By Victor C. Li

A new ductile, bendable concrete offers producers a futuristic material today.

An Engineer's Dream

Over the last few decades, material scientists have improved concrete mix designs using technology that has increased strength, durability, placing, and improved environmental aspects. Perhaps the brittle nature of concrete is the last technological barrier to attack.

Ever since concrete was made by the Romans 2000 years ago, it has been known for this brittleness. Concrete's brittleness has at times been responsible for catastrophic failures of structures, but more often results in a gradual deterioration that requires repeated and costly repairs. Many attempts have been made to modify concrete so it can take tensile load. Today, the most effective modification has been the introduction of fibers, typically made of steel, glass, or polymer, resulting in fiber-reinforced concrete.

It has been a dream of concrete engineers to produce a concrete that retains the beneficial properties of conventional concrete, such as high compressive strength and non-rusting. Yet at the same time, the final product should possess the tensile ductility of steel so yielding, instead of fracturing, occurs when the concrete is overloaded.

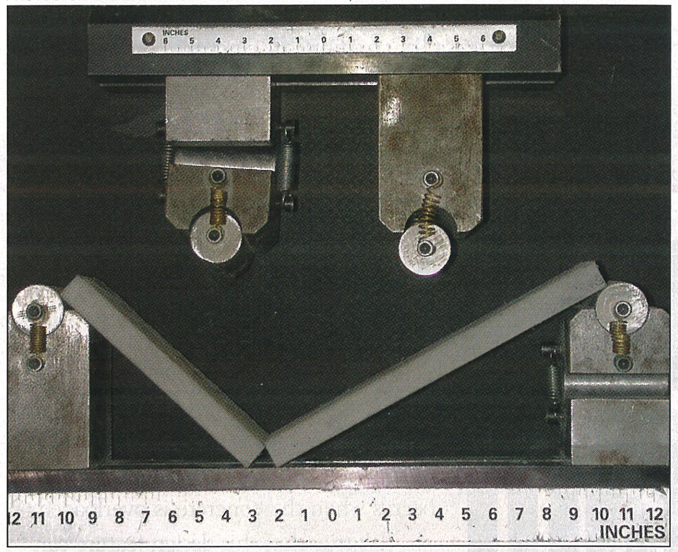
It's true that this design feature can be achieved with fiber reinforcement. However, the past strategy has been to use a lot of fibers (more than 5% in volume), often in aligned or fabric form. While such composites perform well, they are typically too costly to adopt and too difficult to mix and place in the field to become widely used. Very often, these materials require processing with sophisticated equipment available only in a research laboratory.

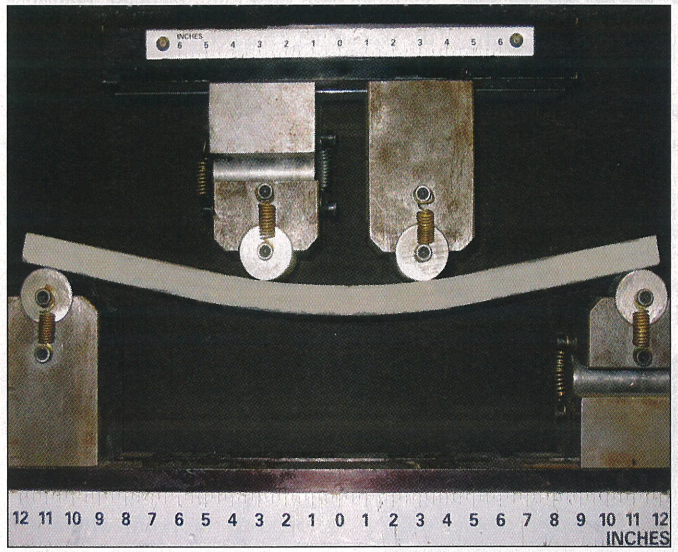
ECC's development

Recently, a ductile concrete material—engineered cementitious composite (ECC)—has been designed and developed to the point where it is emerging in full-scale applications, including on bridge decks

The Nabeaure Tower in Yokohama, Japan, used precast engineered cementitious composite (ECC) coupling beams in the building's core for seismic resistance.

PHOTOS: CIVIL AND ENVIRONMENTAL ENGINEERING, UNIVERSITY OF MICHIGAN





Conventional concrete breaks under flexural loading (top), while ECC merely bends under even higher pressure.

and tall buildings. ECC, developed at the University of Michigan, attains metallic behavior under loading and utilizes only 2% by volume of short fibers. It can be mixed in typical ready-mix equipment and cast as self-consolidating concrete (SCC). The material can also be sprayed as shotcrete.

ECC's tensile ductility is demonstrated by its ability to undergo stretching to about 300 times that of normal concrete before it breaks. It is equally ductile when loaded in shear. In bending, ECC deforms into a curve beam just like a metal plate deforming into the plastic yielding stage. In compression, some versions of ECC reach the same compressive strength as high-strength concrete. However, the material does not explode on failure.

ECC is able to display this unique behavior because of several discoveries: How load can be gradually transferred from the mortar matrix into the reinforcing fibers when the matrix material experiences excessive loading, and how the load can be gradually transferred from the fiber back into the adjacent mortar matrix when the fiber experiences excessive loading.

In this manner, no catastrophic failure occurs either in the matrix or in the bridging fibers. Instead, local bands of material relax and shed load by passing the load to neighboring zones of material. Loads essentially are transferred away from highly loaded regions that undergo a stepping down of elastic stiffness. All of these are carried out automatically in the properly designed composite.

In the example mix design on page 49, no coarse aggregates are used. Instead very fine sand, fly ash, and microfibers are included in the mix. The amount, type, and size of these ingredients are tailored to match the requirements for synergistic interaction during excessive loading as described above.

As an example, the PVA fiber is especially tailored with specific length, diameter, strength, stiffness, and a surface coating to allow its gradual release so that premature fiber fracture is prevented. The resulting composite system develops a "give" at high tensile stress, which translates into a ductile yielding behavior not unlike that of the plastic yielding in ductile steel. The unique metal-like behavior of ECC in tension allows this material to meet demanding mechanical and durability requirements in structures.

Ideal for repairs

In addition to new structures, ECC has also been used in repair projects. These projects have demonstrated that the tensile ductility of ECC contributes to resistance to cracking and/or delamination often seen in failed concrete repairs.

This performance is consistent even after several years of freezing and thawing weathering cycles in cold climates. Recent experiments in the laboratory suggest that ECC can serve as an excellent concrete cover in protecting steel reinforcement from corrosion.

The cost of ECC is currently about three times that of normal concrete per cubic yard. However, a number of commercial projects in Japan and Australia have already demonstrated that initial construction cost savings can be realized when ECC is used through smaller structural member size, reduced or eliminated steel reinforcement, elimination of other structural protective systems, and/or faster construction offered by the unique fresh and hardened properties of ECC. When long-term cost and environmental impacts are accounted for, the advantages offered by ECC over conventional concrete become even more compelling.

ECC is a field-ready ductile concrete that has the potential to significantly contribute to the enhancement of infrastructure sustainability, durability, and safety. The material is currently emerging in the repair, manufactured product, precast, and ready-mix markets, as well as the bridge, pavement, agriculture, housing, and building industries. **TCP**

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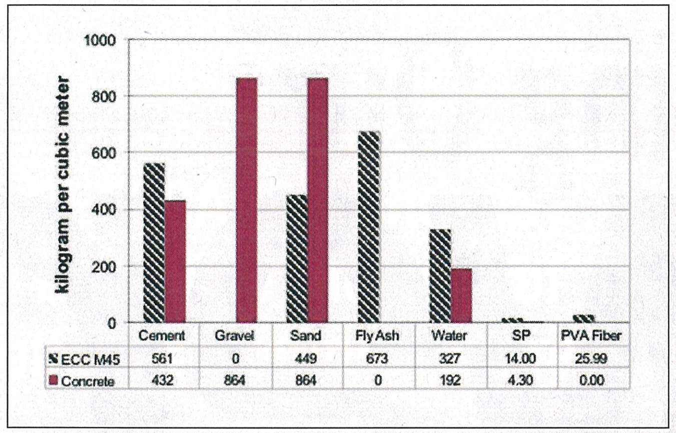
For more information, visit http://acemrl.engin.umich.edu, *and* www.engineeredcomposites.com/.

The University of Michigan's Center for Professional Development offers Fundamentals of Bendable Concrete, a course developed and delivered by Victor C. Li, Dec. 5–7 in Ann Arbor. For more information or to register, visit http://cpd.engin.umich.edu *or telephone Becky Erskine at 734-615-5698.*



	Cement	Gravel	Sand	Fly Ash	Water	SP	PVA Fiber
ECC M45	561	0	449	673	327	14.00	25.99
Concrete	432	864	864	0	192	4.30	0.00

Above: A mix design for ECC and regular concrete. In ECC, there are no coarse aggregates. Instead, very fine sand, fly ash, and microfibers are included. Right: Constructed in 2005, the ECC deck link-slab on the Grove Street Bridge in Ypsilanti, Mich., eliminates frequent maintenance of common expansion joints.