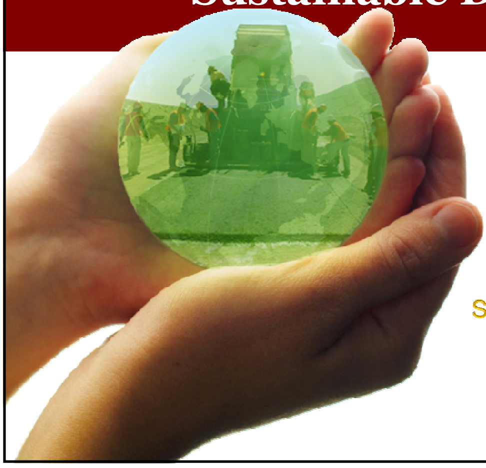
New Pavement Construction Technologies for Environmental and Economical Sustainable Development



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Future of Sustainable Highways

- "**Sustainability**" sustain economic properties and a high quality of life, while protecting natural systems of the planet
- Key components:
  - Economic
  - Environment
  - Social

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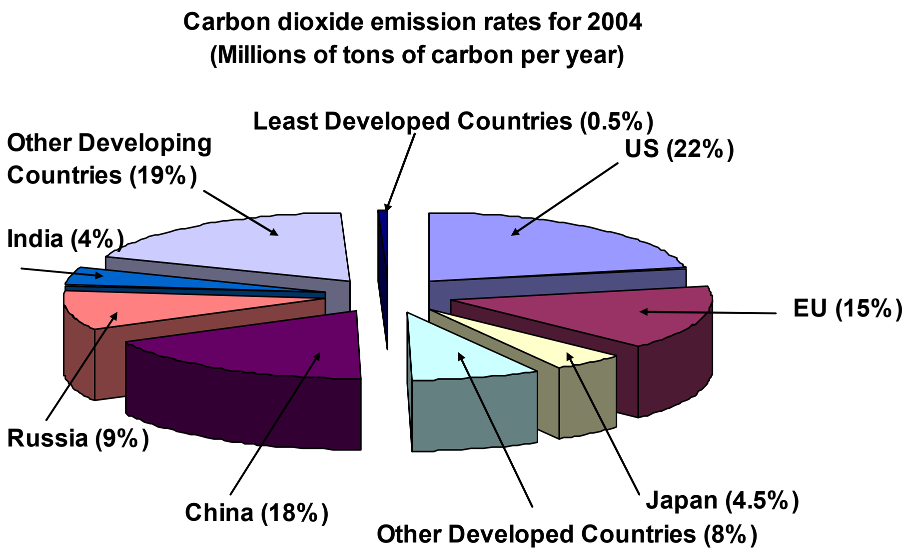
Sustainable Pavement and Green Road



Source: Global carbon Project, US Energy Information Agency

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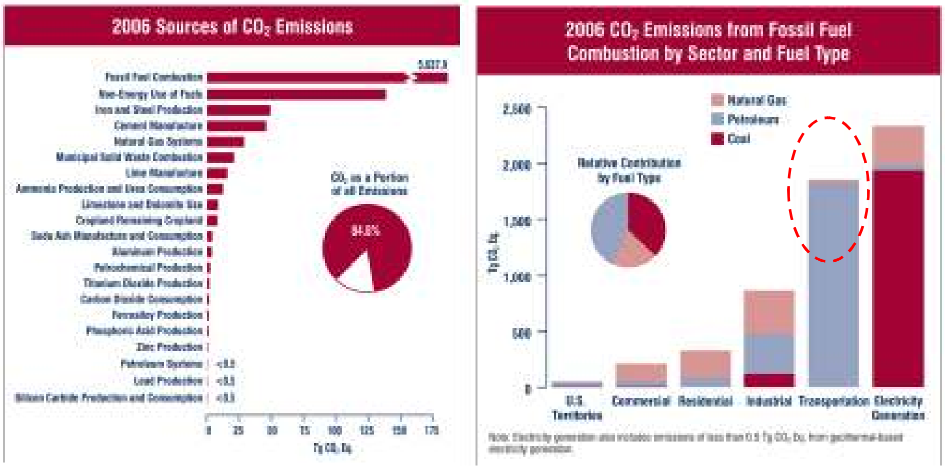
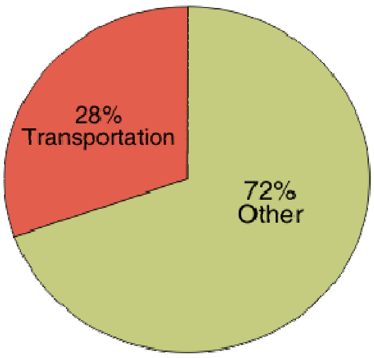
Source of World CO_2 Emission

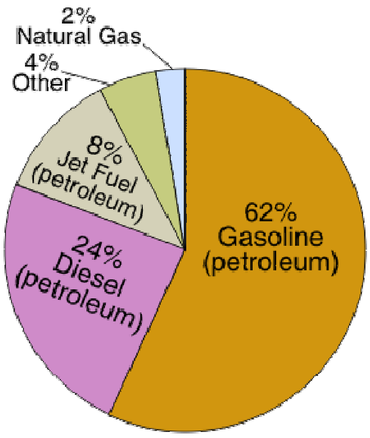


Source: U.S. Greenhouse Gas Emissions Inventory (teragrams of CO2 equivalent) 5

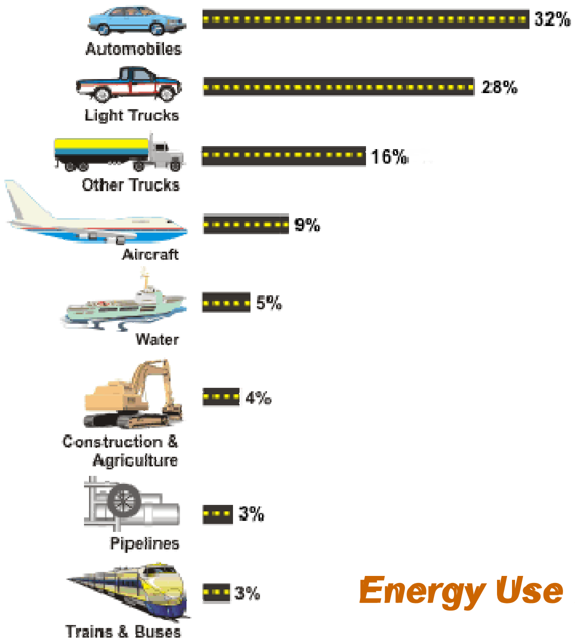
Energy Use for Transportation

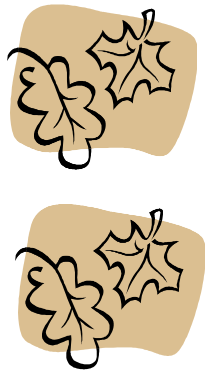


Fuel Used for Transportation



Source: Department of Energy, *Transportation Energy Data Book*: Edition 26-2007. 6





Energy Use by Type of Vehicle

Source: Department of Energy, *Transportation Energy Data Book*: Edition 26-2007.

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Environmental Consumption in Building Roads

- We use lots of raw material
  - In pavements: Agg, Asphalt, Cement
  - 2000 Co2 by sources—transportation 30%
  - Energy use –transportation

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Demand for Quality Materials

- **Long life material design**
  - Crushes and angular aggregate
  - Manufactured sands
- **High friction demand**
  - Improve texture – decrease wear
- **High quality mixes**
  - Selective aggregate size
- **Management and treatment of runoff, Leachate control**
- **Use of industrial by-products**
  - Coal combustion products
  - Slag
  - Foundary sand
- **Use of waste and by-product**
  - Crumb rubber

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Sustainability: System for use

- Concrete pavement
- WMA (Warm Mix Asphalt)
- Porous Asphalt
- Cool pavement

"Green roads" a rating system designed to distinguish performance sustainable new or redesigned/rehab roads

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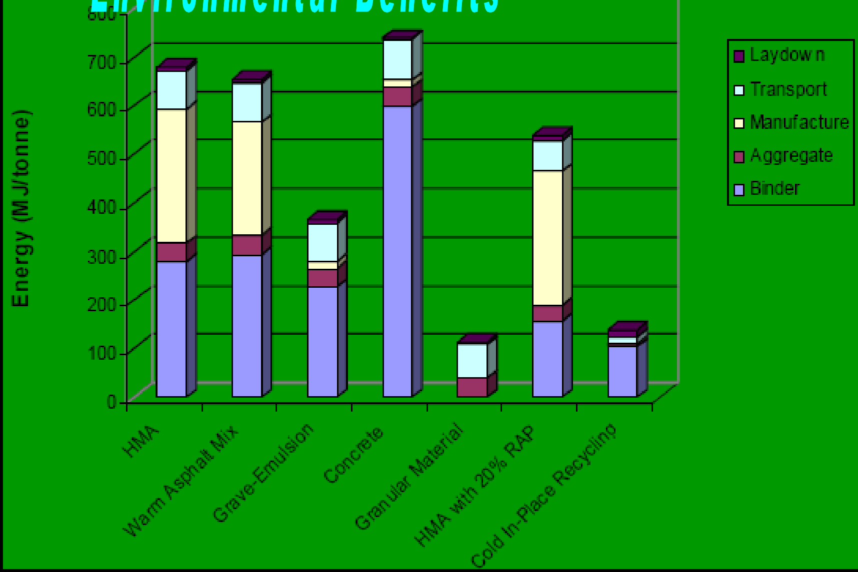
Environmental Benefits



Source: *Road Rehabilitation Energy Reduction Guide for Canadian Road Builders, Natural Resources Canada, 2005, p. 16*

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Treatment	Energy Consumption (MJ/t)	Energy Consumption (MJ/m²)	Percentage Decrease from HMA (%)
Hot Mix Asphalt	680	82	-
Warm Mix Asphalt	654	78	5
Recycled Asphalt Shingle Hot Mix	535	64	12
In-Place Recycling	139	31	62
Micro Surfacing	496	9	89
High Performance Chip Seal	667	12	85

Source: *Road Rehabilitation Energy Reduction Guide for Canadian Road Builders, Natural Resources Canada, 2005, p. 16*

Asphalt Pavement: Energy and Recycling

- Asphalt pavements require about 20% less energy to produce and construct than other pavements.
- Faster construct and rehabilitate → opened to traffic quicker→ no need to wait for material to cure
- Can be recycle

- Other materials are recycled into asphalt pavements such as rubber from used tires, blast furnace slag, glass

Source: http://pavegreen.com

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Asphalt Pavement: Performance

- **Asphalt is Perpetual Pavement**
  Perpetual Pavement is constructed so that distress occurs in the top layer only.

- **Rubblization for sustainability**
  When concrete pavements reach end of life, it is left in place, "rubblized" (fractured), and used as base for Perpetual pavement.
- **Smooth asphalt road gives vehicle tires good contact with the road**
  OGFC allows rainwater to drain through the surface layer and off to the sides, reducing the amount of splash and spray kicked up by vehicles

Source: http://pavegreen.com

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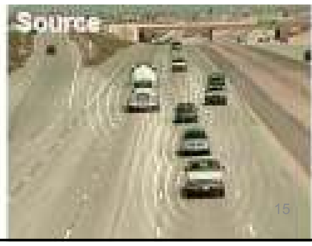
Asphalt Pavement: Performance

- **Noise Reduction**
  - Quiet asphalt pavement technologies include open-graded surfaces, fine-graded surfaces, and two-layer open-graded pavements.
  - Noise reductions of 3 to 10 dB(a).
  - Reducing noise by 3 dB(a) is the same as doubling the distance from the road to the listener, or reducing traffic volume by 50 percent



Source: http://pavegreen.com

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Asphalt Pavement: Performance

- **Smoothness and conservation**
  - Driving on smoother surfaces can reduce fuel consumption of 4.5-5%.
  - When trucks are driven on rough surfaces, the tires bounce and deliver heavy, punishing impacts to the pavement. Some experts estimate that a 25 percent increase in smoothness can result in a 9 to 10 percent increase in the life of pavements.

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Source: http://pavegreen.com

Asphalt Pavement: Water Quality

- **Porous Asphalt Pavement**
  - Permeable surface can turn runoff into infiltration; restore the hydrology of a site, or even improve it; improve water quality; and eliminate the need for detention basins.
- **Asphalt pavements do not leach**

  - Studies show that asphalt pavements and stockpiles of reclaimed asphalt pavement do not leach.

Source: http://pavegreen.com

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Asphalt Pavement: Clean Air and Cool Cities

- Emissions from asphalt plants, including greenhouse gases, are very low and well-controlled.
- Cool Cities
  - Porous asphalt pavements have been shown to lower nighttime surface temperatures as compared to impervious pavements.
  - It can retain, radiate, and/or release heat.
- Traffic relief
  - Asphalt's speed of construction allows planners and managers a way to fix congestion hot spots and bottlenecks, quickly and cost-effectively → consume less fuel and produce less greenhouse gases.

Source: http://pavegreen.com

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Concrete Pavement

- Environmental Impact of Concrete
  - The world's yearly cement production of 1.6 billion ton's accounts for about 7% of the global loading of carbon dioxide into the atmosphere. (Metha, P.K., 1999)
  - "Producing a ton of Portland cement requires about 4GJ energy and Portland cement clinker manufactures releases approximately 1 ton of carbon dioxide into atmosphere (Metha, P.K., 2001)

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Concrete Pavement → "Longevity"

- Less frequent reconstruction
- Lower consumption of raw materials (cement, aggregate, steel)
- Lower energy consumption (Raw material processing, Rehab and reconstruction, Congestion)
- Pollutant reduction (Manufacturing, construction, congestion)
- Lives saved
  - Rigid structure, Profile durability
  - Infrequent construction zones

Longevity is Element for Sustainability

Source: http://pavements4life.com

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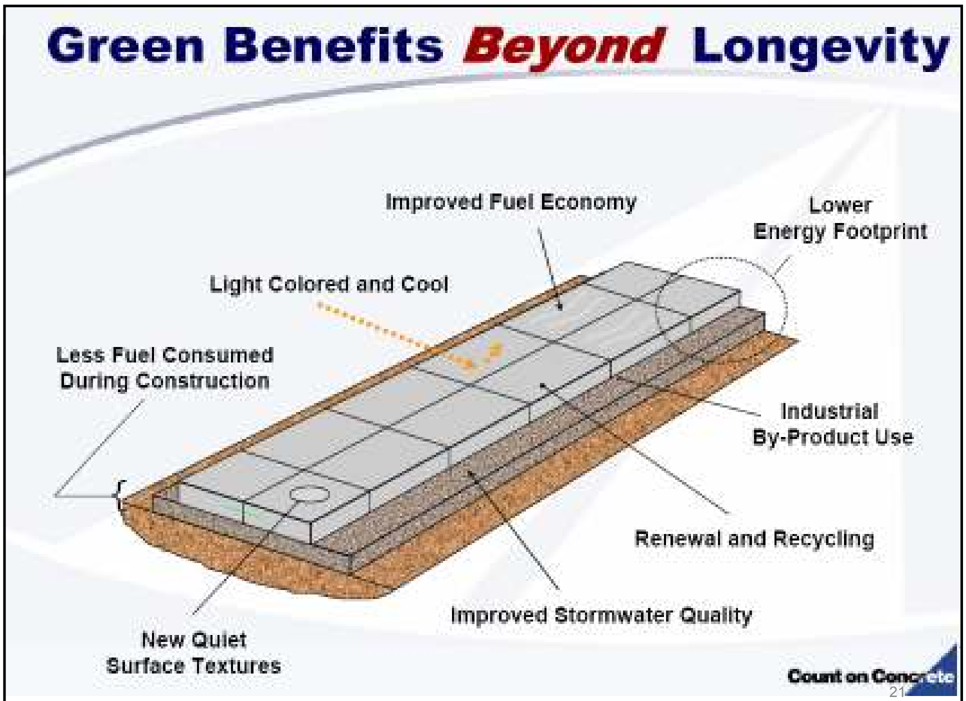
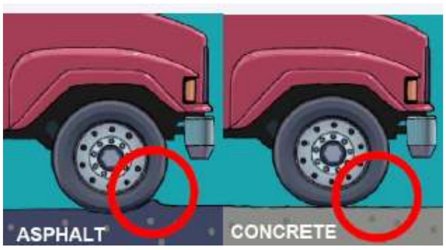


Source: http://pavements4life.com

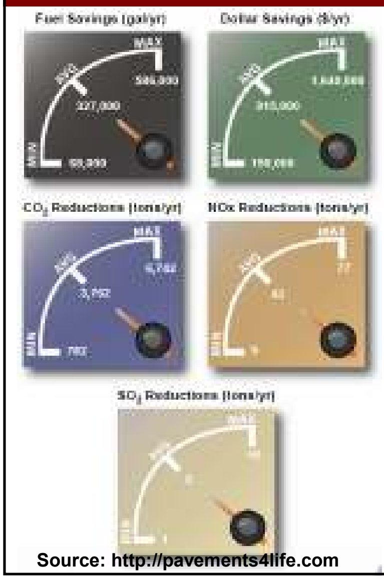
Concrete Pavement: Improved Fuel Economy

- Rigid surface → less deflection →low rolling resistance → reduce fuel consumption
- Significant fuel consumption reductions for trucks on concrete pavement (0.8-6.9%)
- Hugh environment and cost saving..



Source: http://pavements4life.com

Concrete Pavement: Fuel Savings and Emission Reduction



Economical Impact

Environmental Impact

Based on traffic volume of 82,000 vehicles per day with 12% trucks, truck fuel mileage of 5.5 miles/gallon, and a local fuel price of $2.80/gallon

Source: http://pavements4life.com

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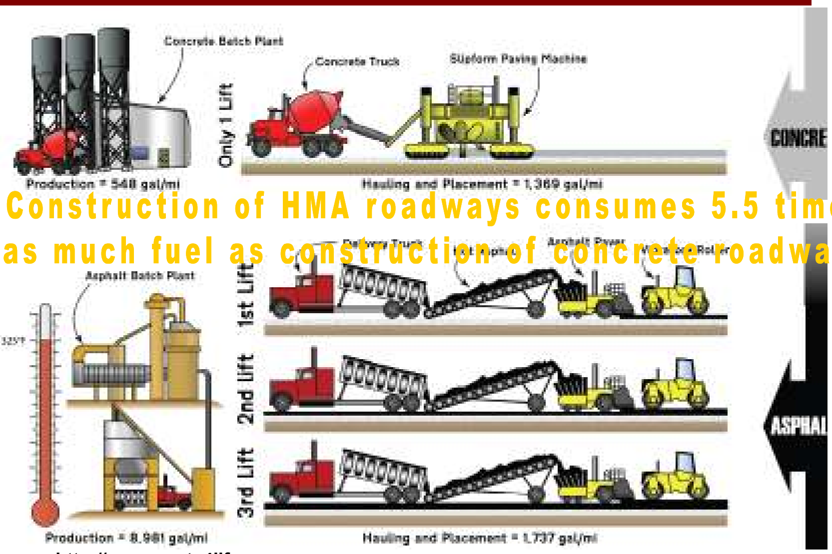
Concrete Pavement: Low Fuel Consumption during Construction



Construction of HMA roadways consumes 5.5 times as much fuel as construction of concrete roadways

Source: http://pavements4life.com

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Concrete Pavement: Use of Industrial By-Products

- Concrete is a huge consumer of industrial by-products.
- Reduces disposal, lowers cement intensity (with its CO2) and improves both performance and longevity
- Fly ash, Slag aggregate, Kiln dusts



Source: http://pavements4life.com

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Concrete Pavement: Recycling and Reuse

- Concrete 100% recyclable-in new concrete, subbases and granular fill (even on site operations)

Source: http://pavements4life.com

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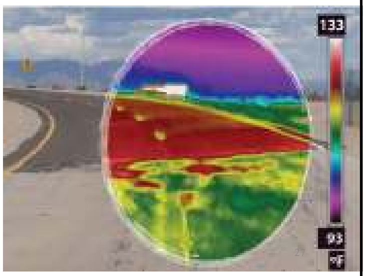
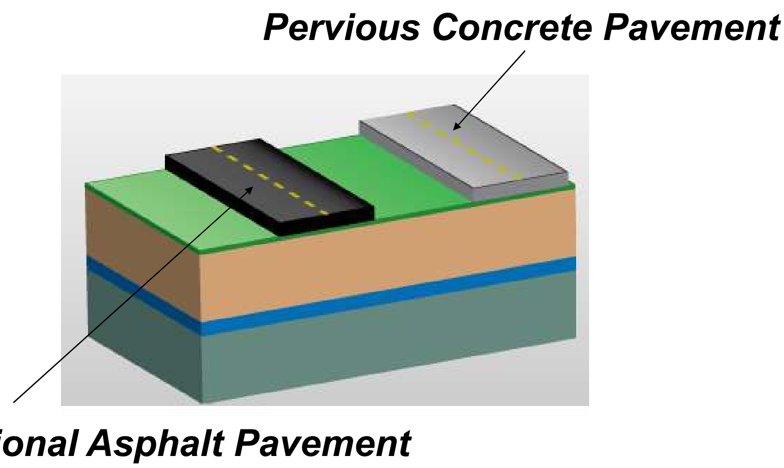
Concrete Pavement: Light Colored and Cool

- Enhanced nighttime visibility:
  - Improved pedestrian and vehicle safety
  - Reduced lighting and energy requirement
- Urban Heat Island Mitigation:
  -Urban areas up to 9ºF warmer due to UHI
  -Lower city temperatures
  -Lower cooling costs
  -Reduce smog formation



Source: http://pavements4life.com

Concrete Pavement: Improved Water Quality



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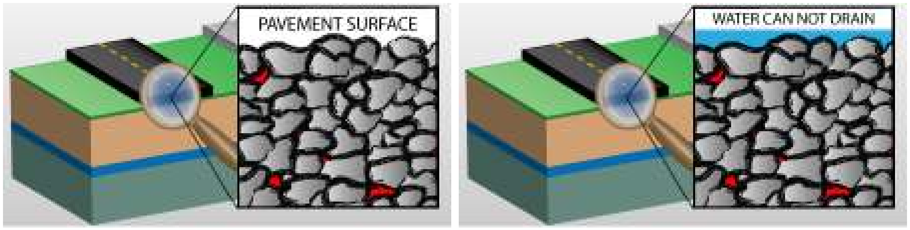
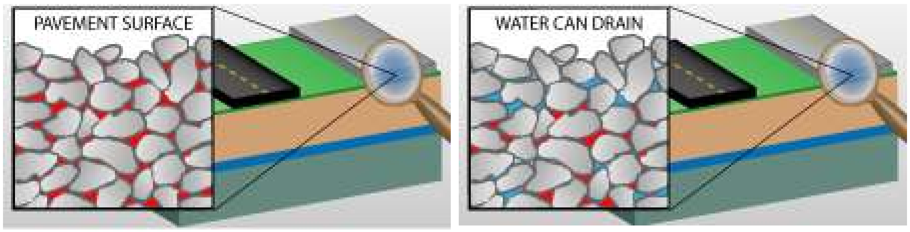
Source: http://pavements4life.com

Concrete Pavement: Improved Water Quality





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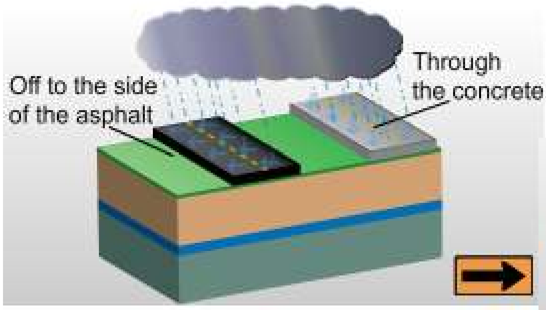
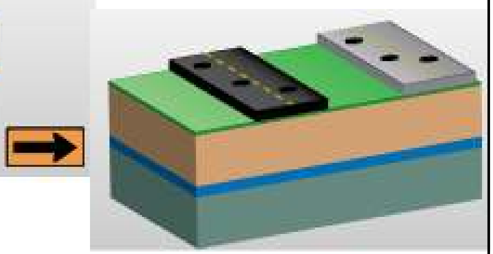
Source: http://pavements4life.com

Concrete Pavement: Improved Water Quality

After raining, where does water goes?





After sometime, vehicle oil will retain on surface

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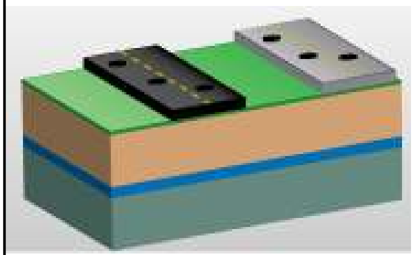
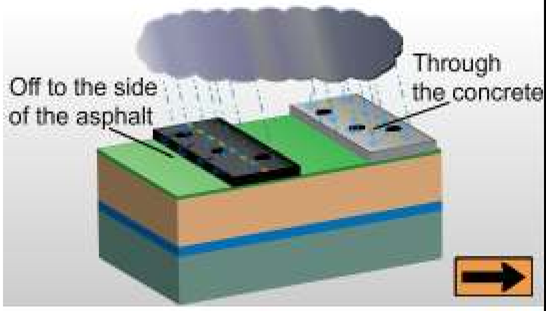
Source: http://pavements4life.com

Concrete Pavement: Improved Water Quality

After raining, where will oil go?

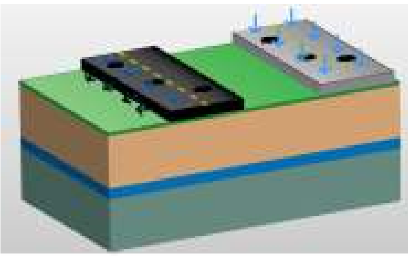




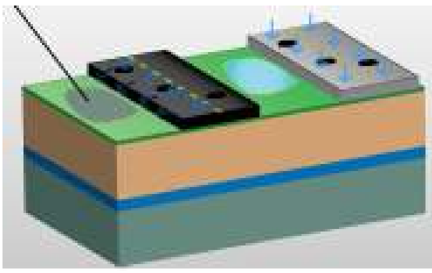
Source: http://pavements4life.com

Concrete Pavement: Improved Water Quality

What happens if there is a water source nearby?



Water source will become slowly contaminated.

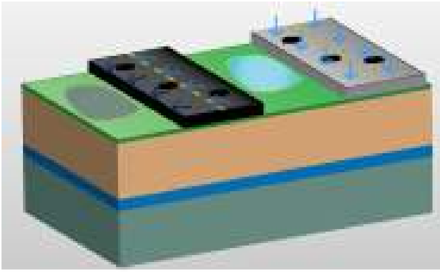


Concrete prevent both flooding and contamination of water source from storm runoff.

Source: http://pavements4life.com

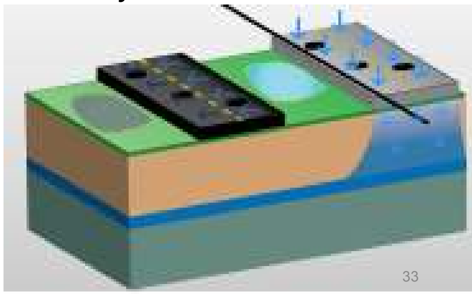
Concrete Pavement: Improved Water Quality

What happen to oil and water when passing through pervious concrete pavement?



Contaminated water penetrates into the ground where it is naturally treated.

Natural cleaning and return of rain water to the earth reduces strain on wastewater facilities



Source: http://pavements4life.com

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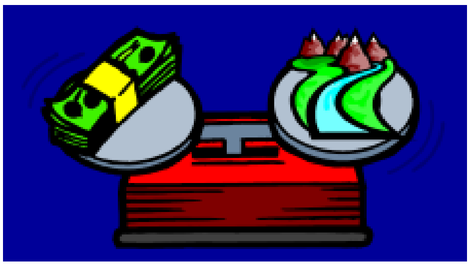
Summary

- Asphalt and Concrete pavement can be both environmentally sensitive and economically sustainable roadways.
- Many technologies have been used to produce sustainable products
  - Save Energy
  - Reduce Emission
  - Urban Heat Island Mitigation
  - Recyclable and Reuse
  - Noise Reduction
  - Improve Safety



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Warm Mix Asphalt (WMA)

Problems in HMA Production

- High energy required
  - HMA production temperature : 160^{o}C or above
  - Compaction temperature: 120^{o}C or above
  - Heating temperature of aggregates before mixing to asphalt binder : 160^{o}C
- High energy costs
- Negative effects to environment
- Harmful effects to construction workers and nearby residents
- Oxidative aging in asphalt mixtures can lead to pavement cracking – shorten service life

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Hot Mix Asphalt (HMA)

- Mixed, spread, and compacted temperature at greater than 150°C

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Warm Mix Asphalt (WMA)

- Produced and constructed at lower temperatures

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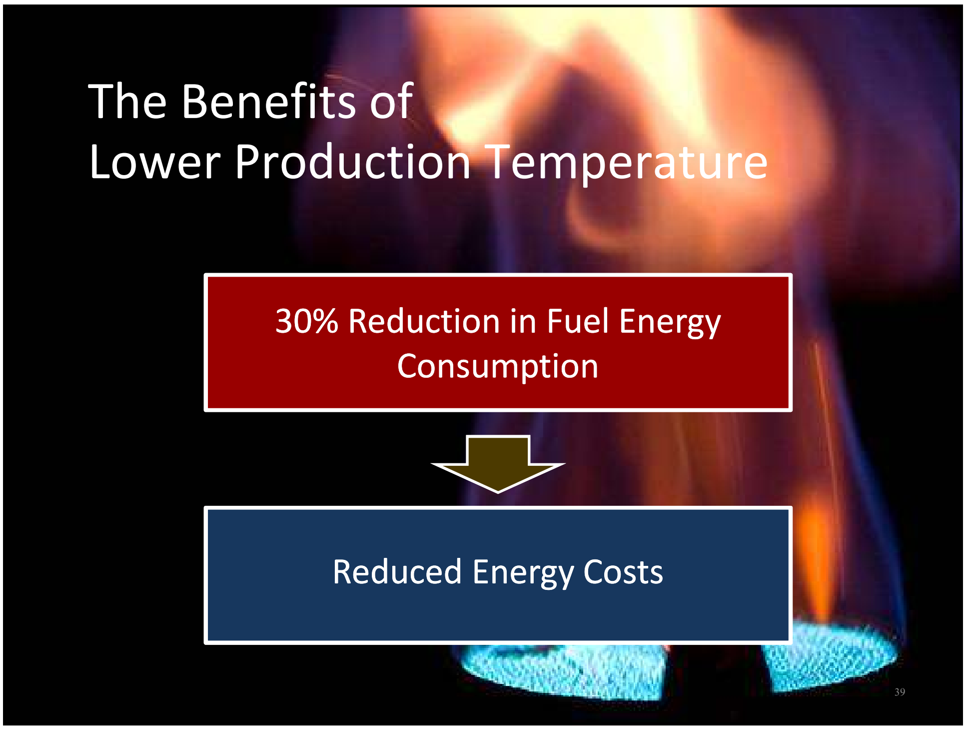
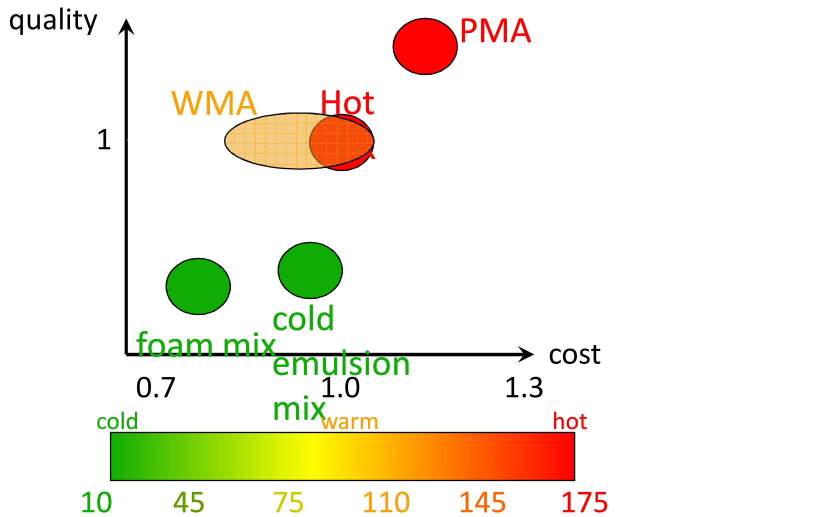


The Benefits of Lower Production Temperature



Source: Shell Global Solutions, France

The Benefits of Lower Production Temperature

- Mixed, spread, and compacted temperature at greater than 150°C

HMA (160 °C)

WMA (120 °C)

Source: US Department of Transportation Federal Highway Administration

The Benefits of Lower Production Temperature

- Reduced harmful effects to the environment and to the health of construction workers or nearby residents

Source: Shell Global Solutions, France

The Benefits of Lower Production Temperature

Minimized oxidative hardening of asphalt

↓

Reduced thermal cracking, block cracking

WMA Technologies

- Materials Processing
  - Two component asphalt binder
    - WAM-Foam®
- Emulsion Technology
  - Chemical structure developed
    - Evotherm®
- Mix Additives
  - Mineral
    - Aspha-Min®
  - Organic
    - Sasobit®
    - Asphaltan®

Source: US Department of Transportation Federal Highway Administration

WAM-Foam®

Source: US Department of Transportation
Federal Highway Administration

Evotherm®

- Emulsion
- Dispersed asphalt technology
  - Chemical structure was developed for WMA
- Mix temperature
  - 140-220F
- No plant modification

Source: US Department of Transportation
Federal Highway Administration

Aspha-Min®

- Manufactured Synthetic Zeolite
  - Sodium aluminum silicate
  - Hydro thermally crystallized

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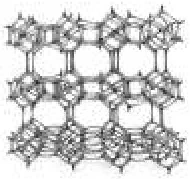
Aspha-Min®

- Zeolites
  - Framework silicates which have large vacant spaces in their structures that can trap water
    - Spaces are interconnected and form long wide channels of varying size
  - Ability to lose and absorb water without damage to their crystal structures
    - The trapped water is driven off by heat

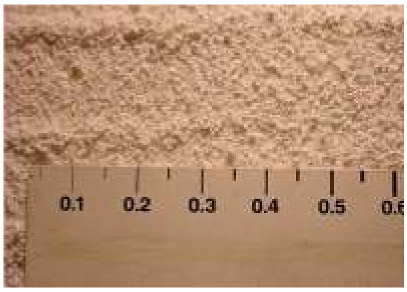


EUROVIA

Source: US Department of Transportation Federal Highway Administration

Aspha-Min®

- Add 0.3 % by mass to mix
  - Water is released at high temperatures
    - Range of 185 to 360o F
    - Foams the asphalt- reduced viscosity
- Reported by Eurovia
  - 54F reduction
  - Fuel savings of 30%



Source: US Department of Transportation
Federal Highway Administration

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SASOBIT®

- Sasol Wax GmbH (Germany)
- Fine Crystalline long chain aliphatic hydrocarbon
- Produced from Fischer-Tropsch Synthesis from coal or natural gas
- "FT paraffin wax"

sasol
reaching new frontiers

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How does Sasobit® work?

- The melting point is approximately 100oC
- Completely soluble in asphalt binder at temperatures above 115oC
  - Reduced viscosity of asphalt binder
  - Decreased the mixing and handling temperatures by 10°C to 30°C

sasol
reaching new frontiers
1

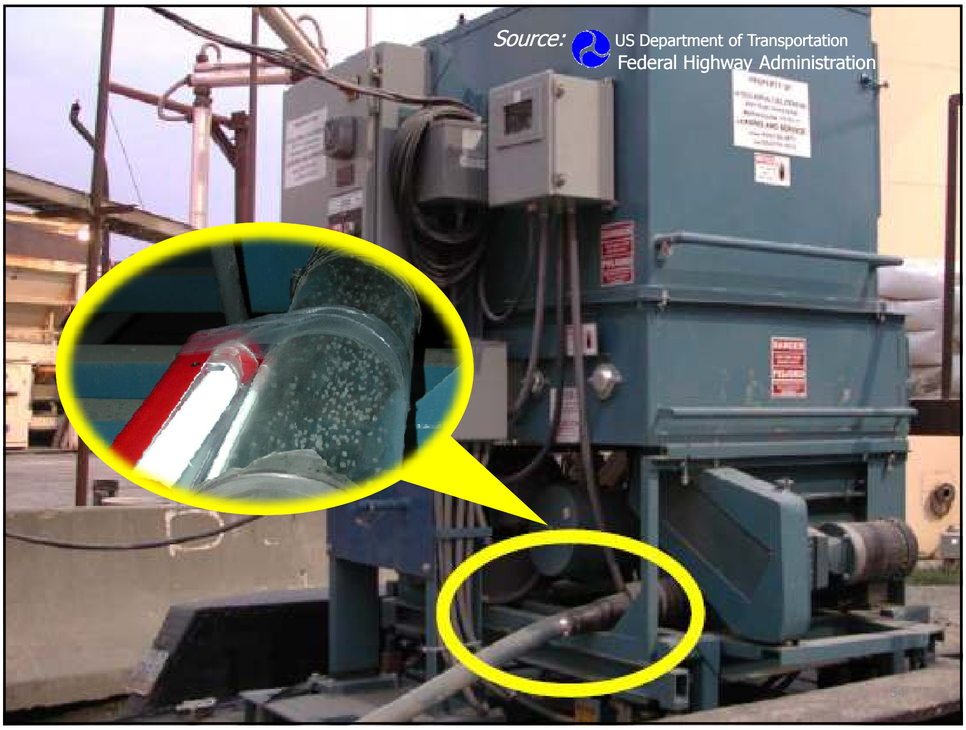
How does Sasobit® work?

- Sasobit® solidifies in asphalt binder at temperature between 115°C and 70°C to regular distributed, microscopic small, stick-shaped particles
  - Increased the binder stiffness

- Electron microscopy (SEM) image of 4% Sasobit® in B50/70
- Framework of small Sasobit® particles reinforces bitumen

sasol
reaching new frontiers
2


sasol
reaching new frontiers
53


Source:
US Department of Transportation
Federal Highway Administration

Experimental design for compaction of specimen

Asphalt	Mixing Temperature (°C)
AC60/70	150 130 110
AC60/70+Sasobit®	150 130 110
PMA	170 150 130
PMA+Sasobit®	170 150 130

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MEASUREMENT OF ASPHALT MIXTURE PROPERTIES

1). Rutting Resistance Test

2). Fatigue Resistance Test

3). Moisture Damage Resistance Test

Rutting Resistance Test

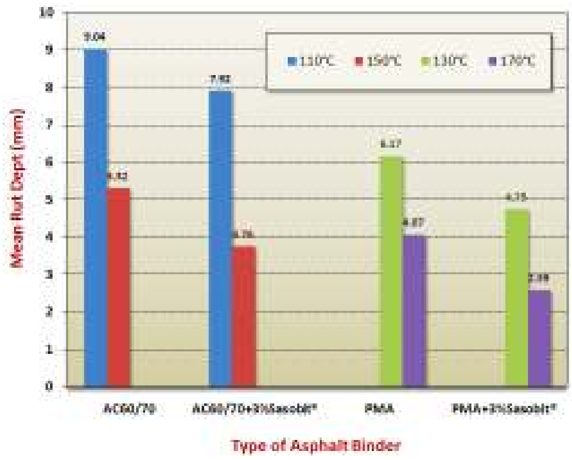
- Load Wheel Tracking Test (LWTT)

Experimental design for the rutting resistance test

Type of asphalt binder	Mixing Temperature(°C)	Number of samples
AC 60/70	110 150	2 2
AC 60/70 + 3% Sasobit®	110 150	2 2
PMA	130 170	2 2
PMA + 3% Sasobit®	130 170	2 2

Rutting Resistance Test

- Mean rut depth of all the mixtures tested



Mixtures produced at lower temperature have higher rut depth

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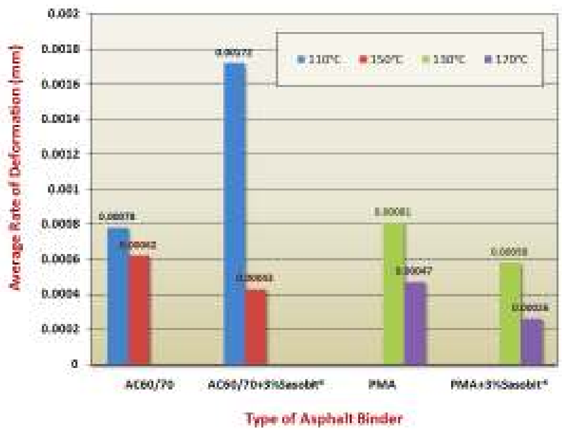
Rutting Resistance Test

- Rate of deformation of all asphalt mixtures vs. Mixing temperature

- Decreasing rate of deformation with increasing temperature, except for AC 60/70 asphalt mixtures
- Sasobit® generally decreases rutting potential of both AC 60/70 and PMA



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Fatigue Resistance Test

- Indirect Tensile Fatigue Test (ITFT)

Experimental Design for Fatigue Resistance Test

Type of asphalt binder	Mixing Temperature (°C)	Compaction Temperature (°C)	Number of samples
AC 60/70	110 130 150	95 115 135	3 3 3
AC 60/70 + 3% Sasobit®	110 130 150	95 115 135	3 3 3
PMA	130 150 170	115 135 155	3 3 3
PMA + 3% Sasobit®	130 150 170	115 135 155	2 2

Fatigue Resistance Test

- Summary of the ITFT results

Fatigue Life
AC60/70+3%Sasobit® > AC60/70

Type of Asphalt binder	Mixing Temperature (°C)	Sample No.	Stress, σ_{max} (kPa)	Stiffness Modulus (Mpa)	Fatigue Cycle to Failure, N_f	Strain (microstrain), ε_{max}
AC 60/70	110	1	550	3339.5	374	338
		2	450	3241.5	568	285
		3	350	3626.0	1209	198
	130	1	550	5817.5	1394	194
		2	450	5749.0	2226	160
		3	350	7286.0	11389	98
	150	1	550	5085.0	899	222
		2	450	7069.0	2732	130
		3	350	7969.5	24352	90
AC 60/70 + 3% Sasobit	110	1	550	6745.5	1165	167
		2	450	6124.0	1879	151
		3	350	7691.5	10255	93
	130	1	550	5208.5	800	216
		2	450	7944.5	5484	116
		3	350	7606.5	14682	94
	150	1	550	10337.0	4673	109
		2	450	10173.5	28965	91
		3	350	10272.5	124531	70

Resistance to fatigue cracking
AC60/70+3%Sasobit® > AC60/70

ε_{max}
AC60/70+3%Sasobit® < AC60/70

Fatigue Resistance Test

Fatigue Life
PMA+3%Sasobit® > PMA

- Summary of the ITFT results (Cont'd)

Type of Asphalt binder	Mixing Temperature (°C)	Sample No.	Stress, σ_{max} (kPa)	Stiffness Modulus (Mpa)	Fatigue Cycle to Failure, N_f	Strain (microstrain), ε_{max}
PMA	130	1	550	3563.0	1454	316
		2	450	3872.0	6570	238
		3	350	1728.0	4410	415
	150	1	550	4020.5	1832	280
		2	450	4763.5	7084	194
		3	350	3339.5	13657	215
	170	1	550	8334.5	17586	135
		2	450	10245.5	90962	90
		3	350	8429.5	130456	85
PMA + 3% Sasobit	130	1	550	4525.0	1565	249
		2	450	5015.0	6538	184
		3	350	5181.5	18576	138
	150	1	550	7015.0	4559	161
		2	450	6942.0	8674	133
		3	350	7406.5	51243	97
	170	1	550	9619.0	6759	117
		2	450	10362.0	103848	89
		3	350	10453.5	156782	69

Resistance to fatigue cracking
PMA+3%Sasobit® > PMA

ε_{max}
PMA+3%Sasobit® < PMA

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Fatigue Resistance Test

- Average stiffness modulus of the mixtures at various temperature

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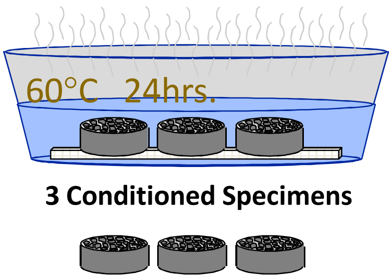
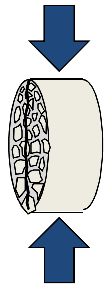
Moisture damage resistance test

- ASSHTO T-283 "Standard Test Method for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage"



3 Conditioned Specimens

3 Dry Specimens



80 % minimum

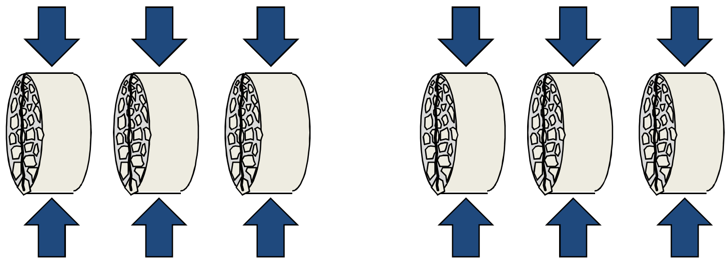
Tensile Strength Ratio (TSR)

Source: National Center for Asphalt Technology (NCAT)

Moisture damage resistance test

- ASSHTO T-283 Procedure

51 mm / min @ 25°C



Avg. Dry Tensile Strength | **Avg. Wet Tensile Strength**

$$\text{TSR} = \frac{\text{Wet}}{\text{Dry}} \geq 80\ \%$$

Source: National Center for Asphalt Technology (NCAT)

Moisture damage resistance test

- Indirect Tensile Strength Test (IDT)

Experimental Design for Fatigue Resistance Test

Type of asphalt binder	Mixing Temperature (°C)	Compaction Temperature (°C)	Number of samples
AC 60/70	110 130 150	95 115 135	6 6 6
AC 60/70 + 3% Sasobit®	110 130 150	95 115 135	6 6 6
PMA	130 150 170	115 135 155	6 6 6
PMA + 3% Sasobit®	130 150 170	115 135 155	6 6 6

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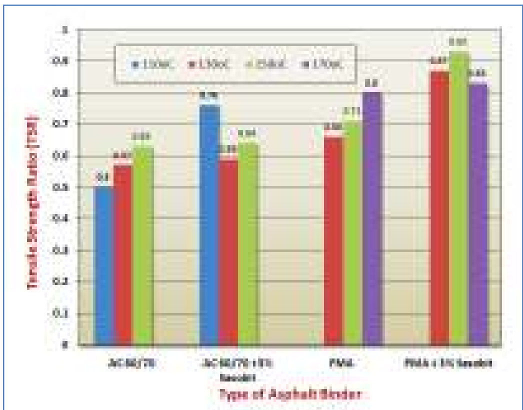
Moisture damage resistance test

- Tensile Strength Ratio (TSR) of all mixtures tested



Improved moisture damage resistance for all the mixtures with Sasobit® compared to the unmodified mixtures.

The degree of improvement in the TSR values of all the mixtures from the unmodified mixtures varies with the type of asphalt binder, mixing and compaction temperature.

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Conclusion

- Sasobit® increases the resistance of asphalt mixtures to rutting under traffic loads, which is confirmed by the lower rut depth measured in the load wheel tracking test (LWTT).
- The addition of Sasobit® improves the fatigue resistance of the asphalt mixtures as shown in the increased number of cycle to fatigue failure (Nf).

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Conclusion

- Sasobit®-modified asphalt mixtures significantly increase the resistance to moisture damage when compacted at lower temperature. This is indicated by improved TSR.
- Sasobit®-modification improves the performance-related properties of asphalt mixtures including rutting resistance, fatigue resistance and moisture damage resistance.

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