A Literature Survey on Engineering Cementations Composites

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Abstract_

Engineered Cementitious Composites (ECC, also known as “ECC Concrete”), developed in the last decade, may contribute to safer, more durable, and sustainable concrete infra-structure that is cost-effective and constructed with conventional construction equipment. With two percent by volume of short fibers, ECC has been prepared in ready-mix plants and transported to construction sites using conventional ready-mix trucks. The mix can be placed with-out the need for vibration due to its self-consolidating characteristics. Furthermore, the most expensive component of the composite, fibers, is minimized resulting in ECC that is more acceptable to the highly cost sensitive construction industry. ECC is ductile in nature. The aim of research work is to study ductile behavior of concrete, crack resistance capacity & concrete should give warning before its failure. Normal concrete is brittle in nature while ECC is ductile in nature, due to this

property; it has wide applications & wide future scope in various fields. The Figure1 shows the typical behavior of ECC- Concrete.

I.INTRODUCTION

One of the lessons from the Japanese current destructive earthquakes including the 1995 Hyogoken-Nanbu Earthquake (Kobe Earthquake) is that most new buildings designed according to the current seismic codes showed fairly good performance with the view of preventing severe damage and/or collapse for life safety. However, the problem was that the seismic performance of buildings was widely ranged from the level of collapse preventing to function keeping, which have not been identified by the current seismic codes. It is, therefore, strongly needed to develop the more rational seismic design codes based upon the performance-based design concept. The performance on seismic resistance of buildings including structural safety and functional soundness during and/or after earthquake, and reparability after earthquake may be explicitly explained. The Japanese Building Standard Low is now under revising to be performance-based regulations. Since the low is a minimum requirement, a new evaluation and statement system of building performance beyond the code requirement is also under developing. Then it is a high priority issue to develop the new structural technologies to meet the high level of structural performance requirement.

A collaborative effort between US and Japanese researchers has focused on the development of high-performance elements for seismic structural applications, based on a new materials technology. The new materials technology involves an Engineered Cementitious Composite (ECC) designed using micromechanical principles [Li, 1993]. ECC exhibits excellent ductile properties and damage tolerance, which are strain-hardening with strain capacity of 1.5% to 7% in tension and multiple cracking properties [Li, 1993, Fukuyama et al., 1999]. The ultra ductile behavior of ECC, combined with its flexible processing requirements, isotropic properties and moderate fiber volume fraction, which is typically less than 2% depending on fiber type and characteristics of interface and matrix, make it especially suitable for critical elements in seismic applications where high-performance are required. Applications of ECC to energy absorption devices and damage tolerant structural elements are considered to meet the performance requirements of structures under the performance based engineering. These new structural elements with ECC are expected to reduce the seismic response and damage of structures.

Objective of this research is to investigate the upgrading effects on structural performance of building elements by using ECC. The ECC employed in this research is Polyvinyl Alcohol (PVA) fiber reinforced mortar designed using micromechanical concepts. A tension-compression reversed cyclic test of material and a structural test with six beam elements were conducted. This paper summarizes the basic mechanical properties of PVA-ECC and the structural performance of PVA-ECC reinforced beam elements with the view of application to seismic resistant structures. The micromechanics concepts, which support the development of ECC, are also briefly presented.

II.MICROMECHANICS CONCEPT FOR ECC

The development of ECC is based on the micromechanics of fiber bridging and matrix crack extension. The theoretical foundation was first described by Li [Li, 1993]. As a result of the micromechanics analysis, it was shown that pseudo strain-hardening under tensile loading can be accomplished with short randomly oriented fiber reinforcement of a cementitious matrix, at moderate dosage no more than 2% by volume. Various fiber types can be utilized as long as the fiber volume fraction V_f satisfies:

$$V_f > V_f^{crit} \equiv \frac{12 J_c}{g\,\tau\left(L_f / d_f\right)\delta_o} \qquad (1)$$

where, $\delta_0 = \tau L_f^2 / [E_f d_f \{1 + (V_f E_f)/(V_m E_m)\}]$ is the crack opening corresponding to the maximum bridging stress, d_f is fiber diameter, E_f and E_m are Young's Moduli of fiber and matrix, respectively, g is snubbing factor, L_f is fiber length, τ is friction between fiber and matrix, V_f and V_m are the volume fraction of fiber and matrix, respectively, V_f^{crit} is the critical fiber volume fraction, and J_c is matrix toughness. Supplementary conditions are described by Li and Leung [Li and Leung, 1992]. The critical fiber volume fraction V_f^{crit} is therefore dependent on fiber, matrix, and fiber/matrix interaction properties. Fiber properties include fiber length L_f, diameter d_f, and modulus E_f. The fiber/matrix interaction properties include friction τ and a snubbing factor g [Li et al., 1990]. The matrix properties include matrix modulus E_m and matrix toughness J_c.

It should be noted that Eq. (1) is applicable only to the case when fiber rupture does not occur, and that the fiber/matrix interface is governed only be simple friction with no chemical bond. Extension of Eq. (1) to composite with these properties have been considered by Kanda and Li [Kanda and Li, 1997]. The reformulation of (1) leads to V_f^{crit} which depends on fiber strength and chemical bond strength, in addition to those already mentioned above.

Equation (1) prescribes the recipe for formulating a ECC material systematically. It guides the composite design by specifying the necessary combinations of fiber, matrix and fiber/matrix interaction properties. Most current FRCs would have these micromechanical parameter combinations which lead to high V_f^{crit}. This means that unless the fiber volume fraction is high, (say e.g. > V_f^{crit} = 10%), psudo strain hardening cannot be achieved. The power of Eq. (1) is to allow systematic tailoring of the micromechanical properties in order to achieve a low to moderate V_f^{crit}.

TENSION-COMPRESSION CYCLIC TEST OF PVA-ECC

A tension-compression reversed cyclic test with PVA-ECC cylindrical specimen, which shape is 100 mm in diameter and 200 mm in height, was conducted to observe the uniaxial mechanical properties. The properties of PVA fiber used and the mix proportions of PVA-ECC are shown in Table 1 and Table 2, respectively. The mix proportion of PVA-ECC was designed using micromechanical concepts. The fiber volume fraction of PVA-ECC was 1.5 %. Fig. 1 shows the loading set up of the tension-compression reversed cyclic test. Since the basic data of material properties under reversed cyclic loading is necessary to discuss about the seismic structural application, a new testing method was developed for reversed cyclic loading test of the composite material. In this method, mechanical chuck is used to grip both ends of the cylindrical specimen for tensile loading. This chuck has a mechanism that gripping force is increased in proportion to the tensile loading force. Continuous tension and compression loading are available, since both plane surfaces of the specimen are attached to the steel plates of the loading machine. Uniaxial glass fiber sheets were wrapped with resin so as to line fibers vertically in Fig. 1 at the top and bottom of the specimen to reinforce the gripping zone and to control the initiation of cracks into the 100 mm of displacement measuring length. Since the size of this cylindrical specimen of PVA-ECC is the same as that of concrete pieces used for compression test, the compressive properties observed in this test can be treated as standard compressive test results.

From the observed stress-strain relationships as shown in Fig. 2, the PVA-ECC employed in this research exhibited multiple cracking and strain-hardening with strain capacity of around 1.5 % in tension. After this capacity point, stress is gradually decreased with increase of strain due to the rupture of PVA fiber. However, the

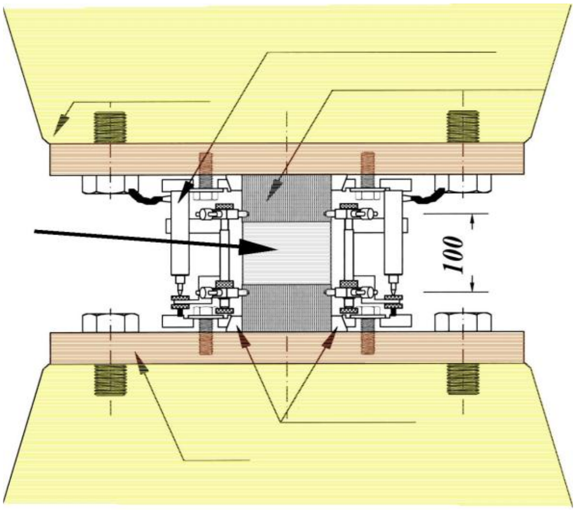
Table 1: Properties of PVA fiber

Diameter	Length	Elastic modulus	Tensile strength	Specific gravity
40.8 micron	*15.0 mm*	*43.9 GPa*	*1850 MPa*	*1.30*

Table 2: Material mix proportions in weight fractions

Materials	Cement (C)	Silica fume (SF)	Super-plasticiser (SP)	Water (W)	Coarse aggregate (CA)	Sand (FA)
(ratio)		SF/C	SP/C	W/(C+SF)	CA/(C+SF)	FA/(C+SF)
PVA-ECC	*1.00*	*0.25*	*0.03*	*0.45*	---	*0.40*
Concrete	*1.00*	---	*0.01*	*0.46*	*2.63*	*2.12*

brittle behavior in compression after maximum strength, and the slip behavior near the horizontal axis when the loading was changed from tension to compression were observed.



III.Results And Discussion

3.1. NORMAL CONSISTENCY OF CEMENT:

Table 3.1 normal consistency of cement

Trail No.	Weight of cement (gm)	Percentage of water	Depth of penetration
1	400	26	14
2	400	27	9
3	400	28	5

Normal consistency of cement is **28%**

3.2. FINENESS OF CEMENT:

Weight of Cement sample taken (W_1) = 100 gms

Weight passed through Sieve (W_2) = 96 gms

$$\% \quad \text{fineness of Cement} = \frac{W1 - W2}{W1} * 100 = \frac{100 - 96}{100} * 100$$

$$= 4\%$$

The percentage of fineness of cement is **4%**

3.3. SIEVE ANALYSIS OF FINE AGGREGATE:

Table 3.3 Sieve analysis of fine aggregate

Sieve size	**Weight Retained**	**% Weight Retained**	**Cumulative % Weight Retained**	**Cumulative % Passing**
10 mm	0	0	0	100
4.75mm	0	0	0	100
2.36mm	0	0	0	100
1.18mm	12	1.2	1.2	98.8
600µ	124	12.4	13.6	86.4
300µ	445	44.5	58.1	41.9
150µ	400	40	98.1	1.9
Pan	19	1.9	100	0
TOTAL	**1000 gms**	100		

As per standards and when compared with the limits, the sand zone is taken as **ZONE-3**.

3.4. BULKING OF SAND:

Table 3.4 bulking of sand

% of water	**Volume of water**	**Volume of bulked sand**	**% of bulking**
0	0	300	0
1 %	5	350	16.67
2 %	10	370	23.33
3 %	15	400	33.33

4 %	20	400	33.33
5 %	25	380	26.67
6 %	30	360	20

The maximum water content for bulking of sand is **4%.**

3.5. PYCNOMETER TEST:

Table 3.5 pycnometer test

SL. No	**Observations and Calculations**	**Trail No.**	
		1	**2**
Observation			
1	Mass of empty Pycnometer (M_1)	665 g	665 g
2	Mass of Pycnometer and aggregate (M_2)	1665 g	1670 g
3	Mass of Pycnometer, aggregate and water (M_3)	2202 g	2200 g
4	Mass of Pycnometer and water (M_4)	1538 g	1534 g
Calculations			
5	$M_2 - M_1$	1000 g	1005 g
6	$M_3 - M_4$	664 g	666 g
7	Calculate G using formula	2.97	2.96

Specific Gravity $$G = \frac{M_2 - M_1}{(M_2 - M_1) - (M_3 - M_4)}$$

Specific gravity of coarse aggregate is **2.97**

3.6. WATER ABSORPTION TEST:

Weight of wet aggregate (A) = 500 g

Weight of dry aggregate (B) = 498 g

$$\text{Water absorption} = \frac{500 - 498}{498} * 100$$

$$= 0.4\ \%$$

Water absorption of coarse aggregate is **0.4 %**

3.7. FLEXURE TEST:

FOR CEMENT-SAND SPECIMENS:

Table 3.7.1 flexure test for cement-sand specimen

Specimen	Maximum load	Displacement (mm)
1	5.12	0.4

FOR ECC SPECIMENS:

Table 3.7.2 Flexure test for ECC specimen

Fiber content	Maximum load	Displacement (mm)
1%	6.1	22.7
2%	5.56	34.5

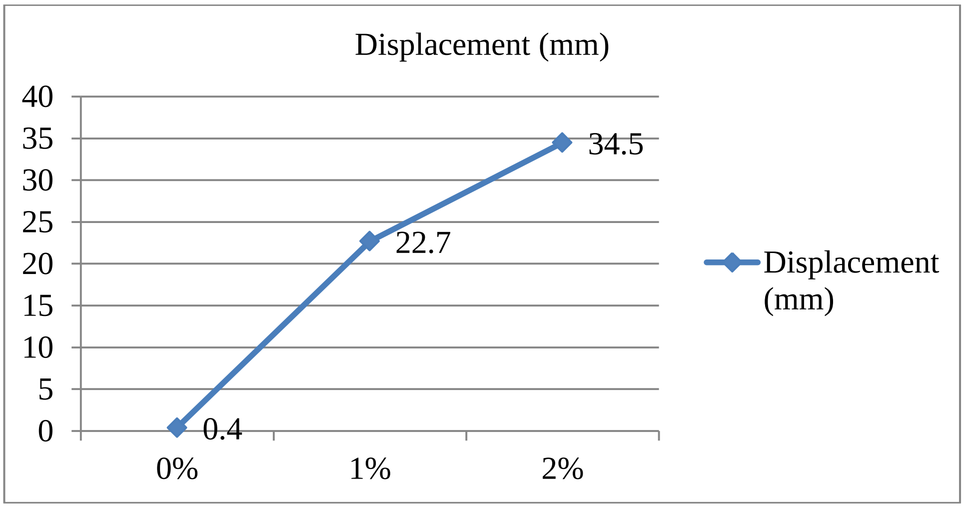


Figure 3.7.1 flexure test

Flexural strength = $3FL / 2bd^2$

Where L= support span,

b= width of specimen

d= depth of specimen

FOR CEMENT-SAND SPECIMEN:

$\sigma_f = (3\times5.12\times255\times10^3) / (2\times75\times35^2)$

= 21.31 KN

FOR ECC SPECIMENS:

For 1%, $\sigma_f = (3\times6.1\times255\times10^3) / (2\times75\times35^2)$

= 25.32 KN

For 2%, $\sigma_f = (3\times5.56\times255\times10^3) / (2\times75\times35^2)$

= 23.14 KN

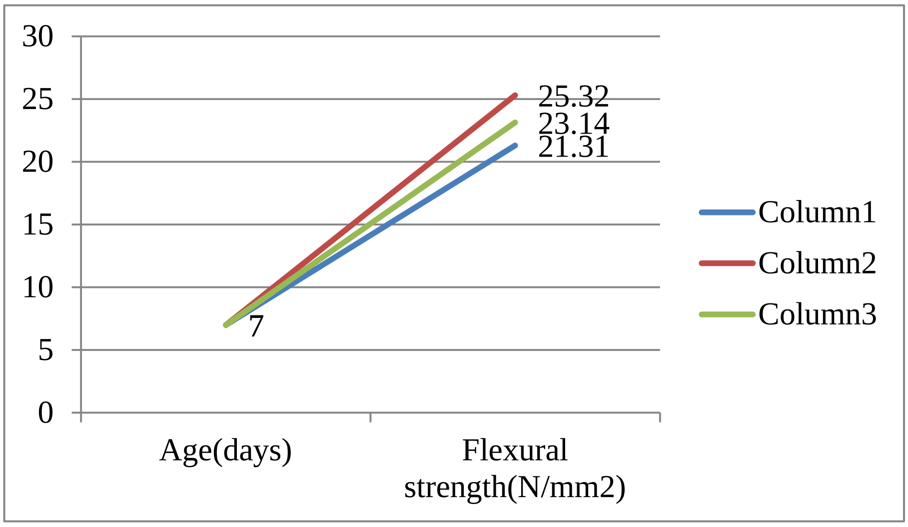


Figure.3.7.2.flexure strength vs age

3.8. COMPRESSION TEST:

Table 5.8.1 compression test

Specimen no	Mix-1	Mix-2	Mix-3
1	490	600	550
2	540	580	530

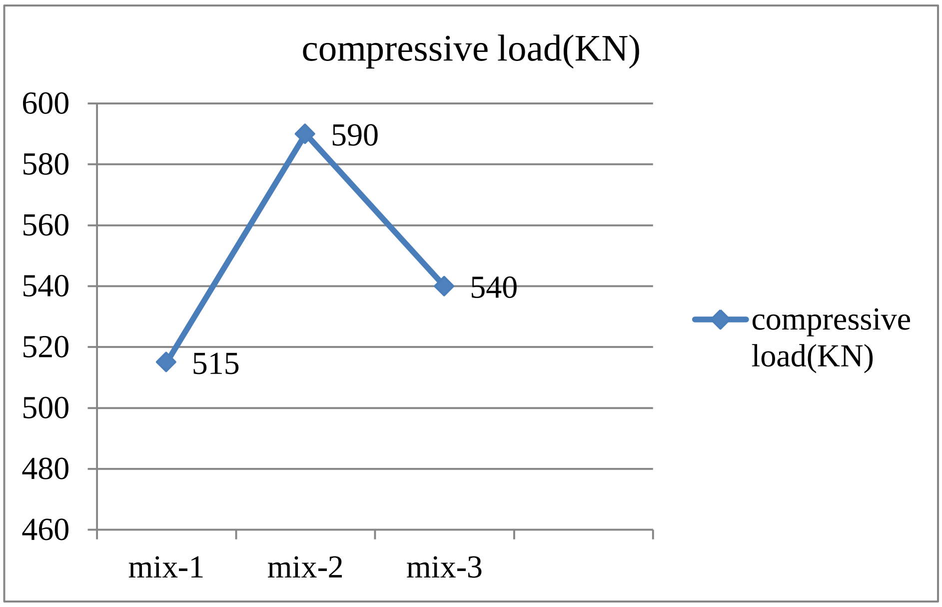


Figure 3.8.1 compression test

IV.CONCLUSIONS

ECC, which exhibits excellent properties in ductility and damage tolerance, was developed for applying to the seismic resistant structural elements. The ECC employed in this research is the PVA fiber reinforced mortar designed using micromechanical concepts.

A tension-compression reversed cyclic test with cylindrical specimen was conducted to observe the uniaxial mechanical properties of PVA-ECC. From this test, PVA-ECC with 1.5 % of fiber volume fraction exhibits strain-hardening with strain capacity of around 1.5 % in tension.

To demonstrate the potential of ECC in structural performance of elements, a cyclic loading test of six beam elements was conducted to investigate the upgrading effects on structural performance of beams with PVA-ECC. The test results indicate that the brittle failures as shear failure and bond splitting failure observed in the RC beams can be prevented by using PVA-ECC in place of the concrete. As a result, the beams with PVA-ECC indicate excellent ductile manner. This means that PVA-ECC worked as the reinforcement for not only shear and bond splitting but also confinement of concrete expansion after yielding of beams. The maximum shear crack widths up to 5 % rad. in deflection angle of some PVA-ECC beams were less than 0.3 mm, which is the maximum limit value for durability. Through this test, it can be clarified that PVA-ECC has much feasibility to upgrade the structural performance and damage tolerance of structural elements.

Continued research will maintain the materials-structure interaction approach, and the academic / industry / government collaborative stance. Additional work will focus on filling in knowledge gaps in material properties and design, as well as on element and system response under seismic loads. The long range output from the collaborative research between US and Japan will include design methods for ECC materials; analytical model and technique for FEM to evaluate the structural performance of element with ECC; and design guideline for structural system with ECC elements.

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