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Analysis of crack formation pattern in Engineered Cementitious Concrete

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ABSTRACT:

The brittleness and cracking of conventional concrete have led to the creation of Engineered Cementitious Composites (ECC), which exhibit "metal-like" tensile behavior as the consequence of the formation of numerous micro cracks prior to fracture failure. The use of fiber, super plasticizer and superfine sand significantly affects the performance of ECC, with fiber and superplasticizer's mainly determining the level of ductility. One significant indicator of the deformation process is the maximum crack width. It is commonly accepted that a crack width is kept under 100 μm , it falls into the harmless category. These results suggest that ECC is a material used in concrete crack repair and has superior properties compared to conventional concrete. The crack width control and mechanical properties of ECC are important factors in its use in concrete crack repair. Overall, the research on ECC crack patterns aims to enhance the durability and performance of concrete structures by comprehensively analyzing the formation and evolution of cracks in ECC materials.

Keywords: Engineered Cementitious Composites (ECC), superplasticizer, tensile, crack width.

1. INTRODUCTION

ECC is a family of materials that exhibit high tensile ductility and fine multiple cracking, making it an ideal material for patching repair on cracked concrete surfaces [1]. The analysis of crack patterns in Engineered Cementitious Composites (ECC) is a crucial aspect of understanding the material's behavior under different loading conditions and time intervals [2]. The analysis of crack patterns in ECC involves the use of advanced imaging techniques, such as Digital Image Correlation (DIC) and image analysis, to capture the strain fields and crack patterns at different strain levels and under different loading conditions. Research studies have shown that ECC can reduce the crack width on the surface and prevent plastic hinge damage in repaired specimens [3-4]. The crack patterns in ECC are influenced by material ductility, boundary conditions, and the bond between ECC and substrate concrete. The use of ECC for patching repair on cracked concrete surfaces has been shown to enhance the durability and performance of concrete structures. Numerical investigations have been conducted to study distributed cracking, strain-hardening behavior, and the influence of repair material properties on crack evolution. Furthermore, the endurance of ECC structures is determined by the crack-width control ability of ECC. The analysis of crack patterns in ECC is thus an important area of research for improving the durability and performance of concrete structures.

2. METHODOLOGY

For the experimental work, mixes were prepared from ECC. A series of ECC mortar mixes with ratio of sand/cement is 1:2 was designed and tested. Poly Vinyl Alcohol (PVA) fibers were used with different percentages as 0%, 1% and 2% fibers. A cube mould with a size of 50 mm was used for finding the 14th and 28th day compressive strength. A total of 6 numbers of cube specimens were casted for all types of ECC mix.

2.1 Materials:

- a) Cement: Cement used to prepare masonry mortar shall meet the requirements either IS: 269-1976* or 455-1976 or IS: 1489-1976. Portland cement (CEM 0.5 to 0.7MPa) with a specific gravity of 3.16.
- b) Sand: Well graded siliceous sand conformed to the requirements of IS: 2116-1980 with a specific gravity of 2.60, absorption of 0.81%, and a fineness modulus of 2.55.
- c) Water: The water used to make masonry mortars must be pure and devoid of harmful amounts of harmful substances. The widespread assumption is that using potable water in brick mortar is satisfactory. For additional guidelines on the maximum amount of harmful compounds allowed, consider IS: 456- 1978.
- d) Admixture: As a superplasticizer, a high range water reducer (HRWR) was utilized, adhering to ASTM C494 type A and F specifications. At room temperature, the admixture is a brown liquid with a density of 1.18 kg/liter. The dosage of HRWR was 0.5% of the powder (sand + cement) weight.
- e) Poly Vinyl Alcohol (PVA) Fiber: Polypropylene fibers were used in the percentage of 1% to 2%. The fibers accounted for the total mix volume.

Tensile Strength (GPa)	Tensile Modulus (GPa)	Diameter (µm)	Length (mm)	Density (g/cm ³)	Elongation (%)
1.56	41	40	12	1.3	6.5

In order to prepare the specimen, the following mixing procedure was used to modify the basic materials.

- (1) First, a 0.8% water-to-binder ratio was added and the cementitious ingredients were agitated until they became viscous;
- (2) After that, the Polypropylene fiber was added and thoroughly mixed; and
- (3) To ensure a consistent dispersion of fibers, the mixture was agitated for a minimum of five minutes after the superfine sand and remaining water were added. The final product had a cream texture after being well blended.



3. EXPERIMENTAL ANALYSIS

3.1 Compressive strength test

Mortar specimens were subjected to a compressive strength test with varying percentages of PVA at curing ages of 14 and 28 days in a water tank to measure the strength of the mortar specimens. PVA fiber reduces its compressive strength compared to standard mortar. The chart shows the increase in compressive strength of all mortar specimens from the 14th day to the 28th day of curing age. So, the compressive strength of mortar increases, while on day 14 of curing ages for specimens, the compressive strength of the mortar decreases as the percentage of PVA fiber in the mortar increases, except for the percentage of 1% fiber, which is higher than the compressive strength compared to control, which is 0% of PVA fiber on the 14th day. The compressive strength of mortar with 0% PVA fiber was 29.25 kN on the fourth day, followed by mortar with 1% PVC fiber at 21.36 kN. Meanwhile, the inclusion of 1% crumb rubber in the mortar for 28 days recorded a slightly lower compressive strength with 28.31 MPa than the control, which contained 0% PVA fiber with 37.16 MPa. At ages 14, and 28 days, the specimen containing 2% PVA fiber demonstrates the lowest compressive strength compared to other specimens. This result shows that poor bonding between PVA fiber particles and other materials, such as cement, resulted in uneven stress distribution. Previous research has observed similar findings due to PVA fiber particles' poor bonding, reducing mortar specimens' strength. The more fiber particles added, the more bonding is lost, resulting in lower compressive strength. Furthermore, with the addition of PVA fiber in the mortar mix, the elasticity nature of the PVA fiber tends to reduce the mixture's interface binding strength, consequently lowering its strength. Meanwhile, state that the capillary porosity is responsible for the degradation in strength due to high surface area constituents such as PVA. They created pores that enabled water to seep into the

specimen at a higher rate by nature, automatically reducing the bonding and thus reducing the compressive strength of the specimen. Moreover, has negativity in the form of a reduction in strength because of PVA fiber's physical properties and compatibility with fine aggregate. The water repels, and air entraps on the surface due to the hydrophobic behavior of PVA fiber particles. Furthermore, Energy absorption capacity for PVA concrete increases with fiber content below 2%. However, the energy absorbing capacity of fiber concrete decreased when the fiber contents was more than 2% and remained constant.

Sr. no	ID Mark	Age (days)	Size of Specimen		Weight (Kg)	c/s Area (mm ²)	Density (kg/m ³)	Load (kN)	Comp. Strength (N/mm ²)
			Diameter (mm)	Height (mm)					
1.	0% fiber	14	150.3	298.5	11.415	17733.22	2156.47	450.00	29.25
2.	1% fiber	14	151.2	298.1	10.340	17341.31	2174.84	378.35	21.36
3.	2% fiber	14	151.3	297.1	10.157	18169.77	2142.77	258.80	18.29
4.	0% fiber	28	151.3	297.5	12.134	18438.57	2252.66	564.70	37.16
5.	1% fiber	28	150.3	298.4	10.765	17257.87	2157.27	489.37	28.31
6.	2% fiber	28	151.2	298 5	10.235	17734.67	2142.77	438.47	23.37

3.2 The Cracking Patterns of ECC

The cracking pattern reflects unsaturated multiple cracking. The figure shows a comparison between 3 samples with fiber contents 0%, 1% and 2% respectively. Increasing in the number of cracks at (0%) fiber while adding (1%) and (2%) fibers to the composite mixture adversely affects the number of cracks. Multiple-crack formation gives the composite a higher energy-absorption capability by preventing crack from localization, and increases both the first cracking load and the deformability. In the mix with (1%), most fibers are broken due to the low bond strength of PP. fibers to the cementitious matrix. On the contrary, high modulus is still undamaged across the cracked zone in the composite. These undamaged fibers enhance the deformability and load bearing capacity of composites, especially in the post- cracking zone. After failure of (2%), the high modulus fibers can transfer the load in composite. From the observations it can be concluded that the adhesion mechanism between (2%) and cement matrix is mainly mechanical interlocking. The chemical adhesion and mechanical adhesion in composite containing (2%) arise from the (0%) and (1%) fiber.

**0% Fibre****1% Fibre****2% Fibre**

4. CONCLUSIONS

1. With addition of PVA fibres, flexibility of concrete increases significantly allowing it to undergo larger strains before failure, which is quite beneficial in earthquake- prone areas.
2. Although it was observed that with increase in amount of PVA fibres, there was a slight reduction in compressive strength that can be tackled during the design.
3. As evident from the tests conducted, there is large deformation visible before failure hence it acts as a warning sign and ample time is available for remedial action.
4. PVA fibers have extra advantages because of their high modulus of elasticity, greater ability to resist cracks, strong tensile and molecular bonds, and resistance to chemicals, alkali, and UV light, among other things.
5. This work demonstrates that the application of ECC is capable of enhancing the ductility of the reinforced concrete beam. It is evident that in the post-cracking regime, the extensive deflection plateau that occurs is also accompanied by the formation of closely-spaced flexural cracks.
6. It is shown that ECC is a damage-tolerant composite where the typical crack width is limited. In addition, the influence of fibre-matrix interaction is proven to maintain the integrity of the structure throughout the course of loading, preventing the beam to experience concrete crushing at the compression zone.

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