Effects on Availability of Road Network (EARN)

International workshop on Recycling: Road construction in a post-fossil fuel society

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

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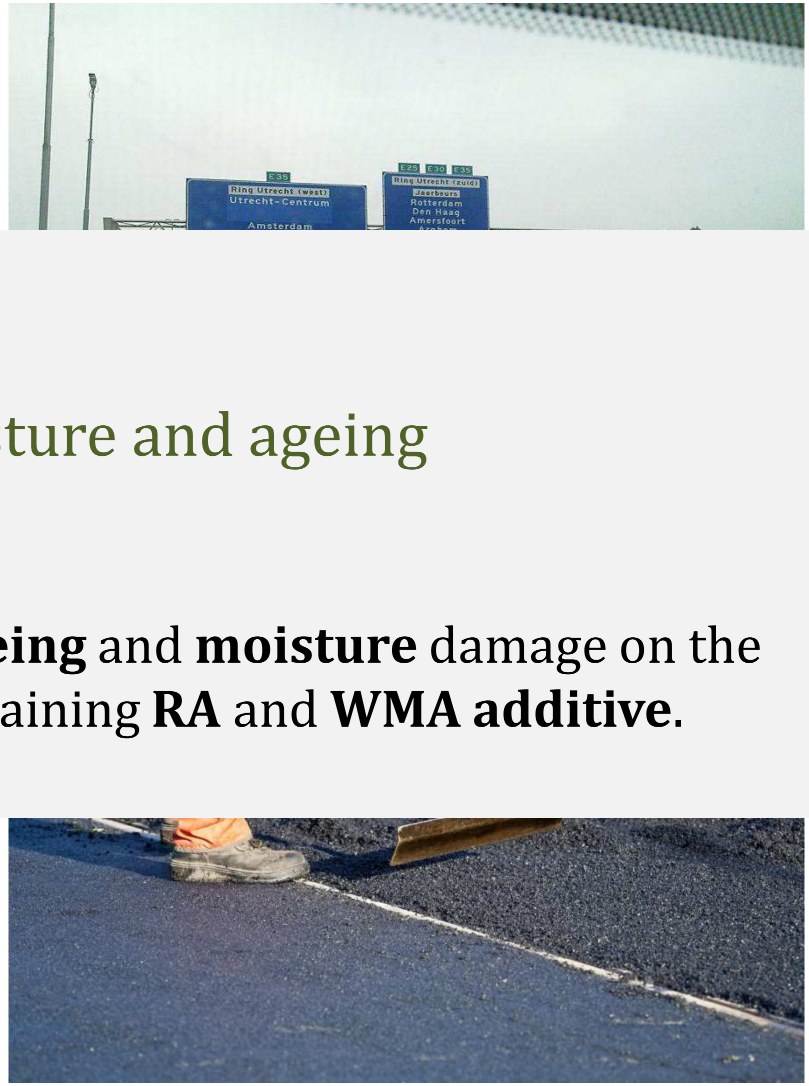
Prague, 24-25 September 2015

Durability of WMA and RA pavements

WMA and RA technologies

on road network

- Decreasing construction and maintenance funds



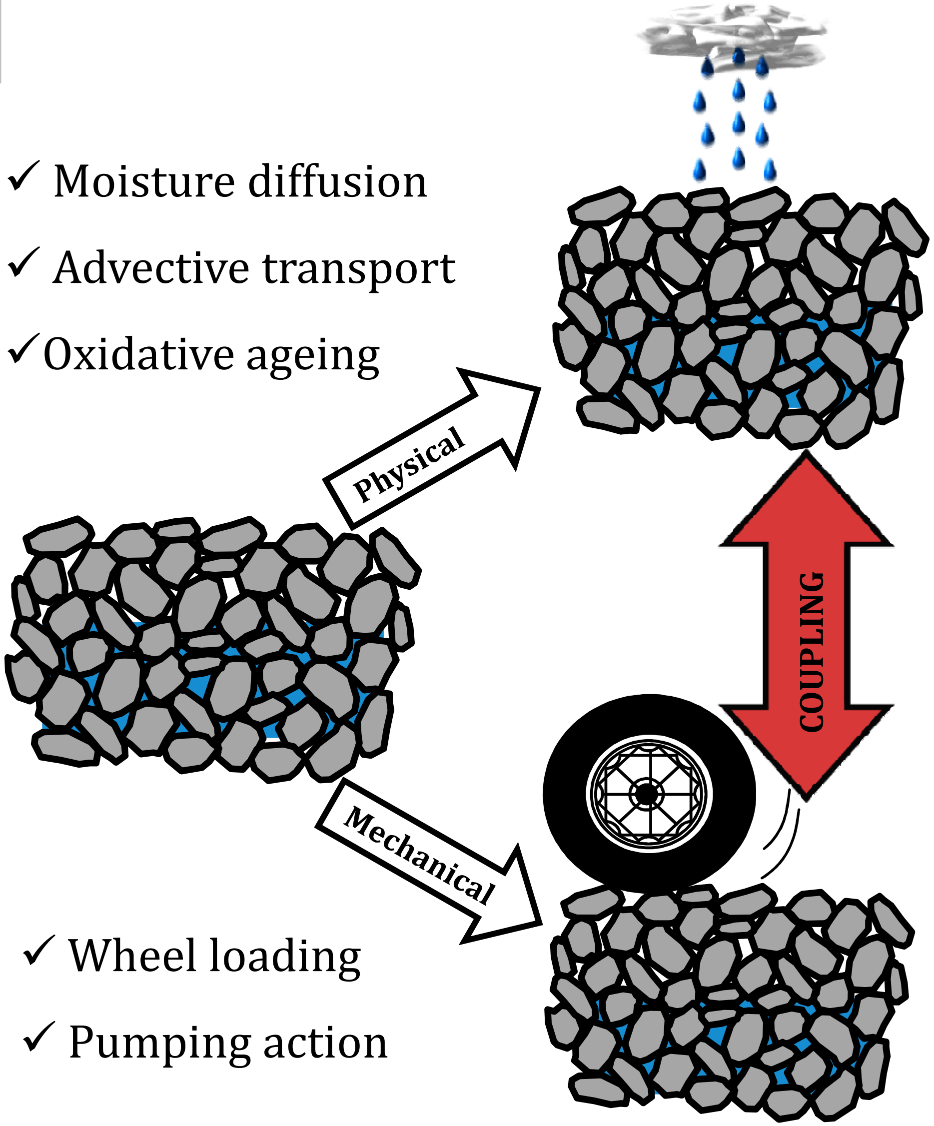
Work Package 3:
Experimental evaluation of moisture and ageing

Objective:

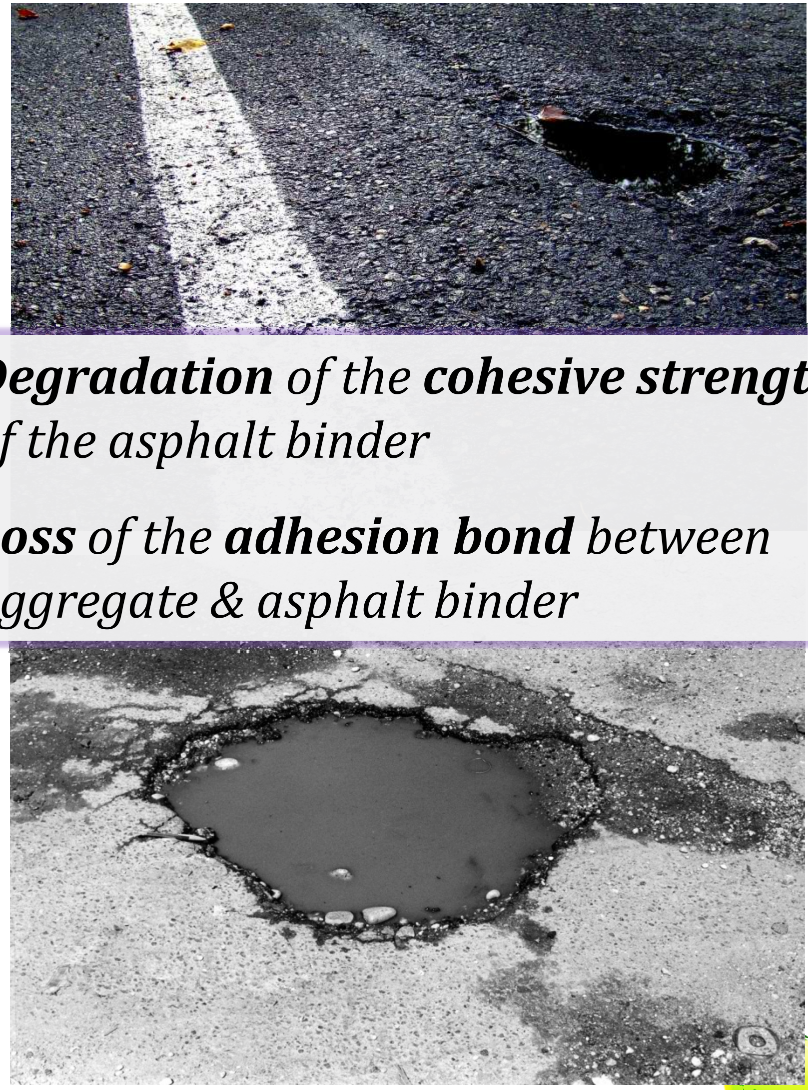
Investigate the **combined effect** of **ageing** and **moisture** damage on the **performance** of asphalt mixtures containing **RA** and **WMA additive**.

Physico-mechanical degradation mechanisms

- ✓ Moisture diffusion
- ✓ Advective transport
- ✓ Oxidative ageing



- ✓ Wheel loading
- ✓ Pumping action

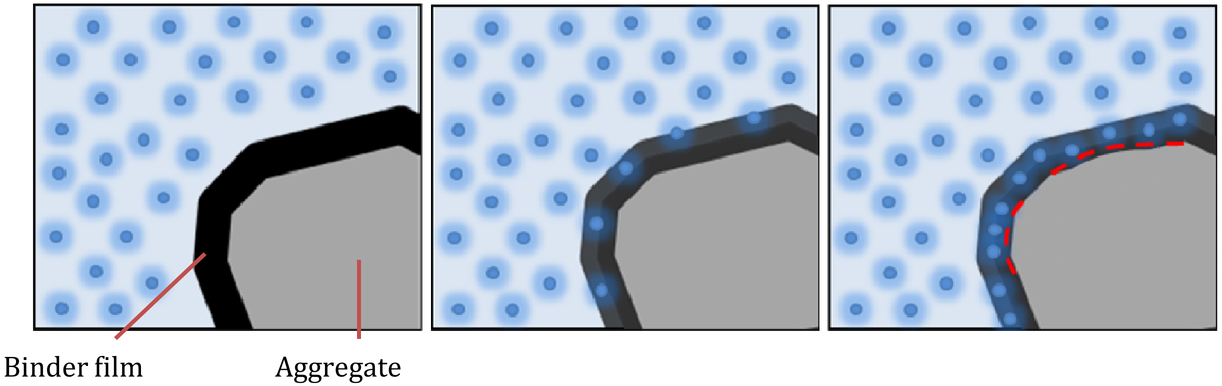


***Degradation** of the **cohesive strength** of the asphalt binder*

***Loss** of the **adhesion bond** between aggregate & asphalt binder*

Moisture induced damage

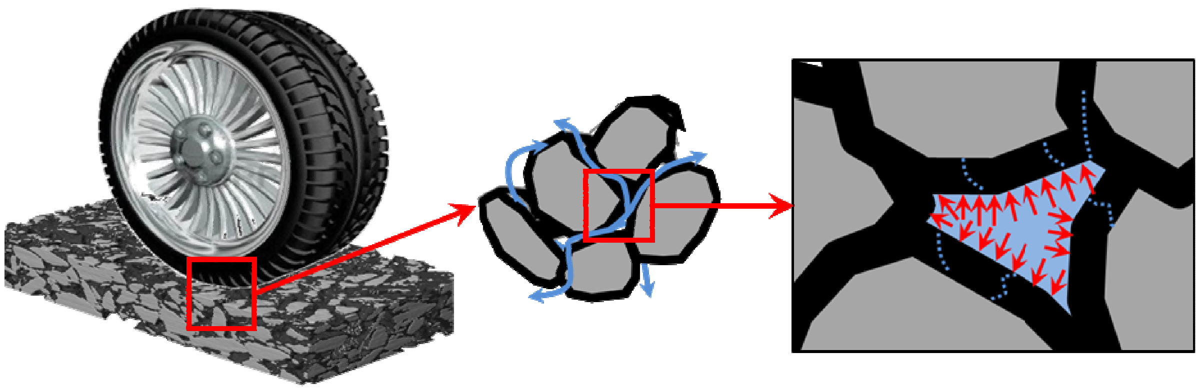
Moisture diffusion



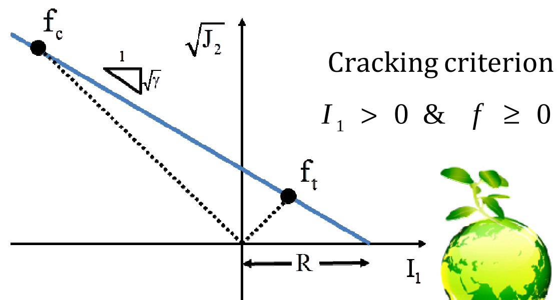
Moisture gradient driven
(does not require a flow field)

$$\frac{\partial \theta}{\partial t} = \nabla\left(D \nabla \theta\right)$$

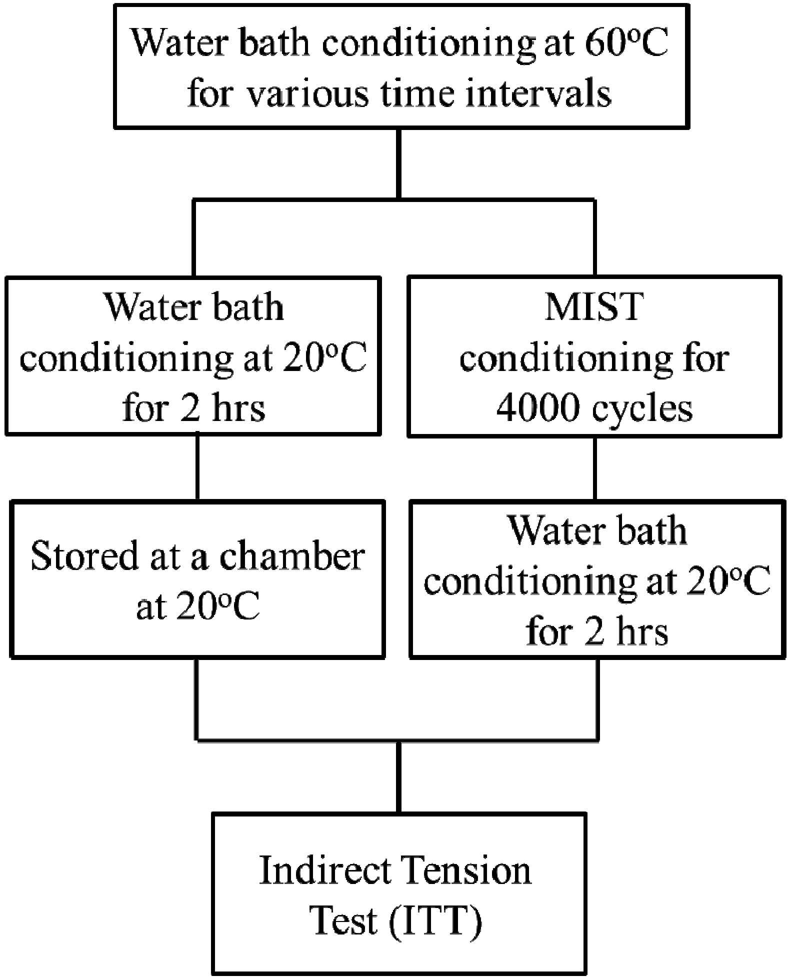
Pumping action (Pore pressure development)

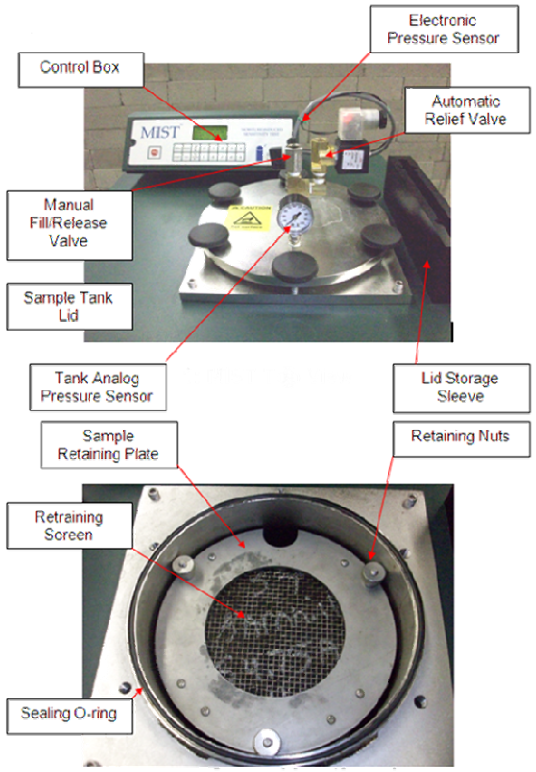


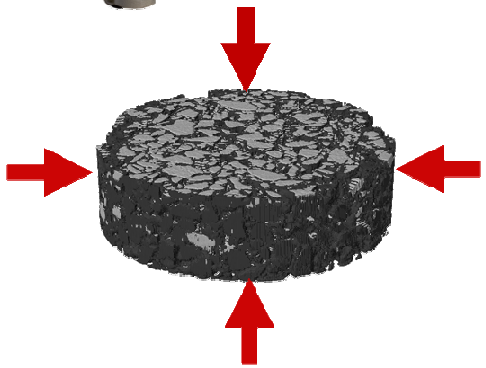
Depends on flow field
and desorption characteristics



Moisture conditioning protocol



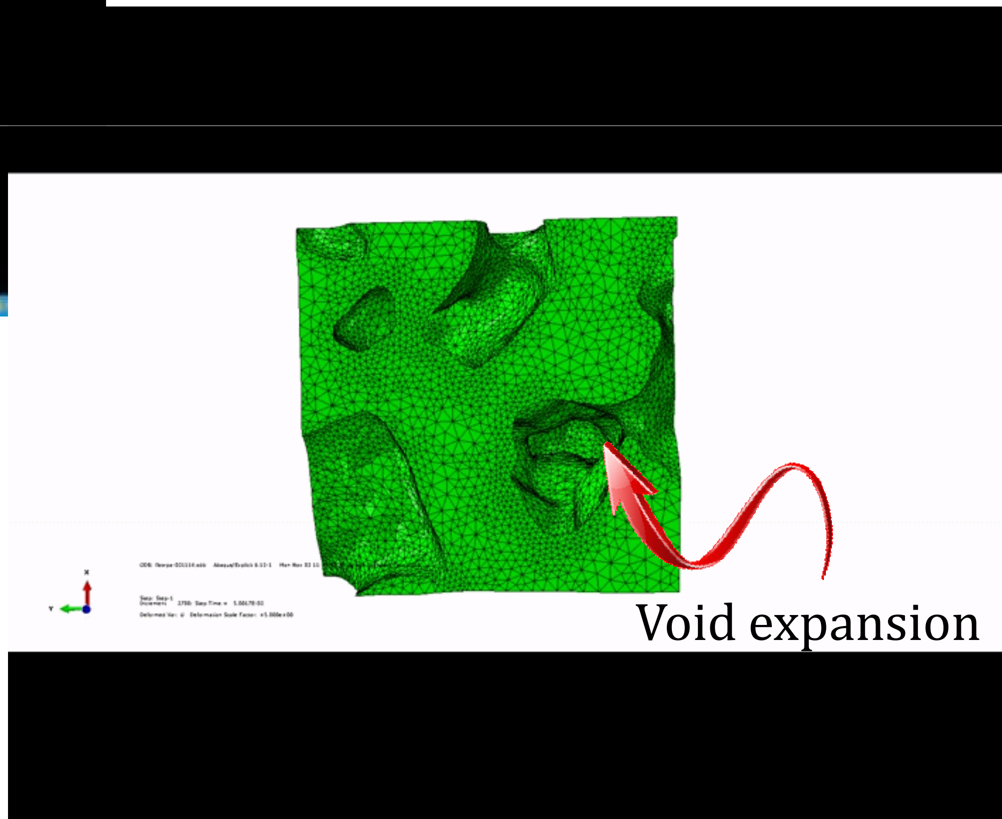




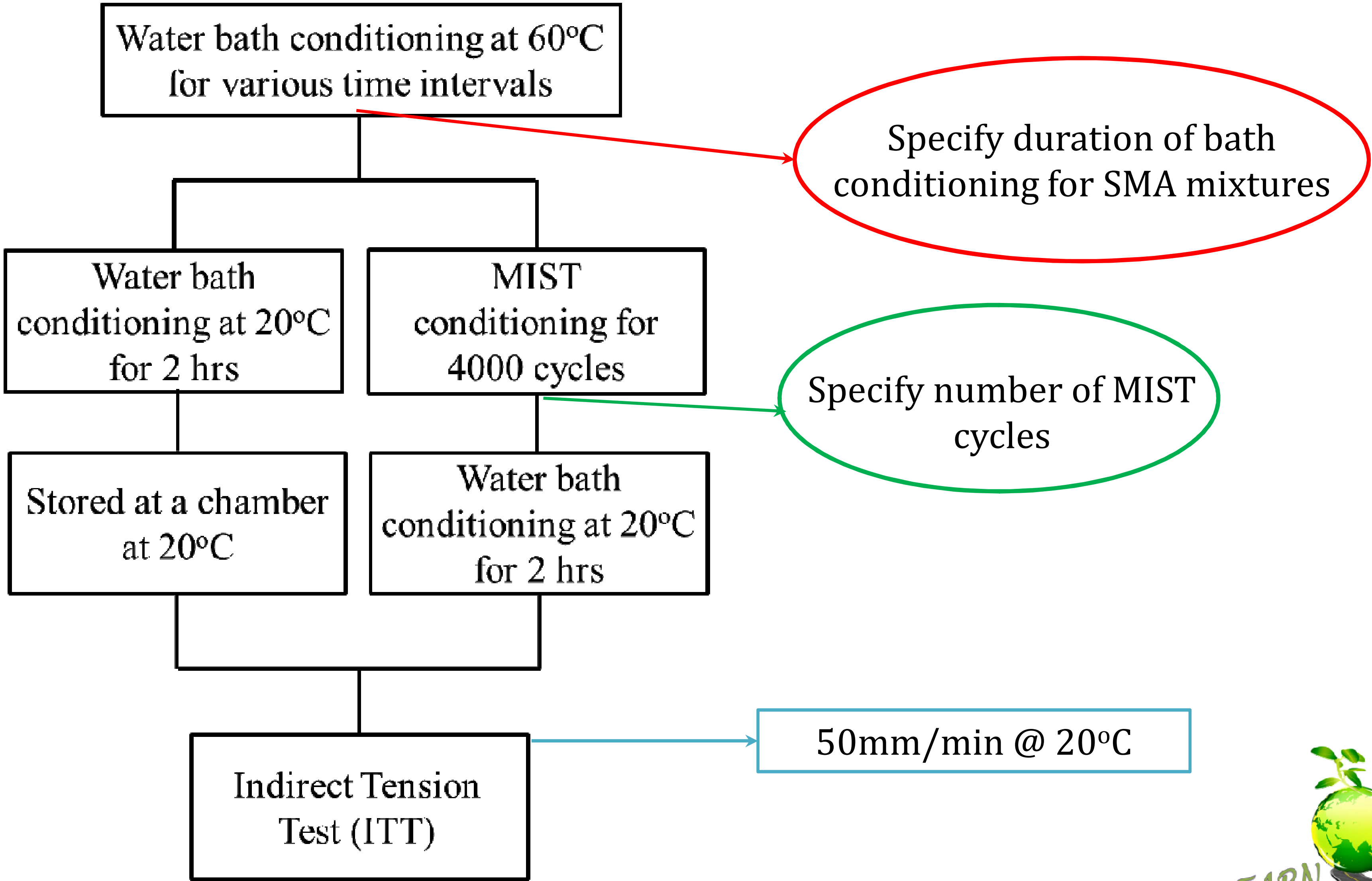
Moisture Induced Sensitivity Tester (MIST)

A. Varveri, S. Avgerinopoulos & A. Scarpas (2015). Experimental evaluation of long- and short-term moisture damage characteristics of asphalt mixtures. *Road Materials and Pavement Design*.
DOI: 10.1080/14680629.2015.1066705

Moisture Induced Sensitivity Tester (MIST)



Moisture conditioning protocol



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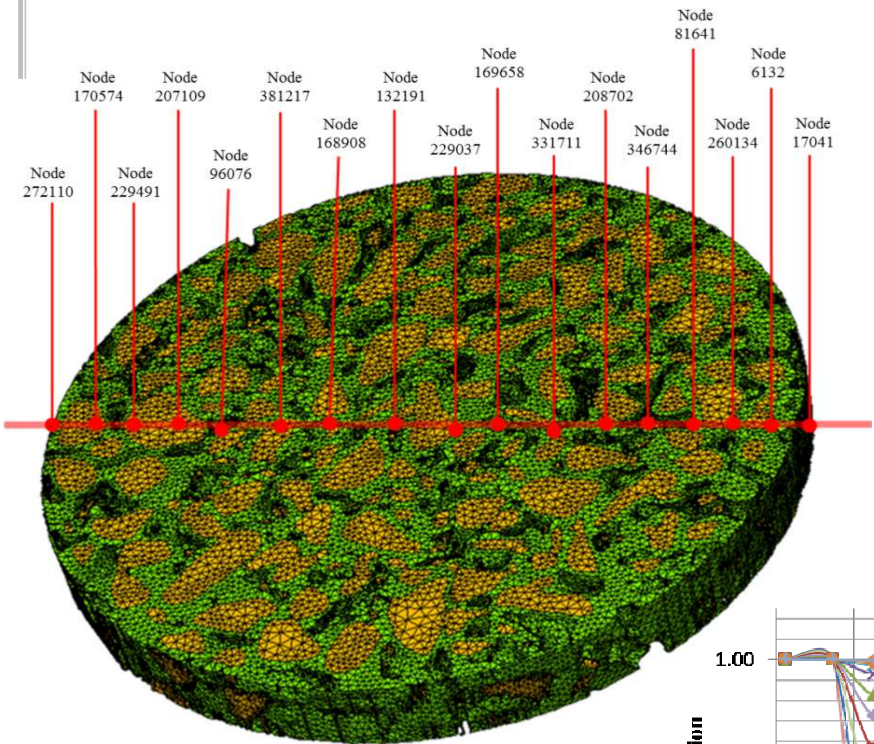
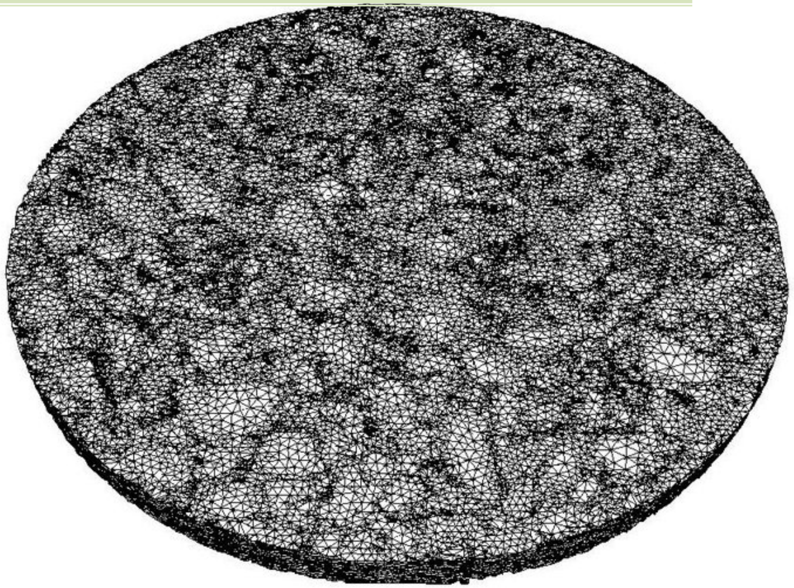
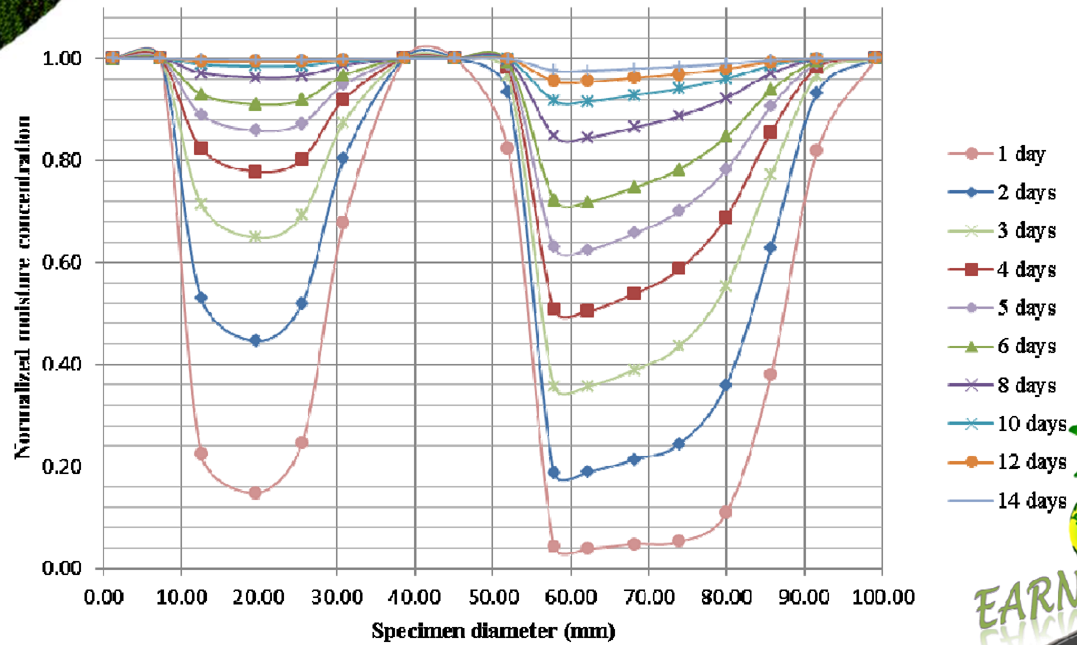
Determination of bath conditioning time



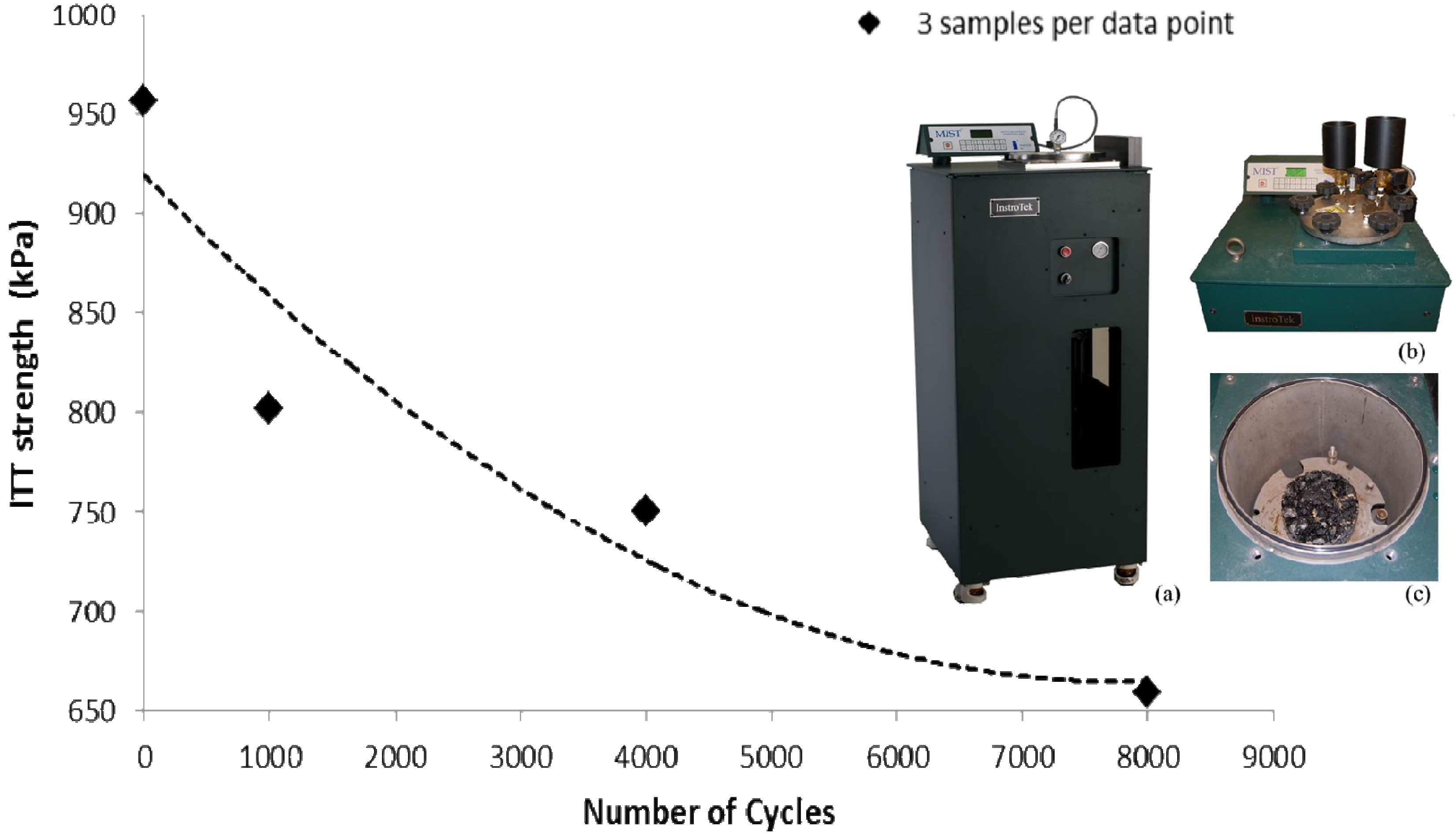


Fick's law

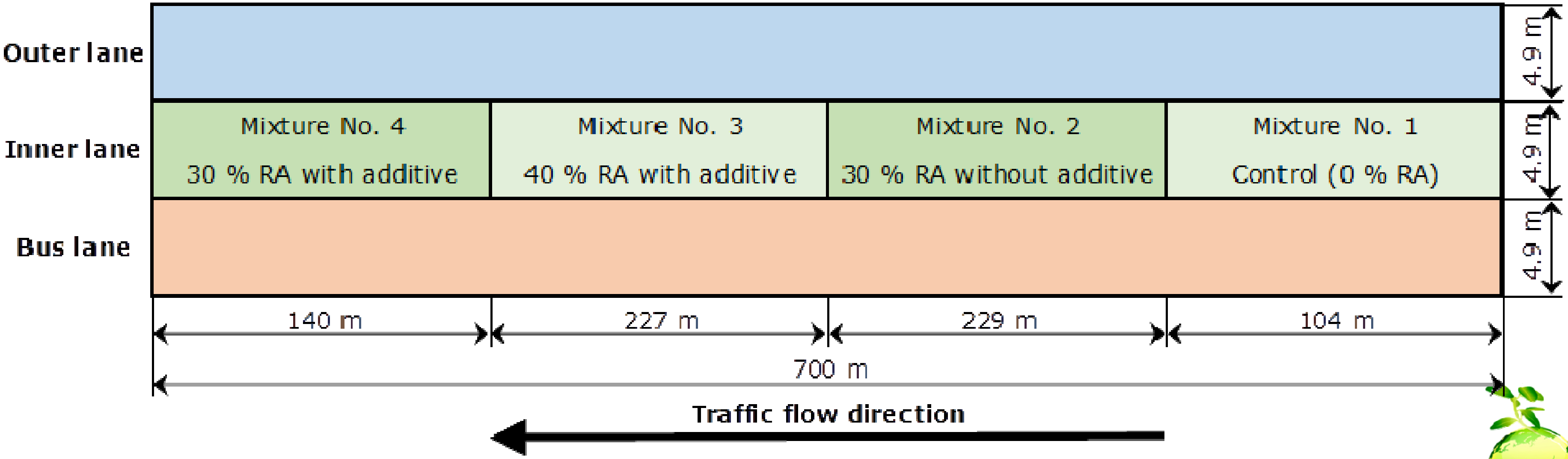
$$\frac{\partial \theta}{\partial t} = \nabla\left(D \nabla \theta\right)$$



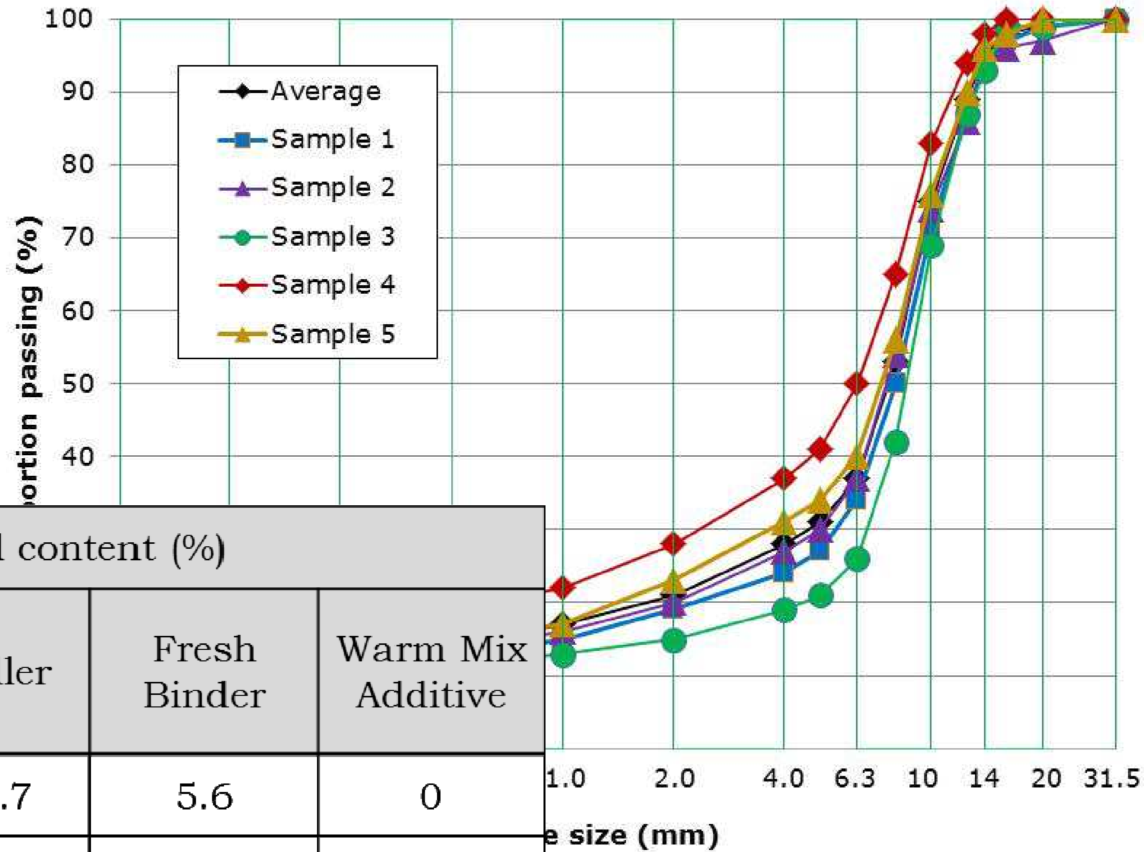
Determination of MIST cycles



Laying of site trials



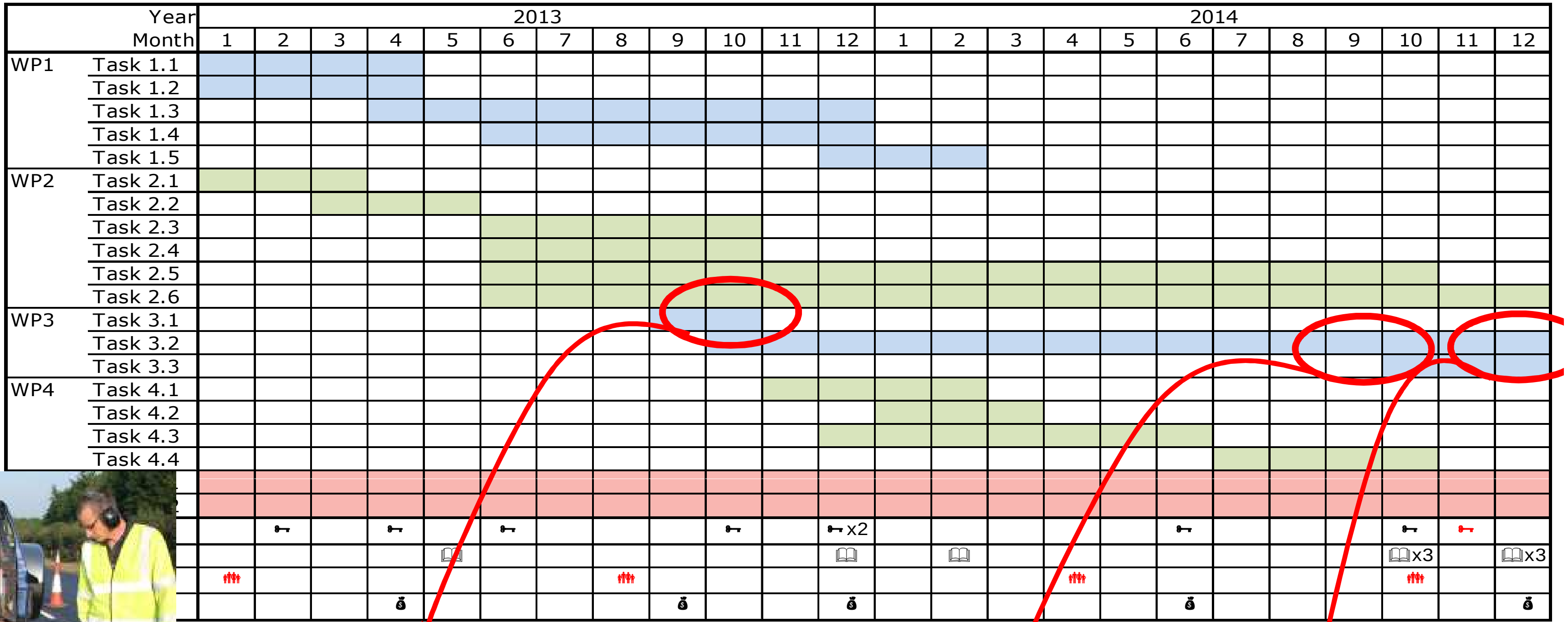
Mix design



Mix No.	Proportional content (%)					
	RA	10 mm	CRF*	Filler	Fresh Binder	Warm Mix Additive
1	0	65.9	22.8	5.7	5.6	0
2	28.6	43.8	17.0	5.7	4.9	0
3	38.1	34.4	17.1	5.7	4.7	0.3
4	28.6	43.8	17.0	5.7	4.9	0.3

*Crushed Rock Fines

Sampling scheme



Phase 1 (2013): Delivery of cores from freshly laid sections

Phase 2 (2014): Delivery of cores after 1yr in service

Phase 3 (2015): Delivery of cores after 2yrs in service

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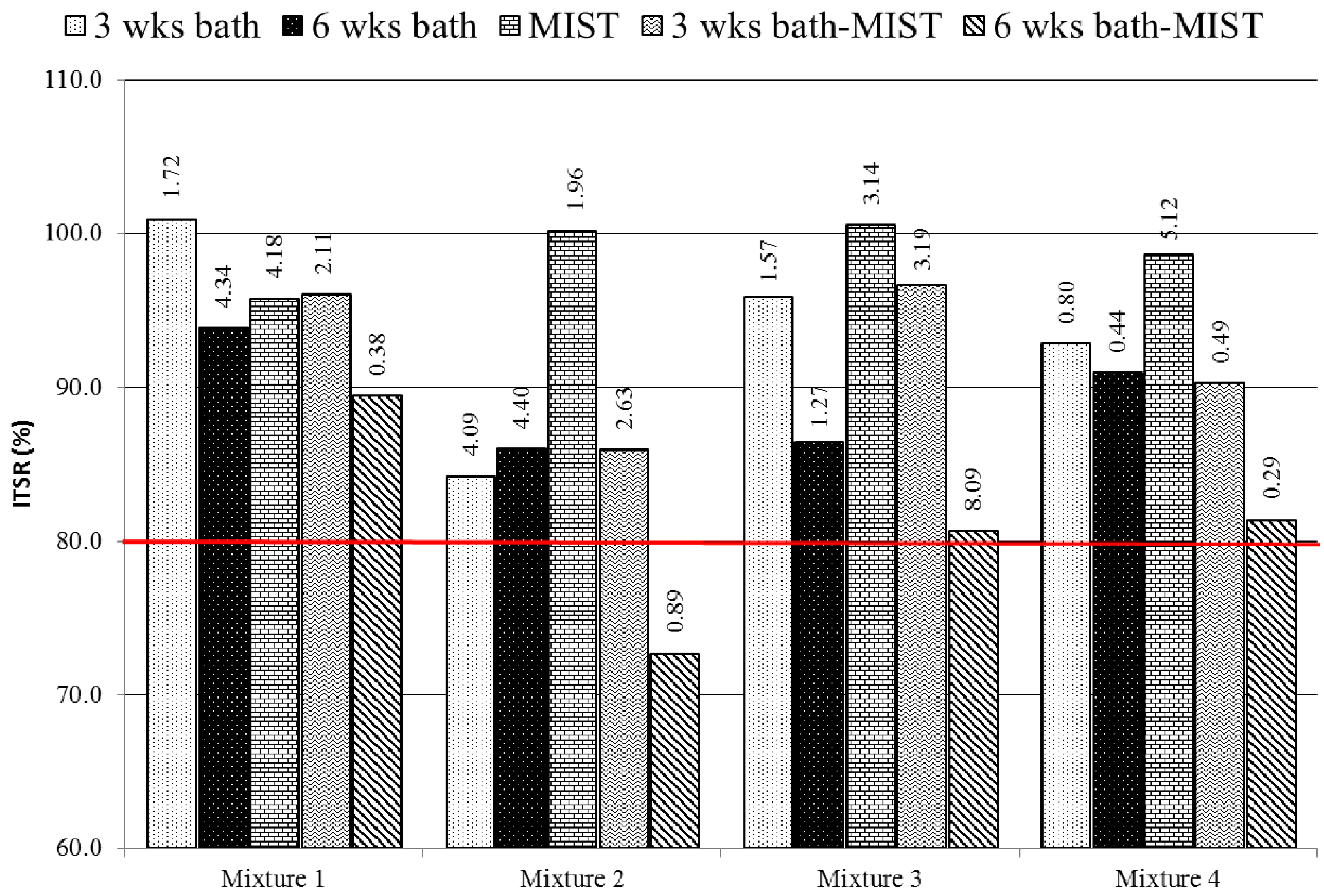
Determination of height and bulk density

Specimen Code	Height (mm)	Bulk Density (kg/m³)	Specimen Code	Height (mm)	Bulk Density (kg/m³)
A1	34.0	2360	**D1**	35.0	2326
A2	38.5	2354	**D2**	35.0	2302
A3	32.5	2319	**D3**	36.0	2370
A4	34.0	2309	**D4**	36.0	2334
A5	36.5	2302	**D5**	40.5	2357
A6	30.5	2368	**D6**	36.5	2348
A7	32.5	2364	**D7**	40.0	2372
A8	31.0	2360	**D8**	37.5	2390
A9	35.0	2347	**D9**	32.5	2388
A10	36.0	2348	**D10**	34.5	2396
A11	32.5	2348	**D11**	39.5	2400
A12	34.5	2392	**D12**	36.5	2378
A13	33.5	2380	**D13**	38.5	2364
A14	34.5	2018	**D14**	35.5	2381
A15	35.5	2347	**D15**	36.5	2385
A16	35.0	2376	**D16**	39.5	2362
A17	35.0	2354	**D17**	38.5	2377
A18	34.5	2367	**D18**	36.0	2388
A19	35.0	2350	**D19**	37.5	2361
A20	40.5	2336	**D20**	40.5	2365
A21	33.5	2336	**D21**	40.0	2396
A22	32.5	2347	**D22**	36.5	2368
A23	34.5	2370	**D23**	39.5	2384
A24	30.5	2342	**D24**	40.5	2387
A25	36.5	2307	**D25**	34.5	2362
A26	34.5	2344	**D26**	33.5	2390
A27	32.5	2362	**D27**	33.5	2354
B1	35.5	2368	**C1**	34.5	2371
B2	34.5	2357	**C2**	34.5	2392
B3	36.0	2371	**C3**	35.5	2384
B4	35.5	2378	**C4**	35.5	2390
B5	34.5	2375	**C5**	34.5	2378
B6	37.5	2357	**C6**	35.5	2383
B7	38.0	2329	**C7**	35.5	2378
B8	36.5	2338	**C8**	37.5	2375
B9	36.5	2357	**C9**	32.5	2387
B10	34.5	2360	**C10**	36.5	2340
B11	36.0	2336	**C11**	36.5	2334
B12	35.5	2331	**C12**	34.5	2335
B13	34.5	2381	**C13**	35.5	2339
B14	36.5	2314	**C14**	36.5	2346
B15	36.0	2344	**C15**	34.5	2344
B16	35.0	2354	**C16**	37.0	2377
B17	35.0	2356	**C17**	38.5	2365
B18	40.0	2302	**C18**	35.5	2389
B19	35.5	2322	**C19**	37.5	2411
B20	36.0	2397	**C20**	39.0	2398
B21	34.0	2380	**C21**	35.5	2378
B22	34.5	2370	**C22**	37.0	2394
B23	34.5	2348	**C23**	39.5	2370
B24	37.0	2341	**C24**	37.5	2372
B25	32.5	2342	**C25**	35.0	2388

ITSR – Fresh (unaged) samples



Mixture 1 (Control; 0% RA), Mixture 2 (30% RA; no WMA)
Mixture 3 (40% RA; WMA), Mixture 4 (30% RA; WMA)

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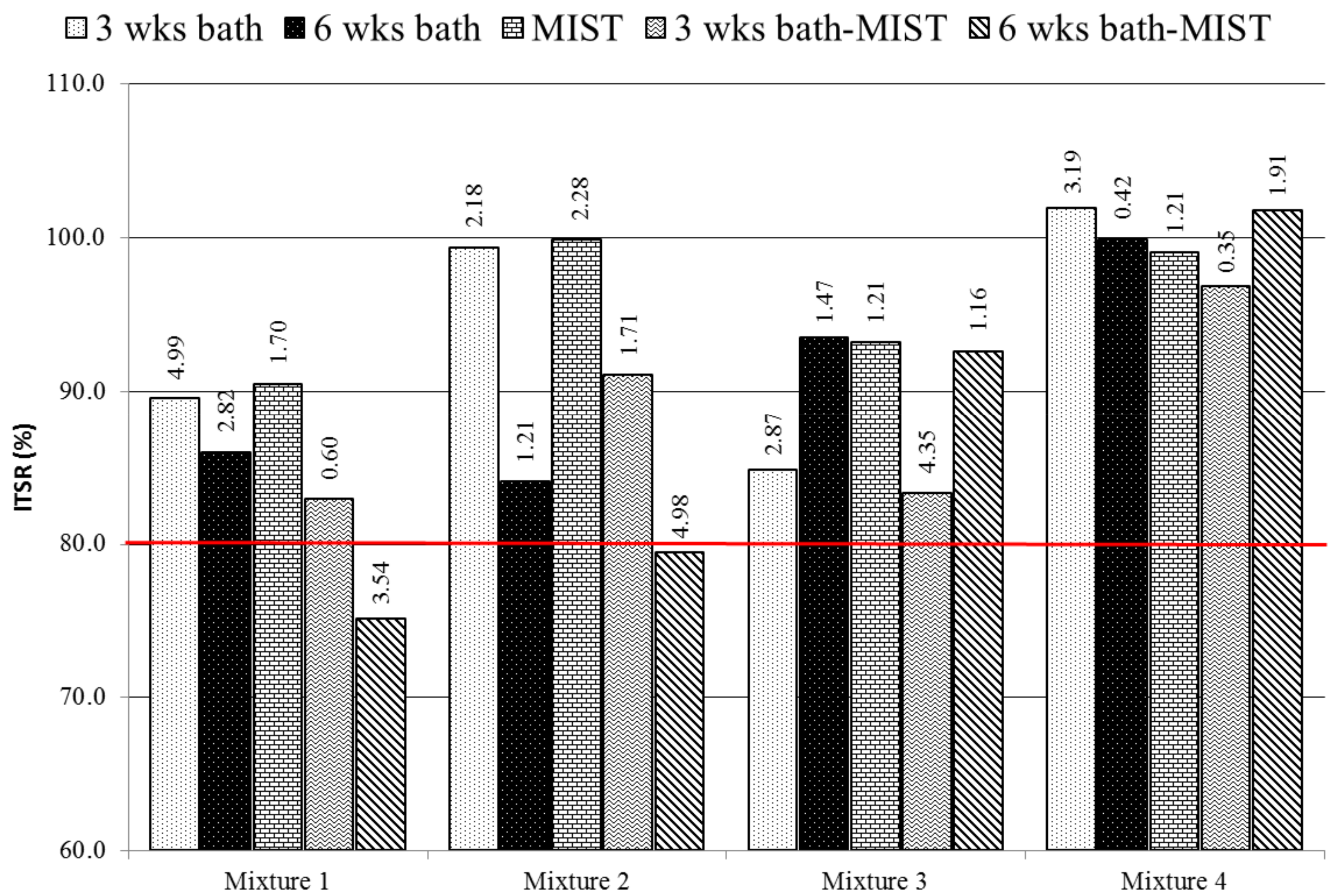
ITSR – After 1 year in service



Mixture 1 (Control; 0% RA), Mixture 2 (30% RA; no WMA)
Mixture 3 (40% RA; WMA), Mixture 4 (30% RA; WMA)

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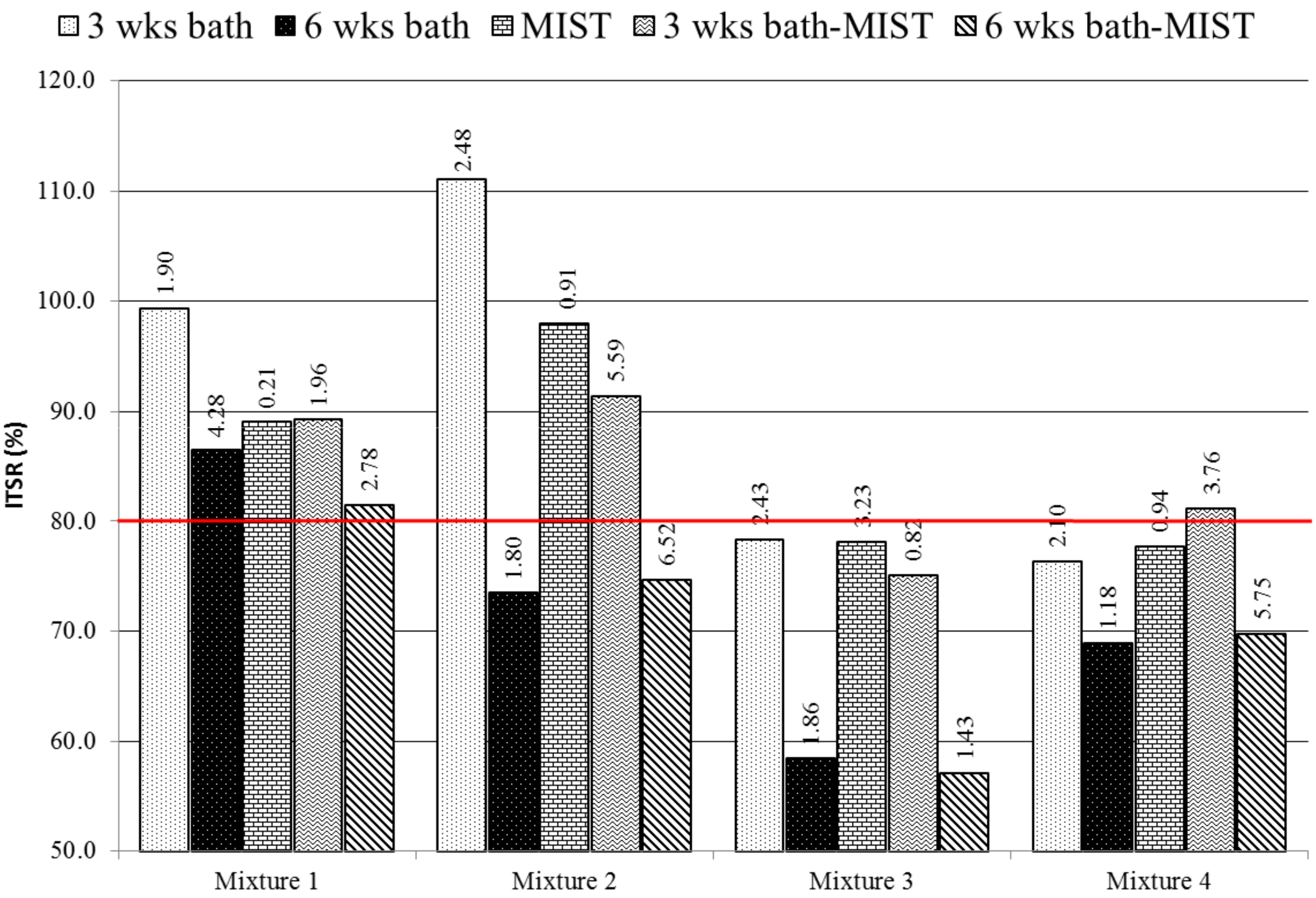
ITSR – After 2 years in service



Mixture 1 (Control; 0% RA), Mixture 2 (30% RA; no WMA)
Mixture 3 (40% RA; WMA), Mixture 4 (30% RA; WMA)

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Evolution of ITSR values

Service lifetime	Conditioning regime	ITSR (%)			
		Mixture 1	Mixture 2	Mixture 3	Mixture 4
0 yrs (right after construction)	3W bath	101.0	84.3	96.0	92.9
	6W bath	93.9	86.0	86.5	91.0
	0W Bath & MIST	95.8	100.2	100.6	98.7
	3W Bath & MIST	96.1	86.0	96.7	90.3
	6W Bath & MIST	89.5	72.7	80.7	81.4
1 yr	3W bath	89.5	99.3	84.8	101.9
	6W bath	86.0	84.0	93.5	99.9
	0W Bath & MIST	90.4	99.8	93.2	99.0
	3W Bath & MIST	82.9	91.0	83.3	96.8
	6W Bath & MIST	75.1	79.4	92.6	101.7
2 yrs	3W bath	99.4	111.1	78.3	76.4
	6W bath	86.5	73.5	58.4	68.9
	0W Bath & MIST	89.1	98.1	78.2	77.8
	3W Bath & MIST	89.3	91.4	75.1	81.1
	6W Bath & MIST	81.5	74.7	57.1	69.8

Mixture 1 (Control; 0% RA), Mixture 2 (30% RA; no WMA)
Mixture 3 (40% RA; WMA), Mixture 4 (30% RA; WMA)

Strength degradation

Cond. method	Time (wks)	Change in strength (%)											
		Mixture 1			Mixture 2			Mixture 3			Mixture 4		
		Unaged	1 yr aged	2 yrs aged	Unaged	1 yr aged	2 yrs aged	Unaged	1 yr aged	2 yrs aged	Unaged	1 yr aged	2 yrs aged
Bath	0	na	na	na	na	na	na	na	na	na	na	na	na
	3	+1.0	-10.5	-0.6	-15.8	-0.7	+11.1	-4.1	-15.2	-21.7	-7.1	+1.9	-23.6
	6	-6.1	-14.0	-13.5	-14.0	-16.0	-26.5	-13.5	-6.5	-41.6	-9.0	-0.1	-31.1
Bath & MIST	0	-4.2	-9.6	-10.9	+0.2	-0.2	-1.9	+0.6	-6.8	-21.8	-1.3	-1.0	-22.2
	3	-3.9	-17.1	-10.7	-14.0	-9.0	-8.6	-3.3	-16.7	-24.9	-9.7	-3.2	-18.9
	6	-10.5	-24.9	-18.5	-27.3	-20.6	-25.3	-19.3	-7.4	-42.9	-18.6	+1.7	-30.2
MIST contribution*	0	-4.2	-9.6	-10.9	+0.2	-0.2	-1.9	+0.6	-6.8	-21.8	-1.3	-1.0	-22.2
	3	-4.9	-6.6	-10.3	+1.7	-8.3	-8.6	+0.7	-1.5	-3.2	-2.6	-5.1	+4.7
	6	-4.5	-10.9	-5.0	-13.3	-4.6	+1.2	-5.8	-0.9	-1.3	-9.6	+1.8	+0.9

** The effect of MIST is given as the difference between bath and bath-MIST conditioning; na: not applicable*

Mixture 1 (Control; 0% RA), Mixture 2 (30% RA; no WMA)
Mixture 3 (40% RA; WMA), Mixture 4 (30% RA; WMA)

Long- and short-term moisture damage

Mixture 1
(Control; 0 % RA)

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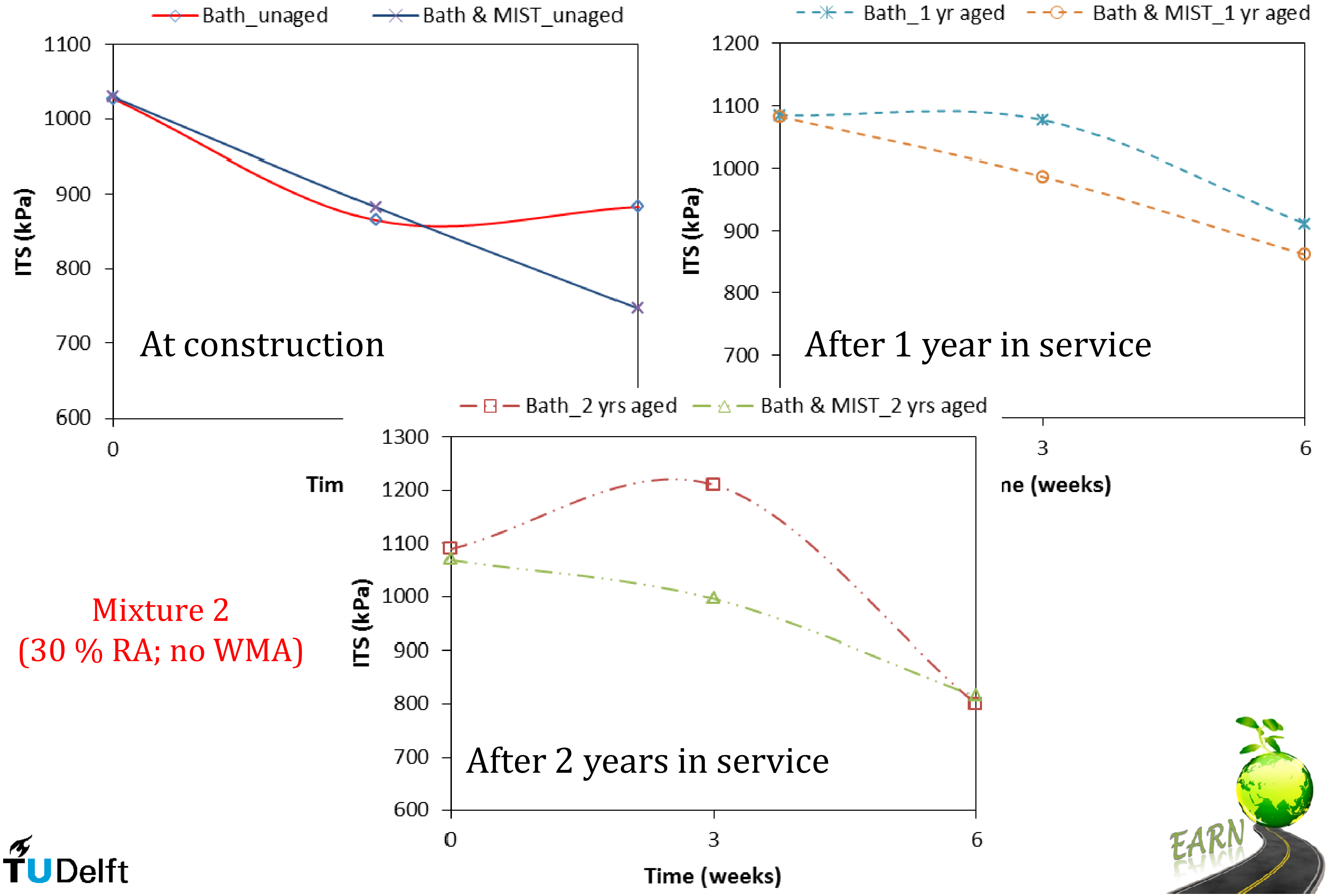
Long- and short-term moisture damage



Mixture 2
(30 % RA; no WMA)

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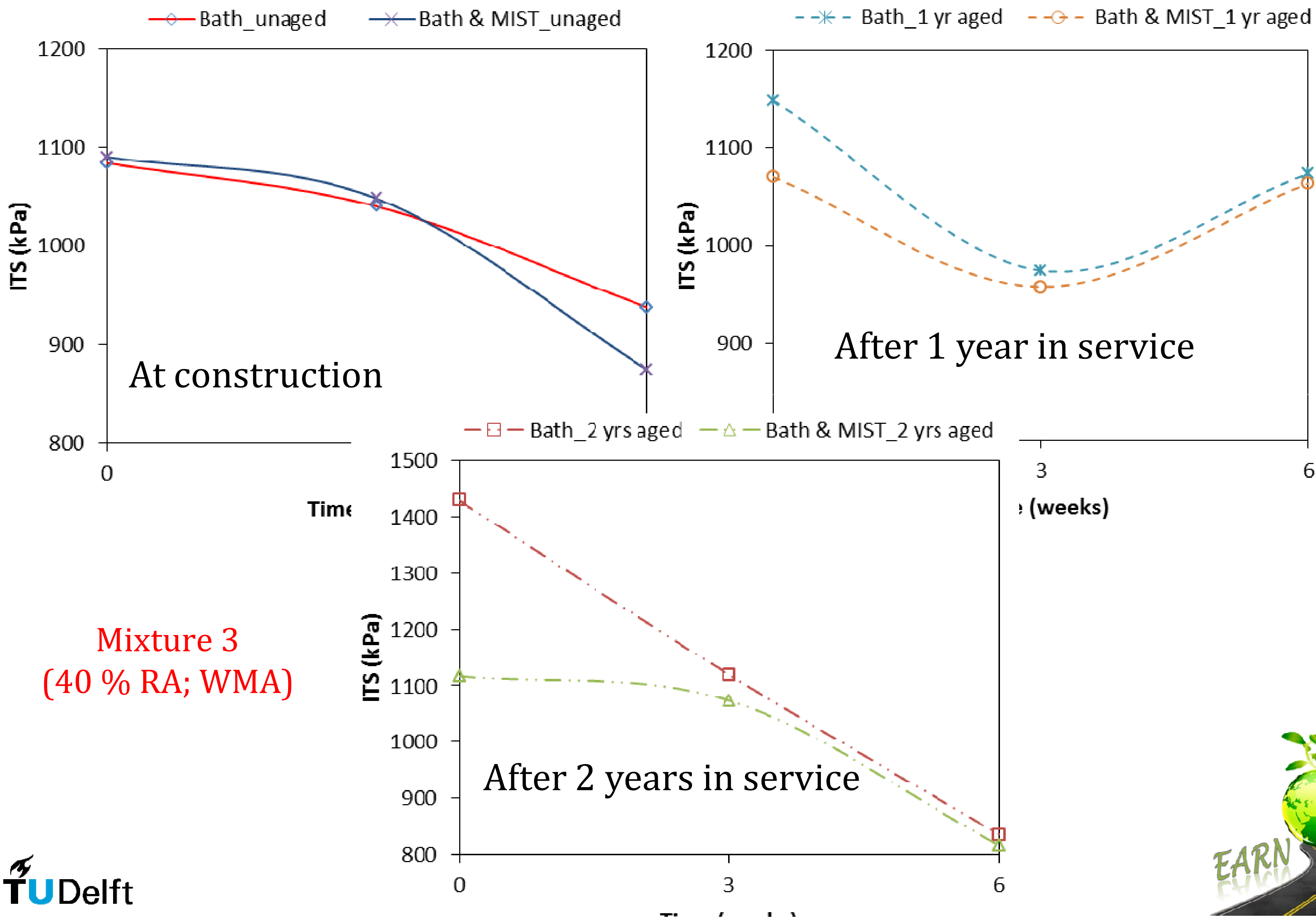
Long- and short-term moisture damage



Mixture 3
(40 % RA; WMA)

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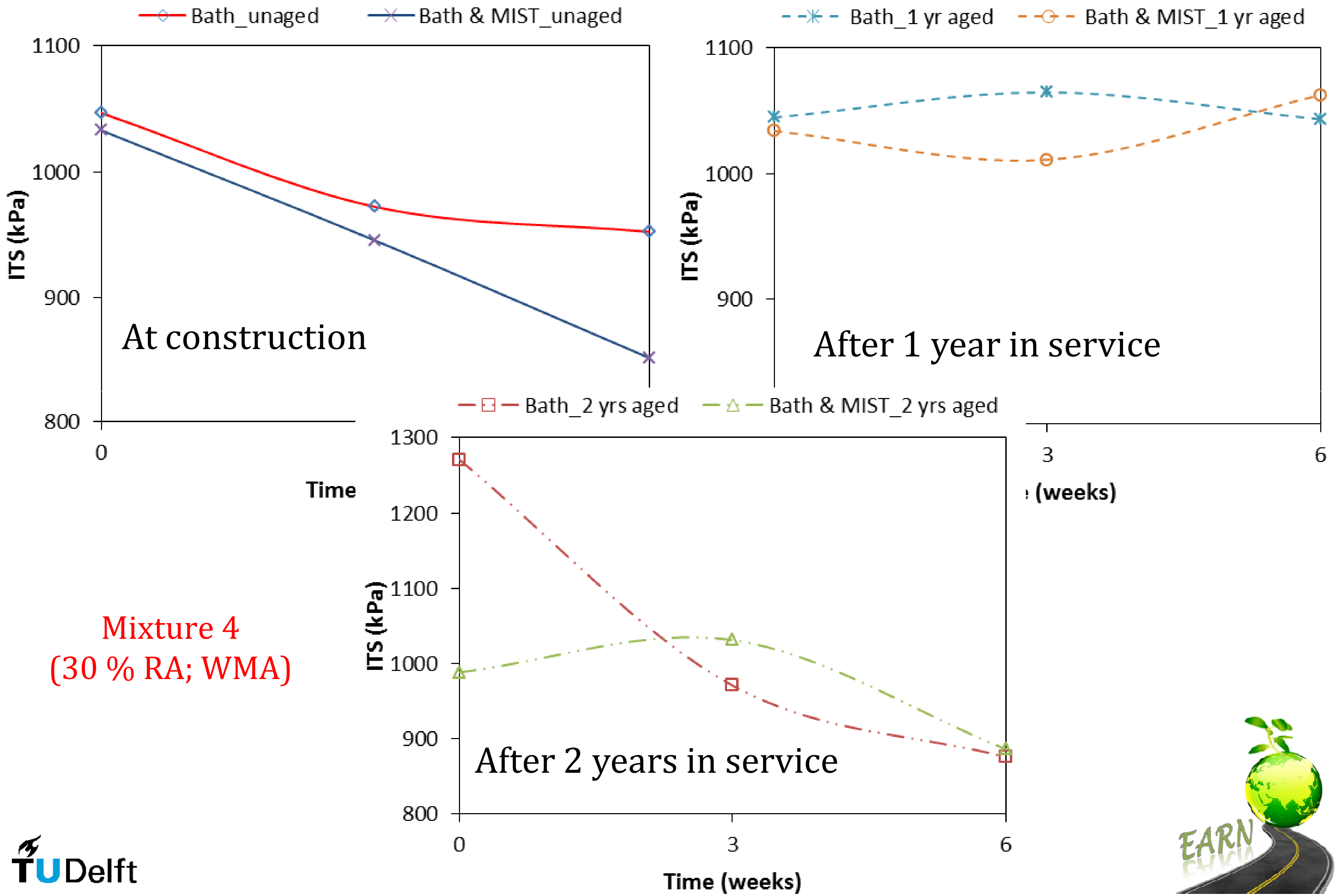
Long- and short-term moisture damage



Mixture 4
(30 % RA; WMA)

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Conclusions

At construction

- **Higher reduction in strength** was observed for the **RA mixtures** than for the **HMA**.
- The **TSR** values of the **HMA** mixture were **higher** than the **RA** mixtures.
- **All mixtures met the specification** requirement of TSR ≥ 80%.

After one year in service

- the **TSR and ITS** values of the **RA mixtures improved**, indicating that the mixtures underwent a curing process that enhanced the performance with respect to moisture damage.
- the use of **WMA additive** was found to **increase** the **resistance to moisture damage**
- the **HMA** mixtures showed **poor performance** with respect to moisture as **compared** to the **freshly-laid mixtures**.

Conclusions

After two years in service

- the **HMA** mixture showed a **stable performance** with respect to moisture damage compared to the previous year.

- the performance of the **RA mixtures with WMA** additive **deteriorated** considerably. The **TSR values failed to meet the specification** requirements, indicating that the mixtures are highly susceptible to moisture damage.

- The performance of **RA mixtures without WMA** additive was **similar to** that of the **HMA** mixture.

General comments

- The **ITS** values **increased** with **increasing RA** content.

- A change in the amount of RA content, from **30% to 40%** did **not influence** significantly **the dry and wet ITS** and **ITSR** values.

- Overall, the **RA mixtures** were more **sensitive** to **long-term conditioning**, rather than to the application of pore pressures; the **reverse** was observed for the **HMA** mixture.

- It is recommended that **ageing** is considered when **validating a mix design** with respect to **moisture damage susceptibility**.

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