0-7030: Synthesis of Engineered Cementitious Composites (ECC) for Applications in Texas

Background

Engineered cementitious composites (ECC) are a special type of high-performance fiber-reinforced cementitious composites that is characterized by high-ductility (3–5% strain) and moderate tensile strength (4–6 MPa) with 1.5–2% fiber content by volume. Under tensile deformation, ECC shows strain-hardening behavior and closely spaced microcracks after the first cracking. ECC possesses excellent shear capacity, improved damage tolerance, ability to control crack width, and synergistic interaction with reinforcing bars. ECC has been proposed as a novel alternative for infrastructure materials but to date has not seen wide application in Texas or the rest of the United States. The objective of this project is to identify high priority applications of ECC appropriate to the Texas transportation system.

What the Researchers Did

The research team conducted seven tasks categorized into three activities: (1) a comprehensive literature review, (2) a survey of state, federal, and international experts, and (3) life-cycle cost analysis (LCCA) and life-cycle assessment (LCA) for selected Texas applications.

The state of the art of ECC technologies was investigated through a literature review, paired with a meta-analysis to identify the relationship between the mixture design and mechanical behavior. Based on these results, a standard mixture design was recommended.

Using a survey, experts from industry and academia were asked about suitable applications, barriers to application, and research and engineering codes needed to support application of ECC, identifying several applications and immediate needs.

Finally, LCCA and LCA were used to evaluate the economic and environmental benefits of two ECC applications recommended by the surveyed experts: pavement overlay and bridge link-slab. Combining the task results, the research team has recommended high-priority high-value applications and suggested topics for further research to facilitate broader application.

What They Found

The literature review provides a comprehensive overview of ECC technology, including the developmental history, mechanical properties, tailoring of fiber-matrix interface bonding, fiber dispersion, mixture design, and field applications.

The earlier ECC mixtures were typically composed of Portland cement, water, silica sand, water reducing agent, and polyvinyl alcohol fibers. Later, investigators learned that adding pozzolanic class-F fly ash can reduce the amount of Portland cement and mprove tensile strength and ductility. The meta-analysis of more than 500 stress-strain curves revealed that a peak improvement in the average tensile strength can be attained at 40% fly ash content in binder (Portland cement +

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fly ash). The most widely used fly ash content is 55% in binder, and the average strength of ECC with 55% fly ash is very close to the strength of theoretical ideal mix design which would use 40% fly ash. Based on this observation, the research team concluded that the fairly standard mixture containing 55% fly ash in binder, which is known as M45, is close to the optimum mixture design and is favored due to the existence of a larger body of data on processing and performance.

Another important observation from the meta-analysis is that the strength and ductility data of ECC produced by various investigators show wide scattering of measured properties even for the same mixture designs. The wide range indicates that a reliable and reproducible quality control process is especially important in ECC applications.

The survey provided the top three recommendations for application of ECC: the repair of concrete structures (pavement repair + bridge deck repair, 35%), pavement overlay (15%), and bridge link-slab (15%). The barriers to widespread use are the lack of standard material test for quality control (26%), lack of the experience (21%), high initial cost (21%), lack of information (16%), lack of the standard specification for construction (11%), and lack of material suppliers (5%). The survey respondents said that development of the material test method for tensile properties of ECC (28%), field demonstration (22%), development of the construction specification (17%), member level performance comparison tests (11%), dissemination of the information (11%), and material suppliers (11%) are necessary precursors to wider applications.

The LCA and LCCA were conducted for three scenarios: 1) pavement overlay with the maintenance timeline suggested by a previous investigator, 2) pavement overlay with the maintenance timeline based on the TxDOT LCCA guide, and 3) bridge link-slab. The life-cycle costs and greenhouse gas emissions of ECC applications were compared to conventional structures; the results show that ECC reduces both agency/user costs and environmental impacts. For the bridge link slab, the agency and user costs (present value) of the conventional expansion joint were 12% and 29% higher than the ECC link-slab, respectively.

Based on the meta-analysis, published results of ECC applications, simulation of system life-cycle costs, and input from the surveyed professional, the research team recommends three ECC applications: 1) bridge link-slab, 2) pavement overlay, and 3) repair of existing concrete structures. The team also suggests four research/implementation projects to facilitate wider adoption of ECC: 1) development of a standard material test protocol for quality control of ECC, 2) development of standard construction specifications, 3) quantitative evaluations of the resistances of ECC to fatigue cracking and environmental attack, and 4) field demonstrations.

What This Means

The project provided the technical and economic background to assess the applicability of ECC to Texas civil infrastructure. Based on prior performance, ECC can be expected to increase service life and to reduce the maintenance cost of civil infrastructure. The results of this work suggest that the TRL of ECC technology can be expected to rise rapidly, particularly if the steps proposed by this project are pursued.

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