology

Property & Environmental tests

❑ **Mortar property Tests - Compared with mortar REF**

✓ Setting time (ref; raw; ED- T - final acid pH)

✓ Compressive strength - (Age: 7, 14, 28 days)

✓ Bending strength - (Age: 7, 14, 28 days)

❑ **Mortar Environmental tests**

✓ Leaching of HM and salts

Methodology

Analytical methods

Characterization and Removal rates

1. Cations & anions - IC- Ion chromatography
2. Heavy metals – ICP - Inductively coupled plasma atomic emission spectroscopy
3. Effluent law parameters - (BOD_5, COD, NH_4, NO_2, N_{total}) - Spectrophotometer DR2800 – kits

Material tests

1. Setting time (min) - Standard ASTM C 191 – Time of Setting of Hydraulic Cement by Vicat Needle – Instruments: Vicat Needle
2. Flexural tests (kN) - Standard EN 196-1 – Methods of testing cement - Instruments: Instron 6022 10 kN - 3-point flex test
3. Compressive strength (MPa) - Standard EN 196-1 – Methods of testing cement – Instruments: Toni machine - Mortar prism 20X20X80mm
4. HM and salts leaching – L/S = 2 – 20 g of mortar powder 40 mL of deionised water, shaking 24 h at 200 rpm.

Results and Discussion

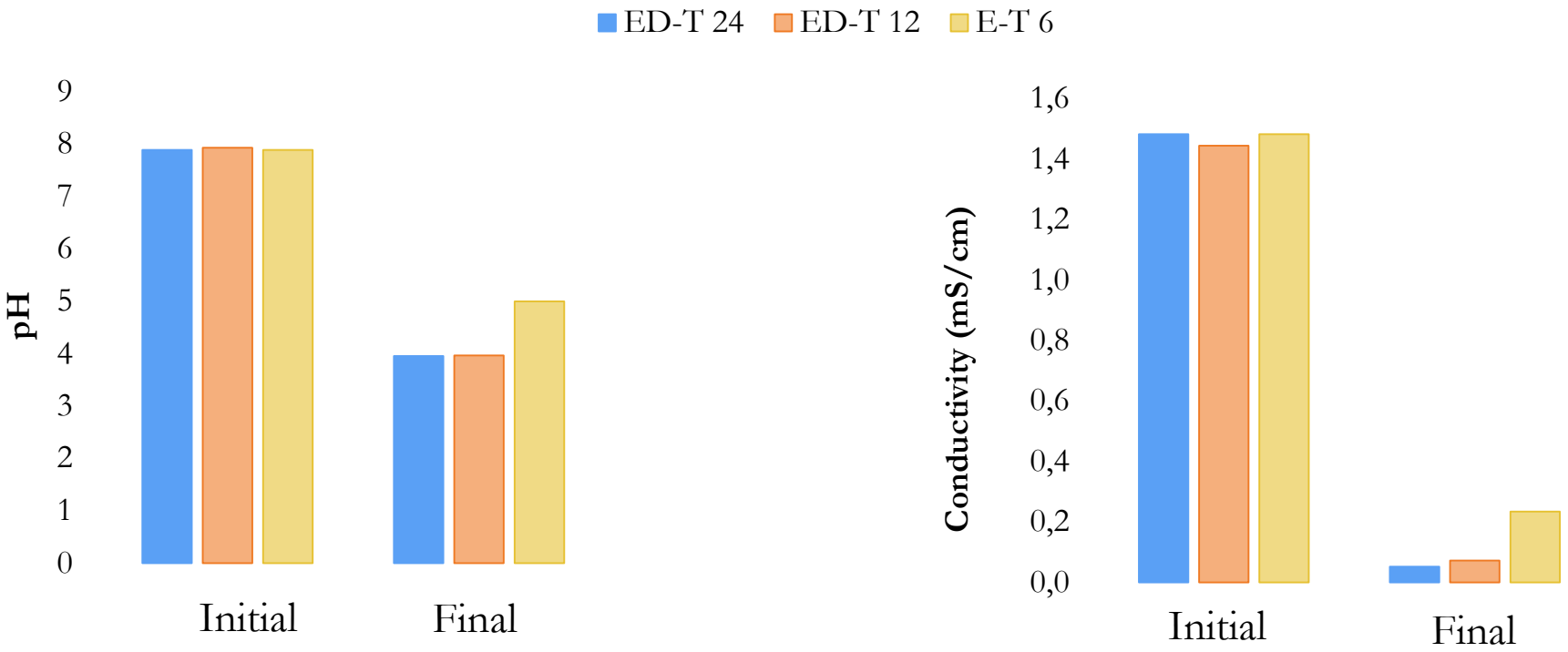
Matrix

Initial characterization

	Effluent	Tap Water
pH	7.9 ± 0.3	7.7 ± 0.1
Conductivity (µs/cm)	1304.5 ± 109.6	755.5 ± 23.3
Macro-elements		
Ca	115.1 ± 13.3	113.9
K	24.2 ± 0.7	5.3
Mg	15.7 ± 0.9	20.7
Na	118.7 ± 0.7	38.5
S	20.6 ± 1.9	8.7
Micro-elements		
Ni	0.04 ± 0.02	0.005
Si	8.4 ± 0.4	8.8
Zn	0.05 ± 0.02	0.35
Salts		
Cl^-	207.3 ± 3.9	63.0 ± 2.2
SO^{2-}_4	65.7 ± 2.3	31.7 ± 2.2

ED-TEC

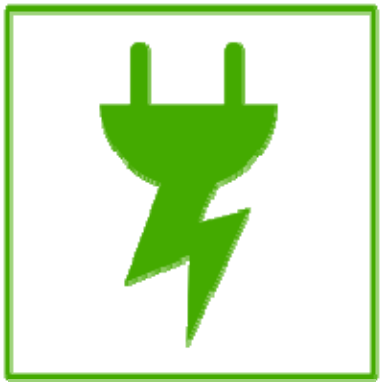
pH and Conductivity (mS/cm)



- Increasing the duration time = Higher acidification of the matrices
  = Lower conductivity

Energy consumption

- ED-T (24) - 25 W/h - 0.0080 €
- ED-T (12) -13 W/h - 0.0040 €
- ED-T (6) - 3 W/h - 0.0009 €



ED-TEC

Elements -Removal Rates (%)

(mg/L)		Ca	K	Mg	Na	Ni	S	Si	Zn
Initial		**115.1**	**24.9**	**14.7**	**117.9**	**0.01**	**22.7**	**79.2**	**0.04**
Final	**ED-T**	0.3	0.5	0.05	0.5	0.004	0.2	24.5	0.01
Removal (%)	**24**	99.8%	98.1%	99.7%	100%	54.8%	99.2%	69.1%	74.6%
Final	**ED-T**	0.3	0.3	0.04	1.5	0.003	0.2	40.0	0.01
Removal (%)	**12**	99.8%	98.9%	99.7%	98.7%	70.7%	99.0%	49.6%	75.1%
Final	**ED-T**	5.9	1.2	1.2	10.2	0.004	3.0	7.5	0.03
Removal (%)	**6**	94.9%	95.4%	92.1%	99.1%	59.8%	87.0%	90.6%	27.3%

- ❑ Ca, Mg, K and Na = complexes with Sulfates = crack formation
- ✓ Removal range of 92-100%

ED-TEC

Removal Rates (%) - Cl^- and SO^{2-}_4

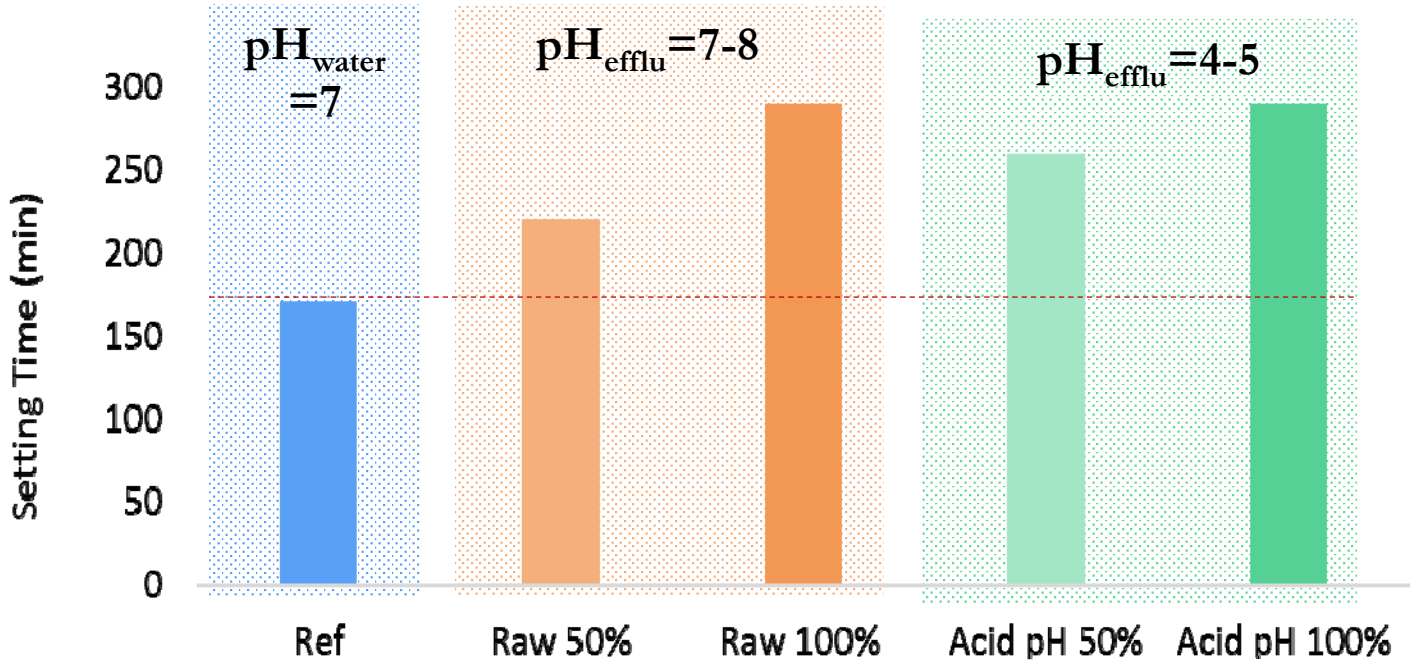
Higher than 85%

		Cl^-	**SO^{2-}_4**
Initial concentration		**207.3**	**65.7**
Final concentration (mg/L) Removal(%)	ED-T 24	1.98 ***99%***	0.40 ***99%***
Final concentration (mg/L) Removal(%)	ED-T 12	2.09 ***99%***	0.20 ***99%***
Final concentration (mg/L) Removal(%)	ED-T 6	*23.14* ***89%***	9.99 ***85%***

- ❑ Cl^- = promoting of iron oxidation = corrosion process
- ❑ SO^{2-}_4 = lead to a crack formation
- ✓ Removal ≥ 85 %

Mortars Tests

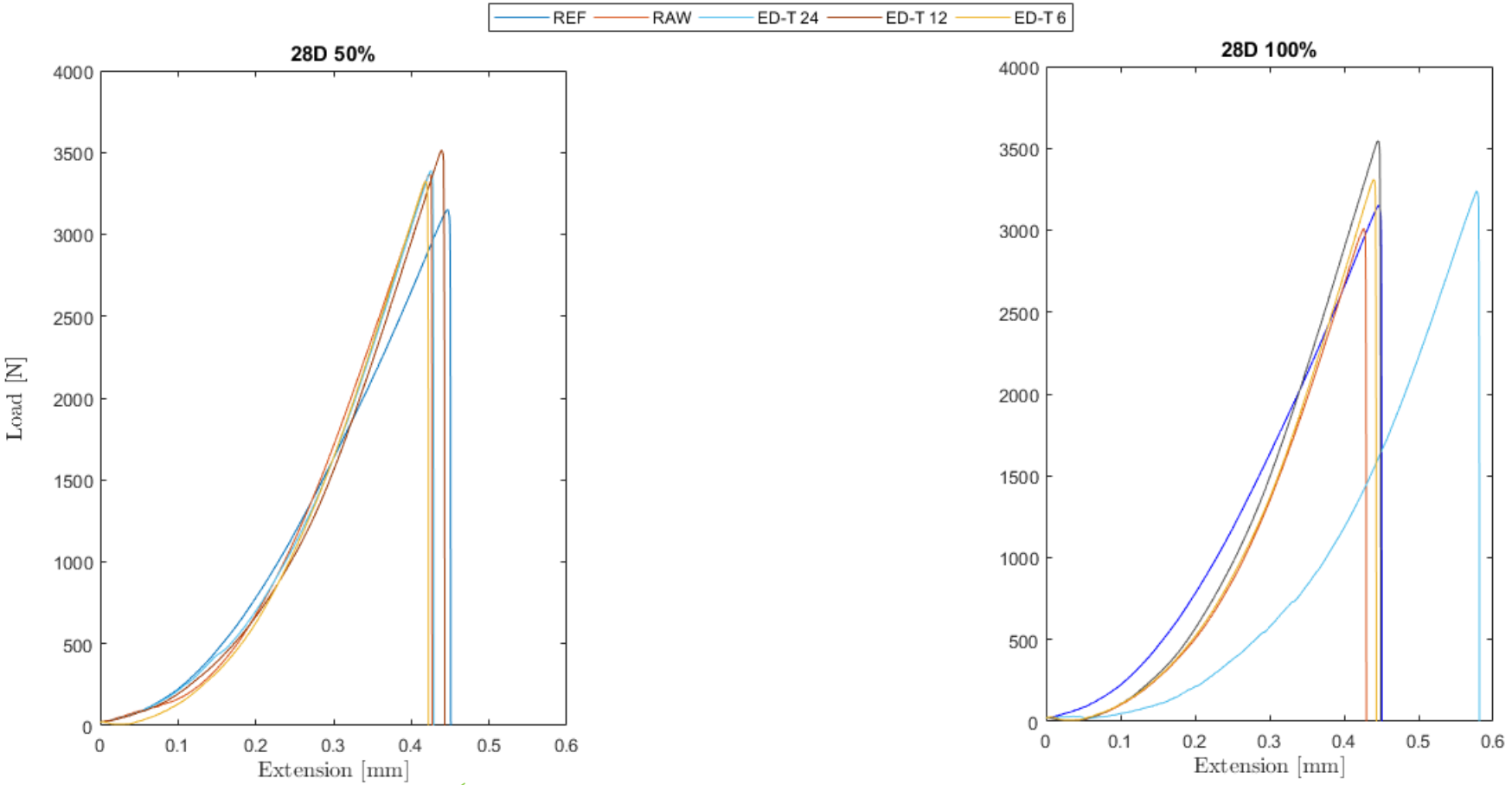
Setting time (min)



- ❑ Delay in the hydration time = impurities and organic matter that still remain in the effluent
- ✓ Still with no significant changes according to Standard ASTM C 191
- ✓ Uses: hot weather conditions

Mortars Tests

Bending strength (kN)

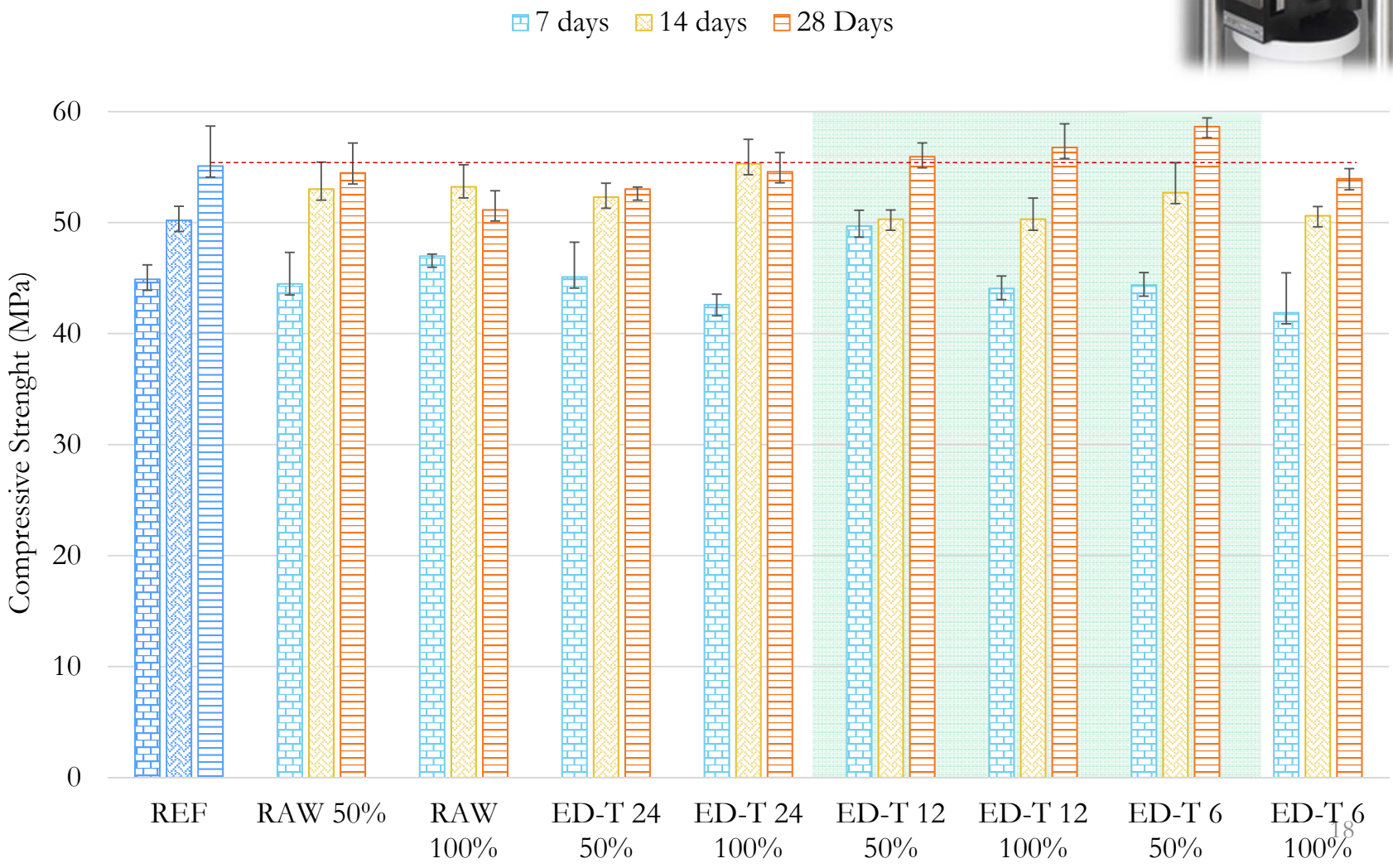


✓ Slight higher ED-T 12h and ED-T 6h

x ED-24h should not be considered – extension change

Mortars Tests

Compressive strength (MPa)



Mortars tests

Leaching HM and Salts (mg/L)

	pH	Cd		Cr		Cu		Ni		Pb		Zn		Cl^-	SO^{2-}_4	
		X	SD	*X*	SD	*X*	SD	*X*	SD	*X*	SD	*X*	SD	*X* SD	*X*	SD
Reference	12.4	0.01	0.00	0.08	0.01	0.03	0.01	0.02	0.00	0.02	0.00	0.05	0.01	n.d.	68.25	4.42
Raw 50%	12.4	0.004	0.00	0.07	0.00	0.02	0.00	0.02	0.00	0.01	0.01	0.02	0.00	n.d.	83.04	3.42
Raw 100%	12.5	0.01	0.00	0.04	0.01	0.02	0.00	0.04	0.00	0.03	0.00	0.03	0.01		43.68	5.32
ED-TEC 24 50%	12.0	0.01	0.00	0.04	0.01	0.03	0.00	0.03	0.00	< LD	0.00	0.03	0.00	n.d.	49.99	3.54
ED-TEC 24 100%	11.9	0.01	0.00	0.06	0.02	0.03	0.01	0.04	0.01	0.20	0.28	0.03	0.00		62.95	0.70
ED-TEC 12 50%	11.6	0.005	0.00	0.04	0.01	0.02	0.00	0.03	0.00	0.19	0.24	0.03	0.00	n.d.	42.93	0.54
ED-TEC 12 100%	12.4	0.005	0.00	0.04	0.00	0.02	0.00	0.04	0.00	0.02	0.00	0.03	0.00		45.59	4.74
ED-TEC 6 50%	12.2	0.01	0.00	0.04	0.01	0.02	0.00	0.03	0.00	0.31	0.08	0.02	0.01	n.d.	44.96	1.47
ED-TEC 6 100%	12.1	0.005	0.00	0.03	0.01	0.02	0.01	0.04	0.01	0.03	0.01	0.02	0.01		45.80	4.06
EEA criteria* ≤ C1 BS EN 1008		**0.04**		**0.5**		**2**		**0.5**		**0.4**		**4**		**500**	**1000**	

***European Environmental Agency** criteria for landfill deposition of waste leaching values
n.d. not detected; LD – detection limit

- ✓ All below the considered legislation limits
- ✓ After ED-T 6h pre-treatment SO^{2-}_4 decresed

Conclusions (1)

ELECTRODIALYTIC EXPERIMENTS - EFFLUENT

Elements removal

✓30% - 99%

Salts removal

✓ 85%-99%

MORTAR PROPERTY AND ENVIRONMENTAL TESTS

Setting times

✓Effluent re-use increased the final setting time

Compressive tests

✓ Strength tests in the range 51-59 MPa (Ref range 53-55MPa)

Flexural tests

✓ ED-T 12 and ED-T 6 slightly higher or with similar resistance comparing to the Ref

Leaching of heavy metals

✓ All the values bellow EEA criteria (HM) and BS EN 1008 (salts)

Conclusions (2)

- **Effluent similar with the tap water**

ED-T 6h

100% or 50% Re-Use

Removal rates of the main concern elements ± 86%

Materials and environmental tests

Energy consumption – 3.4 W/h – 0.0009€

Acknowledgements

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| Thank you |