



To Study the Properties of Hybrid Engineered Cementitious Composites by Adding Waste Materials

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To study the properties of hybrid engineered Cementitious composites by adding waste materials

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Abstract

This paper manifests the mechanical properties of Hybrid Engineered Cementitious Composites (HECC) such as tensile strength, young's modulus of elasticity, flexural strength, and compressive strength. In this experimental investigation, steel fibers and Polyvinyl Alcohol (PVA) are used for hybridization with different volume fraction. When compared to PVA fiber blends, hybrid mixes demonstrate a considerable improvement in mechanical qualities. To study the topography of the sample, scanning electron microscopy test is done and X-ray diffraction analysis is also done to study crystalline structure of the sample.

Introduction

Engineered Cementitious Composite (ECC), also known as bendable concrete or Strain Hardening Cement-based Composites (SHCC), is a mortar-based composite that can be readily molded and reinforced with specifically chosen short random fibers at a volume percentage of 2%. [1]. ECC has the tensile ductility of around 3-5% which is 300-500 times the fiber reinforced concrete or normal concrete [2], [3]. Victor Li developed ECC at the end of the twentieth century [4], [5]. Engineered Cementitious Composites (ECCs) are ultra-ductile fiber reinforced cementitious composites designed for huge material volumes and the building industry's economic constraints. [4], [6]. Engineered Cementitious Composites (ECC)—a unique type of high performance fiber-reinforced cementitious composites (HPFRCC) with high inherent tensile ductility—have seen significant advancements in the last decade thanks to the utilization of lower fiber content. [7].

Some studies show that hybridization of two or more fibers improved strain capacity and ultimate strength. The hybrid composites reap the benefits of each fiber and have a collusive response. [8]. Hybrid composites employ fibres with a variety of material qualities, geometric parameters (length and diameter), and natural behavior to improve the material properties of Hybrid Engineered Cementitious composites (HECC) [9].

The fibers which are generally used in the ECC mix are polypropylene (PP) fiber, Polyvinyl Alcohol (PVA), and Polyethylene (PE) [10]. PVA fiber is widely used due to its high elastic modulus and tensile strength and it is quite compatible with Portland cement in the composites mix [11], [12]. PVA fiber has been chosen in this study due to its above mention properties. Along with the PVA fiber, steel fiber is used because it increases compressive strength and Young's modulus and it exhibits less spalling when exposed to high temperature [13], [14]. Application of hybrid engineered cementitious composites includes seismic, impact, and blast resistant structure [15]. It is used for repair and retrofitting purposes [16]–[18] and SNF storage structures. [19].

Experimental investigation

Materials and mix preparation

The Ordinary Portland Cement (OPC) of 43 grade, silica fume and Class F fly ash are used in this study. Steel fiber of length 13mm and Polyvinyl Alcohol (PVA) fibers are used to develop the Hybrid Engineered Cementitious Composites (HECC), Table 1 shows the chemical composition of silica fume, fly ash and cement. Table 2 shows physical and mechanical properties of fibers. Table 3 shows the HECC used in this experimentation. High range water reducer's superplasticizers (figure 1 shows Polycarboxylic Ether superplasticizers) are added to reduce the water content in the HECC mix. Aggregate of size 4.75mm and with specific gravity of 2.78 and fineness modulus of 2.9 is used as fine aggregate. Mixes are named as ECC-0 for the mix without PVA fibers and steel fibers (Figure 2 shows PVA fiber and figure 3 shows glass fiber) and mix contain only PVA fibers in volume fraction of 2% is named as ECC-1. Mix ECC-2 is made with hybridization of PVA fiber with the concentration of 1.9% and steel fiber with the concentration of 0.1%. Mixes ECC-3, ECC-4, ECC-5 are made with hybridization of PVA fiber with the concentration of 1.8%, 1.7% and 1.6% and steel fiber with the volume fraction of 0.2%, 0.3% and 0.4% respectively. Hybridization process is used to ameliorate the mechanical characteristics and ductile nature of ECC mixes. All the mixes were hand prepared and each mix has slump value between 100 -120mm. All specimens are removed from mould after 24 h, and then cured at the room temperature until the predetermined testing age.

Table 1 Chemical composition of silica fume, fly ash and cement

Materials	SiO ₂ (%)	Al ₂ O ₃ (%)	MgO (%)	CaO (%)	Fe ₂ O ₃ (%)	SO ₃ (%)	Alkalines (%)	Others (%)
Silica fume	97	0.2	0.5	0.2	0.5	0.15	-	1.21
Fly ash	55.37	29.74	1.48	5.31	7.88	0.22	-	-
Cement	21.67	4.49	1.77	64.2	3.51	2.59	1.77	-

Table 2 Physical and mechanical properties of polyvinyl alcohol and steel fiber

Fiber	Tensile strength (MPa)	Length (mm)	Density (kg/m ³)	Young's modulus (GPa)
Polyvinyl alcohol	1600	12	1290	42.5
Steel fiber	1100	13	7850	210

Table 3 Mix design of HECC

Mix	Fly ash	Cement	Silica fume	w/c ratio	Super-Plasticizer (%)	PVA Fiber (%)	Steel Fiber (%)
ECC-0	0.20	0.70	0.10	0.40	1.0	-	-
ECC-1	0.20	0.70	0.10	0.40	1.0	2.0	-
ECC-2	0.20	0.70	0.10	0.40	1.0	1.9	0.1
ECC-3	0.20	0.70	0.10	0.40	1.0	1.8	0.2
ECC-4	0.20	0.70	0.10	0.40	1.0	1.7	0.3
ECC-5	0.20	0.70	0.10	0.40	1.0	1.6	0.4



Figure 1: Polycarboxylic Ether (superplasticizers)



Figure 2: Polyvinyl Alcohol (PVA) fiber



Figure 3: Steel fiber

Test methods

Tensile strength

According to IS: 4031(part 6)- 1988, a cylinder specimen measuring 150x300mm was used to investigate the tensile strength of Hybrid Engineered Cementitious Composites mixtures after 7 and 28 days of curing.[20].Compressive Testing Machine (CTM) has been used for the tensile test; three samples has been cast for every mix and the mean value is taken in order to avoid an error. The experimental setup and cylinder sample details for the tensile test are shown in Figure 4.

Compressive strength

Cube specimens of 150x150x150 mm size are used to study the influence of fiber concentration on the cementitious composites. The samples are cured in the same atmosphere as the tensile specimens for 7 and 28 days. The compressive strength of the mixes was evaluated using a Compressive Testing Machine (CTM). Three samples were cast for each mix, and the mean result was taken into account. Figure 5 shows the experimental setup and cube specimen details for compressive strength.

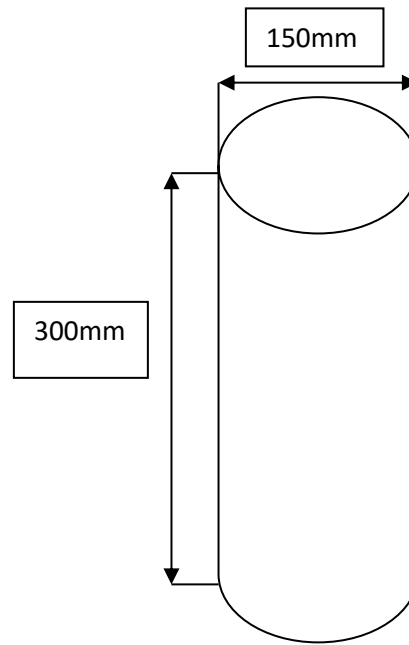


Figure 4: Tensile strength test setup and cylinder specimen detail

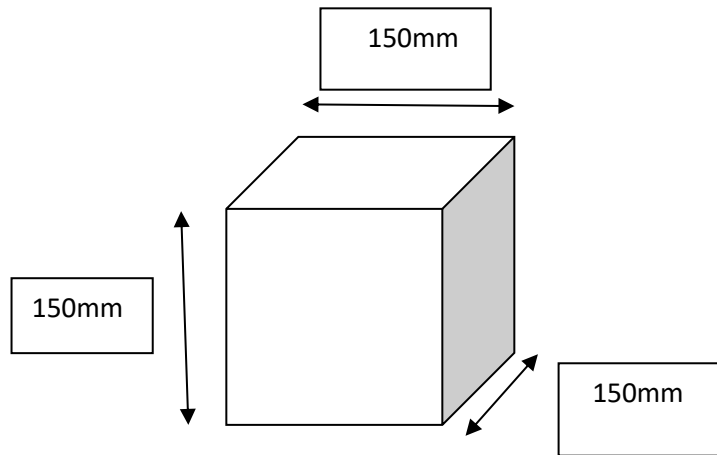


Figure 5: compressive strength test setup and cube specimen detail

Flexural test

To study the flexural behavior of cementitious composite, beam specimens of 100x100x500mm are used. The specimens were cured for the 7 and 28 days in an identical environment as the tensile samples. Two point loading machine is used to determine the flexural behavior of the specimens. For every mix, three specimens are tested and their mean value is recorded. Figure 6 shows the experimental set up and beam specimen details for flexural test.

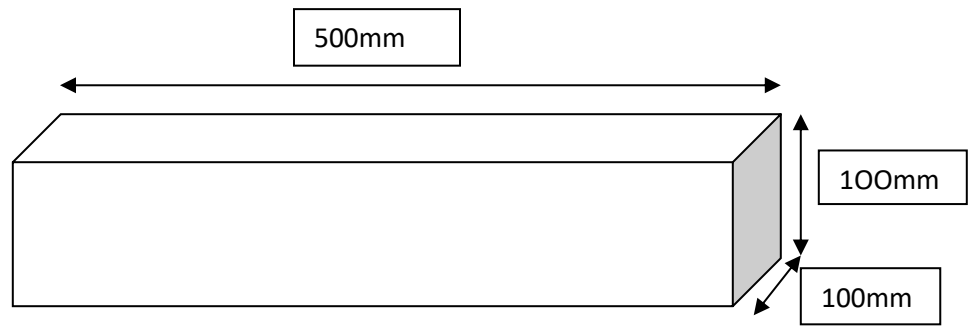


Figure 6: flexural strength test set up and beam specimen detail

Young's modulus

To determine the young's modulus, specimens of 150mm diameter and 300mm height are used. A Compressometer with a dial gauge is used to determine the young's modulus of mixtures. Figure 7 shows the experimental set up and cylinder specimen details for young's modulus of mixes.

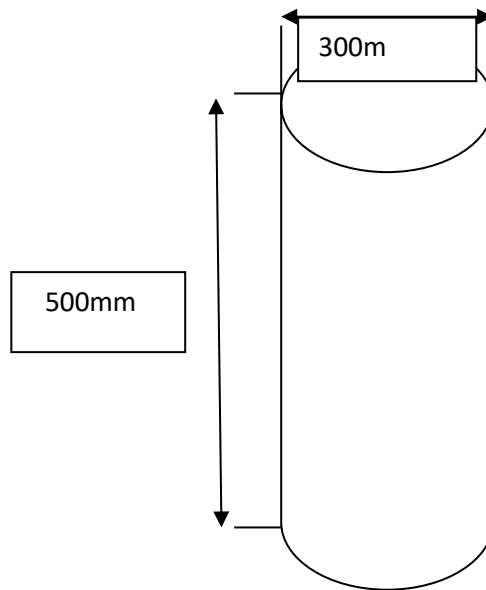


Figure 7: Young's modulus of elasticity test set up and cylinder specimen detail

Water absorption test

Cylinder specimens 150x300mm, cube specimens of size 150x150x150mm and beam specimens 100x100x500mm size are used to determine the water absorption. The weights of the samples are recorded after removing the specimens from the molds in 24 hour and curing for 28 days. After drying in an oven at 100 to 110 degrees Celsius, the specimens must be cooled to room temperature before being weighed.

Heat regime

In order to determine the effect of temperature on the behavior of cementitious composites, cube specimens measuring 75mmx75mmx75mm were placed in a furnace and heated until the desired temperature was reached. Muffle furnace is used, in which the inner chamber and insulation is of ceramic fiber. Once the target temperature is reached, then the temperature remains constant for 2 hour. Figure 8 shows the muffle furnace and cube specimen detail.

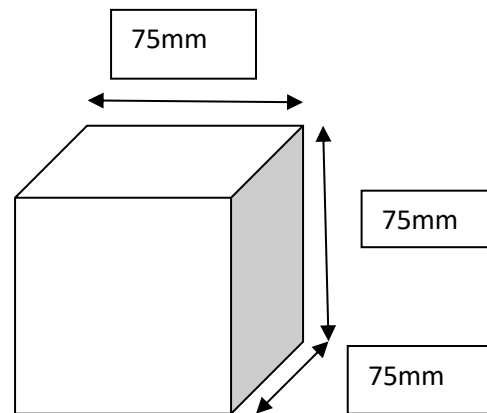


Figure 8: Muffle furnace and cube specimen detail

X-Ray diffraction and Scanning electron microscopy analysis

X-Ray Diffraction (XRD) analysis is a study of the crystal structure and the chemical composition at the surface of any material. Scanning Electron Microscopy (SEM) analysis is the study of microstructure of the material. SEM analysis is done on the sample after compression test, to evaluate the surface morphology of cementitious particle, fiber orientation.

Test results

Tensile strength

After a regular interval of 7 and 28 days of curing, a tensile test is performed. For every mix three sample are tested and their mean value is taken into account. The tensile strength of the mix (ECC-0) without fiber is 3.29 MPa and 4.15 MPa after 7 and 28 days respectively. ECC-1 mix which contains only PVA fiber, exhibits tensile strength of 3.53 MPa and 5.41 MPa after 7 and 28 days respectively. ECC-2 and ECC-3 mix contain both PVA fiber as well as steel fiber, exhibits tensile strength of 3.73 MPa and 4.07 MPa after 7 days and 5.45 MPa and 6.19 MPa after 28 days respectively. ECC-4 mix exhibit high tensile strength of 4.20 MPa and 7.53 MPa after 7 and 28 days respectively, when the concentration of PVA fiber is 1.7% and steel fibers is 0.3%. ECC-5 mix exhibits tensile strength of 3.91 MPa and 6.96 MPa after 7 and 28 days respectively. According to Victor Li, the ultimate tensile strength of ECC mixtures should be approximately 4-12 MPa. [5]. The findings show that all of the mixtures' tensile strength falls within this range.

In the previous studies, when the concentration of PVA fiber is 2% the tensile strength of 5.3 MPa is observed after 28 days [21]. Chart 1 represents the tensile strength after 7 and 28 days.

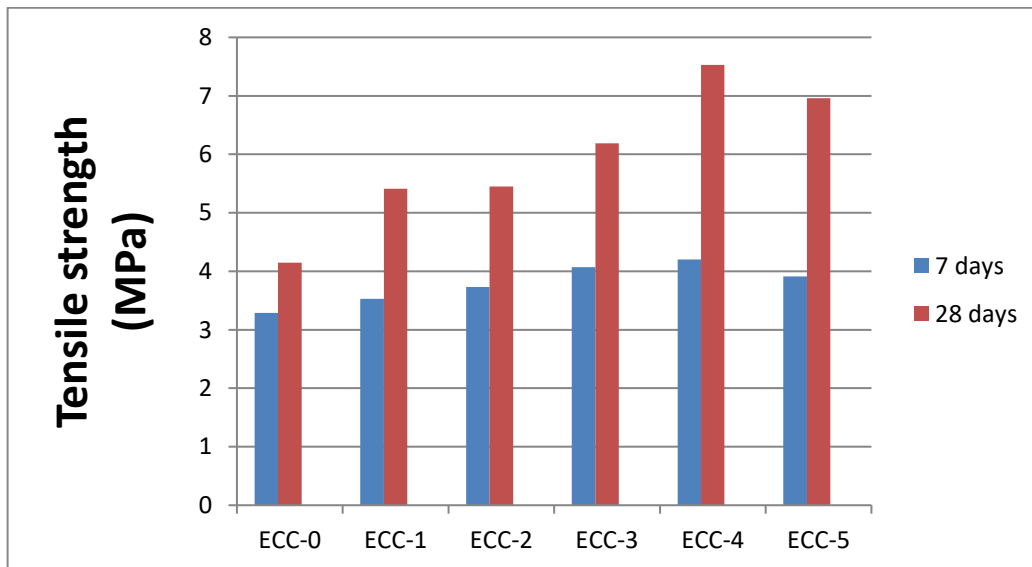


Chart 1: Tensile strength of the mixes

Compressive strength

After 7 and 28 days of curing, the compressive strength of samples of cementitious composites is determined. Three samples are analyzed for each blend, and the mean value is taken into account. ECC-0 mix is normal mix which exhibits compressive strength of 31.78 MPa and 48.90 MPa after 7 and 28 days respectively. ECC-1 mix contains PVA fiber which exhibits compressive strength of 33.05 MPa and 50.85 MPa after 7 and 28 days respectively. The compressive strength of the hybrid mix ECC-2 and ECC-3 is 34 MPa and 52.31 MPa after 7 days and 34.58 MPa and 53.20 MPa after 28 days respectively. ECC-4 exhibits high compressive strength among other mix of 34.89 MPa and 53.68 MPa after 7 and 28 days respectively. ECC-5 exhibits compressive strength of 34.26 MPa and 52.71 MPa after 7 and 28 days respectively. Fiber hybridization has little effect on compressive strength, according to the findings.

In prior investigations, compressive strengths of 13-15 MPa were obtained when steel fiber dosages of 0.6 percent, 1%, and 1.5 percent were used[22]. The compressive strength of 45 MPa is observed when the dosage of PVA fiber and steel fiber is 1.5% and 0.5% respectively[23]. Compressive strength after 7 and 28 days is depicted in Chart 2.

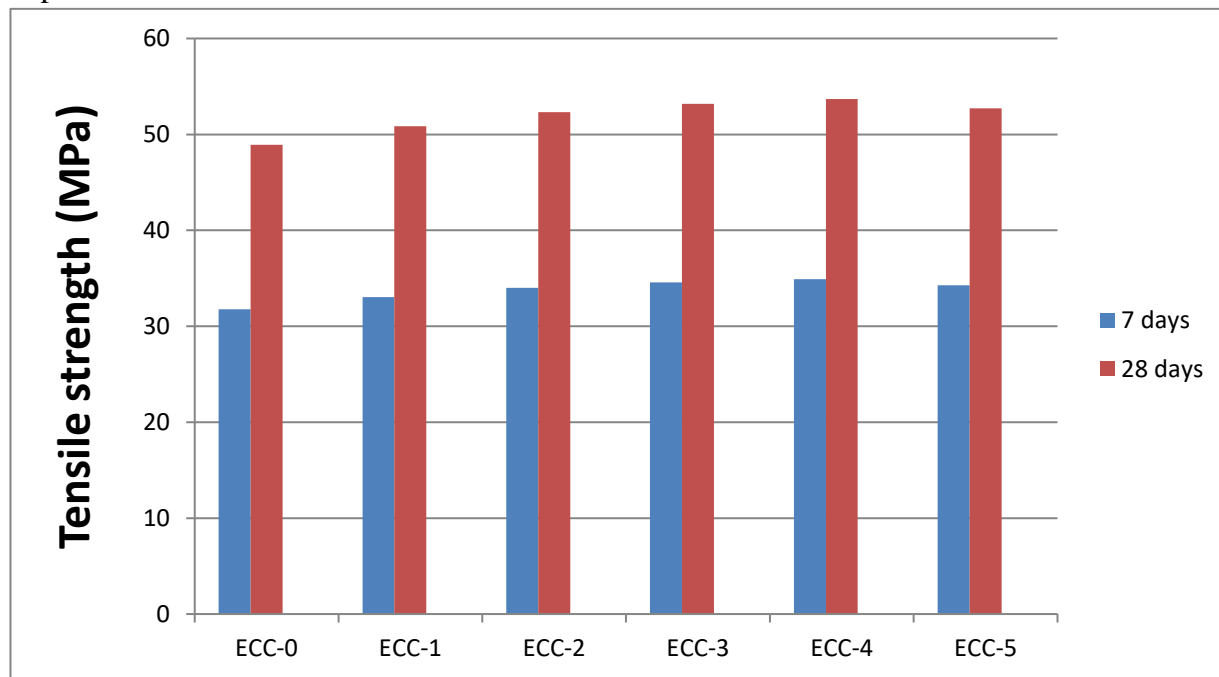


Chart 2: Compressive strength of mixes

Flexural test

The flexural strength is carried on two point loading machine after 7 and 28 days. For every mix, three samples are examined and their mean value is taken. ECC-0 mix is the mix which does not contain any fiber exhibits the flexural strength of 4.9 MPa and 6.28 MPa after 7 and 28 days respectively. When the PVA fiber is added there is increase in the flexural strength of the mix. ECC-1 exhibits the flexural strength of 5.7 MPa and 7.45 MPa after 7 and 28 days respectively. Hybrid mix, ECC-2 and ECC-3 exhibits the flexural strength of 5.81 MPa and 6.3 MPa after 7 days and 8.52 MPa and 9.5 MPa after 28 days respectively. ECC-4 exhibits high flexural strength of 7.3 MPa and 10.3 MPa respectively after 7 and 28 days respectively. ECC-5 exhibits flexural strength of 6.9 MPa and 9.8 MPa after 7 days and 28 days respectively. A significant decrease is observed in the flexural strength of hybrid composites when reducing the PVA fiber content[8]. Chart 3 represents the flexural strength after 7 and 28 days of all the mixes.

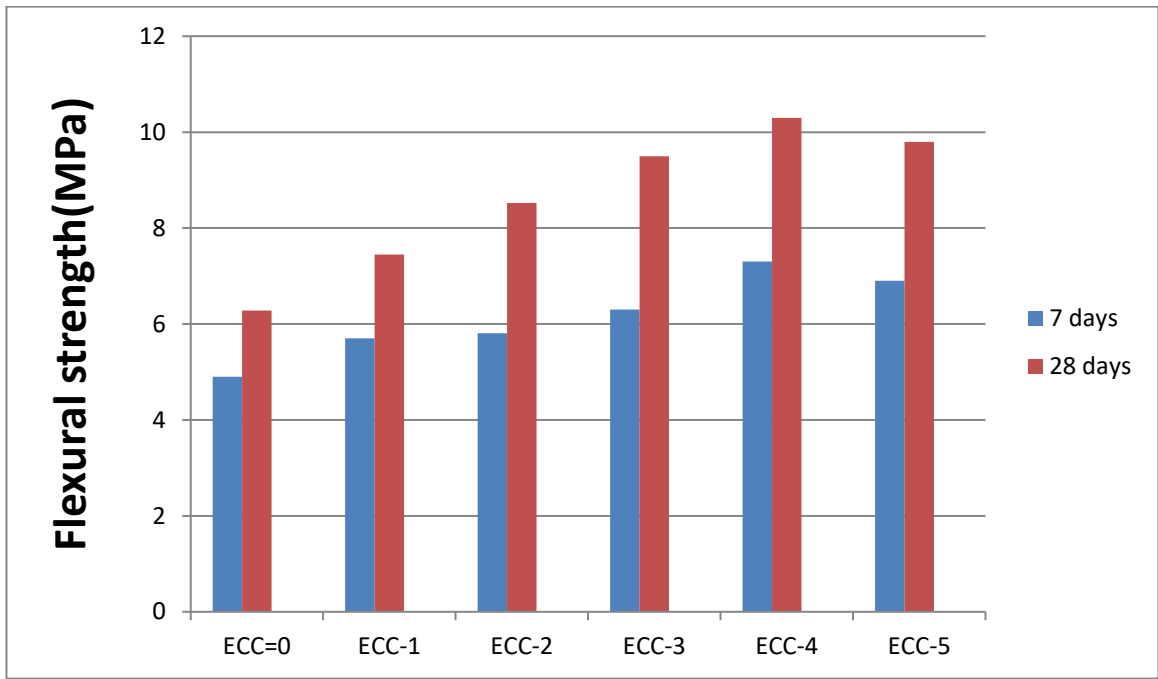


Chart 3: flexural strength after 7 and 28 days of all the mixes

Young's Modulus of elasticity

After 28 days, the specimens' mean Young's modulus is recorded.. ECC-0 mix which does not contain fiber exhibits Young's modulus value of 31.62 GPa. The mix which only contains PVA fiber exhibits Young's modulus value of 32.03 GPa. Hybrid mix which contains concentration of PVA fiber of 1.8% and steel fiber of 0.2 % exhibits high Young's modulus of value 33.95 GPa. Young's modulus value of 32.44 GPa, 33.89 GPa and 32.67 GPa is observed in ECC-2, ECC-4 AND ECC-5 mix respectively. Results suggests that there is not much difference in the Young's modulus value of the mix with fiber to the one without fiber. In the previous studies, 23.67 GPa Young's modulus is observed when there is only PVA fiber in the mix[24]. Chart 5 represents Young's modulus of elasticity after 28 days of all the mixes

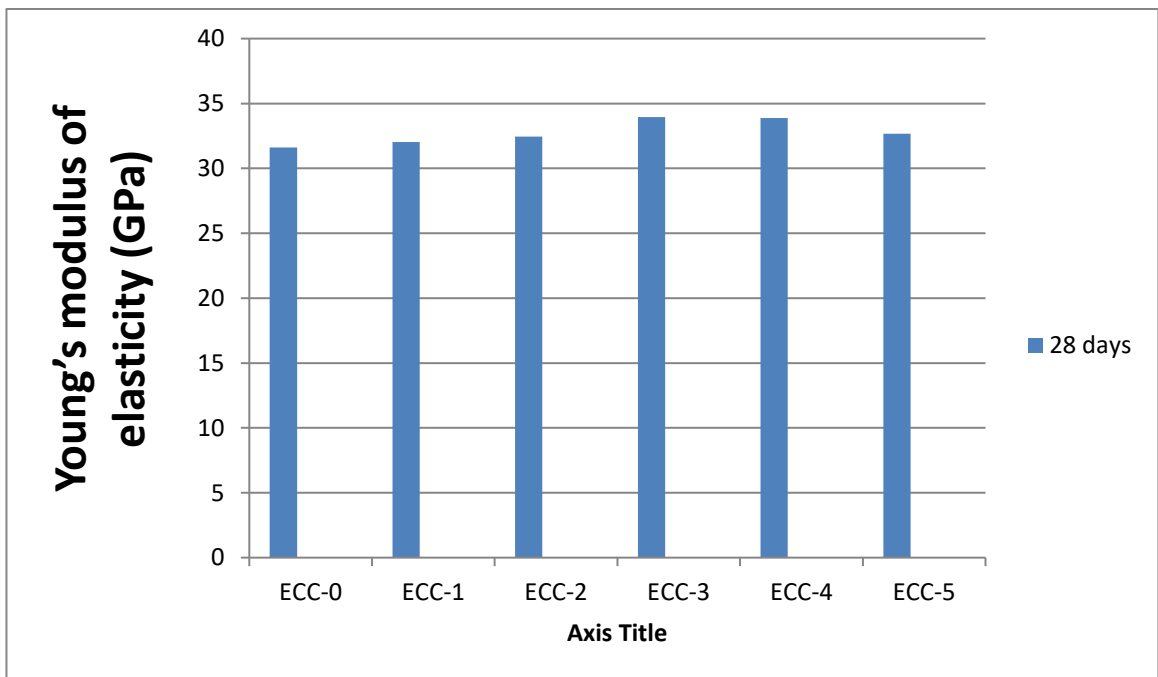


Chart 5: Young's modulus of elasticity of all the mixes after 28 days

Water absorption

The water absorption is expressed as percentage by weight of oven dry specimen and mean of three values[25]. Figure shows water absorption of all the mixes. The cube specimens show the water absorption in the range of 4.35 %, 4.34 %, 4.08 %, 4.59 %, 4.39 % and 4.34 %. The cylinder specimens exhibit low water absorption as compared to other specimens. Beam specimens of ECC-0, ECC-1, ECC-2, ECC-3, ECC-4 and ECC-5 mix exhibit water absorption in the range of 4.20%, 4.00%, 4.01%, 4.20%, 4.20% and 4.3% respectively. Chart 6 represents water absorption after 28 days of all the specimens.

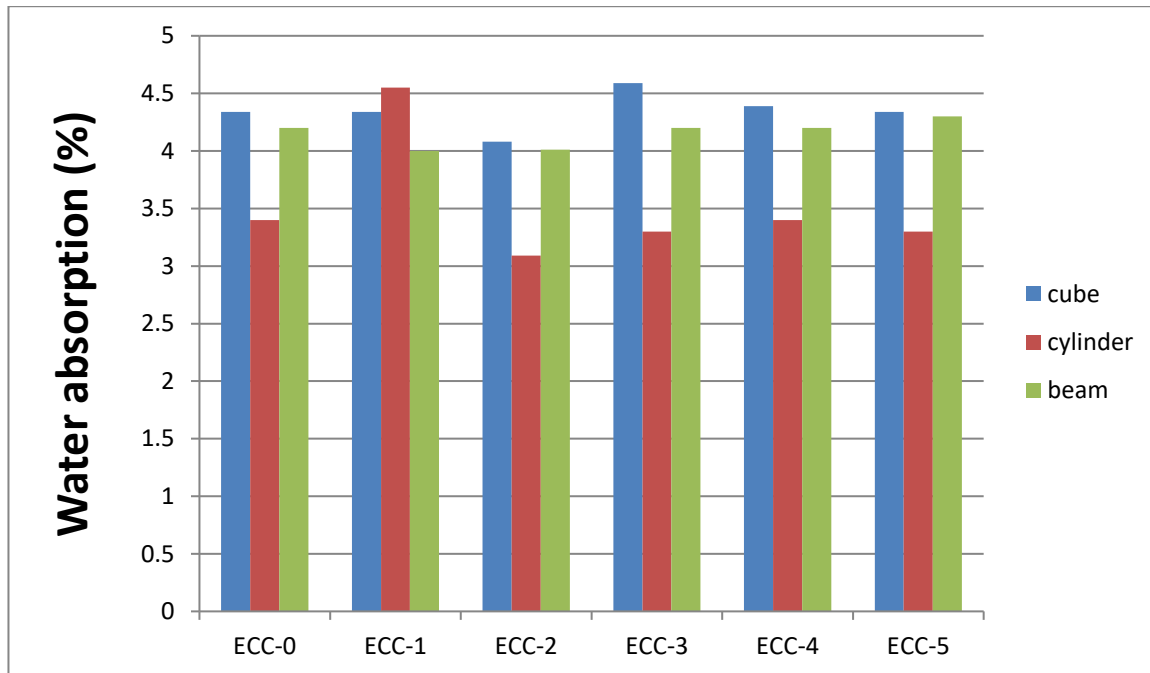


Chart 6: water absorption of all the specimens after 28 days

Heat regime

Specimens are heated at temperature of 200°C, 400°C, 600°C, 800°C, 950°C and 1200°C and then their compressive strength is check. When the specimen reaches at temperature of 1200°C, it crack and hence cannot be check for the compressive strength. The compressive strength is found to be reduced by 70-80% at 950°C. There isn't much of a loss in compressive strength at 200°C. Despite the fact that no spalling was found in any of the specimens, there was a drop in compressive strength. When specimens are subjected to 600 and 800°C, there is a 32-74 percent drop in compressive strength, according to a recent research.[7].

X-Ray Diffraction and Scanning Electron microscope analysis

Scanning electron microscopy analysis is done on ECC-4 mix as it gives the better result among the other mixes. Figure 9 shows the magnifying image in the range 80, 140, 350 and 900. X-Ray Diffraction analysis shows that ECC-4 mix is 63 % crystalline and 37% amorphous as shown in figure 10.

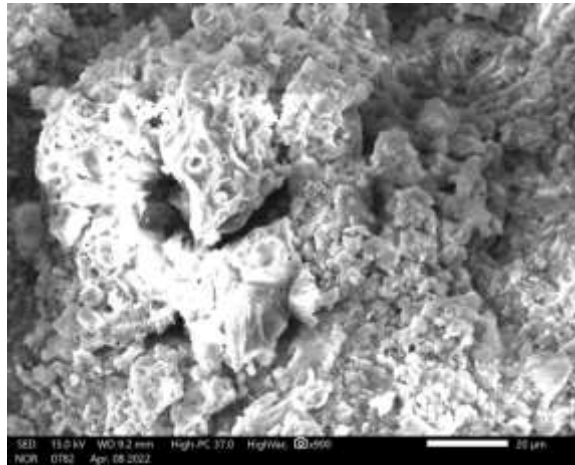
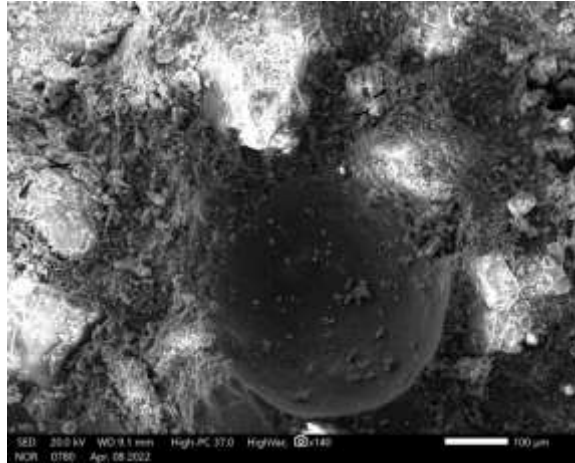
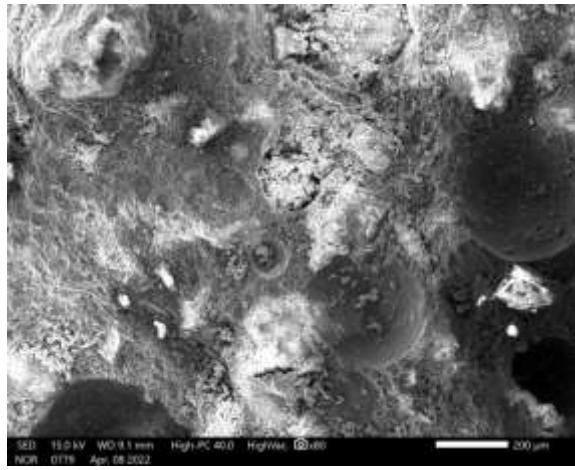


Figure9: Scanning Electron microscopy analysis

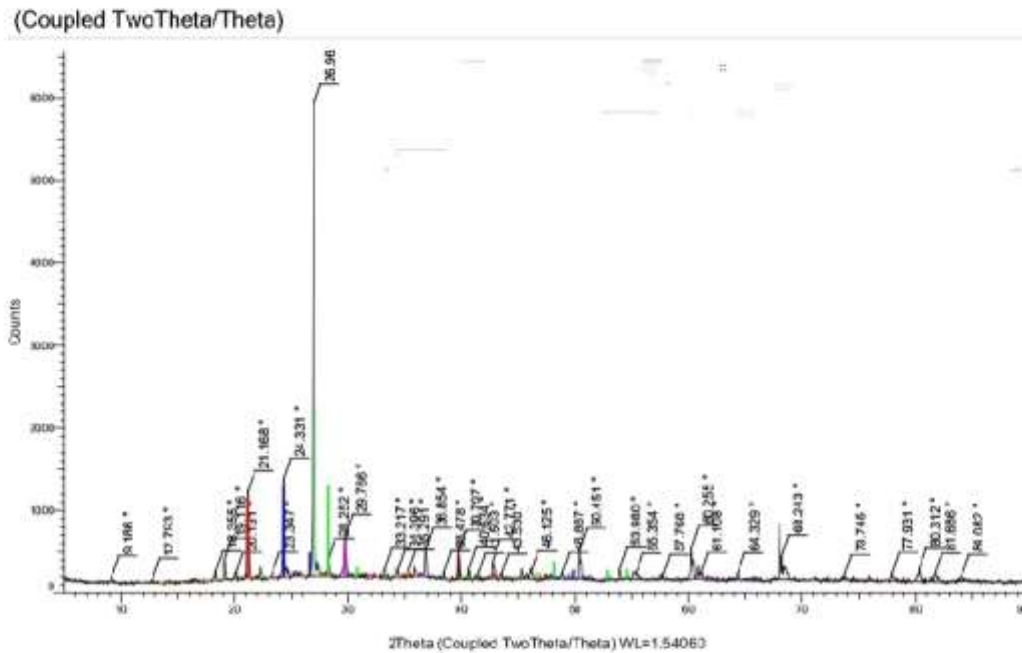


Figure 1: X-Ray Diffraction analysis

Conclusions

In this experimental study, the affect of hybridization of fibers is evaluated and following observations are made:

When there is hybridization, the compressive strength increases. The compressive strength of the ECC-4 mix is 9.79 percent higher than the ECC-1 mix. When the fiber content of PVA fiber is reduced to 1.7 percent and the fiber content of steel fiber is increased from 0.1 percent to 0.3 percent, the compressive strength of the material increases. When PVA fiber is 1.7 percent and steel fiber is 0.3 percent, the best results are obtained.

The tensile strength of the material increases as a result of the hybridization. When conventional concrete is used, the tensile strength is 4.15 MPa, whereas when hybridization is used, the tensile strength is 7.53 MPa. It is noted as steel fiber content increase in the mix, the tensile strength increase.

Hybridization of fiber results in an improvement in flexural strength. The optimum result is observed when PVA fiber is 1.7 % and steel fiber is 0.3%. It is noted that flexural strength increase when steel fiber is in the range of 0.1-0.3% and PVA fiber is 2-1.7% and then decrease when steel fiber is 0.4 % and PVA fiber is 1.6%.

When specimens are subjected to high temperatures, their compressive strength decreases.

Hence, it can be said that there is improvement in the mechanical properties of the hybrid mix. For cost optimization, silica fume and fly ash are used. The optimum result is found with use of 1.7 % PVA fiber and 0.3% steel fiber.

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