Highway, Heal Thyself

Cracking the code of self-healing asphalt could extend the life of roads

By CORINNA WU

A newly paved stretch of road, flat and smooth, slips unnoticed under a driver's wheels. After several seasons, however, driving down that same road requires the obstacle avoidance skills of a downhill slalom skier.

Cavernous potholes and spidery networks of cracks open up in the pavement. Ruts play a rhythmic beat under the tires. In the worst cases, the asphalt deteriorates so much that the road turns into nothing more than a black gravel path.

Crumbling roads are a big problem. Some people call the system of paved roads—about 50 feet wide and 2 million miles in total length—the largest single structure in the United States. Bumps, cracks, and potholes compromise safety, increase fuel consumption, and lengthen travel time. Road repair is a central responsibility of nearly every transportation agency.

Researchers, though, have found some good news about cracking: Asphalt can actually repair itself to a certain degree. Given time and rest, tiny cracks can heal themselves, often sealing before they get big enough to cause the road to fail. Not all asphalt restores itself, though, so some scientists have set out to learn why.

As part of a project commissioned by the Federal Highway Administration (FHWA), a group of researchers at Texas A&M University in College Station and North Carolina State University in Raleigh has recently completed a study into the healing phenomenon. By modeling this process, the researchers hope to improve their understanding of how it affects the life of the finished road.

Furthermore, scientists at the Western Research Institute (WRI) in Laramie, Wyo., working on the same FHWA project are hoping to encourage self-healing in asphalt by tinkering with its chemical composition. This is proving to be a sticky problem, however, and one they are still far from solving.

When asphalt, or indeed any material, experiences stress, the bonds between adjacent atoms or molecules break apart, forming microscopic cracks. If the stress continues, these tiny cracks grow and coalesce into big cracks, says Dallas N. Little of Texas A&M.

In some materials, such as polymers and glasses, microcracks can heal spontaneously as bonds between molecules reestablish themselves. "Healing is often observed when you bring plastics together at a high temperature," says Richard A. Schapery of the University of Texas at Austin, who developed general models for self-repair of polymerlike materials nearly a decade ago. "In fact, that's the way you create bonds between materials." Adhesion and healing are closely related, except that in the former case two different materials come together rather than two surfaces of the same material.

"Although healing is well known in polymers," Little says, "it's not clearly understood in asphalt pavements." Asphalt, a brownish-black goo of hydrocarbons left over from oil refining, acts as the glue that holds together a mix of rocks and sand to form paving material. Since asphalt contains some hydrocarbon polymers, it's not surprising that it exhibits self-healing too, Little adds.

Engineers have long suspected that small cracks in roads could heal themselves, says Y. Richard Kim of North Carolina State. European engineers have reported seeing cracks in roads disappear in the summer, only to reappear in the winter. However, "no one had proved it was happening. Also, there was no method to quantitatively measure microcrack healing in the field," Kim notes.

Kim developed a diagnostic technique that accomplishes both of these goals. By hitting a patch of pavement and measuring the vibrations that travel through it, he can assess the amount of cracking in the asphalt. He then places sensors on asphalt pavement samples and hits them with a spring-loaded hammer. This impact sends a high-frequency wave into the pavement that is captured by the sensors for later analysis.

Kim and his colleagues tested the technique first on a road in Clayton, N.C., then at the FHWA's Turner-Fairbank Highway Research Center in McLean, Va., an outdoor facility with a device designed to simulate the effect of traffic on pavement. He induced varying levels of damage on asphalt samples with the machine, which rolls a large truck wheel carrying a 12,000-pound load across the pavement. He measured the amount of cracking, then took further measurements after 24 hours. After the rest period, the stiffness of the pavement had increased significantly, Kim says.

The 24-hour hiatus was "unrealistic" for real-life conditions, he adds, since roads usually experience much shorter rest periods. Pavement can probably heal itself in about 8 hours, he estimates. For the tests, though, it was important to take measurements at the same time of day, because the technique is so sensitive to temperature change. Early in the morning, the asphalt is cold on the surface but warmer underneath. After a day of sun, the temperature variation is reversed.

The vibration measurements show that "these pavements lose their structural integrity long before you can see cracks on the surface," Kim says. The results highlight the need for early maintenance of roads to prevent their deterioration. How to do that remains "a good question," he concedes. Some researchers have discussed rejuvenating roads with microwaves—cooking them to promote microcrack healing.

A machine called the Accelerated Loading Facility in McLean, Va., rolls a large truck wheel repeatedly across pavement to simulate traffic wear and tear.

Kim and Little also tested asphalt in the lab to determine how healing affects its lifetime. They repeatedly put stress on samples of asphalt and counted how many cycles it took for them to break. This gradual weakening is known as fatigue. "If you perform the fatigue test without rest periods, the asphalt fails in, say, 5,000 cycles," Little says. "But with rest periods, it takes 7,000 cycles."

Rest periods increased the lifetime by about 50 percent. Even though asphalt on roads experiences rest periods and therefore healing, laboratory fatigue tests had ignored the process. The group has developed a new model for asphalt fatigue that is the first to account for healing, Kim says.

"People know that healing is happening, but it's complex," he says. The model has to distinguish between healing and other modes of repair, such as relaxation and restructuring. Relaxation refers to how a compressed material springs back once the stress is removed. Restructuring occurs when molecules rearrange themselves, filling the crack. Healing, relaxation, and restructuring are all beneficial to the material, but they must be kept separate in the model to make clear what is happening. In the lab, under controlled conditions, Kim can analyze his data with special techniques to make those distinctions.

Last week, the team presented its latest results at a meeting of the Transportation Research Board in Washington, D.C.

Even the best theoretical model can't predict exactly what will happen with a particular stretch of road, says Kim, because the myriad conditions are difficult to characterize. For example, sunlight, temperature, moisture, and traffic all affect the lifetime of pavement. A model comes in handy when comparing two different kinds of asphalts, giving road engineers a tool with which to choose an appropriate material.

At WRI, scientists are studying asphalt in order to connect physical and chemical properties with performance. New standards adopted within the last few years give batches of asphalt a performance grade that consists of two numbers—52-10, for example. The first number specifies the lowest temperature, in this case 52°C, at which the asphalt softens to a standard consistency. The second number refers to the highest temperature at which the asphalt achieves a given stiffness. The asphalt in the example begins to turn brittle at -10°C. Chemical processes such as oxidation affect these values. A good-quality asphalt, such as grade 70-40, has a wide temperature range.

Although this grading system is a big improvement over the previous method, the FHWA would like to refine the specifications to include previously ignored factors that affect performance. Thus, WRI brought in the team of researchers from Texas A&M to examine healing.

"They demonstrated clearly that the phenomenon was real," Raymond Robertson of WRI says. "They did an outstanding job of that. It was very labor-intensive to demonstrate how fatigue sets in."

Ideally, scientists would like to know how the various components of asphalt affect performance. That way, they could play with the composition—adding more of one ingredient or subtracting another—to improve the properties.

The WRI group took on the task of separating the components of different stocks of asphalt and analyzing their physical properties. One effect they discovered is that strong acids and amphoterics—molecules that have both an acidic and an alkaline character—"beef up the stiffness," says Robertson. Acids, however, could make asphalt more susceptible to moisture damage.

Connecting composition to performance requires a lot more study before that approach can be used to systematically grade asphalt, Robertson notes.

Self-healing properties are desirable not only in asphalt but in other materials. "If we could make cracks go away, we'd have much better materials," says Stephen J. Burns of the University of Rochester (N.Y.).

The dearth of work on healing is what prompted Schapery to look at the process in the first place. "Fracture had been studied a great deal, but there was almost nothing regarding healing," he says. "Most people think about growing cracks, but these are shrinking cracks."

Similarly, through this research, the FHWA hopes to shrink the problem of crumbling roads down to size. □

Recycling the road

Even if a road can't stay flawless forever, it doesn't have to go to waste. Crumbled pavement is often scooped up, crushed, and recycled into new paving material or other highway structures.

About 80 percent of the 90 million tons of pavement removed during road repairs each year is reused in some fashion. Thirty million tons feeds back into asphalt pavement, while the rest becomes building material for structures such as road foundations, shoulders, or medians, says Margaret Cervarich of the National Asphalt Pavement Association in Lanham, Md.

As mundane as it may seem, asphalt pavement is "scientifically proportioned," Cervarich says. In the production of paving material, determining the right formula of rocks, any recycled material, and liquid asphalt is "not a haphazard process" and requires an engineer's expertise. The properties of the finished asphalt must stand up to the climate and traffic conditions of the particular road. The rock types vary, depending on what's available locally, and waste glass and even rubber from old tires can be added to the mix (SN: 3/7/92, p. 155), thus offering a second life to other materials, too. —*C.W.*