ECONOMICAL DESIGN OF ENGINEERED CEMENTITIOUS COMPOSITE

Final Year Project (2018-19)

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CERTIFICATION

This is to certify that thesis entitled

ECONOMICAL DESIGN OF ENGINEERED CEMENTITIOUS COMPOSITE (ECC)

by

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Has been accepted towards fulfillment of the requirements

For Bachelors in Civil Engineering

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DECLARATION

It is hereby solemnly and sincerely declared that the work referred to this thesis project has not been used by any other university or institute of learning as part of another qualification or degree. The research carried out and dissertation prepared was consistent with normal supervisory practice and all the external sources of information used have been acknowledged.

DEDICATION

This thesis is dedicated to all our beloved teachers, at home in the form of our parents and at university in the form of professors, lab engineers and other instructors. This work would not have been possible without their supervision, support and guidance throughout the term of this project.

ACKNOWLEDGMENT

We thank The Almighty Allah for giving us the strength and belief in ourselves for undertaking this final year project. We also take this opportunity to express our gratitude and respect to our parents, for it is only due to their prayers and wishes that enabled us to complete this work.

It is utmost necessary to acknowledge and thank our advisor and mentor Lecturer Sara Farooq, for all her admirable guidance, assistance and motivation provided throughout our project. It is with her support that we have been successful in achieving our objectives. We would also like to appreciate the assistance and aid offered by our Head of Structures Department Dr. Rao Arsalan for his astounding support, which in fact became the crux in the progress of this project.

We would also like to mention and thank all those departments, construction companies and construction professionals who provided us with their time, assistance and data. Without their cooperation this project would not have seen the light of dawn.

ABSTRACT

Like most countries, major infrastructure construction in Pakistan is done using concrete as a building material due to its various positive aspects such as high compressive strength, durability and stability. To improve tensile strength of concrete, extensive reinforcement is provided. A better proposed solution for enhancing structural performance compared to conventional reinforcing techniques is Engineered Cementitious Composite (ECC). ECC is a composite of fibers, cement, fine sand and water. Other admixtures such as super plasticizer and Supplementary Cementitious Materials (SCMs) can also be used. Due to absence of coarse aggregate and presence of randomly oriented fibers, ECC shows ductile behavior. Hence, ECC can be used to improve structural performance.

Polyvinyl-Alcohol fibers are most commonly used in the production of ECC. Due to the high cost of these PVA fibers, ECC is an uneconomical for use on an industrial scale. Furthermore, ECC requires more cement per unit volume due to absence of aggregate, which further increases the cost.

In order to reduce the cost, the materials used in ECC were replaced with locally available cheaper materials. Instead of PVA fibers, a low modulus locally available fiber was used, and cement was partly replaced with a supplementary cementitious material(SCM) that was cheaper than cement. For this purpose, six mix variations were cast. Two out of these six variations were of mortar, containing no fibers and varying fly ash content at 0% and 60%. The remaining four were ECC variations, all having fiber content at 2% by volume and varying amount of fly ash content at 0%, 60%, 90% and 120%. In order to study the mechanical properties of these variations, cubes measuring 100mm x 100mm x 100mm, cylinders measuring 100mm x 200mm (diameter x height) and prisms measuring 250mm x 100mm x 25mm (length x width x depth) were cast and cured underwater for 7, 14 and 28 days. For testing, these samples were taken out, air dried and used for conducting compressive strength, tensile strength and flexural strength tests.

PVA-ECC has compressive, tensile and flexural strengths in range of 30-90 MPa, 4-12 MPa and 10-15 MPa, whereas Nylon-66 ECC gave these properties in the range of 43.9 - 50.1 MPa, 3.63 - 4.28 MPa and 4.32 - 11.52 MPa respectively.

This clearly shows that ECC produced with nylon 66 fiber having 12mm length and 150µm diameter shows comparable mechanical properties to that of PVA-ECC. Furthermore, the prism samples tested under the three-point bend test showed strain hardening behavior which was absent in the mortar samples. Nylon 66 ECC was found to be 65.5% cheaper than PVA-ECC without the addition of fly ash which reduces cost by 1.73% for each 10% increment but also takes a toll on the mechanical properties i.e. 60% fly ash increment causes a 20% decrease in flexural strength, 8% decrease in tensile strength and 3% decrease in compressive strength.

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CHAPTER 1

INTRODUCTION

1.1 General

As we know conventional concrete is strong in compression but weak in tension. To increase its tensile capacity, it is reinforced with steel bars which arrests tensile crack propagation as well as prevents an abrupt failure. Steel is used for reinforcement because it is strong in tension but extensive steel reinforcement of concrete entails significant expense and labor.

Concrete has a wide range of uses but it has some draw backs. Firstly, the tensile strength of concrete is almost ten percent of its compressive strength. Also, the tensile strain capacity of concrete is in the range of 0.0001 to 0.0002 which makes it a brittle material. The weight of concrete is also very high.

A potential alternative to extensive steel reinforcement, as a method of enhancing tensile and flexural load bearing capacity, is engineered cementitious composites (ECCs).

Engineered Cementitious composite is a specially designed cementitious composite by addition of fibers in a low volume to enhance ductile performance with a large amount of energy dissipation, higher tensile strength and reduction in shear failure. Other admixtures such as superplasticizers are also added to reduce the water demand in order to increase compressive strength. Due to addition of fibers that are randomly oriented in the mix, micro cracks are generated which help in dispersing energy from one point on to the whole surface and hence increase the bearing capacity in tension phase. Unlike normal concrete, the strain capacity of ECC is in the range of 3 to 7 percent compared to only 0.1 percent for ordinary Portland cement paste.

ECC was first formed at the University of Michigan by Victor Li in 1993 with moderate tensile strength of 4-6 MPa with various recommended applications. [1]

Figure 1.1: ECC under 4-point bend test. [1]

1.2 Concept Behind

Unlike Fiber Reinforced Concrete (FRC), these are micromechanically designed composites which feature large tensile ductility. ECC is a broad term which includes composites designed on nano-, micro-and macro- scales. Compared to FRC, these materials does not incorporate aggregates, hence much volume and weight is reduced.

Research and development have been done in many universities including University of Michigan, University of California, Irvine, Delft University of Technology, University of Tokyo, the Czech Technical University, University of British Columbia and Stanford University.

Drawbacks of conventional concrete including lack of durability and failure under high strain values causing brittle behavior are the driving forces for development of ECC.

1.3 Limitations of ECC

As far as having its benefits, ECC has its limitations as well. The topmost is its higher initial cost as compared to conventional concrete that may lead to lesser interest towards ECC. This is primarily due to absence of aggregates and addition of fibers in concrete. ECC mix requires skilled labor as it is necessary to have evenly mixed and randomly oriented fibers within the matrix. The most common issue is the unavailability of the material for ECC. ECC has lesser or comparable strength than conventional concrete but it is expensive.

1.4 Problem Statement

The materials used in the production of “conventional” ECC are not easily available in Pakistan and importing those materials from outside the country is too expensive to be feasible on an industrial scale. To design an ECC which can be used in the Pakistani construction industry one needs to explore materials available in Pakistan that can adequately replace the materials used in conventional ECC without compromising the mechanical properties.

1.5 Objective

ECC is a vast field of materials that incorporate elements that are difficult to procure and each of these elements have their effect on the subsequent properties of ECC. For commercializing ECC in Pakistan, there is a need to formulate an approach to design a cost effective ECC whose components can be easily procured within Pakistan. Hence, this Project aims to understand mechanical properties of ECC and components which control these properties. This requires the in-depth study of materials and to market search for the comparable materials. Hence, this study aims to achieve the following objectives:

1.5.1 Design of ECC

The study involves following two aspects in the design segment

1. To design ECC with locally available materials for its production on commercial scale.

2. To compare mechanical properties of designed ECC with conventional ECC, in order to follow International standards.

1.5.2 Cost Comparison

Cost analysis of the designed ECC will be done to ensure feasible economic production in Pakistan. Following two parameters will be considered:

- To investigate effect of Fly Ash variation in ECC. The use of Fly Ash as SCM may help in lowering the cost of ECC.
- To check cost effectiveness of Designed ECC as compared to Conventional ECC. This will explore the possible economic benefits of this design as compared to conventional design.

CHAPTER 2

LITERATURE REVIEW

2.1 Properties of ECC

ECC exhibits the following mechanical properties.

2.1.1 Tensile Strength

High tensile ductility is one of the most important characteristics of ECC which is represented by a uniaxial tensile stress-strain curve. ECC has a strain capacity as high as 5%. At the end of the elastic stage when the first microcrack appears on the specimen a yield point can be seen showing a metal like behavior. If load is further increased, it results in a strain hardening response accompanied by a rise in load. After the first crack, the load continues to increase without fracture localization. More and more cracks develop resulting in the inelastic strain at increasing stress. When one of the multiple cracks form a fracture plane the samples fails. Beyond this peak load ECC shows a tension softening response just like normal FRC. ECC can offer structural improvements because of its high tensile ductility. The formation of multiple micro cracks is necessary to achieve high composite tensile ductility.

The value of tensile strength of ECC lies between 4-12MPa which is higher than the tensile strength of concrete which lies between 2-5MPa. [1]

The figure given below compares the increase in tensile strain with the tensile stresses and microcrack width. Micro cracks range from 80-100 micrometer.

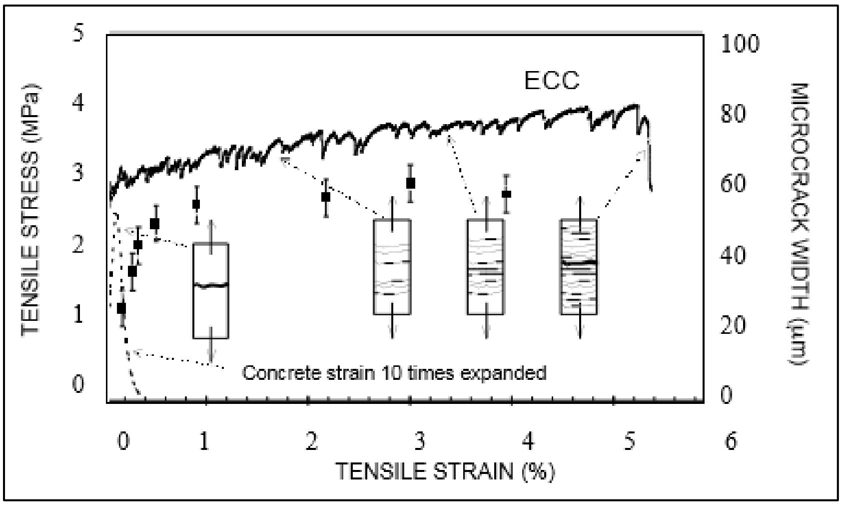


Figure 2.1: Comparison of tensile strain with tensile stress and microcrack width [1]

The micro cracks are so small and so many that it makes it very hard for aggressive media to enter and attack reinforcing steel as well as helping in showing self-healing. In presence of water the unreacted cement particles exposed due to the cracks hydrate and form a number of products which fill up these cracks. This self-healing not only fills up the cracks but mechanical properties are also regained. Above a certain crack width this self-healing becomes less effective.

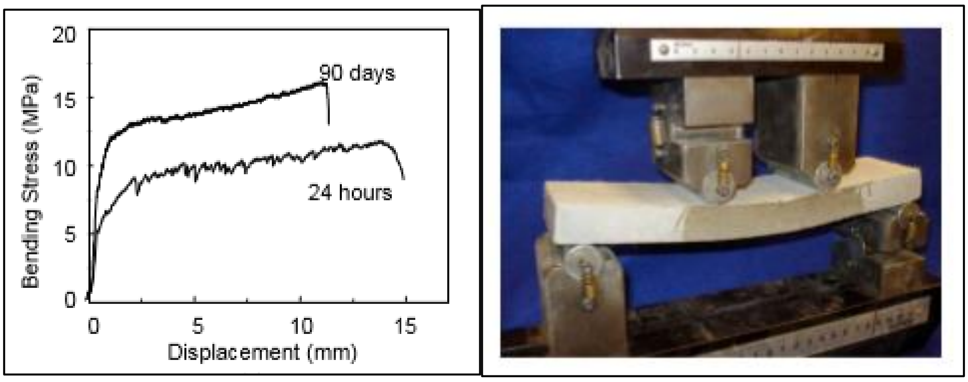
2.1.2 Flexural Strength

The tensile ductility of ECC is reflected by its flexural response. It’s also known as “bendable concrete” because multiple micro cracks are formed at the base of the specimen allowing it to undergo a large curvature development. Flexural strength of ECC usually ranges from 10-15MPa as compared to the flexural strength of concrete which ranges from 4-6MPa.

Fatigue response of ECC is better than normal concrete and FRC. Flexural fatigue tests conducted on ECC show higher ductility and higher fatigue life as compares to polymer cement mortars.

For evaluating the strain-hardening properties the four-point bending test can be used. Micro cracks are uniformly distributed with an average spacing less than 1mm. This cracking pattern also indicates the very good strain-hardening properties of ECC.

Following graph shows that deflection increases as bending stress increases up to a certain limit. The picture demonstrates the mode of behavior of ECC. [1]



(a) (b)

Figure 2.2: (a) Relation of bending stress with displacement in 4 point bend test, (b) ECC beam specimen under 4 point bend test [1]

According to tests performed the midspan deflection at failure was 20.5mm. The first cracking strength was 7.7MPa and flexural strength was 14.7MPa which is much higher than those of normal concrete or mortar. The flexural behavior of ECC is shown below.

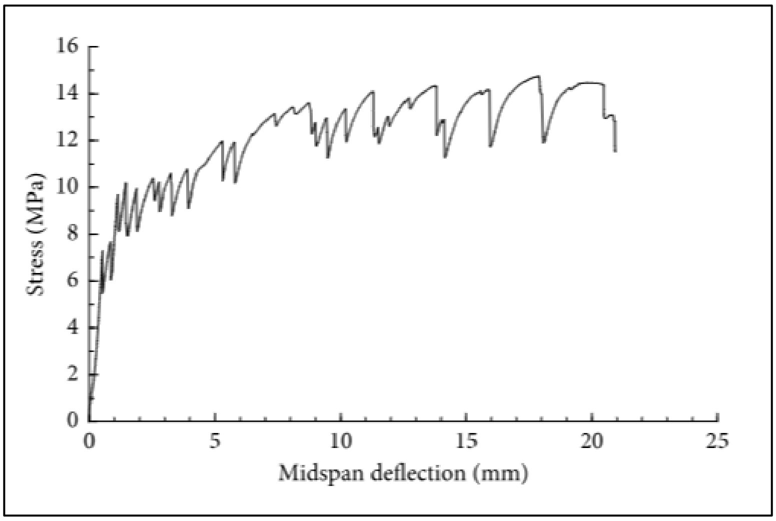


Figure 2.3: Relation of stress with midspan deflection under 4-point bend test [2]

2.1.3 Compressive Strength

The compressive strength of ECC is not that much different from normal-high strength concrete. ECC's compressive strength usually ranges from 30-90MPa.

Due to the absence of coarse aggregate its elastic modulus which is around 20-25GPa is typically lower than concrete. Its compressive strain capacity however is higher at around 0.45-0.65%. [1]

Its post peak behavior descends more gently than concrete under compression. There is a gradual bulging of the specimen instead of an explosive crushing failure.

2.2 Fibers

The inductions of Fibers in concrete have been observed in the past. The initials studies were conducted under the topic of FRC also referred as fiber reinforced concrete which have uniformly distributed and randomly oriented short discrete fibers such as glass, carbon, synthetics, natural fibers and hybrids that combine either different fiber types or fiber lengths.

By the beginning of 1980's, studies were being carried out for creating fiber reinforced concrete with high tensile strength and ductility by using discontinuous fibers at high dosage around 4-20% in concrete, these samples were not brittle but had much less ductility than their continuous fiber and textile reinforced counterparts. These materials were added in the category of ECC have properties of typical moderate tensile strength of 4-6MPa and a higher ductility of 3-5%. The approach was to create a product having synergetic interaction between fiber, matrix and interface, causing higher tensile ductility due to closely space and multiple microcracks while minimizing fiber content (generally 2%).

2.2.1 Reason for adding fibers

In ECC, fibers are added to resist the high brittleness of the densified matrix (cement and sand paste). The combination causes a strong bond between fibers and the rest contents, hence resulting in post cracking strength which becomes effective only when the structural ultimate limit state is approached (more as long as high strength fibers are used). The mechanical properties, durability and sustainability performances influences the decision to use which type of fibers, and their characteristics such has diameter, shape and sizes as well as in case of any necessary need for surface coating of fibers.

2.2.2 PVA Fibers:

PVA Fibers (polyvinyl alcohol) are high-performance reinforcement fibers for concrete and mortar. The optimum amount is found out be 2% of the total volume.

Following are its advantages:

- PVA-ECC delivers tensile strain capacity exceeding 3%, along with tensile strength > 5 MPa, flexural strength > 15 MPa, and compressive strength > 70 MPa.
- Resistant to oil grease and solvents,
- With high melting point up to 230C
- Close to incompressible with Poisson ratio 0.42-0.48.
- Tests showed that without aggregate samples 5% tensile
- Strain capacity was observed prior to the softening stage.
- Help reduce shrinkage and creep of specimen.

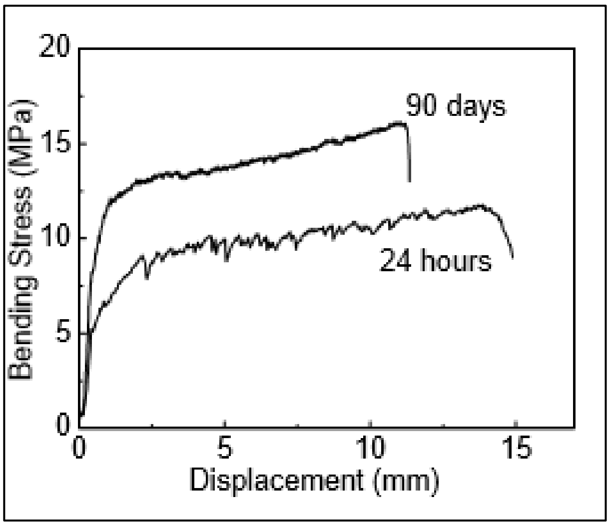


Figure 2.4: Relation of bending stress with displacement in 4-point bend test [1]

Following are disadvantages of using PVA fibers:

- Not locally available
- Cost is high
- Though it is observed that PVA fibers have chemical reaction at some extend with the ECC components due to surface action, for this purpose the

fibers are surface treated before mixing them with the rest components of ECC.

2.2.3 Nylon Fibers:

Nylon 66 is low modulus fiber, yet it is cheaply available and can be used as a substitute for PVA fibers in ECC. Experiments were done on ECC reinforced with addition of Nylon fibers.

Following a research paper, 2% by volume addition of nylon 66 fibers was done, of two lengths 6mm and 12mm and results were compared along with comparing with controlled sample. [3]

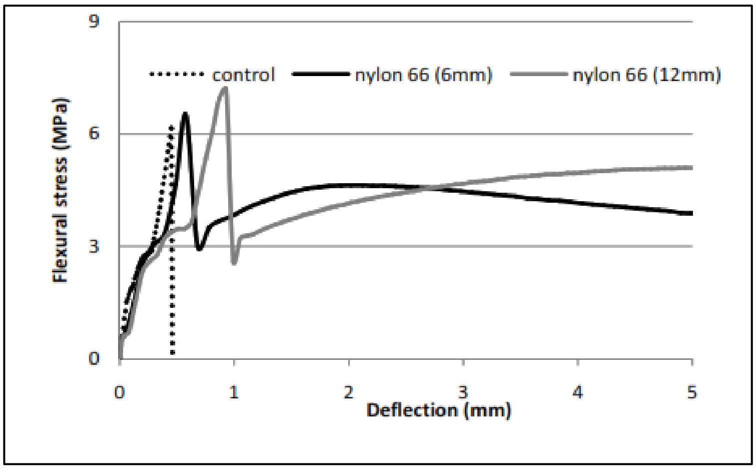


Figure 2.5: Flexural stress vs deflection in 3 point bend test for nylon-ECC [3]

Table 2.1: Three-point bending tests results for ECC specimens [3]

Fiber type in ECC samples	Fiber's length (mm)	Strength (Mpa)	Max deflection (mm)	Stress at second Peak (Mpa)	Deflection at second peak (mm)
Control (w/o fiber)	-	6.15	0.46	-	-
Nylon 66	6	6.51	37.13	4.63	2.12
Nylon 66	12	7.20	76.64	5.10	5.01

It was observed that with increase in length resulted in flexure strength and 130 times better results were obtained. The samples were tested in sheet shapes. Primarily, flexure and tensile property were observed to have better results than the Portland cement. Secondary reinforcement, resulted in the plastic shrinkage control, prevent crack creation and propagation in cement mix.

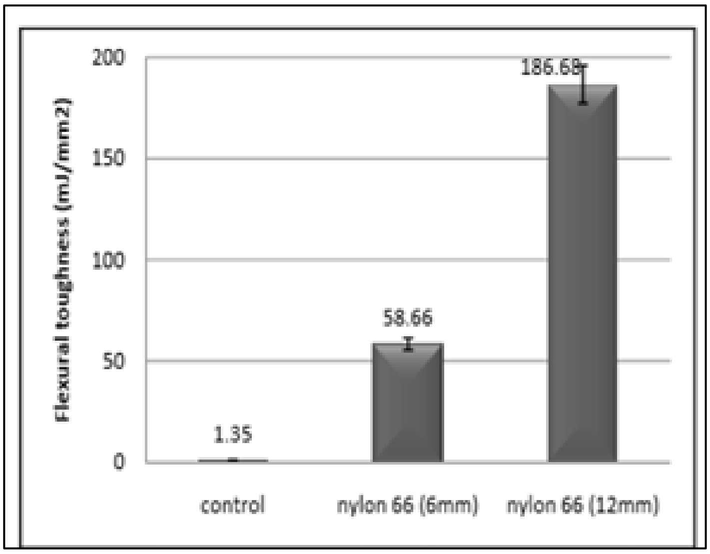


Figure 2.6Flexural toughness for Nylon-ECC with varying fiber length [3]

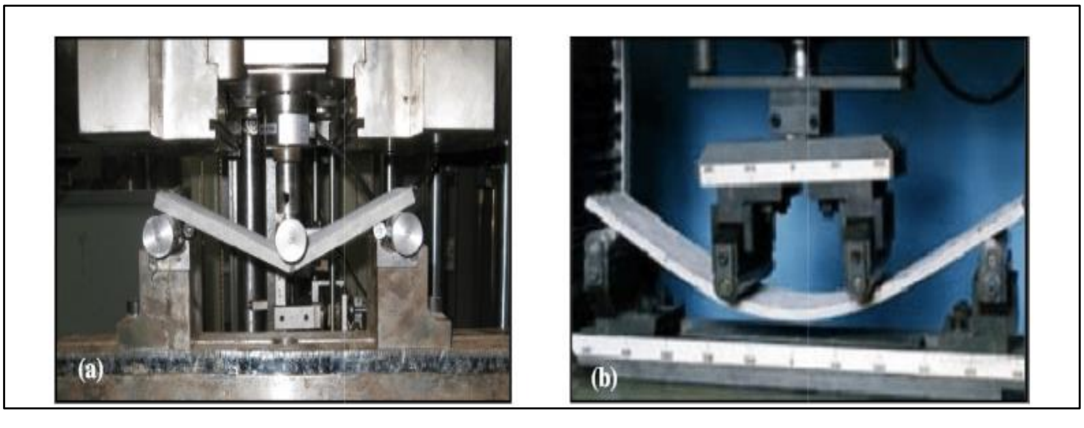


Figure 2.7: Failure mode comparison in Nylon-ECC and PVA-ECC beam specimens [3]

2.2.4 Discussion of Fibers

From above observation, it can be concluded that PVA fibers are better to use for our desired purpose. Yet, the problem that arises is its availability and cost. It is observed that Nylon 66, shows approx. results as that of PVA (as shown in figure 2.7), which can be set as our first priority for testing.

2.3 Cement

Cement consists of a mixture containing calcareous, siliceous, argillaceous and other substances. Cement is used as a binding material in mortar, concrete, ECC etc. The type of cements will govern the properties of the ECC in the same way as the type of cement will affect a conventional concrete. The use of cement content in the ECC is nearly 5 times higher than that in normal concrete High usage results in higher shrinkage, heat of hydration, and cost. The increased utilization of ECC led to increased CO_2 emissions. [4]

Following are the types of cements that are used; [5]

Type I cement

- It is a standard cement used in concrete for paving, flooring, strengthened concrete construction, water tanks, etc.
- Used where other cement characteristics are needed, such as soil and water sulfate attacks or adverse temperature increases.

Type II cement

- It generates less hydration heat so favored in warm climates
- It has mild resistance to sulfate because it includes no more than 8% aluminum tricalcium (C3A).

Type III cement

- Just like sort I, only particles are anchored more finely
- At an early stage, generally a week or less, it offers elevated early strength.

Type IV cement

- Used where hydration heat should be held to a minimum.
- It creates a slower level of resistance than other kinds of cement.
- It is most suitable for use in massive concrete structures, such as large gravity dams, where the temperature rise from heat generated during the hardening process must be minimized to control the cracking of concrete.

Type V cement

- Used where concrete is exposed to sulfate action which is severe
- Its high sulphate resistance is due to its low C3A content of about 4%.
- It is not resistant to acids and corrosive substances.
- Air-Entraining Portland Cements (Types IA, IIA, and IIIA)

Same as original but a small air entraining is introduced.

Table 2.2: Cement type characteristics [5]

Type	**Name**
Type I	Normal
Type IA	Normal, air-entraining
Type II	Moderate sulfate resistance
Type IIA	Moderate sulfate resistance, air-entraining
Type III	High early strength
Type IIIA	High early strength, air-entraining
Type IV	Low heat of hydration
Type V	High sulfate resistance

2.4 Supplementary Cementitious Materials

These are the materials which are used in place of cement in mortar, engineered cementitious composite and concrete. Some of them are relatively cheaper, some of them have high adhesive properties and some add early strength to the mixture. Supplementary cementing materials are replacement for the cementing component of concrete used as per requirements.

Following are the types of SCM’s

2.4.1 Silica Fume

It is conjointly brought up as small silicon dioxide or condensed silica fume. it's a byproduct. silicon dioxide fume rises as associate degree alter vapor from the 2000°C furnaces. once it cools it condenses and is collected in immense material. The condensed silicon dioxide fume is then processed to get rid of impurities and to manage particle size.

It is used in applications requiring a large degree of impermeability and in concrete of elevated strength. Where the concrete must be resistant to deicer-scaling. [6]

Following are the properties of silica fumes

- Silica fume reduce the workability and contribute to the binding
- Reduce the setting time as compared to standard OPC
- Increase in plastic shrinkage cracking due to the effect of low bleeding
- Increases strength as shown in the graphs below

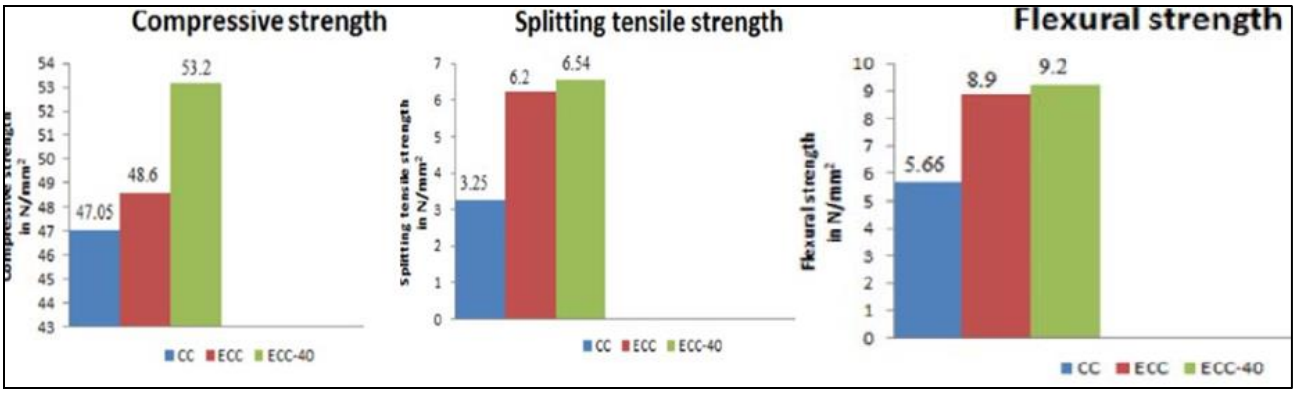


Figure 2.8: Increase in compressive, tensile and flexural strength with addition of Silica fumes [6]

2.4.2 Wood Ash

The Wood Ash (WA) was obtained from open field burning with average temperature being 700 °C.

For the study, six different proportion of concrete mixes) including the control mixture were prepared with water to binder ratio of 0.40 and 0.45 for design compressive strength of 20 N/mm2.10% of Wood ash increases compressive strength while Split Tensile and Flexural Strength don’t vary that much with respect to the quantity of wood ash. [7]

It also imparts other properties like reduced permeability, durability, resistance to fire.

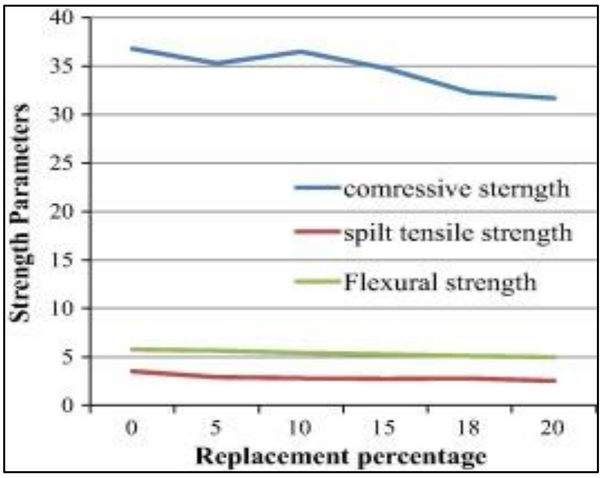


Figure 2.9: Strength parameter variation at 28 days with different replacement percentages. [7]

2.4.3 Fly Ash

Fly ash, also known as Pulverized Fuel Ash (PFA), produced as a byproduct when coal is burned to produce electricity. Following are some characteristics of Fly Ash: [8]

- Fly ash, consists of silicon dioxide and calcium oxide
- The materials which make up fly ash are Pozzolanic, meaning that they can be used to as binder

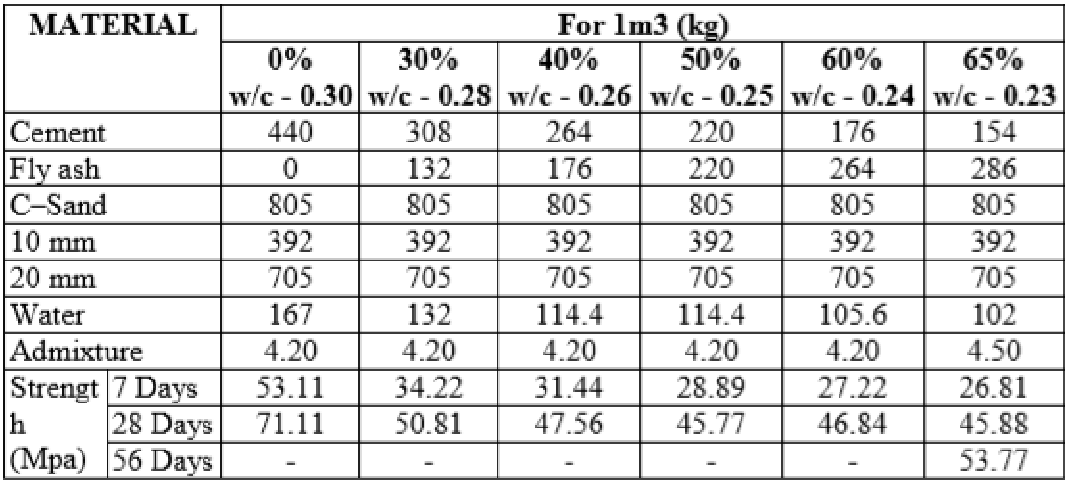
- Adds strength and durability
- Using fly ash cement in place of or in addition to Portland cement uses less energy and reduces both resource consumption and CO2.
- Using fly ash reduces the expenses on (energy & cost) cement. Reduce leaching of lime from concrete. Make cement structures denser and thus improve their durability.
- It increases the workability
- It causes less segregation and also less bleeding than plain concretes.
- Fly ash also causes increases setting time
- The plastic shrinkage also increases
- By adding fly ash rate of hydration get reduced therefore expected results achieve later than 100% cement is used.

From the assorted trials testing taken as shown within the table below, it is often over that replacement of cement by solely ash can be wrapped to sixty fifth. it absolutely as determined that, as we tend to press adding ashen combine style workability gets augmented. commutation cement by ash up to sixty fifth offers regarding forty- six.77% value helpful to it of original combine cost. thence it's a lot of economical. [9]

Test 1

The Indian standard (IS 10262-1982) was conducted to develop the blend for m40-grade concrete with the parameter below. The control blend (without fly ash) was intended in M40 grade and 30, 40, 50, 60 and 65 percent glue was substituted with flyash respectively.

Table 2.3: Strength variation with increasing replacement of cement with flyash [9]



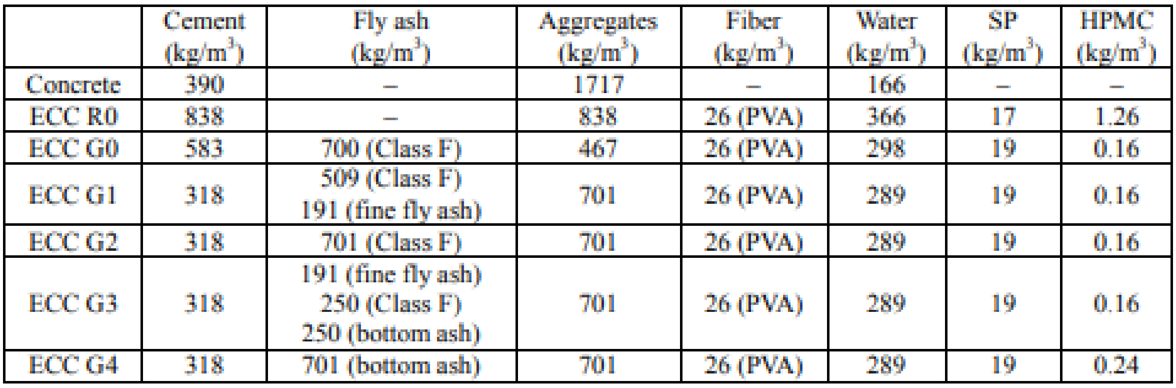
MATERIAL		For 1m3 (kg)					
		0% w/c - 0.30	30% w/c - 0.28	40% w/c - 0.26	50% w/c - 0.25	60% w/c - 0.24	65% w/c - 0.23
Cement		440	308	264	220	176	154
Fly ash		0	132	176	220	264	286
C–Sand		805	805	805	805	805	805
10 mm		392	392	392	392	392	392
20 mm		705	705	705	705	705	705
Water		167	132	114.4	114.4	105.6	102
Admixture		4.20	4.20	4.20	4.20	4.20	4.50
Strength (Mpa)	7 Days	53.11	34.22	31.44	28.89	27.22	26.81
	28 Days	71.11	50.81	47.56	45.77	46.84	45.88
	56 Days	-	-	-	-	-	53.77

From the multiple tests carried out, it can be found that cement can only be replaced by fly ash up to 65%. It has been noted that as we continue to add smoke ash to the blend layout workability increases. Replacing cement with fly ash up to 65 percent provides the cost of the initial mix price to about 46.77 percent. Hence it is more economical. [9]

Test 2

Mix proportions of 5 error correction code mixes (ECC G0-G4) with high ash content are listed, beside the reference concrete combine and a reference error correction code mix (ECC R0). The cement utilized in this study is standard cement (OPC). apart from the concrete, that contains each coarse and fine combination, the aggregates in error correction code mixes entirely consists of fine oxide sand with a median size of one hundred ten μm. vinyl resin REC15 fiber, specially developed for error correction code materials (Li et al. 2002), is employed during this study with a hard and fast volume fraction of twenty-two. body agent hydroxypropyl methylcellulose (HPMC) and superplasticizer (SP) are necessary in error correction code mixes for achieving adequate workability.

Table 2.4: ECC and Concrete mix variation [8]

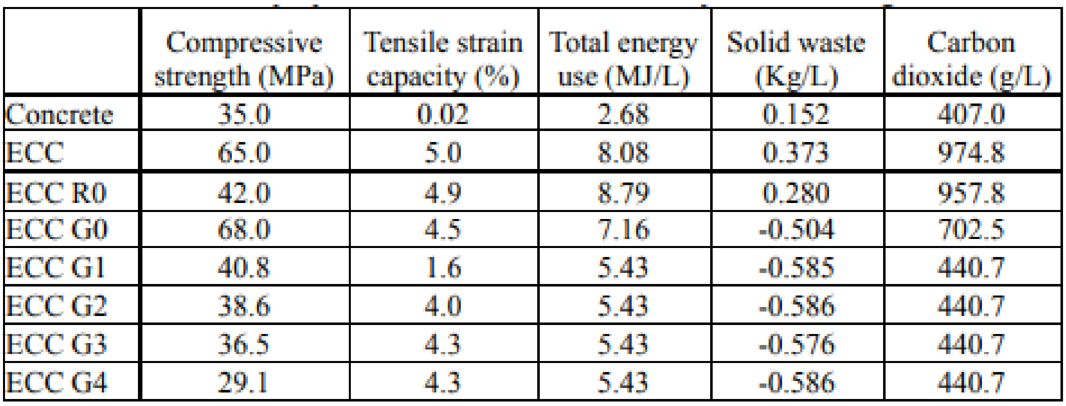


	Cement (kg/m^3)	Fly ash (kg/m^3)	Aggregates (kg/m^3)	Fiber (kg/m^3)	Water (kg/m^3)	SP (kg/m^3)	HPMC (kg/m^3)
Concrete	390	–	1717	–	166	–	–
ECC R0	838	–	838	26 (PVA)	366	17	1.26
ECC G0	583	700 (Class F)	467	26 (PVA)	298	19	0.16
ECC G1	318	509 (Class F) 191 (fine fly ash)	701	26 (PVA)	289	19	0.16
ECC G2	318	701 (Class F)	701	26 (PVA)	289	19	0.16
ECC G3	318	191 (fine fly ash) 250 (Class F) 250 (bottom ash)	701	26 (PVA)	289	19	0.16
ECC G4	318	701 (bottom ash)	701	26 (PVA)	289	19	0.24

There are investigations into two kinds of fly ash and one sort of bottom ash. Fine fly ash is a unique Class C fly ash with a high calcium content and much lower particle size (average 2 µm) than F fly ash (average 13 µm) and low ash (average 50 µm). Table 3 shows the mechanical properties and MSI of the mixes, where the compressive strength and tensile stress capacity are measured at 28 days.

As shown in Table 2.4, the introduction of a high content of ashes ends up in very little amendment in composite malleability, whereas it considerably improves the MSI over current versions of code. though ash has been wide employed in structural concrete, the magnitude relation of ash to cement (typically 10%-30%) is way below in these code mixes (ranging from 120% to 220%). aside from code G1, that shows an outsized variability in strain capability, all different mixes with high ash content demonstrate a high strain capability prodigious four-dimensional. [8]

Table 2.5: Mechanical properties of ECC variation shown in table 2.4 [8]



	Compressive strength (MPa)	Tensile strain capacity (%)	Total energy use (MJ/L)	Solid waste (Kg/L)	Carbon dioxide (g/L)
Concrete	35.0	0.02	2.68	0.152	407.0
ECC	65.0	5.0	8.08	0.373	974.8
ECC R0	42.0	4.9	8.79	0.280	957.8
ECC G0	68.0	4.5	7.16	-0.504	702.5
ECC G1	40.8	1.6	5.43	-0.585	440.7
ECC G2	38.6	4.0	5.43	-0.586	440.7
ECC G3	36.5	4.3	5.43	-0.576	440.7
ECC G4	29.1	4.3	5.43	-0.586	440.7

2.5 Fine Aggregate

Fine mixture (sand) is that the necessary material for construction work. It prepares cement mortar and cement concrete by compounding with cement like binding material. It acts sort of a filler. They stock up the voids in between coarse mixture items in cement concrete.

2.5.1 Properties of Sand with respect to Mortar [10]

BULK: It does not boost the mortar's power. But as an adulterer it operates. The bulk of mortar is therefore boosted, resulting in a decrease in costs

SETTING: If the building material is fat lime, carbon dioxide is absorbed by the sand vacuum and fat lime is efficiently set.

SHRINKAGE:

It avoids excessive mortar shrinkage during the drying process and thus avoids mortar cracking during setting.

STRENGTH: It enables by varying its percentage with cement or lime in the adjustment of mortar strength. It also improves mortar resistance to crushing.

SURFACE AREA: It subdivides the binding material's paste into a thin film and therefore offers more surface area to spread and adhere to it.

2.5.2 Fineness Modulus

Index Number of relative dimensions of both coarse and fine aggregates is called "Fineness Modulus”.

Table 2.6: Fineness Modulus ranges of Sand

Sand Fineness Modulus	
Fine	2.2 to 2.6

Medium	2.6 to 2.9
Coarse	2.9 to 3.2

Various comparisons among different FM of sand w.r.t compressive strength, tensile strength and flexural strength are used in ECC shown in the table below: [11] [12]

Table 2.7: Strength variation with variation of FM of sand. [11] [12]

Fineness Modulus	Compressive Strength	Tensile Strength	Flexural Strength
2.56	41.32	4.92	7.41
2.76	41.6	5.92	6.12
2.85	37.5	5.6	7.64
2.87	39.25	4.32	7.12

AASTHO Designation: M6-93 as the FM increases there is an increase in the strength. For every increase of 0.1 in FA, from 2.3 to 3.1, there is 2.5-3% increase in strength. [13]

2.6 Admixture

We use superplasticizers as our admixture as a result of super plasticizers scale back the water demand up to a particular share counting on their nature and will additionally have an effect on the initial setting time. They enhance workability with a bated water to cement magnitude relation. Primarily, in high strength concretes, super plasticizers are wont to accomplish a well spread cement particle mixture within which the cement inter-particle force is reduced.

Types of super plasticizers available:

i- Polycarboxylate ether (PCE)
ii- Melamine formaldehyde Sulfonate (SMF)
iii- Modified lignosulfonates (MLS)
iv- Sulfonated naphthalene-formaldehyde condensates (SNF)

The amount of superplasticizer that is needed is determined by a marsh cone test.

To achieve proper workability with a w/c ratio of 0.35, chemical admixtures (Polycarboxylate) were used.

2.7 Applications of ECC

Due to having properties such as tensile toughness, and better flexural strength and stain capacity, number of applications was expected that can be performed by the usage of ECC. Due to presences of Fibers randomly oriented, this forms them to have strong bond with the cementitious matrix which ultimately leads to micro-crack generation. The concept of micro-crack generation is that instead of one single crack that will propagate within the structure, multiple micro cracks will be generated that will help to disperse the energy as well as lead to better structural stability and durability. These usages were done on research level as well as practical applications.

Following are the applications proposed on research level:

- Application in energy absorption devices
- Damage tolerance structures
- Upgrade structural performance
- Safety against shear induced joint failures
- Beam Column Interior Connections
- Isotropic energy absorption behavior

In case of its practical application it has been used in:

- Mitika Dam (2003)

The structure was severely damaged and it was repaired by the usage of water proof ECC, due to its energy absorption application and micro cracking. The ECC was composed of water proofing admixture.

Figure 2.10: Application of ECC for repair of Mitika Dam

- Glorio Roppongi high-rise apartment building, Tokyo

ECC Beam coupling were installed in the building which was done to mitigate Earthquake damage (seismic resistance) due it capacity for energy absorption mechanism.

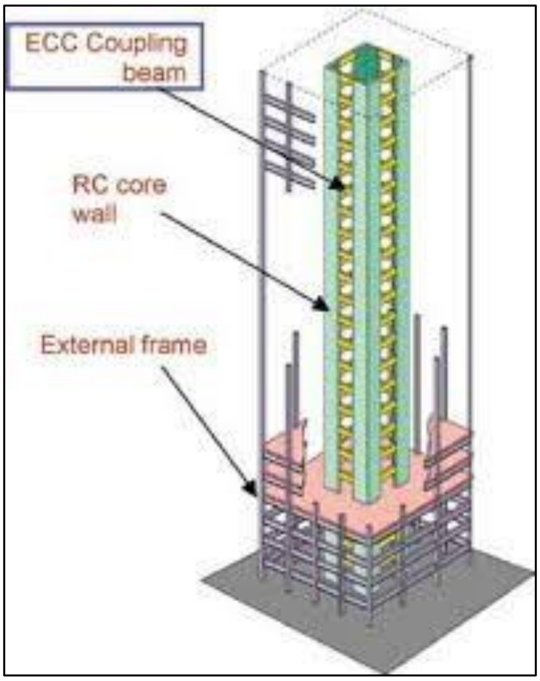


Figure 2.11: ECC beam coupling technique in Glorio Roppongi High-rise [14]

CHAPTER 3

METHODOLOGY

3.1 Selection of Material

3.1.1 Fibers

Nylon 66 selected as suitable fiber with approx. 12mm length and 0.2mm diameter, locally available and available at a cheaper price as compared to PVA(Polyvinyl-Alcohol) fibers. It was procured from Karachi.

3.1.2 Cement

Ordinary Portland Cement Type I is selected because it is commonly available and widely used. This material was procured from within Islamabad.

3.1.3 Sand

AASTHO Designation: M6-93- by increasing the fineness of sand, the strength increases but the Fineness Modulus should less than 3. For every increase of 0.1 in Fineness Modulus, from 2.3 to 3.1, there is 2.5-3% increase of 28 days' compressive strength.

Only **"Lawrencepur Sand"** has the required fineness modulus of sand. The other two are not suitable as shown in the table below for the ECC because the FM of these two sands is very low and hence the desired results can't be achieved.

Table 3.1: Fineness Modulus ranges for locally available sands

Sand Name	Fineness Modulus ranges
Lawrencepur Sand	1.20-2.94

Chenab Sand	0.90-1.32
Ravi Sand	0.71-1.10

Thus, locally available sand can be used in the manufacturing of ECC, sand (fine aggregate) to be used in our project will be “**Lawrencepur sand**” as it is easily available in Islamabad and meets the requirement.

3.1.4 Supplementary Cementitious Materials

Fly Ash has been chosen as the supplementary cementitious material because it is cheaper, making concrete structure denser, thus improving its durability. Various studies have also shown that fly ash has given noticeably well results while being used in ECC([8]). It was procured from Karachi.

3.1.5 Admixture

Polycarboxylate Ether (PCE) based Glenium-51 super plasticizer procured from Karachi is selected as it meets our requirements.

3.2 Casting Variation

In order to understand and fulfil project the objectives, it is necessary to understand the variation of ECC components. For this purpose, the targeted material was SCMs, as it was the main component to influence the cost. The behavior of addition of fiber was also observed by using the optimum amount as used internationally.

3.3 Testing Types

To understand the mechanical properties of ECC, following tests were carried out:

- Compression Test (Standard: BS EN-206)
- Split Tensile Test (Standard ASTM-C496)
- Three-point Bend Test (Standard ASTM-C293)

CHAPTER 4

EXPERIMENTAL WORK

4.1 Material Testing

Each material procured during the course of our project was based on some property that it would impart to the proposed cementitious composite. To ensure that the procured material exhibits the required properties, following tests were conducted.

4.1.1 Cement Tests

The main requirements of cement used to build any structure are its strength, soundness and a rate of setting that is suitable to the demand of the work. There are numerous tests that can be used to ascertain both chemical and physical properties of the cement. For our project the physical tests were more important than the chemical test and hence they were carried out. The physical properties of cement change with its types.

Consistency test:

This test is used to determine the water content that gives us desired consistency. It was carried out in accordance with the ASTM-C187 standard in which Vicat apparatus is used. This test further helps in determining the water content for other tests like the initial and final setting time and soundness test.

Cement type: OPC type I

Room Temperature: 21°

Temperature of water: 23°

Humidity: 55%

Table 4.1: Results for Consistency test

S/no	Cement (g)	Amount of water (%)	Penetration (mm)

1	500	26	12
2	500	26	8
3	500	28	26
4	500	28	30
5	500	30	33
6	500	30	34

Conclusion: The plunger settles to the range of 33 – 35mm with 30% water which is the water content for desired consistency.

Initial and Final setting time test:

This test is carried out to ensure that the cement paste sets at a suitable rate for a particular work. The test was carried out in accordance with the ASTM-C191 standard.

Cement type: OPC type I

Room Temperature: 30^{o}

Temperature of water: 29.2^{o}

Humidity: 58%

Table 4.2: Results for Initial and Final setting time

S/no	**Cement (g)**	**Amount of Water (%)**	**Initial setting time (minutes)**	**Final setting time (minutes)**
1	500	30	78	265
2	500	30	82	272
3	500	30	76	244

Conclusion: The initial and final setting time of cement are well within the defined limits. The initial setting time is greater than 30 mins and the final setting time is less than 10 hours. Hence, cement procured has appropriate rate of setting for our desired work.

Soundness test:

Soundness of cement refers to the ability of cement to retain its volume after setting. This test was carried out in accordance with ASTM-C151 standard in which the Le-chatelier apparatus was used.

Cement type: OPC type I

Room Temperature: 23^o

Temperature of water: 24^o

Humidity: 55%

Table 4.3: Results of Soundness test for cement

S/no	Expansion before boiling (D1) (mm)	Expansion after boiling (D2) (mm)	Difference (D2-D1) (mm)
1	8	9	1
2	9	10	1
3	9	11	2

Conclusion: The OPC type I cement procured in our project is sound as difference of readings taken after curing and after boiling is less than 10mm.

4.1.2 Sieve Analysis of Fine Aggregate

As studied in the literature the fineness modulus of sand to be used in the ECC has a specified range. To ensure whether the procured Lawrencepur sand has the required fineness modulus, sieve analysis was carried out in accordance with

ASTM-C136 standard. Fineness modulus is a representation of particle size distribution and helps in determining behavior of sand.

Sample taken: 500 grams

Table 4.4: Sieve analysis to determine Fineness Modulus of Sand

SIEVE NO.	**Weight Retained(g)**	**Percentage Retained**	**Cumulative % Retained**	**Cumulative % Passing**	**ASTM % passing**
#4	0.9	0.18	0.18	99.81	95-100
#8	21.3	4.27	4.45	95.54	80-100
#16	87.74	17.6	22.06	77.93	50-85
#30	126.26	25.3	47.4	52.59	25-60
#50	147.4	29.5	76.98	23.01	10-30
#100	101.72	20.4	97.39	2.6	02-10
#200	10.38	2.08	99.47	0.52	
Pan	2.6	0.52	100	0	
Total	498.3				

Sum of cumulative retained above sieve #100 = 248.46

Fineness Modulus = 248.46 / 100 = 2.48

Conclusion: The fineness modulus of Lawrencepur Sand is 2.48 which is within the acceptable range which was observed to be above 2.3 in the literature study.

4.1.3 Marsh Cone Test

This test is used to determine the quantity of superplasticizer that is optimum for our cement type. This test was performed in accordance with ASTM-C939 standard.

Table 4.5: Marsh cone time for increasing Superplasticizer content

Superplasticizer dosage(%)	**Marsh cone time(sec)**
0.005	86
0.008	72
0.01	64
0.015	63

Conclusion: superplasticizer dosage of 0.01 % by weight was found to be optimum for our cement type.

4.2 Mix Design

Mix design can be referred to as the selection of suitable materials and determination of their relative proportions in order to make a mix with desirable properties. Design of concrete is a complex task which required knowledge of various properties of the constituent materials and their contribution to the mix. The approach used for conventional concrete is the cement: sand: aggregate approach which is not applicable in case of ECC since it does not contain any coarse aggregate. In order to select a suitable mix design for our study, literature was consulted, and the mix design used in the previous researches most closely related to our work was selected.

Table 4. 6: Mix proportion [3]

Ingredients	Cement	Fly Ash	Sand	Water	Super plasticizer	Fiber (vol%)
Content	1	1.2	0.8	0.56	0.01	2%

This mix proportion is chosen as an incentive mix design to observe the behavior of the mix and make adjustments in accordance with those observations.

4.3 Parameters Under Study

For the purpose of achieving the objectives targeted in this project, the parameter under study is the effect of different quantities of fly ash added in the mix.

Table 4.7: Mix variations cast with varying Fly ash content

Variation Name	Fly Ash Quantity	Fibers Present
C0	0%	No
C6	60%	No
E0	0%	Yes
E6	60%	Yes
E9	90%	Yes
E12	120%	Yes

Variations C0 and C6 having 0% and 60% fly ash content respectively, were cast to check the effect of varying quantities of fly ash in mortar without any fibers present. Variations E0, E6, E9 and E12 having 0%, 60%, 90% and 120% fly ash content, were cast to check the effects of fly ash in ECC. Variation C0 and C6 did not contain any fibers whereas variations E0, E6, E9 and E12 contained 2% fibers by volume fraction as shown in table 4.7.

4.4 Specimen Preparation

Three types of specimens were to be made for the compressive, tensile and the flexural strength tests.

4.4.1 Compressive Strength Test Specimen

Three specimens for each test were made for 7-day, 14-day and 28-day compressive strength. The specimens were cubical with dimensions 100mm x 100mm x 100mm.

Figure 4.1: Cubical Samples for compressive test

4.4.2 Tensile Strength Test Specimen

Three specimens for each test were made for 7-day, 14-day and 28-day compressive strength. The specimens were cylindrical with dimensions 100mm x 200mm (diameter x height).

Figure 4.2: Cylindrical samples for split tensile test

4.4.3 Flexural Strength Test Specimen

Three specimens for each test were made for 7 day, 14 day and 28 day compressive strength. The specimens were rectangular prism with dimensions 250mm x 100mm x 25mm (length x width x depth).

Figure 4.3: Beam/Prism samples for flexural test

4.5 Testing Methods

The tests conducted to determine the mechanical properties conformed to International Standards. Details are as follows:-

4.5.1 Compressive strength test:

The compressive strength of concrete is determined through testing cubical samples by placing them in a compression testing machine. The compressive strength is determined to ensure that the concrete mixture meets the required level of specified strength, f’c. This helps in estimating concrete strength in a structure for scheduling of construction operations i.e. formwork removal, curing needs etc.

This test was performed in conformance with BS EN-206.

Compressive strength was determined using the formula:

$$F'c = \frac{P}{A}$$

f’c = compressive strength in N/mm^2 or Mpa

P = Load in N

A = Surface area of cubical specimen

Furthermore, this test will also be utilized in analysis of strain hardening behavior. Strain hardening behavior refers to the ability of a material to take stress even after the formation of first crack and initiation of plastic deformation. Since nylon fibers are incorporated in the mix the strain hardening of ECC will be observed to get an idea of the ability of ECC to undergo strain after fracture.

A needle deflection gauge was deployed during these center point loading tests to measure deflection of prism samples and their relation to flexural stress in order to get an idea of strain hardening behavior of our ECC.

4.5.2 Split tensile test:

The ability of concrete to withstand pulling force without failure is known as the tensile strength of concrete. It is the amount of units of force per cross-sectional area in N/mm^2 or MPa. Furthermore, the type of failure associated in the tensile test will also be analyzed as it shifts from brittle to ductile due to the addition of fibers.

This test was performed in conformance with ASTM-C496.

Split tensile strength was determined using the formula:

$$Ft = 2P/\pi DL$$

Where, Ft = Split tensile strength (N/mm2)

P = Load at failure (N)

L= load of cylinder (mm)

D= Diameter of cylinder (mm)

4.5.3 Flexural strength test:

Flexural strength is one of the measures of tensile strength of concrete. It is measured by placing a beam specimen under three-point loading or center point loading. It is a direct measure of how much bending stress can a specific concrete take and specifies the beam dimensions required for given load. In this project this is the main strength that is being analyzed to study the effect of nylon fibers that are added in the mix. Nylon has a high tensile strength capacity which in-turn should enhance the flexural strength of ECC. In addition, with a higher flexural capacity the failure mode of ECC will also be analyzed as it should have a ductile mode of failure rather than brittle.

This test was performed in conformance with ASTM-C293.

Flexural strength of the sample was determined by using the following formula:

$$\delta_f = \frac{3FL}{2bd^2}$$

where, δf=Stress in outer fibers at midpoint (N/mm2)

F= load at any given point during the test (N)

L= support span (mm)

b= width of test beam (mm)

CHAPTER 5

RESULTS AND DISCUSSION

On carrying out the test, the results were obtained and tabulated for analysis. A trend was observed due to variation of amount of Fly Ash for which its Cost analysis was also carried out. The addition of fiber caused variation in behavior of the ECC.

5.1 Compressive Strength

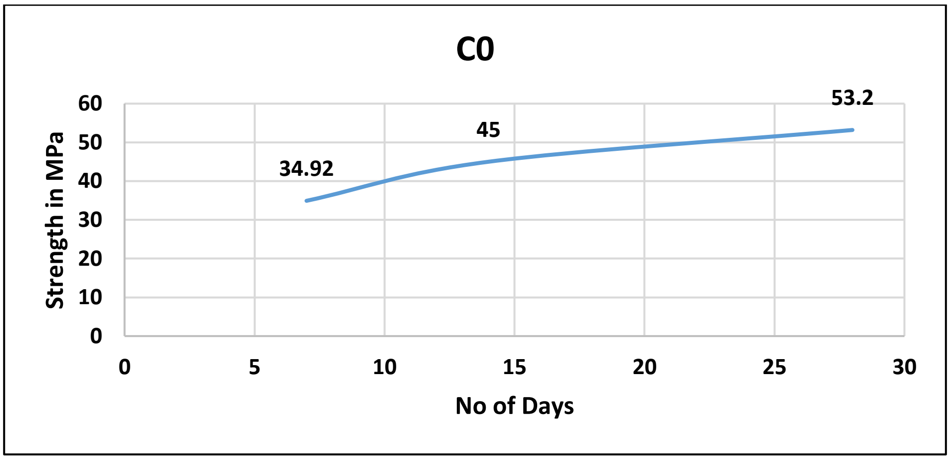
The compressive strengths of all the samples is given in table 5.1

Table 5.1: Summary of Compressive strength test results

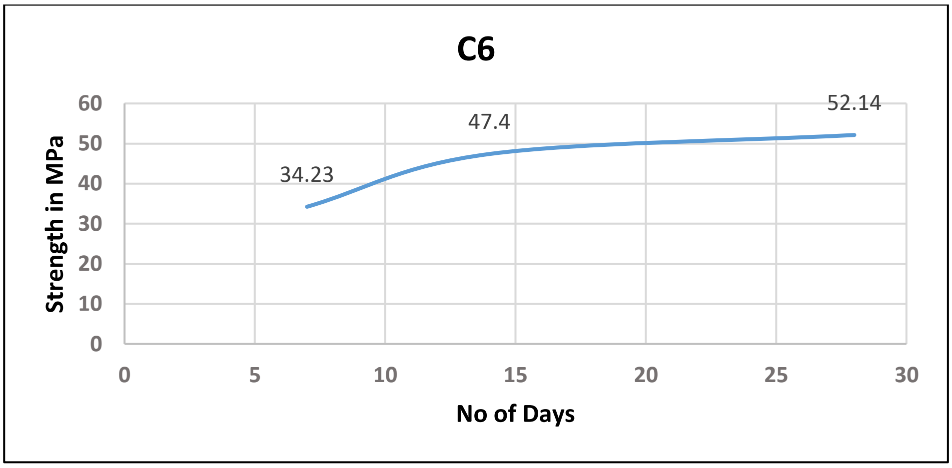
Variation	Days	Compressive Strength (MPa)
C0	7	34.92
	14	45
	28	53.2
C6	7	34.23
	14	47.4
	28	52.14
E0	7	31.6
	14	43.54
	28	50.1
E6	7	35.3
	14	44.14
	28	48.7
E9	7	31.92
	14	41.4
	28	45.8
E12	7	29.91
	14	40.1
	28	43.9

1. **Mix variation C0 gives the highest strength**

Figure 5.1 shows the increase in compressive strength of individual mix variations from 7 days to 28 days.



(a)



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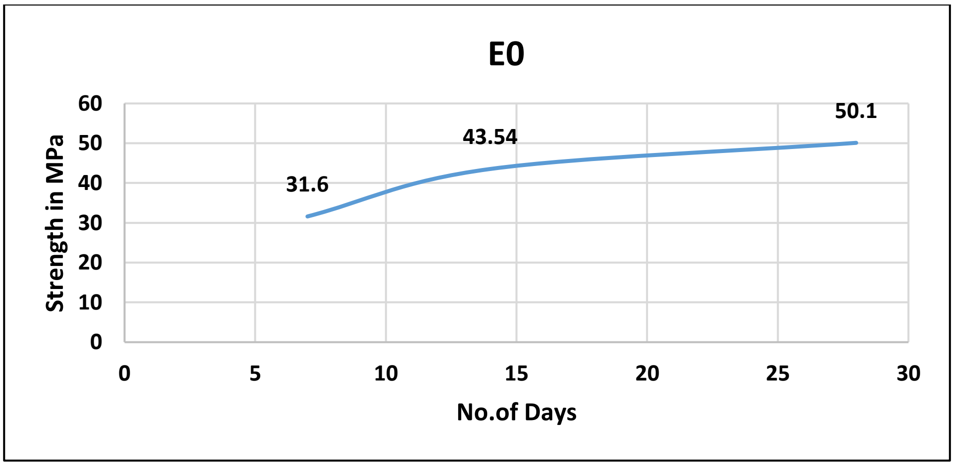
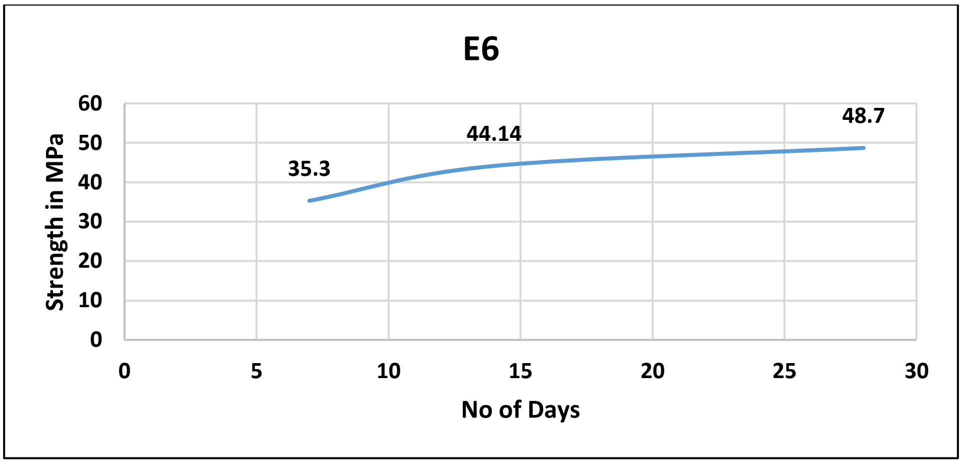
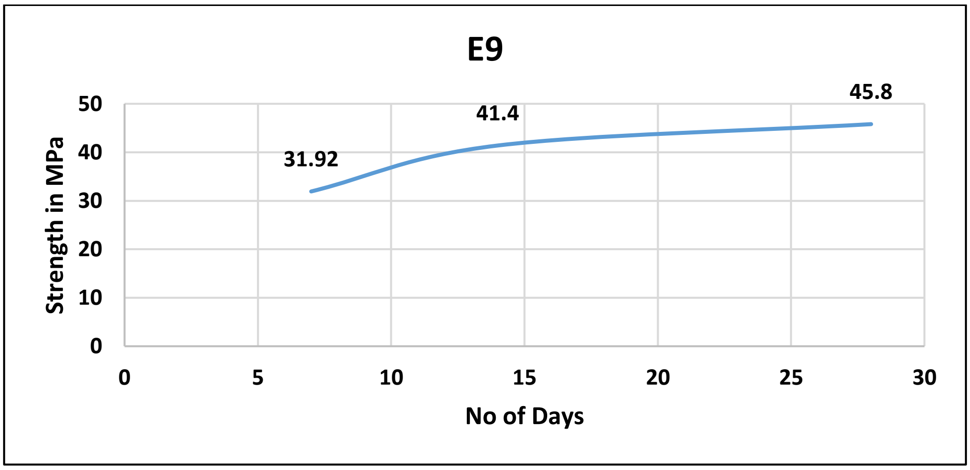


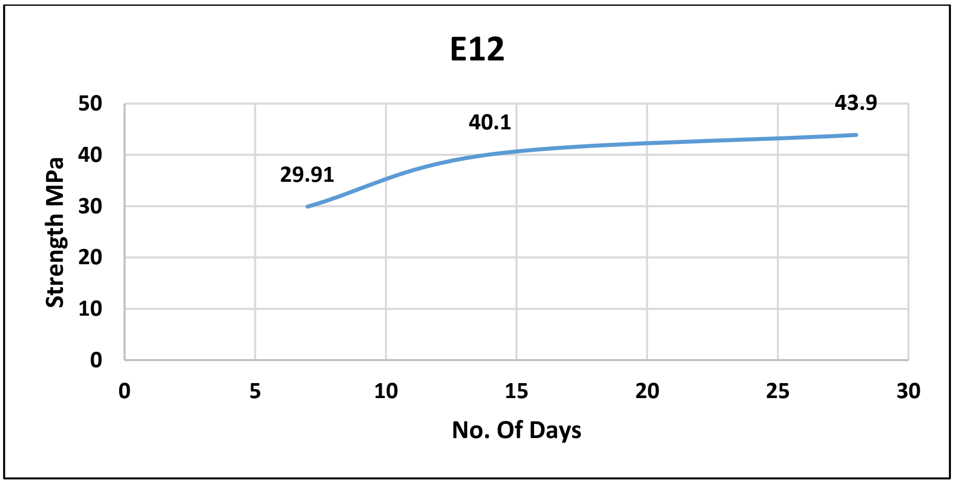
(c)


E6
Strength in MPa
60
50
40
30
20
10
0
0
5
10
15
20
25
30
No of Days
35.3
44.14
48.7

(d)


E9
Strength in MPa
50
40
30
20
10
0
0
5
10
15
20
25
30
No of Days
31.92
41.4
45.8

(e)


E12
Strength MPa
50
40
30
20
10
0
0
5
10
15
20
25
30
No. Of Days
29.91
40.1
43.9

(f)

Figure 5.1: (a) Compressive strength gain of C0 variation (b) Compressive strength gain of C6 variation (c) Compressive strength gain of E0 variation (d) Compressive strength gain of E6 variation (e) Compressive strength gain of E9 variation (f) Compressive strength gain of E12 variation

Figure 5.2 shows how the compressive strength of C0 is greater than all other mix variations. C0 has the highest 28-day compressive strength of 53.2 MPa and E12 has the lowest 28-day compressive strength of 43.9 MPa. Higher the quantity of fine aggregate, higher will be the strength and this is evident from the results achieved as C0 has the highest amount of fine aggregate as compared to others.

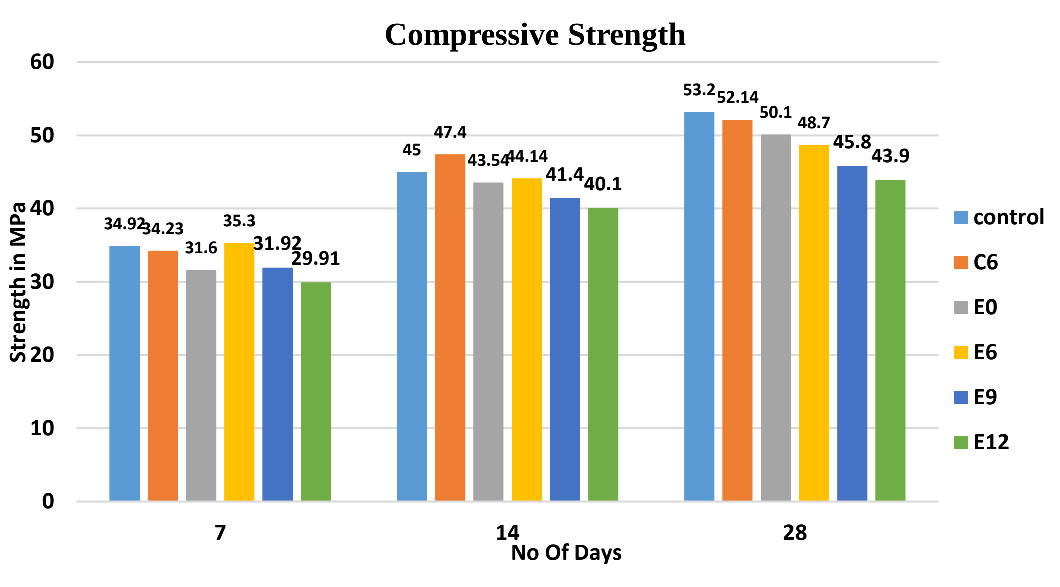


Figure 5.2: Bar chart comparison of Compressive Strengths

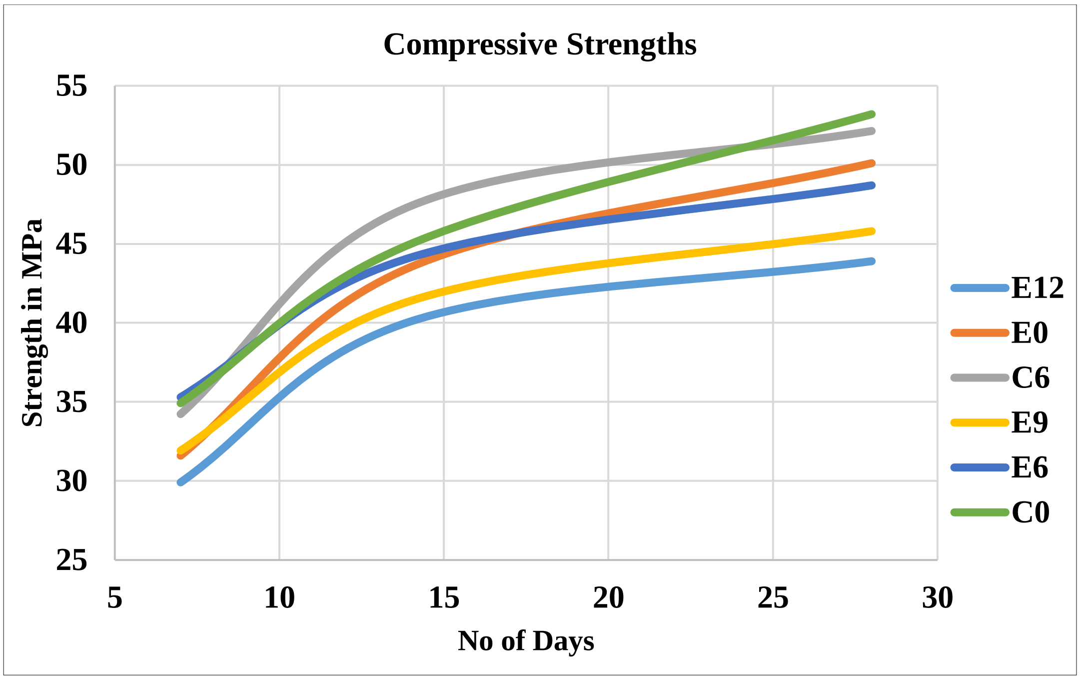


Figure 5.3: Combined graph for Compressive Strength gain

2. Introduction of fibers in the mix decreases the compressive strength

It was observed that introduction of fibers in the mix decreases the compressive strength of the samples. The compressive strength of C0 is 53.2MPa while the compressive strength of E12 is 50.1MPa which is lower than C0 as shown in figure 5.4, this can be explained by understanding the behavior of fibers in FRC (fiber reinforced concrete) in which the addition of fibers provide a confining effect and enhance the compressive strength. But the length of fibers normally used in FRC is around 25 mm to 50 mm which can adequately provide confinement and hence, enhance the compressive strength [15]. When we compare this with our scenario, we see that the fibers used in our study have 12 mm length which is significantly smaller compared to those used in FRC and hence these fibers are not efficiently providing confinement in our samples to enhance the compressive strength, rather these fibers present at 2% by volume fraction become a hindrance in the bonding of the cementitious matrix and hence reduce the compressive strength by some amount.

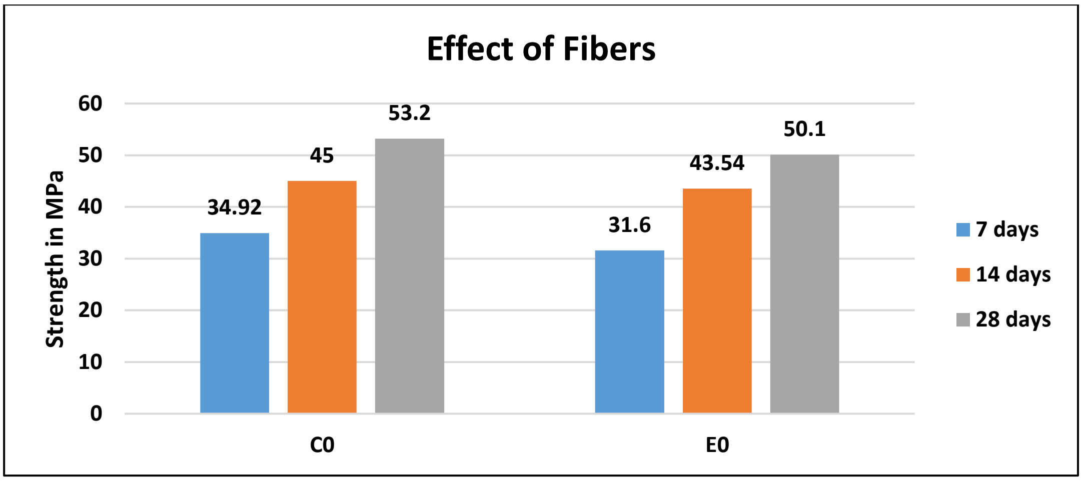


Figure 5.4: Effect of addition of fibers on Compressive Strength

3. Introduction of fly ash in the mix decreases the compressive strength

It was observed that introduction of fly ash in the mix decreases its compressive strength. Compressive strength of C0 is 53.2MPa and compressive strength of C6 is 52.14MPa which is lower than that of C0 as seen in figure 5.5. To explain this decrease in strength due to addition of fly ash we need to understand the effect of fly ash on the hydration process of the composite. When a cement paste is formed $Ca(OH)_2$ is released upon reaction of water with di-calcium silicate and tri-calcium silicate present in the cement. Normally, this $Ca(OH)_2$ saturates the system and starts to crystallize along with CSH (calcium silicate hydrate). Due to the addition of fly ash, some of the Ca^{2+} released upon reaction of cement with water are adsorbed on the surface of the fly ash particles. This causes a delay in the time for Ca^{2+} to reach saturation and hence the hydration process of the entire composite is slowed down for the first 28 days giving us a decrease in the observed strength. [16] [17]

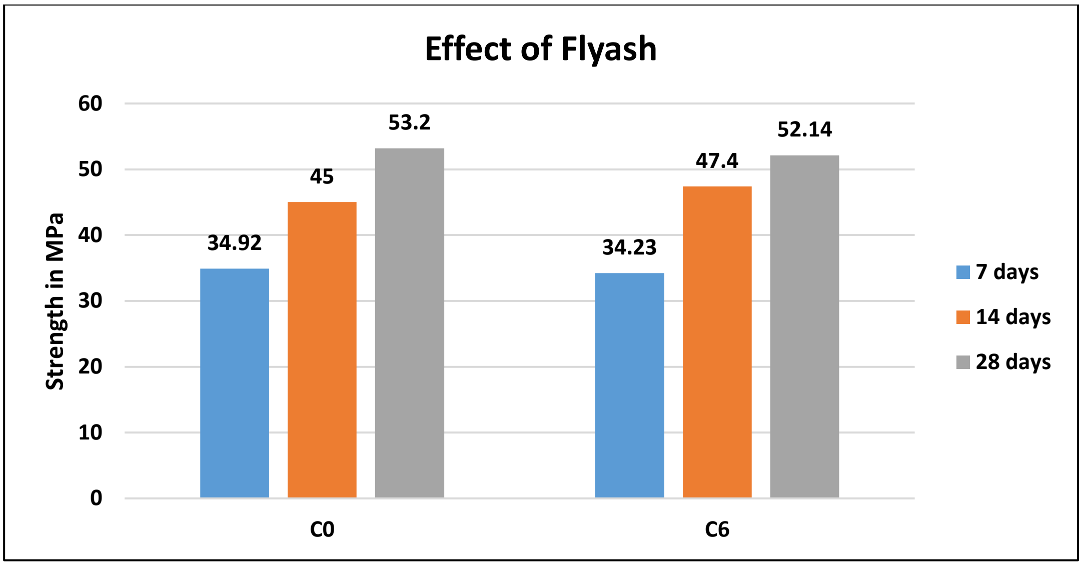


Figure 5.5: Effect of Flyash on Compressive Strength

4. Increment of fly ash in the mix decreases the compressive strength

It was observed that as fly ash is increased in the mix variations its compressive strength shows a gradual decrease. This is due to the fact that the addition of fly ash causes a more effective adsorption of the Ca^{2+} on the fly ash particles and hence, the hydration process is more effectively slowed down with increased fly ash content. Figure 5.6 shows the observed decrease in compressive strength.

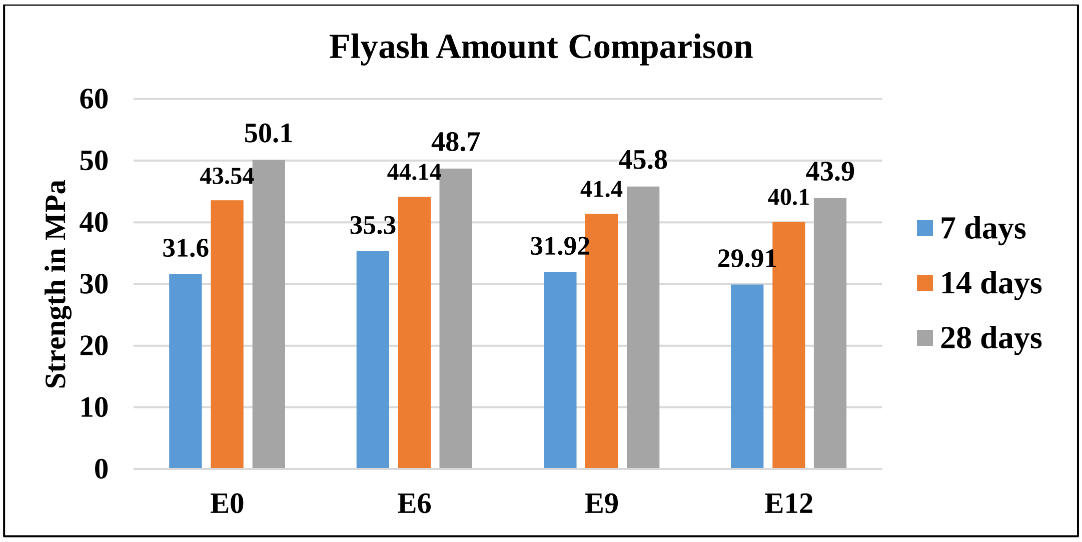


Figure 5.6: Effect of Flyash Increment

5. **Mode of failure**

ECC samples did not crumble but remained a single chunk under compression because of the presence of fibers. Samples without fibers failed in compression and crumbled into pieces because of its brittle nature.

Figure 5.7: Post Failure Compressive test sample

5.2 Split Tensile Test Results

Split tensile strength test performed on all six variations showed the following results.

1. **Mix variation E0 gives the highest strength**

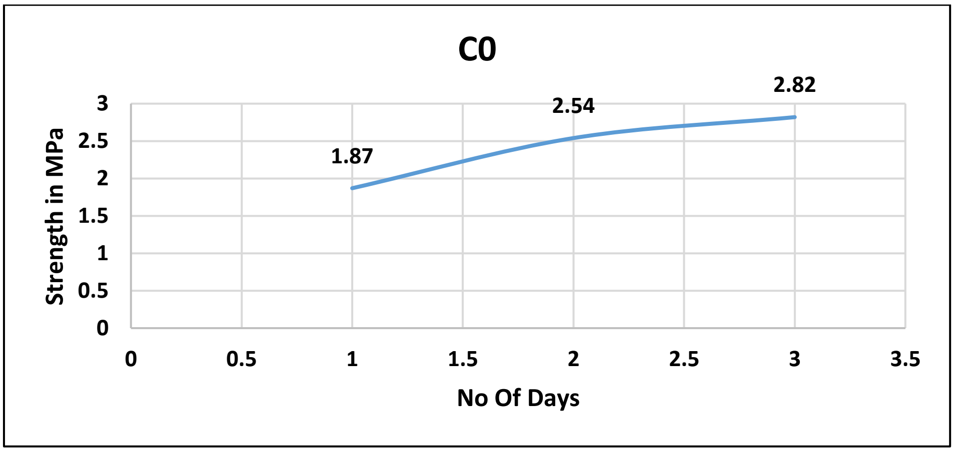
The tensile strengths of all the samples is given in table 5.2

Table 5.2: Summary of Split Tensile test results

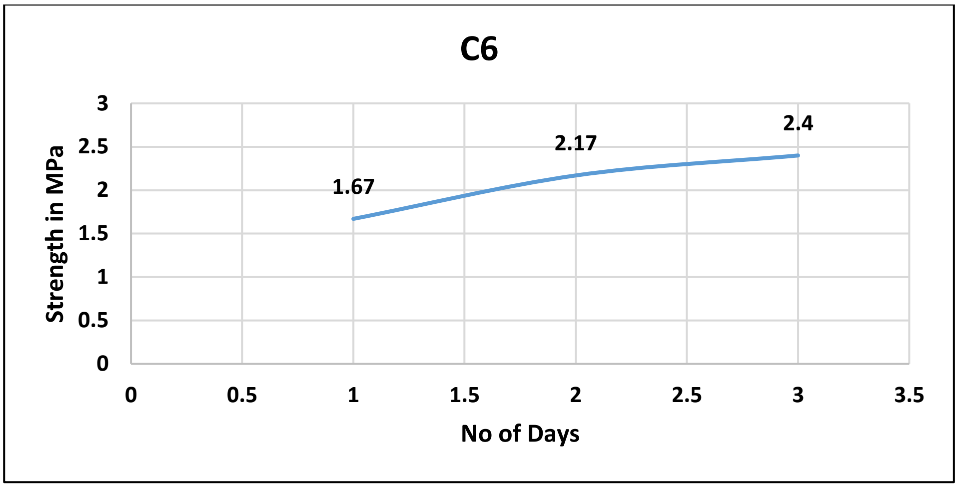
Variation	Days	Tensile Strength (MPa)
C0	7	1.87
	14	2.54
	28	2.82
C6	7	1.67
	14	2.17

	28	2.4
E0	7	2.79
	14	3.86
	28	4.28
E6	7	2.87
	14	3.54
	28	3.93
E9	7	2.69
	14	3.44
	28	3.86
E12	7	2.56
	14	3.28
	28	3.63

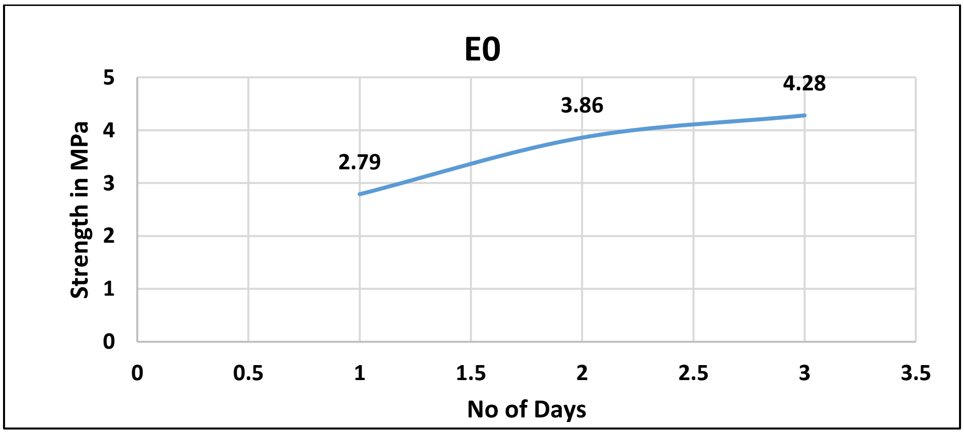
Figure 5.8 shows the increase in tensile strength of individual mix variations from 7 days to 28 days.



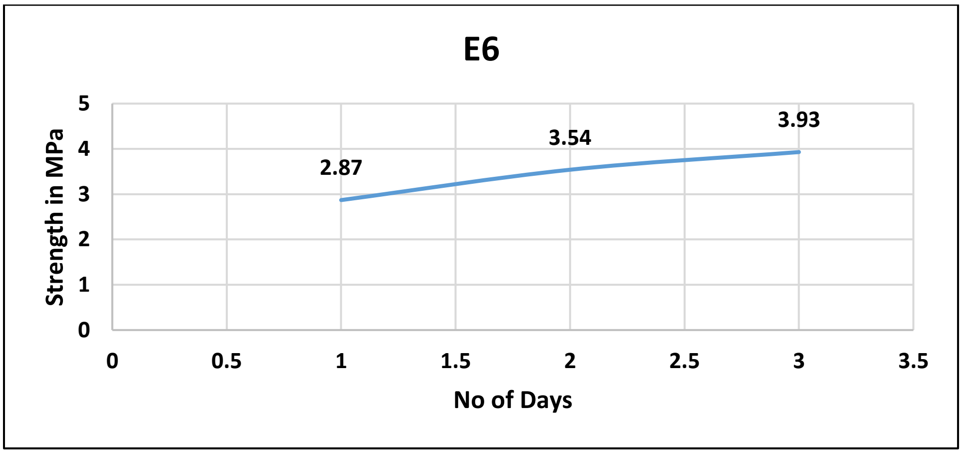
(a)


C6
Strength in MPa
3
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
3
3.5
No of Days
1.67
2.17
2.4

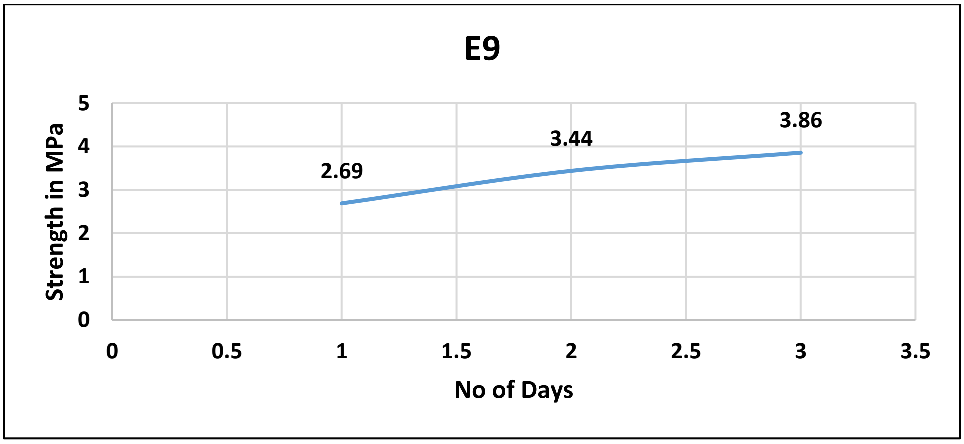
(b)


E0
Strength in MPa
5
4
3
2
1
0
0
0.5
1
1.5
2
2.5
3
3.5
No of Days
2.79
3.86
4.28

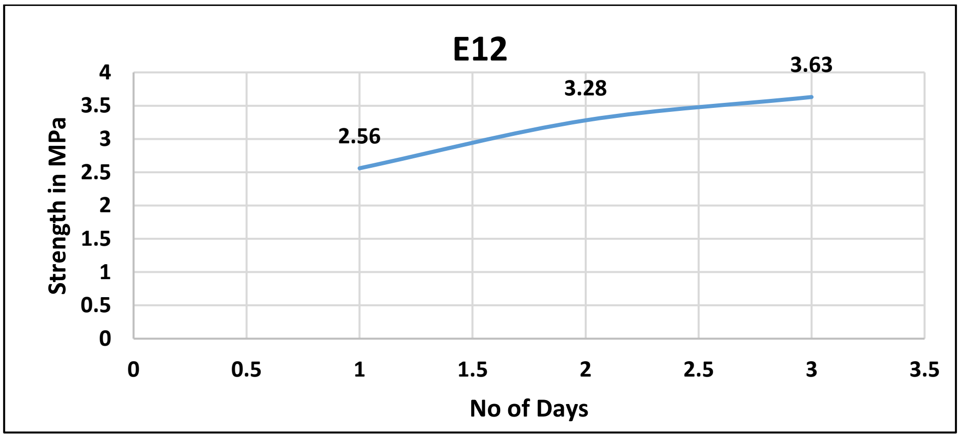
(c)


E6
Strength in MPa
5
4
3
2
1
0
0
0.5
1
1.5
2
2.5
3
3.5
No of Days
2.87
3.54
3.93

(d)



(e)



(f)

Figure 5.8: (a) Tensile strength gain of C0 variation (b) Tensile strength gain of C6 variation (c) Tensile strength gain of E0 variation (d) Tensile strength gain of E6 variation (e) Tensile strength gain of E9 variation (f) Tensile strength gain of E12 variation

Figure 5.9 shows the tensile strength of E0 is greater than all other mix variations, E0 has the highest 28-day tensile strength of 4.28MPa and C6 has the lowest 28-day tensile strength of 2.4MPa. Since fibers are good in tension that is why all the mixes with fibers show a better tensile strength than those which don’t have fibers in them.

It can be clearly observed that sample E12 shows a greater tensile strength than C0.

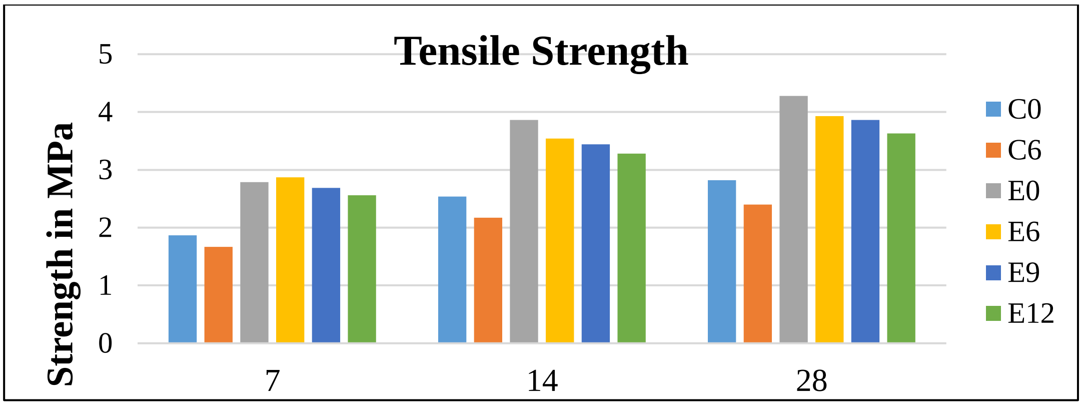


Figure 5.9: Bar chart comparison of Tensile Strengths

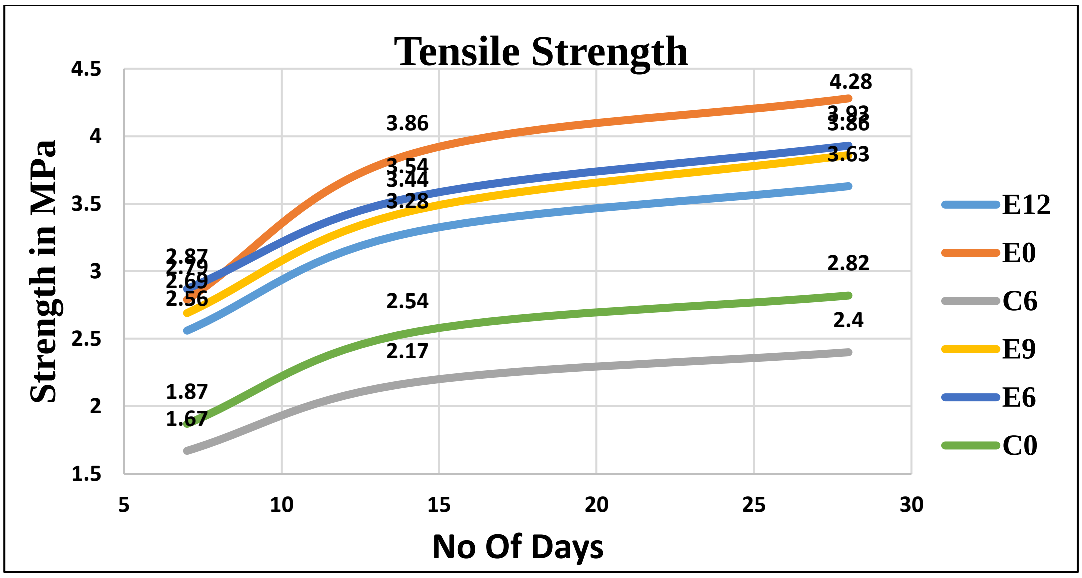


Figure 5.10: Combined graph for Tensile Strength gain

2. **Addition of fibers in the mix increases the tensile strength**

It was observed that addition of fibers in the mix increases the tensile strength of the samples. The tensile strength of E0 is 4.28MPa while the tensile strength of C0 is 2.82MPa which is lower than E0. This increase can be attributed to the fact that the nylon fibers have a high tensile strength and their random orientation disperses the produced tensile stress away from the main plane of failure and hence, the sample has an increased tensile strength. This can be seen from figure 5.11

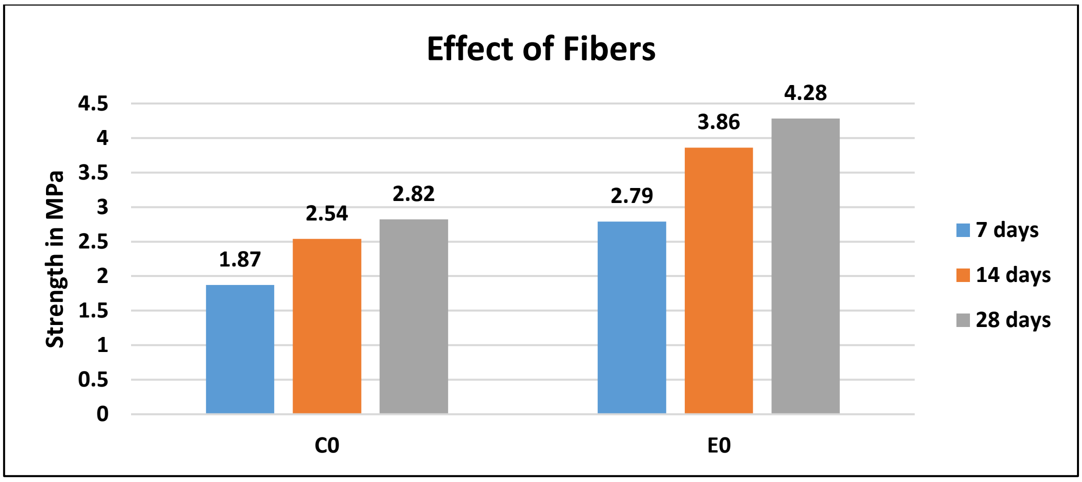


Figure 5.11: Effect of fiber addition on tensile strength

3. Introduction of fly ash in the mix decreases the tensile strength

It was observed that introduction of fly ash in the mix decreases its tensile strength. Tensile strength of C0 is 2.82 MPa and tensile strength of C6 is 2.4MPa which is lower than that of C0 as shown in figure 5.12. As explained earlier, the addition of fly ash slows down the hydration process for the first 28 days due to adsorption of Ca^{2+} on fly ash particles. This causes the entire matrix to gain strength at a slower rate than normal for the first 28 days and hence, the decrease in tensile strength is also observed with fly ash addition. [16] [17]

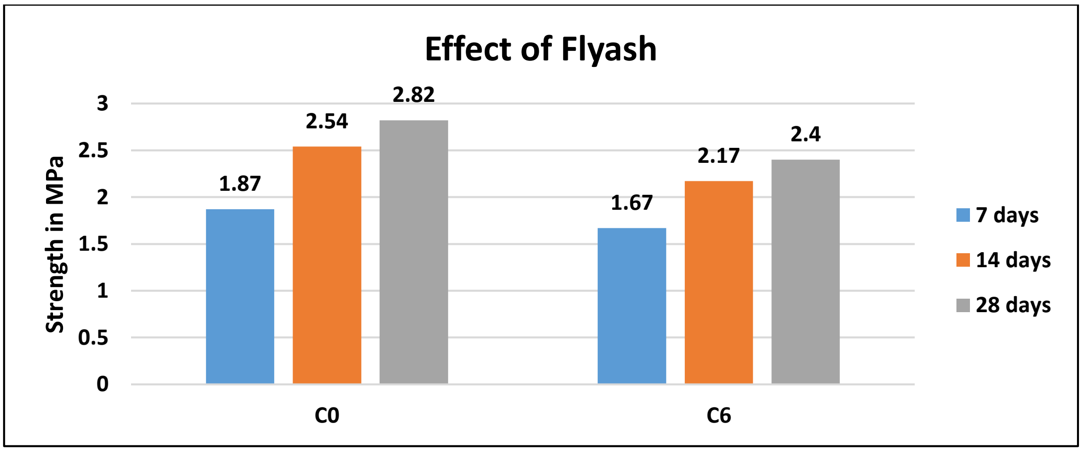


Figure 5.12: Effect of Fly ash addition on Tensile strength

4. Increment of fly ash in the mix decreases the tensile strength

It was observed that as fly ash is increased in the mix variations its tensile strength shows a gradual decrease due to efficient inhibiting of hydration process. This is evident from figure 5.13 which shows the gradual decrease of tensile strength as amount of fly ash is increased in the mix.

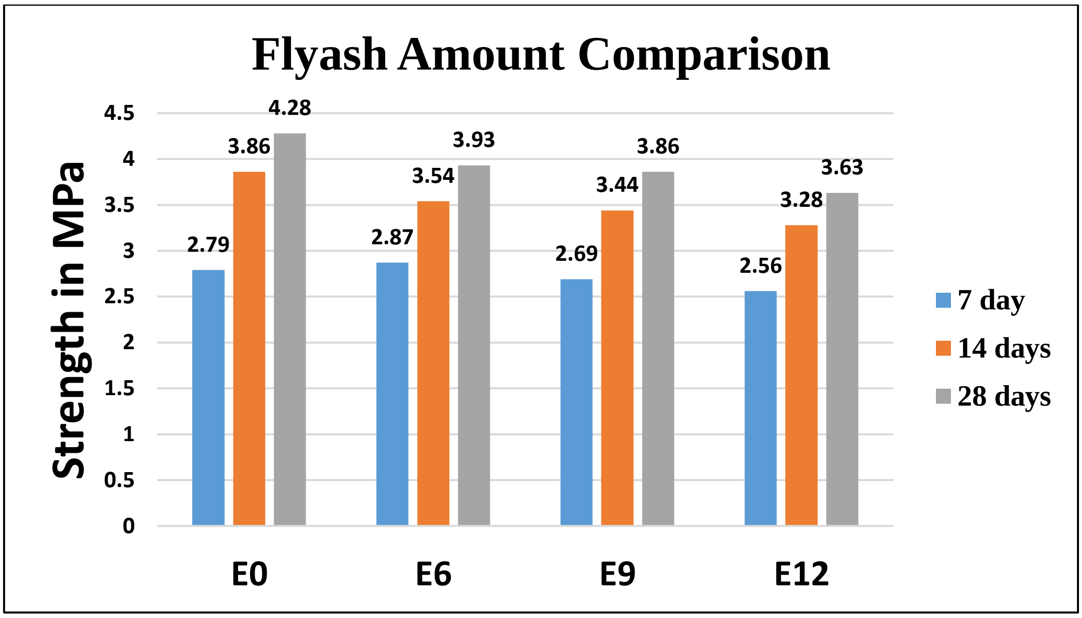


Figure 5.13: Effect of Fly ash Increment on tensile strength

5. Mode of failure

Samples without fibers fail abruptly. When the first crack is formed the sample then splits into two pieces along the fracture plane without taking any further load than the maximum load they can take.

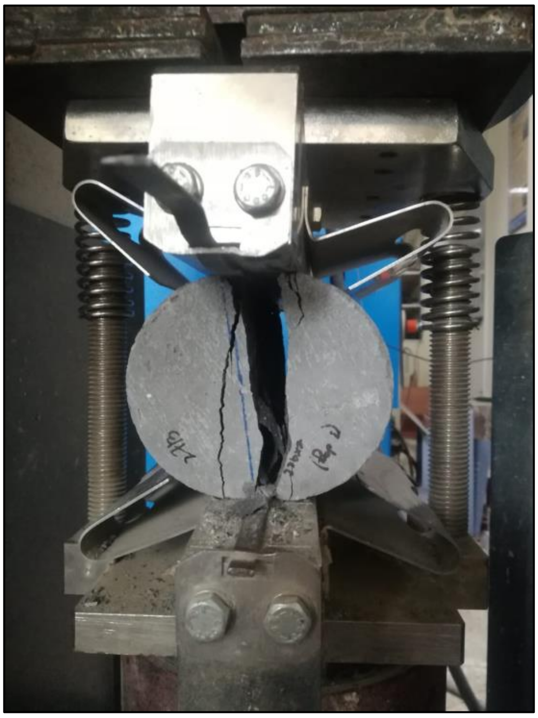


Figure 5.14: Abrupt Failure of mortar sample in split tensile test

Samples with fibers however do not fail abruptly. After the first crack is developed the specimen keep on taking load and does so until it is totally deformed. This shows that the fibers in the mix help in tensile strength keeping the specimen intact and helping it to take more load without failing. This can be observed from the failed sample shown in figure 5.15

Figure 5.15: Ductile mode of failure of ECC sample in split tensile test

5.3 Flexural Test

Flexural test performed on all six variations showed the following results.

1. **Mix variation E0 gives the highest strength**

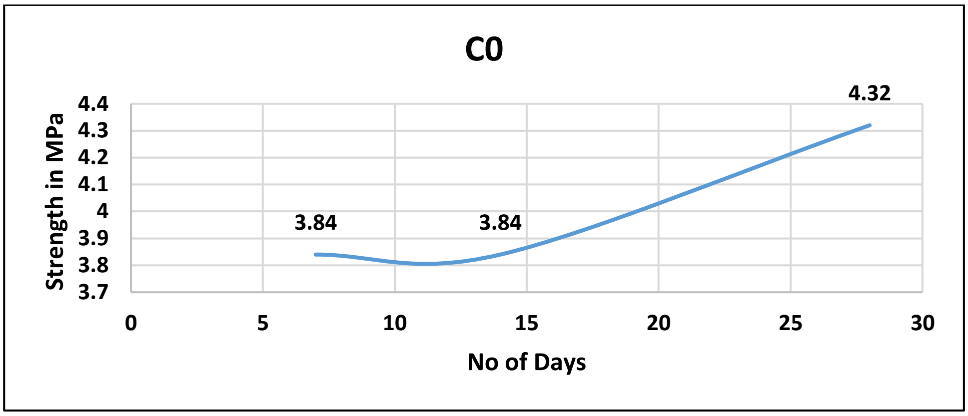
The flexural strengths of all the samples is given in table 5.3

Table 5.3: Summary of Flexural test results for tested variations

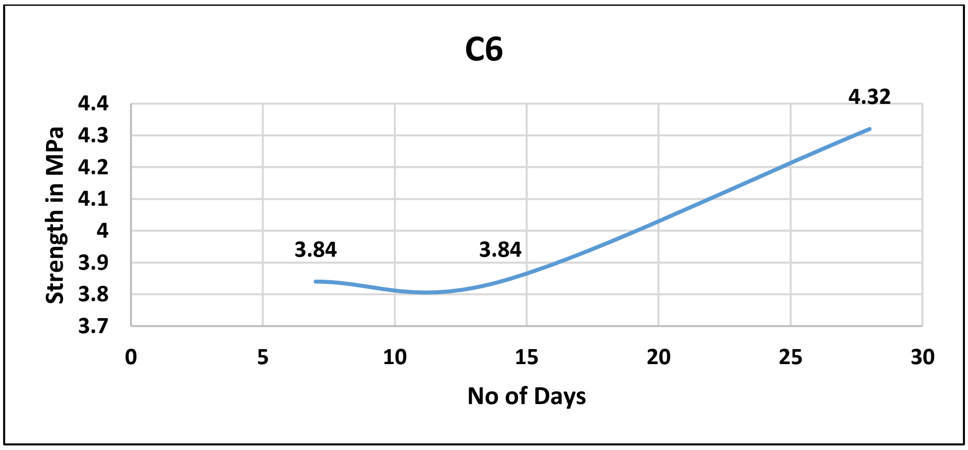
Variation	Days	Flexural Strength (MPa)
C0	7	3.84
	14	3.84
	28	4.32
C6	7	3.84
	14	3.84
	28	4.32
E0	7	6.72
	14	11.04
	28	11.52
E6	7	6.72
	14	8.64

	28	9.12
E9	7	5.28
	14	6.24
	28	6.24
E12	7	3.84
	14	3.84
	28	4.32

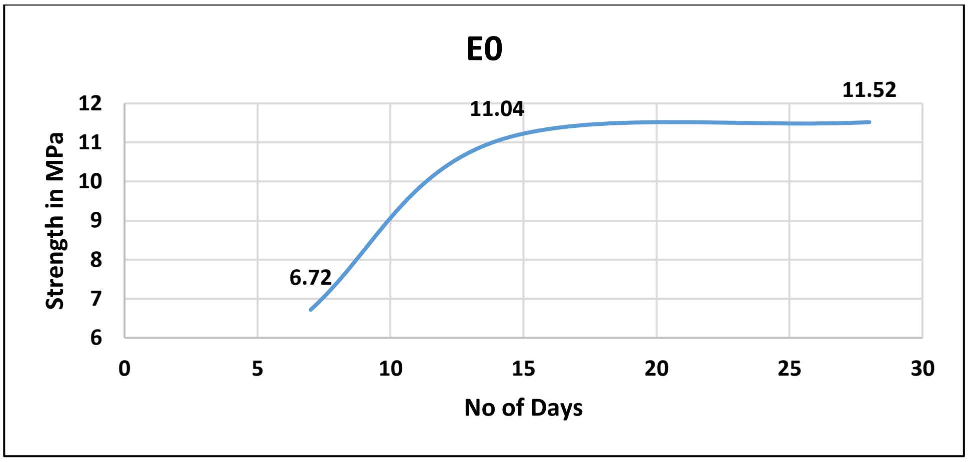
Figure 5.16 shows the increase in flexural strength of individual mix variations from 7 days to 28 days.



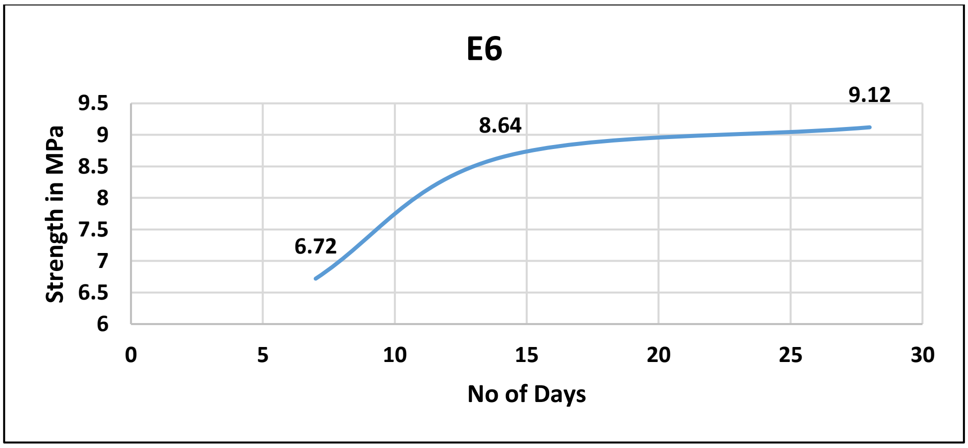
(a)



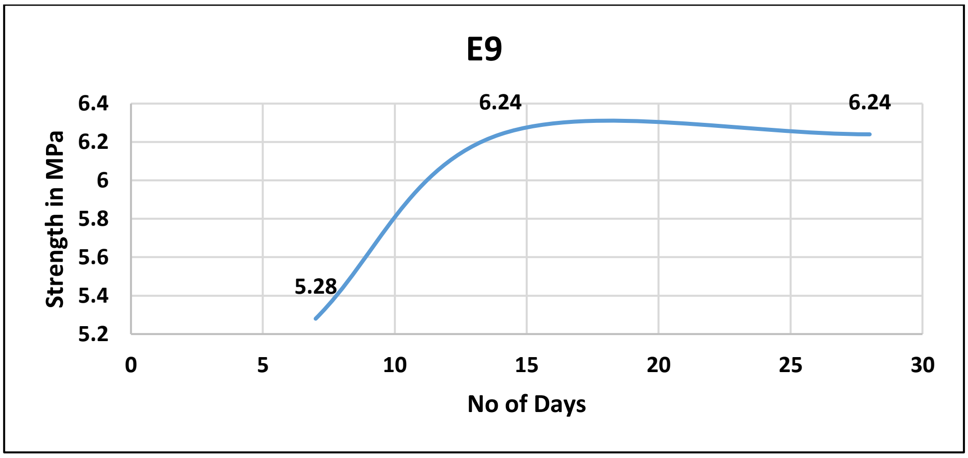
(b)


E0
Strength in MPa
12
11
10
9
8
7
6
0
5
10
15
20
25
30
No of Days
6.72
11.04
11.52

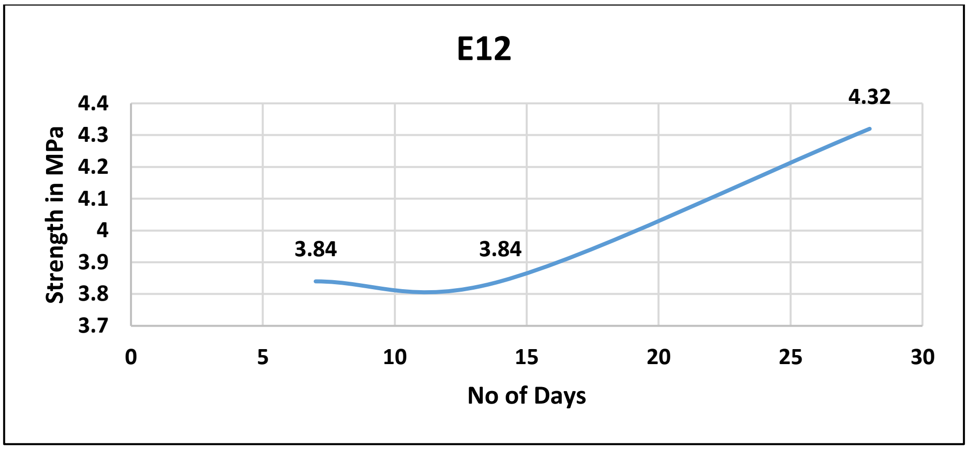
(c)


E6
Strength in MPa
9.5
9
8.5
8
7.5
7
6.5
6
0
5
10
15
20
25
30
No of Days
6.72
8.64
9.12

(d)


E9
Strength in MPa
6.4
6.2
6
5.8
5.6
5.4
5.2
0
5
10
15
20
25
30
No of Days
5.28
6.24
6.24

(e)



(f)

Figure 5.16: (a) Flexural strength gain of C0 variation (b) Flexural strength gain of C6 variation (c) Flexural strength gain of E0 variation (d) Flexural strength gain of E6 variation (e) Flexural strength gain of E9 variation (f) Flexural strength gain of E12 variation

Figure 5.17 shows how the flexural strength of E0 is greater than all other mix variations E0 has the highest 28-day flexural strength of 11.52 MPa and C6 has the lowest 28-day flexural strength of 4.32 MPa. Since fibers are good in tension that is why all the mixes with fibers show a better flexural strength than those which don’t have fibers in them [3].

It can be seen that even sample E12 shows the same flexural strength than C0. This is because of the effects of fly ash which has greatly reduced the flexural strength of the specimen.

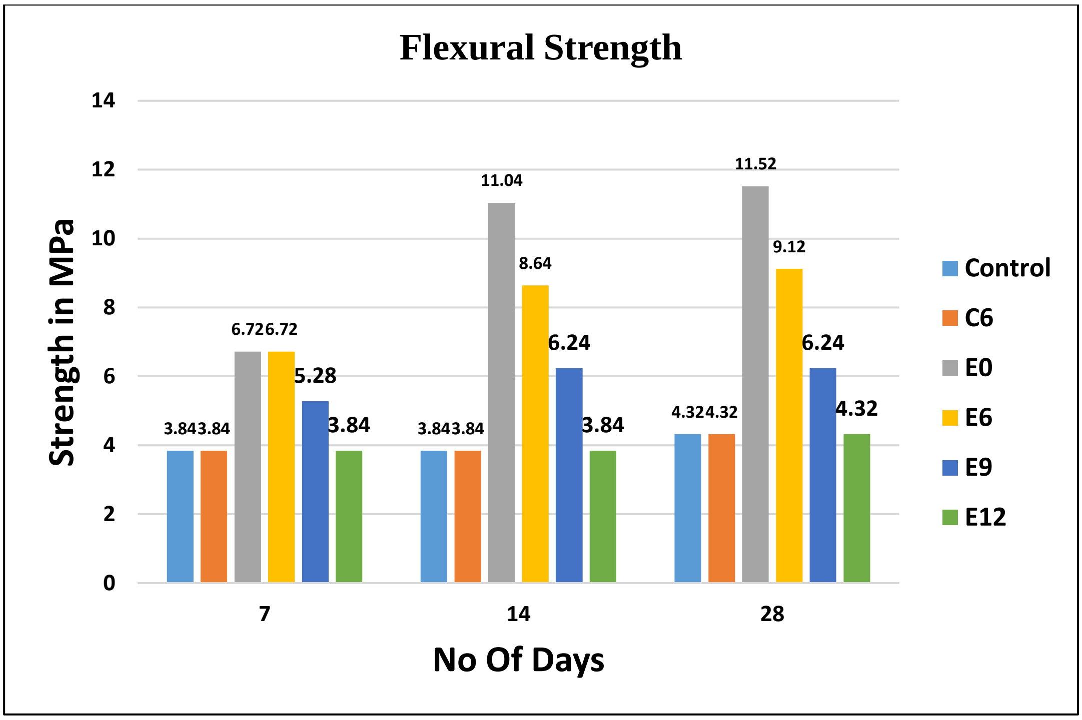


Figure 5.17: Bar chart comparison of Flexural Strengths for tested variations

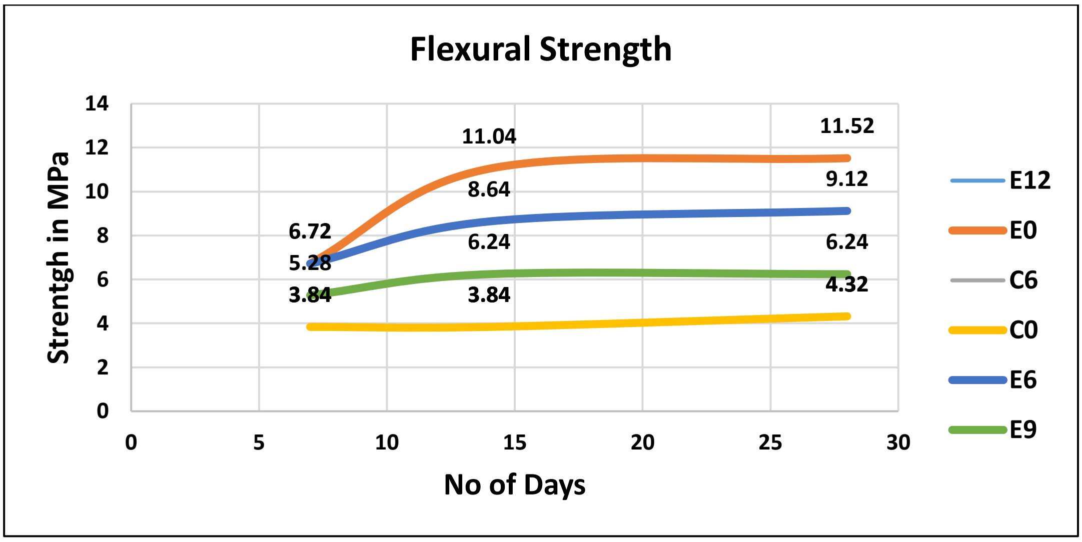


Figure 5.18: Combined graph for Flexural Strength gain of tested variations

2. Introduction of fibers in the mix increases the flexural strength

It was observed that introduction of fibers in the mix increases the flexural strength of the samples. The flexural strength of E0 is 11.52 MPa while the flexural strength of C0 is 4.32MPa which is considerably lower than E0 which is shown in figure

5.19. This increase is due to the fact that the fibers present in the matrix help in dispersing the flexural stress away from its point of application and hence, a higher flexural strength is induced in the sample.

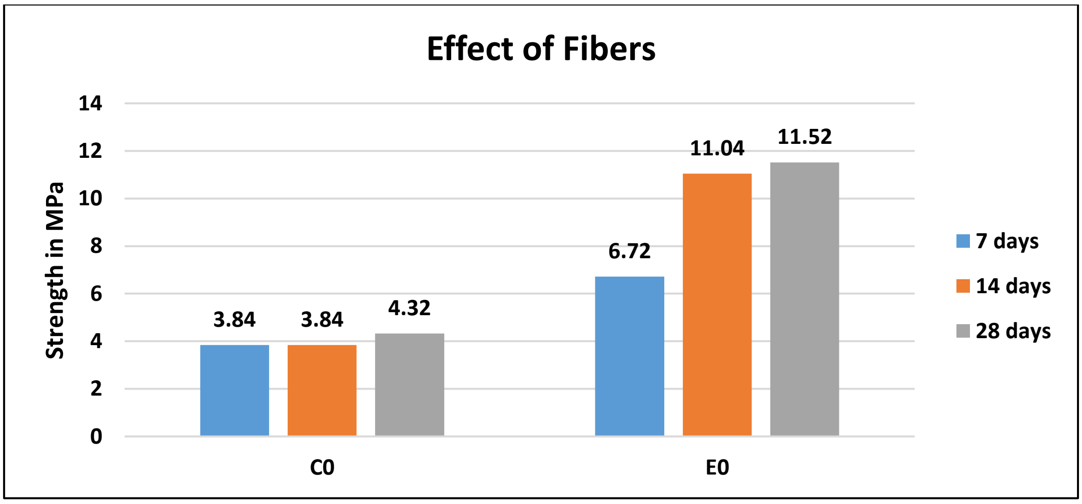


Figure 5.19: Effect of fiber addition of flexural strength

3. **Introduction and Increments of fly ash in the mix decreases the flexural strength**

It was observed that as fly ash in increased in the mix variations its flexural strength shows a gradual decrease. This can also be attributed to the slowing down of hydration process explained earlier in this section. As the hydration process slows down the strength gain of the entire matrix is inhibited causing the flexural strength to decrease as well. [16] [17] This is evident from figure 5.20 which shows the gradual decrease of flexural strength as amount of fly ash is increased in the mix.

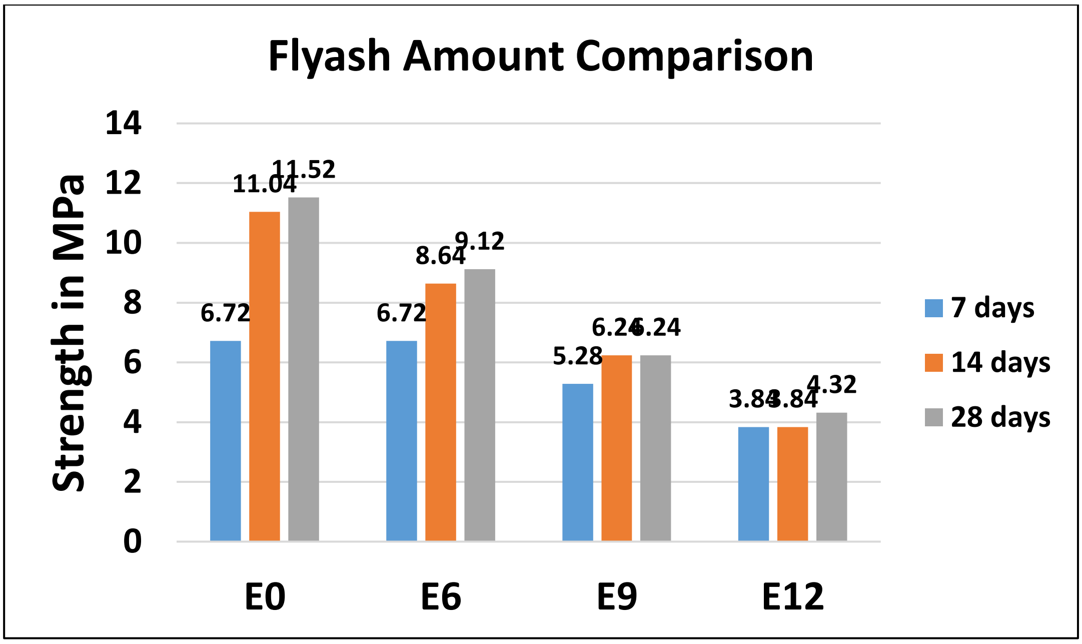


Figure 5.20: Effect of Flyash Increments on Flexural strength

4. Mode of failure

Samples without fibers fail abruptly. When the first crack is formed the sample then splits into two pieces along the fracture plane without taking any further load than the maximum load they can take.

Figure 5.21: Abrupt failure of prism mortar sample in flexural test

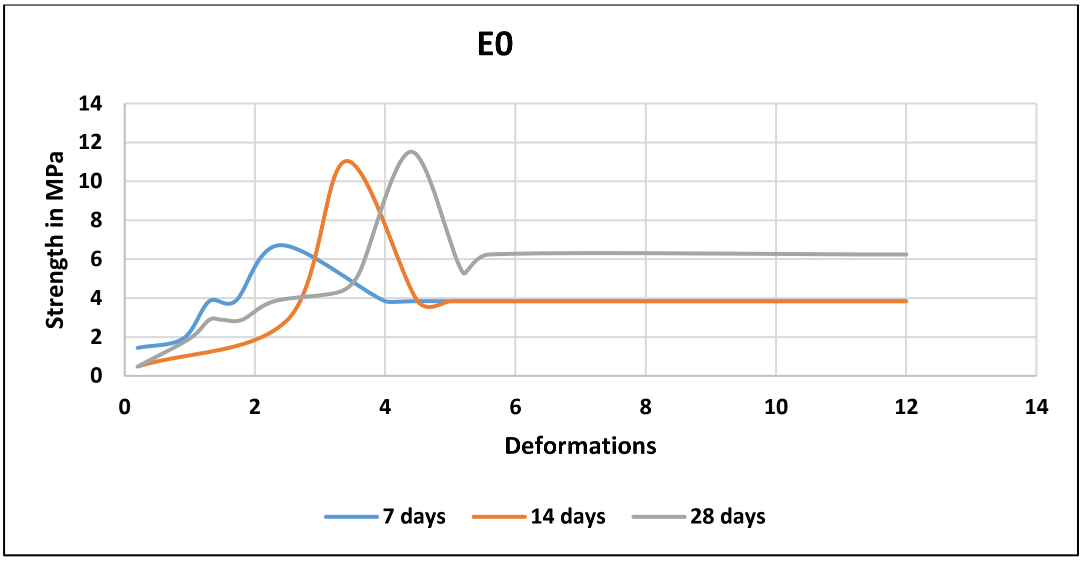
Samples with fibers however do not fail abruptly. After the first crack is developed the specimen keep on taking load and does so until it is totally deformed. The load goes to a peak value and first crack is developed. Afterwards the load goes down a bit and stays constant producing a lot of displacement at the center point. This shows that the fibers in the mix help in flexural strength keeping the specimen intact and helping it to take more load without failing. This can be observed from figure 5.22

Figure 5.22: Ductile failure of ECC prism sample in flexural test

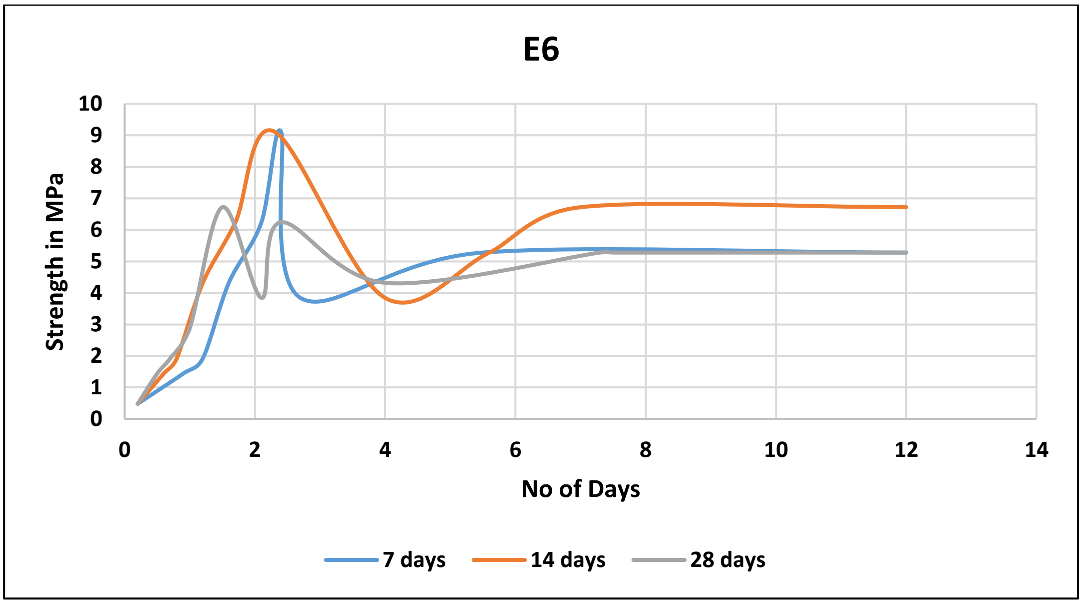
5.4 Pseudo Strain Hardening

As evident from the graphs in figure 5.23, the beam specimen tested under the center-point loading continues to take stress even after the propagation of first crack. The specimens undergo significant deformation and continues to take increment in applied stress. On the other hand, the mortar samples did not show such behavior and failed instantly after rupture stress was reached.

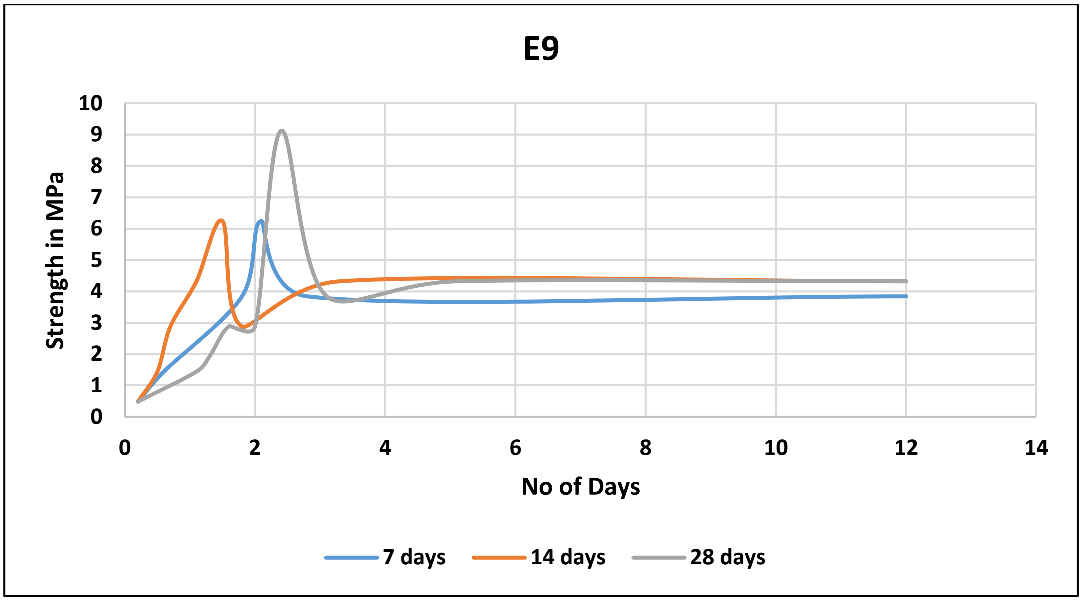
This is evident proof of strain hardening behavior of ECC under flexural stress.


E0
Strength in MPa
0
2
4
6
8
10
12
14
0
2
4
6
8
10
12
14
Deformations
7 days
14 days
28 days

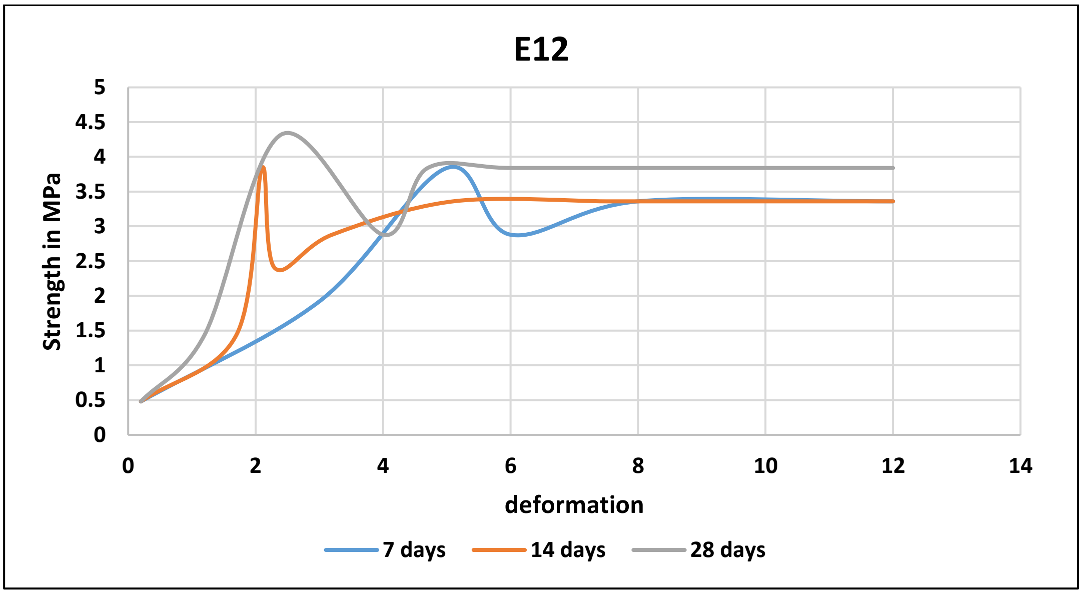
(a)


E6
Strength in MPa
0
1
2
3
4
5
6
7
8
9
10
0
2
4
6
8
10
12
14
No of Days
7 days
14 days
28 days

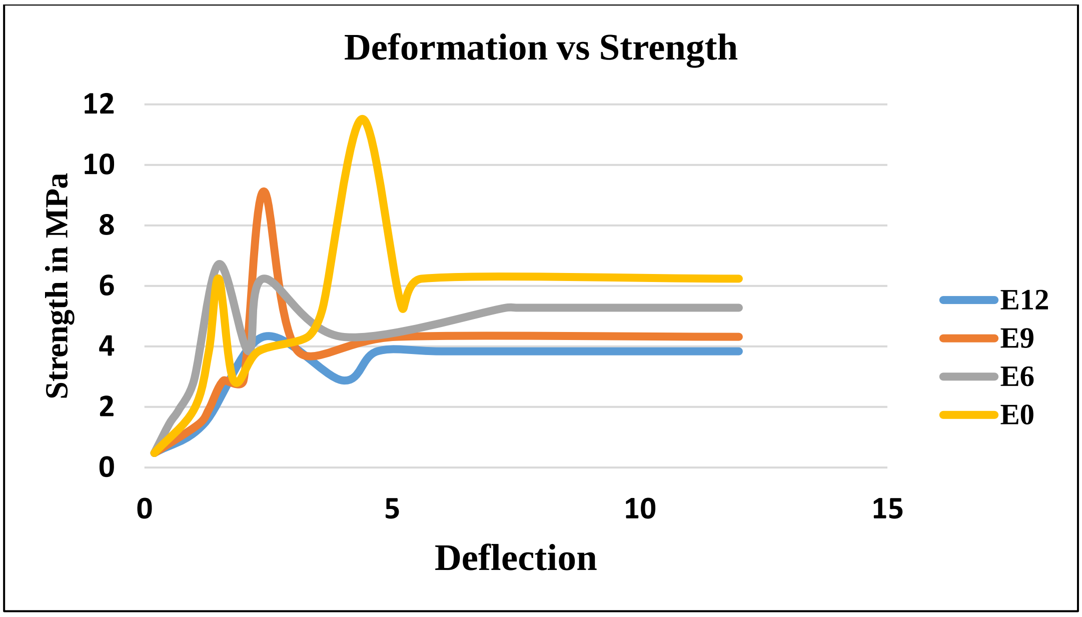
(b)


E9
Strength in MPa
10
9
8
7
6
5
4
3
2
1
0
0
2
4
6
8
10
12
14
No of Days
7 days
14 days
28 days

(c)


E12
Strength in MPa
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12
14
deformation
7 days
14 days
28 days

(d)



(e)

Figure 5.23: (a) Pseudo-Strain hardening of E0 prism sample (b) Pseudo-Strain hardening of E6 prism sample (c) Pseudo-Strain hardening of E9 prism sample (d) Pseudo-Strain hardening of E12 prism sample (e) Combined graph of Pseudo-Strain hardening behavior of all variations.

5.5 Cost Analysis

Cost Analysis was done on all the mix variations and conventional concrete and results were compared with the cost of PVA ECC. The cost with the sample names can be seen in table 5.4

Table 5.4: Cost Analysis for different variations

Sample	Cost (Rupees/cft)	% Cost Reduction
PVA ECC	2196	-
C0	368	83%
C6	322	85.34%
E0	757	65.53%
E6	678	69.13%
E9	637	70.993%

E12	599	72.723%
Concrete	540	75.409%

From the results it is observed that the cost of the sample increases due to addition of fibers as they are costly, yet Nylon 66 acquired from Karachi was cheaper than PVA to be procured from international source which helped in bringing down the cost of the sample by 65.5%.

Fly Ash acts as a substitute for cement as it does have binding properties, but it cannot fully replace the function of cement hence the sample was observed to have lower cost as the amount of fly ash increase as per table 5.4, but this happens at the expense of the strength.

By comparison of cost with the strengths of corresponding samples, the best suitable sample was observed to be E6 having 60% Fly Ash and 2% of Fibers that reduces cost by 69% compared to PVA-ECC and is 25% more expensive in comparison with convention concrete.

CHAPTER 6

CONCLUSIONS

From the results, the corresponding analysis was drawn regarding each of the test results. The trends followed due to change in the components indicated the possible behaviors.

6.4 Mechanical Strength

According to the test results ECC made with locally available material shows comparable properties with that of conventional ECC.

1. ECC variations (E0, E6, E9, E12) showed compressive strength in range of 43.9 - 50.1 MPa, tensile strength in range of 3.63 - 4.28 MPa, and flexural strength in range of 4.32 - 11.52 MPa, while the compressive, tensile and flexural strengths in conventional ECC (PVA-ECC) are in range of 30 - 90 MPa, 4 - 12 MPa and 10 - 15 MPa. This shows that ECC prepared with locally available material exhibits similar mechanical properties as conventional ECC.
2. Owing to the fact that fly ash causes the hydration process of cement composite to slow down for the first 28 days, hence increments of fly ash into the mix decreases it’s compressive, tensile and flexural strength.
3. The addition of Flyash up to 60% causes a 20% decrease in flexural strength i.e. 11.52 to 9.12 MPa. Each subsequent increment in Flyash quantity by 30% causes a 25-30% decrease in the flexural strength.
4. The addition of Flyash up to 60% causes an 8% decrease in tensile strength i.e. 4.28 to 3.93 MPa. Each subsequent increment in Flyash quantity by 30% causes a 2-6% decrease in the tensile strength.
5. The addition of Flyash up to 60% causes a 3% decrease in compressive strength i.e. 50.1 to 48.7 MPa. Each subsequent increment in Flyash quantity by 30% causes a 4-6% decrease in the compressive strength.

6. Since fibers are good in tension hence, their addition improves flexural strength from 4.32 MPa to 11.52 MPa which is an increase of about 166%.
7. Addition of fibers increases tensile strength from 2.82 MPa to 4.28 MPa which is an increase of about 51%.
8. Addition of fibers causes a decrease in compressive strength from 53.2 MPa to 50.1 MPa which is a decrease of about 6%.
9. The sample C0 gives the highest compressive strength of 53.2 MPa while the highest compressive strength from ECC samples was given by sample E0 which is 50.1 MPa.
10. ECC shows ductile behavior with pseudo strain hardening which is not present in mortar. All of our ECC samples i.e. E0, E6, E9, E12 had pseudo strain hardening behavior while the control samples did not.

Hence, the key influencing components that affect the ECC mechanical properties have been determined and the effect of variating their quantities has also been recorded and quantified.

6.5 Cost

According to the cost analysis:

1. Nylon ECC is 65.5% cheaper than PVA ECC owing to the fact that PVA is 525% expensive than Nylon fibers (more than 5 times).
2. An economical ECC was successfully fabricated as E6 which reduced costs by 69%.
3. Addition of 60% fly ash in Nylon ECC reduces its cost by 10.4% because fly ash as a binding agent is cheaper than cement.
4. Every 10% increase in fly ash amount reduces the cost of Nylon ECC by 1.73%.

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