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Is the Road to Sustainable Asphalt Paved with Tires?

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Mixing waste rubber from scrap tires into asphalt binder is one way to make pavement more environmentally friendly.

In 1999, a lightning storm ignited 7 million scrap tires piled on the slopes of a canyon near Westley, California. A near-apocalyptic scene erupted, according to a 2001 case study on the incident. A 60 m roaring “fireball” and “tornado-like vortex” propelled smoke hundreds of meters into the air, spewing soot as far as 100 km away. The blaze was finally extinguished 5 weeks later, but not before it devastated surrounding land, spread noxious emissions, and discharged massive volumes of oil from the melted rubber.

Scrap heaps like these constitute a portion of the more than 50 million waste tires that California generates annually. Those that end up in landfills not only pose fire hazards but also release pollutants and breed pests like mosquitoes. To divert waste tires from such deleterious ends, states like California and some countries around the world have come to a common conclusion: this rubber should meet the road.

A 1991 federal law, the Intermodal Surface Transportation Efficiency Act, required all state departments of transportation (DOTs) to start adding rubber to a prescribed portion of their federally funded roads. However, the technology for doing so was not ready, and the mandate was repealed in 1995. About half the states have experimented with incorporating ground tire, known as crumb rubber, into their asphalt mixes, and a handful—like Arizona, California, Florida, and Texas—have led the way in evaluating rubberized roads or building them as standard practice today.

California in particular has led efforts to increase the amount of crumb rubber used in pavement. State law requires its DOT, commonly known as Caltrans, to use tire rubber in 35% of its paving projects. Caltrans also requires that the binder used in surface pavement contain 18–20% rubber by weight. California’s Department of Resources Recycling and Recovery estimated that asphalt rubber paving consumed more than 35,000 t of crumb rubber in 2018.

Researchers are working to make asphalt concrete and road paving more sustainable. Credit: JK Jeffrey/Shutterstock.

Incorporating tire rubber into pavement has benefits beyond just recycling: it increases resistance to rutting, cracking, and aging. But the process for making asphalt roads is energy intensive. Pavement construction, maintenance, and rehabilitation account for over 1% of total United States greenhouse gas emissions, according to a report prepared for the Federal Highway Administration. Researchers have been working to hone the technology for incorporating rubber into pavement to decrease energy usage and harmful emissions while increasing durability and

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life span. They've also been experimenting with adjusting processing temperatures, recycling used pavement, and mixing in other types of waste materials, including recycled cooking oil, plastic, and even cigarette butts. Of these salvaged ingredients, however, tires are a proven option.

Adding to Asphalt

Over 90% of U.S. roads are paved with what's known as asphalt concrete, which is composed primarily of rocky aggregates and a black, gummy binder that acts as a glue. The binder, a blend of complex hydrocarbons derived mostly from petroleum, generates most of the environmental impact even though it represents just a small portion of the entire mixture. Acquiring, transporting, and refining the binder emits greenhouse gases and volatile organic compounds. During paving, heating the mix of aggregate and binder requires additional energy, producing yet more greenhouse gases and air pollutants. Then, with time, the binder in pavement stiffens from oxidation and begins to crack. As a result, roads demand maintenance and rehabilitation.

Crumb rubber (right) derived from scrap tires can be mixed into asphalt binder to improve its performance. Credit: xpixel/Shutterstock/Md Tareq Rahman.

Tires are made of a mixture of synthetic and natural rubbers, which are heated with sulfur and various auxiliary compounds to form a complex, cross-linked structure. This sturdy composition prevents tires from degrading in landfills, but the polymer bonds come apart when the crumb rubber is heated and mixed with binder. As a result, adding crumb rubber to the binder generally yields more performance benefits than adding it to the aggregate.

Generating crumb rubber from tires involves stripping their steel reinforcement and grinding the tires into particles ranging from roughly 0.2 to 2.0 mm in size. Grinding at or above room temperature produces textured, irregularly shaped particles with large surface areas. When crumb rubber is mixed with the binder, the outer portion of the rubber particles desulfurizes and degrades, releasing soluble polymers that improve the high-temperature performance of the binder and slow stiffening and cracking at low temperatures. At the same time, the remaining rubber core swells as it absorbs the binder's aromatic oils, forming a thin gel cushion that may reduce vibrations and noise.

Scientists are actively researching how to lower the mixing temperature of asphalt concrete to reduce energy use. Mixing and compaction typically require scorching temperatures—around 180 °C—to help decrease the viscosity of the binder and improve workability. Adding rubber increases the necessary temperature even more. Within the past decade, "warm mix" technologies that incorporate foaming water or additives such as organic waxes into the binder have taken off. These technologies lower production and placement temperatures by 10–40 °C.

Huayang Yu of the South China University of Technology is hoping to further decrease the energy use and environmental impact by improving cold mix technologies, which work at ambient temperatures. Existing cold mix methods involve suspending binder globules in water along with emulsifying agents like soap, which remain liquid at room temperature without the need for extra heating during mixing or compaction. After paving, the water evaporates and leaves the binder behind.

Yu is finding ways to apply this technology to the surface layers of roads. Additives like styrene-butadiene rubber polymers and waterborne epoxy resin help cold mix pavement withstand stress and strain in a range of climates. Ingredients like lignan from plants can enhance a binder's workability and adhesive properties. However, he and his colleagues have a long way to go; cold mixes are still used mostly as patching material. "Performance is worse compared to hot mix asphalt or warm mix asphalt especially when the crumb rubber is incorporated," he says. Until about a decade ago, paving with rubber was much less common in China than in the U.S., but the Chinese government now has requirements and incentives in place for doing so.

Reclaiming Pavements

Because rubberized binders improve performance and durability of asphalt concrete, less binder is usually needed over the pavement's life cycle. That is an "environmental win," says John T. Harvey, director of the University of California Pavement Research Center.

Harvey and others are nevertheless looking for ways to improve the environmental profile further. One approach is to remove and reuse the binder from old, cracked roads. This reclaimed asphalt pavement (RAP) has been used in small quantities as an aggregate substitute for decades but

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Combining used cooking oil, palm oil fuel ash, and crumb rubber produces a biobased binder that can be used in asphalt pavement. Credit: *Constr. Build. Mater.* 2017, DOI: 10.1016/j.conbuildmat.2017.05.216.

has been gaining traction as a potential binder replacement in conventional asphalt concrete mixes.

Combining RAP and tire rubber presents new challenges. Harvey's group has shown that adding conventional RAP to new, rubberized mixtures can reduce performance in certain applications, but adding old pavement that already contains rubber crumbs to conventional hot mixes improves resistance to rutting and cracking. "The benefits of the old rubber are carried forward to the new mix," Harvey says. Furthermore, the RAP binder tends to stiffen the mixture, so some researchers have tried to restore the oily, resinous components in asphalt binder called maltenes, improving resistance to hardening and temperature change.

These agents are often derived from petroleum, but researchers are now working on biologically sourced options that could eventually replace petroleum-based binders entirely. Such bio-oils or biobinders are often produced from renewable resources like vegetable oil, plant matter, animal waste, or lipids extracted from algae. The materials are heated rapidly in a vacuum, producing vapors and aerosols that cool and condense into a dark, brown liquid. These bio-oils have served as alternative fuel sources for over a decade, but they can also be coaxed to exhibit the viscosity and other properties of conventional binders.

During his master's research at the University of Technology, Malaysia, Md Tareq Rahman was able to replace up to 15% of a conventional binder with a mixture of crumb rubber, discarded cooking oil from a local Kentucky Fried Chicken, and palm oil fuel ash. Now a Ph.D. student at RMIT University under the supervision of Abbas Mohajerani, Rahman has experimented with encapsulating cigarette butts with binder to prevent toxic compounds in them from leaching into the environment. He has even created binder modifiers from the cellulose acetate fibers in cigarette filters, which can take years to decompose. In Melbourne, Australia, where he works, he has also witnessed initiatives to construct entire strips of highway using crushed glass. Industry players, he says, are finally realizing that recycled items may pave the way to sustainability. "They can actually contribute to the global fight against pollution," he adds.

Developing truly sustainable pavements requires not just incorporating recycled ingredients but also considering their entire life cycle. Ideally, roads would be composed of durable waste materials that allow them to be recycled, forming a zero-waste construction stream.

Harvey has his own three-pronged litmus test to determine whether a given waste material could serve as a sustainable binder modifier. First, it should prolong the life of the pavement. Second, it should not prevent the asphalt mix from being reused. Lastly, it should be economically viable. "Tire rubber in asphalt easily passes all three tests when done right," he says.

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