Effects of Polyvinyl Alcohol fibers in engineered cementitious composite concrete

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ABSTRACT. The present work majorly focused on the effect of Polyvinyl Alcohol fibers (PVA) in engineered cementitious composite concrete. However, PVA fibers are used as added to the ECC concrete with proportion of 0\% to 2\% of weight to cementitious materials. All the concrete samples are prepared with mix proportion of 1 cement: 1.1 silica fume: 0.36 ratio of sand/binder: 0.30 ratio of water/binder: 0.30 ratio of water/binder: 0.01 water reducer, whereas compressive, flexural, split tensile, water absorption and rapid chloride permeability tests are evaluated in order find out the performance of ECC with addition of PVA fibers. Thus, the results, ECC concrete has better mechanical and durability performance than conventional concrete and also its high early strength. From this study concludes that upto 1.5\% of PVA fibers can be used in the ECC concrete, which has 60.12MPa and 18\% of strength increment than the reference mix.

Keywords: Mechanical Properties, Silica Fume, Polyvinyl Alcohol Fibers, Water Absorption, Superplasticizer, Scanning Electron Microscope, Concrete, CO2 emission, Mini Slump Cone Test, Engineered Cementitious Composite

1.INTRODUCTION

Concrete is most consumable material in the universe due to its versatile properties such as high durability, workability, but it has brittle (unbendable) in nature. However, the unbendable characteristics of conventional concrete leads to strain failure. This motivation is the true reason for developing such new bendable concrete called as engineered cementitious composite. Whereas these concretes are reinforced with polymer fibers and ultra-fine cementitious materials, cement and fine sand [1]. In order achieve to achieve higher strength and higher content of paste, there is needed to incorporate the bendable concrete powders. Similarly, to obtain the superior workability; increases the proportion of fine aggregates and water reducers. Also, in this type of of concretes does not require coarse aggregates, unlike concrete. But it requires fibers to arrest the shrinkagecracks [2]. Bendable concretes are nearly, 40times lighter and 50 times flexible than conventional concrete, which behaviour more materials are more appropriate for structural construction in earthquake prone zones [3]. However, utilization of port land cement causes excess co2 emission, which causes global warming [4-7].

Ding et al.(2020) conducted study on mechanical performance of PVA based ECC for canalling and study concluded that, PVA based ECC has well crack resistance, durability and strain hardening Yu Zhu et al. (2012) prepared new ECC with industrial bi-products such as GGBFS and Fly ash. However, upto 70\% of cement has been replaced by these bi-products and concrete samples were prepared with
constant W/C-0.25 and evaluated the mechanical properties of the ECC. Thus, the results, ECC with Fly ash and GGBFS enriches the mechanical properties such as strain hardening and tensile strength. ECC with 40% of fly ash and 30% of GGBFS proportioned mixes has shown high compressive strength and low shrinkage [9]. Meng et al.(2017) has prepared PVA fibers based ECC concrete with locally available materials and evaluated its mechanical behaviour. However, experimental data was validated with finite element model and good calibration has observed between each other. Thus, the results, ECC concrete cost was economical and tensile strain capacity was reduced and matched with standard reinforced concrete [10]. In the present study, majorly focus is on the effect of Polyvinyl Alcohol fibers (PVA) in engineered cementitious composite concrete. To full-fill these, PVA fibers are added to the ECC concrete with proportion of 0% to 2% of weight to cementitious materials and evaluated mechanical and durability properties.

2. MATERIAL AND METHODS

2.1 Materials
OPC 53 grade has used for preparing concrete samples, which confirmed by IS 12269-2013 [11]. Whereas physical and chemical properties Table 1-2. Similarly, Silica Fume has been used supplementary cementitious material in order to achieve high strength and table 1 and 2represents it properties. Whereas fine aggregates are confirmed by the Zone-II as per IS 383-2016 [12]. In the present study Polyvinyl Alcohol fibers are used additive to the concrete and it has size of 12mm length and 39 mm in diameter, Modulus of elasticity 42.8 GPa and Nominal strength of 1620MPa. In order to reduce the demand of more water, in the present study ConplastSP430dis. 1 cement: 1.2: 0.36 ratio of sand/binder: 0.3 ratio of water/binder: 0.01 water reducer. Whereas PVA fibers addition varies from the 0% to 2% of binder material weight.

2.2 Test methods
As per IS: 516-2013 compressive strength test was conducted on concrete samples prepared with size of 150 mm³ [13]. Similarly, cylindrical samples were prepared with size of 150mm x 300mm for split tensile strength and tested as for IS:5816 (1999) [14]. The prism samples were prepared with the size of 700×150×150mm³, for conducting flexural strength as per IS 516: 1959 [15]. To find out the durability behaviour of ECC concrete in the present study water absorption test (as per IS 1199: 1959) and rapid chloride permeability (As per ASTM C1202) tests were conducted [16].Slump cone test is conducted to identification of flow ability properties of ECC by using mini slump cone experimental apparatus with dimensions of 100×70×60mm as per Dubey et al 2013 [17]. Fig. 1,3,5,7,10 shows experimental photos.
Table 1. Physical property of materials

| Materials     | Specific gravity | Fineness | Zone          |
|---------------|------------------|----------|---------------|
| Cement        | 3.12             | 5%       | -             |
| Silicafume    | 2.21             | 1%       | -             |
| Fineaggregates| 2.71             | -        | ConfirmedbyZone -II |

Table 2. Chemical compounds of silica fume and cement

| Materials     | SiO2  | Fe2O3 | CaO    | Al2O3 | MgO  | Na2O  | Loss of ignition |
|---------------|-------|-------|--------|-------|------|-------|-----------------|
| Cement        | 20.93 | 3.95  | 63.29  | 4.73  | 0.45 | 0.22  | 2               |
| Silica fume   | 92.1  | 0.23  | -      | 0.48  | 0.87 | 0.63  | 1.51            |

3. RESULTS AND DISCUSSION

3.1 Slump cone test

Fig. 2 represents the mini slump cone test results of ECC concrete with addition of various additional weight percentages of PVA fibers i., 0%, 0.5%, 1%, 1.5% and 2%. The experimental work conducted as per Dubey et al. 2013 [17]. From the experimental results, it was observed that slump values are reduced with addition of PVA fibers into the ECC concrete. However, 24mm of slump was observed in reference mix. Similarly, 22mm in ECPVA0, 21.5mm in ECPVA1, 19mm in ECPVA1.5, 16.5mm in ECPVA and 15mm in ECPVA2 has been observed. This effect may be explained due to the PVA fibers uniform distribution in the ECC concrete was not allowed to flow easily.

Figure 1. Mini slump cone test apparatus
3.2 Compressive strength

Fig.4 represents compressive strength of ECC concrete with various percentages of polyvinyl Alcohol fibers addition. Thus, the results increased with increases the additional levels of PVA fibers in concrete. However, maximum compressive has observed in 1.5% of PVA fibers replaced mix, which has 60.12MPa strength and 18% of strength increments found as compared to the reference concrete. Similarly, 53.14MPa, 55.61MPa, 57.41MPa, and 56.75MPa strengths have been observed in 0%, 0.5%, 1% and 2% of addition of PVA fibers based concrete. Also, it was observed that ECC concrete has high early strength than reference concrete.
Figure 3. Compressive strength experimental setup
3.3 Split tensile strength

The split tensile strength of ECC concrete was increased with increases the addition of PVA fibers as shown in Fig. 6 ECC concrete has high tensile strength than reference; 3.79MPa, 4.35MPa, 4.6MPa, 4.75MPa, 4.98 MPa and 6.81MPa was observed in reference mix, 0%, 0.5%, 1.0%, 1.5% and 2% of PVA fibers replaced mixes in case of 7days of curing. Similarly, after 28days curing the split tensile strengths increased from up to 1.5% of PVA replacement afterwards strength reduction was observed at 2% PVA fibers replaced mix, 0%, 0.5%, 1.0%, 1.5% and 2% of PVA fibers replaced mixes, respectively. The reason for increases the split tensile strength is proper distribution of fibers, which discontinuous the micro-cracks and voids.

Figure 4. Compressive strength of PVA fibers based ECC concrete
Figure 5. Split tensile experimental setup

Figure 6. Split tensile strength of PVA fibers based ECC concrete
3.4 Flexural strength

Fig. 8 depicts the flexural strength of ECC concrete; the addition of PVA fibers has shown positive effect on the flexural behaviour of concrete. In case of 7 days curing, 4.06MPa, 4.22MPa, 4.34MPa, 4.41MPa, 4.51Mpa and 5.27MPa has been found in reference, 0%, 0.5%, 1.0%, 1.5% and 2% of PVA fibers replaced mixes, respectively. However, the minimum flexural strength was observed at 1.5% PVA fibers replacement mixes, which has 6.21MPa and 24.2% strength improvements as compared the reference mix. However, after 28 days of curing the flexural strength of ECC concrete increased 17% in ECPVA0,19.4% in ECPVA0.5,21.2% in ECPVA 1.0, 24.2% IN ECPVA1.5 and 20.6% in ECPVA2 than reference concrete.

![Figure 7. Flexural strength experimental setup](image)

![Figure 8. Flexural strength of PVA fibers based ECC concrete](image)
3.5 Water absorption

The water absorption has conducted to identify the water absorption of PVA fibers based ECC concrete. From the obtained results, ECC concrete observed the less water than reference concrete as represented in Fig. 9. However, the reduced with increases the PVA fibers into the concrete; 7.2%, 6.8%, 6.3%, 5.9%, 5.5%, 5.3% in reference concrete, 0%, 0.5%, 1.0%, 1.5% and 2% of PVA fibers replaced mixes. The reason for reduction of water observation in PVA fibers concrete was fibers were arrested the micro-cracks and voids, which retard the absorption of more water in hydrated concrete samples.

![Figure 9. Water absorption of PVA fibers based ECC concrete](image)

3.6 Rapid chloride permeability test

As per ASTM1202, in the present study rapid chloride permeability has been concrete for PVA fibers based ECC concrete. From the table 3 depicts, the passage of coulombs was reduced with increases the additional levels of PVA fibers into the concrete. Whereas, 2120 in reference concrete, 2002, 1954, 1853, 1660 of coulombs charge was passed through the ECC concrete prepared with 0%, 0.5%, 1%, 1.5%, and 2% of PVA fibers added ECC concrete mixes.
Figure 10. RCPT experimental setup

Table 3. Passage of coulombs

| Mix          | Passage of coulombs |
|--------------|---------------------|
| Reference    | 2120                |
| ECPVA0       | 2002                |
| ECPVA0.5     | 1954                |
| ECPVA1       | 1853                |
| ECPVA1.5     | 1660                |
| ECPVA2       | 1600                |

3.7 Scanning electronic microscopic
In the present investigation, scanning electron microscope analysis conducted on reference concrete mix and optimum PVA fiber added that concrete i.e., ECPVA1.5 mix as shown in the Fig. 11-12. However, all the PVA fibers are uniformly distributed and it has good bond to the surrounding mortar. Also concrete became dense after addition of PVA fibers into the concrete. this may be the reduction of water absorption and passage of coulombs in durability studies. Moreover, this is the significant evidence for achieving high strength at this mix.
4. CONCLUSIONS

- The addition of PVA fibers into ECC concrete has positive effect on the durability and mechanical performance.
- From the results, upto 1.5% of PVA fibers could be added to the concrete, which mix has high mechanical strengths such as 60.21MPa of compressive strength, 7.82MPa of tensile strength and 6.21MPa of flexural strength.
- Similarly, passage of coulombs and water absorption values reduced with addition of PVA fibers into the ECC concrete, whereas ECPVA2.0 fiber mix has shown lower passage of coulombs (1600 C) and water absorption 5.3%
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