AMERICAN GILSONITE

University of Nevada, Reno, conducts scientific analysis of attributes and benefits.

Evaluation of Gilsonite-modified asphalt mixtures

Cost-effective additive improves strength, reduces rutting and cracking

Gilsonite® has been used as an additive to enhance the performance of asphalt pavements for more than 100 years. While field experience had demonstrated the advantages of using Gilsonite, the unique properties of Gilsonite-modified asphalt had not been well-documented due to the lack of a comprehensive evaluation.

However, a 2015 study by the Western Regional Superpave Center at the Department of Civil and Environmental Engineering of the University of Nevada, Reno, thoroughly analyzed various asphalt pavements using the latest advancements in materials testing, pavement modeling and life-cycle analysis.

Executive summary:
Findings from comprehensive testing demonstrated that Gilsonite-modified binders showed significant improvement in:

> **Tensile strength** – The addition of Gilsonite significantly increased both the unconditioned and moisture-conditioned tensile strength.

> **Compressive strength** – Gilsonite-modified binders showed significant improvement in compressive strength.

> **Rutting strength** – Gilsonite-modified binders significantly increased projected pavement life. In all but one case, adding Gilsonite yielded a ten-fold increase.

> **Fatigue resistance** – The projected pavement life is 1.5 to 5 times longer with the Gilsonite-modified binders.

Key points of the study

The evaluation was conducted under rigorous standards:

- An independent supplier provided control samples and Gilsonite-modified versions of two performance grades (PG) of asphalt: PG64-28, indicating performance engineered for a pavement temperature range of 64°C to -28°C; and PG76-16, designed for a pavement temperature range of 76°C to -16°C.
- All asphalt binders met the applicable state highway agencies' specifications based on the Superpave PG System for Asphalt Binders.
- The optimum binder content (OBC) of each asphalt mixture was identified by following the Superpave Volumetric Mix Design Method.
- Laboratory equipment included the industry-recognized Asphalt Mixture Performance Tester (AMPT).
- The engineering properties of the asphalt mixtures were measured at their OBCs in terms of the dynamic modulus E* master curve.
- The following performance characteristics of the asphalt mixtures were evaluated:
  - Resistance to rutting in terms of the Flow Number
  - Resistance to thermal cracking in terms of fracture temperature and fracture stress
  - Resistance to fatigue cracking in flexural bending

Quantifying performance

Gilsonite has long been used to increase the performance of asphalt binders. Now, a respected study has documented its advantages.

Researchers

- Peter E. Sebaaly, PhD., PE
- Elie Y. Hajj, PhD.
- Western Regional Superpave Center
- Department of Civil & Environmental Engineering, University of Nevada, Reno

AMERICAN GILSONITE COMPANY

Superpave PG characteristics used in testing

The Superpave Performance Grading (PG) system uses the rheological properties of the asphalt binder to identify its performance under the prevailing environmental conditions at the location of the project. The characteristics of the binders used in the testing are summarized in the table below.

Superpave PG of binders used in the mix designs and mixtures testing

Property/Test Conditions	PG76-16 Control	PG76-16 Gilsonite	PG76-16 Specs	PG64-28 Control	PG64-28 Gilsonite	PG64-28 Specs
Flash Point (°C)	230+	230+	> 230	230+	230+	> 230
Rotational Viscosity (Pa.s)	1.006	1.092	≤ 3.0 @ 135°C	0.861	0.681	≤ 3.0 @ 135°C
Dynamic Shear Rheometer on Original, G*/sinδ, 10rad/sec, (KPa)	1.500	1.370	≥ 1.0 @ 76°C	1.820	1.600	≥ 1.0 @ 64°C
Rolling Thin Film Oven (RTFO), mass loss (%)	0.9	0.1	≤ 1.0	0.5	0.2	≤ 1.0
Dynamic Shear Rheometer on RTFO-aged, G*/sinδ, 10rad/sec, (KPa)	4.175	2.890	≥ 2.2 @ 76°C	3.550	4.225	≥ 2.2 @ 64°C
Required by Caltrans Dynamic Shear Rheometer on RTFO-aged, delta (δ), 10rad/sec, degrees	65.0	83.3	NA	64.3	77.6	≤ 80° @ 64°C
Dynamic Shear Rheometer on PAV-aged, G*/sinδ, 10rad/sec, KPa	2620	1150	≤ 5000 @ 34°C	1720	2185	≤ 5000 @ 22°C
Bending Beam Rheometer on PAV-aged, S, 60sec, MPa	136	62	≤ 300 @ -6°C	133	119	≤ 300 @ -18°C
Bending Beam Rheometer on PAV-aged, m-value, 60sec	0.345	0.358	≥ 0.300 @ -6°C	0.342	0.300	≥ 0.300 @ -18°C

A close examination of the data shows that the addition of Gilsonite to the PG76-16 mixture resulted in an asphalt binder that is less susceptible to short-term and long-term aging.

The industry standard

The most commonly used asphalt binder specification in the U.S. is the Superpave Performance Grading (PG) system.

The same amount of binder, significant increases in strength

The Superpave system determines optimum binder content (OBC) based on an air voids level of 4% while meeting the remaining specified volumetric properties. Tests showed that the OBC was comparable for control samples and Gilsonite-modified samples. The PG64-28 mixtures required the addition of hydrated lime in order to meet moisture sensitivity specifications. Gilsonite modified binders showed significant improvement in both tensile strength (TS) and unconfined compressive strength (UCS).

Summary of optimum binder contents and lime contents, unconditioned and moisture-conditioned TS and UCS properties of the various mixtures

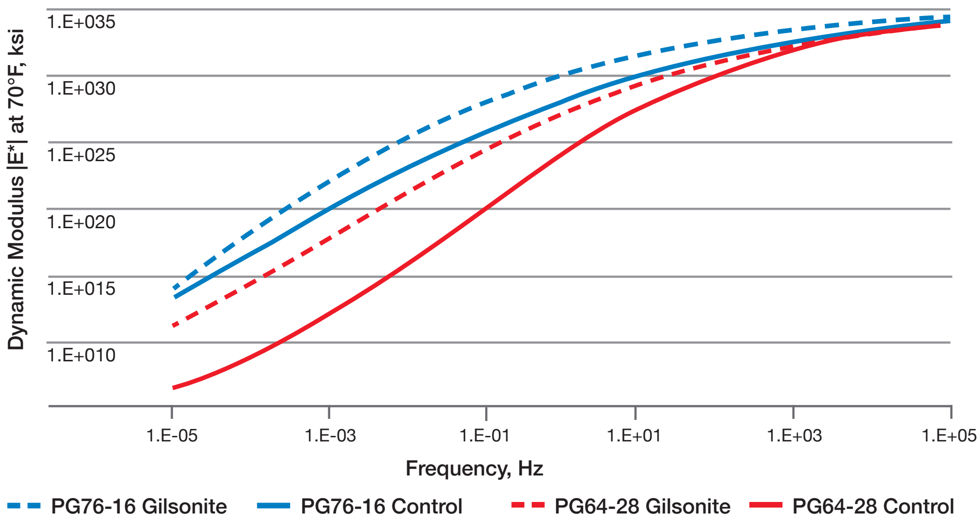
	PG76-16 Control	PG76-16 Gilsonite	PG64-28 Control	PG64-28 Gilsonite
Optimum Binder Content (%), total weight of mix	5.20	5.10	4.50	4.50
Air Voids at Optimum Binder Content (%)	4.0	3.9	4.2	4.2
Lime Content (%), dry weight of agg.	None	None	1.00	1.00
Unconditioned TS, 77° F, psi	168	265	115	126
Conditioned TS, 77° F, psi	102	154	95	113
Unconditioned UCS, 77° F, psi	734	909		
Conditioned UCS, 77° F, psi	448	573		

Dynamic modulus (E*) represents strength and stability

The American Association of State Highway and Transportation Officials (AASHTO) Mechanistic-Empirical Design uses the dynamic modulus (E*) master curve as the engineering property of the asphalt concrete layer to evaluate the structural response of asphalt pavement under various combinations of traffic loads, speed and environmental conditions.

A higher E* property indicates a stronger, more stable mix and leads to lower stresses generated in the asphalt pavement under given loading and environmental conditions. The master curves data in the figure below indicate that the Gilsonite mixtures exhibit significantly higher E* properties compared to the control mixtures over the entire range of loading frequency.

Dynamic modulus master curves for the PG76-16 and PG64-28 mixtures



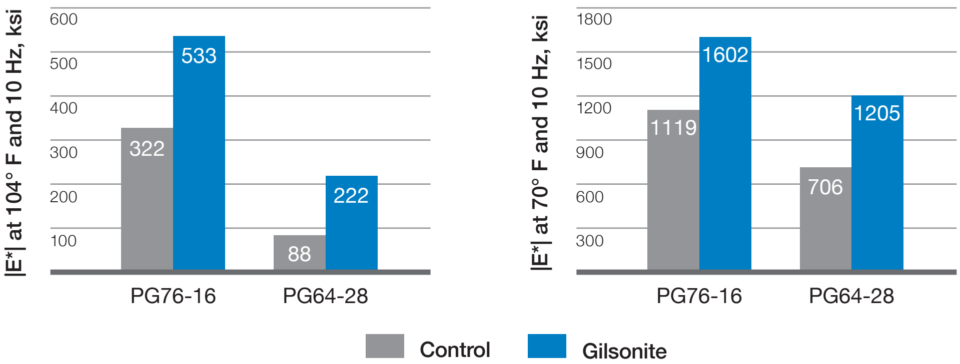
Capturing a range of variables

The dynamic modulus curve represents various combinations of loading frequency and temperature.

The data in the charts below compare the E* property of the mixtures at 10Hz loading frequency representing a truck traveling at 60 mph (108 kph). The 104° F (40° C) and 70° F (21° C) temperatures were selected since they represent the critical temperature of rutting and fatigue, respectively.

Dynamic modulus properties for rutting analysis (short-term aged)

Dynamic modulus properties for fatigue analysis (long-term aged)



The addition of Gilsonite increased the E* property of the PG76-16 and PG64-28 mixtures at both temperatures, indicating a reduction in stresses leading to rutting and fatigue of the asphalt concrete layer.

Gilsonite helps reduce rutting

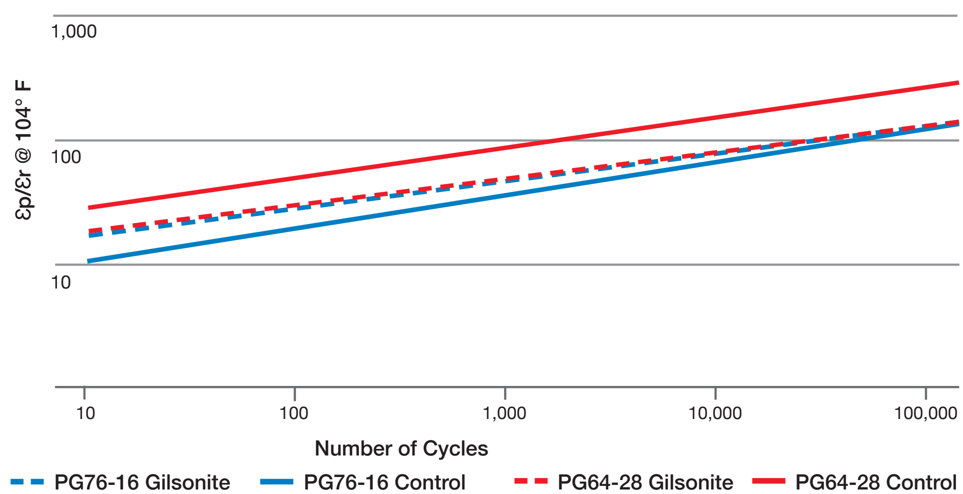
Gilsonite increases the viscosity of asphalt so roadways resist deformation and fatigue, even under temperature extremes.

Resistance to rutting

The flow number property was evaluated to assess the rutting resistance of mixtures and to determine the rutting models coefficients.

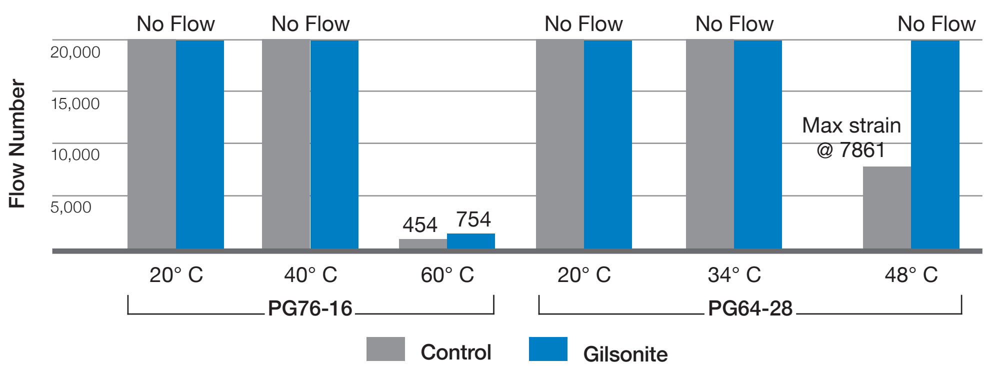
The figure below compares the rutting models of mixtures. The PG64-28 Gilsonite-modified mixture exhibited a lower rutting model at 104°F (40°C) than the control mixture, indicating that the Gilsonite mix would offer higher resistance to rutting. The PG76-16 Gilsonite-modified mixture exhibited a slightly higher rutting model at 104°F (40°C) than the control mixture.

Rutting models of the PG76-16 and PG64-28 mixtures



As shown below, adding Gilsonite to the PG76-16 mixture increased the flow number at 60°C (140°F) by 66% (754 vs. 454). The addition of Gilsonite to the PG64-28 mixture resisted the tertiary flow at 48°C (118°F). This indicates that Gilsonite-modified mixtures will offer significantly more resistance to rutting at the elevated pavement temperature.

Flow numbers of the PG76-16 and PG64-28 mixtures



Relevant sample preparation

Since rutting is an early pavement life failure, the mixtures for the flow number test were only short-term aged.

Resistance to thermal cracking

To determine an asphalt mixture's ability to withstand low temperatures without cracking, tests measured both the temperature at which fracturing occurred as well as the stress required to initiate fractures.

In the PG64-28 samples, both the control and the Gilsonite-modified binders exceeded cold temperature specifications and thus were not expected to crack. The Gilsonite-modified PG76-16 sample showed cracking at 2°C warmer than specifications. However, the calculated crack initiation energy was 20% higher than the control, so it would not be expected to crack under normal conditions.

Thermal cracking properties of the evaluated mixtures

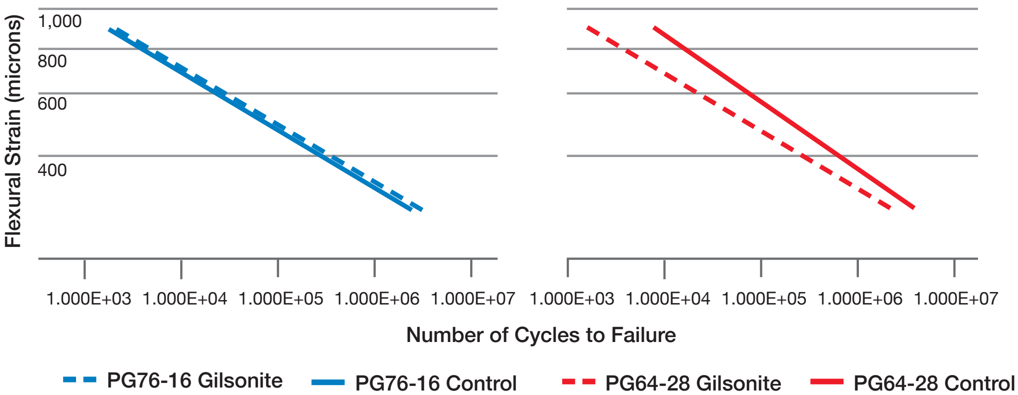
Mix	PG76-16 Control	PG76-16 Gilsonite	PG64-28 Control	PG64-28 Gilsonite
Average Air Voids (%)	6.9	7.1	6.2	7.1
Average Fracture Temperature (C)	-19	-14	-35	-30
Average Fracture Stress (psi)	340	335	550	420
Crack Initiation Energy (Pa/mm/mm)	322	387		

Resistance to fatigue cracking

The resistance of the various mixtures to fatigue cracking was evaluated using the flexural beam test wherein a beam specimen was subjected to a constant bending moment over the center portion of the specimen. Initial flexural stiffness was measured at the 50th load cycle. Fatigue failure was defined as the number of cycles corresponding to a 50% reduction in the initial stiffness.

Figures below compare the fatigue models of mixtures. The cycles-to-failure tests showed similar results for the PG76-16 control and Gilsonite-modified samples. In the PG64-28 mixtures, the control sample exhibited slightly higher fatigue relationships than the Gilsonite mixture. It should be noted, however, that the calculated values do not account for the effect of the much higher E* in the Gilsonite-modified binder.

Fatigue cracking models for the PG76-16 and PG64-28 mixtures at 70°F



Testing at the right time

Thermal cracking and fatigue cracking are later pavement life failures, generally occurring after five years. Test mixtures were aged accordingly.

Mechanistic analysis assesses effect of actual conditions

In addition to sophisticated laboratory tests, the university's evaluation included mechanistic analysis. A lab test designed to compare the fatigue cracking models of two asphalt mixtures only assesses the relative behavior of the mixtures without any indication on their relative impacts on pavement life. The main advantage of the mechanistic analysis is its ability to combine the engineering property of the asphalt mixture (E*) with its rutting and fatigue cracking characteristics to determine the true impact of traffic loads on pavement life.

The analysis evaluated thin pavements – <4" asphalt cement (AC) layer and 8" crushed aggregate base (CAB) layer – and thick pavements – 6" AC layer and 12" CAB layer. Dynamic conditions included the heavy load imposed by a legally loaded 18-wheeler traveling at 60 mph (96 kph) without any braking, and traveling at 10 mph (16 kph) with braking.

The mechanistic analysis of rutting resistance demonstrated that the Gilsonite-modified mixtures had ten times the projected pavement life in every instance except one. For fatigue resistance, the Gilsonite-modified mixtures had a projected pavement life of 1.5 to almost 5 times that of the control mixture.

In theory and in practice

Mechanistic analysis completes the picture begun with lab testing.

Summary of the comparative mechanistic analyses of the various mixtures

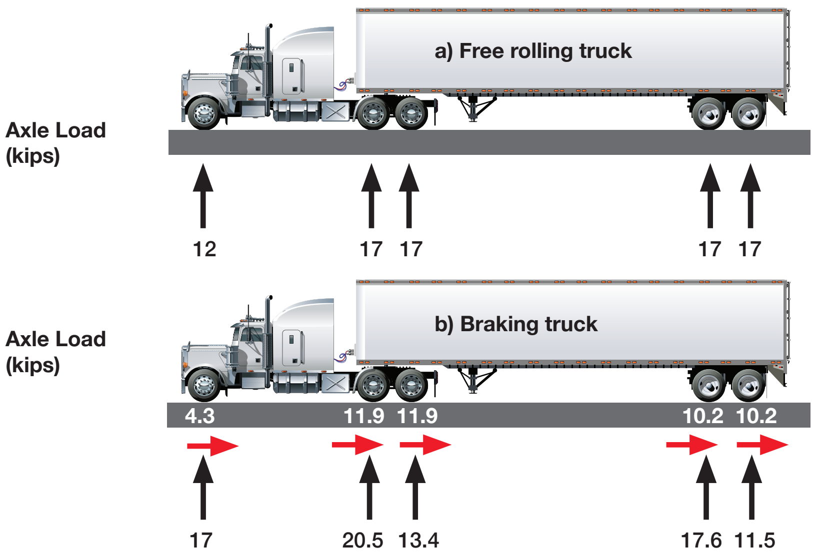
Pavement	Speed	Mixture	Rutting @ 104°F (40°C)			Fatigue @ 70°F (21°C)		
			ε_r (micron)	N_r (million)	Rutting Life Ratio	ε_r (micron)	N_r (million)	Fatigue Life Ratio
Thin 4″ - AC 8″ - CAB	60 No-Braking	76-16C	138	6.8		160	8.7	
		76-16G	82	>100	>10	131	36.7	4.2
		64-28C	429	0.01		196	44.9	
		64-28G	185	6.2	>10	153	>100	2.2
Thin 4″ - AC 8″ - CAB	10 Braking	76-16C	242	0.94		185	3.7	
		76-16G	137	20.4	>10	147	18.0	4.9
		64-28C	1101	No-Design[1]		248	12.2	
		64-28G	350	0.37	>10	181	59.1	4.8
Thick 6″ - AC 12″ - CAB	60 No-Braking	76-16C	134	25.4		98	>100	
		76-16G	81	>100	4.0	81	>100	
		64-28C	400	0.05		120	>100	
		64-28G	178	33.6	>10	94	>100	
Thick 6″ - AC 12″ - CAB	10 Braking	76-16C	230	3.8		114	66.5	
		76-16G	132	>100	>10	90	>100	1.5
		64-28C	1001	No-Design[1]		156	>100	
		64-28G	330	2.2	>10	112	>100	

[1]The type of mixture is not applicable for this condition.

Vertical and horizontal forces affecting pavement life

When an 18-wheeler is in the free rolling condition, the vertical loads are distributed evenly among the various axles. Under braking, there is a significant re-distribution of the vertical loads among the axles and the development of significant horizontal loads at the tire/pavement interface. These horizontal loads significantly increase the shear and vertical stresses within the AC layer and represent the main cause of accelerated failures in rutting and shoving at intersections and on off-ramps.

Distributions of axle loads for 18-wheeler at free rolling and braking conditions



Mechanistic analysis findings:

> The PG64-28 control mixture cannot be adequately designed to withstand the braking action of the 18-wheeler for both the thin and thick pavement structures.

> The PG76-16 and PG64-28 Gilsonite-modified mixtures significantly improved the rutting life of the thin and thick pavements under the no-braking and braking conditions.

> The PG76-16 Gilsonite mixture significantly improved the fatigue life of the thin pavement under the no-braking and braking conditions.

Bearing the load

Mechanistic analysis shows which mixtures significantly improved road life.

Specific conclusions and recommendations

In summary, the evaluation program concluded that the addition of Gilsonite to the PG76-16 neat and PG64-28 polymer-modified asphalt binders resulted in unique, measurable characteristics that offer excellent alternatives in the following situations:

> The PG76-16 mixture provides extremely high resistance to rutting and shoving with excellent long-term aging characteristics for use in the wearing course of asphalt pavements.

> Both the PG76-16 and PG64-28 mixtures provide extremely high resistance to fatigue cracking beneficial for use as the binder/base course of perpetual asphalt pavements.

> The PG64-28 mixture can successfully withstand the braking actions at traffic lights on urban streets and off-ramps.

Cost effectiveness

By imparting properties that increase resistance to rutting, shoving and fatigue cracking, the addition of Gilsonite can significantly extend the useful life of asphalt pavement. Industry reports of Gilsonite-modified asphalt lasting more than twice as long as unmodified mixtures are common.

In addition, the high modulus provided by Gilsonite allows the base and binder courses to be up to 20% thinner while still providing the same level of performance, enabling the use of less material.

Gilsonite can also act as a lower-cost, performance-enhancing extender in a mixture including SBS polymers.

By significantly extending the useful life of asphalt pavement and allowing a reduction in the amount of paving material required, Gilsonite has proven to offer substantial cost effectiveness.

Performing under pressure

Gilsonite has been scientifically proven to help build stronger, longer-lasting roads.