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FHWA-HIF-21-001

Asphalt Rubber Gap-Graded

The asphalt rubber gap-graded (ARGG) mix is a gap-graded asphalt mixture that uses aggregate with a top size of either ⅜ inch or ½ inch, as well as an asphalt-rubber binder containing approximately 20 percent ground tire rubber. Since the asphalt rubber binder provides a greater volume of asphalt due to the rubber particles, the aggregate gradation in this type of mixture is adjusted (gap-graded) to allow for a higher binder content. This type of mixture is very durable with resistance to reflective cracking, rutting, thermal cracking and oxidation, and generally has good frictional characteristics – depending on the aggregate. The compacted thickness of this mixture ranges from 1.25 inches to 2.25 inches, depending on the size of the aggregate used. These types of mixes can be used in a wide range of traffic levels in urban areas with considerable stop and go traffic, such as intersections.

ARGG mixes have been used and evaluated extensively in Arizona and California, and have also been evaluated at the Federal Highway Administration Accelerated Loading Facility, the National Center for Asphalt Technology (NCAT) Pavement Test Track, and in Louisiana, Taiwan, and Sweden. Overall, the various field performance studies carried out in different parts of the world indicate ARGG mixes present enhancement in asphalt pavement performance characteristics with varying traffic and environmental conditions.

A 2002 study by the Turner-Fairbank Highway Research Center using an ARGG test section showed reduction in fatigue and reflective cracking. Similar findings also occurred at the NCAT Pavement Test Track, where ARGG mix has been used as surface, intermediate, and base layers in test sections that were designed around the enhanced cracking resistance.

CalTrans frequently uses ARGG mixes, which it calls rubberized hot mix asphalt-gap graded (RHMA-G). RHMA-G is used as a structural surface course on many projects, and is commonly used to retard reflection cracking, resist thermal stresses created by wide temperature fluctuations, and add elasticity to a structural overlay.

Asphalt rubber gap-graded surface. *Source: National Center for Asphalt Technology*

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Crack Attenuating Mix

Crack attenuating mix (CAM) was originally designed by the Texas Department of Transportation (TxDOT) in 2007. CAM is a fine-graded mixture with a high-binder content that is placed as an interlayer between the existing pavement and a thin asphalt layer to reduce the reflective cracking without jeopardizing rutting resistance. Although CAM typically serves as an interlayer, it has also been placed as a 0.5 to 1-inch thick mat surface course. CAM design relies on the traditional volumetric approach and performance tests (Hamburg Wheel Tracking and Texas Overlay Test).

Even though CAM evolved from the rich bottom layer mixes and both mitigate reflective cracking, CAM is rut resistant, and therefore can be used as a final riding surface. As a surface course, CAM not only meets the structural specifications (resist cracking and rutting), it should also provide enough skid resistance (functional requirement), particularly on high-volume roads with high-speed limits. As such, the use of quality aggregate (high durability and friction) is suggested to alleviate the lack of surface macrotexture due to being fine-graded. Using quality aggregate, as well as around 7 percent polymer-modified binder results in an expensive mix; however, it costs less per square yard because CAM is applied in thin layers.

CAM has been used extensively in the Houston and Dallas districts on top of old concrete pavements. TxDOT reported having successfully used CAM on U.S., interstate, and State highways, as well as farm-to-market roadways, loops, and business highways as both a surface course and an interlayer. It was reported that rutting, in the form of shoving and shear failure, is the predominant distress for surface CAMs, particularly at intersections under the action of heavy stop-and-go traffic.

Crack attenuating mix on Houston's IH-69 project.
Source: Tom Scullion, Texas A&M Transportation Institute

There are several State DOTs including Arizona, California, Florida, Massachusetts, Nevada, Utah, Iowa, and Minnesota that specify the use of specialty mixtures, referred to as stress relief course, to mitigate reflective cracking in asphalt overlays. These mixtures are not necessarily rut-resistant and therefore, they are placed as interlayer mixtures. Cost analysis shows that even though such mixtures have a higher initial cost of materials, the agency and user life cycle costs per lane mile are lower and result in an average 20 percent cost savings.

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Highly Modified Asphalt

The highly modified asphalt (HiMA) mixture is produced using asphalt binder containing 7 to 8 percent polymer, mostly styrene-butadiene-styrene, which is more than twice what is used in conventional polymer-modified binders. By increasing the polymer content, the binder-polymer structure changes from asphalt binder, with a dispersed swollen polymer phase, to a swollen polymer with a dispersed asphalt binder phase. The phase reversal in the HiMA acts as an elastic reinforcement in the asphalt binder and improves asphalt mixture cracking resistance. In addition, considerable improvement to the rutting performance of HiMA mixtures has been reported. A special low viscosity polymer eliminates the compatibility and workability problems during production and construction, as well as concerns associated with heavily modified mixes.

HiMA mixtures have been used over a wide range of applications ranging from full depth to thin asphalt overlays under different traffic conditions. Although long-term pavement performance data for HiMA mixtures are not readily available in the field, where promising performance in early pavement life have been reported, accelerated performance was observed over multiple 3-year research cycles on the National Center for Asphalt Technology Pavement Test Track.

HiMA mixture:

- Offers cost-effective and durable asphalt pavements with a reduced thickness.
- Can be constructed on pavement sections consisting of weak foundation layers.
- Have similar workability as polymer-modified mixtures and therefore, no special plant adjustment is needed for production.

Location	Description
Alabama	• Intermediate course on U.S. 231 • Early rutting in the existing asphalt layer
Georgia	• Thin AC overlay at the junction of Routes 138 and 155 • Rutting and shoving were the main concerns
Minnesota	• Mill and overlay on Normandale Road, City of Bloomington • Subjected to heavy traffic due to its location adjacent to the airport
New Hampshire	• NH Route 101 with a high level of traffic • Mill and fill operation with a 2-inch intermediate course followed by a 1.5-inch HiMA wearing course
Oklahoma	• I-40 (west of Oklahoma City) with 25,300 AADT (17 million ESALs) • Mill and a 1.5-inch HiMA wearing course
Oregon	• Thin overlay on I-5 in Oregon • Ruts and raveling in the existing pavement due to heavy trucks and high traffic volumes
Vermont	• US-7 with 4,500 AADT • Existing pavement with 14 years of service and in “fair to good” condition

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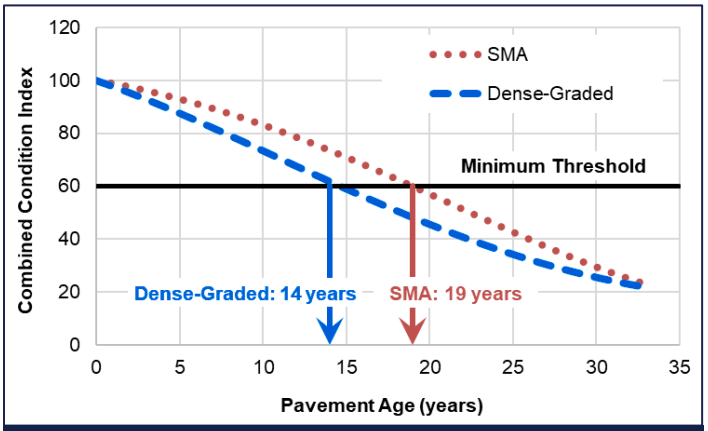
Stone Matrix Asphalt

Stone matrix asphalt (SMA), also called stone mastic asphalt, is a tough and rut-resistant gap-graded asphalt mixture that relies on a stable stone-on-stone skeleton offering strength and a rich mixture of asphalt binder, along with stabilizing agents such as fibers and/or asphalt modifiers that provide durability. SMA was developed in Germany in the 1960s to provide a durable, rut-resistant wearing course resistant to damage from studded tires for heavily traveled roads. SMA was first introduced into the U.S. in the early 1990s and by 2018, SMA was used in at least 40 States. SMA is routinely used by 18 State departments of transportation (DOTs), while it is not a common practice in other States.

SMA mixtures are commonly placed on pavements with heavy traffic such as State and interstate routes, high-stress pavement areas (e.g., intersections, bus stops, and toll booths), thin overlays, airfields, and racetracks due to the expectation of increased service life. There is no consistent conclusion on comparing the cost effectiveness of SMA versus conventional dense-graded mixtures. SMA is generally more expensive than the conventional mixtures, mainly due to higher asphalt contents, specifications for more durable aggregates, and inclusion of fibers as stabilizers. SMA mixtures range between $6 to $31 more per ton than polymer-modified dense-graded mixtures. On the other hand, SMA generally had equivalent or better field performance (varied from 1 to 13 years) than conventional dense-graded mixtures. Thus, selection criteria and policies to identify when SMA should be used are agency specific.



Example of life expectancy for flexible pavements in Virgina. *Source: National Asphalt Pavement Association*

Examples of SMA policies:

- Alabama DOT: Projects with 20-year design traffic greater than 30 million equivalent single axle loads (ESALs); projects with rutting concerns (such as intersections).
- Illinois Tollway: All mainline pavements.
- Maryland DOT: Projects with 20-year design traffic greater than 30 million ESALs; projects with a functional class of principal arterial or greater.
- Virginia DOT: Projects with greater than 3 million ESALs; heavy to extremely heavy traffic volume where the higher cost can be justified with improved performance.
- Wisconsin DOT: Projects with 20-year design traffic greater than 5 million ESALs; projects where low maintenance is beneficial (such as high-traffic areas); projects where SMA is economically feasible.

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Open-Graded Friction Course

Open-graded friction course (OGFC) is a gap-graded asphalt mixture with a high percentage of coarse aggregates that are almost uniform in size resulting in a high percentage of air voids (usually 15 to 25 percent). OGFC is also known as permeable European mix, porous asphalt, plant mix seal, and popcorn mix. Because of its safety and environmental benefits, OGFC has been widely used in Europe (e.g., Netherlands, France, Germany), Asia (e.g., China, Japan, Korea), and the U.S.

OGFC has an open-graded aggregate skeleton with interconnecting voids that provide vertical drainage of rainfall to an impermeable underlying layer, and eventually to the pavement edge. The fast drainage of standing or flowing water from the pavement surface substantially reduces the likelihood of hydroplaning. OGFC is placed as the final riding surface to maintain frictional resistance in wet weather, reduce splash and spray and nighttime glare during wet conditions, enhance the visibility of pavement markings, and provide a smooth pavement.

Reduced splash and spray and improved visibility on OGFC section. *Source: National Center for Asphalt Technology*

Research conducted by several State highway agencies including Pennsylvania, Louisiana, Nevada, New York, Oregon, and Virginia, reported significantly higher skid resistance of OGFC in wet conditions compared to the conventional mixtures resulting in reduced wet weather vehicle crashes and accident rates. However, there is concern associated with the confidence in driving faster on OGFC surfaced pavements, which may result in a higher accident rate. From the environmental perspective, OGFC is effective in reducing the tire/pavement noise and improving the water runoff quality. Tire/pavement noise can be reduced by 3 to 6 dBA, which is equivalent to decreasing the traffic volume by 50 percent or constructing a noise wall.

A National Center for Asphalt Technology 2015 survey revealed 20 States, mostly located in areas with high rainfall intensity, use OGFC mixes. Although OGFC is effective to enhance pavement safety in rainy environments, it imposes challenges in zones where extensive snow plowing is used. More frequent frost and ice formation on OGFC makes it more susceptible to moisture damage and raveling, which results in shorter service life compared to conventional dense-graded mixtures. In addition, the material cost of OGFC is usually 20 to 40 percent higher than conventional mixes.

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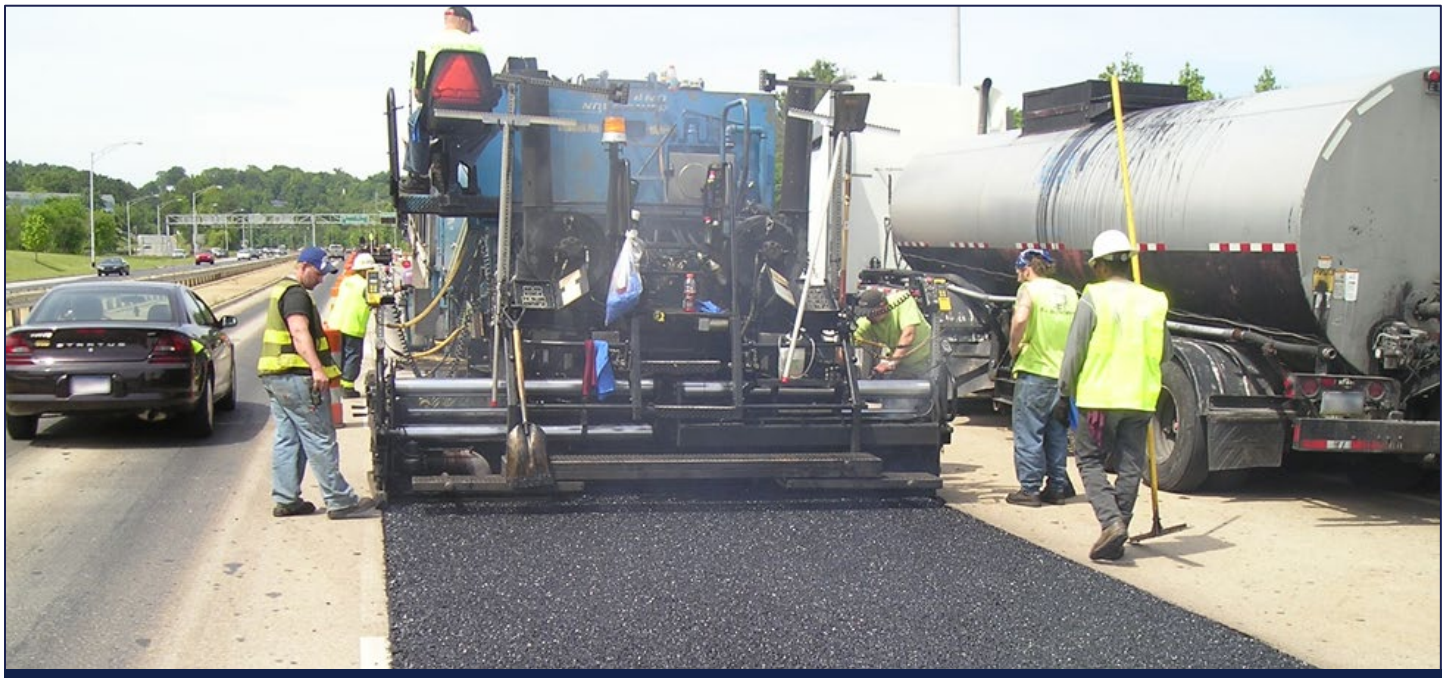
Ultra-Thin Bonded Wearing Course

Ultra-thin bonded wearing course (UTBWC) is a thin (3/8 inch – 3/4-inch-thick) open-graded asphalt layer placed on a polymer-modified emulsified asphalt membrane. A specialized paver is used to place the emulsified asphalt membrane and then the polymer-modified asphalt mixture on the surface in a single pass. It is used as a treatment method on asphalt pavements to correct surface distresses such as raveling or minor cracking or restore surface characteristics such as friction and smoothness. The open surface texture can reduce noise as well as splash and spray. These mixes are suitable for all types of asphalt and concrete pavements and have demonstrated performance for preventive maintenance on major urban highways as well as residential streets.

UTBWC mixtures were first introduced in the U.S. in 1992, with successful projects constructed in Texas and Alabama. In 1993, additional projects were built in New Jersey and Pennsylvania, followed by other projects in the northeast. Since 1998, the use of UTBWC has spread throughout the U.S. and has been successfully used on projects from Florida to California, and as far north as Minnesota and Maine.

The Minnesota Department of Transportation (MnDOT) may have the most experience with UTBWC mixtures. MnDOT began using it in 1999, and has built more than 40 projects in metro areas, including I-35, I-394, I-494, U.S. 10 and U.S. 52; and approximately 20 projects in non-metro areas, including projects on I-94, and U.S. 10.



Crews place ultra-thin bonded wearing course. *Source: National Center for Asphalt Technology*

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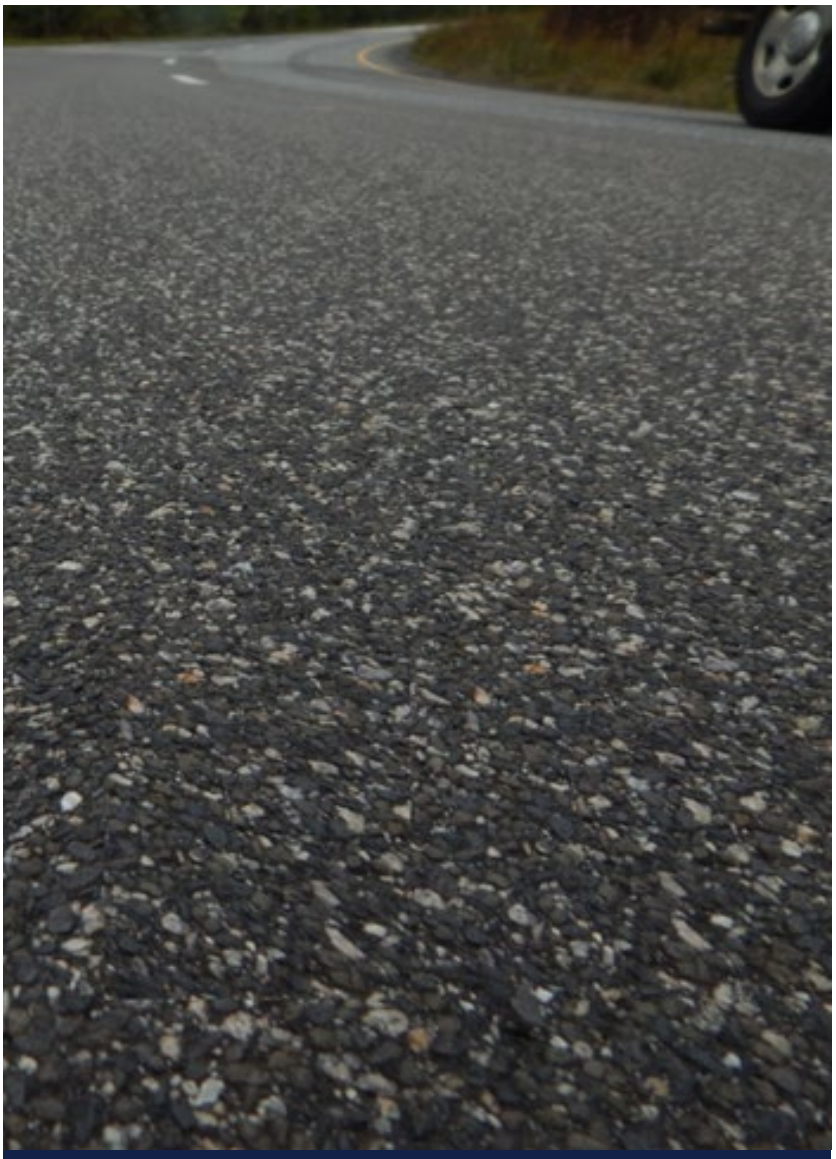
Enhanced Friction Overlay

The enhanced friction overlay (EFO) is a 4.75 mm nominal maximum aggregate size gap-graded mixture that uses enough calcined bauxite (~40 percent) to enhance friction. Calcined bauxite is a hard, angular aggregate, which enhances friction when exposed on a pavement surface. Calcined bauxite is commonly used in high-friction surface treatments (HFST). The EFO uses a polymer-modified asphalt binder and has a gradation and appearance similar to a stone matrix asphalt mixture. As such, it typically has a higher asphalt binder content (~8 percent) than conventional mixtures.

The EFO mixture is most suitable in locations with higher crash rates due to inadequate pavement friction, such as horizontal curves, deceleration ramps, and intersection approaches. It can be placed on either milled or unmilled surfaces and has a total compacted thickness of ¾ inch. Preliminary studies indicate the EFO has comparable friction values to HFST with the expectation of better longevity and reduced cost.

As of late 2020, EFO has only been placed on the 2015 research cycle and is still in service in 2020. Through 12½ million equivalent single axle loadings, the frictional characteristics of the EFO are comparable to the values measured on the HFST at the same level of loading.



Enhanced friction overlay in horizontal curve on National Center for Asphalt Technology (NCAT) Pavement Test Track. *Source: NCAT*

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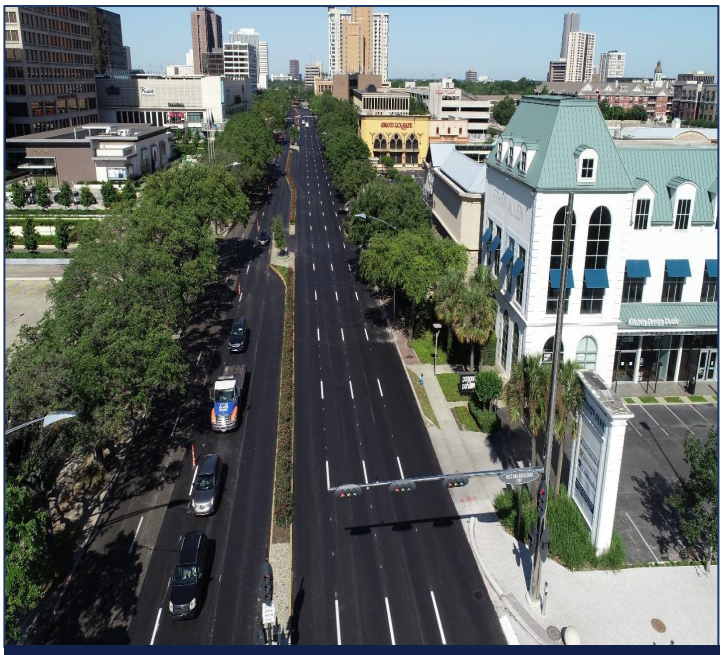
High-Performance Thin Overlay

High-performance thin overlay (HPTO) mixture is a fine-graded polymer-modified asphalt mixture that uses aggregate with a top size of approximately ⅜ inch. It is designed using a modified Superpave design methodology with restrictions on the use of reclaimed asphalt pavement and sand. It is performance tested for rutting and cracking resistance during design and production. HPTO mixes are typically used in maintenance and pavement preservation applications, but can also be used as a leveling course when extended staging times are expected for temporary pavements during construction. It is a rut-resistant and durable mixture most often placed at a thickness of 1 inch either on a milled or unmilled surface. HPTO has been used as a maintenance application on high-volume interstate projects and on heavy-duty parking lots.

Two States with experience using HPTO mixes are New Jersey and Texas. New Jersey Department of Transportation (DOT) has used HPTO mixes on numerous interstate projects such as I-295, I-287, I-280, and at least 16 other projects statewide. Texas DOT also has significant experience with the HPTO mix, which it refers to as thin overlay mix or TOM, having placed more than 1,500 lane miles. It is Texas DOT's surface of choice in both Houston and Austin and has been used on I-35, I-45, and I-10 with average daily traffic counts in excess of 300,000 in both directions. Other States have used HPTO on lower-volume roadways, such as the West Virginia Division of Highways, which placed a section on County Route 9 in Beaver, West Virginia.

HPTO thickness
Source: West Virginia Division of Highways



Houston's Westheimer Project (2020)
Source: Stacy Hilbrich, Angel Brothers, Inc.

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