# A Study of Engineered Cementitious Composites by Investigating its Compressive and Flexural Strength

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**Research Article**

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# Abstract

Concrete has become an essential material as a part of construction field. Its behavior is weak in tension and strong in compression. The demand for tensile strength is high for concrete because higher loading requires more than 10% of compressive strength which make a critical issue for engineers. Another major issue faced by normal concrete is lack in ductility and strain capacity. Engineered Cementitious Composites (ECC), also known as Bendable Concrete, has been designed to overcome the brittleness of concrete. It has tensile ductility of 3–5% and its self-controlled tight crack width is less than 100μm.It is a unique type of cement mixture with composition of low volume fibers (~ 2%) so as to impart ductility, ability to repair and high tensile strength besides. It also has low maintenance and is environment friendly in nature.The ECC composition does not contain coarse aggregate because they develop larger crack width which tend to have a negative effect on ductile behavior of ECC. This paper demonstrated a detailed review on properties of ECC and experimentally identified the best ECC mix by analysing the compressive the flexural strength at different ratios: 0.5%, 1%, 1.5%, 2% and 2.5% of PVA fibre. Fifteen cubes (150mm x 150mm x 150mm) were casted for compressive strength test and fifteen beams (500mm x 100mm x 100mm) were casted for flexural strength and tested at the age of 28 days. Workability test have been conducted to access the fresh properties and consistency of the concrete.


# 1. Introduction

Concrete is one of the commonly used construction material throughout the world. In spite of its high compressive strength, it has low bending nature and the strain capacity of concrete is only up to 0.1 percent which is one of the main reasons for its rigidity and brittleness which leads to its failure under strain. Therefore, an improvement of a more efficient material is a specific requirement of concrete structure which leads to the evolution of a material namely, Engineered Cementitious Composites (ECC), which is also called as Bendable concrete. It belongs to a family of ductile concrete. The tensile strain capacity of ECC can ranges from 3–5%, and thus the material can exhibit considerably enhanced flexibility. This results in 300 to 500 times the tensile strain capacity as compared to normal concrete and fiber reinforced concrete. It is a highly ductile composite with tight crack width control property, more durable, have lower cost and lower carbon emitting mix with a higher strength as compared to conventional concrete. The composition of a bendable concrete includes cement, fine aggregate, fiber and chemical admixture. The coarse aggregate is not used in ECC mix to reduce the crack propagation. Thus, ECC have various applications & wide future scope in various construction fields especially like bridge construction, highway structures, pavement and slabs.

In this work, ECC is made using 0.5%, 1%, 1.5%, 2% and 2.5% of PVA fibre and an experimental investigation is carried out to find the mechanical properties of ECC with different fibre ratios which include its slump test, compressive strength on cubes and flexural strength on beams.

# 2. Literature Review

Chao Wu and Victor C. Li (2016), in their study, CFRP-ECC (Carbon fiber reinforced polymer- Engineered Cementitious Composites) hybrid was bonded to concrete structure externally and ECC was used as adhesive for strengthening purpose. ECC was used for its desirable multi cracking and strain hardening properties in tension. The mechanical properties of ECC which include compressive strength and tensile strength was studied under elevated temperatures up to 500°C and compared with mortar specimen. The study also came to the conclusion that ECC have anti-spalling properties under elevated temperature.

Adeyemi Adesina and Sreekanta Das (2020), in their study, the durability properties of ECC which include shrinkage and permeability properties by using recycled concrete(RC) fines as aggregates were analyzed. The use of recycled concrete as aggregate with a complete replacement of the silica sand in ECC mix shows reduction in drying shrinkage which increase the durability of ECC. The study also indicated that the use of RC as aggregate in ECC is sustainable as well as economical.

Munshi Galib Muktadir et.al,(2020), in their study, the flexural strength and compressive strength of ECC that is reinforced with Polyvinyl Alcohol (PVA) fibre at different ratios of 0%,0.5%,1% and 1.5% were analyzed and compared with conventional concrete. The best acceptable result was obtained for 1% PVA content with high compressive and flexural strength value. It was found that the flexural strength and compressive strength of the ECC mix was comparatively higher than the conventional concrete due to the presence of fibre content as reinforcement.

Fathumathul Anasi K, Sankaranarayanan K. M (2020), study was done to find out the best ECC mix among twenty-four developed mixes and compressive strength, tensile strength and flexural strength of ECC was compared with M25 concrete mix. The flow table test was also done to analyze the consistency of ECC mix. The ECC mix having 1% of fibre content was chosen as the acceptable mix from high split tensile and compressive strength value.

Victor Li et.al, (2017), study was done to analyze compressive strength and tensile strength of ECC under long-term exposure to aggressive environment such as sodium sulphate and sulphate chloride solutions by micromechanical study. The results show that ECC remains stable after 420 days of exposure to aggressive environment which helps to enhance durability performance and to increase the life of hydraulic structure. It also retained multiple cracking and showed strain-hardening behaviour with desirable high tensile ductility above 2% under the exposure of concentrated sodium sulphate and sulphate chloride solutions after 200 days.

Sagar Gadhiya (2015) has carried out study on ECC to determine the compressive strength, flexural strength and deflection characteristics of different types of fibers and it was compared with Conventional Concrete. All beams were tested under four-point loading test at different age in UTM. The results show that the Flexural Strength of ECC with Steel, PVA and Hybrid Fibers was found to be more in comparison with Conventional Concrete. The failure patterns shows that the conventional concrete fails into two parts whereas in ECC only cracks were developed which reflects its ductile behaviour.

Victor C. Li et.al,(2015), conducted a study on the mechanical properties of ECC with high-volume fly ash and PVA fibers (HVFA-ECC) under varied temperature exposures. The test results shows that HVFA-ECC maintained a pseudo strain hardening characteristics and unique multiple cracking within the applied temperature range. The tensile properties of ECC was increased up to 100°C of temperature but dropped significantly after undergoing higher temperature because the tensile strength value of fibre was retained at sub-elevated temperature but diminishes at higher range of temperature (≥ 200°C). The test results concluded that tensile properties of ECC were enhanced by moderate temperature treatment and HVFA-ECC can resist and remains durable under sub-elevated temperature exposure.

Michael D. Lepech et.al, (2008), a new version of more sustainable cement-based green materials was designed for a specific infrastructure application. The study shows that there is a reduction in tensile strain capacity of green ECC over 50% as compared with virgin materials on the addition of green foundry sand, which can be imposed by the bridge deck link slab applications. The characterization of the matrix fracture properties and fiber pull out behaviour showed that when carbon residue on green foundry sand particles leads to 40% reduction in matrix fracture toughness and there observed a corresponding 80% reduction in bridging stress complementary energy which resulted in strain-hardening potential and multiple cracking compared to original ECC.

## 3. Methodology And Material Used

The material used in this work includes cement, M-sand, Fly ah, PVA fiber, super plasticizer, and water. Ordinary Portland Cement 53 grade is used in this study. The physical properties of cement are determined by conducting various laboratory tests. The M-sand used in the experiment is fine aggregates which passing through 150µm and retained in 90µm sieve. Class F fly ash is used in the experiment. Fly ash is produced in thermal power stations. The water reducing agent used is Modified Polycarboxylate ether (PCE). The polycarboxylate based super plasticizers are made of HI- PCE HR50 which is Polycarboxylate ether. It has excellent water reduction by dispersing effect, high retardation and good flow-ability. In this work, PVA fibre is used for making ECC at a different volume fraction of 0.5%, 1%, 1.5%, 2% and 2.5%. The dimensions of PVA fibre used in the study are 6mm length and 39µm diameter. And the density of fibre is 1500 kg/m3. The PVA fibre used in the experimental investigation is shown in Fig. 1. The quality of water used for this study was potable water.

## 3.1 Mix Proportioning

A regular ECC mix as found in Thermal behaviours of CFRP-ECC Hybrid under elevated temperatures [9] is used in this study. The mix proportion of ECC is shown in Table 1.

Table 1
Mix proportioning of ECC

| Mix proportion | Cement ($kg/m^3$) | Fly ash ($kg/m^3$) | Sand ($kg/m^3$) | PVA ($kg/m^3$) | Water ($kg/m^3$) | Superplasticizer ($kg/m^3$) | PVA Percentage |
|---|---|---|---|---|---|---|---|
| M1 | 393 | 865 | 457 | 6.5 | 311 | 5 | 0.5 |
| M2 | 393 | 865 | 457 | 13 | 311 | 5 | 1 |
| M3 | 393 | 865 | 457 | 19.5 | 311 | 5 | 1.5 |
| M4 | 393 | 865 | 457 | 26 | 311 | 5 | 2 |
| M5 | 393 | 865 | 457 | 32.5 | 311 | 5 | 2.5 |

## 3.2 Mixing and Curing

A mixer with 30L capacity is used to prepare the ECC mixtures. Firstly, the solid ingredients like cement, sand and fly ash are dry mixed for 6 minutes. Then water and HRWR admixture are mixed together and then added slowly into the dry mixture and mixed for next 4 minutes. The mixture was then checked and any clamping found in the mixture was broken to ensure a complete homogenous paste. The mixing is continued for another 3 minutes in order to attain a good fluidity. The PVA fibers were added slowly into the mortar mix and mixed until the fibers were well dissipated. The fresh ECC was casted into cubes of 150×150×150mm that were moderately vibrated using a concrete vibrator. The beams of 500×100×100mm were also casted and compacted using a vibrator. Specimens were remoulded after 24 hours. After remoulding the specimen were cured and the values of compressive strength and flexural strength are taken at 28days. Slump test is also carried out to determine the workability of ECC.

## 4. Test Done

## 4.1 Slump Test

The slump test was conducted to check the consistency of ECC mix for .25 water/binder ratio. The slump value of ECC mix for different ratios of PVA fibre is shown in Table 2.

Table 2
Slump Value of ECC mix

| SL No. | Mix | Slump(mm) |
|---|---|---|
| 1 | M1 | 135 |
| 2 | M2 | 120 |
| 3 | M3 | 118 |
| 4 | M4 | 110 |
| 5 | M5 | 103 |

## 4.2 Compression Test

Compressive strength is measured using compression testing machine and the maximum compressive load a material can bear before fracture was measured. In this study, cube of size 150 mm×150mm×150mm were used and it is shown in Fig. 2. The specimen is placed in the machine and load was applied. The maximum load at which specimen fails is noted. The maximum load divided by the original area of the specimen gives the compressive strength. Compressive strength of the cube was evaluated after 28 days and the obtained compressive strength value of ECC mix is shown in Table 3. Compressive strength is calculated by the following formula:

$$F=\frac{P}{A} \tag{1}$$

P = Maximum load in N applied to the specimen

A = Area of a cross section in $mm^2$

Table 3
Compressive strength of ECC at different ratios PVA fibre after 28 days

| SL.NO. | MIX | Compressive strength (MPa) |
|---|---|---|
| 1 | M1 | 23.4 |
| 2 | M2 | 26.22 |
| 3 | M3 | 34.67 |
| 4 | M4 | 36.14 |
| 5 | M5 | 30.44 |

## 4.3 Flexural Strength Test

Flexural strength is measured using a flexural testing machine and it is shown in Fig. 3. Beam specimen of 500mm×100mm×100mm was used for the study. The bed of testing machine must be provided with two rollers, and all rollers shall be mounted in such a way that the load is applied axially without any torsional stresses or restraints. Flexural strength of the beam was evaluated after 28 days and the obtained values are shown in Table 4. Flexural strength of beams can be calculated by:

$$f = \frac{PL}{bd^2} \qquad (2)$$

where,

P = Maximum load in N applied to the specimen

L = Length of the specimen in mm

d = Depth measured in mm of the specimen at the point of failure.

b = Breadth of specimen in mm

Table 4
Flexural strength of ECC beam at different ratios of PVA fibre after 28 days

| SL.NO. | Mix | Flexural strength (MPa) |
|---|---|---|
| 1 | M1 | 5.25 |
| 2 | M2 | 6.5 |
| 3 | M3 | 7.5 |
| 4 | M4 | 8.25 |
| 5 | M5 | 8.5 |

## 5. Conclusion

This paper experimentally analysed the compressive and flexural strength of ECC with 0.5%, 1%, 1.5%, 2% and 2.5% of PVA at 28 days of curing. Conclusion can be drawn as follows:

1. The compressive strength and flexural strength of ECC was found to be high with ECC mix of 1.5% of PVA content and hence chosen to be the best ECC mix.

2. ECC have good workability and lies between the standard values of concrete. The value slump was increased without changing water/cement ratio because of superplasticizer ( High Reducing Water Reducing agent)
3. The ECC specimen beams produced greater flexural strength than what would be normally produced by conventional concrete beams.
4. The ECC specimen cubes produced slightly lesser compressive strength than that which would have been produced by conventional concrete.
5. ECC technology focuses more on increasing the flexural strength of the concrete and does not significantly increases the compressive strength of the concrete.

The contrivance of ECC emphasis civil engineers to provide a safer, lighter, more durable, economic and sustainable construction environment for society. ECC also have self-healing and self-consolidating properties. The results from life cycle assessment modelling confirmed that the use of ECC technology leads to a reduction of carbon and energy footprints of constructed facilities. The various investigations are done by several engineers for further development of Engineered Cementitious Composite (ECC) and its applications in the real field proves to be one of the best alternative and sustainable concrete materials of the future decades.

# 6. Declarations

- **Ethics approval and consent to participate** Note applicable in this section
- **Consent for publications** Note applicable in this section
- **Availability of data and materials** All the data generated or analyzed during this study are included in this published article
- **Competing interest** The authors declare that they have no competing interests in this section

- **Funding** There is no funding provided

- **Authors' contributions** All authors are equally participated in writing the manuscript. Ms, Mareena George conceived of the presented idea. Cenya S Kumar, Shivani Ittuvettil, Sona Rose Bins and Sona Togi carried out the experiment and wrote the manuscript with the support of Mareena George. All authors discussed the results and contributed to the final manuscript.

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## Figures

**Figure 1**

PVA fibre

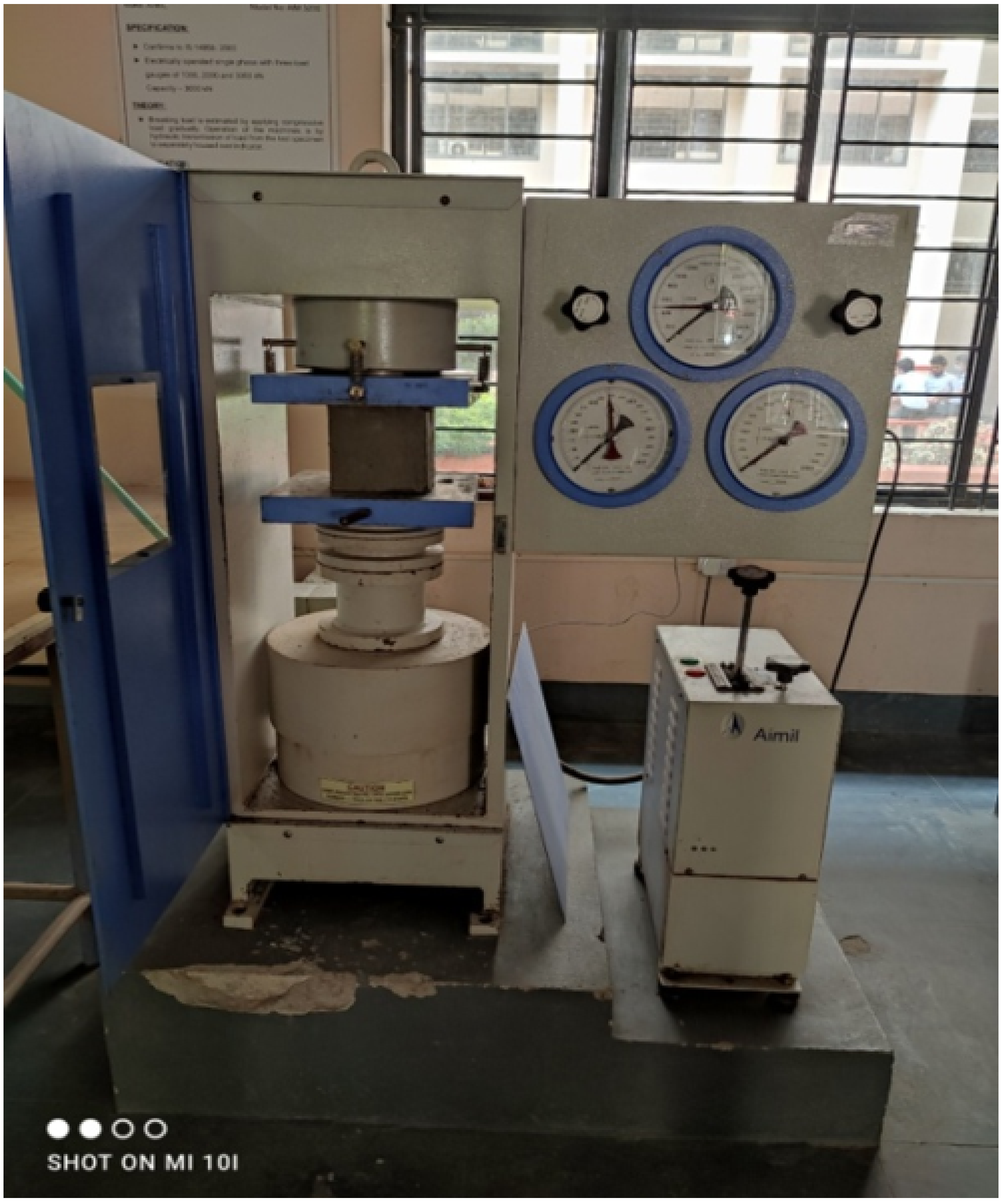
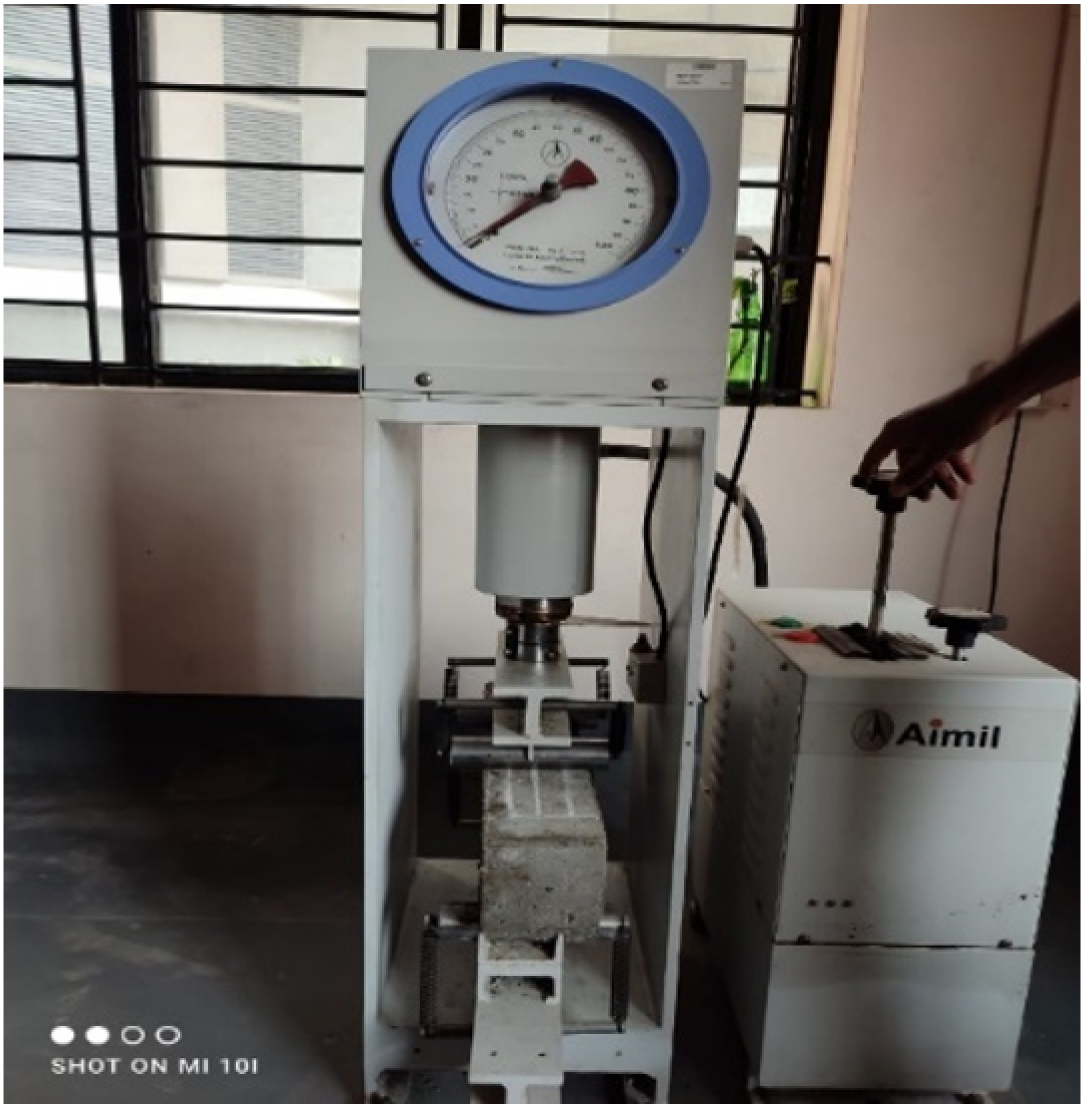



**Figure 2**

Compression testing on cube




### Figure 3

Flexural strength test