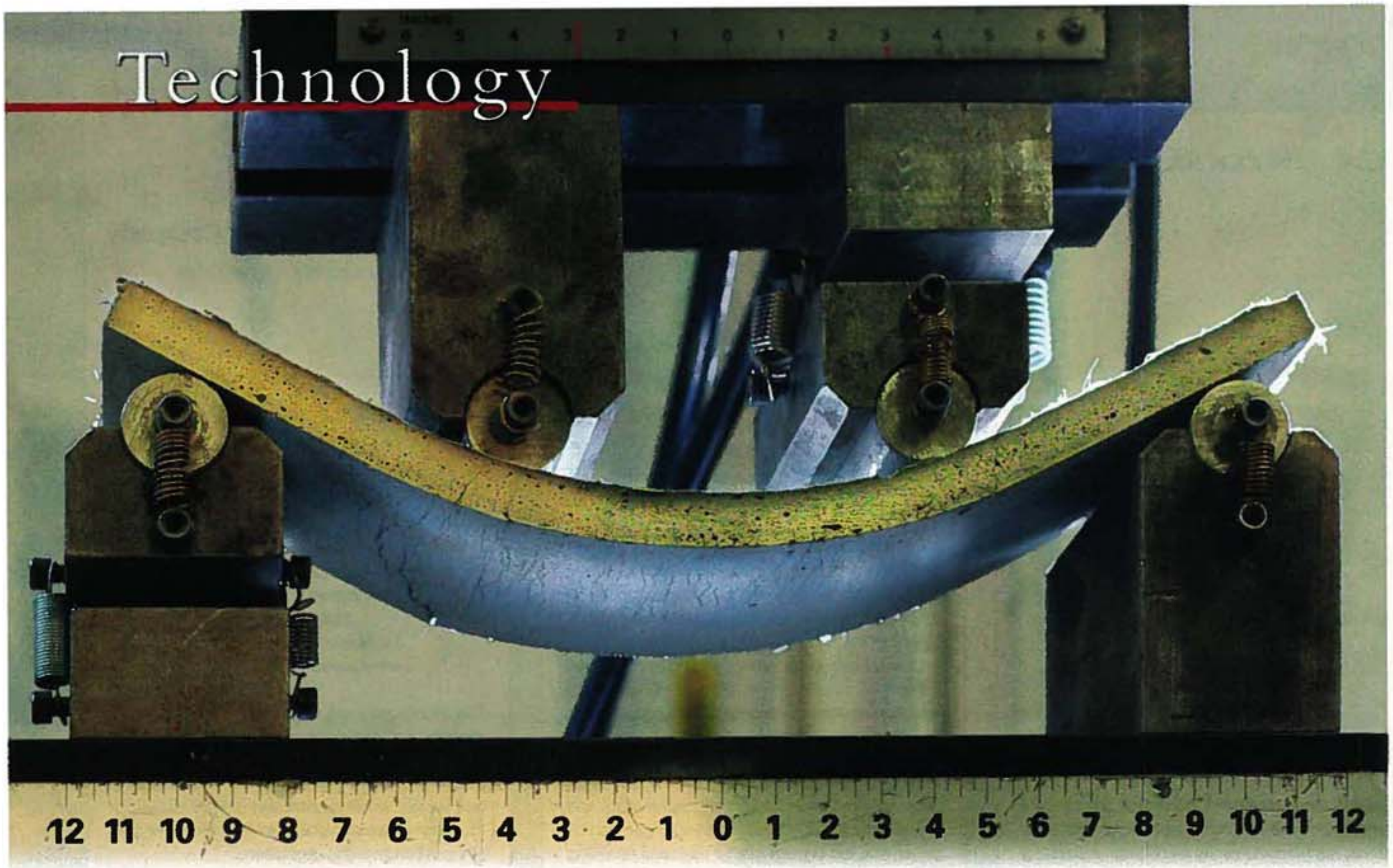

Bendable Concrete Repairs Its Own Cracks

CONCRETE HAS ALWAYS BEEN a brittle material, and to say that cracked concrete remains cracked until someone repairs it is surely a truism. Recently, however, researchers have turned such conventional wisdom on its head by developing a new type of concrete that not only is more ductile than ordinary concrete but also heals itself when cracked.

When ordinary concrete is subjected to tensile load, it tends to fracture and break into pieces. For this reason, researchers have long been interested in making concrete more ductile, that is, more likely to bend than to break under load. Researchers at the Advanced Civil Engineering Material Research Laboratory, in Ann Arbor, Michigan, for example, have spent the past 15 years developing what they call an engineered cementitious composite, in essence a highly ductile type of fiber-reinforced concrete.

According to Victor Li, Ph.D., F.ASCE, who heads the laboratory and is a professor specializing in civil and environmental engineering and materials science at the University of Michigan, the composite performs well, remaining intact and able to continue bearing its load under tensile strains as high as 5 percent. (Conventional concrete, in contrast, has been known to fracture and fail under a tensile strain of just 0.01 percent.) Instead of fracturing, the material undergoes a process called microcracking, wherein the energy of the tensile strain is diffused into a number of tiny cracks.

The process is well controlled, says Li, and the cracks are extremely small, averaging less than 60 µm in width, roughly half the width of a human hair. Nevertheless, in some applications even such tiny cracks are undesirable. To address that problem, Li and his team of researchers have improved the makeup of their composite material so that the cracks can actually heal themselves.

For the most part, the self-healing process simply takes advantage of materials already present in conventional concrete, explains Li. Even in ordinary concrete a significant percentage of the cement grains remain unused and dormant because they are never hydrated. Cracks in the concrete expose these residual cement grains to the air and water in the surrounding environment. Under the right conditions, the unhydrated grains react chemically with water and the carbon dioxide in the air to form strong compounds known as calcium carbonates.

The engineered cementitious composite developed at the Advanced Civil Engineering Material Research Laboratory, in Ann Arbor, Michigan, is much more ductile than ordinary concrete, continuing to bear its load under tensile strains as high as 5 percent. Instead of fracturing, the material bends and undergoes a process called microcracking. Later, under the right conditions, the tiny cracks can actually heal themselves.

The fractures in conventional concrete are generally so wide that even when calcium carbonates do form they provide virtually no benefit. However, when the cracks are small enough—no more than 50 µm—these compounds can accumulate in such a way as to fill the cracks, thus repairing the concrete and leaving behind nothing but a scar. Most important of all, the self-healing concrete recovers its essential properties, including its ductility, its stiffness, and its ability to resist the intrusion of such corrosive agents as water and road salt, Li says.

In general, the self-healing concrete

NICOLE CASAL MOORE, UNIVERSITY OF MICHIGAN consists of the same portland cement, water, sand, and chemical admixtures that are already present in conventional concrete. The difference is that the chemical, mechanical, and geometric properties and proportions of these ingredients are fine-tuned to promote the self-healing process, Li says. The composite contains no coarse aggregate, but it is reinforced by microfibers. As cracked areas are restored, the calcium carbonates form on and among the microfibers, with the result that the healed areas retain the benefits of fiber reinforcement.

To examine the self-healing ability of the new concrete, Li's team of researchers conducted a series of laboratory experiments in which specimens were subjected to a 3 percent tensile strain, that is, a force capable of increasing the specimens' lengths by 3 percent. The microcracks in the specimens were then allowed to undergo self-healing by being exposed to water and air. The researchers found that, on reloading, the specimens exhibited a tensile strength and tensile strain capacity nearly as great as in virgin material with no cracks.

Next on Li's research agenda is determining how well the concrete can recover after repeated damage. In these tests, which are currently under way, specimens are deliberately damaged and then exposed to a cycle of wet and dry conditions to simulate exposure to the natural environment. Researchers use sound waves to measure the material's structural properties and repeat the process numerous times. "So far, our preliminary results are very promising," Li says.

Although self-healing concrete must undergo more tests before it can be used in the field, Li envisions a number of applications, especially in transportation infrastructure. For example, the material could be used in an overlay to repair a deteriorated highway. Its high ductility would help to prevent cracks in the substrate from propagating upward into the overlay in a process known as reflective cracking, one of the most common causes of failure in concrete roadway surfaces, Li says. Furthermore, he says, such an overlay could be made much thinner than one of conventional concrete and would require less frequent maintenance.

The material might also be used as an alternative to expansion joints in bridges, which often require repeated maintenance, notes Li. A slab of bendable, self-healing concrete would accommodate the kinds of bridge movements that typically require more complex expansion joints, yet the material would appear continuous with the remainder of the bridge deck. In addition to a variety of repair applications, the material could see use in watertight structures, underground structures, tunnel linings, and pipelines.

At present, self-healing concrete costs roughly three times as much as conventional concrete. Although continued research is expected to reduce its cost, it is unlikely that self-healing concrete will be used as an alternative to conventional concrete throughout a structure, Li says. Instead, a cost-effective design would employ the new material only in areas that could take full advantage of its properties. In this way, Li says, the material's long service life and lower maintenance requirements could actually end up saving bridge owners money in the long term. —JEFF L. BROWN