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# Effect of high strain-rates on the tensile constitutive response of Ecofriendly Ductile Cementitious Composite (EDCC)

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**Abstract**

Eco-Friendly Ductile Cementitious Composites (EDCCs) are a newly developed class of engineered cementitious composites that contains reduced amounts of cement and very high volumes of fly ash (or other SCMs) and show very high ductility and elastoplastic response in pure tension. These characteristics make EDCCs a promising material for seismic retrofit applications. This paper describes an experimental program where the effects of higher rates of loading on the tensile behaviour of EDCC are assessed. Strain-rate ratios of the orders of 103 (static to dynamic) are investigated. The rate of loading is chosen to coincide with strain-rates normally observed during earthquakes. The EDCCs tested are fiber reinforced concrete materials having a total fiber volume of 2%. Non-oiled Poly-Vinyl Alcohol (PVA) fibers and Poly-Ethylene Terephthalate (PET) fibres are used in the EDCC mixes in three different combinations: 2% PVA, 2% PET, a hybrid mix of 1% PVA + 1% PET fibers. For the quasi-static tests, a normal closed-loop test set-up is used. For the dynamic tests, a newly designed test setup using an air gun is utilized. This investigation discloses that the approximate static to dynamic ratio for the tensile strength of EDCC varies between 0.75 and 1.00 in magnitude; and, the strain capacity varies between 1.0 and 3.0 for this material. Results demonstrated that EDCCs are highly strain-rate sensitive materials and their performance during an earthquake should not be assessed from routine quasi-static tests.


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*Keywords:* EDCC; ECC; FRC; Eco-Friendly Ductile Cementitious Composite; Engineered Cementitious Composite; Fiber Reinforced Concrete; High Strain Rate; Tensile Strength; Dynamic Effect; Dynamic Loading; High Rates of Loading; Strain Rate Effect; Loading Rate Effect

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## 1. Introduction

Over the past few decades, the general use of Fibre Reinforced Concrete (FRC) has been constantly increasing within the construction industry due to its noticeable performance in terms of crack control and toughness. In fact, FRC has some great structural and non-structural applications, such as shotcrete projects, tunnel linings, or industrial type slabs on grade. One innovative type of FRC is called Engineered Cementitious Composite (ECC) which is a class of the ultra-ductile fiber reinforced cementitious composites, developed for applications in the large material volume usage generally.

During the initial development phase of EDCC, the material is tested for its mechanical properties at slow rates of loading. However, many structures could be subjected to high strain rates of loading caused by earthquakes, impacts, or blasts. In fact, EDCC is targeted to be used for seismic retrofit applications for its ductility, great toughness, and high energy absorption capacity. Thus, studying the effects of high loading rates on EDCC and how to improve its performance under these circumstances has become an important topic [1].

Generally, there are three phases in a typical FRC mix: matrix, fibre, and the aggregates. It is known that the overall impact resistance capacity of concrete is increased by introducing randomly distributed fibres into the mix. However, this capacity is limited due to the poor bonding and week interactions between the three phases within the fiber reinforced concrete. Also, the dominant failure mechanism is usually the fibre-matrix debonding caused by tensile and shear deformations. Therefore, the use of polymer and polyester fibres is more effective in increasing the energy absorption of the concrete because of their enhanced bond with the matrix [2].

When incorporated into the matrix, these fibres are also effective in reducing the weight of the concrete and enhance ductility, toughness, and crack resistance [3]. In addition, increased durability is vivid from the high fiber content mixes because of the reduction in permeability caused by the pore refinement from the addition of the fibers.

### *1.1. EDCC with a high volume of fly ash*

EDCC (Eco-Friendly Ductile Cementitious Composite) is a new type of high performance fiber-reinforced cementitious composites (HPFRCC) with 2% volume fraction of fibre that shows high ductility. Under tensile loading, EDCC shows a relatively significant strain-hardening type behavior with great ultimate strain capacity.

Adding a high volume of fly ash to these composites helps to reduce the matrix-fibre interfacial bond strength and the matrix toughness; thus, contributing in the achievement of high strain capacities during tensile loading. This high capacity is obtained through development of multiple cracking.

The previously developed ECC is achieving the multiple cracking by using 2% volume fraction of oil coated PVA fibers [6]. However, EDCC is achieving similar capacities to ECC by 60% replacement of the cement content by fly ash and using only 1% non-coated PVA fibers in conjunction with 1% of PET fibers; whereas the conventional ECC uses pure cement with over 2% of coated PVA fibers to achieve similar performance.

This has caused EDCC to become a more sustainable as well as more economically feasible material than ECC. This type of material has many great applications such as dam repairs, bridge deck overlays, and seismic retrofits [4].

### *1.2. Fibers*

There are two types of fibres used in the development process of EDCC: non-coated Poly-Vinyl Alcohol (PVA) fibres and Poly-Ethylene Terephthalate (PET) fibres. Below are brief introductions to these fibre types.

#### *1.2.1. Poly-Vinyl Alcohol (PVA)*

Poly-Vinyl Alcohol (PVA) fibres are produced through processing of polyvinyl alcohol which is a nontoxic, water-soluble, and fully biodegradable polymer. During this process PVA fibres are made with high crystallinity and crystal orientation, which results in them having excellent tensile strength of 0.9 – 1.9 GPa and the elastic modulus of 11 – 43 GPa. In addition, PVA fibres have high alkali resistance, good adhesive properties, and great resistivity to hot weather. Therefore, they are a very good choice of fibre to be used in FRC mixes [3].