An Experimental Investigation Of Self-Healing Property On Ecc With Pp And Pva Fibers Using Bacteria Under Different Exposure

A. Richard, p. Krithika

Abstract*: *This study focuses to develop the self-healing property of Engineered Cementitious Composites (ECC) with Polypropylene (PP) and Poly Vinyl Alcohol (PVA) fibres with Bacteria. Self-healing property of ECC based on Calcium Acetate precipitation induced through bacterial activity has been investigated in this project. This technique is highly desirable because the mineral precipitation induced, result and discussion are natural and pollution free. ECC specimen containing Bacillus subtilis were pre-cracked at 7 days. The conclusion on the mechanical properties and durability properties of ECC due to the mixing of bacteria is also discussed. Scanning electron microscope (SEM) is used to document the role of bacteria in microbiologically made mineral precipitation. The Bacterial ECC increase in mechanical and durability properties than the normal ECC, it also gives more workability when it is replaced with 10%, 20% and 30% of bacteria in water content with polypropylene fibre and polyvinyl alcohol fibre. It shows that PVA fibres give better performance compared to PP fibres and self-healing takes place under different exposures of the ECC specimens.

Index Terms*: *Self-Healing, Engineered cementitious composites (ECC), Polyvinyl alcohol (PVA), Polypropylene (PP), Sodium Hydroxide (NaOH), Sodium sulphate (Na_2SO_4)

I. INTRODUCTION

In the construction Industry, cement materials are the most consumed construction materials over and done with the world in the past century. Cracks and Deterioration in concrete will occur since the early day of construction. Therefore, inspection and maintenance of the concrete are increasing in the focus of attention. But regular inspection and maintenance of the concrete structure for the large scale of infrastructure are difficult. Repair work in the location like highways and bridges are becoming much more difficult compared to conventional buildings[1], The combined effect of mechanical and environmental exposure under different condition, steel corrosion in the many reinforced concrete structures are deteriorated. Engineered Cementitious composite is the cement-based material that exhibits multiple cracks due to its brittle behaviour, leading to increase in strain capacity and ductile behaviour[2] Engineered Cementitious Composite (ECC) is used to control the width of the crack and to enhance the structural durability in many studies. ECC exhibits strain- hardening with multiple micro-cracks below 60μm wide ECC reaches 3-5% more than the normal concrete [3], [4] Artificial self-healing things are inspired by altered materials in our nature. The self-healing phenomenon in the damaged skins of plants and animals are automatically healing themselves[1], [5], During the initiation of the cracks in the concrete, bacteria that are attached to the concrete are activated due to contact of the moisture, and precipitate of calcium carbonate to heal the cracks[6], [7], By adding the bacteria directly in the mixing to investigate the self-healing and mechanical properties. Also, the bacterial cells that are suspended in the water during mortar mixing had an improvement in the compressive strength [8], Thus the self-healing serves as a medium for self-repair in many non-reachable places especially in the large infrastructure.

Engineered cementitious composites have been investigated under various environmental loads in past decades. Ozbay et al. had an investigation in the durability of the ECC under sulphate attack and freeze-thaw cycles in both water and sodium sulphate solution that results in a decrease of 300 freeze-thaw cycles[9], [10], Much single deterioration mechanisms (sulphate attack) are in severe condition. But the concrete structures are exposed to the combined condition of chloride and sulphate in the marine environment, in hydraulic structures, many studies were conducted to get the clear interaction between the two phenomena[10], [11].ECC[12].Split tensile strength[13].

ECC is the different type of cement-based material which has designed based micromechanics compared to conventional concrete. Micromechanics has a link in composite properties like tensile strength, crack width and had a microscale property like fibre interfacial bond.[10]

This present study is focused on the Self-healing behaviour on the bacterial incorporation in ECC. Mechanical and durability properties of Bacterial ECC were studied by replacing the bacteria in 10%, 20% and 30% with water. Cracks are made initially and get cured in different environments like water, NaOH and Na_2SO_4 solutions. Mechanical properties like compressive, split tensile, flexure strength are also discussed.

II. INVESTIGATION PROCEDURE

A. Material and mix proportions

The regular mix for ECC is found in the literature[12] and used in this study. The constituent material for ECC mixture is ordinary Portland cement grade 53, river sand, class F fly ash, water,

Revised Manuscript Received on May 06, 2019

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High range water reducers (Ceraplast 300), and fibre. Fibre content is varied in this study with polyvinyl alcohol (PVA) and polypropylene (PP). The length of PP fibres 6mm with a density of 0.92 Kg/m^3 and PVA Fibres used here is 12mm with a density of 1.29 Kg/m^3 as a bunchy monofilament and the interaction between the fibre and cement are used to create a molecular bond with the materials. ECC mix design for M45 in ratio 1:1.2:0.8 is used to cast the specimens.

The bacterial engineered cementitious composites are the same as the regular ECC mixture but bacteria are replaced with water in 10%, 20% and 30% of its water content. Samplings are cast for compression strength, split tensile strength and flexure strength.

B. Durability test procedure

The specimens are prepared by the same bacterial ECC as mentioned earlier. After mixing, the fresh bacterial ECC is cast into a cube specimen in size of 70.6 x 70.6 x 70.6 for the compression test. The specimens are immersed in 426 grams of Sodium Chloride (Na_2SO_4) in 6 litres and 24 grams of Sodium Hydroxide (NaOH) in 6 litres solution for 28 days.[10] Also, self-healing behaviour is investigated after the cracks were initiated.

C. Self-healing strategies in cementitious material

Bacillus Subtilis is the bacteria used in this study. The bacteria extracted here was obtained from the soil, gastrointestinal tract of the human being and ruminants. In this study, the bacteria is directly added to the ECC mixture by replacing with the water content. The calcium lactate is added to trigger the self- healing behaviour in the specimens. The calcium lactate is highly resolvable in water due to its natural pH and makes it easily absorbable.[14]

Table 1: ECC mix design for M45

Mix Design	Cement	Sand	Fly ash	Water	HRWR%	Fibre%	Mix Design
M45	1.0	1.2	0.8	0.55	1.2	2	M45

Table 2: Mixture proportion in kg/m^3

Material	Cement	Sand	Fly ash	Water	HRWR	Fibre
ECC	590	710	470	350	7.08	Based on density

D. Methodology

Engineered Cementitious Composite is a cementitious based mortar material with outstanding strain hardening, tensile strength and exhibits multiple micro-cracks, leading to an increase in strain capacity and ductile behaviour. After infusing of bacteria in ECC with PP and PVA fibres the mechanical and durability properties are investigated. Experimental tests like compression, split tensile, flexural, sodium sulphate and sodium hydroxide tests were conducted. The experimental tests were conducted to study the beam behaviour that was cast to find flexural behaviour. By comparing test results with PP and PVA fibres in ECC are done with the experimental results.

III. EXPERIMENTAL WORKS

A. Compressive strength in normal curing

The size of the specimen used to find the compressive strength of the cube is 70.6mm x 70.6mm x 70.6mm. The ECC cubes are cured at 7, 14 and 28 days and it was found to have increased compressive strength in bacterial ECC. The normal ECC has the compressive strength of 50 N/mm^2 with PVA fibres and 45 N/mm^2 with PP fibres by the end of 28 days of curing. While replacing 30% of bacteria with water content, the compressive strength of the bacterial ECC shows an increase of 8% with PVA fibres and 7% with PP fibres.

Fig. 1. Compression test on ECC cubes

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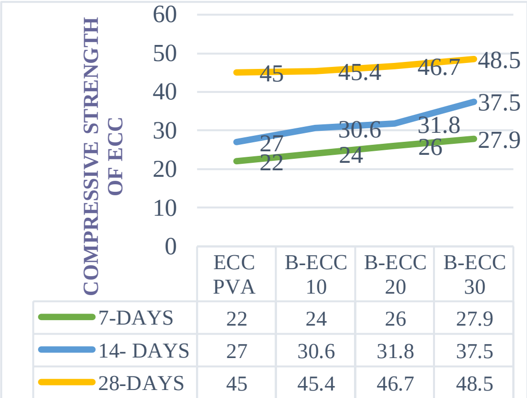

Fig. 2. Compression strength of ECC using bacteria in PP fibres

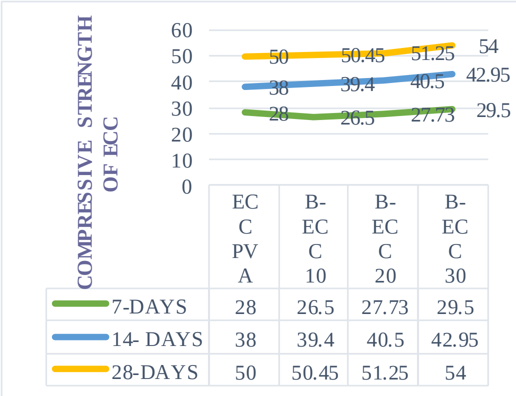

Fig. 3. Compression strength of ECC using bacteria in PVA fibres

B. Compressive strength on Na_2SO_4 and NaOH solution

The 28 days compressive strength of Na_2SO_4 treated specimens is found have 47.9 N/mm^2 with PP fibres and 54.7 N/mm^2 with PVA fibres. In replacement of 30% of bacteria with water content, it has 49.95 N/mm^2 with PP and 59 N/mm^2 with PVA fibres. Therefore, it shows an increase of 4.2% with PP fibres and 7.8% with PVA fibres.

The 28 days compressive strength of NaOH treated specimens is found have 46.95 N/mm^2 with PP fibres and 52.56 N/mm^2 with PVA fibres. In replacement of 30% of bacteria with water content, it has 47.62 N/mm^2 with PP and 56.5 N/mm^2 with PVA fibres. Therefore, it shows an increase of 1.4% with PP fibres and 4.2% with PVA fibres.

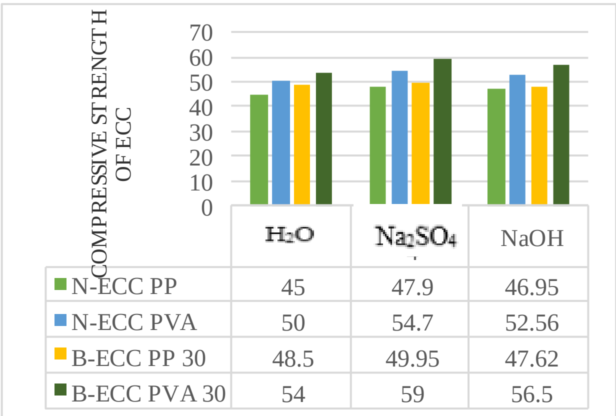

Fig. 4. Compression strength under different exposure

C. Split tensile strength

The cylinder size 100 x 200 mm is cast-off find the split tensile strength in this study. The ECC cylinders are cured at 7, 14, 28 days and it was found to have increased in split tensile strength in bacterial ECC that are cast with PVA and PP fibres. The normal ECC has a split tensile strength of 4.19 N/mm^2 with PVA fibres and 4.03 N/mm^2 with PP fibres by the end of 28 days of curing. While replacing 30% of bacteria with water content, the split tensile strength of bacterial ECC shows an increase in 3.8% with PVA fibres and 2.9% with PP fibres.

Fig. 5. Split tensile strength of ECC cylinders

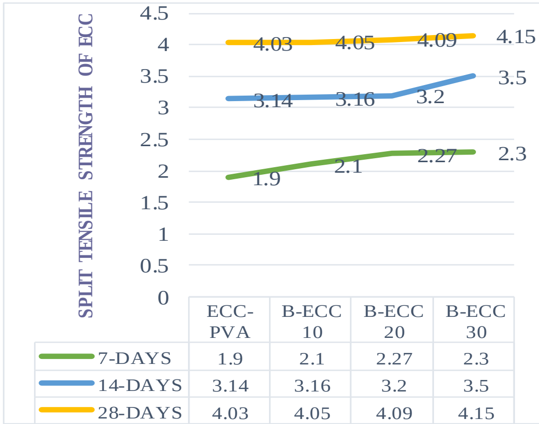

Fig. 6. Split tensile strength of ECC using bacteria in PP fibres

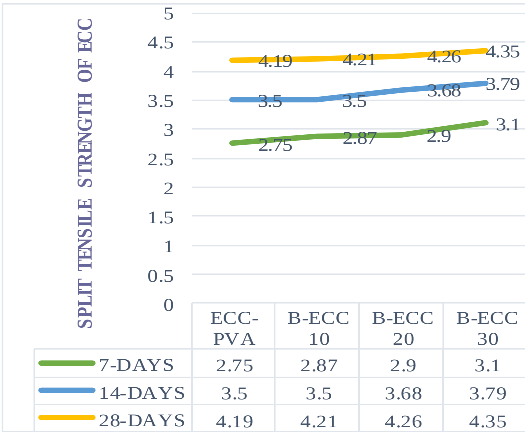

Fig. 7. Split tensile strength of ECC using bacteria in PVA fibres

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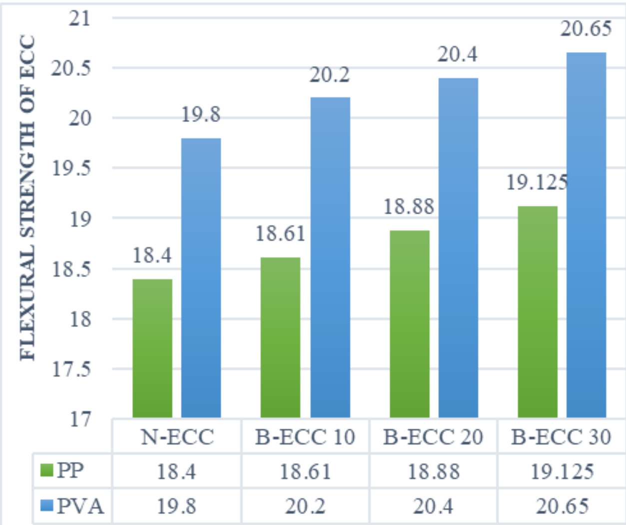
D. Flexural strength

Beams without reinforcement

The size of the beam used to find the flexure strength is 160mm x 40mm x40mm. The ECC beams are cured at 28 days and it found to have an increase in flexural strength with the bacterial ECC that are cast with PVA and PP fibres. The normal ECC has 19 N/mm^2 PVA fibres and 18.40 N/mm^2 with PP fibres by the end of 28 days of curing. While replacing 30% of bacteria with water content, the flexural strength of bacterial ECC shows an increase in 4.29% with PVA fibres and 3.9% with PP fibres.

Fig. 8. Flexural Strength of ECC beams



	N-ECC	B-ECC 10	B-ECC 20	B-ECC 30
PP	18.4	18.61	18.88	19.125
PVA	19.8	20.2	20.4	20.65

Fig. 9. Flexural strength of ECC using bacteria in PP and PVA fibres

Beams with reinforcement

The casting of three different groups of ECC mixtures is done and tested with steel reinforcement. The normal ECC mixture has ordinary Portland cement, river sand, class F fly ash, water, superplasticizer, and Polyvinyl alcohol fibre. So, In this study the bacteria is replaced with the water content, the above flexure strength of the beam without reinforcement shows the increase of flexure strength at the 30% replacement of the bacteria. Thus by replacing the 30% of water content with bacteria in the beam size of 1000mm x 200mm x 200mm with reinforcement were cast using PP and PVA fibres. The central deflection of the beam is noted and the test setup is made to find the moment to deflection curves in the Bacterial Engineered cementitious composites with polyvinyl alcohol fibre (B-ECC PVA), Bacterial engineered cementitious composites with polypropylene fibre (B-ECC PP) and Normal ECC.

Fig. 10. Beams with reinforcement

Fig. 11. The casting of beams with reinforcement

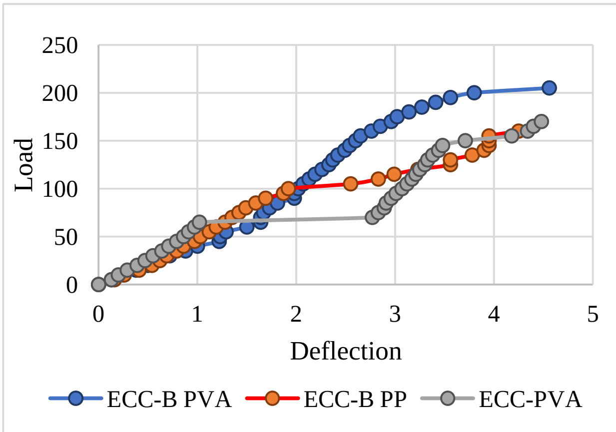


Fig .12. Load-Deflection Curve

E. Self-healing of ECC using Bacteria

As many studies were conducted using of biological repair technique by the introduction of bacteria in concrete. Self-healing phenomenon in ECC is also investigated and also by adding Bacillus halodurans and its mutant cells into ECC to find its mechanical properties. By replacing the Bacillus subtilis bacteria with the water content it shows a slight increase in mechanical and durability properties. The cracks are trends to heal due to its carbonate precipitate in the cracks. The calcium lactate is an admixture that is used to trigger the self-healing in the ECC.

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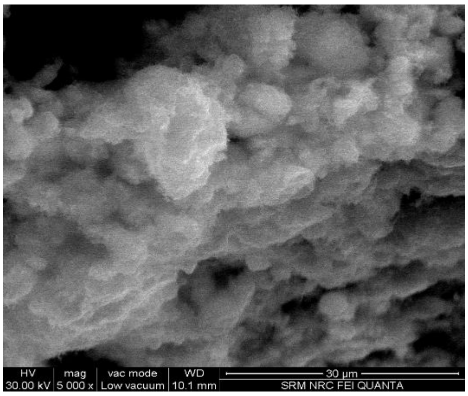
Thus self-healing that is occurred in various forms of ECC are discussed below.

(a_1) & (a_2)

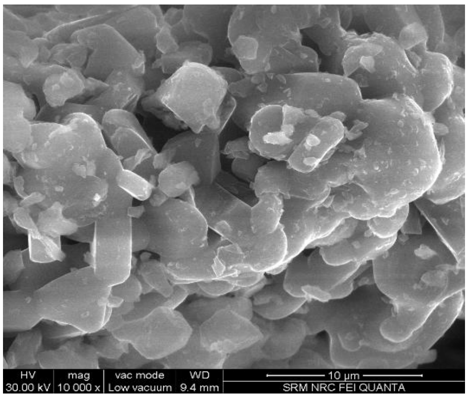
(b_1) & (b_2)

(c_1) & (c_2)

Fig. 13. Bacterial induced ECC cube Specimen are healed under (a) water (b) Na_2SO_4 (c) NaOH



(a) White precipitate (Calcium lactate)



(b) Rod-shaped (Bacteria)

Fig .14. FESEM showing self-healing activity in bacterial ECC calcium carbonate produced by concrete and rod-shaped bacteria are examined

IV. CONCLUSION

- While replacing 30% of bacteria with water content, the compressive strength of the bacterial ECC shows an increase of 8% with PVA fibres and 7% with PP fibres.
- In replacement of 30% of bacteria with water content, bacterial ECC specimen has 49.95 N/mm^2 with PP and 59 N/mm^2 with PVA fibres. Therefore, it shows an increase of 4.2% with PP fibres and 7.8% with PVA fibres in compressive strength under Na_2SO_4 exposure
- In replacement of 30% of bacteria with water content, bacterial ECC specimen has 47.62 N/mm^2 with PP and 56.5 N/mm^2 with PVA fibres.

Therefore, it shows an increase of 1.4% with PP fibres and 4.2% with PVA fibres in compressive strength under NaOH exposure.

- While replacing 30% of bacteria with water content, the split tensile strength of bacterial ECC shows an increase in 3.8% with PVA fibres and 2.9% with PP fibres.
- While replacing 30% of bacteria with water content, the flexural strength of bacterial ECC shows an increase in 4.29% with PVA fibres and 3.9% with PP fibres.
- In this study, it shows that the mechanical properties and durability properties are 1% - 8% increased while replacing the water content with bacteria in 10%, 20% and 30%. It also shows better results while the bacteria are replaced with 30% in both PP and PVA fibres.
- The self-healing property of bacterial ECC specimen is triggered by calcium lactate on reacting with water precipitates calcium carbonate which acts as a healing agent under sodium sulphate and sodium hydroxide
- The performance of the PVA fibres gives better results than PP fibres.

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