



Flexural performance of concrete beams containing engineered cementitious composites

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HIGHLIGHTS

- Performance of concrete beams with Engineered Cementitious Composites ECC.
- Variable volume fractions of (PVA) and (PP) fibers were used.
- ECC materials exhibits an improvement in ductility.
- Load carrying capacity is more significant for using PVA rather than PP.
- Non-linear finite element analyses were performed and assessed with experimental results.

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ABSTRACT

Engineered Cementitious Composites (ECC) considers a type of ultra-ductile cementitious composites with fiber reinforcement. It is developed for applications for economic purpose in the construction industry. ECC characterizes by strain hardening and multiple cracking. This paper experimentally investigates the performance of ECC concrete beams reinforced with conventional reinforcement bars. Advanced Polyvinyl Alcohol Engineered Cementitious Composite (PVA-ECC) fibers were selected in this purpose. Twelve RC beams were poured and tested to study flexure behavior under four-point loading test. Two different longitudinal reinforcement percentages, variable volume ratios of (PVA) and polypropylene fibers (PP) were used. Optimizing the usage of PVA material trails to put it in the lower layer of the section at point of maximum tension with variable thicknesses was conducted. Initial flexure cracking load, ultimate load, the ductility and the load-to-deflection relationship at various stages of loading were evaluated. Experimental outcomes revealed that the enhancement in maximum capacity is more significant in the case of using PVA rather than PP. The maximum load increases by 20% and 34% for 1.0% and 2.0% of PVA contents in total section respectively. The relative ductility factor increases by 30% and 45% for 1.0% and 2.0% of PVA content. Results also depicted that a reasonable considerable increasing in the load capacity when used limited layer thickness of PVA concrete. Nonlinear Finite Element Analysis (NLFEA) was conducted for the purpose of simulating the behavior of experimentally tested beams, regarding crack behavior and load-deflection response. Reasonable agreement was achieved between the experimental results and NLFEA results.

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1. Introduction

The development of fiber reinforcing material for concrete has undergone at the few last decades. In the 1960's, the effectiveness of short steel fibers in reducing the brittleness of concrete was studied [12,11]. This improvement has continued using extension

of varied fiber types, such as carbon, glass, and synthetics. Recently, hybrids mixture in which a combination of varied fiber types or fiber lengths has been arises. Concrete with discrete fibers, like polypropylene exhibits drop in the tensile resistance as a distinct crack expands during tension-softening. (PVA-ECC) fiber is considered a promising alternative for fiber reinforced concrete [15]. Deformation for ECC during the elastic and strain-hardening phases is suitably defined as straining. The tensile resistance continues to rise during multiple micro cracking and the strain increased continuously. Based on the load-to-deflection curve of

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concrete, the participation of concrete in uni-axial tension can be defined as the tension-stiffening effect [1].

ECC concrete reveals its tensile ductility under tension load [7,16,17,6,8]. When ECC concrete beam subjected to bending, a multiple micro-cracking mechanism was formed at the zone of maximum tension stresses. In addition, allowing it to encounter a high curvature progress – an occurrence that has resulted in the general name of “bendable concrete”. Regardless the element geometry, deflection hardening is an essential property of ECC. This is not the response for tension-softening FRC beam, in which deflection hardening comes to be challenging to achieve as beam depth increases [13]. The cost of PVA is estimated about 1/8 of high modulus polyethylene (PE) fiber, and is even less than steel fiber of the same volume basis. With some certain improvements in fiber properties, PVA fiber introduces a promise as ECC reinforcement [15].

Yuan et al. [18], studied the effects of the ECC concrete layer thickness and position on the manners of the steel reinforced specimens with ECC/concrete composite. The stresses provided by ECC at tension region lead to larger area of concrete participating in compression. Hence, the maximum moment capacity was enhanced. Doo-Yeol Yoo et al. [4], investigated the behavior of beams including ultra-high performance ECC. They recorded a strain-hardening characteristic though the formation of fine micro cracks at failure load. PAN JinLong et al. [10], carried out a four-point load test to study the flexural characteristics of PVA with different ratio. It concluded that the ductility and bending strength of ECC material are significantly larger than those of plain concrete. In addition, when the volume fraction increased, the ductility increases.

Alfonso [2], was presented the results of flexural behavior eight beams with SFRC external layers and RC internal layer. The SFRC beams exhibited 70% greater energy absorption than RC beam. Fang et al. [5], tested beam-column joints with ECC composite exposed to cyclic loads. According to the results, the additions of ECC materials in joint zone significantly enhance the load capacity and ductility. In addition, the higher shear strength and ductility of ECC concrete, the higher the energy dissipation encountered. D. Nicolaides et al. [3], established a constitutive material model by using the extracted results from the experimental outcomes of beams with fiber reinforcement and subjected to three-point bending tests. Inverse analysis (least-square method) method was used to develop a material model for which reaching to optimum correlation between the test results and numerical load-deflection relationships. Most of the previous research works were limited to use one kind of fiber as ECC material. for that reason, the performance of beams with ECC material using mix of two kinds of fiber need to be investigated.

The aims of this paper are, experimentally and analytically investigate the performance of beams with ECC regarding the cracking load, ultimate load, the ductility and the load-to-deflection response. Two kinds of fibers were used for that purpose, ECC in the form of PVA and polypropylene PP fiber. The paper aims also to develops a numerical models using (NLFEA) to simulates ECC beams performance and help to conducts more future parametric studies. The developed numerical models were performed using ANSYS software [22].

2. Test program

2.1. Test specimens

In this investigation, twelve concrete beams were cast. Two control beams were poured without fibers for comparison, and the rest of specimens included fibers. Two types of fiber materials

have been utilized in this investigation; ECC material in the form of Poly vinylalcohol fibers (PVA) and Polypropylene fibers (PP). The geometrical and mechanical properties of the used fibers were measured, Sayed et al. [23]. PVA fibers have a length of 12 mm, a diameter of 39 μm , an elastic modulus of 42.8 GPa, nominal strength of 1620 MPa and 6.0% elongation. Polypropylene fibers (PP) have a length of 12 mm, a diameter of 22 μm , an elastic modulus of 3.45 GPa, nominal strength of 550 MPa and 21.0% elongation. Two specimens were poured without adding any fiber as control beams with longitudinal reinforcement two 16 mm diameter and two 12 mm diameter respectively. Another two beams were cast totally with PVA volume ratio of 1.0% and 2.0%. Two more beams were cast totally with PVA and PP fibers with volume ratio of 0.50% and 1.0% for each fiber. Three more beams containing 200 mm layer of PVA and PP fibers with volume content of 0.50% and 1.0% were casted. Three more beams containing 100 mm layer of PVA and PP fibers with volume content of 0.50% and 1.0% were cast. The cross sectional dimensions and the span of the specimens were kept constant for all the ten beams. The dimensions of all specimens were 115 mm x 280 mm x 1850 mm. Seven beams were reinforced using two steel bars of 16 mm diameter at the bottom face that serves as the main reinforcement, the other five beams were reinforced using two of 12 mm diameter. The yield stress was measured to be 400 MPa. Two bars of 8 mm diameter were used as top RFT and 8 mm diameter stirrups @ 100 mm c/c spacing were used as shear reinforcement as presented in Fig. 1 and Table 1.

2.2. Test setup

The specimens were tested in a machine of 1000 kN capacity. Beams were simply supported over a span of 1650 mm. The load was distributed on two plates kept 350 mm apart. The two loads are symmetrical to centerline of the beam. The dimension between the two loading plates is 350 mm. the edge dimension between the load plate and the nearest support is 650 mm. The specimens were tested under load control with the rate of 30–70 increments to failure. Strain gauges have been fixed at the longitudinal reinforcement bars to record the strain in the steel bars as illustrated in Figs. 2 and 3. Deflection at the centerline was measured for every 0.5 kN increment of load using a linear variable differential transformers (LVDT) fitted at the center. The cracks during loading stages were mapped out and other observations were recorded during loading and at the failure; Fig. 4 shows crack propagation of beam B1.

3. Experimental results and discussion

3.1. Initial crack load and ultimate load

All beam specimens were visually observed till the initial crack occurred, the corresponding load was noted. Table 2 provides a summary of the important experimental results for tested specimens. The load at initial crack increases as the volume content of fibers increases. PVA and PP material improve the residual strength of concrete through additional fracture energy. After the first cracks, fibers began to work during applying loads up to failure. However, with the addition of polypropylene fibers (PP), the increase in ultimate load is very marginal compared to (PVA). Compared to control beam B1 for group A, the maximum load increases by 20% and 34% for 1.0% and 2.0% of PVA fibers content ratio in total section, respectively. The increasing ratio reaches to 11% and 24% when using a mixer of both PVA and PP fiber with the ratios of 0.5% and 1.0% for B4 and B5, respectively. It can be noticed that using both PVA and PP with the volumetric ratios, 0.5% and

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