Engineered Cementitious Composites – A Replacement of Conventional Concrete for Sustainable Infrastructure

Broad Area

Design and Development

Need for the Study in the Context of Future of Cities

Concrete is the one-of the most widely used construction materials in the world. In spite of its high compressive strength, cracks originate and evolve in concrete structures subjected to in-service loading situations because of its low tensile resistance. Propagation and widening of cracks eventually may result in catastrophic failure, typically when the structures, during their service-life, are being subjected to natural and/or man-made hazards. Thereby improvement of tensile durability (without degrading other characteristics – such as compressive strength) is a specific requirement for concrete structures. The motivation of the study is not to eliminate the formation of micro-cracks in concrete by modifying the constituents, but to impart a pseudo strain-hardening behaviour which eventually prevents the agglomeration of the micro-cracks which lead to catastrophic failures through the formation of macro-cracks. In view to this, in the present proposal, we aim to develop a material which is much more ductile compared to conventional concrete used for construction. Using indigenous, low cost, and abundant ingredients, successful execution of the proposed work will lead us to develop Engineered Cementitious Composites (ECC) with superior strength and ductility as compared to the conventional concrete.

For any major infrastructure in a city, concrete is utilized to a large extent as construction material. Being brittle in nature, traditional concrete cracks easily under mechanical and environmental loads. The concrete materials used for Future Cities need to have four major characteristics: *first* the concrete should deform considerably under tensile load, *second*, it should be impermeable to sulphate and other corrosive agents, *third*, the concrete should be lighter than the traditional concrete, and *finally*, it should have self healed characteristics. Additionally, future cities need to be built with structures with minimal maintenance and made with easily available resources. The built structures should also not consume significant amount of energy, and there should be marginal imprint towards environmental pollution.

When stressed under tensile load, ECC develops micro-cracks as opposed to localized Griffith crack observed in conventional concrete. As mentioned earlier, micro-cracks in ECC provides strain hardening and retards water and chloride ion penetration minimizing the corrosion of steel reinforcement. Durability of ECC (with higher tensile and comparable compressive strength to that of conventional and fibre reinforced concretes) is presumed to be due to lower permeability and diffusion rate of water and chloride ion penetration in hardened composite. The self healed characteristics stem out to be due to the reaction of Ca^{2+} ion with carbonated water leads to the formation of $CaCO_3$ which filled the micro-crack to impart the so called self healing of the composite structure.

In view to this we foresee the Engineered Cementitious Composites as an effective alternative to both traditional as well as fibre reinforced concrete. As compared to these building materials, ECC with low fibre volume contents offer smaller crack width, superior tensile strength, significantly higher ductility, and self-healing characteristics. Since stone chips are not used, skyscrapers and other load bearing ECC structures would be comparatively light weight than conventional RCC or steel fibre reinforced concrete structures. ECC is environment friendly, as blasting of igneous rock (to yield coarser aggregates) becomes redundant, and also due to extended maintenance cycles of ECC, consumption of cement and thereby the CO_2 foot-print is grossly reduced (note that production of 1 ton cement clinker releases equivalent amount of CO_2 in the ambient). Using ECC, structures could be built by casting, extrusion, or by spraying. The shape flexibility together with self consolidated and self healed characteristics of ECC will be very attractive for the adoptability of ECC in Future of Cities. Using novel, easily available, sustainable and cheaper ingredients, in the present work we aim to develop indigenous engineered cement composites adaptive to various structures of Future of Cities.

Objective and Scope of Work

The major objective of this work is to develop an indigenous cementitious composite for the replacement of conventional concrete. Development of such composite is very much desirable for sustainable infrastructure for urban areas especially in seismic prone zones. Engineered Cement composite (ECC), originally developed and patented by Victor Li (Univ. of Michigan), has the potential to improve the tensile strength of the conventional concrete. The broader scope of this work is to develop cementitious composite which has similar properties as that of ECC (patented by Li), but by using different and relatively cheaper constituents including but not limited to manmade or natural fibres. Apart from the development of cementitious composite with higher tensile resistance, it is envisaged that the developed material will be lighter than the conventional concrete and should yield higher early strength, self-consolidating and self-healing characteristics. The specific objectives are itemized as follows:

- To identify the ingredients and optimize the mix proportion and process methodology to make cementitious composites with significantly higher tensile strength and comparable (or better) compressive strength to both conventional and fibre reinforced concretes.
- To delineate the role of specific or combined ingredient/(s) towards hydration kinetics, micro-crack formation, permeability, and self healing characteristics of these cementitious composites.
- Using selective ECC compositions with superior mechanical properties fabricate prototype structures such as steel reinforced sewer pipe and pre-stressed electric poles.
- Fabricate large component models and prototype models with ECC and conventional concrete and perform experimental investigations which are realistic and experienced by structural components ad/or prototype models in event of earthquake and/or wind loading on structures.

Methodology

Ingredients such as OPC, fly-ash, sand, different types of admixtures/super-plasticizers, man made/natural chopped fibres, silica fume and various types of natural fibre modifiers will be used to prepare cementitious composites without any coarse aggregates. Experimental investigations such as slump and flow-table test will be performed to determine consistency of the mix.

During and after the of curing of the composites, a wide array of material characterization [viz. field emission scanning electron microscopy (FESEM), Fourier transform infra-red spectroscopy (FTIR), X-ray diffraction (XRD), differential scanning calorimetry (DSC) etc] will be carried out to investigate the fibre-matrix bonding and the hydration characteristics of the mix. The hardened ECC will be characterized in terms of their tensile, compressive, flexure, fracture toughness, and impact strength characteristics. Sorption and rapid chlorine penetration tests will also be performed to investigate the self-healing characteristics of the synthesized ECC. Subsequently, the physical and mechanical properties of these composites will be compared with those of conventional concretes for benchmarking. The work would primarily be exploratory in nature.

Using ECC with optimized physical and mechanical characteristics, it is planned to fabricate prototype structures which include but not limited to steel reinforced sewer pipes and pre-stressed electric poles. We have identified and will take help from a few local industries to fabricate these prototypes using ECC. The relevant characterization facilities available with these companies will be utilized to evaluate the performance of the fabricated proto-types.

To test the durability, a model ECC made structure will be fabricated at IIT Kharagpur. The research executed in the present work would prepare the stage for real-life field applications in Future of Cities.

Outcome/ Deliverables

Through this study the fundamental understanding of the pseudo-strain hardening behaviour of the ECC will be strengthened. The effect of different constituents controlling the ECC characteristics (viz. strain hardening, self healing etc) will be delineated. The major deliverable of the project will be the indigenous development of cementitious composite prepared from low-cost sustainable materials. It is expected that the synthesized composites would yield high tensile durability, light-weight, high-early-strength, self-consolidating and self-healing property without compromising the compressive strength obtained in conventional concrete.

The deliverables of the project would be as follows:

- Guidelines for design of engineered cementitious composite mix which would retain the compressive strength characteristics of conventional concrete in addition to ensuring higher tensile strength, lighter weight, development of early strength, self-consolidation and self-healing nature.
- Delineate the role of specific ingredients controlling the micro-crack formation, ductility, self consolidation and self-healing characteristics of process optimized ECC compositions.
- Understanding on the structure-property correlation of these engineered cementitious composites.
- Fabrications of prototype ECC based products and develop physical and mechanical benchmarks for these prototypes for prospective use in Future of Cities.

- 2 Ph.D students will be trained during the execution of the proposed work. Selected mix designs and process methodologies will be patented. Novel findings will also be reported in peer reviewed quality journals.

Team Composition

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