Analysis of Bridge Deck Link Slabs with Ductile ECC

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***Abstract* - In recent years, a number of full-scale applications of ECC have been carried out in various countries. Foremost among these is the use of ECC in precast R/ECC coupling beams in the core of two high-rises in India. This application exploits the high energy absorption capability of R/ECC to aid in the seismic resistance of these tall buildings. The aim of the present work is to carry out the comparative analysis of three different fibre PP, PE and PVA containing ECC as the bridge deck slab linking material. The Experimental examination for physical properties for example Functionality and Self-Consolidating Property, Density and Air content test has been completed. The research has shown that the Self-Consolidating Index is maximum for PP fibres. Analysis revealed that the incorporation of PP, PE and PVA fibers at a volume fraction of 2% resulted in an 8%, 29% and 38% reduction in density compare with fresh concrete. The PP, PE and PVA fibers into engineered cementitious composites has resulted in an increment in air content. ECC containing PVA fibre has the highest compressive and flexural strength, while PE and PP fibre content has shown lower compressive and flexural strength compared with the PVA-ECC specimens.**

I.INTRODUCTION

1.1 Cementitious Material

Conventional mortar and concrete are often used as repair materials in relatively thick sections and large areas, such as the repairs of slabs, walls, columns, piers, hydraulic structures and the full-depth repairs of bridge decks and parking structures. In order to reduce shrinkage, repair materials often have a low water-to-cement (w/c) ratio and a high percentage of aggregates [ACI 546.3R 2006]. Admixtures, such as water-reducing admixtures, expansive agents, and accelerators, are often used to reduce water requirements, improve workability, lower shrinkage, accelerate strength gain and adjust other properties.

Fibre reinforcement

Reinforcing a material enables the creation of new properties that neither of the parent materials would have on their own. Different types of fibre are available for use to reinforce cement-based material such as paste, mortar, or concrete. Table 1.1 presents different types of fibre with their respective physical characteristics and properties.

The choice of fibres for a particular application depends on their characteristics and the ultimate use of the composite, but there will inevitably be a process of compromise. A range of fibres are available which offer high to very high strengths; however, ultimate strain should also be a consideration which will enable the material to be pseudo-ductile under stress. For example, steel fibres are often used due to their high stiffness (modulus of elasticity), but under some specific conditions depending on the exposure environment and crack widths, are prone to corrosion and present a relatively low ultimate strain capacity compared with other available fibres.

Polymeric PVA fibres are likely to be, in this case, the reinforcement of choice. Concrete made of cement and relatively coarse aggregates allows a specific type of fibre such as steel to be effective as a reinforcing material for thicker sections of the composite thanks to the rigidity of the steel fibres.

Table 1.1 Properties of structural fibres

Material	Diameter (µm)	Unit Weight (t/m3)	Tensile Strength (GPa)	Modulus of Elasticity (GPa)	Ultimate Strain (%)
Steel	5-500	7.85	0.5-2.0	200-210	0.5-3.5
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Glass	09-15	2.62	2.0-4.0	70-80	2.0-3.5
PP	20-400	0.93	0.4–0.8	3.5-10	15.0-25.0
Aramid	10-12	1.45	2.3-3.5	63-120	2.0-4.5
PVA	25-40	1.31	1.2-1.6	25-40	7-8'
Carbon	23-400	1.65	2.5-4.0	230-380	0.5-1.5

Engineered Cementitious Composites

ECCs typically consist of a cementitious matrix reinforced with a relatively low volume fraction of small diameter polymeric fibres (less than 50 µm). Initial developments of ECCs date back to the 1990s, when research was directed at improving the cement matrix properties. The reinforcing fibrous phase, present at 2 % by volume, has been shown to lend the subsequent cement matrix composite a degree of pseudo-ductility1 under stress, preventing failure in a brittle manner, which is more typical of cementitious mortars. More specifically, ECCs are able to undergo a process of multiple cracking under stress with the structure being preserved through stress transfer and a fibre-bridging mechanism: even at significant strain levels, crack widths are kept below 100 µm. In addition, at this level of reinforcement, the matrix of the fresh material remains workable during construction, an important feature of cementitious.

materials deployed on construction sites, particularly those where access is limited, and the material must be pumped.

Micromechanics for ECC Design

Significant research and development in ECC have been carried out to understand how the microstructure and material optimisation can lead to a greater ductility. Materials selection also plays an important role in reducing the cost especially as PVA fibres are relatively expensive. Li (2002b) used a micromechanics approach to relate the macroscopic properties to the microstructure of the composite. A summary of the relevance of this in the current work is presented in this section.

Fibre bridging properties

Li (2002b), studying ECCs, demonstrated the link between the micromechanical parameters (fibre, matrix and interface) and the pseudo-ductile behaviour of the resulting composite under stress. Figure 1.4 shows that the pseudo-ductile behaviour of ECCs under stress comes from the ability of the fibres to bridge the cracks. More precisely, the performance of ECCs is associated with the load transfer from the fibres to the matrix for the formation of successive cracks, especially in the early stages of the applied load and later to the ability of the fibres to bridge the cracks holding the composite material together.

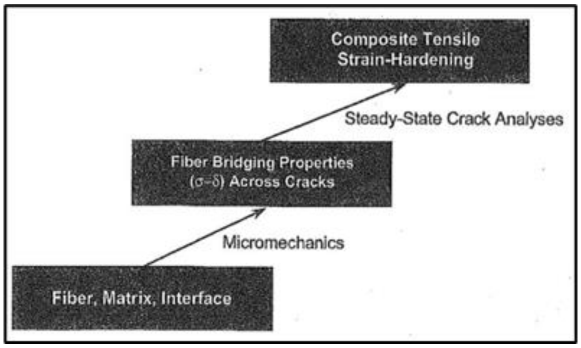

Figure 1.1 Link between composite material constituents: (Li, 2002b)

Applications of ECC

In recent years ECCs have been utilized in numerous field applications, most of which require limited crack widths, reduced cross sections, or a high tensile strain capacity Examples of applications include link slabs in bridges, retrofitting of dam claddings and irrigation channels,

the surface repair of retaining walls, a bridge deck replacement, or even dampers for high-rise reinforced concrete buildings.

II-LITERATURE REVIEW

Yeon Lee et al. developed a new evaluation method for PVA fiber dispersion in the ECC matrix using a fluorescence technique combined with an image processing analysis.

M. Li and V.C. Li found a strong positive correlation between the fiber dispersion coefficient in the fresh state and tensile strain capacity of the ECC composite. They stated that it is important to control material rheology during processing to achieve a composite with robust mechanical properties.

Similar to other fiber types, PVA fibers can reduce the water absorption of cementitious composites. Thong et al. reported that the incorporation of PVA fibers into oil-palm shell concrete reduced the water absorption of the concrete with different curing conditions and immersion periods compared with the control sample.

Sahmaran and Li also reported that the sorptivity of ECC with PVA fibers is significantly lower than that of normal concrete because of the dense and thick transition zone between the fibers and matrix as a result of fly ash in the composite.

Sahmaran et al. reported an increase in the compressive strength of ECC composite of approximately 3.5% upon PVA fiber addition. A similar improvement for concrete containing PVA fibers has also been reported by Kim et al. and Han et al.

Qiu et al. reported that fatigue deterioration of the PVA/matrix interface, de-bonding and hardening, as well as fiber strength reduction, contribute to the fatigue deterioration of fiber bridging in the ECC composite. These fatigue-induced mechanisms reduce the bridging ability of PVA fibers and strain hardening capacity of cementitious composite. Zhao et al. studied the creep behavior of concrete containing a 0.07% volume of PVA fibers. They observed that PVA fibers cannot reduce concrete creep at this lower dosage because of their lower modulus of elasticity in comparison with the concrete (Ef / Ec = 0.95).

Said and Abdul Razak investigated the performance of PVA-ECC composites for exterior beam-column joints under reversed cyclic loading. They observed that for the concrete without fibers, the cracks propagated and severely widened within the joint, and the concrete was crushed into several pieces in the joint. However, for the concrete containing PVA fibers, an improvement in the ultimate load capacity of approximately 22.6% and damage tolerance because of the perfect ductility, energy absorption ability and gradual failure were obtained. The column joint with PVA-ECC after loading exhibited a dense network of tiny crack developments with reduced crack spacing and width.

Zhang et al. developed a new ECC composite with a low shrinkage cement binder as a substitute for ordinary Portland cement. The new ECC composite containing a 1.7% volume of PVA fibers exhibited better performance in strain capacity with lower tensile strength than did the conventional ECC composite. The tensile strain capacity of the developed composite was reported as 7 times higher than that of the conventional ECC. They stated that the lower matrix shrinkage reduced the bond strength between the fiber and matrix as a result of a decrease in the clamping pressure acting on the fiber surface.

III-MATERIAL AND METHODS

(A)Link Slab Design

(i) Link Slab Design Using Conventional Reinforced Concrete

Run of the mill to numerous territorial and state divisions of transportation inside the US, the State of Michigan Department of Transportation (MDOT) has effectively built and developed answers for the extension joint issue. Preceding executing ECC link slab innovation, MDOT built various solid link slabs inside Michigan.

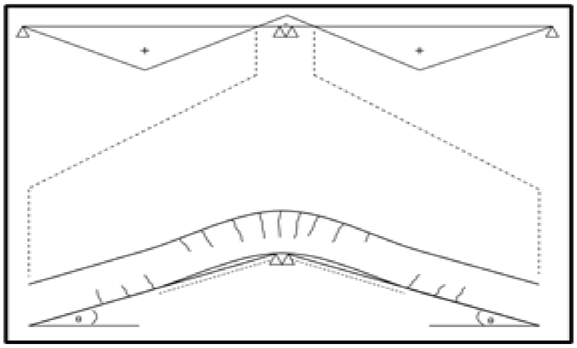

Figure 3.1 Bridge moment distribution and link slab hinging mechanism

(ii)Design of an ECC link slab

As per the design specification provided by Lepech et al; 2009, the overall length of the link slab and the length of the link slab debond zone are calculated in Equation 3.1 and 3.2, respectively.

$L_{ls} = 0.075\ (L_1 + L_2) + G_{1-2}$ ……… (3.1)

$L_{dz} = 0.05\ (L_1 + L_2) + G_{1-2}$ ……… (3.2)

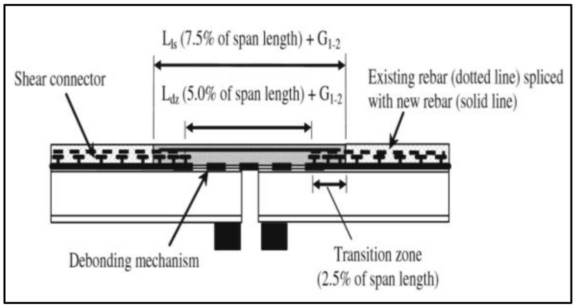

Figure 3.2 Schematic of ECC link slab

This debonding instrument might be either standard roofing tar paper (for use with steel supports) or plastic sheeting (for use with precast solid braces). While composite activity is kept up in the contiguous ranges, this debonding inside the link slab permits it to work all the more efficiently as a pivot between the two neighbouring ranges while they deflect (as appeared in Fig. 3.2).

(B) Materials

(i) Cementitious matrix

ASTM Type I ordinary Portland cement (OPC) and a low-calcium Class F fly ash were used. The fine sand had a maximum particle size of 300 mm and a mean particle size of 200 mm. Viscosity agent, i.e. high-range water-reducing admixture (HRWRA), was added in order to achieve adequate workability.

(ii)Mix Designs

For the present analysis there are 3 mixes are considered. Composition A was made of Portland cement (PC) containing fly ash, fine aggregates, water, admixtures, and PP fibres, while the Composition B was made using PE fibre and the third composition has been made using PVA fibre. For the analysis the amount of fibre is kept constant i.e. 2% by weight for all the three composition.

Table 3.2 Mix Proportion of ECC in Current Study

Cement (wt%)	Fly Ash (wt%)	Sand (wt%)	Water (wt%)	Admixture (wt%)	Fiber (vol%)
1.0	3.0	1.4	1.1	0.022	2.0

IV-RESULTS AND DISCUSSION

(A)Physical Properties

(i) Workability and Self-Consolidating Property

The slump cone considered for the analysis has the upper and bottom diameter 100 and 200mm respectively. The measurement of maximum diameter of flow (d1), perpendicular to max diameter(d2) are measured and flowability using following formula are calculated.

$$Flowability = \frac{(d_1 \times d_2) - (slump\ cone\ dia)^2}{(slump\ cone\ dia)^2}$$

It has been observed that the workability is maximum for PP fibre ECC and minimum for PVA fibre ECC. The Self-consolidating Index also shows the same trend. The addition of PVA fibers to a concrete mixture causes a significant reduction in the workability of the mixtures. PVA Fibers increase the viscosity of concrete and restrict the distribution of the cement matrix, resulting in a reduction of workability reduction in the workability of the mixtures.

Because of the hydrophilic nature of PVA fibers, their effect on the reduction of flow rate is higher than other hydrophobic fibers, such as PP fibers. The incorporation of PVA fibers into a cementitious mixture (2.0% volume fraction) resulted in a significant reduction of slump flow by 3% and 2% respectively. The Self-Consolidating Index for PVA, PE and PP fibres are 0.75, 0.79, 0.815 respectively.

Table 4.1 Slump-cone and Self Consolidation Test

	Slump Cone Test				Self-Consolidation Test		
	d1	d2	Slump Cone Diameter	Flow-ability	Initial Height	Flow of Height	Self-Consolidating Index
Polyvinyl alcohol (PVA)	650	645	200	9.48125	150	400	0.75
Polyethylene (PE)	670	665	200	10.13875	158	400	0.79
Polypropylene (PP)	685	680	200	10.645	163	400	0.815

(ii)Density

Since PP fibers were mostly added in a low volume fraction to the concrete mixture, their influence on the weight reduction of ECC is significant. Analysis revealed that the incorporation of PP, PE and PVA fibers at a volume fraction of 2% resulted in an 8%, 29% and 38% reduction in density compare with fresh concrete.

Table 4.2 Density variation for different Fibre-ECC

	Density (gm./cc)
Polyvinyl alcohol (PVA)	2.2
Polyethylene (PE)	1.7
Polypropylene (PP)	1.5

(iii)Air content

A concrete specimen shows the air content about 6%. The PP, PE and PVA fibers into engineered cementitious composites has resulted in an increment in air content. PP, PE and PVA fibers in a volume fraction of 2% increased the air content by 26%, 42% and 60% respectively.

Table 4.3 Air-Content variation for different Fibre-ECC

	Air Content %
Polyvinyl alcohol (PVA)	26%
Polyethylene (PE)	42%
Polypropylene (PP)	60%

(B) Mechanical Properties

(i)Compressive and Flexural Strength

It has been observed that the ECC containing PVA fibre has the highest compressive strength with the value of 38.35 MPa and 43.68 MPa for 7 and 28 days of curing respectively. The compressive strength increases with the PVA fibre. This is due to the fact that PVA fiber-reinforced foamed exhibited a densification regime under compression due to the maintained specimen integrity by fibers after failure.

Table 4.4 Compressive Strength and Flexural Strength Test Results

	Compressive Strength (M Pa)		Flexural Strength (M Pa)	Mid-Span Deflection (mm)
	7 days	28 days		
Polyvinyl alcohol (PVA)	38.35	43.68	8.3	2.24
Polyethylene (PE)	29.5	33.6	7.5	2.93
Polypropylene (PP)	25.075	28.56	6.8	2.52

(ii)Experimental Load-Deflection Analysis

In the present work, an experimental test has been carried out to find out the structural performance of ECC link slab in bridge deck systems using 1/6 scale test models. The main objectives of this laboratory test were to study the structural behaviour of ECC link slabs under the monotonic cyclic load simulate traffic loading with different fibres for reinforcing materials on the behaviour of ECC link slabs

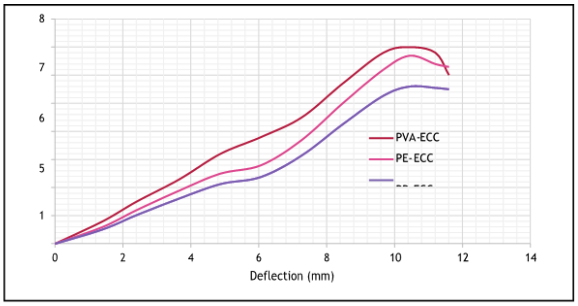

Figure 4.1 Load- Deflection Curve

V.CONCLUSION

The following conclusion can be made after the present study:

- It has been observed that the workability is maximum for PP fibre ECC and minimum for PVA fibre ECC.
- The addition of PVA fibers to a concrete mixture causes a significant reduction in the workability of the mixtures.
- PVA Fibers increase the viscosity of concrete and restrict the distribution of the cement matrix, resulting in a reduction of workability reduction in the workability of the mixtures.
- Since PP, PE and PVA fibers were mostly added in a low volume fraction to the concrete mixture, their influence on the weight reduction of ECC is significant.
- The PP, PE and PVA fibers into engineered cementitious composites has resulted in an increment in air content. PVA, PE and PP fibers in a volume fraction of 2% increased the air content by 26%, 42% and 60% respectively.
- For all ECC link slabs, a steady increase in deflection was evidenced when the applied loading was increased. This proves that all ECC link slabs clearly defined the ductility and strain hardening behaviour without the aid of the reinforcing bars.

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