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Effect of Marble Powder and PVA Fibres on the Strength and Microstructure of Engineered Cementitious Composite by using Non-Destructive Test

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Abstract

Generally, it is a known fact that concrete is the main material used in engineering projects for all the important works. This material has high compressive strength, but it is weak in tension. A smart material, namely Engineered Cementitious Composite, commonly known as bendable concrete, was introduced to rectify this problem.

This research emphasizes the influence of marble powder as a binder in engineered cementitious composites. Composites containing different marble powder levels with partial replacement of ordinary Portland cement by 5%, 10%, 15%, and 20% are examined. To determine the effect of PVA fibers in ECC and to find the compressive strength, the matrix was produced and tested using a non-destructive test such as the Ultrasonic pulse velocity test. The microstructure analysis and the matrix's chemical composition were determined by scanning electron microscopy and X-ray diffraction test.

The result showed that the velocity obtained for the concrete cubes comes in the range of 3.5 to 4.5 km/Sec. This indicates that the quality of concrete is good and can be used for construction purposes. An effort has been taken to analyze chemical compounds' micro level formation by scanning electron microscope (SEM) and X-ray diffraction (XRD).

Keywords - *Engineered Cementitious Composites, Marble Powder, Ordinary Portland Cement, Ultrasonic pulse velocity, Scanning Electron Microscope, X-ray Diffraction.*

I. INTRODUCTION

In the present scenario, concrete is considered a basic construction industry due to its durability. Concrete is very brittle, dense, and has diversified microstructure in nature but weak in tension.[8].The main constituent of normal concrete is cement, sand, aggregates, water, and sometimes admixtures to modify the properties such as strength and workability. The normal proportion of the material is as shown in figure 1.[5] When stress applied on concrete exceeds the ultimate limit, cracks are formed, and it achieves a micro visible level, which allows the flow of various chemical agents and water in the concrete, and further, the structure is declining with the corrosion of steel. This leads to structural failure due to the durability of concrete.[14]. To increase the durability and strength of the structure, reducing the crack width should be found out. [11]

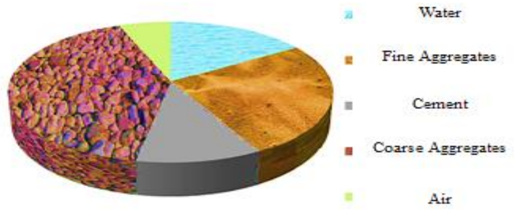


Fig1: Typical composition of normal concrete (Source: A Khitab 2012)

In recent years, attention has been given on the performance-based concept for various civil engineers' structures and is gradually replacing the conventional design of structures. Efforts have been taken to improve brittle concrete behavior and have resulted in a ductile material known as engineered cementitious composites (ECC), commonly known as bendable concrete. Professor Victor Li invents it at the University of Michigan. ECC is a special design based concept of concrete to modify the brittle nature of concrete. ECC is similar to conventional concrete except that coarse aggregates are eliminated in the matrix[10]. The main materials used in the ECC matrix are ordinary Portland cement, silica sand (Gujarat sand), fly ash, polyvinyl alcohol fibers, high range water reducing agent.[14]. The normal ranges of ECC are as shown in figure 2.[5]Thus, it is a mortar rather than concrete, according to prof. Victor Li, the composite material is 500 times more crack resistant and 40% lighter than normal concrete. This property is due to the presence of short fibers that take flexible stresses. ECC's compressive strength varies from 20-95 MPa, and the flexural strength is 10-30 MPa. [7]

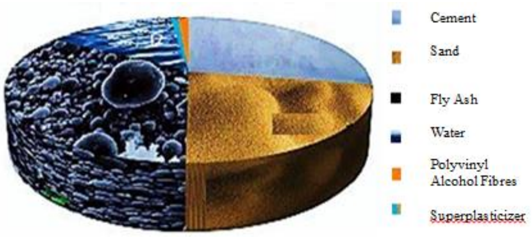


Fig 2: Typical composition of ECC (Source: A Khitab 2012)

In the present paper, experimental analysis was conducted to determine the compressive strength of matrix by non-destructive test by partially replacing ordinary portland cement with MP by 5%,10%,15%, and 20%. The microstructure analysis of the matrix was also analyzed by scanning electron microscope, and the chemical analysis was determined by X-ray diffraction method. Also, the cost comparison is carried out between the conventional concrete and ECC.

II. LITERATURE REVIEW

Many research scholars have done lots of studies on the engineered cementitious composite. The effect of various environmental conditions on ECC has experimented

Mustafa Şahmaran et al. (2011) studied the effect on ECC's fire resistance and microstructure by the impact of high volumes of fly ash and micro polyvinyl alcohol (PVA) fibers. An investigation was conducted on the matrix by partially replacing cement with fly by 55% and 70% by weight of total cementitious materials. Xia Hua (2010) studied the original ECC with local waste materials embedded in capsules to observe the modified ECC material's self-healing potential. The self-healing was carried out using Super Absorbent Polymers (SAP) enclosed in the capsules and water. The self-healing process was carried out when the capsules were ruptured by cracking. Khitab et al. (2012) describe the applications and benefits of ECC. The mechanism of PVA fibers in the matrix is emphasized. The use of technology to enhance the flexibility of different types of concrete has been mentioned. Aggarwal and Siddique (2014) investigated the effect on mechanical properties, durability characteristics, and microstructural analysis of concrete using bottom ash and waste foundry as a partially replacing with fine aggregates in varying proportions from 0 to 60%. Kilic, Toprak, and Ozdemir (2015) investigated the effect of calcium hydroxide on the stability of calcium carbonate particles with respect to surface potential and size of particles. Results showed that the zeta potential of $CaCO_3$ particles when placed in $Ca(OH)_2$ solution was greater than +30mV compared to a zeta potential of -10mV when placed in water.

III. OBJECTIVE

Many civil engineers had done a thorough study on Engineered Cementitious Composites by replacing fly ash with different materials and studying mechanical, physical, and self-healing properties. The microstructural changes in the matrix after the addition of MP by replacing OPC have not been mentioned anywhere. The objectives of the research study are as follows:

- To analyze the compressive strength of the matrix by using the UPV test.
- To study the microstructural characteristics of the matrix after adding marble powder in the ECC matrix.
- To examine the chemical compounds of the matrix after the addition of marble powder in the mix

IV. PROBLEM STATEMENT

Concrete is a universal material used as a construction material all over the world. Concrete has high compressive strength, but the main drawback is that concrete fails in tension. Conventional concrete has a strain capacity of 0.1%, making the material brittle and rigid. This lack of bendability is the main cause of failure under strain. Under strain, the conventional concrete forms large cracks that allow different fluids to enter the matrix, and the structure's depreciation occurs. The various non-destructive tests such as ultrasonic pulse velocity test, scanning electron microscopy test, and X-ray diffraction test on cubes and matrix powder were conducted in the laboratory as per the flowchart is shown in figure 3.

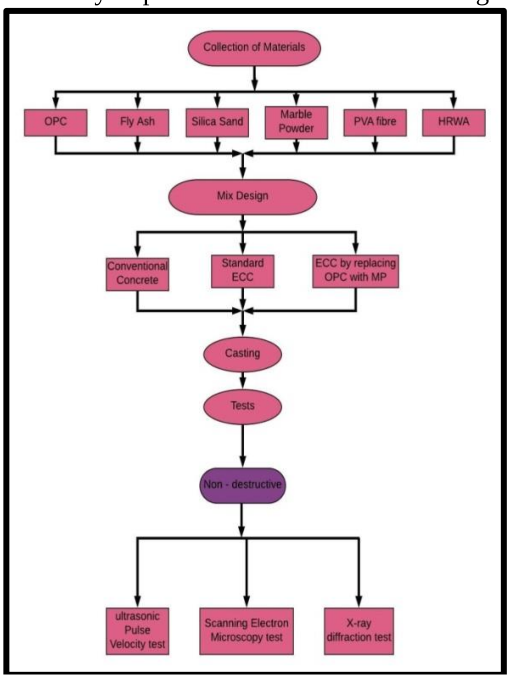


Fig3: Methodology of Preparing Engineered Cementitious Composite

V. METHODOLOGY

A. Materials and Mix Proportion

The cementitious ingredients used in preparing the ECC matrix were Ordinary Portland Cement (OPC) 53-grade type 1complying with IS 269:2015 having Blaine's surface area as 297 m2/kg, Class F Fly ash having a specific gravity as 2.33, and Blaine's fineness as 378 m2/kg, water, silica sand, PVA fibers, HRWA and marble powder having a specific gravity as 3.15 and Blaine's fineness as 306 m2/kg is provided respectively. Hence it is a mortar rather than concrete. The physical and chemical characteristics of fly ash and marble powder are presented in Table 1. Polyvinyl alcohol (PVA) fibers light yellow having length 6mm, modulus of elasticity ≥ 210cm/dtex, denier 2.0±0.2 dtex, tensile strength ≥6 cn/dtex, and elongation at break at 6-11%. PVA is short discontinues fibers covered with a slick coating, which allows the fiber to begin slipping when overloaded without any fracture, thus preventing cracks. High range water, reducing agent SikaViscocrete 5201 NS having a specific gravity 1.10 and PH value of 6.67 is used to form the cementitious matrix. Silica sand is used in place of ordinary river sand in the mortar. A normal river sand range in diameter from 0.0625 mm to 2 mm. Silica sand contains 80 to 90% silica (SiO2) polymers. Marble powder is a metamorphic rock formed after the transformation of pure limestone. The powder produced after the shaping and sawing of marble is additional material in concrete and mortar.

Table 1. Chemical Characteristics of Fly ash and Marble Powder

Parameters	Chemical Characteristics (%)						Physical properties	
	SiO_2	MgO	SO_3	Na_2O	LOI	$SiO_2 + Al_2O_3 + Fe_2O_3$	SG	BF
FA	46.32	1.34	0.74	0.44	2.8	87.84	2.33	378
MP	0.05	1.7	1.2	1.4	2.9	76.9	3.15	306
Note: BF= Blaine Fineness (m^2/kg), LOI= Loss on ignition, SG= Specific gravity								

At the initial stage, the evaluation of the pozzolanic activity index of MP was done in accordance with ASTM C311 by a strength activity test. In this test, 20% of the cement was partially replaced with MP, and a matrix was prepared with the same flow as a normal matrix. The mortar was mixed properly, and 3 cubes of size 70.6 mm × 70.6mm were cast using a vibrating table. Three cubes of control mix mortar were also molded. After 24 hours, the blocks were denuded and placed in water for curing for 28 days. The cubes were removed after the curing period, surface dried, and tested for the compression test. Compressive strength results were computed from three test mixture and three control mixture.

As per equation 1, the Strength Activity Index was calculated from the cubes.

$$SAI = \left(\frac{\text{Test mixture average compressive strength}}{\text{Control mix average compressive strength}}\right) * 100 \quad \text{Eq. (1)}$$

The control mixture's average compressive strength came to be 41.96MPa, and that of the test mixture came to be 39.27MPa. The strength activity index of marble powder with Portland cement at 28 days came to be 92.75 %, according to equation 1. According to ASTM C 311, the required physical requirements for marble powder are a minimum of 75 %. Thus, according to the equation, marble powder can produce high-performance concrete by replacing it with cement. These results proved that marble powder could be considered as good pozzolanic material. Five distinct ECC mixtures were prepared with and without MP, as summarized in Table 2. One ECC mixture (ECC 0%) without MP was prepared and used as a reference. For ECC-based MP (ECC 5%, ECC 10%, ECC 15% and ECC 20%), OPC were systemically replaced by MP at 5, 10, 15 and 20% by mass. A Water-cement ratio of 0.3 is adopted respectively to produce ECC mixtures. All ECCs were produced using a concrete mixer. During the casting of ECC-based specimens with high MP replacement levels, difficulties were observed in introducing the fibers with the uniform distribution throughout the entire mix. To reduce this phenomenon's negative effect, additional HRWA was added, which explains the higher volume of HRWA with MP replacement level.

B. Preparation of specimen and testing

After casting, all the cube and beam specimens were kept inside the molds 24 hours at normal temperature. Subsequently, specimens were cured at the laboratory medium in water for 7 and 28 days, respectively. Three cubic specimens 150 mm x150 mm from each ECC mixture ratio were cast to determine compressive strength at 7 and 28 days. Beams of dimension 700 x 150 x 150 mm were also prepared to determine the flexural strength of ECC

Table 2.Mix Proportions of ECC

Mixture Proportions	Mix Proportions (Kg/m^3)				
	*ECC 0%	ECC 5%	ECC 10%	ECC 15%	ECC 20%
Ordinary Portland Cement	703	656	609	563	516
Fly Ash	234	234	234	234	234
Marble Powder	-	46.88	93.75	140.63	187.50
Silica Sand	932	925	918	911	905
PVA	0.94	0.94	0.94	0.94	0.94
HRWA	2.81	2.81	2.81	2.81	2.81
Water	300	300	300	300	300

Note: *ECC 0% indicates standard ECC without marble powder

VI. RESULT

A.Compressive Strength of ECC by Ultrasonic pulse velocity test

Ultrasonic pulse velocity is an NDT test conducted to assess concrete quality as per IS: 13311 (Part 1)-1992. In this method, a ray of the ultrasonic pulse was allowed to pass through the concrete being tested. The concrete cube's strength and quality were determined by measuring the velocity of an ultrasonic pulse passing through a concrete cube, and the time taken by the pulse to get through the structure was measured. Figure 4 shows the experimental setup to perform an ultrasonic pulse velocity test. The higher velocity of the ultrasonic pulse indicates the concrete is of good quality, and the lower velocity of the ultrasonic pulse indicates concrete is of low quality, i.e., with many cracks or voids. Table 3 indicates the quality of concrete based on velocity. The result is summarized that the concrete cubes' velocity comes in the range of 3.5 to 4.5 Km/Sec. This indicates that the quality of concrete is good and can be used for construction purposes.

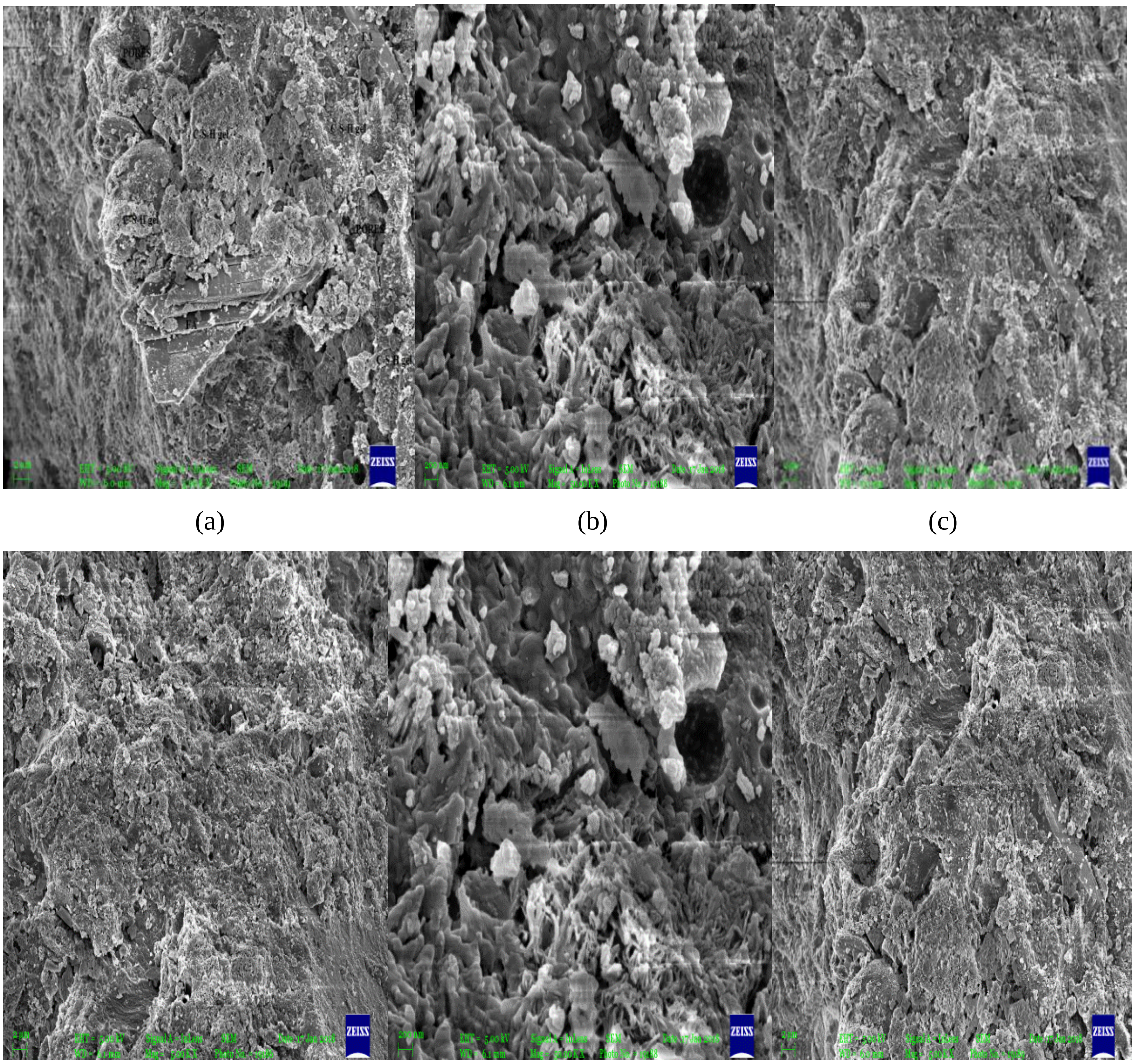
Table 3 Results of UPV

Sr.No	Member	Distance (mm)	Time (micro sec)	Velocity (Km/sec)
1	Concrete Cube	150	35.40	4.24
2	Concrete Cube	150	34.90	4.30
3	Concrete Cube	150	34.90	4.30

Fig 4: Experimental setup to perform ultrasonic pulse velocity test (Actual photograph of the setup)

B. Microstructural Examination

The microstructural evaluation on concrete powder was done using Philips XL 30 SEM machine. The sample was prepared by crushing and sieving it through a 90-micron sieve. The spot magnification was carried out on the sample, which can be seen in Figure 4.5 (a), (b), (c),(d), (e), and (f).



(a) (b) (c)

(d) (e) (f)

Fig 5: Microstructure and self-healing of the sample after 28 days curing comprising of (a), (b),(c),(d), (e), (f) of SEM

The spot magnification done with 5.00KX and 50.00 KX was observed with pores at their various crusts followed in varying sizes. The reaction product, i.e., calcium silicate hydrate, was found with continuous deposits on the surface, which can be identified as presented in Figure 5 (a). The identification of products was similar in texture when referred to Aggarwal and Siddique (2014). Another product, i.e., Calcium hydroxide (Ca(OH)2 after the reaction was found as a dense material, which can be identified as indicated in Figure 5 (e) when referred to Kilic, Toprak, and Ozdemir(2016)

C. Investigation of chemical compounds using XRD Analysis

The XRD analysis of concrete powder was done to examine the c chemical compounds that may have occurred due to suppl supplementation of marble powder, silica sand, and PVA fiber. The examination was done in Philips X'pert pro panananalyticalsystem

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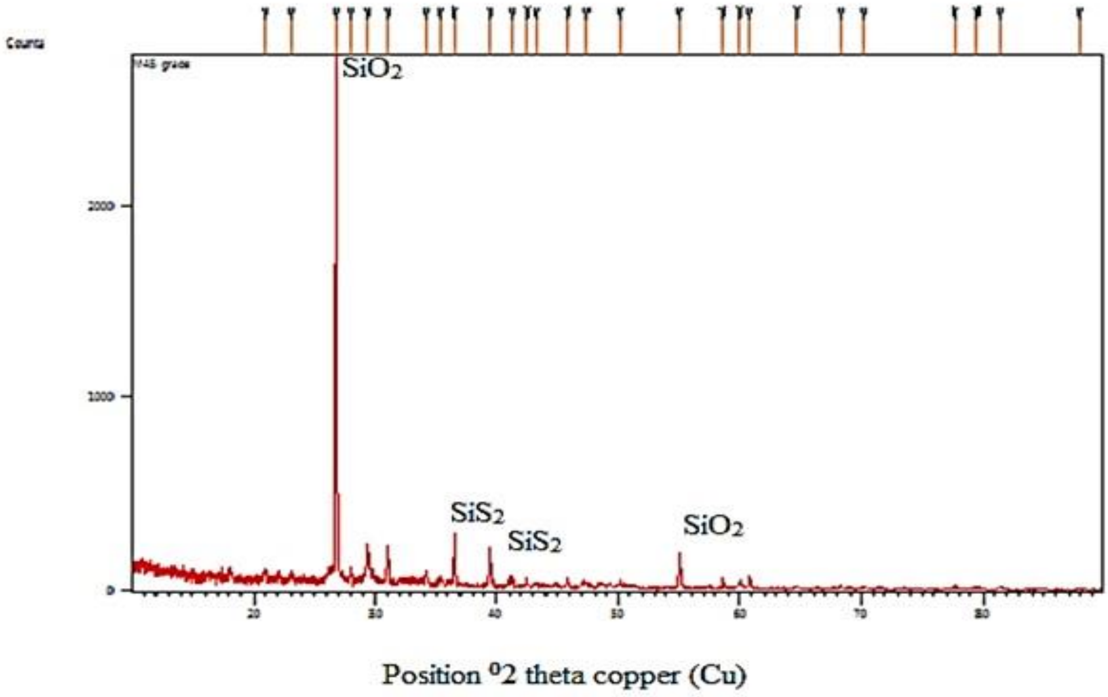

Fig6: XRD Analysis

The XRD test's main purpose was to identify the chemical compounds' changes occurring due to supplementation of varied materials. The sample, which was concrete powder, was examined on Philips X'pert pro pan analytical system. But, before the test's conduction, the sample was prepared by attaching it to the sample holder, and a glass slide smeared an upper surface of the powder to get a smooth and uniform surface. The specimen was prepared then placed in the machine on a diffractometer to scan in a continuous manner from 4o-90o with a constant scanning rate. The graph was formed on the system attached to the machine, as shown in Figure 4.6, further analyzed. The analysis supported with the research article of Aggarwal and Siddique (2014) articulates that the peak obtained at 27 with o2 theta copper with a rise of 2727 is SiO2i.e. Silica dioxide, which is further followed by small peaks as compared with it. Further, the silicon disulfide was found near 36.5714 and 39.5114 at o2 theta copper with a peak near 264.35 and 188.

VII. CONCLUSIONS

1. The velocity of concrete evaluated by ultrasonic pulse velocity test showed a value between 3.50 to 4.5 km/sec. Hence the quality of concrete is good.

2. SEM and XRD images indicate that the effect of MP and PVA fibers in ECC shows self-healing of cracks in concrete.

3. In the SEM test, spot magnification was observed with pores of varying sizes.

4. The reaction product of calcium silicate hydrate was found with continuous deposits on the surface by using the SEMtest.

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