



Evaluation of the Stiffness Modulus and Phase Angle of Cold In-place Recycled Mixtures for Long Curing Periods

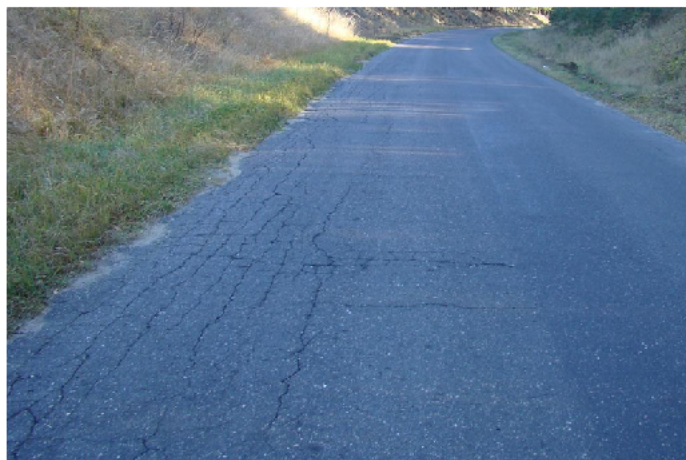
Bohdan Dołżycki

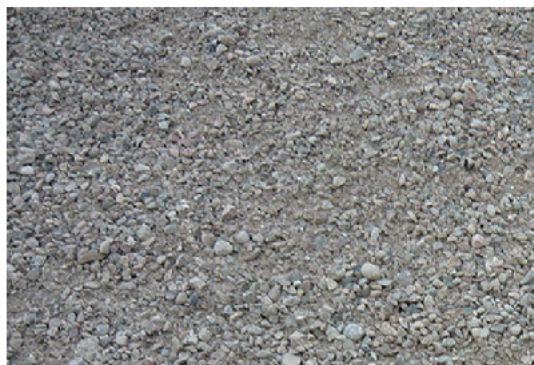
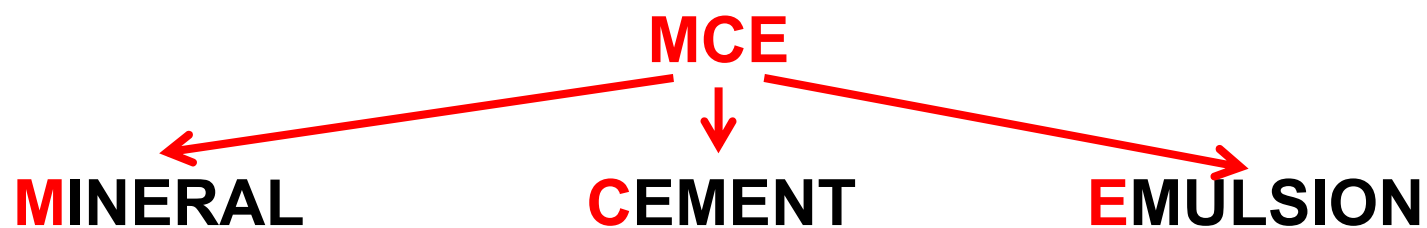
Mariusz Jaczewski

Cezary Szydłowski



MCE – cold deep recycling





~90%



1÷4%



2÷6%



AIM OF RESEARCH PROJECT

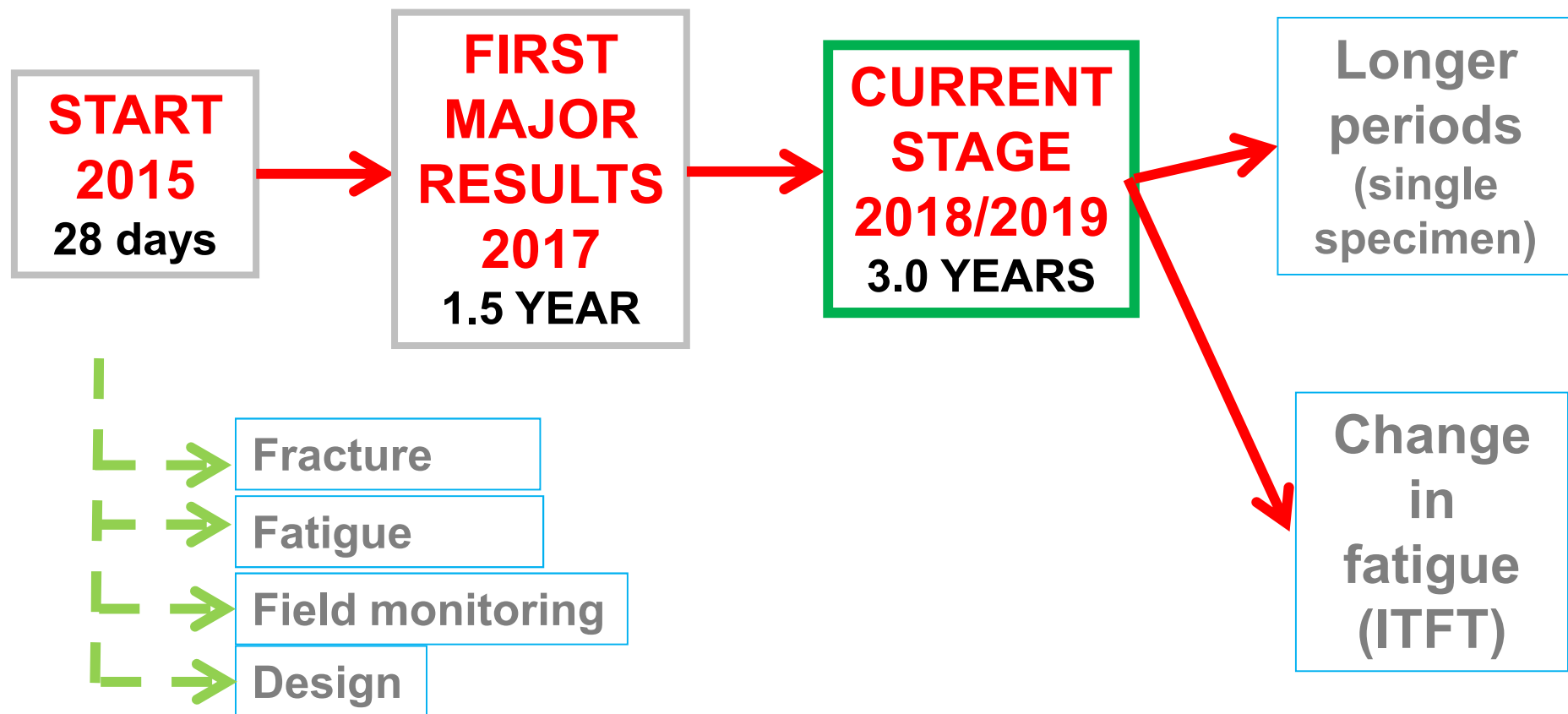
Evaluation of behaviour of cold recycled mixtures in the whole period of service

- Viscoelastic properties (influence of bitumen)
- Curing properties (influence of cement)
- Change of fracture properties with curing time
- Change of fatigue properties with curing time



CURRENT STAGE OF RESEARCH PROJECT

FUTURE



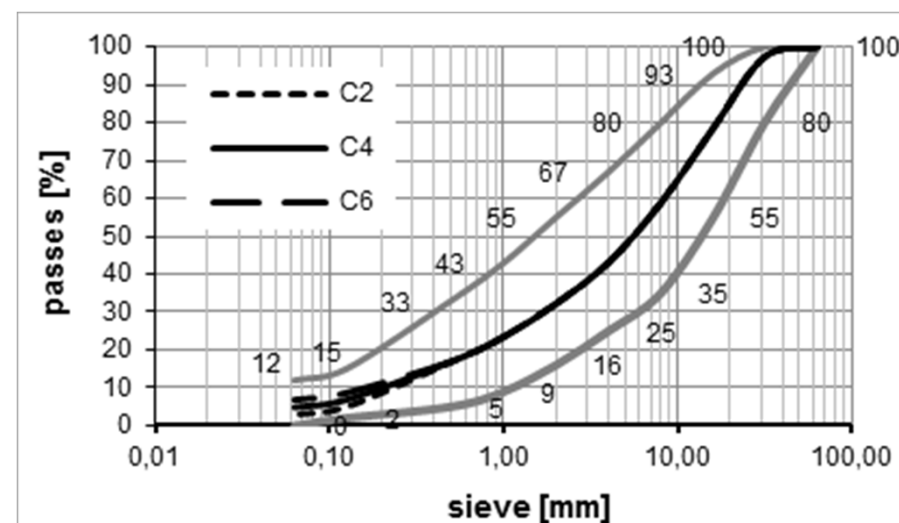


CURRENT STAGE OF RESEARCH PROJECT

- **Analysis of the change of Stiffness moduli and Phase angles for 28 days, 1.5 year, 3.0 year**
- **Development and evaluation of the multi-regression model on the basis of test results**

TESTED MATERIALS

	mineral mixture		
	C2	C4	C6
cement, CEM I 32,5 R [%]	2	4	6
fine aggregate 0/2, [%]	10	8	6
continuously graded aggregate 0/31,5, [%]	18	18	18
reclaimed asphalt pavement, [%]	70	70	70




**Generalna Dyrekcja
Dróg Krajowych i Autostrad**


**POLITECHNIKA
GDAŃSKA**
Katedra Inżynierii Drogowej

**INSTRUKCJA PROJEKTOWANIA
I WBUDOWYWANIA MIESZANEK
MINERALNO-CEMENTOWO-EMULSYJNYCH
(MCE)**

Wersja z dnia 31.11.2013



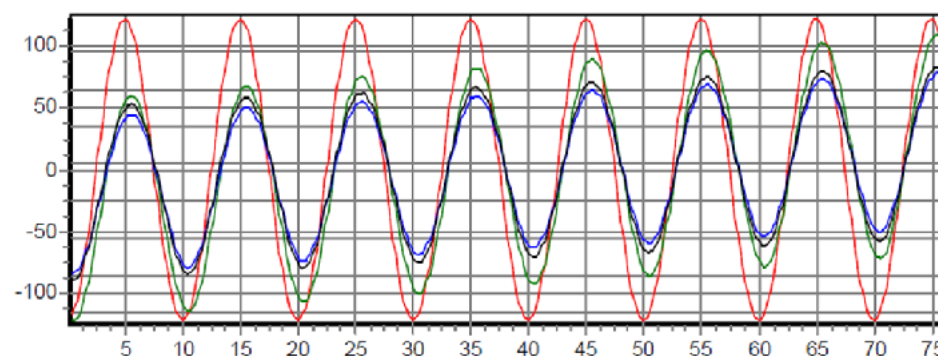
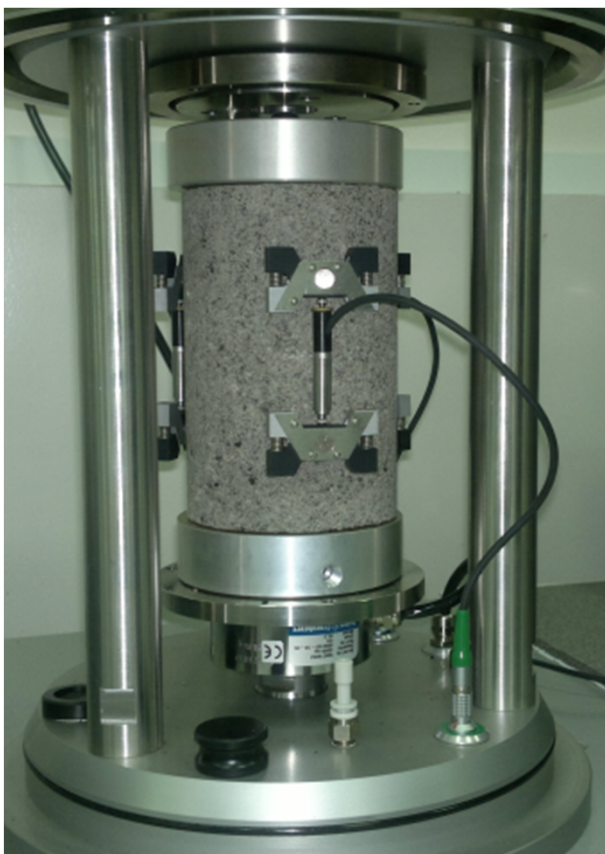
Gdańsk, 2013

Combination of binding agents

	mineral-cement-emulsion mixture (MCE)								
mixture designation	C2E2	C2E4	C2E6	C4E2	C4E4	C4E6	C6E2	C6E4	C6E6
cement content, [%]	2	2	2	4	4	4	6	6	6
emulsion content, [%]	2	4	6	2	4	6	2	4	6

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TEST METHOD: STIFFNESS MODULUS - AASHTO TP79

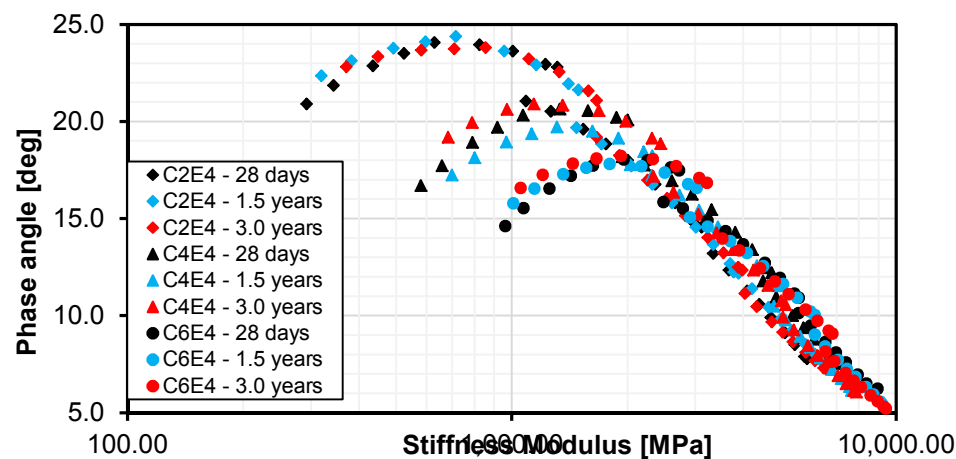
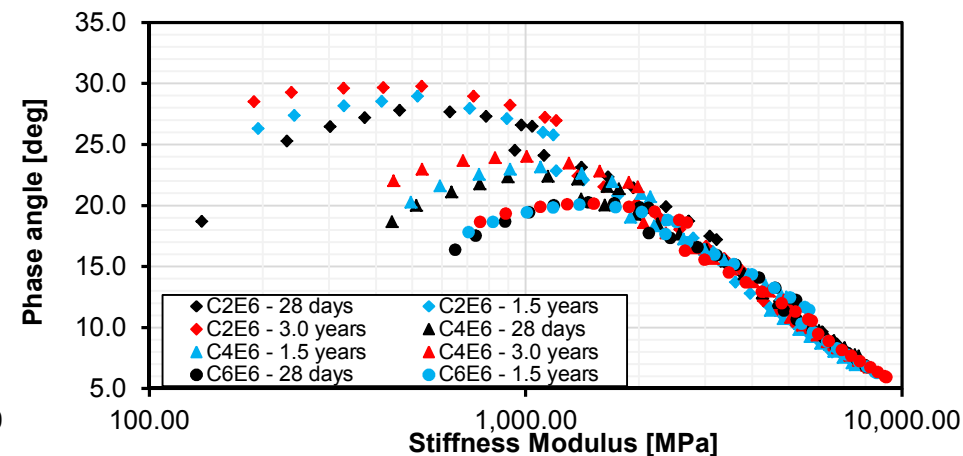
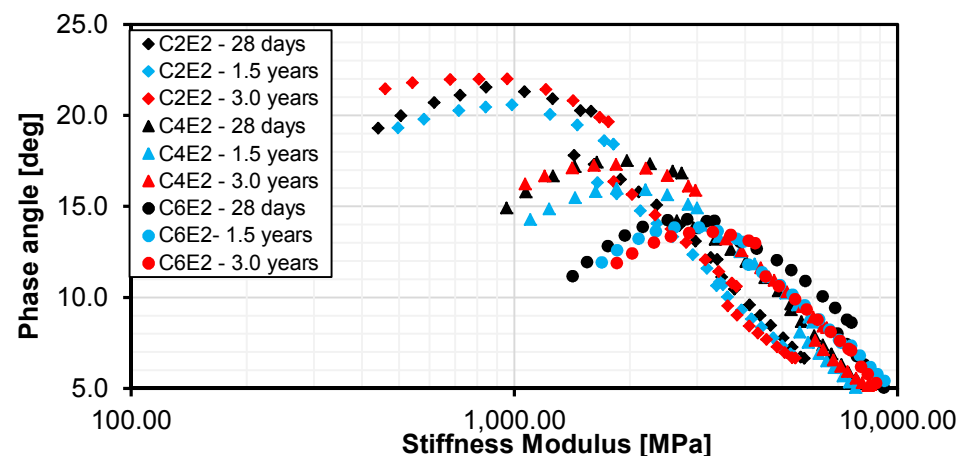


Temperature: +4C, +20C, +40C

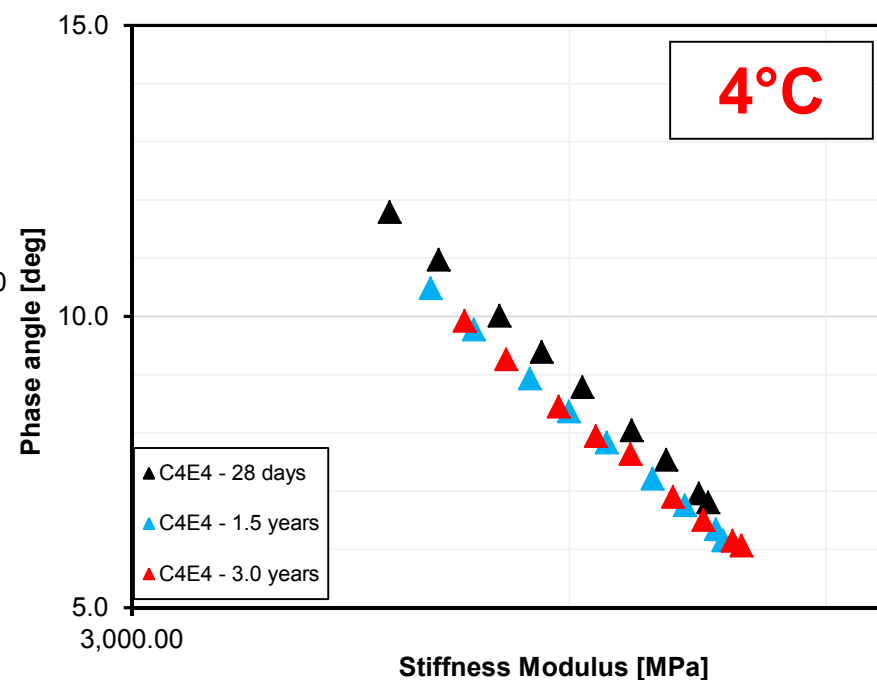
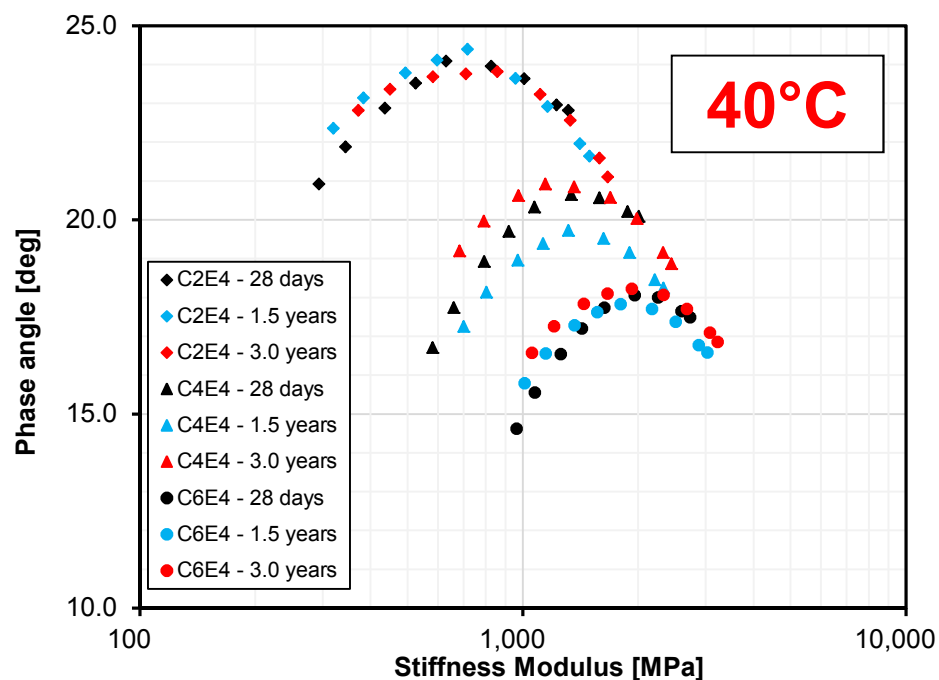
Frequency: 0,01 Hz – 25 Hz

Results: E^* , Φ

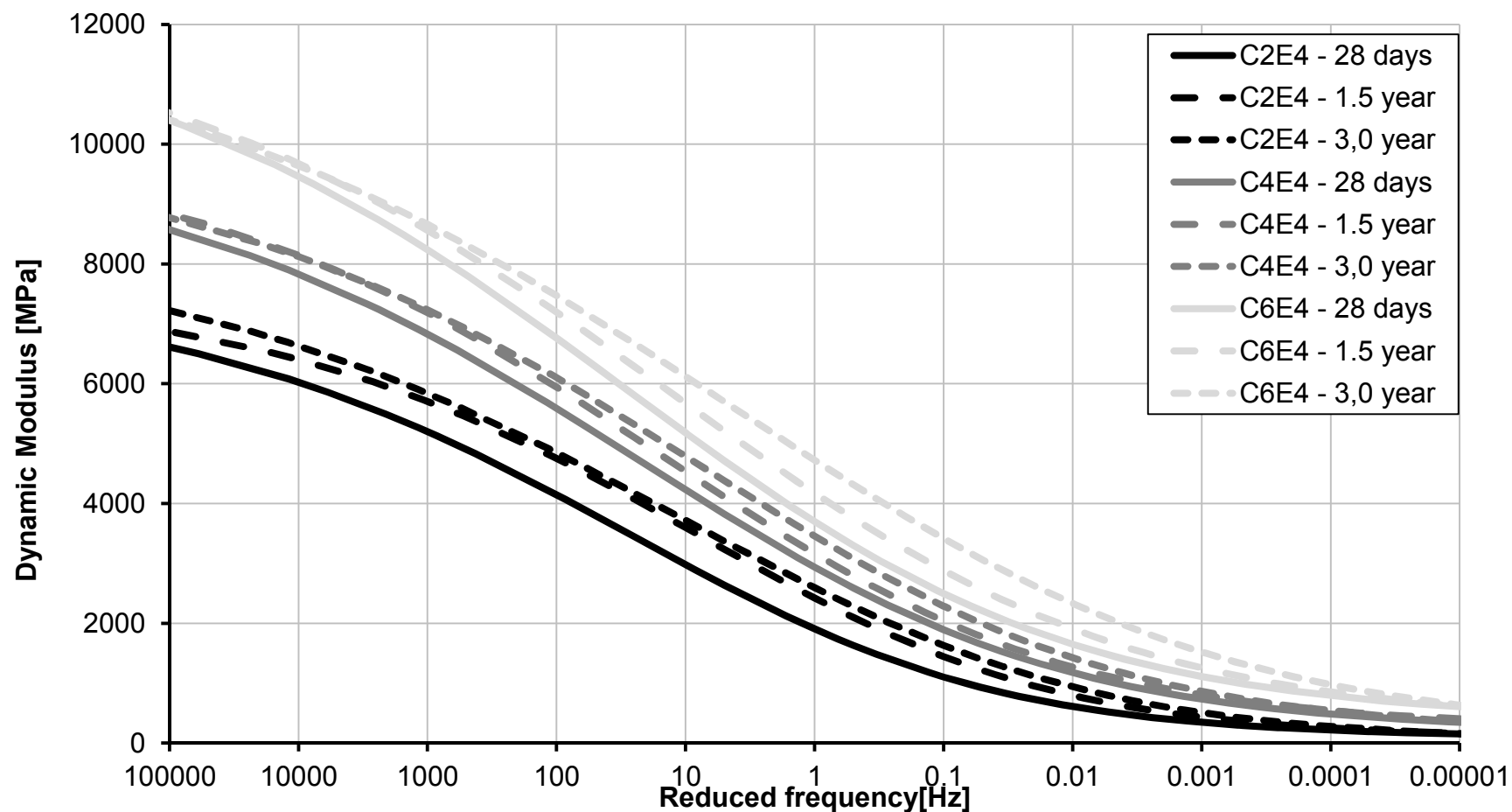
TEST RESULTS (BLACK DIAGRAM)



TEST RESULTS (BLACK DIAGRAM DETAILS)

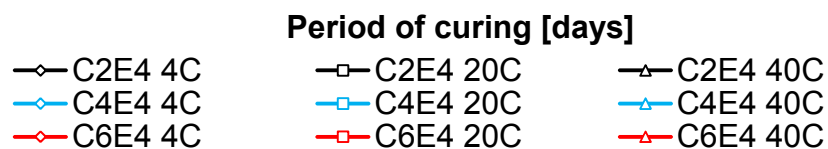
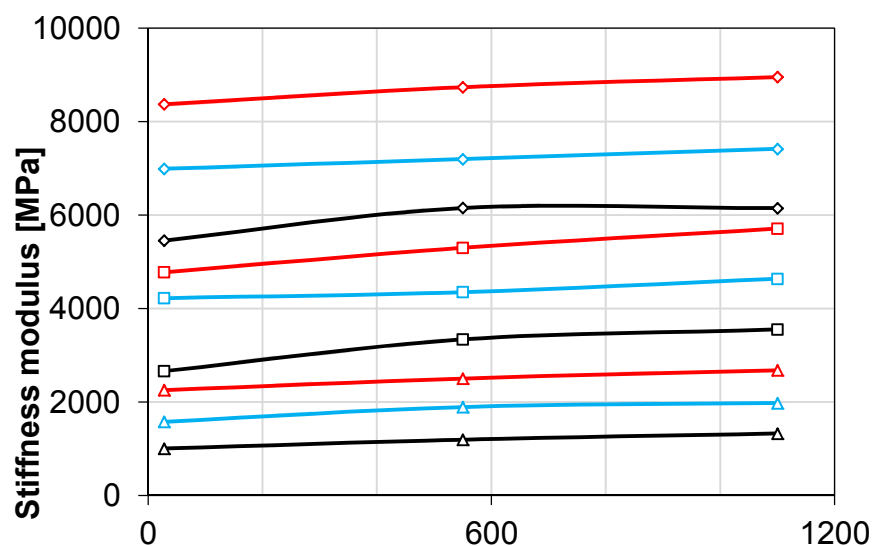


TEST RESULTS (Master Curve)

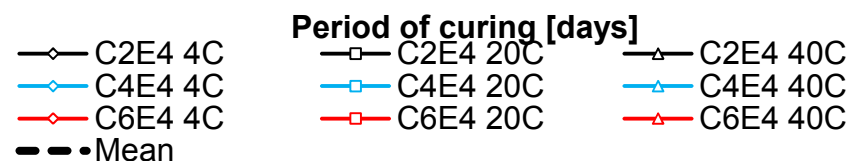
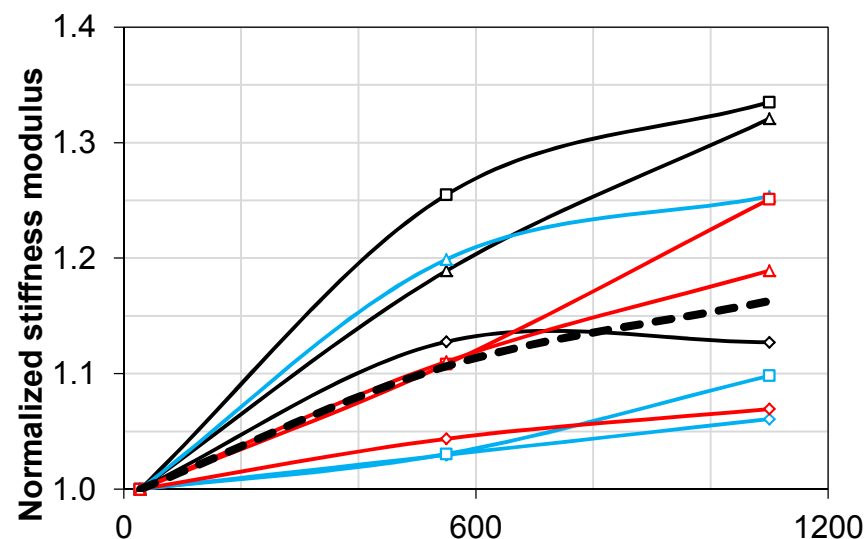


CHANGE OF THE STIFFNESS MODULI

Nominal change

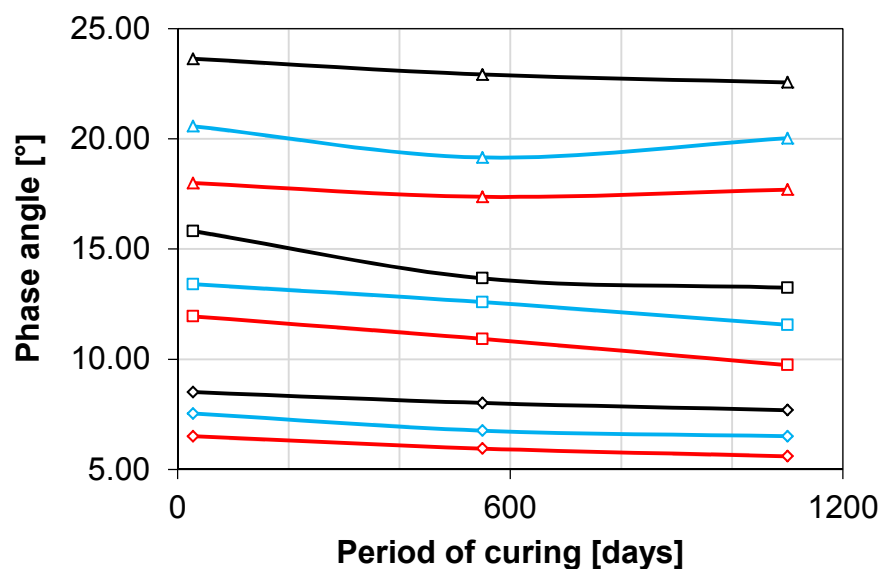


Relative change



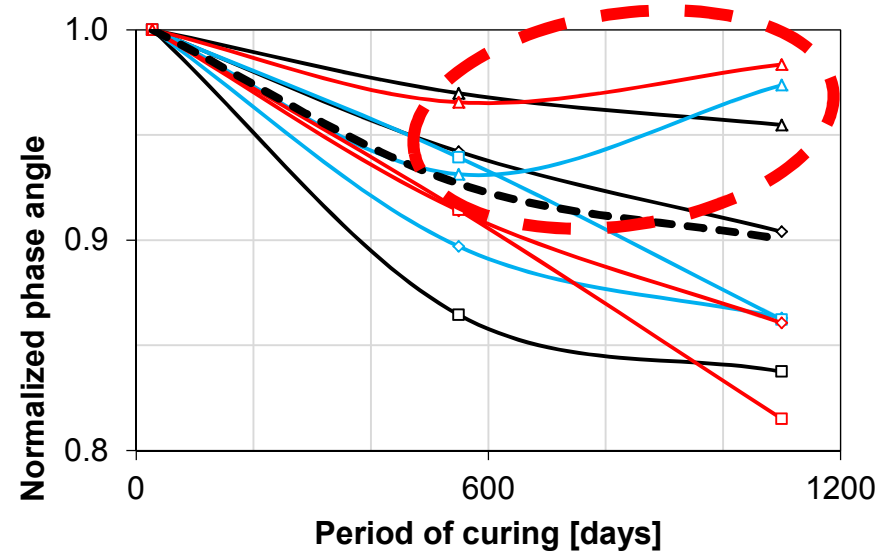
CHANGE OF THE PHASE ANGLES

Nominal change



◇ C2E4 4C □ C2E4 20C △ C2E4 40C
 ◇ C4E4 4C □ C4E4 20C △ C4E4 40C
 ◇ C6E4 4C □ C6E4 20C △ C6E4 40C

Relative change



◇ C2E4 4C □ C2E4 20C △ C2E4 40C
 ◇ C4E4 4C □ C4E4 20C △ C4E4 40C
 ◇ C6E4 4C □ C6E4 20C △ C6E4 40C
 - - - Mean



MULTIPLE REGRESSION MODELS

$$y_i = a_i \times x_i + \dots + a_2 \times x_2 + a_1 \times x_1 + a_0$$

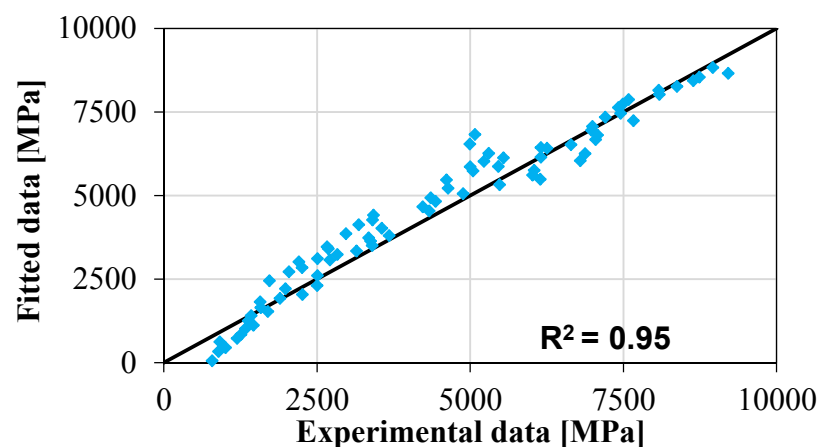
y_i – dependent variable (either stiffness modulus or phase angle),

$x_i, \dots, x_2, x_1$ – independent variables,

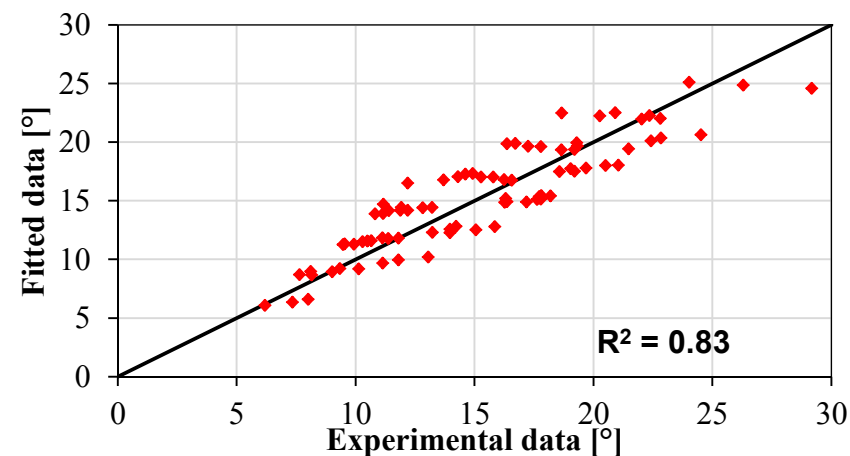
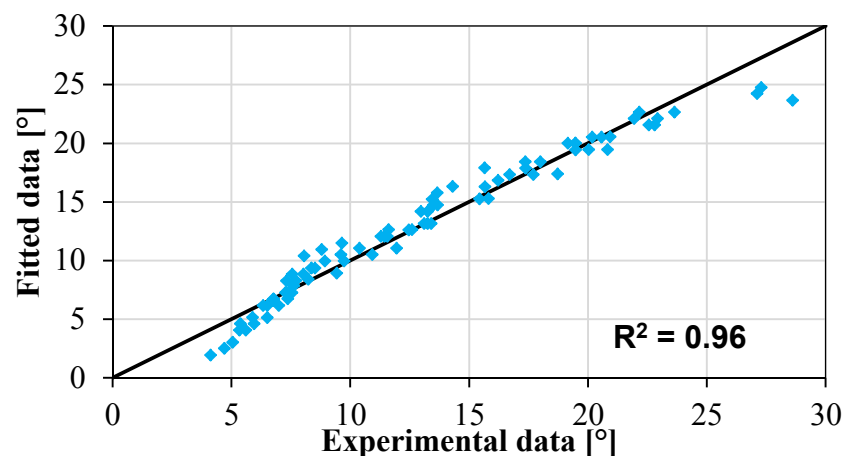
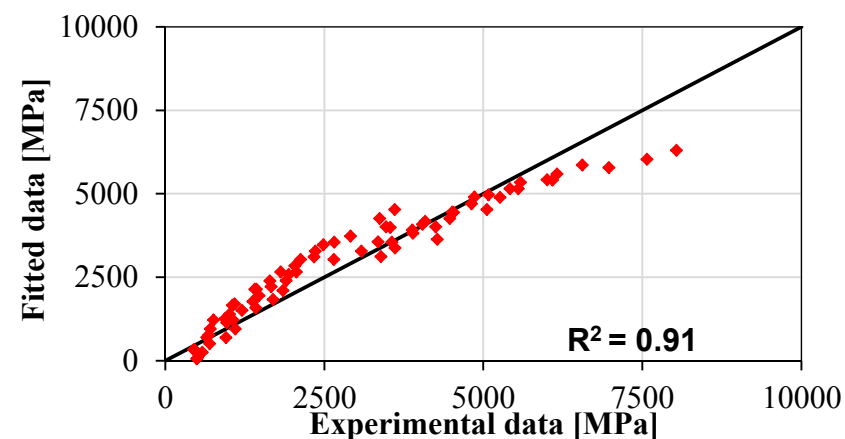
$a_i, \dots, a_2, a_1, a_0$ – regression coefficients

MULTIPLE REGRESSION MODELS

10 Hz



0.1 Hz



MULTIPLE REGRESSION MODELS

Property	Factor	Frequency 10 Hz				Frequency 0.1 Hz			
		4°C	20°C	40°C	4-40°C	4°C	20°C	40°C	4-40°C
Stiffness modulus [MPa]	C [1 %]	767	664	362	598	671	443	198	444
	E [1 %]	-78	-285	-225	-196	-238	-296	-150	-221
	Curing period [1 day] / [1 month]	0.556 / 16.67	0.688 / 20.63	0.332 / 9.95	0.525 / 15.75	0.736 / 22.08	0.580 / 17.39	0.097 / 2.91	0.485 / 14.45
Phase angle [°]	C [1 %]	-0.55	-0.96	-1.66	-1.06	-0.81	-1.33	-1.97	-1.31
	E [1 %]	0.50	1.09	1.57	1.06	0.82	1.43	1.46	1.29
	Curing period [1 day] / [1 month]	-0.001 / -0.026	-0.002 / -0.059	-0.0002 / -0.007	-0.001 / -0.030	-0.002 / -0.056	-0.002 / -0.045	+0.002 / +0.066	-0.0005 / -0.014

CONCLUSIONS

- Curing period influences the behaviour of cold recycled mixtures similarly to the cement concrete (stiffness modulus).
- The mean value of Stiffness moduli is slowly increasing –
 - first test period - increase by around 8% per year
 - second test period – increase by around 4.5% per year.
- The mean value of Phase angles is slowly decreasing –
 - first test period - decrease by around 5.8% per year
 - second test period – decrease by around 3.5% per year.



CONCLUSIONS

- At the temperature of 40°C the behaviour of cold recycled mixtures is more complex. The change of properties is not as evident and regular as it is at lower temperatures, probably due to stronger influence of bituminous emulsion.



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