Bendable Concrete Minimizes Cracking and Fracture Problems

The Pitch

Bendable concrete (technically called "engineered cementitious composites," or ECCs), which is reported to overcome the brittleness of conventional concrete, is under development at the University of Michigan. In direct tension, ECCs, which have a tensile strain capacity of 3%, are 300 times more deformable than typical concrete. Their tensile stress–strain curves resemble that of a ductile metal with a yield point and subsequent strain-hardening behavior. However, only 2% by volume of short-fiber reinforcement is required to achieve ease in casting or field construction. This cost-effective technology enhances concrete structural and product performance while reducing both initial and long-term costs. While concrete brittleness can be compensated to a large extent with steel reinforcement on a structural scale, the intrinsic tensile ductility of bendable concrete eliminates cracking and fracture problems. This results in increased structural durability and safety as well as improved performance in infrastructure sustainability.

The initial cost savings of introducing bendable concrete depends on the particular product in which the material is used. Cost savings are associated with more efficient design as well as reductions in material volume, labor cost, and steel reinforcement. Markets that can benefit from the introduction of ECCs include transportation, building, water, and energy supply infrastructure as well as the housing, architectural, and concrete manufactured product industries. The U.S. market size for the precast and prestressed concrete product industry alone, for example, has been estimated at over $9 billion. The civil infrastructure repair business in the highway, street, bridge, and tunnel construction industries had annual revenues of about $60 billion in 1997. The market size for decorative concrete for housing applications is on the order of several billion dollars per year. By eliminating one of the most significant shortcomings of conventional concrete, ECCs could further extend the use of concrete as a major construction material. Potential customers include owners and contractors of constructed facilities, precast product manufacturers, fiber cement producers, and repair professionals.

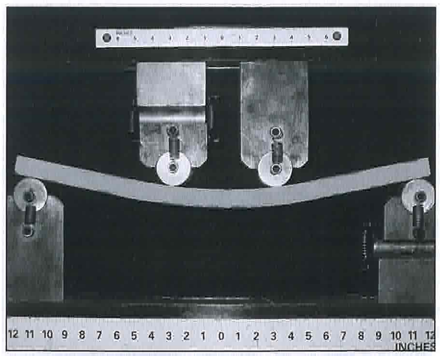

Figure 1. Bendable engineered cementitious composites (ECCs) subjected to flexural loading. The beam specimen measures 304.8 mm long by 76.2 mm wide by 12.2 mm deep; deflection is 22 mm at a peak load of 0.6 kN. The maximum tensile strain capacity shown here reaches 3–5%.

Figure 2. The Glorio Tower Roppongi high-rise residential building, located in central Tokyo, which uses ECC coupling beams in its core for seismic resistance. The building is 27 stories (95 m) high. Built by Kajima Corp., construction on the building was completed in 2005.

The Technology

The non-brittle nature of ECCs can be visualized in a flexural test of an ECC beam, shown in Figure 1. The beam is withstanding a high load and a large deformation (hence ECCs' common name, "bendable concrete") without succumbing to the brittle fracture typical of normal concrete, even without the use of steel reinforcement. The ductile behavior of ECCs is the result of the deliberate selection of combinations of type, size, and amount of ingredients guided by micromechanical models also developed by its University of Michigan developers. These ingredients are specifically tailored to produce a composite that gives under excessive loading through controlled microcracking while suppressing brittle fracture localization.

A sample composition for an ECC in mass percent is 27.9% cement, 22.3% sand, 33.5% class F fly ash, 14.2% water, 0.9% superplasticizer, and 1.2% polyvinyl alcohol (PVA) fiber. The volume fraction of the fibers, which are pretreated with a proprietary oil coating, is 2%. ASTM Type I Portland cement and low-calcium ASTM class F fly ash are used. Large aggregates are excluded in the ECC mix design, and only fine sand is incorporated. The silica sand has a maximum grain size of 250 μm, with an average grain size of 110 μm. The PVA fibers, which constitute 1.2% by weight, are 39 μm in diameter, 12 mm long, and have an overall Young's modulus of 25.8 GPa. The apparent fiber strength when embedded in the cementitious matrix is 900 MPa.

Lightweight ECCs with a density between 900 kg/m^3 and 1600 kg/m^3 and a high early-strength ECC that delivers a compressive strength of 23 MPa within four hours after placement have been developed within the past few years. ECC varieties adapted for casting, extrusion, and shotcrete applications have been developed through the rheological control of properties. For on-site casting execution, ECCs use conventional construction equipment and are self-consolidating without the use of vibration. On-site casting of bridge decks and off-site manufacturing of coupling beams for tall building applications (shown in Figure 2) have been demonstrated. Thin-walled, bendable ECC pipes and an ECC shotcrete for repair applications have been commercialized.

Opportunities

The University of Michigan researchers welcome inquiries about joint application R&D. The licensing of ECC technologies, which are owned by the University of Michigan, is also available.

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