Design & Optimization of a Rubber-Bitumen Blend in Preparation for a Rubberized-Asphalt Road Trial in the State of Kuwait

KISR
Kuwait Institute for Scientific Research

Dr Salah Zoorob & Eng. Suad K. Al-Bahar
Construction & Building Materials Program

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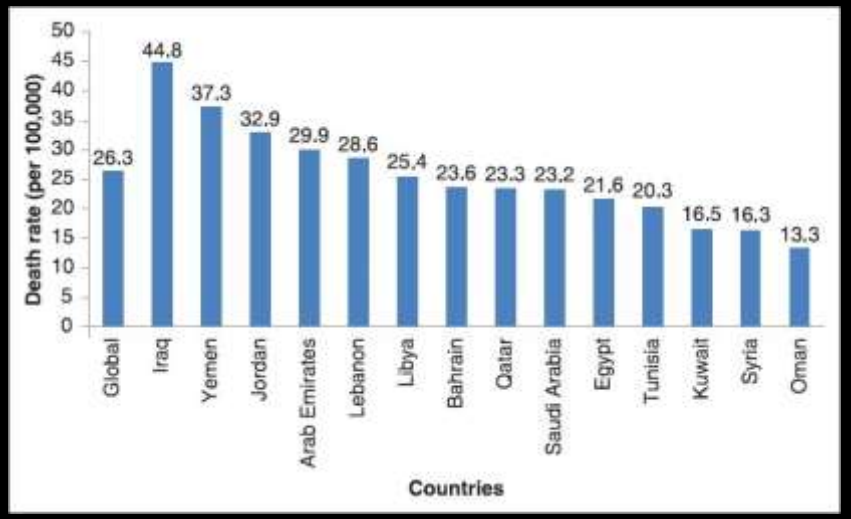
Smart Rehabilitation & Maintenance in Civil Eng. for Sustainable Construction
Solo, Indonesia, July 11-12, 2018

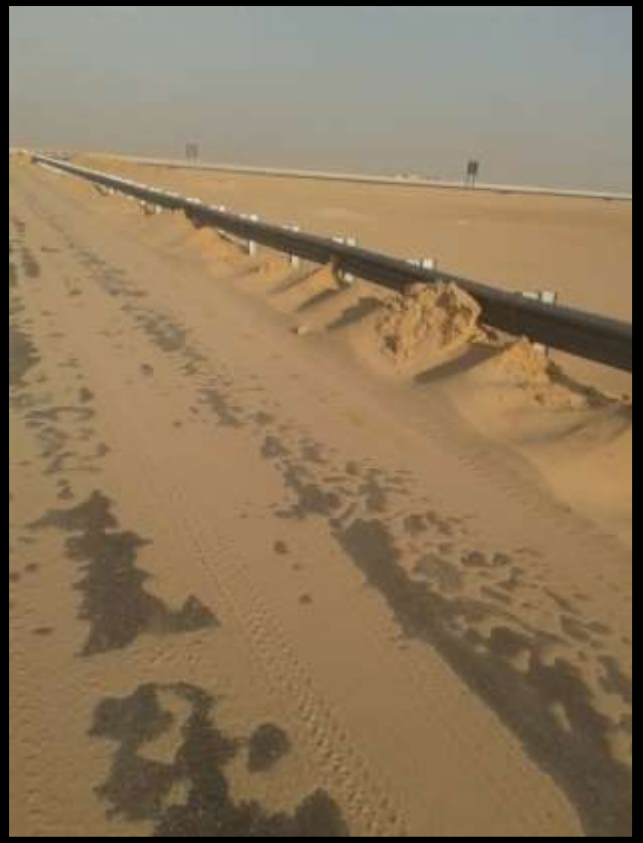
Total Area = 17,818 km^2
Citizens = 1.38 million
Expatriates = 3.19 million

Total Road Length ≈ 7600 km
Road Area ≈ 90 million m^2



World Meterological Organization

21 July 2016, Kuwait set a new record for the Eastern hemisphere & Asia, with a reported temp. of 54.0°C (129.2°F)




منطقة شاليهات
Chalets Area
مدينة الكويت
Kuwait City
6
العبدلي
Abdaly
300 m

- Rutting (ambient temp., binder grade, quality control,
- Cracking (oxidation, weak base, …)
- Fretting (moisture damage, wet agg., compaction, …)

Approx. 28 million whole tyres at “Rehaya”.

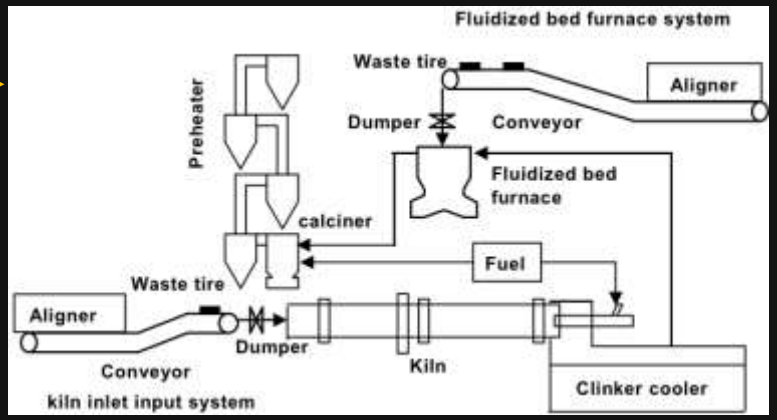
Some of the old pits are 20m deep

Tyres are being cut on site, transported & stored at “Salmi”.
Kuwait also adds between 5000-6000 waste tyres/day.

Uses of Waste Tyres

Large Cuts

Crumb Rubber



Pyrolysis Plant

- 45-50% Fuel Oil
- 10-15% Steel Wire
- 30-35% Carbon Black

Fuel

e.g. cement kiln

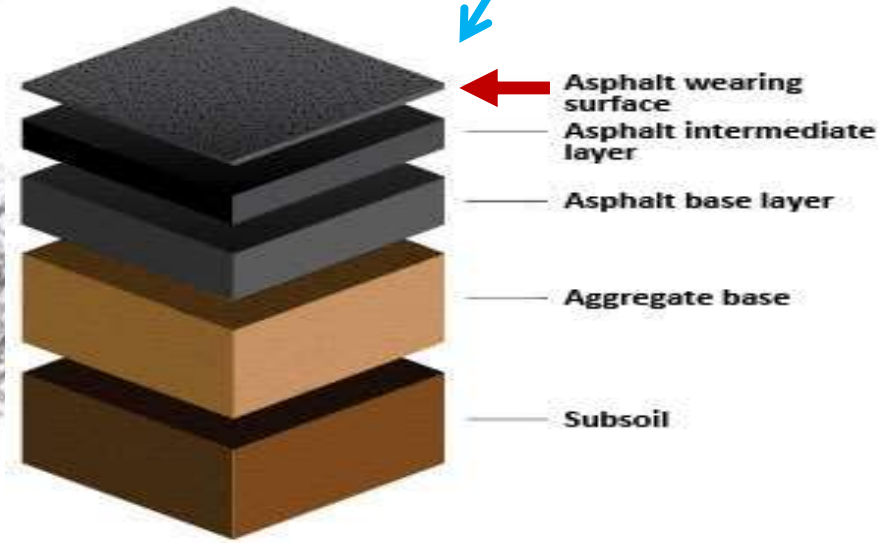

rubber 6 mm


rubber 10 mesh
2.0mm

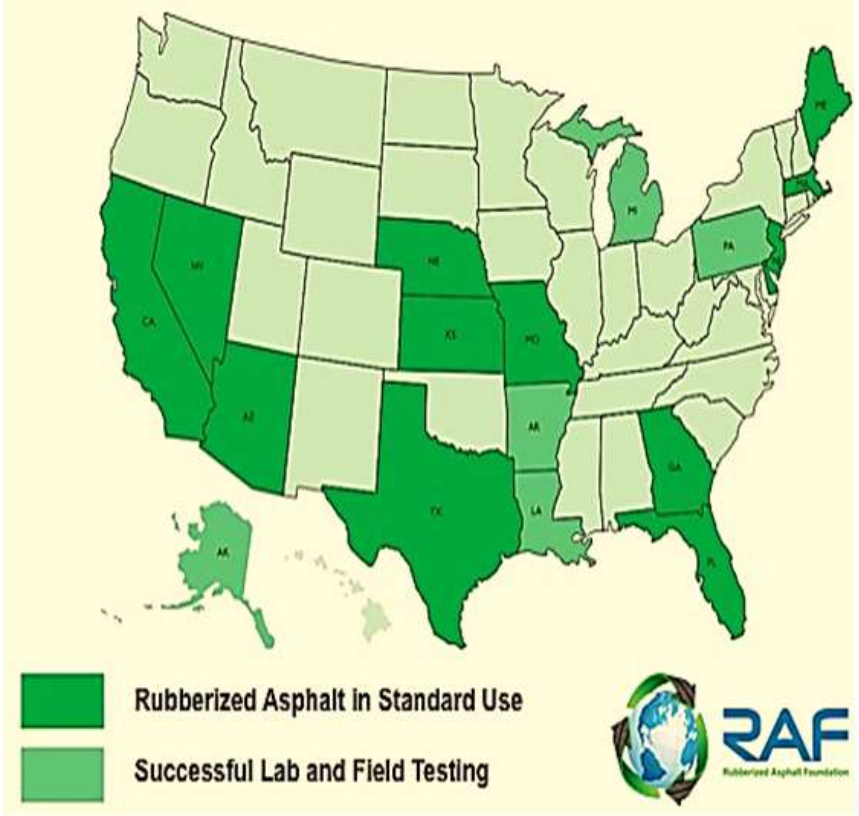

rubber 20 mesh
0.85mm


fiber


steel

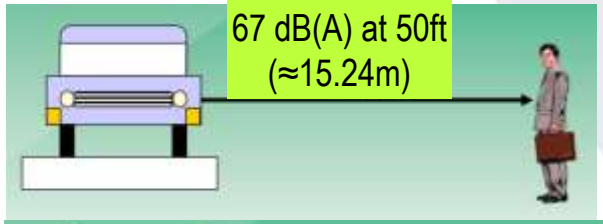

Asphalt wearing surface
Asphalt intermediate layer
Asphalt base layer
Aggregate base
Subsoil


SAKAI

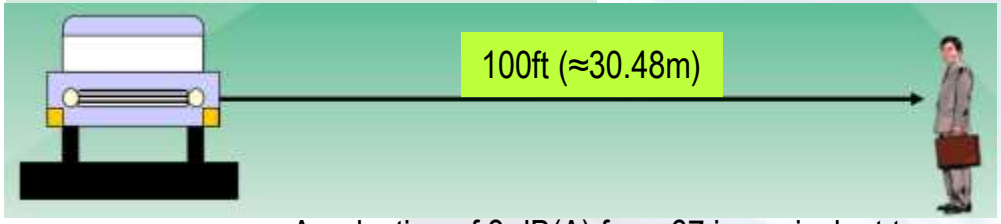


- Rubberized Asphalt is the largest single market for ground rubber in the US, consuming ≈ 12 million tyres annually.
- Typically between 15 & 20% of the normal bitumen may be replaced by crumb rubber.
- 13 DoTs currently implement use of rubberized asphalt (dark green).
- 5 States have performed successful lab & field testing (lighter green).

- Assuming; 1 lane width = 3.75m, wearing course thickness = 5cm, % b.c. = 5%, HMA density = 2.4 ton/m^3.
- For 20% rubber blend, we will require 4.5 tons rubber per 1 km length per 1 lane (i.e. approx. 500 scrap car tyres).



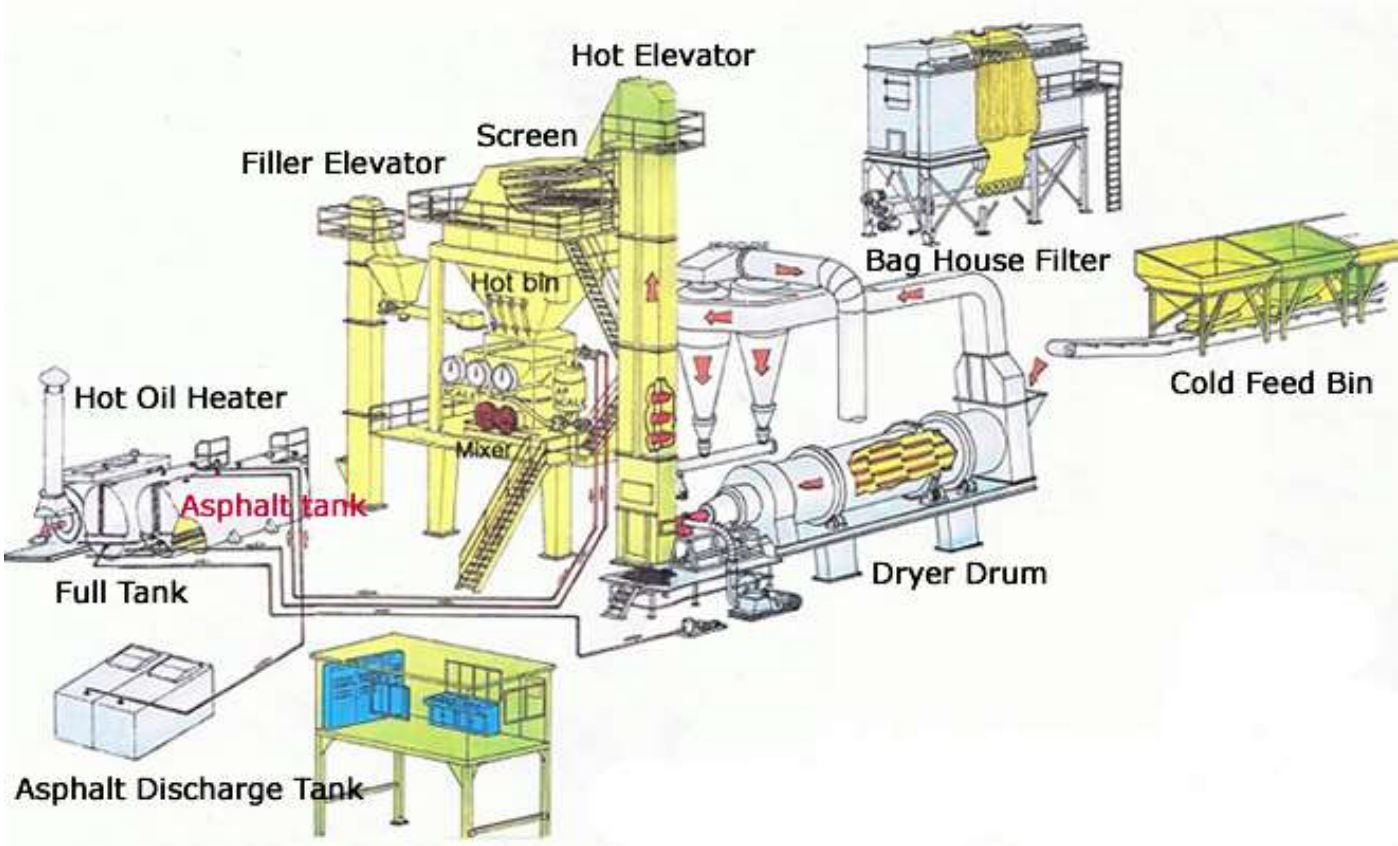
FHWA recommends that 67 dB(A) is the level where noise mitigation must be considered.



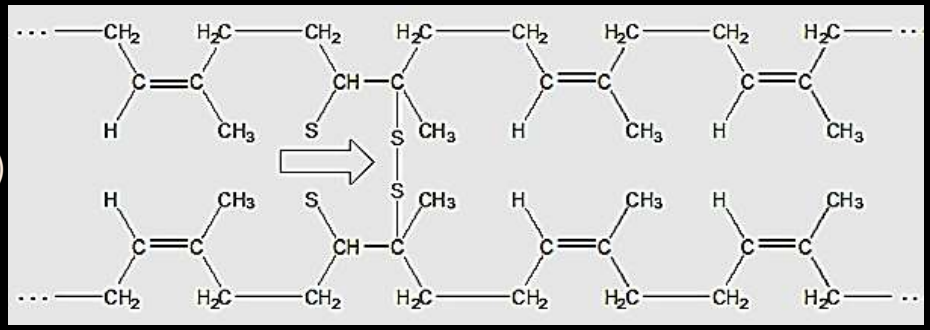
A reduction of 3 dB(A) from 67 is equivalent to:

- Doubling the distance from the noise
- or reducing the traffic volume by 50%
- or reducing traffic speed by 25%

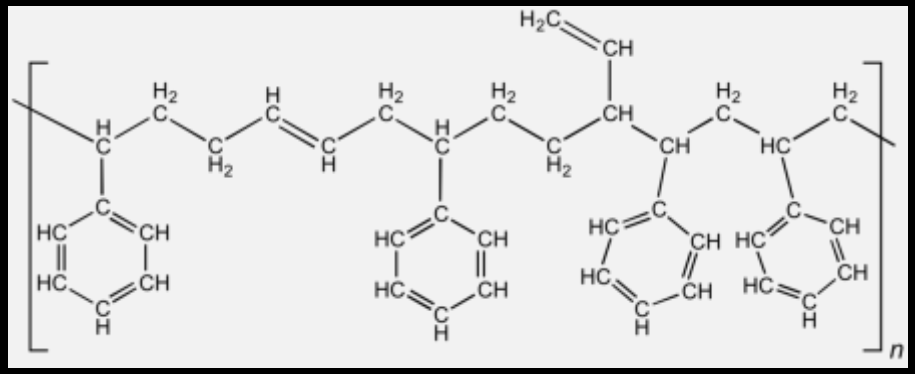
- The **AR150 blending unit** is a portable unit that holds a control house, a crumb rubber hopper, & a series of pumps & augers upto a blending vessel that you pump into.
- The bitumen & crumb rubber are combined in a blending pot at 3500 rpm & immediately pumped into reaction tank.
- The reaction tank, or holding tank, is a second portable unit. It's a 30,000 gallon tank split into 2 halves of 15,000 gallons each. In that tank, the rubber reacts with the virgin bitumen & the mix is held for a specified period of time while it cures.
- The tank is heated & has agitators at the bottom & mid-level so that the material rotates from the bottom to top & then back down the sides in one continuous motion.



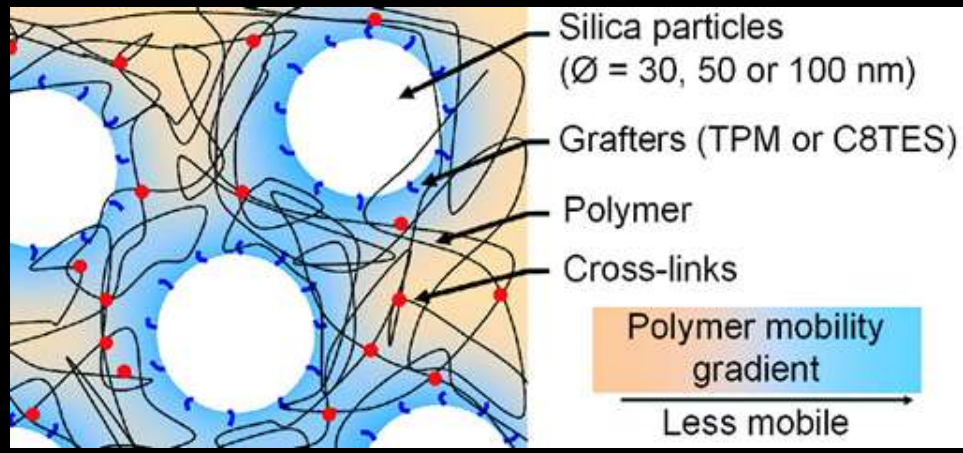
Polyisoprene or
Poly(cis-1,4 isoprene)

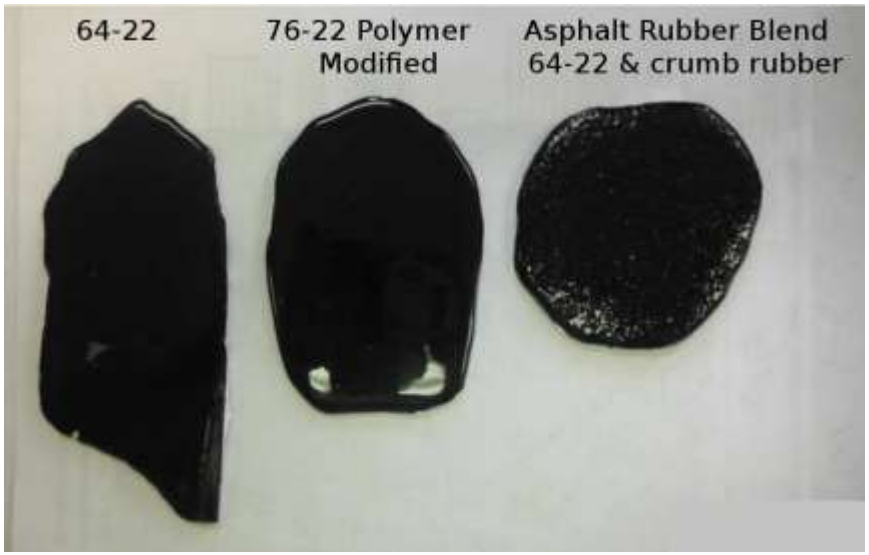


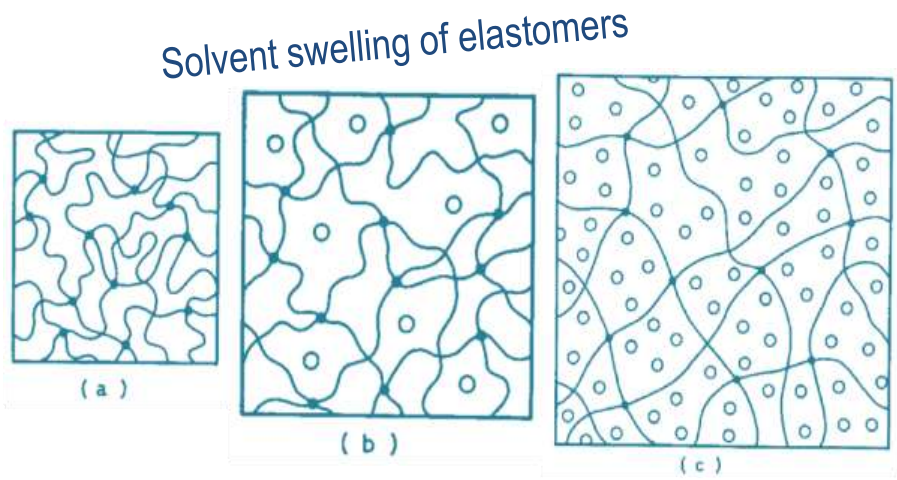
Styrene-Butadiene
Rubber

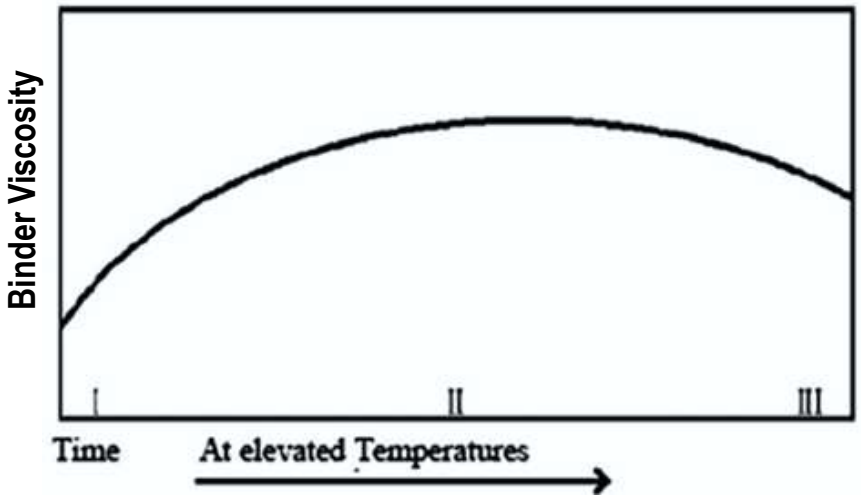


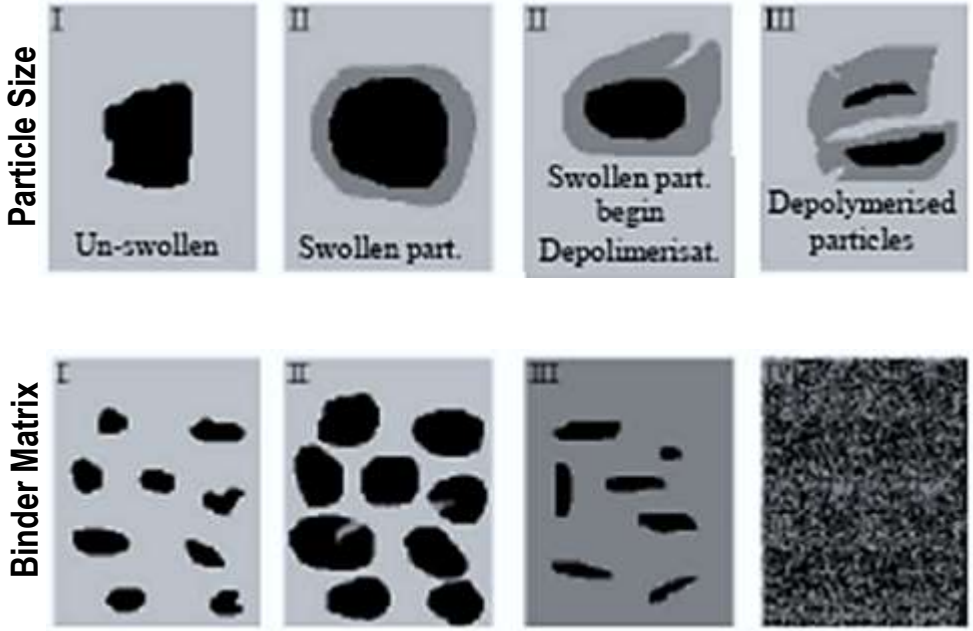
Composition % by mass	Passenger tyre	Truck tyre
Natural Rubber	14 %	27 %
Synthetic rubber	27 %	14 %
Carbon black	28 %	28 %
Steel	14 – 15 %	14-15 %
Fabric, fillers, accelerators, antizonants	16 – 17 %	16-17 %
Average Weight	New 11 kg, Scrap 9 kg	New 54 kg, Scrap 45 kg




64-22
76-22 Polymer Modified
Asphalt Rubber Blend 64-22 & crumb rubber


Solvent swelling of elastomers
(a)
(b)
(c)

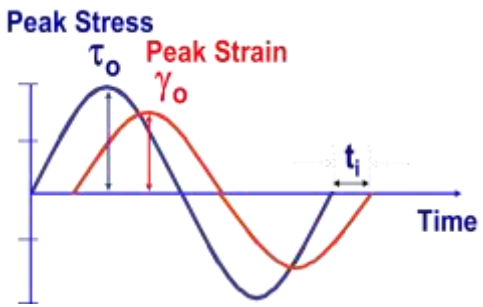

Binder Viscosity
I
II
III
Time
At elevated Temperatures

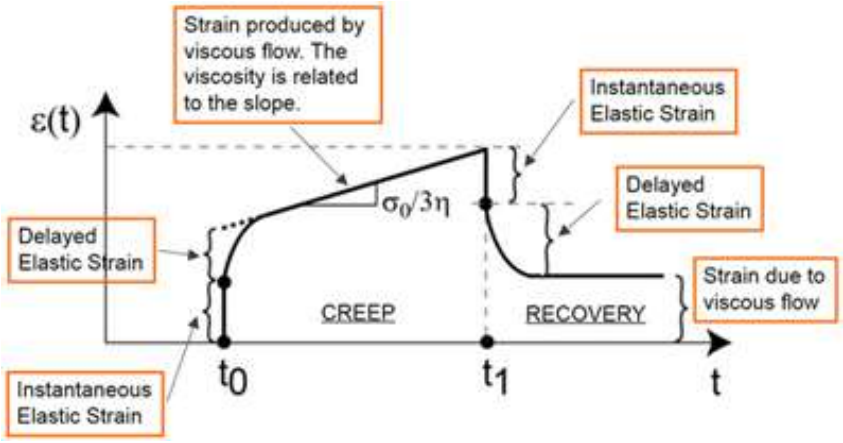

Particle Size
I
Un-swollen
II
Swollen part.
II
Swollen part. begin Depolimerisat.
III
Depolymerised particles
Binder Matrix
I
II
III

Variables Affecting Binder Performance:

- Bitumen grade & chemistry
- Rubber type & chemistry
- Rubber content
- Rubber gradation (particle size distribution)
- Shearing Energy (blending equipment used)
- Shearing time
- Shearing temperature
- Holding time (before & after shearing) at elevated temp.
- etc.

Design of Optimum Crumb Rubber Content





PG grading results at 10 rad/s & 12% strain

	Test Temp. (°C)	Phase angle (deg)	Ave. G* (kPa)	G*/sinδ (kPa)	Pass/Fail temp. (°C)
Inman	70	88	0.7	0.68	Pass 67
Q8	76	87.7	0.5	0.54	Pass 70.7
Inman +15%	100	48.6	0.7	0.91	Pass 97.9
Inman +18%	100	54.1	1.0	1.28	Pass 100
Q8+18%	94	51.2	0.6	0.81	Pass 89.1

Multiple stress creep recovery (MSCR), % elastic recovery test results

	Ave. Recovery at 0.1kPa (%)				Ave. Recovery at 3.2 kPa (%)			
	40°C	50°C	60°C	70°C	40°C	50°C	60°C	70°C
Inman	-	7.97	1.76	0	0	2.08	0	0
Q8	28.43	12.52	3.36	0	25.27	6.11	0	0
Inman +15%	91.07	91.55	93.15	99.41	82.21	70.59	34.77	9.84
Q8+15%	92.27	98.32	99.55	99.73	76.47	57.95	22.48	5.18
Inman +18%	94.92	98.56	99.12	97.6	87.53	80.4	49.05	16.72
Q8+18%	97.65	99.51	99.71	99.91	88.9	92.81	79.18	29.94

Multiple stress creep recovery (MSCR), non-recoverable creep compliance (J_{nr}) results

	Ave. J_{nr} at 0.1kPa (1/kPa)				Ave. J_{nr} at 3.2 kPa (1/kPa)			
	40°C	50°C	60°C	70°C	40°C	50°C	60°C	70°C
Inman	-	0.8532	3.9024	14.4025	0	0.945	4.3377	15.7782
Q8	0.0862	0.5366	2.455	9.0424	0.0899	0.5926	2.765	10.1493
Inman +15%	0.004	0.0129	0.0297	0.0055	0.0082	0.0456	0.3521	1.6916
Q8+15%	0.0023	0.0018	0.0014	0.0015	0.0072	0.0477	0.3401	1.5496
Inman +18%	0.0015	0.0012	0.002	0.0118	0.0036	0.017	0.1429	0.8841
Q8+18%	0.0005	0.0003	0.0005	0.0002	0.0024	0.0049	0.0399	0.443

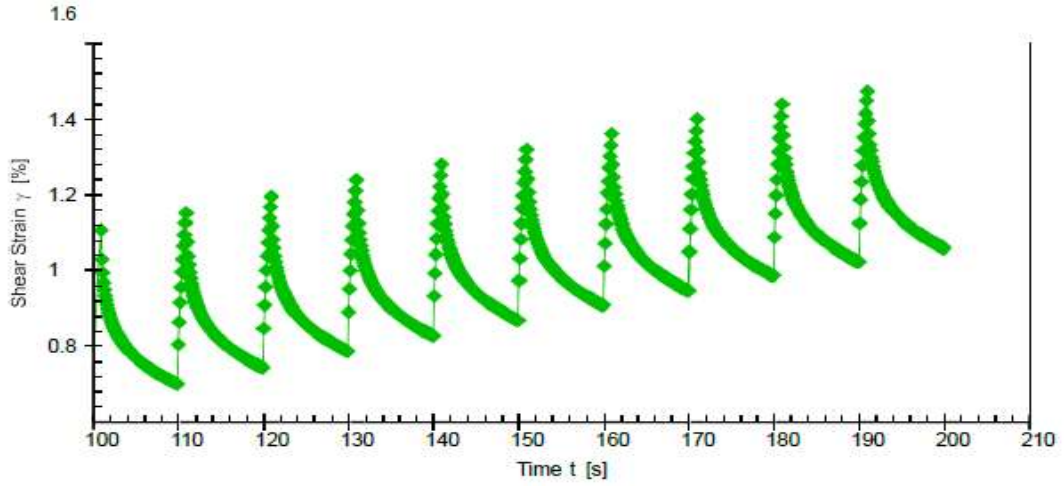
Example of MSCR Test Output

MSCR-Test (AASHTO T350-14) - Final Report

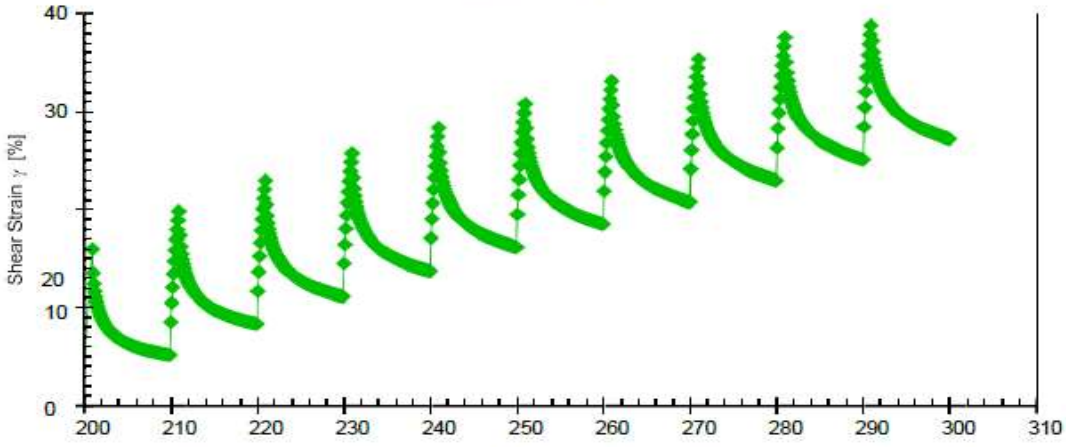
Project name: 10/24/2017_MSCR (V2)

Date, Time: 10/24/2017 5:10:18 PM
Test name: 10/24/2017_Inman+15%CRM-40C MSCR_0.1/3.2kPa
Operator: DSR
Sample:
Batch no.:
Description:
Configuration: Anton Paar SmartPave 102 SN82228255
PP25/PE SN51061 P-PTD200+H-PTD120 SN82196592-82219505

MSCR 0.1kPa (conditioning cycles are not shown)



MSCR 3.2kPa



PelletPAVE

- No need for agitated storage tanks
- No more field blending at the hot plant site
- No additional equipment required
- No chance of material separating in storage tanks
- Typically 2% PelletPave per ton of asphalt

Technical Director
Mr Kelly Ray Sockwell

- Customs, Port Clearance, Inspection Charges, Enviro. Public Authority, KOC, …
- Unloading Containers
- 850kg PelletPave sacks
- Cover from Sun

- Extremely hot summer
- All sacks burst
- Some material fused
- Re-bagging into 15kg PE bags

Traditional Marshall Method of Mix Design

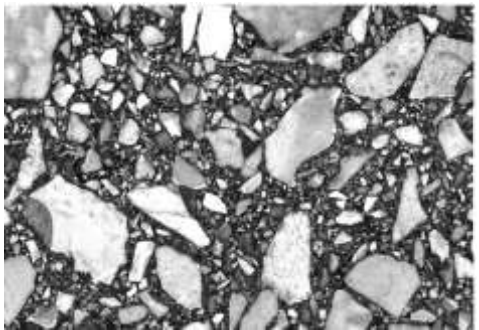
- Stability v.s. bitumen content
- Flow v.s. bitumen content
- Bulk density v.s. bitumen content
- Air voids v.s. bitumen content
- Voids filled with bitumen v.s. bitumen content

Preliminary Rubberized-Asphalt Marshall Mix Designs (by Consultant)

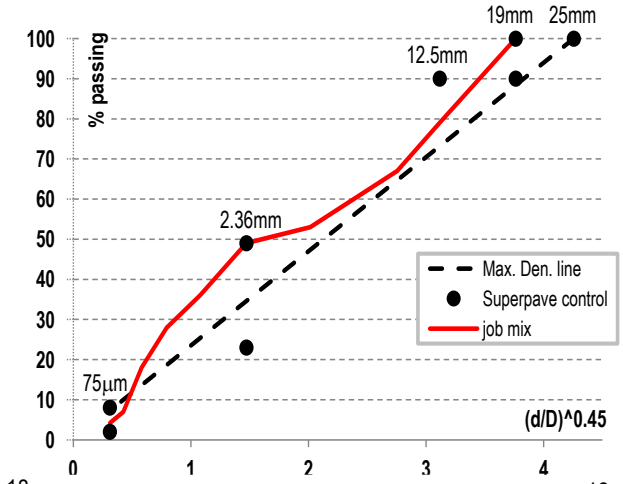
Phoenix Ind. Mix Designs	2.5% Pellet -Pave	3.0% Pellet-Pave	3.5% Pellet-Pave
Optimum binder content (%)	5.50	5.70	5.80
Air voids in total mix (%) (allowable range 4-6%)	4.48	4.48	4.48
VMA (%) (min. requirement 14%)	17.30	17.30	17.30
Dust to bitumen ratio	0.77	0.74	0.73
Effective Specific gravity	2.622	2.621	2.617

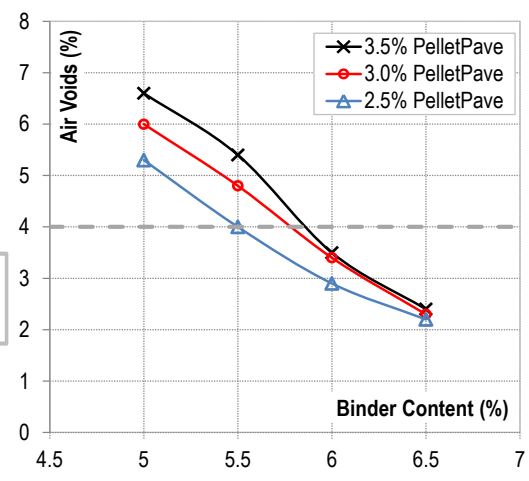
Kuwait MPW Marshall design criteria for Type III wearing course asphalt concrete mix HMA

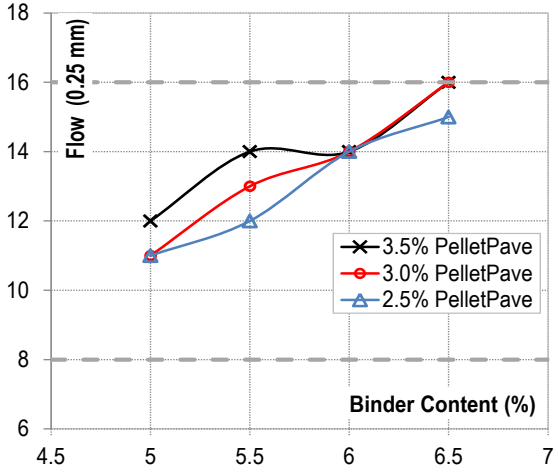
	Min.	Max.
No. of compaction blows		75
Stability (kN)	18	-
Flow (0.25mm)	8	16
VMA (%)	14	-
Air Voids (%)	4	6
VFB (%)	63	75

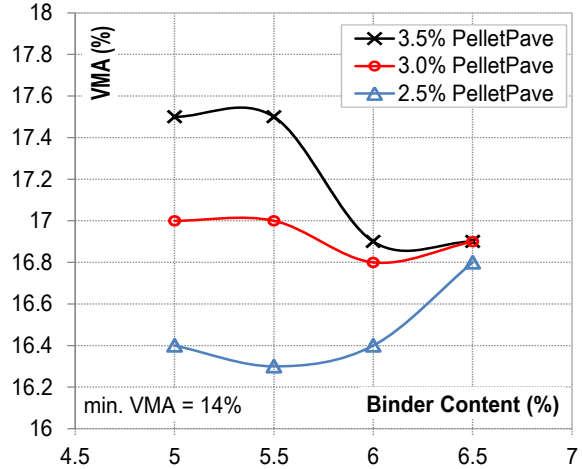


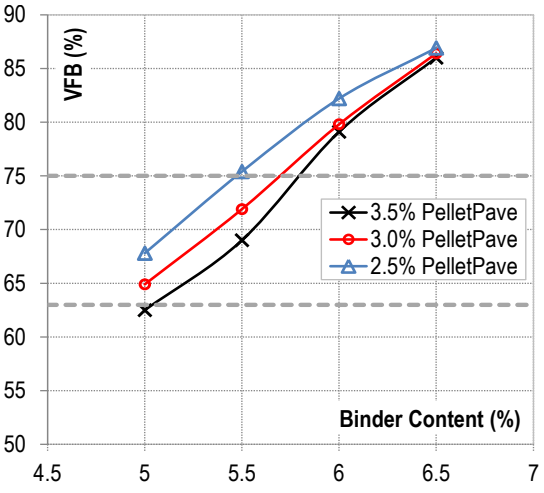
Dense-Graded HMA

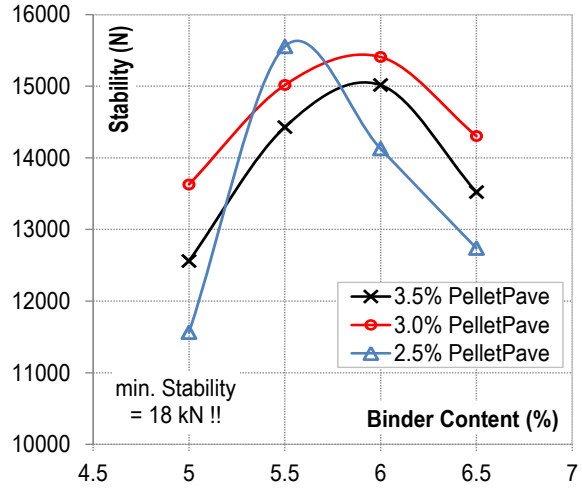












Confirmation of Rubberized-Asphalt Mix Designs

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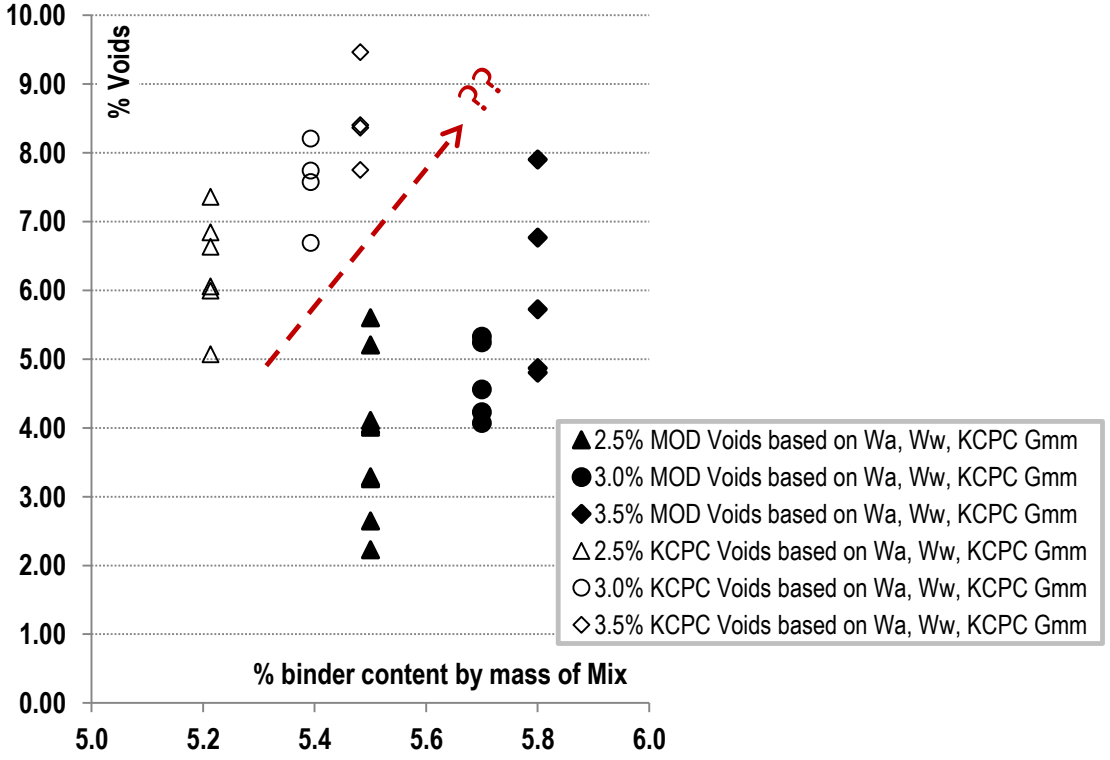
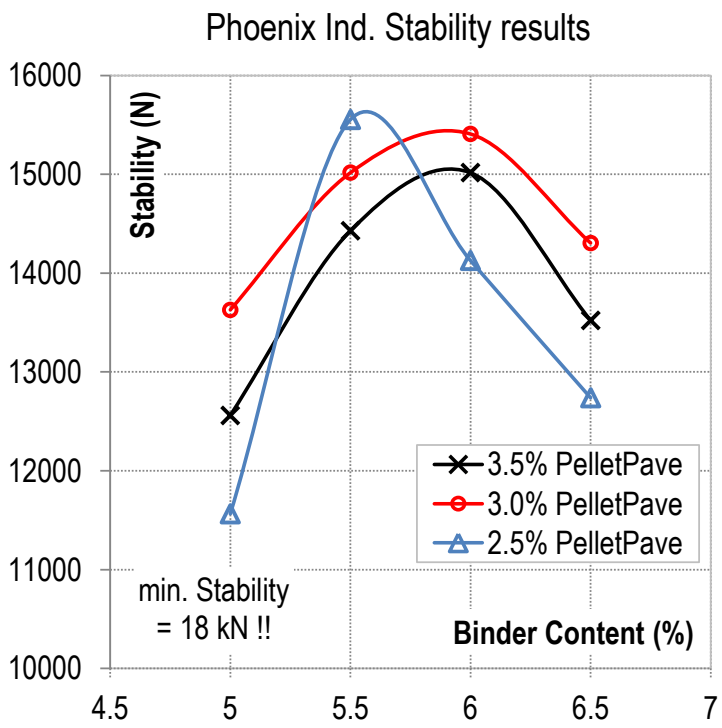
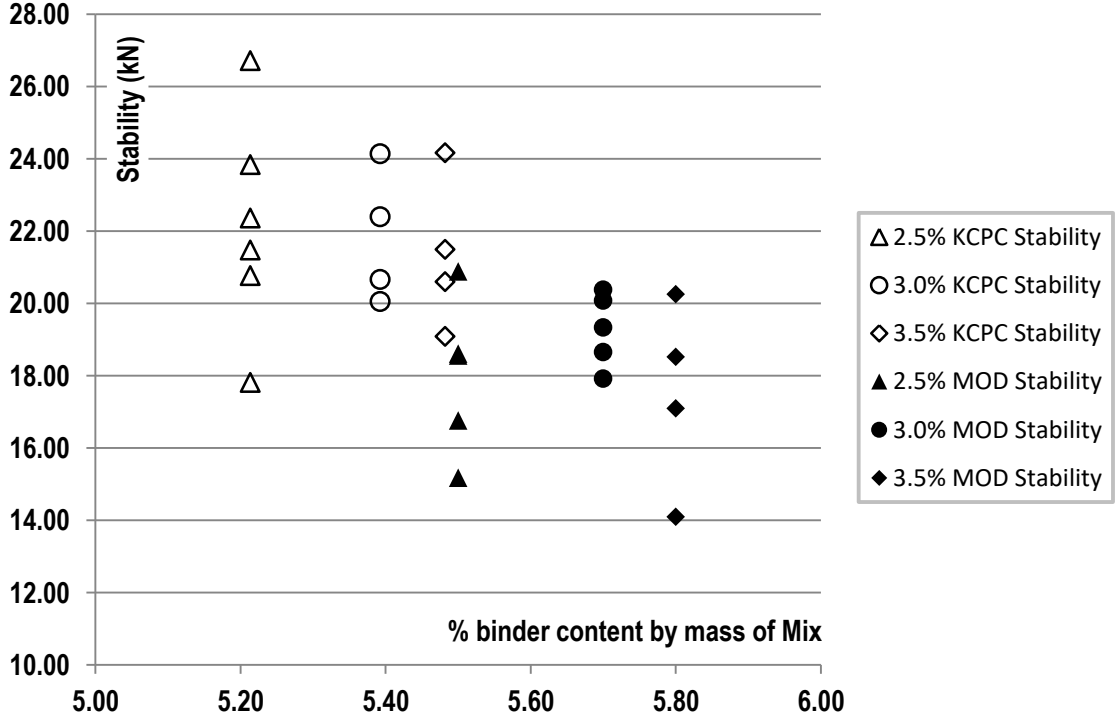


Comparison of Marshall Voids results
(based on W_a, W_w, SSD & KCPC G_{mm})
Contractor lab. (by mass of agg.)
MOD-HE lab. (by mass of mix)

Compare the MOD 2.5% PelletPave (binder content = 5.5% by mass of mix) with KCPC 3.5% PelletPave (binder content 5.48% by mass of mix) as both mixes have almost the same total binder content. Evidently, for the same total binder content one can observe an almost doubling of the voids content as one moves from 2.5% to 3.5% PelletPave. This is irrefutable evidence that the rubber component is causing de-compaction of the mix during the compaction process.





Marshall Stability results from
Contractor lab. (by mass of agg.)
MOD-HE lab. (by mass of mix)
at 2.5%, 3.0% & 3.5% PelletPave contents.

Note from Fig., at any one PelletPave content adding extra ≈ 0.3% additional binder causes significant drop in Stability, (mix sensitivity to binder content)

Ongoing Laboratory Activities

Gyratory Compaction


Indirect Tensile Stiffness Modulus Test


Wheel-Tracker Small Device

Quality Control on Site

Reflux hot Extractor
(wire mesh cone set)

Binder Recovery by Solvent Extraction (ASTM D2172)

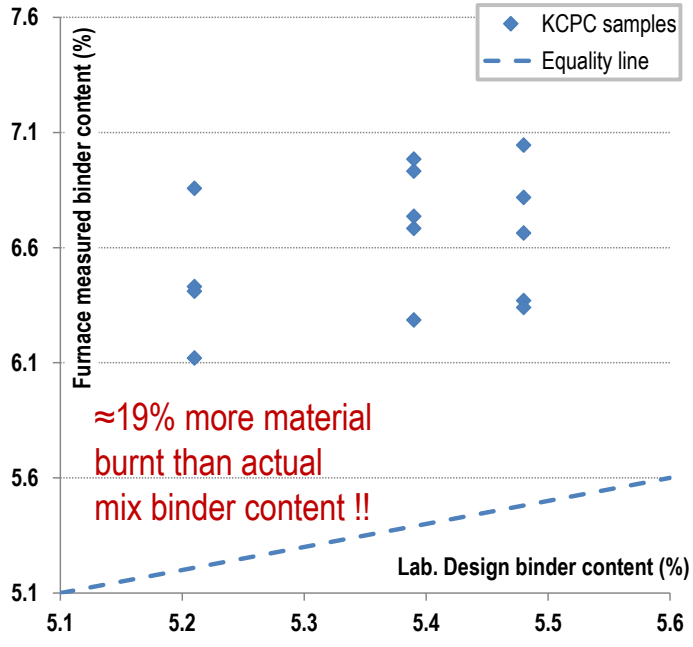
PelletPave content	Total binder content (by mass of agg.)	Amount of solvent insoluble matter (% by mass of total binder)
2.5%	5.5%	22%
3.0%	5.7%	23%
3.5%	5.8%	24%

Results confirm that solvent recovery is not a reliable tool for determination of binder content of rubberized-asphalt mixes.

Asphalt content of Hot Mix Asphalt by Ignition Method
ASTM D6307, 540°C, 1 hour

Rubberized-Asphalt Mix

Mix after Furnace



Ignition Method on sample of PelletPave modifier

PelletPave

Pure PelletPave in Furnace at 540°C

Ignition Method on sample of PelletPave modifier

PelletPave sample before Furnace

PelletPave sample after Furnace,
average amount unburnt ≈ 26%

Raw Materials (parts per hundred parts rubber)	Reference compound
S-SBR Buna® VSL 5025-0 HM	70
BR Buna® CB 24	30
Silica Ultrasil® 7000 GR	80
Carbon Black Statex® N 234	10
Silan Si 69®	8
Mineral oil TDAE Viva Tec® 500	**20**
IPPD Vulkanox® 4010	1
6PPD Vulkanox® 4020	2
TMQ Vulkanox® HS	0.5
Ozon wax Antilux® 654	1
ZnO Zinkoxid Rotsiegel®	3
Stearic acid	1
Resin	**0**
Sulfur	1.5
CBS Vulkacit® CZ	1.5
DPG Vulkacit® D	2

+ added filler
(e.g. hydrated lime !)

KISR
Kuwait Institute for Scientific Research

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