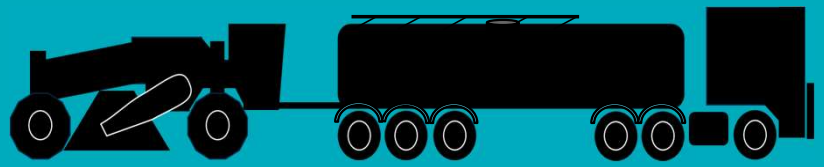
Effects of '*hot storage and duration*' on class 170 binder properties and foamed bitumen stabilisation performance.

Damian Volker, Principal Engineer

Department of Transport and Main Roads



Australian Pavement Recycling and Stabilisation Conference

Pavement Recycling for Sustainable Roads

Novotel Brighton Beach, Sydney • 10th August 2022

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Traditional Owners Acknowledgement

TMR Artwork storyline Travelling by Gilimbaa.

About us

Effects of '*hot storage and duration*' on class 170 binder properties and foamed bitumen stabilisation performance

Bulk bitumen tanker leaving refinery (point of release)[1].

Bulk bitumen tankers can travel up to 700km for Foamed Bitumen projects in Queensland.

Foamed Bitumen Road Stabilisation

Between the 'refinery' and the jobsite 'point of delivery', class 170 bitumen used in foamed bitumen stabilisation can be exposed to temperatures above maximum specified 190°C; or held at 190°C for multiple days prior to use (incorporation). What are the impacts on foamed bitumen performance/pavement life?

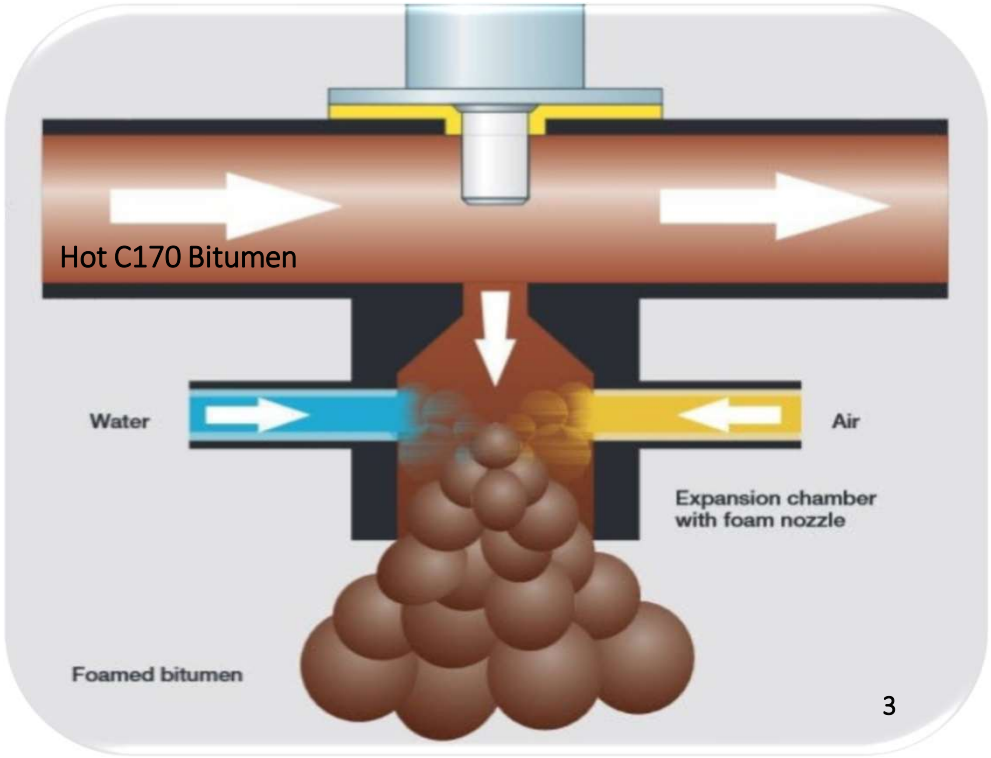
Hot Storage: C170 Bitumen heated to 185°C (control sample), over-heated to 200°C, 210°C and 220°C.

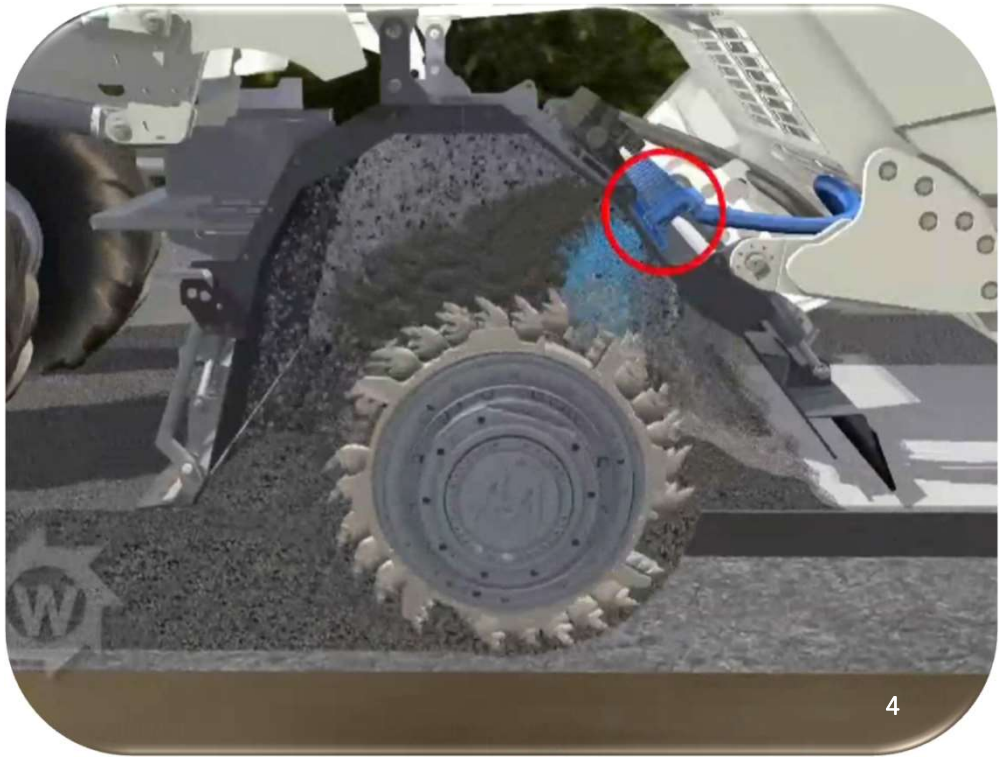
Duration: C170 Bitumen maintained at 185°C for prolonged periods 0 day (control sample), 2, 4, 6 & 8 days.

Exsitu Plant-Mixed Foamed Bitumen

Insitu Foamed Bitumen

What is Foamed Bitumen Road Stabilisation?





Benefits of Foamed Bitumen pavements

- Foamed bitumen improves the stiffness and load bearing capacity

Strong and flexible pavement

Moisture resistant pavement

- Offers better resilience to flooding

- Better fatigue resistance than using a cement stabilised base

Reduces shrinkage cracking

Using lime as a secondary additive

- Provides longer construction working times

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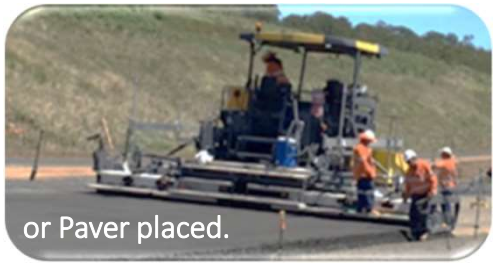
Techniques: Insitu and Exsitu (plant-mixed) foamed bitumen

1. Insitu Foamed Bitumen: In-place recycling utilising existing pavement base materials

2. Exsitu: Plant-Mixed Foamed Bitumen produced in a pugmill (located at a quarry) and delivered to site in trucks



Problem formulation

MRTS07C and MRTS09 specifications:

'The bitumen shall be incorporated at a temperature between 180°C and 190°C. Bitumen temperature shall not fall below 170°C throughout the bitumen incorporation process'.

MRTS17 Bitumen Specification referenced Advisory Note 7

AAPA Advisory Note 7 - Guide to heating and storage.

Binder Supplier	Sealing Binder	Austroads binder class (AG:PT/T190)	Recommended spraying temperature range (°C) (Note 1)	Recommended maximum holding time at spraying temperature (Notes 2 & 3)	Recommended medium-term storage temperature (°C)	Recommended medium-term storage time (Notes 2 & 3)
PAVING GRADE BITUMEN AS2008 bitumen grades	Class 170		175 - 185	7 days	130 - 150	30 days

Notes:

1. Adjustments of the spraying temperature may be required to allow for prevailing conditions, such as pavement temperature and wind speed, but should not exceed the recommended maximum spraying temperature. The listed temperature ranges apply to the binder before the addition of cutter or additive. For further information, refer to the Austroads Bituminous Materials Safety Guide.
2. All polymer modified binders must be stirred prior to use and regularly circulated during storage dur to the possibility of polymer segregation. Refer to binder manufacturer/supplier for advice on storage of binders for periods longer than shown.
3. Longer storage times apply at lower storage temperatures, shorter storage times apply at higher storage temperatures.

Problem - circumstances investigated

Project 1 (2018): Insitu foamed bitumen project

Bitumen arrived onsite at 200°C.

Background: Project was 700km from the refinery and loads were arriving the previous evening for works the following day. The bitumen transport operator suggested it was common practise to heat the bitumen as high as 220°C during the night and allow the bitumen to reduce in temperature to the required 180-190°C at point of delivery.

Project 2 (2018): Exsitu plant-mixed foamed bitumen project

Due to project delays, Class 170 bitumen was held in an auxiliary bitumen tank at 185°C for >7 days prior to manufacture of the foamed bitumen mix.

Background: Electric elements in auxiliary storage can maintain a high temperature of 180-190°C. However, heating from a lower temperature to the required 180-190°C is slow (approximately 1°C per hour).

Literature review – Class 170 binder

Binder test results obtained for C170 bitumen after different storage times at 180°C.

Property	C170 bitumen				AS 2008 specification for C170 bitumen[1]
Storage time at 180 °C (days)	0	2	5	6	–
Viscosity at 165 °C (Pa s)	0.09	–	–	0.11	–
Torsional recovery at 25 °C (%)	2	–	–	2	–
Softening point (°C)	47.0	48.0	49.0	49.5	–
Consistency at 60 °C – mould B (Pa s)	178	187	222	244	–
Consistency 6% at 60 °C – mould B (Pa s)	165	172	203	227	–
Stiffness at 25 °C (kPa)	12	–	–	23	–
Stiffness at 15 °C (kPa)	150	–	–	> 187[2]	–
Viscosity at 60 °C (Pa s)	170	174	232	234	140–200
Penetration at 25 °C (0.1 mm)	71	–	–	57	62 min.

1 Standards Australia AS 2008-2013.

Austroads 2014, '*Technical report ap-t271-14: Effects of Hot Storage on Polymer Modified Binder Properties and Field Performance*', Sydney, Austroads Pty Ltd

Ageing of class 170 small samples at 163°C.

Time	Control Sample		
	Visc60	Visc135	Pen25
0 hours	167	0.510	72
5 hours	176	0.370	62
24 hours	189	0.510	55
3 days	226	0.410	49
8 days	343	0.500	23
15 days	762	0.633	12
19 days	958	0.833	9
26 days	1302	1.250	8

Emery, S, O'Connell, J & White, L 2004, '*Monitoring bitumen quality from refinery to pavement*'

Literature review – Class 170 binder for foamed bitumen

Technical Guideline 2 (TG2 South Africa)
Indicates that bitumen should never be heated above 195°C. The normal bitumen temperature for foaming is recommended at 175°C and must always be above 160°C to provide sufficient heat energy for the water to change state and create foam.

Asphalt Academy 2009, 'A guideline for the design and construction of bitumen emulsion and foamed bitumen stabilised materials', (TG2).

Unlike the NZ specification, the South African TG2 fails to adequately address a maximum storage duration for the bitumen binder at elevated temperatures.

Foamed bitumen temperature limits for storage and application of bitumen in NZ.

Material	Maximum storage temperature (°C)		Application temperature (°C) (within 2 hours of use)	
	>24 hours	<24 hours	Minimum	Maximum
80/100 Pen grade	125	175	175	190

Transit New Zealand 2008, 'Specification for in-situ stabilisation of modified pavement layers', (TNZ B/5)

Literature review – foaming properties

Comparison of foamed bitumen specification foaming properties.

Elements		Austroads specification	South African specification (TG2 2009)	TMR specification	New Zealand specification
Foaming properties	Expansion rate	≥ 15	8 - 12	≥ 10	≥ 10
	Half time (seconds)	30-45	≥ 6	≥ 20	6

Hard bitumen should be avoided due to the poor quality of foam produced, which leads to insufficient dispersion of binder in the FBS mixture.

Wirtgen GmbH 2012, '*Wirtgen cold recycling technology*', Wirtgen Group, Windhagen, Germany.

Jenkins theoretical explanation into the physics of bitumen foamability, the energy transfer when using a stiffer binder reduces the explosive expansion from the generation of steam, effecting surface tension of the bitumen film.

Jenkins, K, Van de Ven, M & De Groot, J 1999, '*Characterisation of foamed bitumen*'

Literature review – foamed bitumen performance

?

Research gap identified that warranted the investigation into the:

Effects of '*hot storage and duration*' on class 170 binder properties and foamed bitumen stabilisation performance.

Thesis testing strategy

Thesis investigation split into two parts

1. Hot Storage: 185°C, 200°C, 210°C, 220°C

2. Duration: @ 185°C 0, 2, 4, 6 and 8 days

Obtain materials for testing → Preparation of samples for laboratory testing → Bitumen oven heating simulations → Test bitumen properties: Viscosity and foamability → Manufacture & compaction of foamed bitumen samples → Test foamed bitumen performance ITRM → Analysis of results: Pavement design modelling software

Materials

Sample	Karreman Quarry Type 2.1 C (Stockpile 180504C)	Sample Position	Chainage	XX.YZE	Direction	A

Input Data	
% Passing 0.075mm	9
% Passing 2.36mm	43
Liquid Limit (W_L)	23.8
Plasticity Index (I_P)	5
Linear Shrinkage (LS)	2.6
D10	0.112
D30	1.091
D60	5.455
Coefficient of Uniformity (Cu)	48.8
Coefficient of Curvature (Cc)	2.0
Weighted Plasticity Index (WPI)	90
Weighted Linear Shrinkage (WLS)	46.8

Particle Size Distribution	
Sieve Size (mm)	% Passing
75	100
53	100
37.5	100
26.5	100
19	100
9.5	73
4.75	57
2.36	43
0.425	18
0.075	9

Composition			
% Coarse Grained	91	% Gravel	63
		% Sand	37
% Fine Grained	9	CL - ML	

PSD Trendline	
$y=ax^b$	
Min Size	0.075
Max Size	9.5
a	27.88
b	0.44
R^2	0.9973

Grading Envelope	Compliance
C	100%

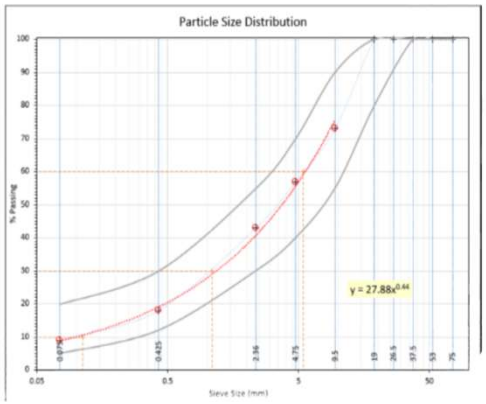
Complies with: C; Modified C; E; Type 1; Type 2 or 3 Subtype 1 or 2; Type 2 or 3 Subtype 3 or 4; Type 2 or 3 Subtype 5

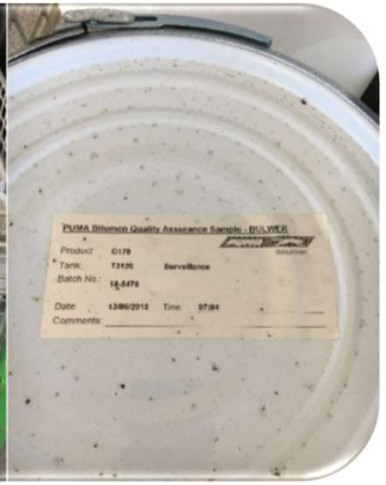
Material Classification	sandy GRAVEL (GP-GM) with silt and clay
Degree of Plasticity	Low Pasticity
Grade of Gravel	Well Graded
Grade of Sand	Well Graded

Note: If classification highlighted in yellow then proceed to determination of grading.

Note: Data input required in green highlighted cells.

Best Fit	Target PSD	Fit Error





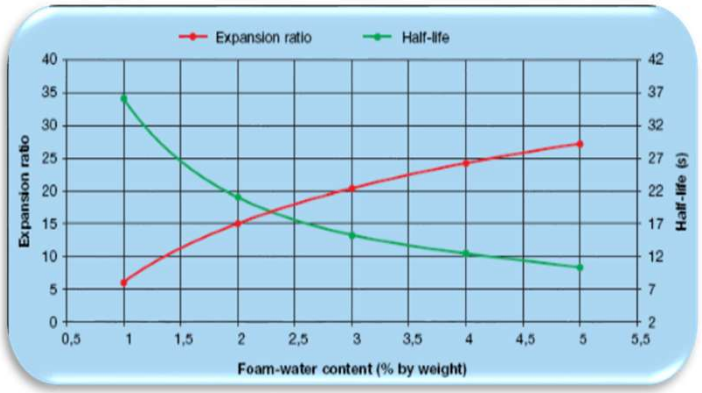
Laboratory bitumen heating, binder properties testing and Foamed bitumen mix performance testing

Bitumen Properties Testing

Bitumen heating regime


Bitumen viscosity


Foaming properties



(Expansion Ratio and Half-life)

Foamed Bitumen testing

Foamed bitumen equipment


Foamed bitumen mix

Compacted specimen


Vacuum saturation (soaked)


Indirect Tensile Resilient Modulus (ITRM)

Damian Volker S268296

Heating simulations – Hot storage: 185°C, 200°C, 210°C, 220°C

1. Hot Storage: 185°C, 200°C, 210°C, 220°C

- Four separate tins
- 8 Litres C170 in a 10L tin (20% air)
- Lids on
- Bitumen was initially heated overnight at 105°C
- Elevated temperature maintained for 1 hour
- C170 cooled to 185°C then transferred to WLB10s kettle for sampling and foaming at 185°C.

Oven heating of Class 170 bitumen simulations - temperatures exceeding maximum specified 190°C (up to 220°C).

Reference 185°C Control sample	Oven heated @ 200 °C and maintain for 1 hour	Oven heated @ 210 °C and maintain for 1 hour	Oven heated @ 220 °C and maintain for 1 hour
Pour into Wirtgen WLB10S kettle and circulated until 185°C	Pour into Wirtgen WLB10S kettle and circulated until 185°C	Pour into Wirtgen WLB10S kettle and circulated until 185°C	Pour into Wirtgen WLB10S kettle and circulated until 185°C
Sample 125ml for viscosity (AS2341.2)	Sample 125ml for viscosity (AS2341.2)	Sample 125ml for viscosity (AS2341.2)	Sample 125ml for viscosity (AS2341.2)
Add 0.5% foaming agent and circulate @ 185°C	Add 0.5% foaming agent and circulate @ 185°C	Add 0.5% foaming agent and circulate @ 185°C	Add 0.5% foaming agent and circulate @ 185°C
Expansion Ratio and Half Life foaming properties test (AGTP301) @ 185°C	Expansion Ratio and Half Life foaming properties test (AGTP301) @ 185°C	Expansion Ratio and Half Life foaming properties test (AGTP301) @ 185°C	Expansion Ratio and Half Life foaming properties test (AGTP301) @ 185°C
Preparation and Compaction of foamed bitumen stabilised material (Q138) tested @ 185°C	Preparation and Compaction of foamed bitumen stabilised material (Q138) tested @ 185°C	Preparation and Compaction of foamed bitumen stabilised material (Q138) tested @ 185°C	Preparation and Compaction of foamed bitumen stabilised material (Q138) tested @ 185°C

Control is the Class 170 binder at 185 °C (0 days)

Heating simulations – Duration: @ 185°C 0, 2, 4, 6 and 8 days

2. Duration: @ 185°C 0, 2, 4, 6 and 8 days

- Four separate tins
- 8 Litres C170 in a 10L tin (20% air)
- Lids on
- Stirred daily
- Sampled and foamed at 185°C.

Oven heating of Class 170 bitumen simulations - temperatures maintained at 185°C for durations of time up to 8 days (2, 4, 6 and 8 days).

Reference 185°C Control sample (same control sample as table 9)	8 Litres C170 oven heated @ 185°C (lid on) and maintained for 2 days	8 Litres C170 oven heated @ 185°C (lid on) and maintained for 4 days	8 Litres C170 oven heated @ 185°C (lid on) and maintained for 6 days	8 Litres C170 oven heated @ 185°C (lid on) and maintained for 8 days
-	Stir daily	Stir daily	Stir daily	Stir daily
Pour into Wirtgen WLB10S kettle	Pour into Wirtgen WLB10S kettle	Pour into Wirtgen WLB10S kettle	Pour into Wirtgen WLB10S kettle	Pour into Wirtgen WLB10S kettle
Sample 125ml for viscosity (AS2341.2)	Sample 125ml for viscosity (AS2341.2)	Sample 125ml for viscosity (AS2341.2)	Sample 125ml for viscosity (AS2341.2)	Sample 125ml for viscosity (AS2341.2)
Circulate in Wirtgen WLB10S kettle until 185°C	Circulate in Wirtgen WLB10S kettle until 185°C	Circulate in Wirtgen WLB10S kettle until 185°C	Circulate in Wirtgen WLB10S kettle until 185°C	Circulate in Wirtgen WLB10S kettle until 185°C
Add 0.5% foaming agent and circulate	Add 0.5% foaming agent and circulate	Add 0.5% foaming agent and circulate	Add 0.5% foaming agent and circulate	Add 0.5% foaming agent and circulate
Expansion Ratio and Half Life foaming properties test (AGTP301) @ 185°C	Expansion Ratio and Half Life foaming properties test (AGTP301) @ 185°C	Expansion Ratio and Half Life foaming properties test (AGTP301) @ 185°C	Expansion Ratio and Half Life foaming properties test (AGTP301) @ 185°C	Expansion Ratio and Half Life foaming properties test (AGTP301) @ 185°C
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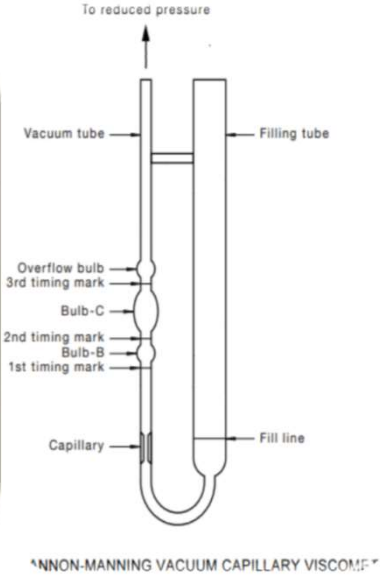
Control is the Class 170 binder at 185 °C at 0 days.

Testing - bitumen viscosity (AS 2341.2)



Bitumen viscosity limits at 60°C between 140 Pa.s and 200 Pa.s (MRTS17 2017).

Property	Test Method	Unit	Class 170	
			Min	Max
Viscosity at 60°C	Q330 or AS 2341.2	Pa.s	140	200

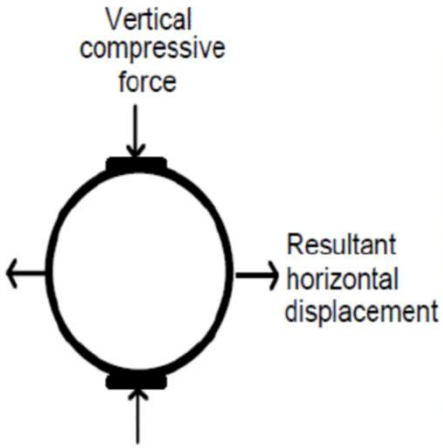
Testing - foaming properties (AGPT301)

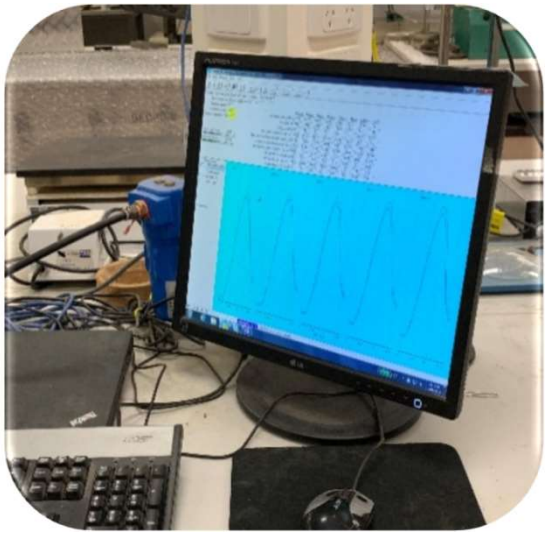
Manufacture of 8 foamed bitumen mix designs – (Q138)

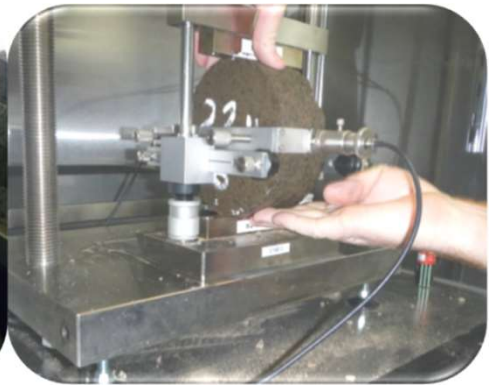
- Karreman Quarry type 2.1 gravel
- 3% Bitumen
- 2% Hydrated lime
  - Available lime index 94.5%
- 0.5% foaming agent
- Target 70% of OMC (Optimum Moisture Content)
- Foaming water 12 litres per hour (3.3%)

Compaction and curing of the 8 mix designs – (Q138)

Testing - Indirect tensile resilient modulus – (Q139)



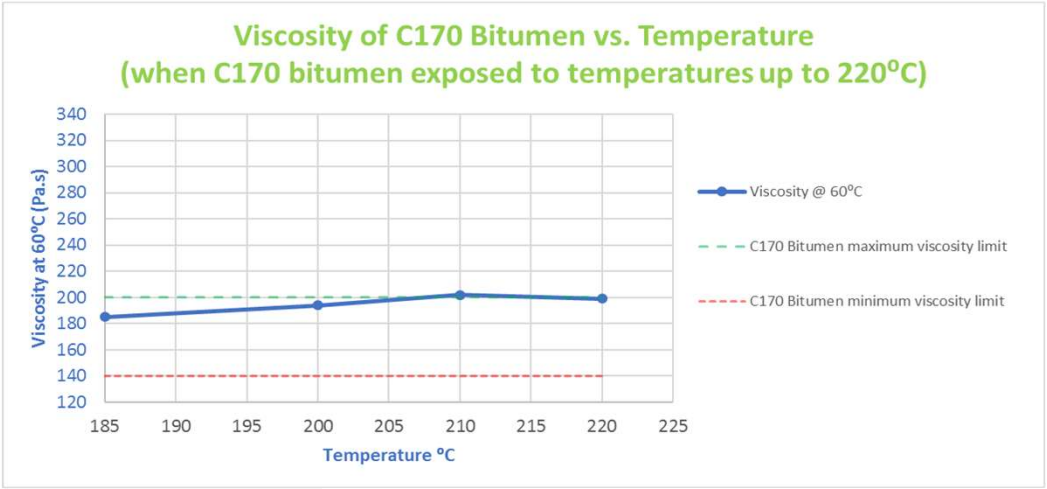


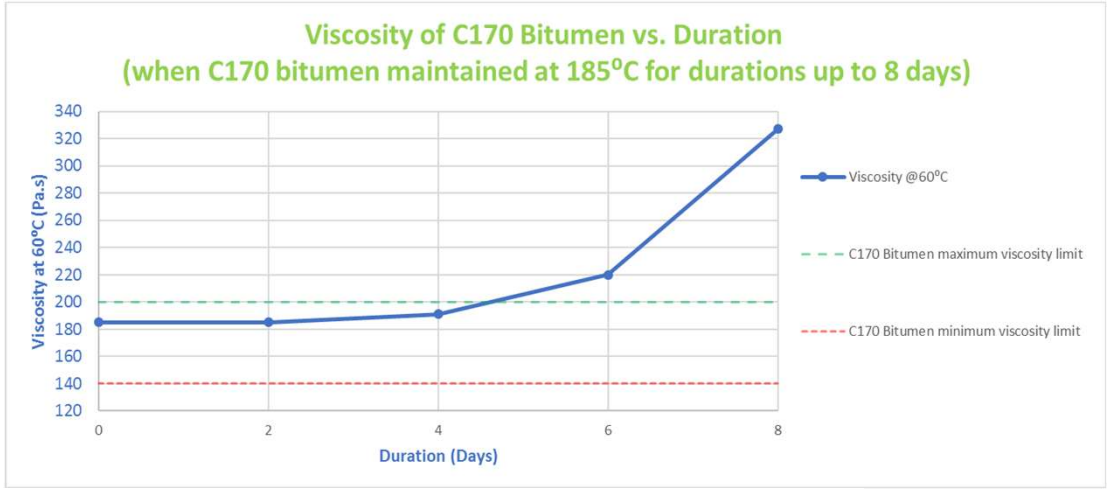


Summary of test results

Article Number	BS18/186 A	BS18/186 B	BS18/186 C	BS18/186 D	BS18/186 E	BS18/186 F	BS18/186 G	BS18/186 H
Bitumen Heating Test Parameters	Reference 185 °C (Control)	Heated 200 °C for 1 hour, Foamed at 185 °C	Heated 210 °C for 1 hour, Foamed at 185 °C	Heated 220 °C for 1 hour, Foamed at 185 °C	Maintain @ 185 °C for 2 days, Foamed at 185 °C	Maintain @ 185 °C for 4 days, Foamed at 185 °C	Maintain @ 185 °C for 6 days, Foamed at 185 °C	Maintain @ 185 °C for 8 days, Foamed at 185 °C
Q142A - MDR	2.191 t/m³ @ 8.1 %							
AS4489.6.1 - Lime Index	94.50 %							
C170 Bitumen	3 %							
Hydrated Lime	2 %							
Q139 – 3-day cured (Dry) (MPa)	3633	3510	3336	3052	3555	3217	3372	2781
	3460	3552	3427	3194	3590	3191	3230	2517
	3232	3544	3408	3274	3869	3414	3586	2525
	-	3679	3376	3208	3692	3400	3255	3020
Average	3442	**3571**	**3387**	**3182**	**3677**	**3306**	**3361**	**2711**
Q139 – Soaked after 3-day cured (MPa)	1903	1675	1648	1471	2135	1595	1651	1314
	1920	1692	1801	1496	1695	1660	1587	1464
	1915	1676	1703	1551	2207	1458	1712	1346
	-	1747	1673	1518	2275	1637	1634	1630
Average	1913	**1698**	**1706**	**1509**	**2206**	**1588**	**1646**	**1439**
Retained Modulus (%)	52	48	49	48	60	50	49	47
	55	48	53	47	47	52	49	58
	59	47	50	47	57	43	48	53
	-	47	50	47	62	48	50	54
Average	56	**48**	**50**	**47**	**60**	**48**	**49**	**53**
Q147B - Compacted Dry Density (t/m³)	2.23	2.23	2.22	2.22	2.24	2.23	2.24	2.23
	2.24	2.23	2.23	2.24	2.23	2.23	2.23	2.23
	2.24	2.22	2.22	2.24	2.23	2.23	2.24	2.22
	-	2.23	2.22	2.23	2.24	2.24	2.24	2.22
Average	2.24	**2.23**	**2.22**	**2.23**	**2.24**	**2.23**	**2.24**	**2.23**
(%) Target moisture ratio	70	70	70	70	70	70	70	70
Moisture ratio achieved (%)	69.1	67.9	69.1	67.9	69.1	65.4	67.9	67.9
Expansion Ratio Checks - PUMA Bitumen C170								
Target Water Content %	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
Interfoam (%)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Water (l/h)	12	12	12	12	12	12	12	12
Expansion (mm)	86	76	87	82	80	78	82	110
Half Life (s)	74	51	26	48	55	50	22	10
Expansion Ratio	11	10	11	10	10	10	10	14
Viscosity Checks - PUMA C170								
Article #	BS18/221-5	BS18/221-8	BS18/221-10	BS18/221-6	BS18/221-3	BS18/221-9	BS18/221-4	BS18/221-7
AS2341.2 - Viscosity (Pa.s)	185	194	202	199	185	191	220	327

Laboratory test results – viscosity (at 60°C)

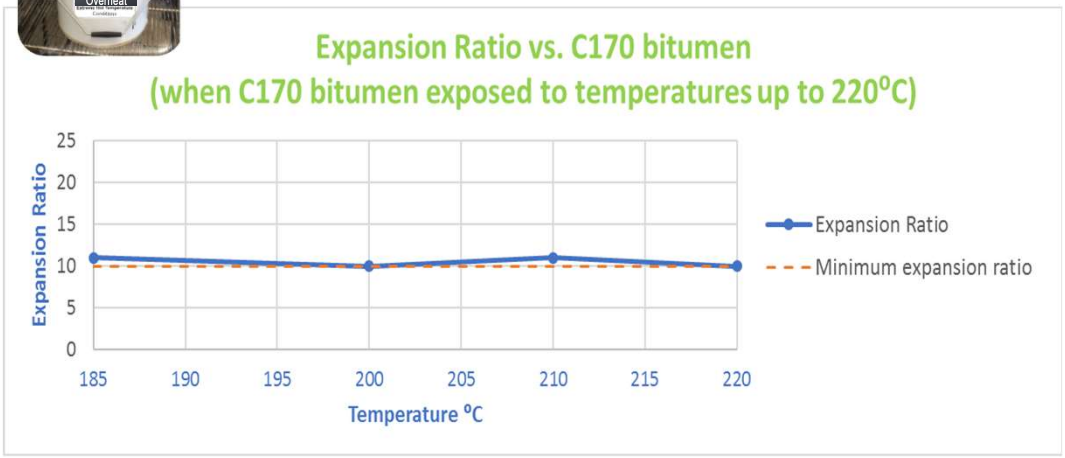


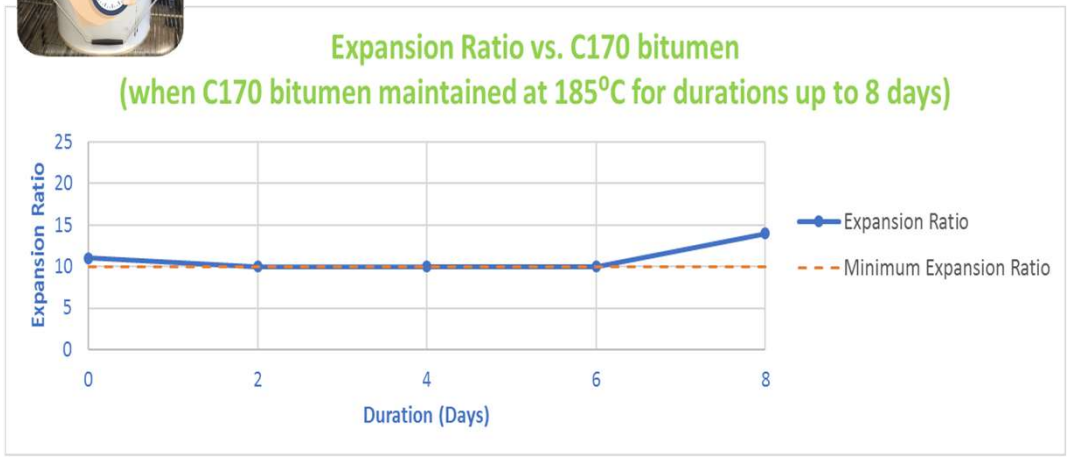


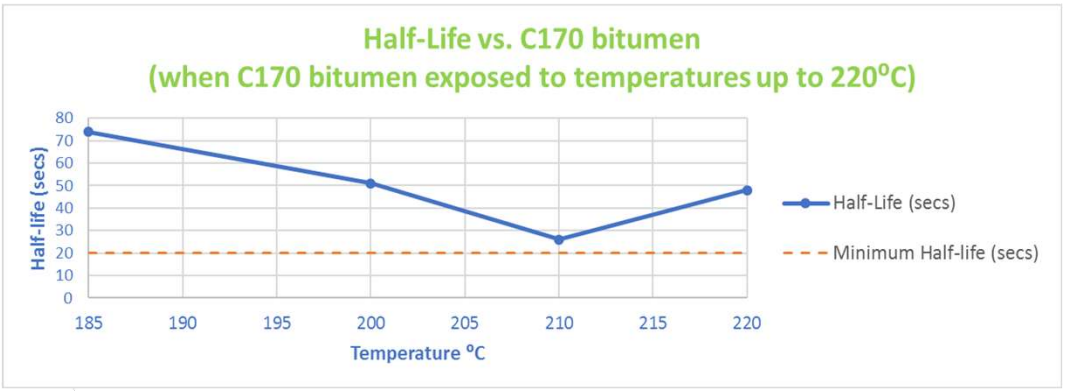
Bitumen viscosity limits at 60°C between 140 Pa.s and 200 Pa.s (MRTS17 2017).

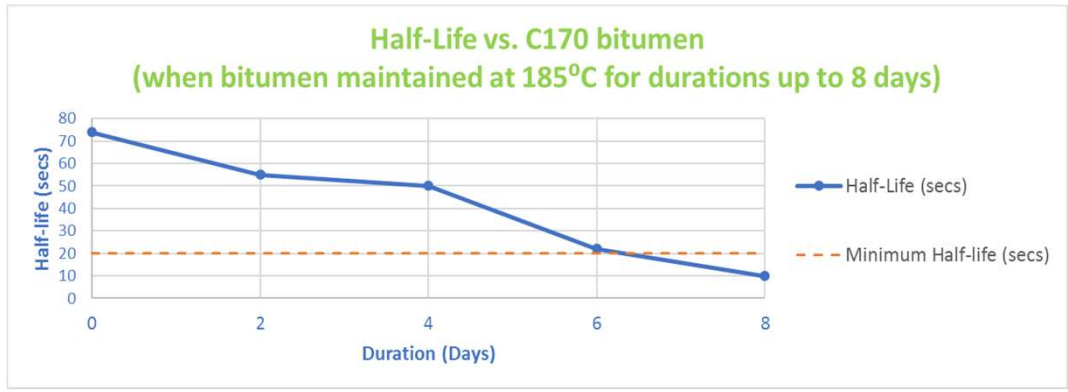
Property	Test Method	Unit	Class 170	
			Min	Max
Viscosity at 60°C	Q330 or AS 2341.2	Pa.s	140	200

Laboratory test results – foaming properties

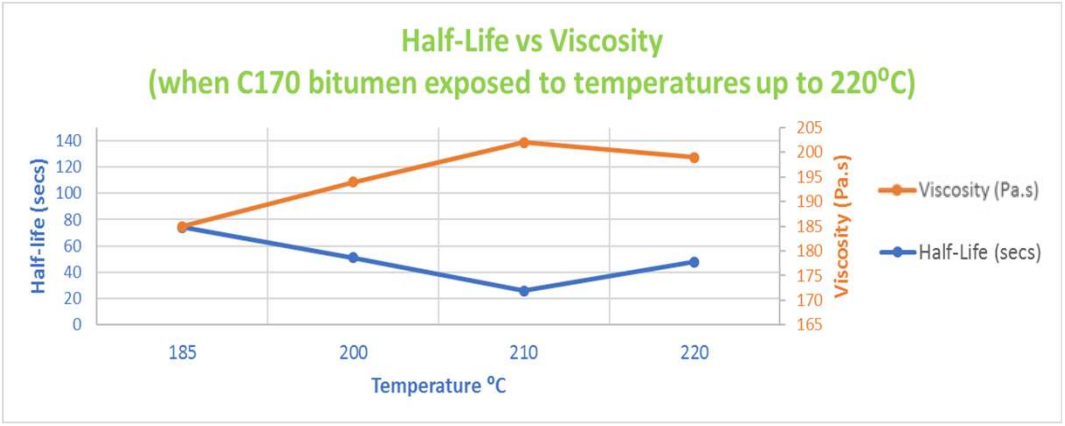


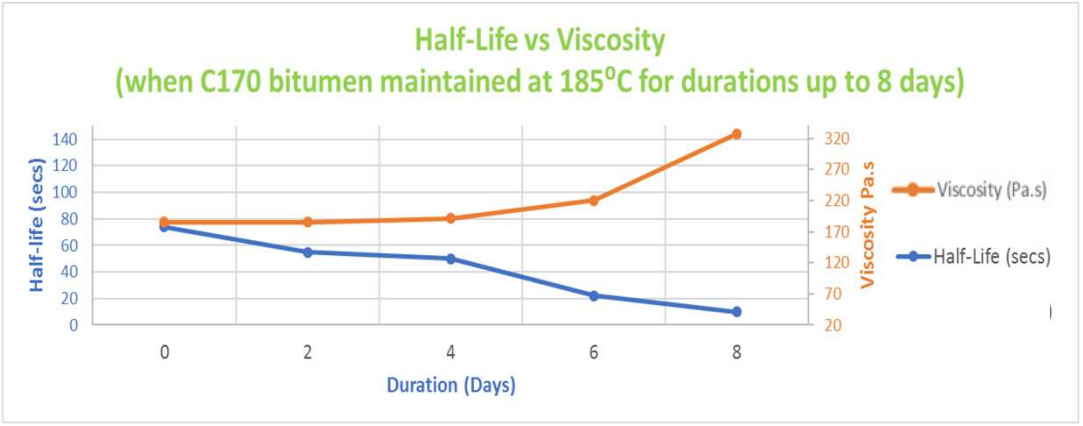




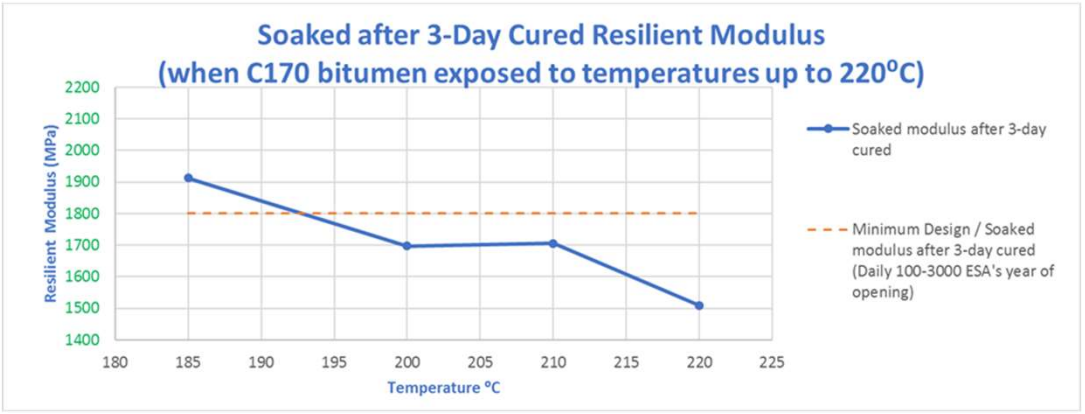


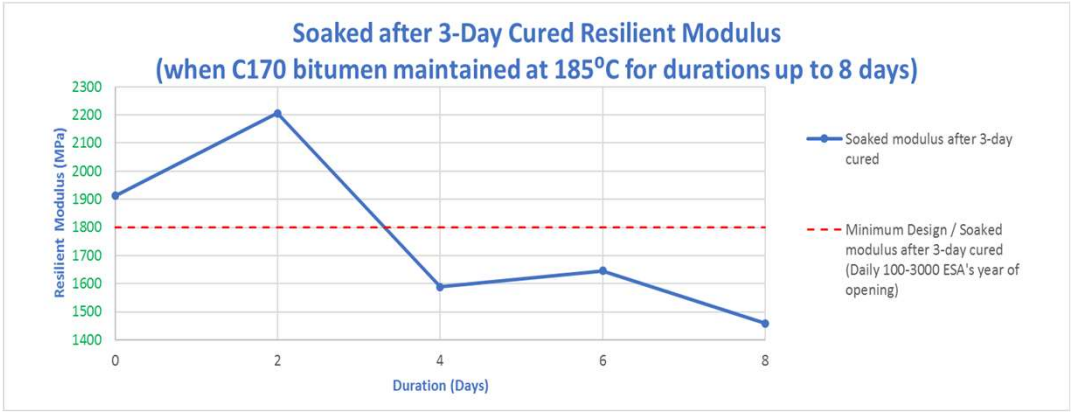
Laboratory test results – viscosity vs half-life





Laboratory test results – Viscosity vs Soaked after 3-day cured modulus



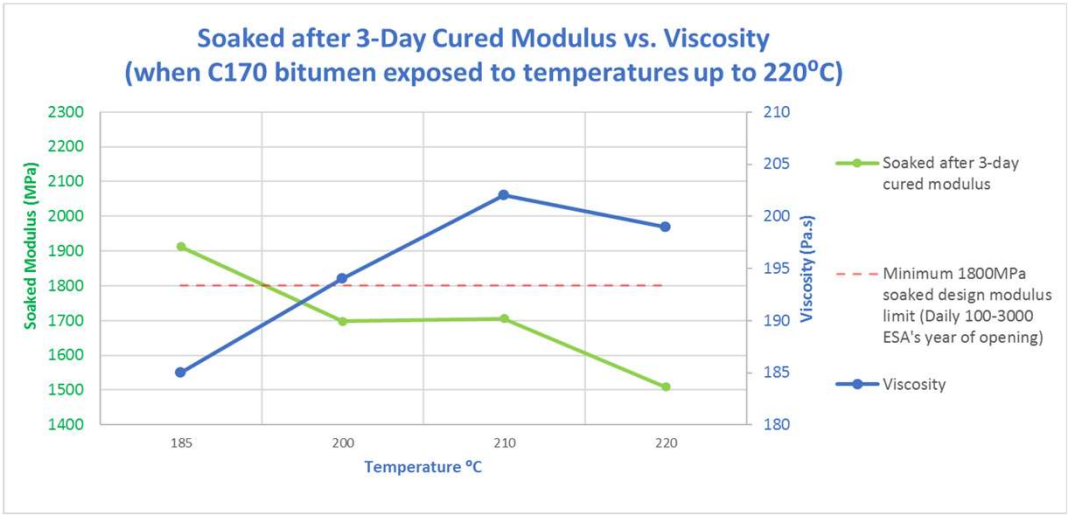


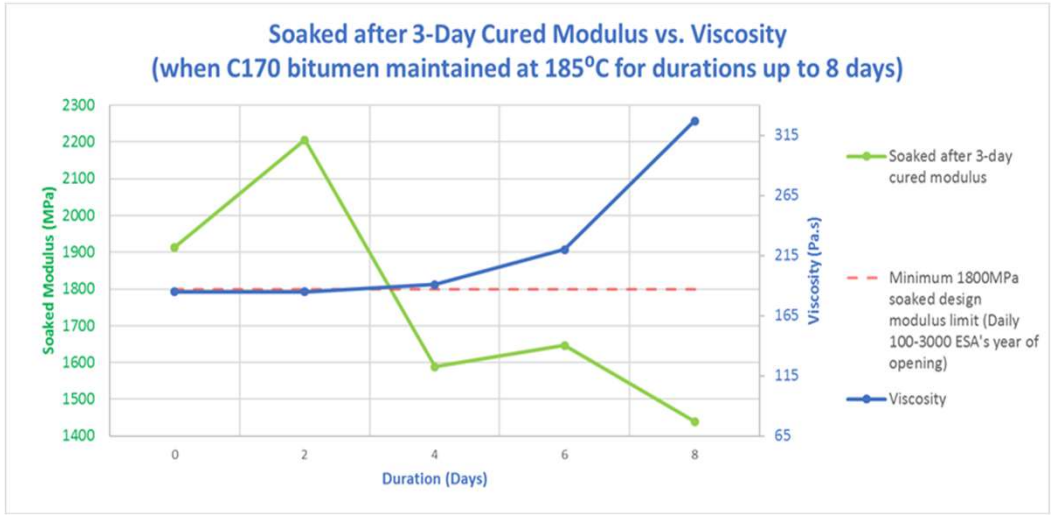
Cured resilient modulus mix design limits for foamed bitumen stabilised materials.

Average daily ESA in design year of opening	Minimum '3-days cured' modulus (MPa)	Minimum 'soaked after 3-days cured' modulus (MPa)	Minimum retained modulus[1]
< 100	2500	1500	0.4
100 to ≤ 3000	3000	1800	0.45
> 3000	4000	2000	0.5

Note [1]: Retained modulus ratio = 'soaked after cured' modulus divided by the 'cured' modulus.

Laboratory test results – Viscosity vs Soaked after 3-day cured modulus





Foamed bitumen stabilised pavement 'Flexural Modulus' [E_f] = 'Soaked after 3-day cured Indirect Tensile Resilient Modulus' (MPa)

$E_f = ITRM_{soaked\ after\ 3\text{-}day\ cured}$

Analysis approach - effect on pavement life

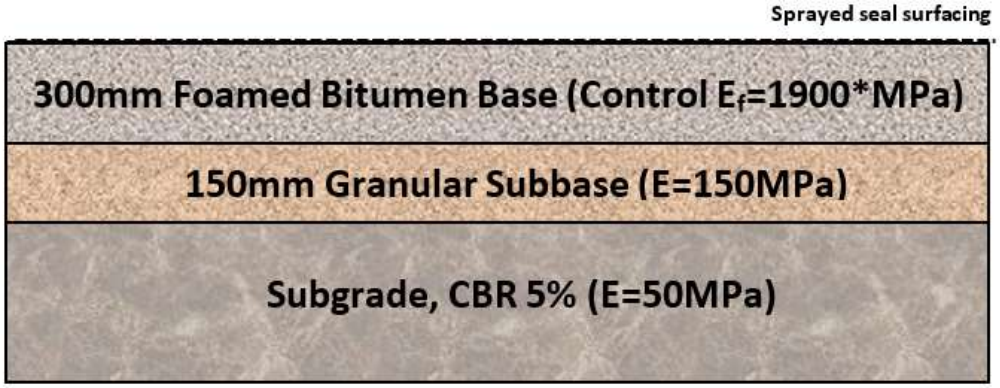
- Reduction in pavement design life (in years)
- Required layer thickness compensation to meet design life (in mm), and
- Additional costs of FBS material for layer thickness compensation:
    - IFBS (in $\$/m^2$)
    - PMFBS (in $\$/m^3$)

Effect on pavement life – Traffic and pavement configuration

Summary of results for design traffic periods and Daily ESA for design year of opening.

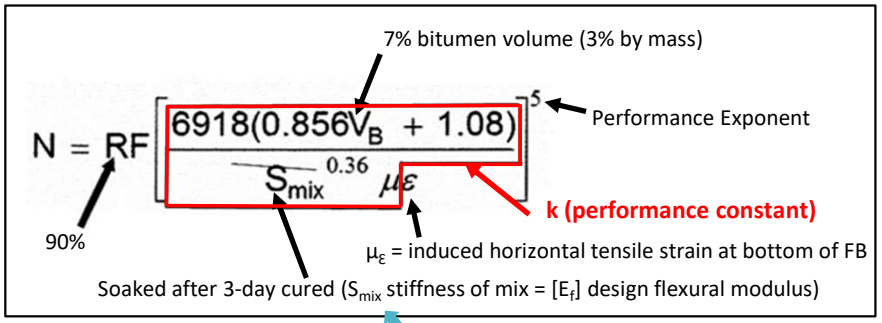
	10 years	20 years	30 years	40 years	Damage Index	Value
N_{DT}	2.45E+06	5.75E+06	1.02E+07	1.61E+07	N_{HVAG}	2.800
DESA	2.21E+06	**5.18E+06**	9.17E+06	1.45E+07	ESA/HVAG	0.900
DSAR5	2.43E+06	5.70E+06	1.01E+07	1.60E+07	ESA/HV	2.500
DSAR7	3.54E+06	8.29E+06	1.47E+07	2.33E+07	SAR5/ESA	1.100
DSAR12	2.65E+07	6.21E+07	1.10E+08	1.74E+08	SAR7/ESA	1.600
Daily ESA in design lane at opening				528	SAR12/ESA	12.000

Where
N_{DT} = Cumulative number of heavy vehicle axle groups over the design period
DESA = Design Equivalent Standard Axles (Design Traffic)
DSAR5 = Design Standard Axle Repetitions (fatigue of asphalt)
DSAR7 = Design Standard Axle Repetitions (rutting and shape loss)
DSAR12 = Design Standard Axle Repetitions (fatigue of cemented materials)
N_{HVAG} = Average number of axle groups per heavy vehicle
HVAG = Heavy Vehicle Axle Groups
ESA = Equivalent Standard Axle
HV = Heavy vehicle



Layer configuration for pavement design life analysis.

Structural pavement design inputs for foamed bitumen



(1900MPa)

Pavement design modelling software (CIRCLY 6.0) was used to analyse all the modulus test results data to assess the impacts on pavement life.

Test Results

Sample ID	Resilient Modulus (Mpa)			Retained Modulus (%)
	Initial	3 day cured	3 day soaked	3 day
BIL18W-0133-S01	448	3633	1903	52
	470	3460	1920	55
	393	3232	1915	59
Average	**437**	**3442**	**1913**	**56**
Date tested	27/08/2018	30/08/2018		

E_f = soaked modulus from Q139 test results

Cured modulus mix design limits for foamed bitumen stabilised materials

Average daily ESA in design year of opening	Minimum '3-days cured' modulus (MPa)	Minimum 'soaked after 3-days cured' modulus (MPa)	Minimum retained modulus[1]
< 100	2500	1500	0.4
100 to ≤ 3000	3000	1800	0.45
> 3000	4000	2000	0.5

Note [1]: Retained modulus ratio = 'soaked after cured' modulus divided by the 'cured' modulus.

Effect on pavement life – Adopted design moduli and inputs

Summary of temperatures for 'hot storage' and 'duration' vs. 'Soaked after 3-day cured' modulus values for pavement life analysis.

Parameter	Temperature	Duration	Mean 'Soaked after 3-Day Cured' Design Modulus (MPa)	Adopted design flexural modulus [E_f] for the pavement life analysis (MPa)
Hot storage	*185 °C (Control*)*	*1 hour*	*1913*	***1900 (Benchmark)***
	200 °C	1 hour	1698	**1700**
	210 °C	1 hour	1706	**1700**
	220 °C	1 hour	1509	**1500**
Duration	*185 °C*	*1 hour (Control*)*	*1913*	***1900 (Benchmark)***
	185 °C	2 days	2206	**2200**
	185 °C	4 days	1588	**1600**
	185 °C	6 days	1646	**1650**
	185 °C	8 days	1439	**1450**

***Same sample represented twice (control).**

CIRCLY inputs: k Factors, Poisson Ratio, Performance Exponent, Pavement Temperature and Traffic Multipliers.

Binder Volume (%)	Adopted Foamed Bitumen Design Moduli (MPa)	*k Factors for CIRCLY Inputs	Poisson's Ratio	Performance Exponent	WMAPT (°C)	Traffic multiplier Asphalt / FB	Traffic multiplier Subgrade
7	1450	0.003560	0.40	5.00	32.0	1.1	1.6
7	1500	0.003517	0.40	5.00	32.0	1.1	1.6
7	1600	0.003436	0.40	5.00	32.0	1.1	1.6
7	1650	0.003398	0.40	5.00	32.0	1.1	1.6
7	1700	0.003362	0.40	5.00	32.0	1.1	1.6
7	1900	0.003230	0.40	5.00	32.0	1.1	1.6
7	2200	0.003064	0.40	5.00	32.0	1.1	1.6

****k factors calculated from volume of bitumen (V_B) and adopted FB design moduli (from 'soaked after 3-day cured' test results).***

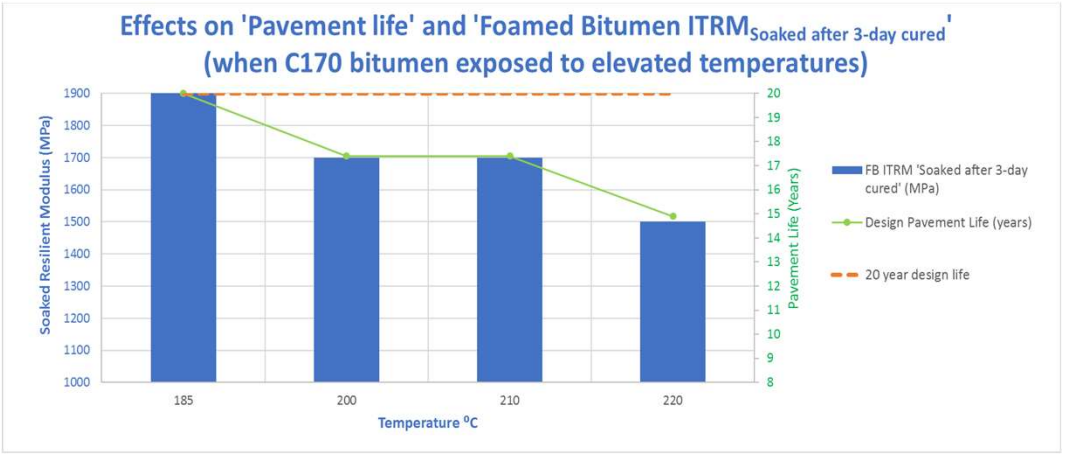
Effect on pavement – Life in years

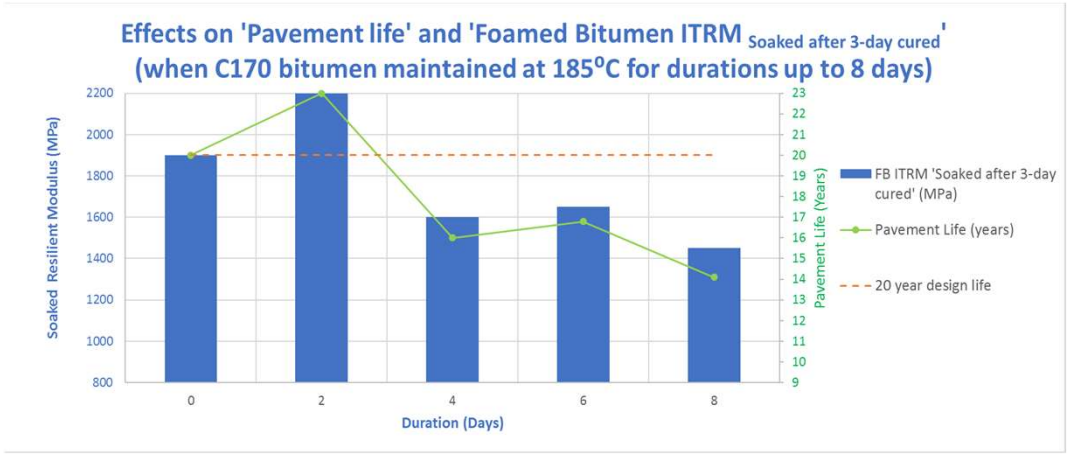
Effects of hot storage and duration on foamed bitumen stabilisation performance (Allowable loading and Pavement life).

Parameter	Temp. (°C)	Duration	Foamed bitumen Thickness (mm)	Design Flexural Modulus [E_f] (MPa)	Cumulative Damage Factor (CDF)	Allowable Loading (DESA)	Pavement life (years)	Effects on pavement life (years)
Hot Storage	***185* (control)***	***1 hour***	***300***	***1900***	***1.93E-07***	***5.18E+06***	***20.0***	***0.0***
	200	1 hour	300	1700	2.32E-07	4.31E+06	17.4	-2.6
	210	1 hour	300	1700	2.32E-07	4.31E+06	17.4	-2.6
	220	1 hour	300	1500	2.85E-07	3.51E+06	14.9	-5.1
Duration	***185***	***1 hour (*control)***	***300***	***1900***	***1.93E-07***	***5.18E+06***	***20.0***	***0.0***
	185	2	300	2200	1.49E-07	6.71E+06	23.2	3.2
	185	4	300	1600	2.57E-07	3.89E+06	16.0	-4.0
	185	6	300	1650	2.44E-07	4.10E+06	16.8	-3.2
	185	8	300	1450	3.01E-07	3.32E+06	14.1	-5.9

***Same sample represented twice (control).**

Effect on pavement life





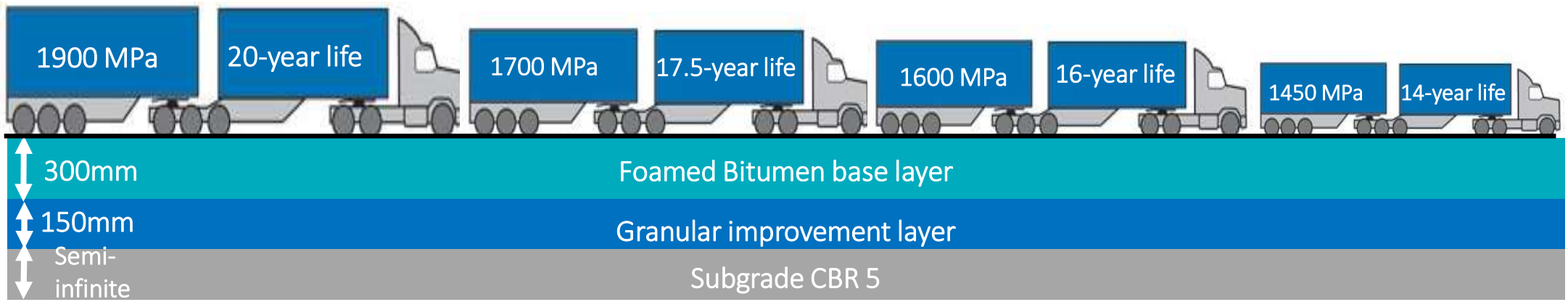
Effect on pavement life – Costs

Cost[#] of layer thickness compensation for structurally inadequate foamed bitumen stabilisation.

Parameter	Temperature (°C)	Duration	Foamed bitumen Thickness (mm)	Design Modulus [E_f] (MPa)	Cumulative Damage Factor (CDF)	Allowable Loading (DESA)	Thickness required to meet 20 year life (mm)	Cost increase per m^2 of insitu foamed bitumen for thickness compensation ($/$m^2$)	Cost increase per m^3 exsitu foamed bturnen for thickness compensation ($/$m^3$)
Hot Storage	185* (control)	1 hour	300	1900	1.93E-07	5.18E+06	300	0.0	0.0
	200	1 hour	300	1700	2.32E-07	4.31E+06	309	1.8	7.5
	210	1 hour	300	1700	2.32E-07	4.31E+06	309	1.8	7.5
	220	1 hour	300	1500	2.85E-07	3.51E+06	317	3.4	14.2
Duration	185	1 hour (*control)	300	1900	1.93E-07	5.18E+06	300	0.0	0.0
	185	2	300	2200	1.49E-07	6.71E+06	290	-2.0	-8.3
	185	4	300	1600	2.57E-07	3.89E+06	312	2.4	10.0
	185	6	300	1650	2.44E-07	4.10E+06	310	2.0	8.3
	185	8	300	1450	3.01E-07	3.32E+06	319	3.8	15.8

Note[#] Foamed bitumen costs were selected from a range of rates provided in the *Stabilisation Practices in Queensland* (ARRB, 2015). $60 per m^2 (insitu - existing road material) and $250 per m^3 (plant mixed – new quarry material) was used for the above assessment.

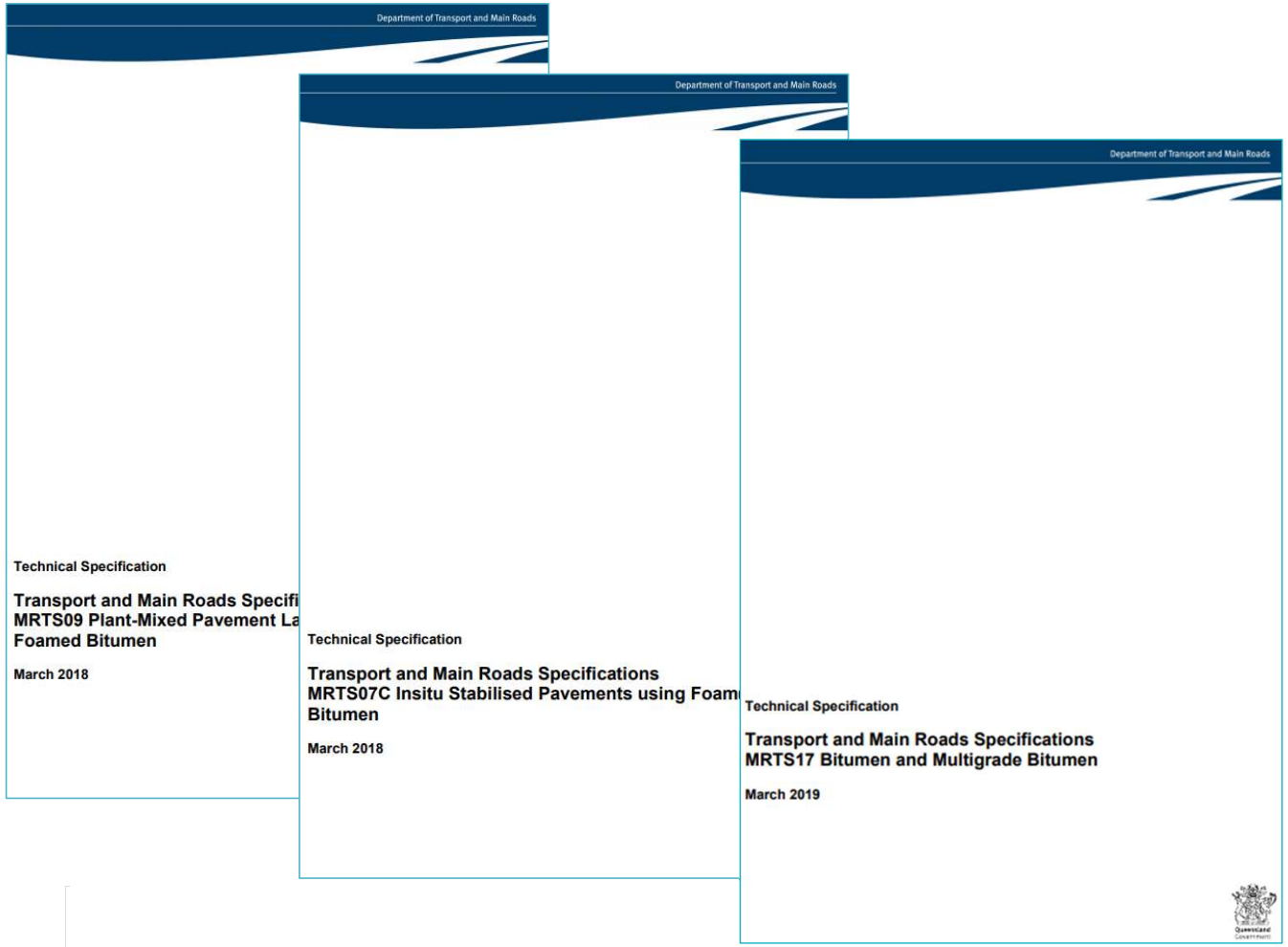
Discussion - Summary



As bitumen '*hot storage*' temperatures and '*durations*' increase, Indirect Tensile Resilient Modulus (in MPa) decrease, and pavement life (in years) significantly declines.

Impacts are up to 30% reduction in pavement life from a 20-year design (14 years instead of 20 years). A 6 year loss of pavement life is not acceptable.

Recommendations



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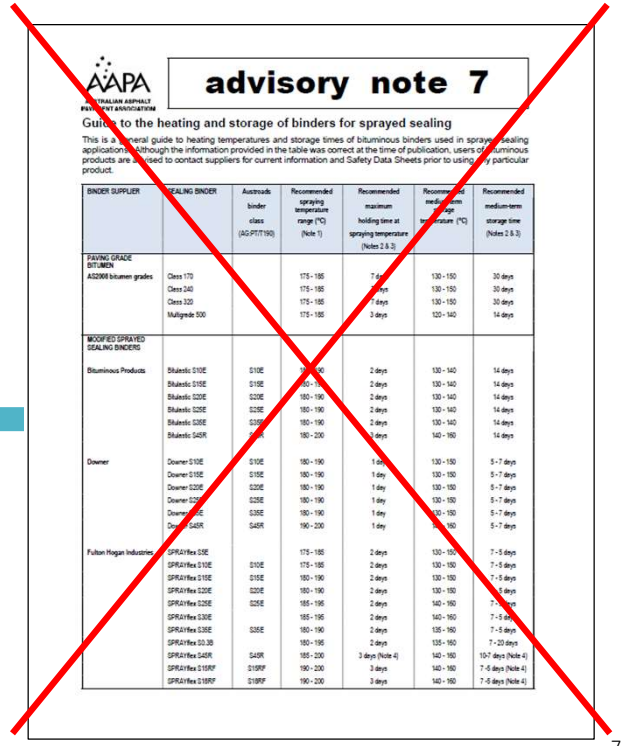
Improvements needed: *Technical specifications, governance, and industry bitumen heating practices.*



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Recommendations adopted by TMR in specifications

Remain Unchanged

The bitumen incorporation shall commence at a temperature between 180ºC and 190ºC. Bitumen temperature shall not fall below 170ºC throughout the bitumen incorporation process.

Adopted

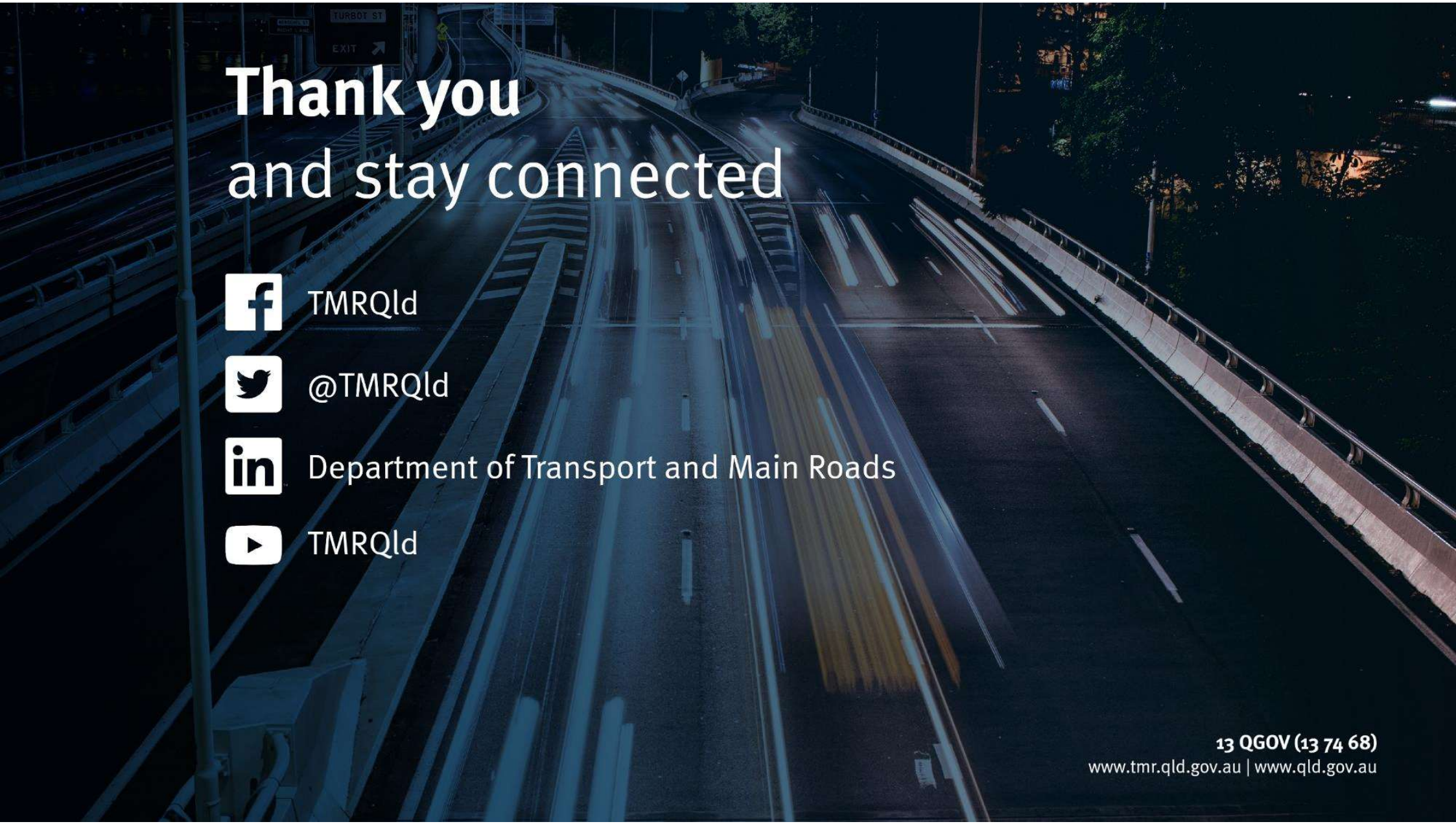
The total time at which the Class 170 bitumen shall be held in the bitumen tanker (or onsite bitumen storage container) at foaming temperature (170ºC to 190ºC refer to Clause 8.8.5), shall be no greater than 72 hours.

Future research, development and implementation considerations

Bulk bitumen tanker leaving refinery (point of release).

Implementation of wireless data loggers in bulk bitumen tankers and auxiliary storage tanks to monitor bitumen temperatures during transport and storage between point of release from the manufacturer until such time the C170 bitumen is incorporated into the foamed bitumen works.

References:
[1]Bitumen tanker Viva Geelong https://www.vivaenergy.com.au/products/bitumen
[2] Roadmap slides https://slidemodel.com/
[3]Wirtgen GmbH 2012, 'Wirtgen cold recycling technology', Wirtgen Group, Windhagen, Germany.
[4]Wirtgen GmbH 2012, 'technology', Wirtgen Group, Windhagen, Germany.
[5]https://www.amazon.com/Ideal-Sciences-Temperature-Monitoring-Historical/dp/B07SG7BPM3
[6]Transport and Main Roads Specifications, 2019 MRTS07C MRTS09 MRTS17
[7]Australian Asphalt Pavement Association 2016, Advisory note 7: Guide to the heating and storage of binders for sprayed sealing.
[8]https://www.amazon.com/Ideal-Sciences-Temperature-Monitoring-Historical/dp/B07SG7BPM3
All other photos, charts and wording produced by author.



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