Realizing the roads of the future

Researchers are seeking simple ways to make asphalt pavements safer, quieter, and more eco-friendly.

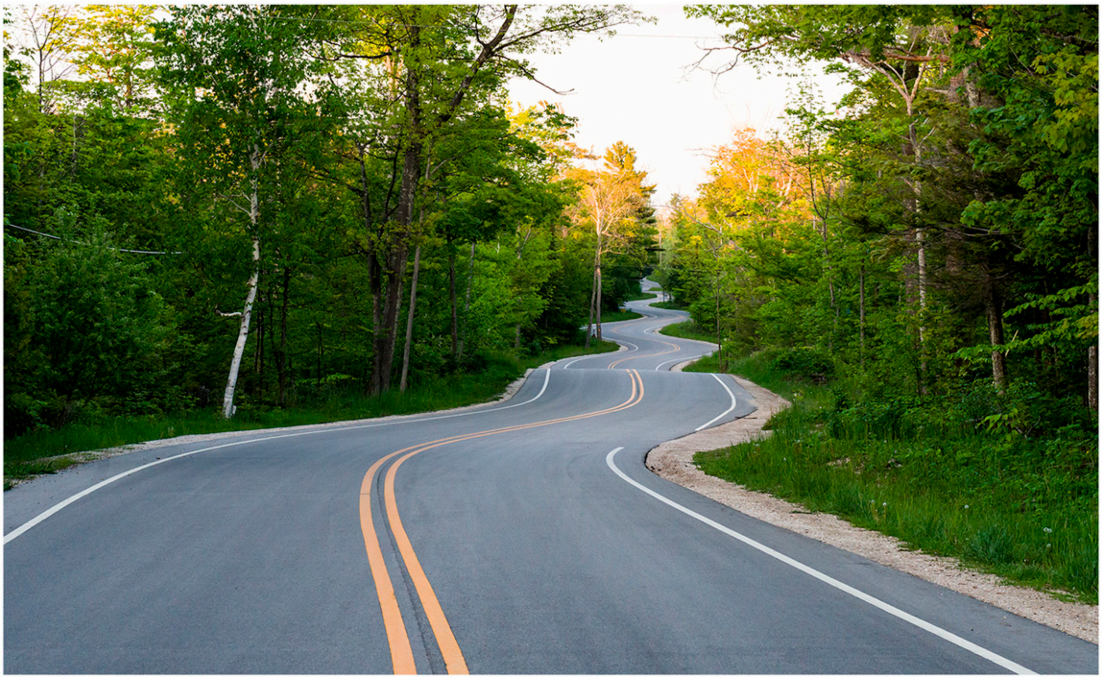
Sid Perkins, *Science Writer*

Roads encircle the globe in arterial networks that seem more pervasive each year. To some, they are a sign of progress; to others, they are a growing scar on the landscape. The United States alone hosts millions of miles of asphalt pavements, materials that aren't particularly sustainable or good for surrounding ecosystems. Yet the United States and many other nations keep building and replacing the same sorts of roads year after year, using the same basic design that's been around for centuries.

Despite humanity's road-making rut, asphalt pavement upgrades are certainly possible. In recent years, researchers have started to work on a range of refinements that could make highways safer, quieter, and more sustainable. Modifications could include changing the aggregates and binders in the pavement or adding recycled materials into the mix. Even altering the pavement's stiffness could improve the efficiency of vehicles using the road. Some of these changes could offer substantial reductions in the emissions of planet-warming CO_2 and other pollutants. "There are all sorts of things that can be changed," says Jeremy Gregory, a sustainability researcher at the Massachusetts Institute of Technology (MIT) in Cambridge. "We're constantly looking for improvements."

Dimple Dilemma

Road design today is fundamentally the same as that used by the Romans. In general, a surface layer of pavement is laid atop thick layers of compacted



We keep building and replacing the same sorts of roads year after year, using the same basic design that's been around for centuries. But researchers and engineers have designs on some much safer, more sustainable pavements. Image credit: Shutterstock/Keith Homan.

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One way to improve road sustainability is to find substitutes for the traditional building blocks of pavement's foundations, such as limestone aggregate. Image credit: Shutterstock/Andrei Ksenzhuk.

granular materials that help transmit traffic loads to the underlying soil or bedrock. Modern pavement is typically made from either concrete, a mixture of aggregates such as sand, pebbles, and gravel that are bound together with cement, or "asphalt concrete," in which sand and gravel are bound together by a black, sticky petroleum byproduct known as asphalt.

Although cement concrete is typically much stiffer than asphalt pavements and is more resilient to wear and tear, it also tends to be more expensive. In many states, the department of transportation selects pavement materials based on initial costs rather than including long-term costs such as maintenance, so it's hardly surprising that about 94% of paved roads in the United States are capped with asphalt concrete or other types of flexible pavement (1).

Softer pavement certainly has its uses—not least when cyclists or pedestrians take a tumble (see A Softer Touch)—but flexibility can cause problems for road traffic. As a heavy truck passes across asphalt concrete, it creates a dimple in the road akin to the hollow produced when a person stands on a trampoline. The vehicle has to expend extra energy to climb out of the dimple as it moves, which decreases its gas mileage and increases its CO_2 emissions.

Gregory and his colleagues have calculated that if US traffic volumes continue to increase as expected over the next 50 years, vehicles will generate an extra 2.66 billion metric tons of CO_2 by climbing out of these dimples (2), in addition to the regular emissions caused by driving from one place to another. "It's clear that the way we design and maintain our nation's pavements affects the fuel economy of our vehicles," Gregory says.

Gregory's team estimates that using the stiffest forms of concrete or asphalt concrete could help to curb this dimple effect. Gradually replacing the nation's interstates, highways, and streets with these materials could cut the emissions related to pavement flexibility by about 18% over 50 years, amounting to a 0.5% reduction of total emissions from the entire transportation sector, the researchers say.

Although they did not include the additional CO_2 emissions that might be generated by this reconstruction spree, Gregory says that their calculations underscore the basic principle that when it comes to fuel efficiency, stiffer roads are better.

Witches' Brew

Cars and trucks aren't the only sources of pollution from our roads. Asphalt pavement itself can emit a witches' brew of organic compounds that contributes to harmful smog, especially on hot sunny days.

As fuel efficiency standards, catalytic converters, and other technological improvements have curbed tailpipe emissions from individual vehicles, the relative fraction of noxious droplets and particles—dubbed secondary organic aerosols—resulting from asphalt emissions has increased. Yet these emissions are rarely included in computer-based models of road pollution, says Drew Gentner, an environmental engineer at Yale University in New Haven, CT, because researchers and engineers don't know enough about the extent of asphalt's emissions.

To help plug that information gap, Gentner and his colleagues set out to measure how much pollution comes from asphalt pavement. They heated up samples of a commonly used road asphalt in a sealed chamber and exposed the samples to simulated solar radiation. In September, they reported that overall emissions of organic compounds at 60 °C (typical for asphalt baking in summer heat) were twice those measured at 40 °C. And from 60–140 °C (typical temperatures experienced during the storage and application of the material), emissions increased by about 70% for every 20 °C rise in temperature (3).

Paved surfaces account for about 45% of the area in US cities, and roofs—often clad in asphalt shingles or tiles—make up another 20% or so, says Gentner. New results suggest that these ubiquitous surfaces may actually release more organic pollutants than vehicles over the course of a year. "What's interesting about this study is that it came out of left field and pointed to a source of emissions that hadn't been thought of before," says George Ban-Weiss, an environmental engineer at the University of Southern California in Los Angeles.

Ban-Weiss is already working on ways to take the heat off asphalt. Pavement can absorb about 90% of sunlight's radiation, but a surface coating of light-colored pigments could help to reflect some of that sunlight and lower the temperature of roads and parking lots. Besides decreasing the emissions of pollution precursors from the underlying asphalt, this coating could also tackle the urban heat island effect, in which the central areas of a large city can be substantially warmer than nearby rural areas. By reducing urban air temperature, the chemical reactions that generate ozone and other noxious aerosols would proceed more slowly, reducing smog.

When Ban-Weiss and his colleagues simulated an increase in pavement reflectivity from around 10% to 40% within a neighborhood in Los Angeles, mid-afternoon air temperatures above the reflective streets

Researchers are trying to devise a better, cheaper way to fill potholes by combining solids from wastewater with calcium oxide, magnesium oxide, and a weak acid to make a cement-like binder. Image credit: Zhongzhe Liu (California State University, Bakersfield, CA).

were up to 2 °C cooler than above regular asphalt pavement (4). In another simulation, the researchers increased pavement brightness in urban areas across California and found that, over the course of a year, the average reductions in mid-afternoon air temperature ranged from 0.18 °C in Palm Springs to about 0.86 °C in San Jose (5).

Such reflective coatings may bring their own problems, such as other kinds of chemical emissions or even a dazzling glare that could distract drivers. Ban-Weiss says that detailed lab and field studies of reflective coatings are now needed to assess the overall benefits and potential disadvantages of the strategy.

Recycled Roads

Whereas researchers like Ban-Weiss have focused on revamping road surfaces, others are digging deeper. They hope to improve the sustainability of roads by finding substitutes for the traditional building blocks of pavement's foundations. Limestone aggregate, for example, is typically used to build the strong, durable base needed for roads, which creates a huge demand for the crushed stone. According to the US Geological Survey, the United States uses roughly 1 billion tons of such aggregate in road construction and maintenance every year.

Replacing some of that aggregate with recycled materials could help to reduce the environmental impact of road building, says Cesare Sangiorgi, a materials engineer at the University of Bologna in Italy. He and his colleague Piergiorgio Tataranni have studied whether powdered basalt, a waste product from some quarry operations, could take the place of limestone without affecting the strength of the pavement (6).

The researchers mixed powdered basalt with a strongly alkaline solution, rolled the mixture into small balls, hardened them in an oven at 60 °C for 12 hours, and then sieved the basalt balls to pick out aggregates of 6.3–12.5 millimeters in diameter. Then they did the same with powdered limestone and produced two sets of samples: one with nothing but powdered limestone and a binder, and another in which 21% of the aggregates had been replaced with basalt balls. After further processing, the researchers packed each of the samples together in conditions simulating those of actual road-paving operations.

Lab tests revealed that both types of pavement had a similar resistance to being pulled apart, indicating that the basalt-seeded pavement should stand up to road wear. The two types of pavement were equally permeable and also endured 10 freeze–thaw cycles in the lab without damage. The researchers now plan to test different mixtures of aggregates, including ones based on 100% basalt powder.

In another study, Sangiorgi and his colleagues found that mixtures containing powdered glass were also as strong and stiff as conventional limestone aggregates. Pavements that included glass were just as resistant to a type of long-term deformation under heavy weight called creep, and they may be even more resistant to traffic cutting ruts into them than conventional pavement (7).

Other researchers are investigating whether gravel and sand carried in wastewater could be used to repair roads. Typically, these extraneous solids are filtered out of water destined for treatment plants and hauled away for dumping in landfill sites. "We had an idea to divert wastewater grit from landfills and turn it into a marketable product," says Zhongzhe Liu, an environmental engineer at California State University, Bakersfield. His team is incorporating the grit and gravel into a material called a chemically bonded phosphate ceramic (CBPC). Commonly used to encapsulate hazardous or radioactive waste for disposal, the researchers wondered whether it could also be used to patch potholes.

To test the idea, they sieved the grit and kept only the bits smaller than 6 millimeters across. Then they added calcium oxide and magnesium oxide to wet grit to make an alkaline slurry that killed any microbes on the aggregates. Finally, they added a weak acid that converted the slurry into a cement-like binder to hold the aggregates together. Laboratory tests showed that the team's new material is just as strong as conventional pothole fillers for asphalt pavements. Besides being cheaper than asphalt-based patches, Liu adds, harmful organic compounds do not leach or evaporate from the filler. He and his colleagues described the research in August at the American Chemical Society's online fall meeting.*

The researchers are now testing their pothole patches in the parking lot of the Milwaukee Metropolitan Sewerage District, the source of their grit. Trucks driving through the lot will provide a real-world test of how well their patches bind to underlying

*Liu Z et al., American Chemical Society Fall Meeting, August 17–20, 2020.

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Box 1. ***A Softer Touch***

In developed nations, falls are a major source of accidental injuries, particularly among the elderly. Viveca Wallqvist, a senior researcher at the Research Institutes of Sweden in Stockholm, is part of a team that has investigated whether changing the properties of sidewalks, bike paths, and other pavements could help to prevent such injuries.

The researchers mixed up samples of nine different types of pavement, which included various amounts of aggregates, rubber granules, and recycled rubber. Laboratory tests showed that pavement containing 60% recycled rubber aggregates was only 1% to 2% as stiff as that containing only mineral aggregates. Computer models of a person's head striking this spongier surface during a fall suggest that the rubberized pavements could be a lifesaver (10). At an impact speed of 3 meters per second, a person's risk of skull fracture was reduced by as much as 45%, and their risk of experiencing a subdural hematoma—a pooling of blood between the skull and brain resulting from a broken blood vessel—was reduced by up to 20%.

Besides being squishier than normal pavement, the rubberized pavements were also more likely to remain frost-free in winter, which would also help to prevent slips and falls.

pavement and stand up to heavy traffic, which should reveal whether the filler's recipe needs any tweaks to improve its durability, says Liu.

Meanwhile, researchers in Algeria have studied how low-density polyethylene (LDPE), the same sort of plastic used to make shopping bags, can be added to a pavement's asphalt binder to make the material stiffer and more water-resistant (8). Researchers in India have found that using waste plastics in this way allowed them to reduce the amount of bitumen needed in pavement by 10 to 15% (9). In principle, such efforts could keep millions of tons of plastics out of landfills.

Quiet Please

As anyone who lives near a busy highway can tell you, the noise can be incessant. What may be surprising to some, however, is that most of that noise—Italian sports cars and old pickups sans mufflers aside—comes from the vehicles' tires, says Sangiorgi. Traffic noise is itself a form of pollution, which can increase the risks of coronary artery disease, hypertension, and a range of psychological health impacts, according to the World Health Organization.[†]

Tweaking the design of a tire's tread can help to quiet traffic noise. But Sangiorgi has found that changing the pavement on which the vehicle travels can deliver an even larger reduction in noise—in some cases a drop of 10 decibels, equivalent to a 50 decrease in the loudness of the sound.

Unveiling the results at the American Association for the Advancement of Science meeting last February,[‡] Sangiorgi pointed out that a particularly effective modification involves making the pavement more porous. That allows air squeezed beneath a tire to be forced into the pavement, where pressure waves are muffled, instead of being forced aside at high pressure and creating noise. Using smaller aggregates, which tend to leave more pores in the material, should make the quietest pavements. A porous pavement could also enhance road safety by allowing fallen rain to drain through the pavement rather than ponding on the surface, Sangiorgi says.

Besides creating less noise, a porous pavement can actually help absorb noise, says Tiago Vieira, a civil engineer at the Swedish National Road and Transport Research Institute in Linköping. During a field test in 2018, the team measured normal noise levels by towing a microphone-laden trailer along a 600-meter-long stretch of a major thoroughfare in Linköping. Then city workers laid down two layers of porous pavement atop the existing street: a 55-millimeter-thick bottom layer whose aggregates measured about 16 millimeters across, and a 25-millimeter-thick top coat whose aggregates were about 11 millimeters in diameter. Both pavements were designed to have about 25% porosity, says Vieira.

Measurements taken 45 days after the new pavement was laid showed that the porous surface cut noise levels by about 5 decibels for vehicles travelling at 70 kilometers per hour. The team reported the results in 2019 at the International Congress on Sound and Vibration in Montreal, Canada.[§] Samples taken later from the road suggested that even more noise reduction might have been possible, says Vieira, because the lower layer of pavement ended up being less porous than they had intended.

An even simpler way to reduce road noise might be to produce less of it in the first place, says Vieira. If a road's surface is rough, tires—especially at high speed—vibrate and generate a lot of noise (noise potentially made worse in the case of rigid, cement roads consisting of slabs connected at joints). Grinding the pavement and making it smoother—somewhat akin to a woodworker sanding a rough board—will reduce vibration in tires, thus quieting them substantially, he suggests.

Despite all of the promising developments in road materials, MIT's Gregory cautions that improving one aspect of pavement—its porosity, composition, or

[†]"Burden of Disease from Environmental Noise" (2011). Retrieved from https://www.euro.who.int/__data/assets/pdf_file/0008/136466/e94888.pdf.

[‡]Sangiorgi C, Annual Meeting of the American Association for the Advancement of Science, February 13–16, 2020, Seattle, WA.

[§]Vieira T et al., 26th International Congress on Sound and Vibration, July 7–11, 2019, Montreal, Canada.

stiffness, for example—can sometimes end up causing problems in other areas, which can hold back efforts to use these innovative materials more widely. "A lot of times, we're trying to satisfy competing objectives," he notes.

Aside from the materials science challenges, Gregory says that the tendency for public bodies to choose road materials based solely on their short-term costs, rather than their sustainability, is the most significant barrier to reducing the environmental impact of roads. That is unlikely to change until the long-term costs of maintenance—or the impacts of ill health caused by noise, greenhouse gas emissions, or other forms of pollution—are also considered in purchasing decisions. "Our biggest challenge is getting people to take a long-term perspective," he says.

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