Faculty of Science
Discovering for tomorrow

Nelson Mandela Metropolitan University
for tomorrow

WHERE POLYMERS MEET THE ROAD

“ A closer look into modified bituminous binders”

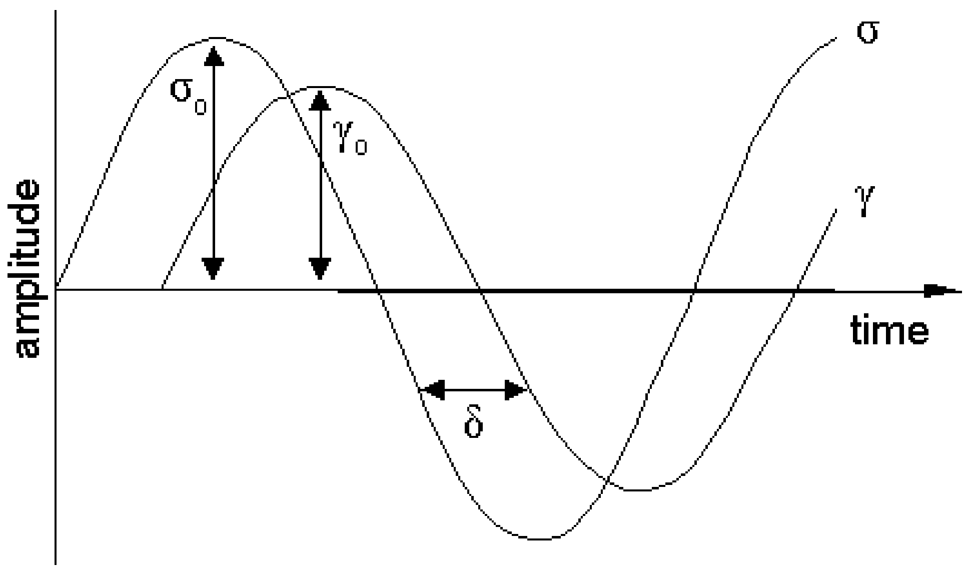
31st Road Pavements Forum
Africanos Country Estate, Addo, Eastern Cape
05 May 2016

Keith D Nare
MSc Chemistry Candidate

Rheology

- Science of deformation and flow behaviour of materials
- Different measuring systems for viscoelastic modified binders

- Gap setting usually 5-10 times larger than the largest dimension of the polymer (0.425mm crumb sizes)



Mezger TG, 2014, The Rheology Handbook, 4th edition, Vincentz Network, Hanover, Germany
http://ciks.cbt.nist.gov/~garbocz/SP946/node11.htmretrieved25/04/16

Materials

- PG 70/100 Bitumen and PG 50/70 Bitumen
- EVATANE 20-20
- Crumb Rubber 40 mesh
- PolyMod AP-1 EVA modified industrial standard
- AR-1 Crumb Rubber modified standard industrial standard
- 17 mixes of EVA:Bitumen:Crumb-Rubber (co-blends)

Nelson Mandela Metropolitan University
for tomorrow

Methods

- AASHTO T315-12 Original Binder Grading
- AASHTO T350-14 RTFOT Binder Grading

- Multiple Stress Creep Recovery (AASHTO T350-14)
- Rolling Thin Film Oven Tests (ASTM D2872 and MB-3 of TG1)
- Amplitude sweeps (DIN EN 14770) then Frequency sweeps
- Glover-Rowe Parameter sweep

Nelson Mandela Metropolitan University
for tomorrow

Lab equipment relevant to my study

Penetrometer PNR 12

MCR 502

Brookfield Viscometer

Compressor DK50 10S/M

MODULAR

builds on your applications

COMPACT

builds on your working day

RHEOMETER

builds on technological innovation

Viscotherm VT2

Nelson Mandela Metropolitan University

for tomorrow

SARA Analysis of 70/100

- Depicts the amount of Saturates, Aromatics, Resins and Asphaltenes in neat bitumen.

- Component analysis to aid in interaction chemistry

Table 3: SARA Analysis of Chevron 70/100

	Minimum	Maximum	Range	Average
Saturates	5.00	6.47	1.47	5.55
Aromatics	40.57	60.45	19.88	46.71
Resins	22.58	45.38	22.80	38.70
Asphaltenes	6.71	10.49	3.78	8.99

Nelson Mandela Metropolitan University

for tomorrow

Mixture Design (User Defined)

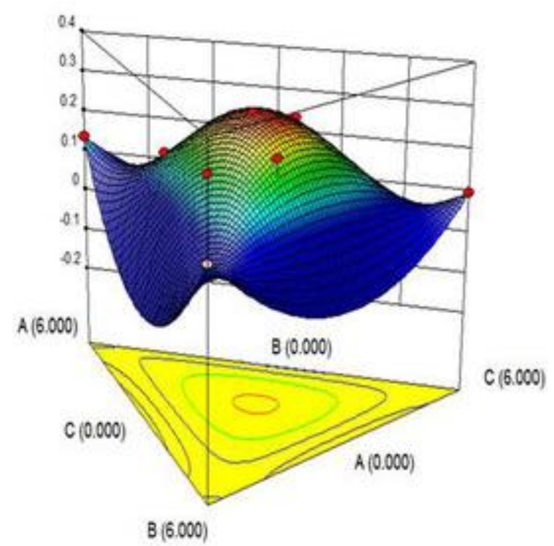
- 3 component Response Surface Methodology Approach

Table 1: Mixture Design for RSM approach.

Mix Number	EVA	Crumb Rubber	Bitumen
1	7.5	8.75	83.75
2	0	20	80
3	2.5	18.75	78.75
4	5	23.75	71.25
5	5	5	90
6	7.5	16.25	76.25
7	2.5	13.75	83.75
8	5	30	65
9	10	30	60
10	0	10	90
11	10	0	90
12	5	17.5	77.5
13	7.5	23.75	68.75
14	0	30	70
15	5	11.25	83.75
16	10	15	75
17	2.5	23.75	73.75

Table 2: Design Constraints

	Minimum	Maximum
Crumb Rubber	0	30
EVA	0	10
Bitumen	60	90



http://www.nature.com/articles/srep04715retrieved25/04/16

Nelson Mandela Metropolitan University
for tomorrow

Phase Angle (□) at T_{max}

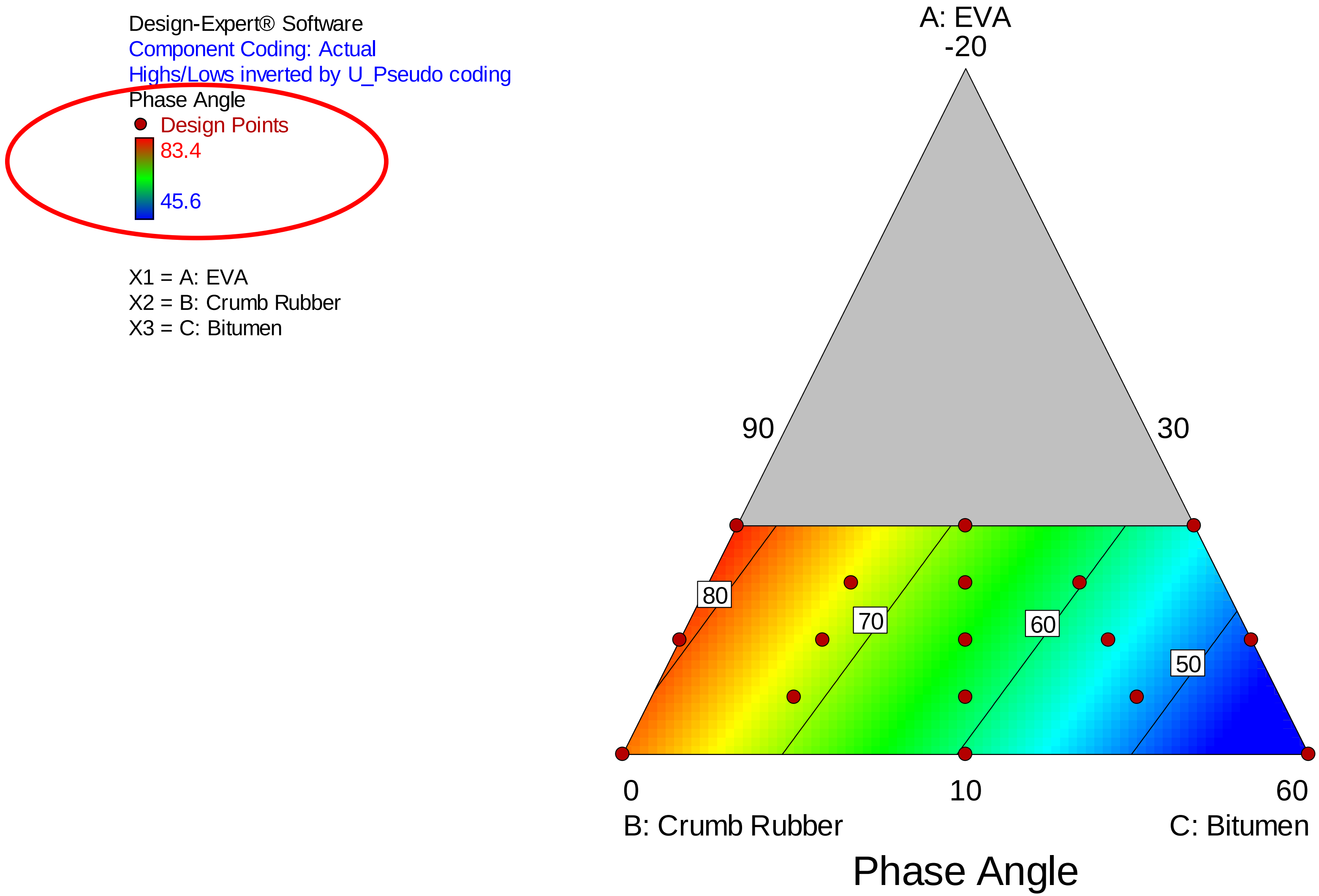
Source	Sequential p-value	Adjusted R-Squared	Predicted R-Squared	
Linear	< 0.0001	0.8834	0.8352	Suggested
Quadratic	0.2196	0.8991	0.8294	
Special Cubic	0.3640	0.8982	0.7356	
Cubic	0.4436	0.8985	0.4153	
Sp Quartic vs Quadratic	0.4608	0.8977	0.6245	
Quartic vs Cubic	0.6534	0.8773	-88.6627	
Quartic vs Sp Quartic	0.6570	0.8773	-88.6627	

Final Equation in Terms of Actual Components

Phase Angle = -0.67*EVA - 0.36*CR + 0.95*Bitumen

Nelson Mandela Metropolitan University
for tomorrow

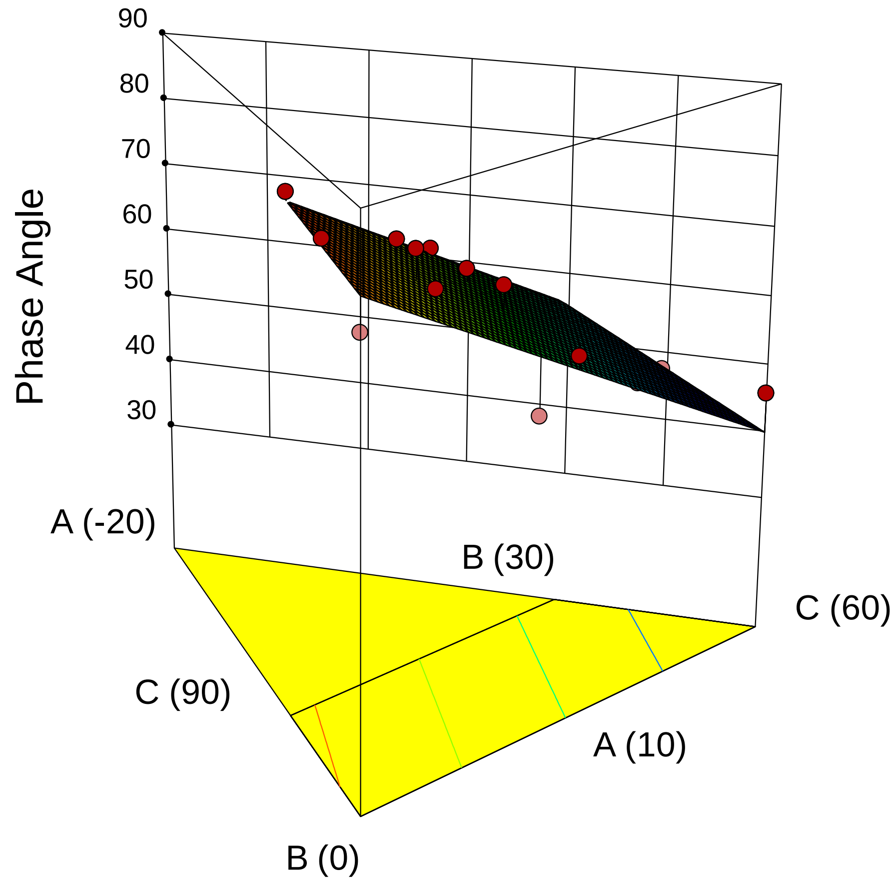
Phase Angle (□) at T_{max}



Phase Angle (□) at T_{max}

Design-Expert® Software
Component Coding: Actual
Highs/Lows inverted by U_Pseudo coding
Phase Angle
● Design points above predicted value
● Design points below predicted value
83.4
45.6

X1 = A: EVA
X2 = B: Crumb Rubber
X3 = C: Bitumen



Rutting parameter (G*/sin□) at T_{max}

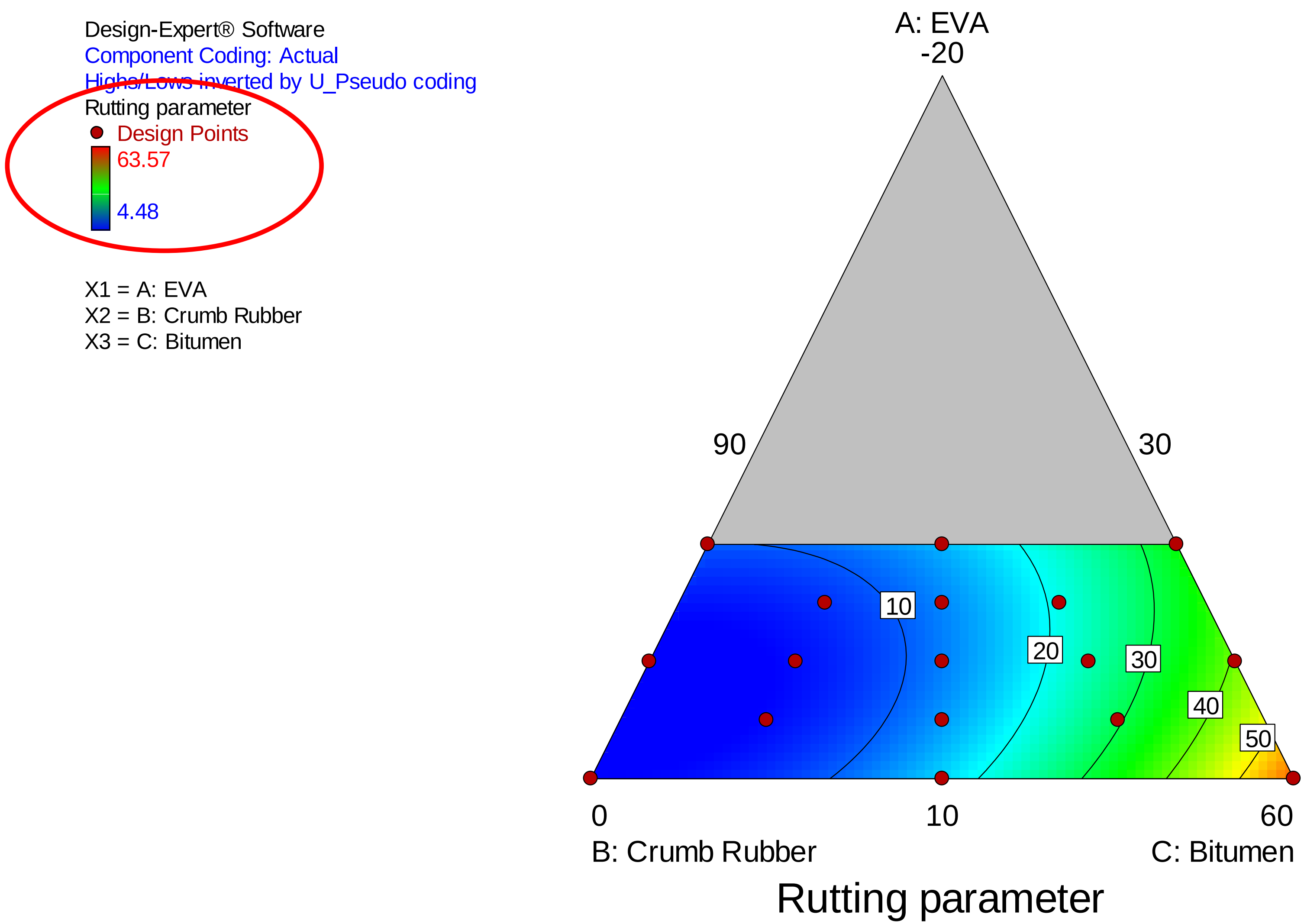
Source	Sequential p-value	Adjusted R-Squared	Predicted R-Squared	
Linear	< 0.0001	0.7712	0.6014	
Quadratic	0.0025	0.9170	0.7028	Suggested
Special Cubic	0.0753	0.9345	0.6173	
Cubic	0.1296	0.9562	0.5142	
Sp Quartic vs Quadratic	0.3496	0.9226	0.3523	
Quartic vs Cubic	0.5094	0.9620	-21.5512	
Quartic vs Sp Quartic	0.3246	0.9620	-21.5512	

Final Equation in Terms of Actual Components

Rutting parameter = +17.89* EVA + 5.17*CR + 0.17*Bitumen-0.15*EVA*CR -0.21*EVA*Bitumen - 0.064*CR*Bitumen

Nelson Mandela Metropolitan University
for tomorrow

Rutting parameter (G*/sin□) at T_{max}

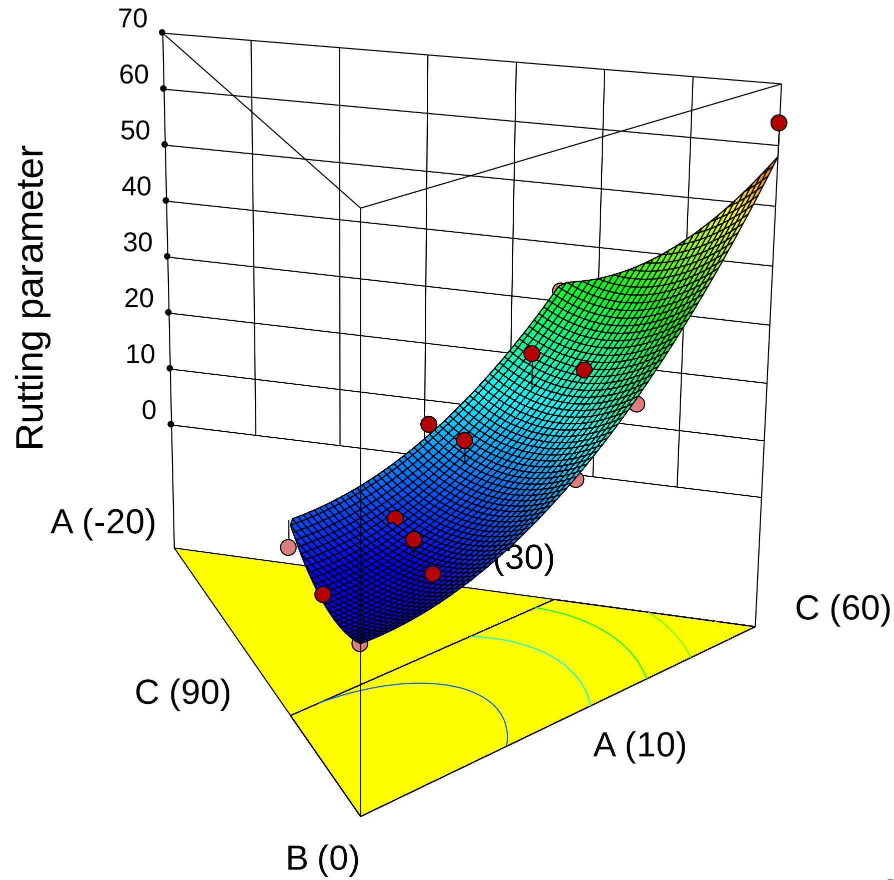


Rutting parameter (G*/sin□) at T_{max}

Design-Expert® Software
Component Coding: Actual
Highs/Lows inverted by U_Pseudo coding
Rutting parameter
● Design points above predicted value
● Design points below predicted value
63.57

4.48

X1 = A: EVA
X2 = B: Crumb Rubber
X3 = C: Bitumen



Complex Shear Modulus (G*) at T_{max}

Source	Sequential p-value	Adjusted R-Squared	Predicted R-Squared	
Linear	< 0.0001	0.7782	0.6265	Suggested
Quadratic	0.0224	0.8779	0.6001	Suggested
Special Cubic	0.0616	0.9069	0.5600	
Cubic	0.1540	0.9343	0.2229	
Sp Quartic vs Quadratic	0.2455	0.8972	0.1699	
Quartic vs Cubic	0.3815	0.9598	-20.0879	
Quartic vs Sp Quartic	0.2655	0.9598	-20.0879	

Final Equation in Terms of Actual Components:

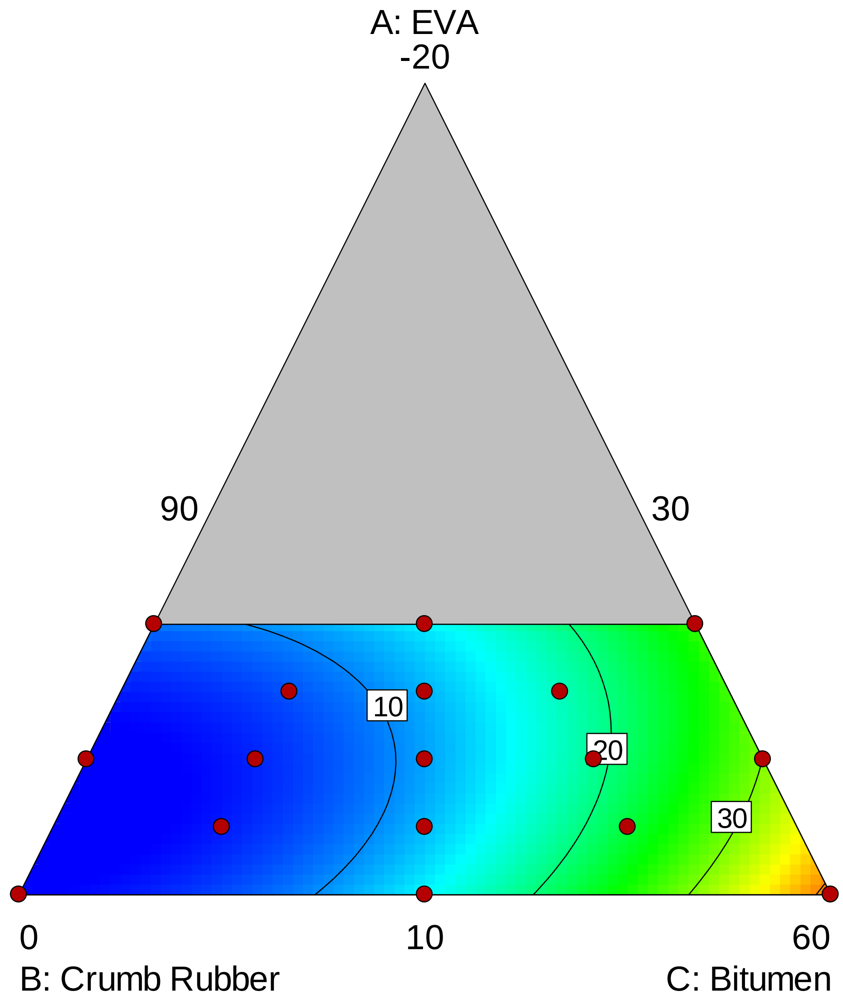
Complex Shear Modulus = +13.53*EVA+3.18* CR+0.11*Bitumen-0.12*EVA*CR-0.16*EVA*Bitumen-0.04*CR*Bitumen

Nelson Mandela Metropolitan University
for tomorrow

Complex Shear Modulus (G*) at T_{max}

Design-Expert® Software
Component Coding: Actual
Highs/Lows inverted by U_Pseudo coding
Complex Shear Modulus
Design Points
45.4
4.3

X1 = A: EVA
X2 = B: Crumb Rubber
X3 = C: Bitumen



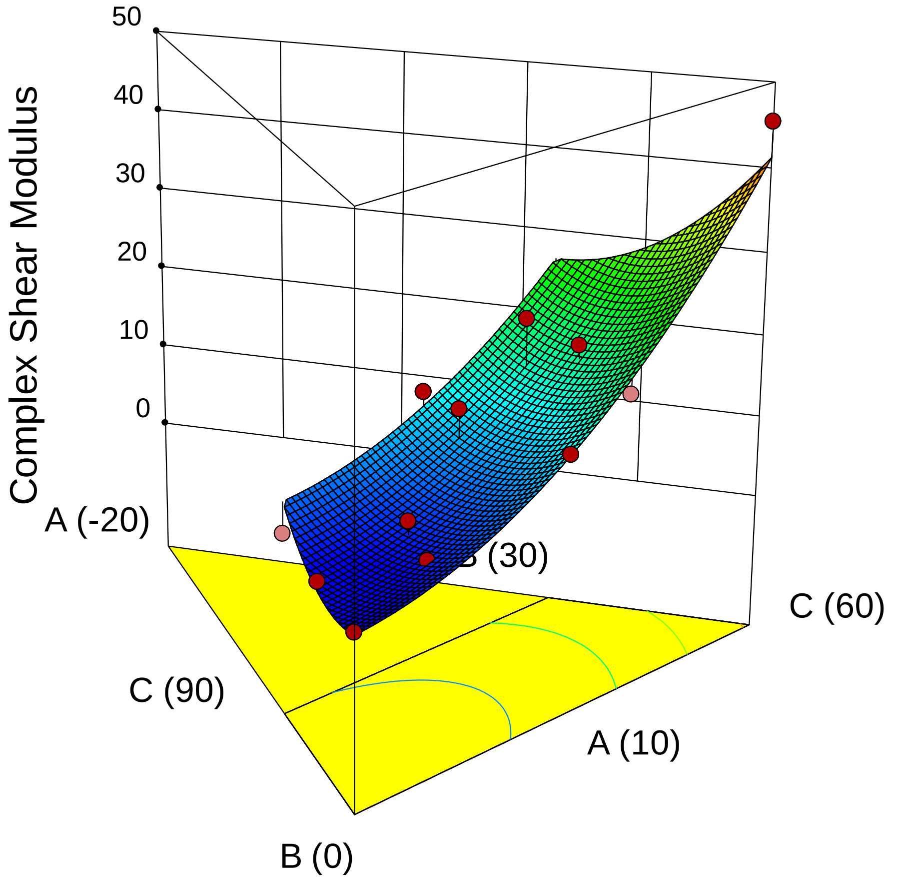
Complex Shear Modulus

Nelson Mandela Metropolitan University
for tomorrow

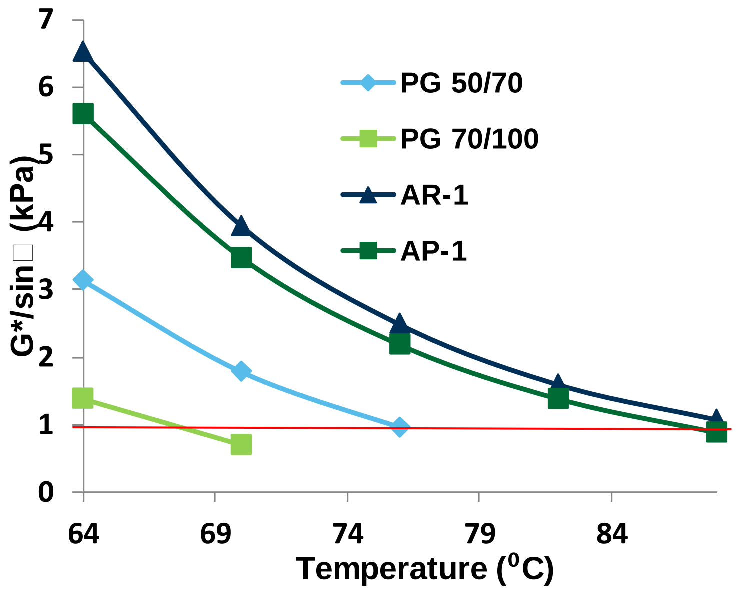
Complex Shear Modulus (G*) at T_{max}

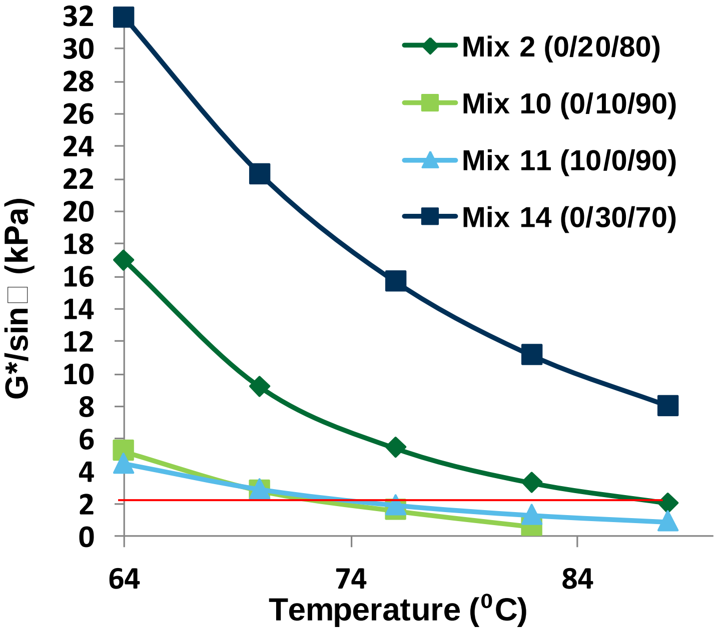
Design-Expert® Software
Component Coding: Actual
Highs/Lows inverted by U_Pseudo coding
Complex Shear Modulus
● Design points above predicted value
● Design points below predicted value
45.4
4.3

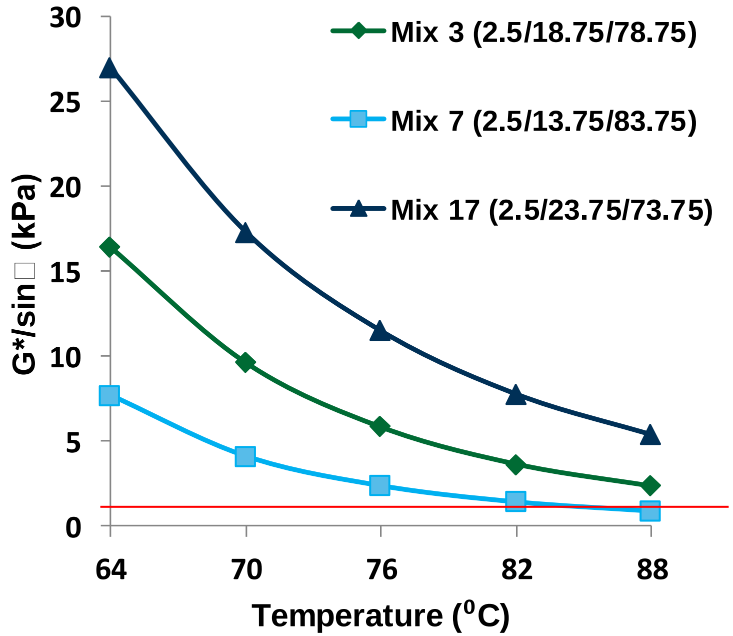
X1 = A: EVA
X2 = B: Crumb Rubber
X3 = C: Bitumen



EVA Increments Approach

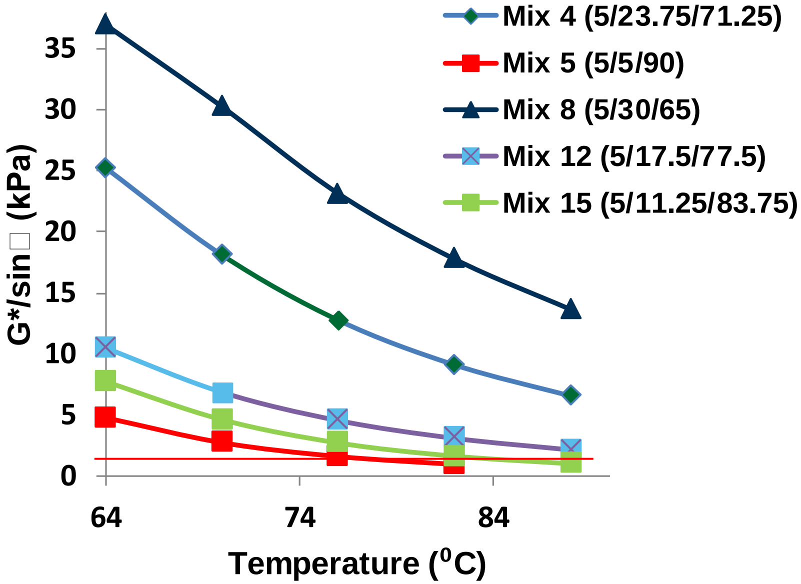


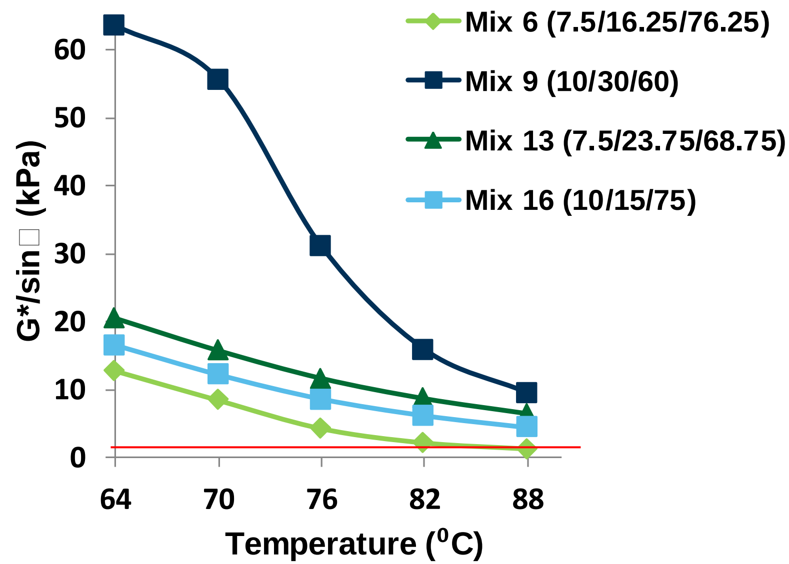




Nelson Mandela Metropolitan University
for tomorrow

EVA Increment Approach

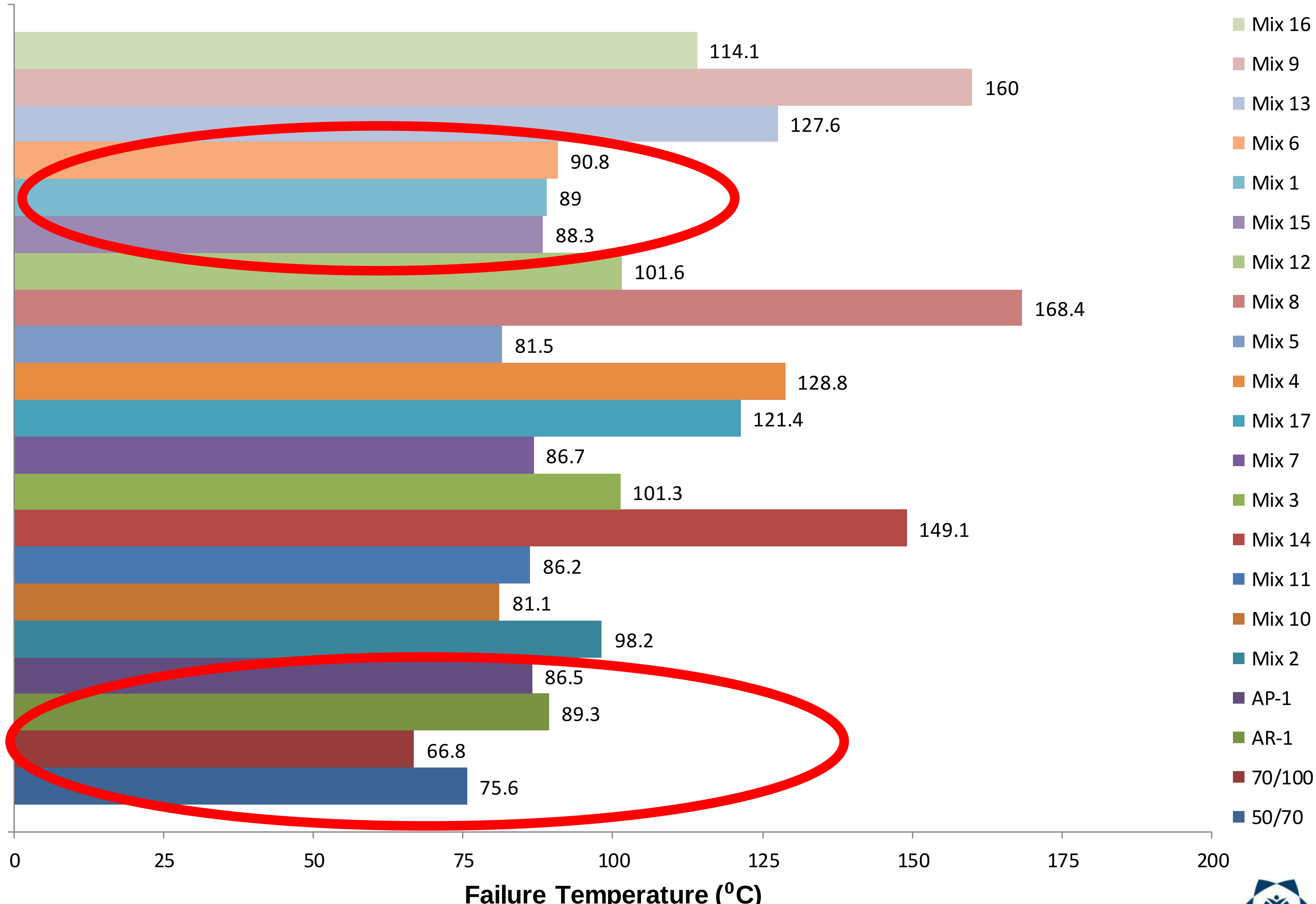




- AASHTO T315 Original Binder Performance Criterion:

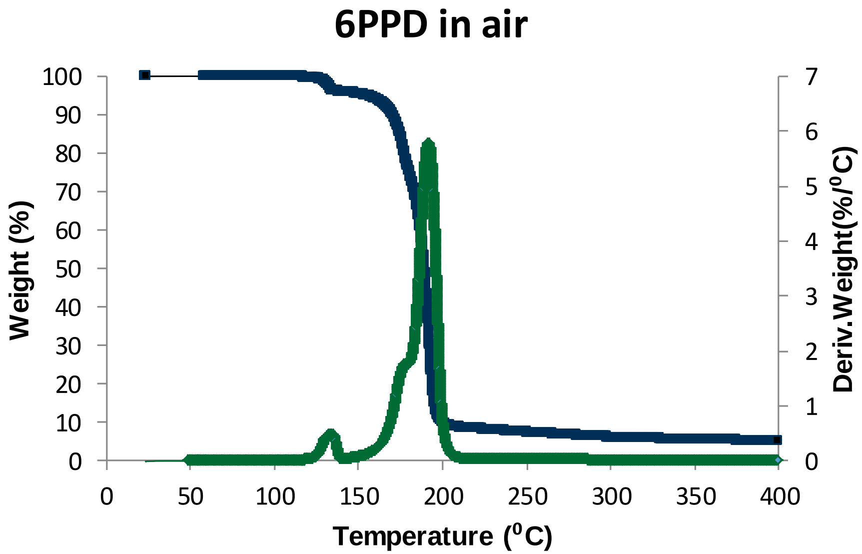
IG*I/sin(delta) ≥ 1.00 kPa **(depicted by red line in graphs)**

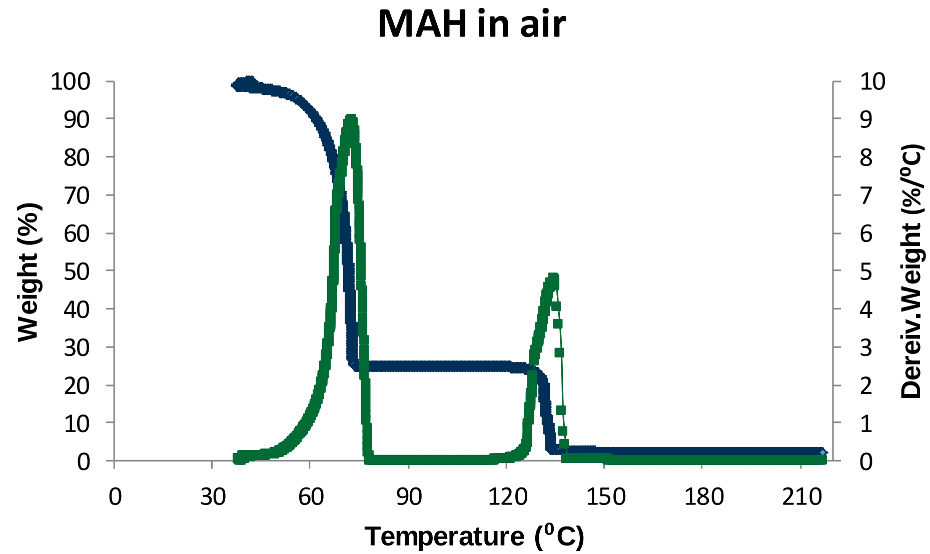
Failure temperature Approach



Nelson Mandela Metropolitan University
for tomorrow

Antioxidant Thermal Stability



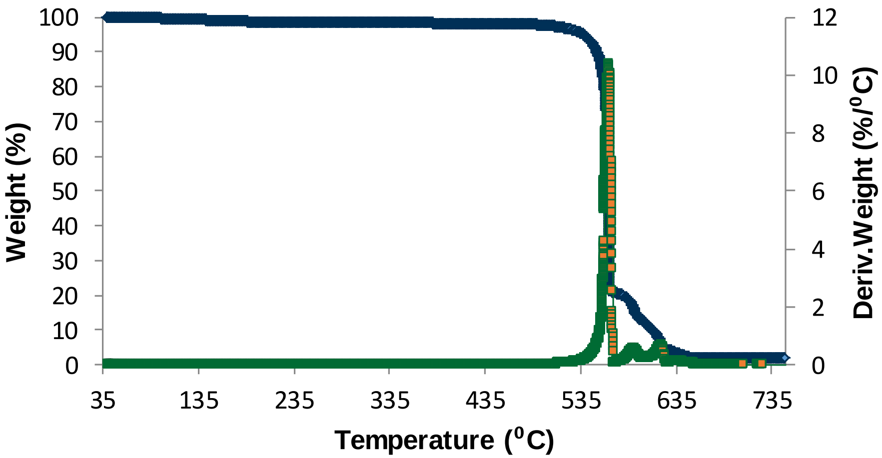


Nelson Mandela Metropolitan University

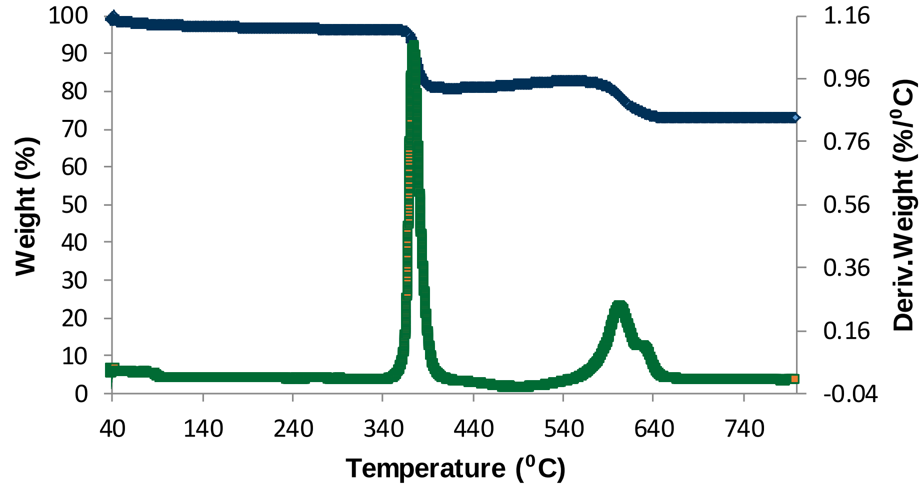
for tomorrow

Antioxidant Thermal Stability

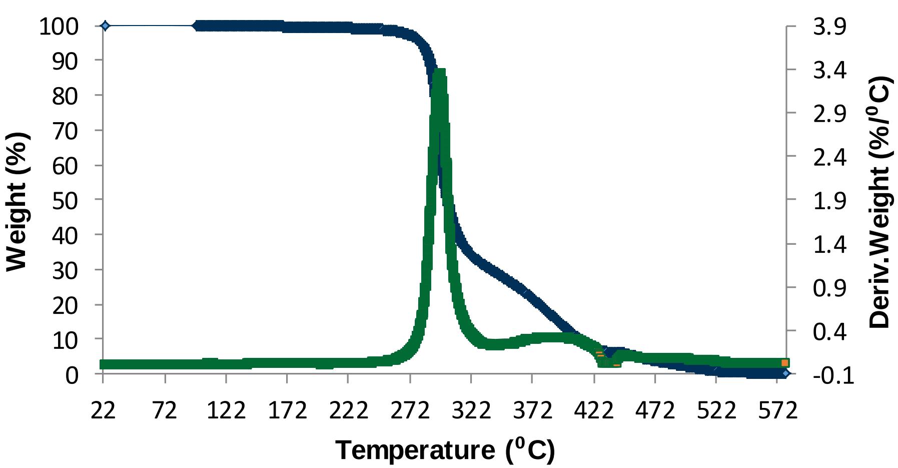
CB in air



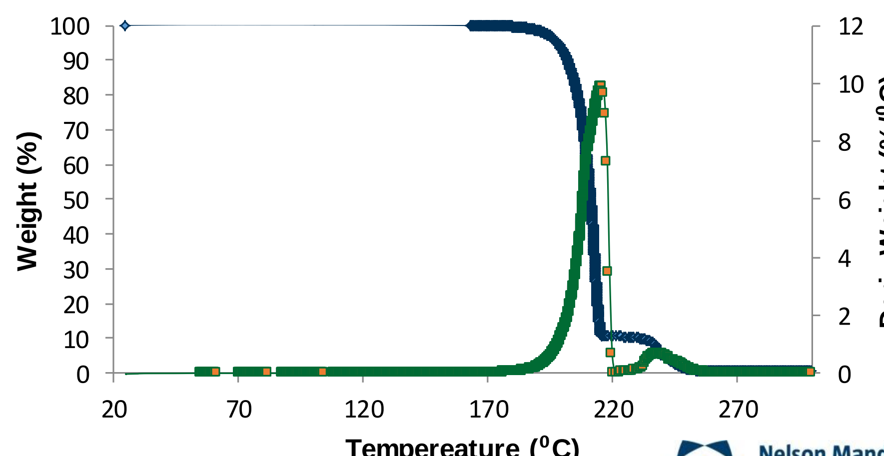
HL in air



Irganox 1010 in air



Irgafos 168 in air



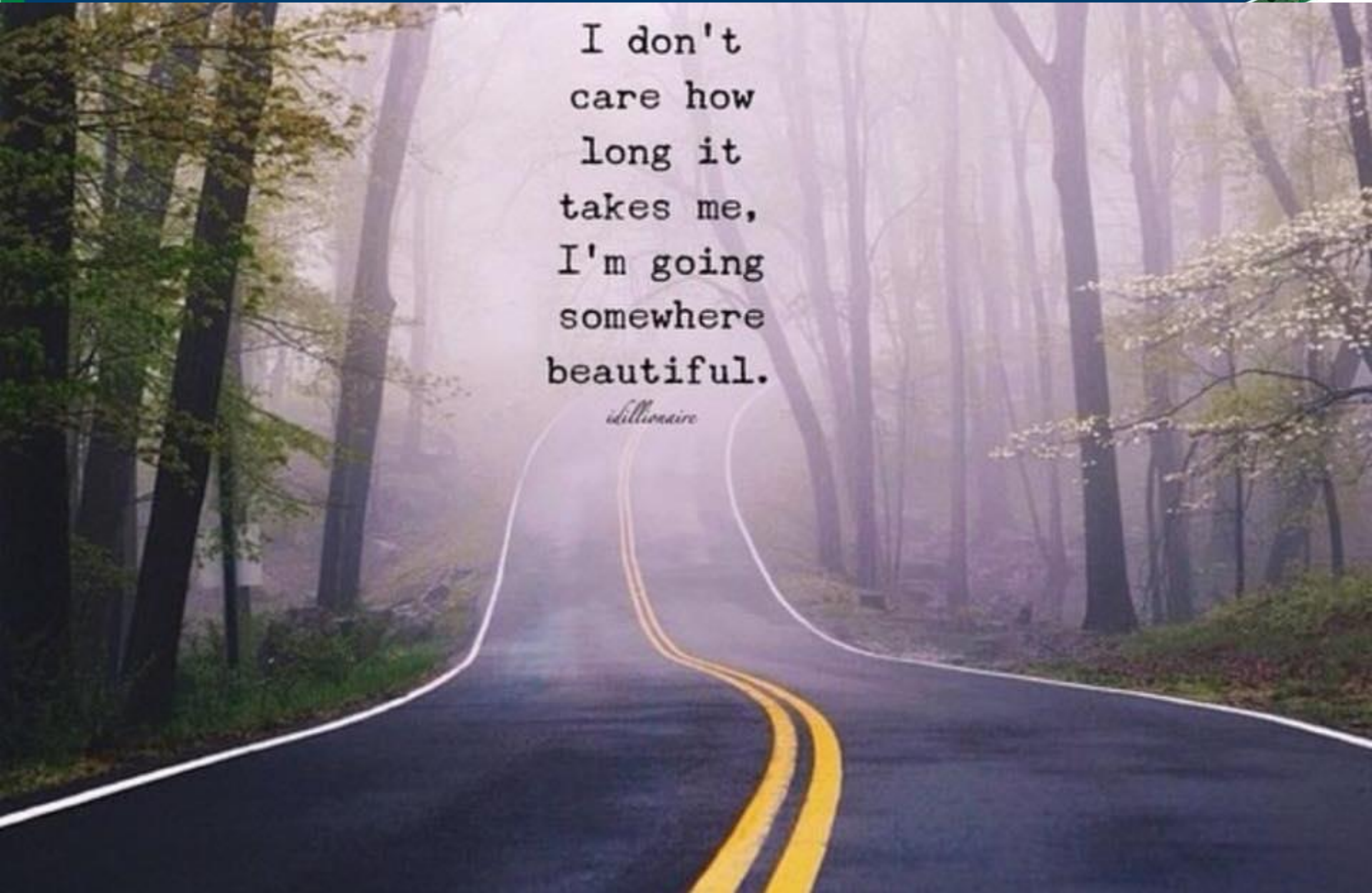
Nelson Mandela Metropolitan University
for tomorrow

Future Work

- Antioxidant mixes using different loadings
- Test for synergism and antagonism of antioxidants
- Storage stability studies of optimised mix
- Compaction of then quality passed optimum mix with aggregate
- Set up an thermorheology application based database of mixes
- Compare with conventional bitumen tests

Nelson Mandela Metropolitan University
for tomorrow

Project Forecast ☺



Acknowledgements

- Dr. Percy Hlangothi (Supervisor)
- Dr. James Carson (Co-Supervisor)
- REDISA, NRF and NMMU (Funding)
- Dr. Mohau Phiri (Experimental Design)
- Christiaan de Jager (COLAS, Port Elizabeth)
- Colin Brooks (Much Asphalt, Western Cape)
- Jacques van Heerden (TOSAS, Johannesburg)
- Donald Mathonsi and Enerst Koboka (Civil Engineering)
- Pumza Fibi and Lukhanyo Bolo (Technical Support)

Nelson Mandela Metropolitan University
for tomorrow

Contact Details

KEITH NARE

MSc Candidate

DEPARTMENT OF CHEMISTRY

NMMU, Summerstrand, Port Elizabeth, 6031

060 672 8957

s211225193@nmmu.ac.za

Phase Angle (□)

	Sum of		Mean	F	p-value	
Source	Squares	df	Square	Value	Prob > F	
Model	2238.18	2	1119.09	61.63	< 0.0001	significant
[1]Linear Mixture	2238.18	2	1119.09	61.63	< 0.0001	
Residual	254.22	14	18.16			
Cor Total	2492.40	16				

Rutting parameter (G*/sin□)

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	3527.25	5	705.45	36.36	< 0.0001	significant
[1]Linear Mixture	2991.90	2	1495.95	77.10	< 0.0001	
AB	38.91	1	38.91	2.01	0.1844	
AC	76.39	1	76.39	3.94	0.0727	
BC	309.22	1	309.22	15.94	0.0021	
Residual	213.43	11	19.40			
Cor Total	3740.67	16				

Nelson Mandela Metropolitan University
for tomorrow

Complex Shear Modulus (G*)

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	2333.84	6	388.97	24.53	< 0.0001	significant
[1]Linear Mixture	2238.18	2	1119.09	70.58	< 0.0001	
AB	3.53	1	3.53	0.22	0.6470	
AC	0.82	1	0.82	0.052	0.8248	
BC	9.64	1	9.64	0.61	0.4537	
ABC	14.34	1	14.34	0.90	0.3640	
Residual	158.57	10	15.86			
Cor Total	2492.40	16				

Nelson Mandela Metropolitan University
for tomorrow