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Electrical Methods to Characterize and Monitor Concrete

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Resistivity vs. time due to concrete composition and exposure to various curing regimes

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Background

- Corrosion of reinforcing steel is the major cause for deterioration of concrete structures.
- The diffusivity of chloride in concrete is an important for service life of reinforced concrete structures.
- Resistivity has been correlated to chloride diffusivity in concrete.

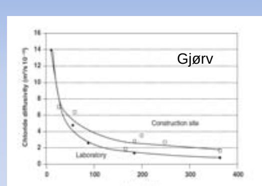
Background

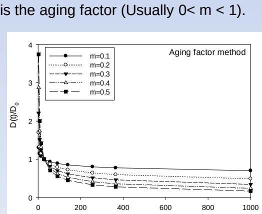
- Diffusion is time dependent
- Aging factor method:

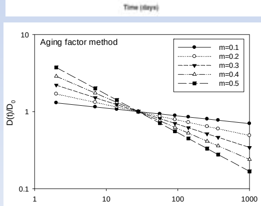
$$D(t) = D_0\left(\frac{t_0}{t}\right)^m$$

After Mangat, Thomas, Bamforth, others

D(t) is the diffusivity as age t;
D_0 is the diffusivity at reference age t_0 *m* is the aging factor (Usually 0< m < 1).







Background

❖ Determination of m values:
- ➢ Value of *m* varies with mix proportions and curing conditions
- ➢ Effect of elevated temperature curing is not known
- ➢ Time consuming to determine *m* by traditional methods.

❖ Correlation between diffusivity and electrical resistivity and concrete by Nernst-Einstein equation:

$$D = \frac{K}{\rho},\quad D(t) = D_0\left(\frac{t_0}{t}\right)^m \;\Rightarrow\; \rho(t) = \rho_0\left(\frac{t_0}{t}\right)^{-m} \;\Rightarrow\; m = \frac{\log\left(\frac{\rho_t}{\rho_{28}}\right)}{\log\left(\frac{t}{28}\right)}$$

❖ Aging effect on diffusivity of concrete can be studied non-destructively by electrical resistivity method. Binding and Change in Cs not included (unless exposed to chlorides). Andrade and collaborators suggested the use resistivity to calculate m.

Objectives

- ❖ To study how resistivity and the aging factor changes with time
- ❖ To study how the aging factor is affected by curing regime (full immersion, fog room, high humidity, immersed in lime water)
- ❖ To study the effect of elevated temperature curing on the aging factor.
- ❖ To study the effect of w/cm on the aging factor
- ❖ To study the effect of pozzolanic admixtures on the aging factor.

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Experimental – (Group 1)

Concrete group	ID	Cement (kg/m^3)	FA (kg/m^3)	SF (kg/m^3)	Water (kg/m^3)	Fine agg. SSD (kg/m^3)	Coarse agg. SSD (kg/m^3)*	Numbers of specimens used for resistivity
1-OPC	1cyl	390	-	-	156	734	996	12
2-FA-a	2cyl-a	312	78	-	156	734	996	12
2-FA-b	2cyl-b	312	78	-	156	733	955	11
3-FA+SF	3cyl	281	78	31	156	734	996	18

*2cyl-b limestone #57, all others #67

Curing Regimes: Fog Room all the time, Fog Room followed by High Humidity,
Fog Room followed by lab Humidity and then High humidity (90-95% RH)
Immersed in Tap Water (FA-b and FA+SF series)
Immersed in 3% NaCl (FA-b and FA+SF series)

Experimental – (Group 2)

Mix Name	Pozzolan	w/cm ratio
DCL1	20% FA	0.35
DCL2	20% FA	0.41
DCL3	20% FA	0.47
DCL4	20% FA + 8% SF	0.35
DCL5	20% FA + 8% SF	0.41
DCL6	20% FA + 8% SF	0.47

Mix Name	Pozzolan	w/cm ratio
DCL7	50% Slag	0.35
DCL8	50% Slag	0.41
DCL9	50% Slag	0.47

Coarse aggregate Florida Limestone #57

RT curing in High Humidity Chamber

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Experimental – Mix Design (Group 3)

Mix	Coarse agg.	Cement kg/m^3	Fly Ash kg/m^3	Slag kg/m^3	Fine agg. kg/m^3	Coarse agg. kg/m^3	FA %	Slag %
A	Limestone	312	78	-	777	930	20	-
J	Limestone	273	117	-	739	951	30	-
B	Limestone	234	156	-	712	916	40	-
D	Limestone	195	195	-	720	927	50	-
E	Limestone	195	-	195	739	951	-	50
F	Limestone	117	-	273	736	947	-	70
I	Limestone	117	39	234	732	943	10	60
H	Limestone	117	78	156	732	942	20	50
C	Granite	312	78	-	736	1061	20	-
K	Granite	273	117	-	720	1038	30	-
L	Granite	195	195	-	709	1023	50	-
G	Granite	195	-	195	739	1067	-	50

- 12 mixes with various replacement ratio/type of Fly Ash and Slag. Gradation of Coarse Aggregate #89
- w/cm =0.41
- 10 cm diameter x20 cm cylinders
- All the specimens were prepared at SMO/FDOT

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Experimental (group 3)– Curing Regimes

- Two curing methods:
  - 21 °C lime water bath at room temperature (RT)
  - 38 °C lime water bath at elevated temperature (ET)
- Three curing regimes
  - RT (All the time at room temperature)
  - 2RT/ET (2 days in RT then transfer to ET (38 °C))
  - 2RT/26ET/RT

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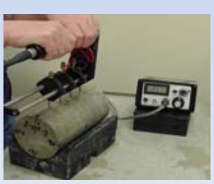
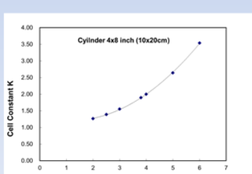
Experimental - Resistivity Measurement

- Wenner method was used to measure resistivity
- All the measured resistivity was corrected by a geometry factor (K_g=1.89 for electrode spacing =3.8cm)
- The resistivity values measured at 38 °C were normalized to the values at 21 °C.





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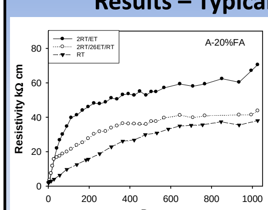
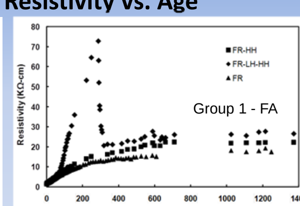
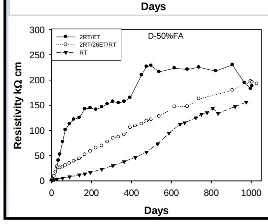
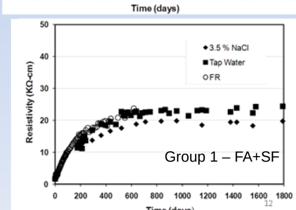
Results – Typical Resistivity vs. Age









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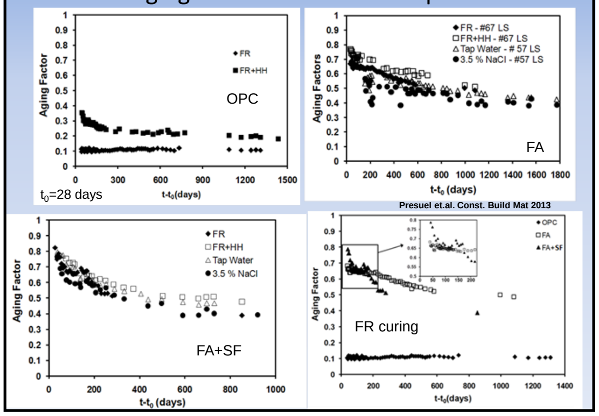
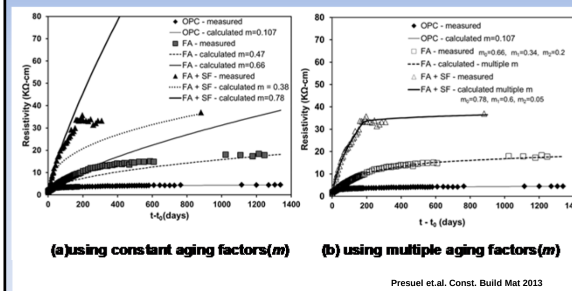
Aging Factor vs. time - Group 1



Projected vs. Measured Resistivity



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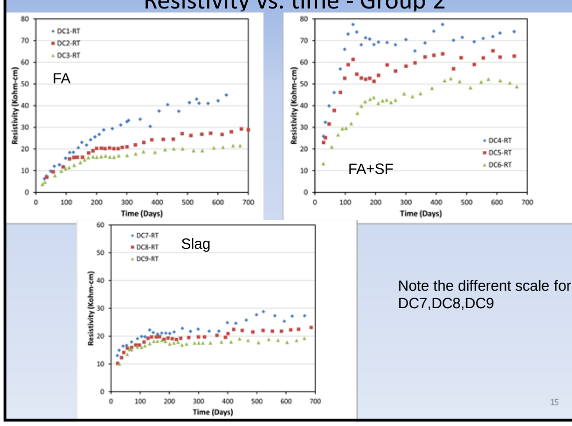
Resistivity vs. time - Group 2



Note the different scale for DC7,DC8,DC9

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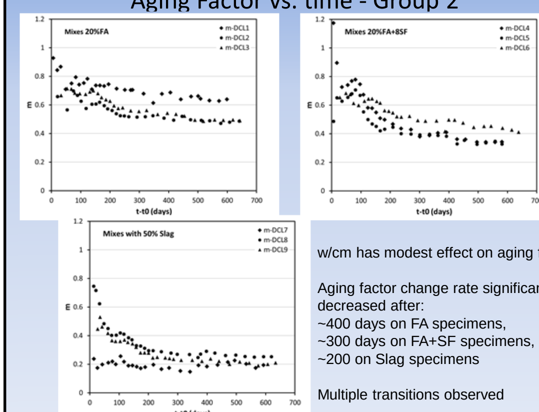
Aging Factor vs. time - Group 2



w/cm has modest effect on aging factor

Aging factor change rate significantly decreased after:
~400 days on FA specimens,
~300 days on FA+SF specimens,
~200 on Slag specimens

Multiple transitions observed

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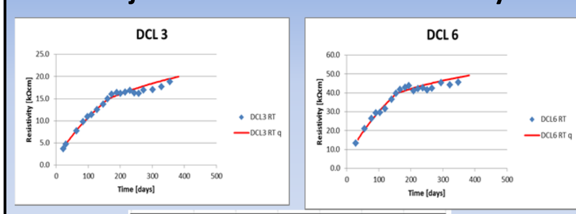
Projected vs. Measured Resistivity



Mix & Curing	m0	m1	ρ0	t0	ρ1	t1
DCL1 RT	0.77	0.35	6.3	29	28.8	224
DCL2 RT	0.63	0.39	7.02	36	18.2	174
DCL3 RT	0.69	0.34	4.7	30	15	161
DCL4 RT	0.81	0.13	25.9	29	68.1	153
DCL5 RT	0.60	0.13	23	29	46.1	84
DCL6 RT	0.64	0.24	13.3	28	39.8	154
DCL7 RT	0.20	0.18	14.9	28	19.1	91
DCL8 RT	0.47	0.16	10.2	23	15.7	56
DCL9 RT	0.48	0.11	10	29	16.1	91

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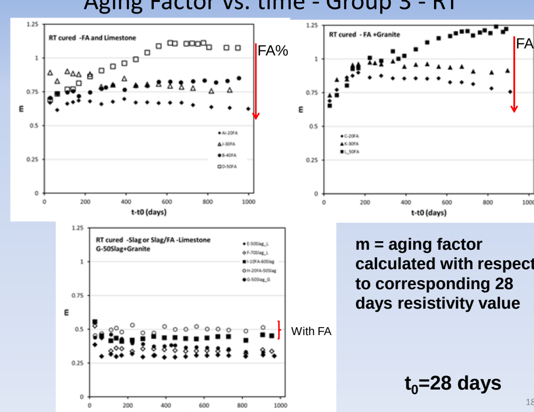
Aging Factor vs. time - Group 3 - RT



m = aging factor calculated with respect to corresponding 28 days resistivity value

t_0=28 days

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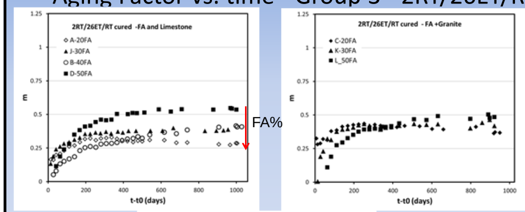
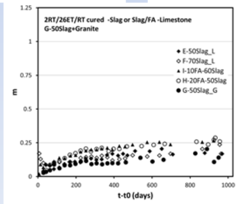
Aging Factor vs. time - Group 3 - 2RT/26ET/RT



< 0.5



Transfer to RT on Day 28
Causes change in how
m evolves with time

< 0.25

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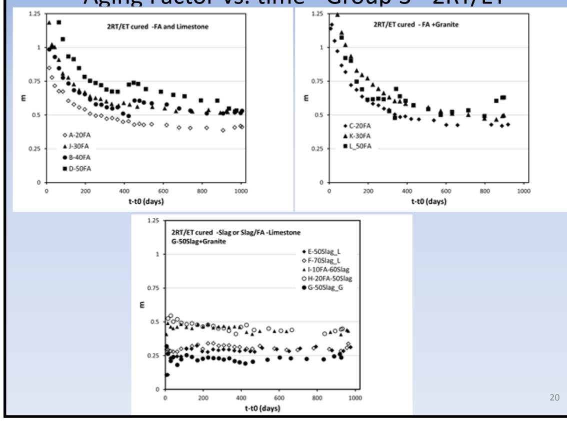
Aging Factor vs. time - Group 3 - 2RT/ET



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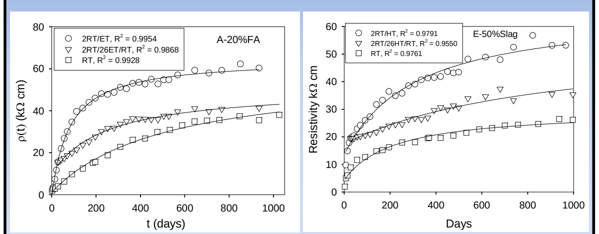
Research in Progress – Hyperbolic Method



$$\rho(t) = \rho_u \frac{k(t-t_0)}{1+k(t-t_0)}$$

$\rho(t)$: Resistivity at age t

ρ_u: Limiting (ultimate) resistivity

k: Rate constant

t_0: Age at which resistivity development begins ($t_0 < 0$)

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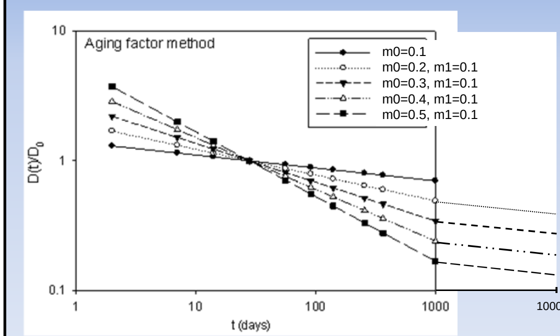
Schematic Implication on D(t) of m(t)



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Conclusions

- Electrical resistivity measurement could be used to calculate the aging factor for diffusivity.
- For most compositions the aging factor changes vs. time.
- Depending on composition and curing condition the aging factor experiences one or more transients.
- For specimens with large amount of FA (≥30%) cured at RT, aging factor via resistivity sometimes exceeded 1.
- Caution should be taken when using aging factor method to predict D(t), as the value of *m* depends on: age; replacement ratio; type of mineral admixture, and the curing regimes.
- After some time (100 to 500 days) the rate at which the aging factor changes slows down significantly.

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Thank you!

Questions?

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