Diamond Grinding:

A Safe, Sustainable, Quiet and Cost-Effective Solution to Better Roadways

Over the past hundred years, the expectations and capabilities of highways have shifted. In the 21st century, drivers and passengers expect long lasting, efficient, comfortable and safe travel on highways. Engineers can achieve those standards—and also meet the challenges of sustainability, noise levels, urban head island effect and budget—through the use of pavement diamond grinding.

IGGA
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Diamond Grinding Offers Solutions to Many Pavement Challenges

Highways have come a long way over the last 100 years. In generations past, the goal of roads was to keep people and goods moving to market and prevent vehicles from getting stuck in the mud of country roads. In the 21st century, the expectations and capabilities of highways have shifted. Today, users expect long lasting, efficient, comfortable and safe passage from location to location. When evaluating pavements for surface characteristics, three of the most important considerations are sustainability, safety and comfort. There are many statistical realities that engineers can take advantage of when trying to achieve these goals.

First implemented in the early 1960s, pavement diamond grinding is the process of stacking diamond saw blades next to each other on a machine-driven shaft. As this shaft spins, the diamond blades are lowered on to the surface of the pavement. They abrade the surface when they contact the pavement material, removing high spots in the road profile and leaving behind a superior surface texture.

Diamond grinding is like using a belt sander to remove edges and knots from a wood plank. By making the surface smoother, the number of localized and continuous elevation changes in the pavement surface are reduced.

Diamond grinding has many additional benefits, particularly related to carbon and cost savings, less vehicle wear and tear, and increased safety.

A Pavement that Lasts

In a 2000 article by the FHWA, **Enhancing Pavement Smoothness**, data was evaluated showing that the smoother a pavement is, the longer it will last. This is the result of reduced frequency and severity of dynamic loads applied to the pavement surface.

Vehicles bouncing due to a bump can result in an impact load more than 1.5 times the design capacity.

Highways typically are designed for 18-kip axel loads. When vehicles bounce due to a bump, the weight of the vehicle paired with the down force induced by gravity can result in an impact load more than 1.5 times the design capacity. When this increased loading continuously happens throughout the day, the structure of the pavement can experience significant fatigue. This premature breakdown of the pavement structure will cost owner agencies because they will not experience the expected lifespan of their investments. Similarly, the surface deterioration of these failing pavements will create cracks and potholes that pose a safety risk to the traveling public.

Three years of maintenance neglect resulted in six times the repair cost; five years resulted in up to 18 times the repair cost.

The longer maintenance needs are left unattended, the more likely issues will expand—which can quickly increase the cost to repair. Surface damage that is fixed almost immediately may have negligible negative impact to users and modest repairs costs, but damage left for an extended period can propagate an area of structural damage, requiring a more expensive repair in the future.

Transport Notes from the World Bank evaluated the relationship between maintenance timing and cost on South African highways. It was determined that three years of maintenance neglect resulted in six times the repair cost. **Five years of neglect resulted in up to 18 times the repair cost**. This relationship is due to the level of invasive work required to remediate a pavement section.

For example, if a concrete pavement suffers from slab curling, the very cost-effective diamond grinding treatment can be performed using heaving machinery and minimal hand work. However, if that pavement is left to be beaten by dynamic loads for an extended period, the need for crack and full-depth repairs will be more prevalent—and drive-up costs.

Reducing the International Roughness Index (IRI) before significant damage is done will mitigate this untimely wear and tear on pavements, resulting in a more efficient use of tax dollars and building materials.

CASE STUDY: ASSET MANAGEMENT IN ARKANSAS

The Arkansas Department of Transportation (ArDOT) collects data on interstates every year. Once data collection is complete, it is processed and a pavement condition index (PCI) summary is calculated, using a weighted average of four types of pavement metrics: environmental cracking, structural cracking, roughness, and rutting. Conditions are assessed using FHWA threshold criteria for each 1/10-mile-long pavement section. The index is then used to assign a pavement condition rating, or "grade," which describes the pavement condition of the state highway system as good, fair, or poor.

Pavement Preservation Efforts Maintain Rideability at a Competitive Cost

Several sections of the pavement on I-40 in Arkansas are constructed of concrete, and a 4.3-mile section in Johnson County, constructed in 2002, provides one example of the advantages of pavement preservation. This portion of I-40 sees an average daily traffic (ADT) of 28,000 vehicles per day, with 36% of that traffic being trucks. The pavement is constructed of a 4-inch stone base, 4-inch treated permeable base and 12-inch jointed concrete pavement. The outside lane is 14 feet wide with an 8-foot asphalt shoulder. The cost of the 12-inch concrete pavement at the time of original construction was $24.15 per square yard in 2002 dollars, for a total of $9.4 million. At the time of construction, the pavement had an average international roughness index (IRI) of approximately 100 inches per mile. Pavement preservation was triggered in 2019 when an IRI of 112 was measured, since the department's goal is to keep IRI measurements close to 100. No maintenance had been performed on the pavement since it was built; the only maintenance activities had been periodic asphalt shoulder patching and cleaning of edge drains.

In 2020, the department performed the concrete pavement preservation (CPP) work. The existing pavement was in excellent structural condition with very few cracked slabs, so CPP consisted of patching 138 square yards—or 0.1% of the area—along with diamond grinding for smoothness and joint rehabilitation. The project was ground to an average IRI of 43 inches per mile. The cost for diamond grinding was $825,000 and the cost for joint resealing was approximately $300,000. The total cost for the project was $1.125 million, or $65,400 per lane mile.

Based on the positive outcome of the original concrete construction, combined with diamond grinding and other minimal CPP at the 15- to 18-year point, ArDOT integrated additional diamond grinding and CPP into its road management efforts, notably planning their use on two large sections on I-30.

Save On Fuel

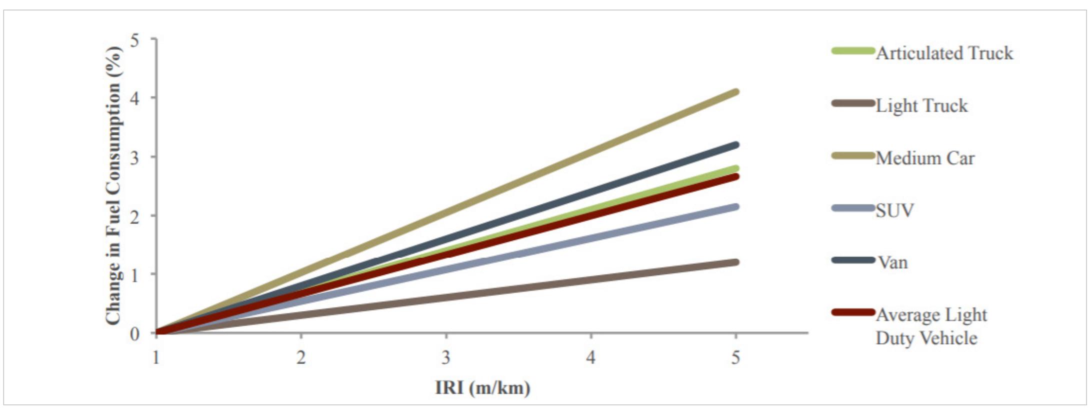
With more attention than ever being focused on energy conservation, vehicle fuel efficiency, and new alternatives such as hybrid cars and biodiesel, few people realize the significant impact that road rehabilitation methods like diamond grinding can have on energy use.

Research by the MIT Concrete Sustainability Hub concluded that roughness and deflection of pavements impact the fuel economy of vehicles that traverse the pavement. When the surface of a pavement is smooth, vehicles traverse it more efficiently, with more of the expelled energy dedicated to forward movement rather than fighting vertical bouncing movements.

When highway maintenance crews reduce the IRI of a pavement by 40%, it saves truck operators about .002 gallons of diesel or about .7 cents per truck per mile, according to **IGGA's Fuel/Carbon Savings Calculator**. While this figure seems negligible, it has a significant impact when entire highway sections are evaluated.

Even when considering alternative fuel vehicles, such as electric vehicles (EV), it is important to recognize that the battery of an EV traveling on a smooth, diamond ground pavement will carry the vehicle for a longer distance because it can move more efficiently. Although at this time research has not been done to show exactly how much improvement takes place, MIT researchers suggest the expected increased distance would be the same as the percent of fuel saved for their gasoline-powered counterpart.

By removing faulting, slab warping, studded tire wear and unevenness resulting from patches, diamond grinding creates a smooth, uniform pavement profile. The longitudinal texture created by diamond grinding also enhances macro texture and skid resistance in polished pavements.



» *From the MIT Concrete Sustainability Hub.*

How Much Fuel Can Be Saved?

The Federal Highway Administration (FHWA) provides data about the fuel used in various aspects of highway construction including hauling, site preparation, producing materials and placing (construction). Using FHWA's information, the diesel fuel used to build a mile of asphalt and concrete pavements can be calculated and is compared in the ACPA document **QD023P**.

Using that FHWA information, as well as information from actual diamond grinding and joint resealing operations, the table compares the fuel consumption of a typical 3-inch asphalt overlay over an existing concrete pavement. It also compares the fuel consumption of a typical milling and 2-inch overlay operation that repairs a concrete road previously overlaid with asphalt. It then compares the fuel consumption for both options to diamond grinding and joint resealing.

- » It takes an average of 3,215 gallons of fuel per mile to place a 3-inch asphalt overlay over an existing concrete pavement.
- » It takes an average of 3,043 gallons of fuel per mile to mill and overlay with 2-inches of asphalt, a concrete pavement previously overlaid.
- » It takes an average of 935 gallons of fuel per mile for diamond grinding and joint resealing.

DIAMOND GRINDING USES FEWER RESOURCES

Research shows a **correlation between rough pavements and reduced driving speeds**, which can lead to congestion. Pavement congestion can increase drive times and idle time on highways, resulting in higher fuel consumption. Smooth pavements can help increase driving speed thus reducing roadway congestion.

The nature of diamond grinding makes it one of the most efficient pavement preservation techniques. It can be completed in short lane closures for less time than typical asphalt overlays, and may even be performed in a rolling closure next to live traffic.

Overlays require the mining, producing, and hauling of virgin material. Each one of these steps has a significant cost and carbon impact to the project. Comparatively, a diamond grinding project only requires the removal of a small amount of material from the jobsite in the form of slurry.

It is also important to consider the life-cycle cost of paving and rehabilitating both types of pavement surfaces. An asphalt surface should be replaced approximately eight to 15 years into its life with a new layer of asphalt. In that time frame and given the material hauling parameters, it is unlikely that asphalt overlays have the opportunity to be cost or carbon neutral. Diamond grinding on concrete pavements can last decades before requiring remediation. Pair this with the aforementioned material mining and hauling benefit, as well as the re-opening of concrete surfaces for carbon sequestration, and cost carbon neutrality becomes commonplace for diamond grinding. Highways with heavy traffic can even show a net negative cost and carbon impact.

In fact, milling an asphalt overlay off an existing concrete road and then diamond grinding can be even more fuel efficient than milling and replacing with a 2-inch new overlay.

DIESEL FUEL USED DURING REHABILITATION

(Gallons per mile on a 12-foot-wide pavement)

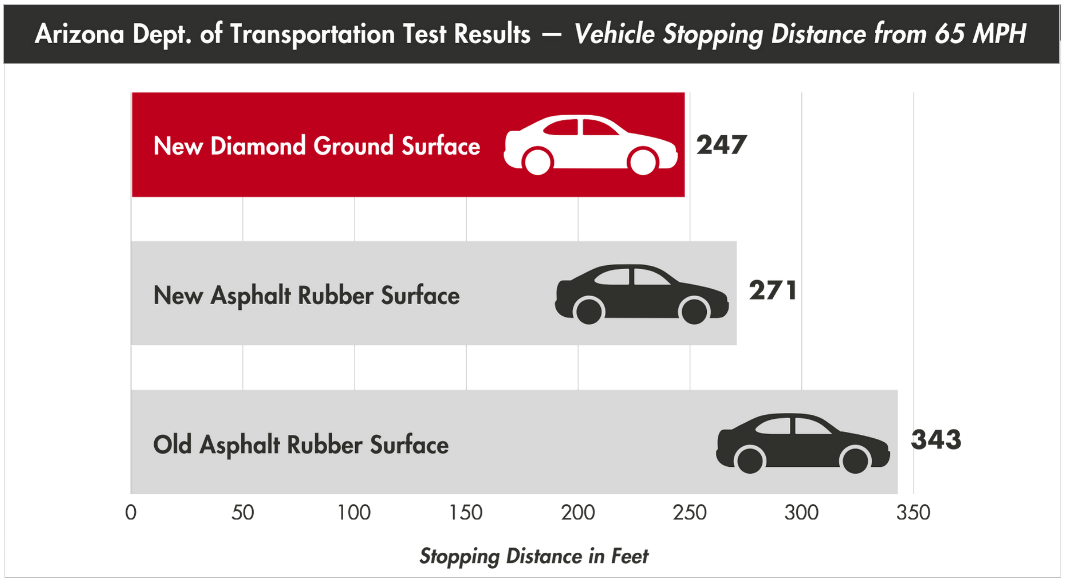
Asphalt Overlay (3")	Low	Average	High
Production	1940	2694	3880
Hauling (0-10 miles)	310	366	377
Placing	66	155	221
Asphalt Total	**2316**	**3215**	**4478**
Mill & Asphalt Overlay (2")			
Mill & Sweep	785	900	1035
Production	1350	1796	2510
Hauling	215	244	250
Placing	43	103	145
Mill & Asphalt Overlay Total	**2393**	**3043**	**3940**
Diamond Grind & Joint Reseal			
Diamond Grinding Operation *(includes all support vehicles)*	585	670	825
Joint Sawing & Resealing	255	265	280
Grind & Reseal Total	**840**	**9353**	**1105**

Safer Surfaces

Highway users are constantly at risk of motor vehicle accidents. Rough pavements increase this risk because they can cause the suspension of the vehicle to bounce. In extreme instances, this can result in tires leaving the surface of the pavement, causing them to momentarily lose friction. Potholes also can jolt the steering mechanism of a vehicle, causing the operator to lose control. Proactive drivers may even swerve to avoid potholes, causing them to depart from their driving lane and increasing the risk of contact with vehicles in adjacent lanes. Surface irregularities may impact drainage during wet weather events, increasing the risk of hydroplaning.

Additionally, aggregates (rocks) dislodge and ravel out of an asphalt rubber overlay as it ages. These loose rocks lay on the pavement, acting like marbles on the roadway surface and reducing the braking ability of tires. This raveling of the pavement is also the reason the asphalt rubber gets louder over time.

The University of Maryland compiled data from the United States, Australia and New Zealand. The results suggested **a linear correlation between pavement roughness and vehicle accidents**. The document also noted that pavements with 10 millimeters (mm) of rutting showed a higher risk and higher severity of vehicle accidents.



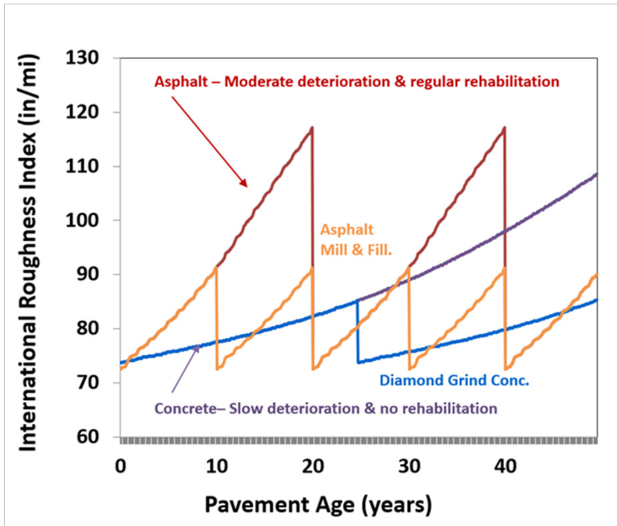
» *From the Coalition for Responsible Roads.*

Concrete pavement preservation (CPP) with **diamond grinding is proven to be safer**, with 42% fewer accidents in all-weather conditions when compared to a tined pavement surface. And construction required to perform diamond grinding is a safer alternative as well.

Diamond grinding can be constructed all year long in day and night shifts without closing the freeway. This allows for construction at times that least impact the consumer, unlike asphalt rubber, which can only be placed during certain times of the year. Diamond grinding significantly reduces the amount of traffic congestion and consumer delays during construction as well, which results in far fewer accidents.

SAFE SURFACES REDUCE VEHICLE MAINTENANCE

The FHWA recognizes that smooth pavements reduce the need for maintenance on vehicle suspension and tires. Research cited in **the Journal of the South African Institute of Civil Engineering** concluded that in 2004, California drivers using roads in disrepair paid an average of $700 in vehicle maintenance and replacement cost compared to a national average of $400.



The 43% increase in repairs to vehicles associated with road roughness was coined "the hidden tax of California road users." These costs are significantly more when applied to commercial trucking equipment compared to passenger vehicles. This same function also translates to the goods being transported, as rough roads impact the condition of products before hitting store shelves.

Tests have shown that roughness, as measured by the IRI, grows faster on asphalt versus concrete and asphalt will be rougher at 20 years old. Concrete pavement experiences a much slower deterioration and can take decades to reach the same condition level. Mill and fill must be performed on asphalt pavement about every 10 years to keep roughness under control; even then, it experiences periods of poor condition compared to concrete, which can be diamond ground every 25 years and remain fairly smooth. Because CPP-treated pavements stay smoother, they provide a quieter, better ride for motorists as well.

Lower Roadway Noise

Rough pavements and transversely tined pavements have a **higher decibel reading** compared to smooth and longitudinally ground pavements. According to the FHWA, highway noise is typically 70 to 80 dB(A) when standing 50 feet from the highway. Sounds in excess of 80dB(A) can cause hearing damage after extended exposure.

The World Health Organization (WHO) attributes excess noise pollution to social, physical and mental health issues. Highways that run through urban areas can make it difficult for people to carry on conversations and interrupt concentration, having a negative social impact. Excess background noise has been shown **to increase heart rate as well as increase potential for mental health episodes**, creating an increased risk of physical harm, according to the WHO.

Typical building codes for noise in the United States requires 45 to 55 dB(A) in living spaces during the day. This means that highway noise in urban areas must be kept at manageable levels to allow developers to build livable communities near highways.

CASE STUDY: CALIFORNIA STATE ROUTE 85 TESTED FOR QUIETEST PAVEMENT

Route 85 near San Jose, Calif., has a high level of traffic—and noise is a major concern for local residents. With a truck ban in effect for Route 85, the main traffic noise source is from the interaction between passenger vehicle tires and the pavement surface. Parts of Route 85 are depressed and there are sound walls along the roadway. Previous noise studies have indicated that raising the height of the existing sound walls would not be effective in further reducing the noise levels.

In response to these issues and complaints from the local citizens, a .88-mile diamond grinding test section was constructed between DeAnza Blvd. and Saratoga Ave. The citizens responded favorably to the test section. In June 2005, Caltrans contracted with Illingworth and Rodkin, Inc., to conduct tire pavement noise evaluations of the existing longitudinal tined surface and the diamond ground texture.

The tire pavement noise evaluations found the diamond ground surface was almost 2.5 dBA lower in overall noise level and exhibited significantly less variability. The frequency content of the diamond ground texture was superior to all others, particularly in the 800- to 1,250-hertz range where human hearing is particularly sensitive to these frequencies. According to the Valley Transit Authority (VTA) project report, "diamond grinding caused a downward shift in the tonal characteristics of the sound and decibel reductions at frequencies that are easily heard by human ears."

The public responded favorably to the test section and, as a result, the VTA constructed a full-scale diamond grinding and grooving project on Route 85 between I-280 and Highway 87 in 2005. The goal of the project was to remove the roadway's existing surface texture that was creating the offending sound. For the safety of the public and construction workers, traffic control measures including temporary lane closures and detours were used when needed. The cost of the project, which began in mid-2005 and was completed in mid-2006, was $9 million.

The result for the citizens who had complained of noise from the highway before the changes is a quiet highway that has significant reduction in decibels and improvement in tonal qualities. The result for taxpayers is a low-noise highway surface that will last for the next 15 years or more.

Diamond Ground Concrete Proves to Be an Effective Way to Preserve Pavements

Since its inception in the 1960s, diamond grinding has proven time and again to be the best solution to many common roadway issues. From its ability to provide a long-lasting surface for motorists while also reducing fuel and maintenance costs, to its natural tendency to capture carbon and reduce greenhouse gas emissions, diamond ground concrete pavements are a cost-effective option for roadway repair and replacement.

Reduce IRI and Improve Roadway Smoothness

As old concrete pavements begin to wear, they can lose their friction properties. Maintaining these properties is key to keeping highway systems safe for consumers. The **State of Wisconsin determined** that diamond ground surfaces resulted in a 42% reduction in all-weather vehicle accidents and a 57% reduction in wet weather accidents when compared to tined surfaces.

In a publication in the ***Journal of Performance of Constructed Facilities***, data was evaluated to determine estimated expected performance improvements due to diamond grinding in Texas. Data showed a single pass of diamond grinding reduces IRI by approximately 40%. Many contractors affiliated with IGGA have reported even better results.

When encountering extremely rough or faulted pavements, a high-quality finish can be achieved by implementing a light bump grind first to remove localized roughness before the full production grind. The same Journal entry also reported a 30% improvement in skid number (SN), the metric used to identify friction issues in pavements.

CASE STUDY: KENTUCKY IMPROVES SMOOTHNESS WITH DIAMOND GRINDING

Through implementing pavement management systems, Kentucky serves as an example of successfully staving off the need for extensive and expensive pavement reconstruction. By exploring the options available with CPP, the Kentucky Transportation Cabinet made strides in determining data that can be used to trigger CPP.

The most common CPP technique used in Kentucky is diamond grinding. The state has been performing diamond grinding since the mid-1990s, but at that time they were just exploring options—little diamond grinding was being done. That changed in 2007, when the state increased its pavement preservation activities in an effort to improve the roadway system.

Between 2007 and 2012, 536 interstate lane miles were diamond ground statewide, primarily in the Louisville area. During this period, IRI measurements for Kentucky's interstate concrete pavements improved from an average of 112.1 inches per mile to an average of 74.5 inches per mile—the longest sustained improvement in the state's IRI and their lowest recorded average IRI ever. The improvement was attributed to the 536 miles of diamond grinding that had taken place.

The combined cost of the diamond grinding projects (including traffic control, patching, joint resealing and more) was $101 million, or $188,000 per lane mile. Reconstruction costs would have been an estimated $1.5 to $2.5 million per lane mile, so CPP saved the state more than $1 billion. The expected pavement life extension for ground pavement is 10 to 15 years. The average cost of diamond grinding in Kentucky during this five-year period was $2.75 per square yard.

Of the state's approximately 62,000 lane miles of roadway, about 1,800 are concrete; 820 of their 3,800 interstate lane miles are concrete. Therefore, finding an effective way to prolong concrete pavement life while improving performance is vital.

When assessing its road network for needed repairs, the main indicator that Kentucky uses is pavement smoothness. Inertial profilometers are used to annually measure roughness on the interstate system and IRI values greater than 130 inches per mile will generally trigger CPP.

Undertaking CPP is contingent on a situation in which there is moderate to low cracking and faulting. (Kentucky defines low faulting as ¼ to ½ inch. Faulting greater than ½ inch generally would necessitate full restoration rather than preservation.) Similarly, if a third or more of the slabs needed replacement, full restoration typically would occur. Pavements with IRI measurements lower than 130 still could trigger CPP if it appeared that cracking and faulting were about to become a major problem; conversely, if a road is expected to require major work (such as widening) within the upcoming five to 10 years, the cabinet will not recommend it for CPP.

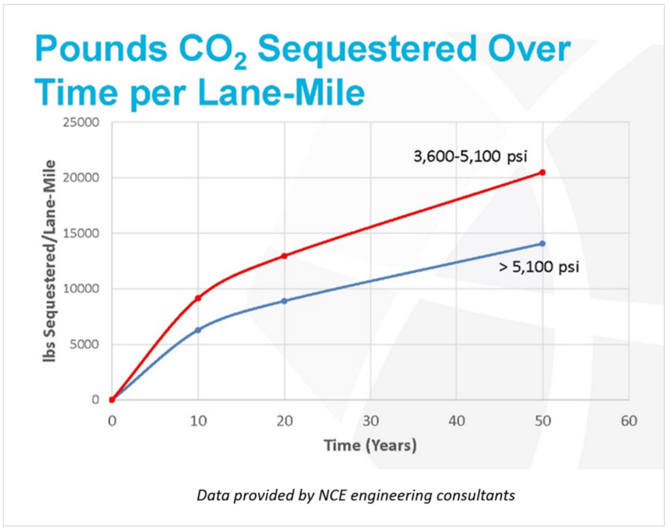
Inherent Sustainability

While new technologies and modes of transport receive a lot of attention as carbon-reducing strategies, traditional pavements—specifically, concrete pavement—also can offer sustainability benefits. Concrete's sustainable qualities, especially when paired with diamond grinding, are numerous. Diamond ground concrete pavements require little maintenance when compared to heavily modified thin-lift asphalt treatments and are naturally sustainable with the following attributes:

- Concrete pavement is produced locally, with local labor, supporting local communities, which is great for the economy.
- Concrete has a high level of light reflectivity, making it safer to drive on at night. During the day, heat and light are reflected, reducing urban heat islands (UHI).
- **Concrete pavement increases fuel efficiency by 3% to 7% for semitrucks** (saving 40 gallons per 1,000 miles driven) with similar savings in cars and light-duty trucks.
- Concrete is not petroleum based. There is no odor or stench when concrete pavement is placed or reheated daily by the sun.
- Concrete is fully recyclable; more than 140 million tons of concrete are recycled and reused every year.

In addition to carbon-reducing changes occurring at the materials production level, in-service concrete contributes to carbon neutrality by absorbing atmospheric carbon.

This carbon capture, known as carbonation, occurs when hydrated portland cement is exposed to atmospheric CO2, which reacts with the water and calcium compounds in concrete and produces calcium carbonate. Carbonation takes place over the lifetime of a pavement; while there is a risk of the rate of carbonation slowing over the years due to the pore-blocking effect of the calcium carbonates being formed, it is possible to remove the carbonated surface and expose a fresh, uncarbonated layer.



» *Over a time span of 50 years, concrete achieves carbonation of roughly 14,000 to 20,000 pounds per lane mile.*

The simplest way of doing this is by diamond grinding—a technique that is commonly performed as part of pavement preservation. Diamond grinding as often as every 10 to 15 years will enable a concrete pavement to restart the carbonation process and continue offsetting the carbon emitted by concrete production.

After only 3.5 years of service, diamond ground pavement will be carbon negative.

For example, Chisago County, Minn., diamond ground 26.4 lane miles on I-35 and measured the carbon savings. Using the **fuel/carbon calculator** available on the IGGA website, it was determined that while the carbon dioxide released by equipment to perform the work was around 500,000 pounds, the annual carbon savings associated with improved ride quality and carbon sequestration was 152,000 pounds. That means that after only 3.5 years of service, the pavement will be carbon negative. While the cost of diamond grinding was approximately $850,000, the 10-year cost savings for users was in excess of $3.5 million in fuel alone—$66,000 dollars in estimated fuel savings or 16,139 gallons per mile per year.

Harness the Power of Data

The amount of carbon offset achieved via carbonation can be impressive. According to the MIT CSHub, carbonation “has been estimated to offset up to 43% of calcination emissions that occur during cement production.” But how can one determine the actual amount of carbon capture that is occurring on a given stretch of concrete pavement? The answer is to quantify inputs, then perform the carbon accounting.

To help with this, MIT’s CSHub has made available a material- and facility-specific calculator for carbon uptake in concrete. With its broad focus—initial concrete mixture, location and exposure characteristics during the concrete’s service life, and eventual stockpiling conditions—the tool can help users assess the true rate of carbon capture for a given area of installed concrete.

Diamond ground pavement is carbon negative and has a higher ROI than asphalt overlayed sections.

Many engineers lean on asphalt overlays as the most effective repair method for ride quality and surface texture issues. While in extreme cases this may be the best viable solution, the mining of new materials, hauling of new materials to a job site, and loss of carbon sequestration benefits make asphalt a more expensive and less environmentally conscious choice when compared to diamond grinding.

While a diamond ground surface can remain effective in excess of 20 years, Asphaltmagazine.com states asphalt overlays of concrete can last about 12 years when properly maintained. Twelve years of service is not enough time to offset the environmental benefit of a smoother riding surface. A diamond ground pavement is the only carbon negative surface treatment with a higher return on investment than asphalt overlayed sections.

Lower Temperatures

Heat is the number one weather-related killer in the United States, and city planners and other decision-makers are beginning to consider ways to enhance urban heat island (UHI) resilience.

The UHI effect is caused when features of the built environment absorb and re-emit the sun's heat more than a natural landscape. Concrete pavements are lighter in color than asphalt pavements and twice as reflective when new, leading to a reduced UHI. The result is lower temperatures in the areas surrounding concrete pavements that have been remediated using diamond grinding as opposed to ones overlayed with asphalt.

A surface's degree of reflectance is known as its albedo, which is expressed as a numerical value between 0 and 1. A light-colored object has a high albedo—near 1, or 100% reflectance. A dark-colored object has a low albedo—closer to 0.

The albedo of a new asphalt pavement is about 0.05. Aged asphalt, which has faded to a lighter color, generally has an albedo between 0.10 and 0.18. New, cured gray cement concrete pavement, however, has an albedo in the range of 0.35 to 0.40. As concrete ages, it tends to darken because of dirt and tire wear, so older concrete may have an albedo in the range of 0.20 to 0.30. The use of light-colored aggregates, white cements and slag cements can improve albedo; white cement concrete pavements have albedos in the range of 0.70 to 0.80 when new and 0.40 to 0.60 after aging.

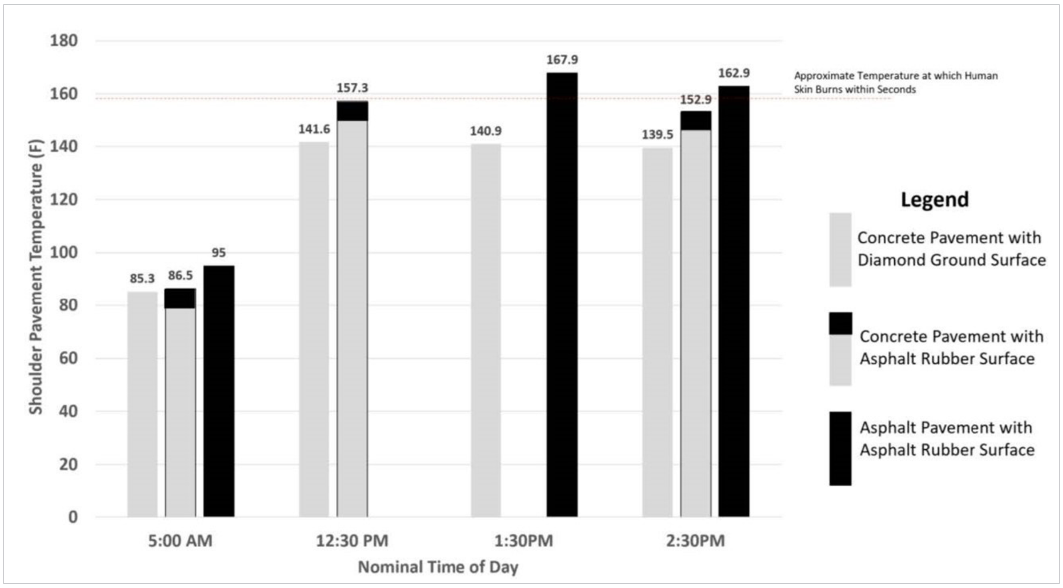
Concrete surfaces become darker over time due to oxidation and petroleum-based fluids leaking from vehicles. Diamond grinding removes this darkened layer, re-establishing the like-new light color of the pavement and enhancing the reflective nature.

CASE STUDY: HIGH ALBEDO LOWERS TEMPERATURES

Phoenix is one of the nation's fastest-warming big cities. In August 2021, IGGA partnered with the American Concrete Pavement Association (ACPA) to conduct infrared testing of diamond ground concrete and asphalt-rubber-surfaced pavements in the Phoenix area.

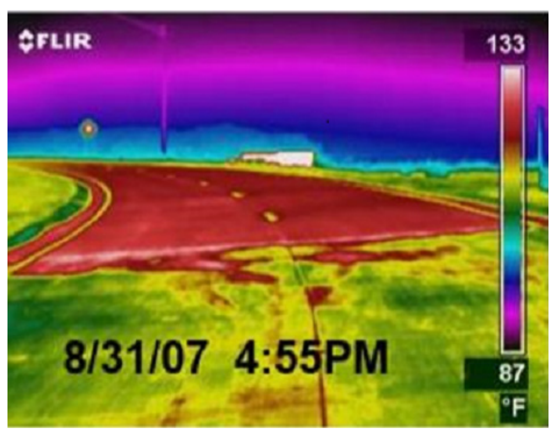
Data was collected for three pavement structures on eastbound SR 202 between 40th Street and Dobson Road.

1. A concrete pavement with a diamond ground surface.
2. A concrete pavement overlaid with a 1-inch-thick asphalt rubber surface.
3. An asphalt concrete pavement overlaid with a ½-inch-thick asphalt rubber surface.



» *Pavement shoulder temperatures for three pavement structures from a drone infrared test. The roadway's shoulder best represents the heat disparity among surface types because it is a non-trafficked area with minimal convection cooling from traffic.*

Test results showed higher temperatures on the asphalt rubber compared to diamond ground concrete over a 24-hour period.



Diamond ground concrete surfaces consistently remained cooler. Just before sunrise, diamond ground concrete measured 1 degree to 10 degrees F cooler than asphalt rubber surfaces. At peak temperature, diamond ground concrete was 27 degrees F cooler than asphalt pavement overlaid with asphalt rubber.

As cities respond to rising temperatures, diamond ground concrete surfaces offer a solution to increase albedo, reduce the UHI effect and overall greenhouse gas emissions, improve the health of local residents, and decrease roadway maintenance costs.

Solutions Emerge for Next-Generation Concrete Preservation

As good stewards of the public domain, engineers should always strive to help users save money and mitigate the environmental impact of pavements. Diamond grinding, grooving, and next generation concrete surfacing (NGCS) are all ways to provide the most value to taxpayers while increasing safety, sustainability and more.

Diamond Grinding

Conventional diamond grinding often is used to create the smoothest and safest pavements available today. It is appropriate for new construction and existing pavement repairs and can be performed at any time during a pavement's life.

Diamond grinding removes a thin layer of the hardened concrete surface using a self-propelled machine outfitted with a series of closely spaced diamond saw blades mounted on a rotating shaft. Unlike diamond-impregnated carbide bits, which use impact to chip away the concrete surface, diamond grinding blades use abrasion to gently remove the surface layer without the risk of introducing microcracking of the aggregates. After diamond grinding, the pavement texture consists of grooves and lands, with the grooves laying beneath the pavement interface.

THE PROBLEM	HOW IS IT SUSTAINABLE?	HOW DOES IT IMPROVE COMFORT?	HOW DOES IT IMPROVE SAFETY?
Stay smooth longer	Optimizing the investments that owner agencies make by reducing costs through long lived pavement surfaces	Reduced construction cycles means less traffic disruption and improved physical driving comfort associated with motion sickness	Smooth pavements are safer for motorists
Improved fuel economy	Reduced use of natural resources	Reduced economic pressure on the travelling public as well as goods being brought to market	Improved fuel economy means improved air quality in areas surrounding the highway
Reduced wear and tear on vehicles	Reduced use of natural resources and machined parts	Reduced economic pressure of maintenance costs on vehicles and shipping equipment	Vehicles that maintain good working order are less susceptible to catastrophic failure while in use
Improved safety	Preservation of human life and functionality of vehicles	Peace of mind of loved ones and reduced physical injury	Improved safety is improved safety
Reduced noise pollution	Allows for healthier communities	Prevents social disruption and promotes concentration	Prevents physical and mental ailments

» *Credit: Nick Davis, IGGA*

Diamond grinding has been in use since the 1960s, with nearly 20 million square yards of pavement diamond ground each year in the United States alone. In addition to using diamond grinding to improve the performance of existing, in-service pavements, several state DOTs specify diamond ground surfaces as the final surface on newly placed portland cement concrete pavement (PCCP). The technique is also becoming more popular for cost effective remediation of ride quality in asphalt pavements.

Diamond grinding and safety grooving are the clear solution to remediating the surface texture of new asphalt and concrete roadways as well as bridge decks. Not only is it one of the cheapest highway treatments available, it's likely the only treatment that is often cost and carbon negative. The table above shows how diamond grinding can address the three goals (sustainability, comfort and safety) for each of the problems identified.

Safety Grooving

A road's surface texture can be lost through tire wear and by the action of abrasives, tire chains, salt, freezing and thawing. With the loss of texture comes loss of friction between the pavement and vehicle tires.

Vehicle accidents increase when there is a loss of friction between the tire and pavement surface and conditions become slippery. Highway departments have found the best way to decrease accidents during inclement weather is to remove water from the surface and increase the traction between the tire and the road. Safety grooving is a technique of surface saw cutting designed specifically to improve friction and reduce water ponding. Grooving a pavement's surface increases traction, reduces hydroplaning, minimizes splash and spray, and provides a more-effective braking surface. Unlike diamond grinding, safety grooving is not attributed to an improved ride quality.

Municipalities and departments of transportation find grooving is an easily constructed and economical surface treatment that increases driver safety in wet conditions and saves on the costs of replacing or overlaying the pavement surface.

To groove a pavement surface, machines equipped with circular diamond-tipped saw blades are used to cut grooves into the surface. The blades are mounted and spaced on a horizontal shaft and are cooled constantly by water pumped from a tanker, which is recovered by an on-board vacuum system.

These discrete channels can be constructed transversely or longitudinally into concrete and asphalt surfaces. Engineers typically specify grooves 1/8- to 3/16-inch deep and approximately 1/10- to 1/8-inch wide. The spacing is typically 3/4-inch center-to-center—which leaves too large of a landing area between blades to impact the surfaces profile—although random spacing of blades is used at times when grooving transversely to control tire/pavement noise.

Safety grooving is less expensive than diamond grinding as it requires fewer diamond blades to perform, but it is the most-effective tool for mitigating hydroplaning.

The Department of Civil Engineering at the National University of Singapore conducted a study to evaluate the impact of various grooving patterns on hydroplaning. A very in-depth evaluation of 132 different grooving patterns concluded that the speed a typical passenger vehicle could obtain before hydroplaning increases by about 2.8 kilometers per hour h for every mm increase of groove depth, by about 3.5 kilometers per hour for every mm increase of groove width and by about 1.0 kilometers per hour for every mm decrease of groove spacing.

Research at NASA's Langley Research Center concluded that safety grooving of runways had a significant impact on wet weather landing of aircraft as well. This research led to the standard acceptance of safety grooving of asphalt and concrete commercial runways around the world. In 1990, safety grooving was inducted into the NASA hall of fame.

CASE STUDY: CALIFORNIA MEASURES THE SUCCESS OF GROOVING

As early as the 1970s, **Caltrans evaluated the effect of safety grooving** on 39 pavement sections. The results showed a 20% reduction in all accidents, a 50% reduction in fatal accidents and a 70% reduction in wet weather accidents. While the data also showed a 15% average increase in Skid Number (SN), the researchers gave primary credit of improved safety to the reduction of hydroplaning, not the improvement of friction.

Additionally, the California Department of Transportation conducted a study of 322 lane-miles of longitudinally grooved concrete pavement and compared it to control sections of 750 miles of ungrooved concrete pavement. The study found grooving produced an overall average 69% decrease in accident rates for the highways studied in wet and dry conditions.

Another study in California showed how roads wear over time, causing a decrease in friction and an increase in accidents. On Interstate 5 at Laguna Canyon Road near El Toro Marine Air Station, there were no wet weather accidents when the road was newly constructed using a burlap drag surface texture. As the road aged, eight wet weather accidents were recorded during the next year and 47 wet weather accidents in the year after. As the road was being used over time, the pavement was wearing, causing the friction values to drop.

To correct the problem, the road was longitudinally grooved, using a specified 1/8-inch by 1/8-inch on 1/2-inch center pattern. Accidents for the following five years were reduced to a total of eight wet weather accidents. This study shows how grooving can increase wet weather traction, reduce hydroplaning potential and make the road a safer place for motorists.

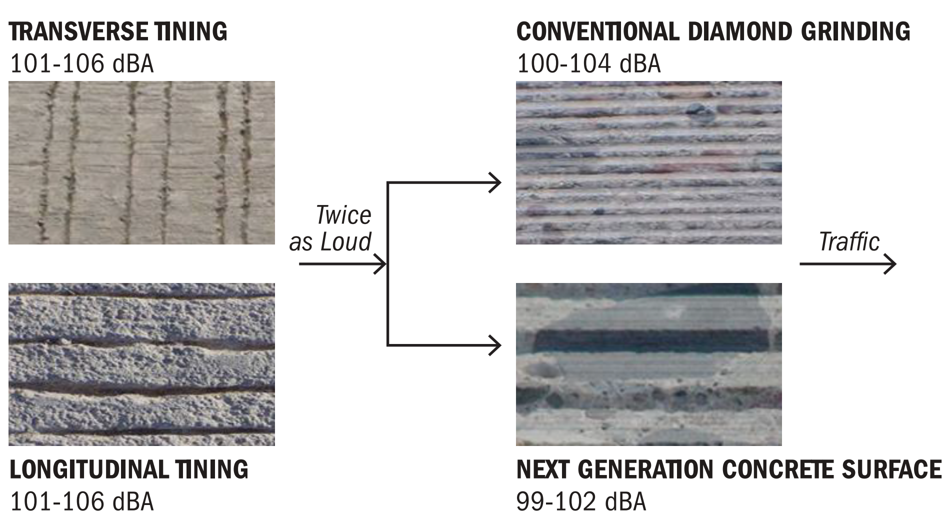
NGCS

NGCS is the first new non-porous concrete texture to be introduced in the last 20 to 30 years. It took three years to research and develop, but less than one year to construct field test sections.

NGCS is the smoothest and most quiet pavement surface treatment available. In an effort to create a quieter concrete pavement surface, Purdue University conducted research to develop a machined surface texture that would offer superior noise characteristics.

NGCS consists of a three-step process.

1. If the pavement has localized roughness, it should be removed using a bump grind with a conventional diamond grinding head. The goal of this step is to have no significant bumps or faults and to have an average IRI at or below 80 inches per mile.
2. Production grinding using an NGCS grinding head to remove approximately 1/8 inch of surface material over 100% of the surface area of the project. A NGCS head is a diamond grinding head that has a tighter spacing between saw blades than a traditional diamond grinding head. This tight spacing will result in the removal of positive or upward texture typically left between saw blades, offering a very quiet riding surface. The IRI after this step typically is at or below 45 inches per mile.
3. Safety groove the surface. The safety grooving also adds the benefits of improved macro texture for friction and improved drainage to prevent hydroplaning.



The NGCS was conceived as a "manufactured surface" which would result in consistent and predictable properties at the time of construction and throughout its life. The preceding photo shows typical on-board sound intensity levels associated with the various textures, and the NGCS surface has met the low noise goals and demonstrated the lowest variability in as-constructed results to date. With the improved lateral stability and hydroplaning resistance afforded by the NGCS texture, there are additional benefits than just noise reduction. As demonstrated by both quiet pavement research efforts, NGCS surfaces also produced the smoothest pavements of any texture evaluated.

NGCS is the most superior texture available for new and existing concrete pavements, combining all of the forementioned benefits offered by saw cut surface textures.

Friction testing of the surfaces for over a decade has indicated a stable surface with a good frictional resistance. Initial concerns that the flush grind process would produce a low friction surface were not accurate. The grooving used in the NGCS provides similar ribbed and smooth tire test results and enhances hydroplaning resistance.

Today, 14 states have constructed NGCS surfaces and two major state quiet pavement research efforts have evaluated this texture. Millions of square yards of NGCS have been constructed across the globe with positive results.

Slurry Disposal

Concrete grinding residue (CGR) is an inert, non-hazardous byproduct of the diamond grinding process. When diamond grinding concrete highways, water used to cool cutting blades combines with hardened cement paste and aggregate particulates to generate CGR, also known as slurry. The slurry is similar to a weak agricultural lime.

Many states do not have the benefit of clear, localized guidance on disposal methods for CGR. This leads to a situation in which CGR disposal is potentially posing unnecessary costs for projects—and leaves the beneficial effects of slurry underutilized.

Often, states limit how much slurry can be discharged along the roadside during the diamond grinding process. But hauling slurry off-site for processing and disposal is costly for DOTs and for taxpayers. The elimination of unnecessary regulations in areas with site conditions that allow for the discharge of CGR directly to the road's shoulder would benefit roadway owners and taxpayers by reducing construction costs.

» *Credit: J Roberts*

To determine the real impact of slurry on roadside soil and vegetation, multiple studies have been performed. They all have found slurry to be safe. For more information, see the IGGA white paper, "**Studies Show Slurry Roadside Disposal is Safe**."

In accordance with research showing a lack of negative environmental effects from slurry disposal along roadways, states are changing regulations. For example, Minnesota recently enacted legislation redefining their solid waste definition throughout the state, exempting concrete saw-cut slurry from the solid waste classification and allowing slurry to be spread along adjacent slopes. This was done in part because there was no evidence showing slurry constituted a threat to the environment.

In the above linked resource, IGGA developed best management practices for CGR disposal to help slurry byproduct continue to be handled in a professional, environmentally responsible way. When following the best management practices, studies show slurry is not harmful to soil or plant life and can even be beneficial as a soil additive.

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