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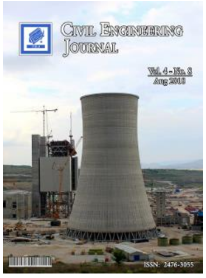
Civil Engineering Journal

Vol. 4, No. 8, August, 2018



Experimental Analysis on Tensile Behavior of Engineered Cementitious Composite (ECC) using Polypropylene Fiber

Ali Raza Khoso [a], Muhammad Fahim [a], Shanker Lal Mehgwar [a], Muhammad Akram Akhund [b*]

[a] *Civil Engineering Department, Mehran UET, Jmashoro. 76020, Pakistan.*

[b] *Civil Engineering Department, ISRA University, Hyderabad, 313, Pakistan.*

Received 11 May 2018; Accepted 10 August 2018

Abstract

The high demand of tensile strength in concrete is always a critical issue for engineers, as 10% of the compressive strength is not sufficient to withstand higher loadings. Lesser ductility and strain capacity is another major issue of normal concrete. In the queue of modern researches, this paper is an attempt to study Engineered Cementitious Composite (ECC) from research of Professor Victor Li, the University of Michigan. ECC is an ultra-ductile cementitious composite which is highly crack resistant, with a high tensile strain capacity over that of normal concrete. The composite replaces coarse aggregates and fine aggregates by sand and fly ash respectively. ECC is made up of OPC, sand (passing from 250 µm and retained on 150µm), Fly Ash (Class F) with addition of Polypropylene fiber on different percentages i.e. 0%, 0.25%, 0.5%, 0.75%, 1.0% were studied. Tensile Strength of ECC was measured by casting & testing cylinders of 4"x 8" in Universal Testing Machine (UTM). The experimental results revealed that 111.40% increment in tensile strength was found at 0.5% PP fiber at ECC 1:1:1 and an increment of 74.74% was observed at ECC 1:0.8:1.2 at 1% PP fiber. The study concludes that this composite could substitute the normal concrete where high tension is the ultimate requirement with higher strain capacity.

Keywords: ECC; Tensile Strength; Polypropylene Fiber; Concrete.

1. Introduction

Amongst all construction materials, concrete is most versatile material man have ever made. Due to its versatile characteristics, it is most widely used construction material of world. According to one study, its consumption is around 11.4 billion tons annually worldwide [1]. The tensile strength of normal concrete is within the range of 10 % of the compressive strength of the concrete. This figure is never sufficient for the cases where the tensile strength is higher priority. The low tensile strength of the material kept the material engineers indulges in experiments and resulting in modern researchers on concrete. This tensile behavior of concrete is amongst a priority in the development of fiber concrete and other invention and researches in the field of concrete technology. Keeping in view the various drawbacks of normal concrete (i.e. cement matrix micro-cracks resulting from shrinkage or excessive loading, destruction of the material in a brittle manner etc.), numbers of researchers in past were carried to make this material ideal for construction. In the same queue, a modern type of composite has developed by Prof. Victor Li known as Engineered Cementitious Composite (ECC). According to him, Engineered Cementitious Composite (ECC) is an easily molded mortar-based composite reinforced with polymer fibers [2]. In the upcoming developments of safer, lighter, long lasting concrete

* Corresponding author: akhund42@gmail.com

http://dx.doi.org/10.28991/cej-03091112

infrastructure, the ECC can play vital role. Due to its numerous characteristics, now a days ECC is being prepared in ready mix plants also.

Engineered cementitious composites (ECCs) are improved version of the fiber-reinforced cementitious composites (FRCC) with noticeable enhancement in strain-hardening behavior. This composite basis on modelling of micromechanical with strain capacity ranging from 3 to 5%, claimed by [9]. This is reinforced with micromechanically designed polymer fibres. Teresa Zych (2014) done experimental work on ECC with the significant reduction of w/c ratio, exclusion of coarse aggregates in order to obtain a material of much higher homogeneity, the addition of super-plasticizer to achieve good workability of composites and inclusion of fibers in order to strengthen the matrix [3]. En-Hua Yang et.al, (2007) included four parameters in experiment work i.e. amount of high-range water reducer, class C Fly ash ratio to Class F Fly ash ratio, amount of viscosity modifying admixture and water to binder ratio to investigate the composition effects on fresh and hardened properties of ECC [4].

An experimental study done by E. Ramya et al. (2015) on Polypropylene fiber in Engineered Cementitious Composites in which an effort was made to study the effect of PP fibers on the mechanical properties of mortars incorporating silica fume. From the experimental investigation it was noted that, in addition of fiber with silica fume to cement mortar at lower volume fraction (0.2%), the strength of mortar achieves 2% higher than normal cement mortar and further concluded that formation of crack is arrested by using polypropylene fiber in the composite [5]. Shuxin wang and Victor c. Li. (2007) using PVA fiber and addition of fly ash and bottom ash checked the flexural ductility of beams. It is discovered that to attain high tensile strain capacity and increasing matrix toughness a high volume faction of fly ash is required. In addition to this, it tends to reduce the polyvinyl alcohol fiber and matrix interface [6]. Another attempt were made by Gowda et.al. (2014), on flexural investigation of ECC using PVA fiber. The study results in higher load carrying capacity of beams with higher deflection using Fly Ash as compared to rice husk [7]. Varsha Bhamare et.al. (2017) did research on comparative study of ECC and Cement Concrete (CC) on the basis of compression and tensile strength. According to the results, the compressive strength of ECC and CC both is nearly same. Also without the coarse aggregate it is possible to gain strength with the use of PVA fiber volume fraction less than 2%. Nearly 65.70% strength is developed within 7 days for compression. The results show the 27% higher tensile strength for ECC [8].

Various researcher were conducted on ECC by mixing natural and manmade minerals. An experimental study was conducted on ECC using fly ash and rice husk on beams of 304.8 × 76.2 × 12.2 mm size. The mixture was prepared using PVA fiber at different curing days such as 14, 28 and 56 days. The result concludes that the mixture containing fly ash with 1.4% fiber resulted with maximum load carting capacity. However, the mixture with rice husk showed comparatively lesser load carrying capacity [7]. A cement substitute mineral admixture namely metakaolin was used in a study along with nano silica and epoxy without fiber. The mixture showed better results over another mixture of M45 ECC. The metakaolin possess high pozzolonic properties hence it resulted in enhancing the microstructure of concrete and overall durability of mixture. The mixture finally resulted in higher strength as compared to M45 ECC without this admixtures [10]. Yu Zhu et. al. (2014) mixed various mineral admixture into ECC such as fly ash, silica fume and slag. The study compared compressive strength of ECC against toughness, deflection, flexural strength and fracture energy. The study found that deflection, fracture energy and toughness has inverse relationship however, flexural strength is directly proportional to compressive strength of ECC [13]. Another study used fly ash along with micro PVA fiber in ECC to investigate compressive strength, tensile strength and flexural strength. The mix achieved 55 N/mm^2 compressive strength, 5 N/mm^2 tesnile strength and 5.7 N/mm^2 of flexural strength [14].

The ECC is extremely ductile in nature. During higher loadings normal concrete fails in brittle curve. On the contrary, a higher curvature of ductility can be achieved like a ductile metal plate using this product. Such high ductile materials could be utilised to achieve higher strength of concrete and could be utilised where high ductility is required in structural applications of concrete. Beside tensile strength, the bending properties of ECC were also investigated in past. An ECC mixture was prepared by adding PVA fiber, steel fiber and hybrid fiber with different proportions. A conventional concrete was compared with this mixture using four point loading test setup in UTM. The result found that if steel fiber is added from 3 to 4% there was nearly increment of 15% in flexural strength of ECC as compared to conventional concrete. However, highest increment in bending strength (i.e. 20%) is achieved at 1.5 to 2% steel fiber [11]. The study of PP fiber with steel also studies by S.Divya et.al, 2016. The investigation includes 0.1%, 0.15%, 0.2%, 0.25% of polypropylene (PP) fiber with 0.5%, 1.0%, 1.5%, 2% of steel fiber and compressive strength, tensile strength and flexural strength were studied. The study claimed that optimum strength is achieved at 1.0% of steel fiber and 0.1% of polypropylene fiber [16]

A relationship study was carried out by (Anu T Eldho and Divya Sasi, 2016) to determine the relationship between mechanical properties of ECC and compressive strength with recron fiber and PP fiber. The study concludes that with same grade i.e. M35, the ECC has higher compressive strength, flexural strength and tensile strength as compared to same grade concrete [16]. Various viscoelastic properties such as drying shrinkage, autogenous shrinkage and tensile creep along with mechanical properties of ECC were also investigated by [12]. The results showed higher compressive strength of ECC using fibers. The durability properties of Engineered Cementitious Composites were studied by

R.Sathish Kumar and S.Ranjith, 2017. To verify the properties Coir fiber and polyvinyl alcohol fiber with various proportions of mineral admixtures such as rice husk ash and silica fume has been used in ECC [20].

A stress strain relationship study on ECC using simulation were also carried in past. In this work, a numerical model was used to simulate the overall stress strain relationship. From the model, study suggest that ECC is a good material for higher mechanical properties and to have high durability [21]. A latest research was carried out by Dr. Elson John et.al. 2018 to investigate the expansion gap issues of bridge deck, a very critical issue in bridge deck. Along with this density variation, flow characteristics and abrasion resistance of different ECC mixes were studied. The study finally suggests ECC with PVA fiber for expansion gap issue of bridge slab [17]. Another latest research was conducted by Brinila Bright B N et.al, 2018 on Experimental Investigation of ECC by mixing Jute and Nylon as natural and artificial fibers. This research was an attempt to increase the ductile properties of ECC by replacing natural and artificial fibers over coarse aggregates. The best results of bending strength achieved at 1.5% of each fiber i.e. 15.86 N/mm^2. Beside this compressive and tensile strength were also investigated. The best result of both achieved at same percentage of fibers i.e. 21.34 and 4.1 N/mm^2 respectively [18]. To improve the ductile property of ECC, another attempt was made by Ganesh S. Ghodke et.al. 2017. The study tests beams specimen and also investigated the cracking pattern [19].

In past, the development on ECC in terms of tensile strength is not much mature. In some cases, the tensile strength of ECC remains same as of PCC while in other cases, it increases but up to little extent [7-8]. The development of this material surely not only enhance the safety and durability of structure but tends to reduce long term burden of cost which, otherwise, would require for high degree of maintenance and causing environmental degradation due to extra material production.

In this study, ECC is made by inclusion of polyvinyl alcohol (PVA) fibers. The high range brittle behavior of dense matrix is being counteract by the fibers inclusion. Thus the high post cracking is eliminated by the reaction of fiber with the matrix, forming a strong bond between the two. Regardless of its geometry, polypropylene has several distinctive properties that make it compatible for use in this composite. The fibers are chemically inert and stable in the alkaline environment of concrete, with a relatively high melting point, and low cost. The study aims to investigate the tensile behavior of ECC using laboratory tests. All the tests were performed on modern digital Universal Testing Machine (UTM) in Mehran University of Engineering and Technology, Jamshoro, Pakistan. This experimental analysis of ECC on cylindrical specimens results in extreme increment of tensile strength which is ultimate goal of structural engineers.

2. Research Material

In this research work, two types of materials were cast and tested in laboratory. The plain cement concrete and engineered cementations Composites (ECC). Table 1 describes the raw materials used in both composites.

2.1. Cement

Locally available Ordinary Portland Cement (OPC) was used as binding material. It was used in both ECC and PCC as binding agent. The lab tests conducted on cement were Unit weight, Fineness of cement, and initial and final setting time. The Unit weight of cement was measured as 1400 kg/m^3 whereas Fineness of cement was 12.5% retained on No. 200 sieve. The initial and final setting time of the cement was 40 and 148 minutes respectively.

Table 1. Materials of ECC and PCC

PCC	ECC
Cement	Cement
Fine Aggregates	-
Coarse Aggregates	-
-	Sand
-	Fly Ash
-	Polypropylene Fiber
-	Admixture (Superplasticizer)
Water	Water

2.2. Fine Aggregate (FA)

It was used in the preparation of normal concrete only i.e. PCC. First of all gradation of FA was done on sieve shaker machine and results are enumerated in grading curve of Figure 1. The aggregates passing from 4.75 mm sieve were used in concrete manufacturing. The lab tests conducted on fine aggregates are mentioned in Table 2. The aggregates were clean, dry and hilly sand obtained from Bohlari quarry.

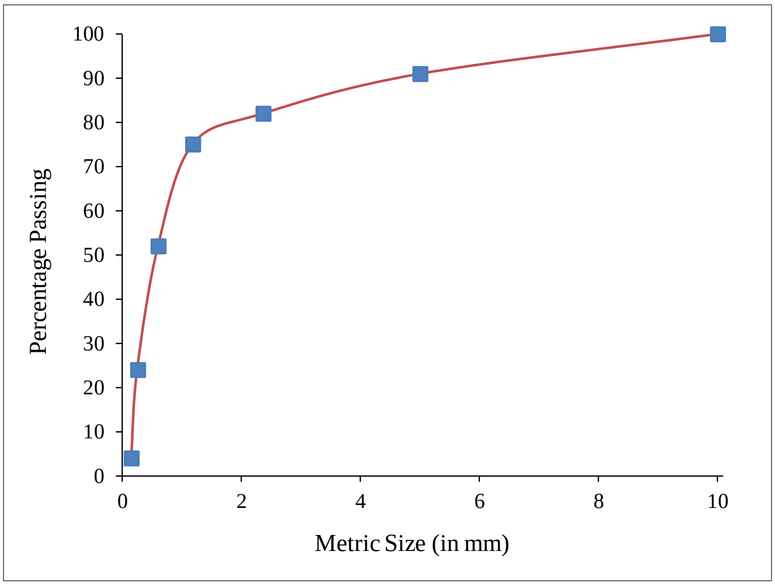


Figure 1. Grading curve of FA

2.3. Coarse Aggregate

In PCC, 13 mm nominal size coarse aggregates were used in this study. Sieve analysis is done as per ASTM C33 for assuring the well graded size of CA and resulting gradation curve is shown in Figure 2. The tests conducted on coarse aggregates are given in Table 2 with their results. Coarse aggregates are mixed with the cement to produce concrete. These aggregates were brought from Petaro crushing plant.

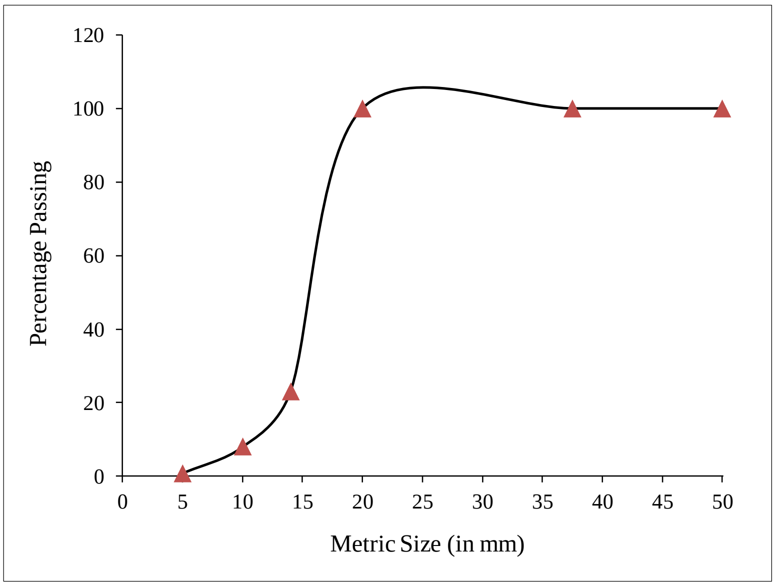


Figure 2. Grading curve of CA

2.4. Fine Sand

The sand which is used in casting of ECC is very fine. This is obtained by sieving the same fine aggregates used in PCC. The fine sand is obtained by passing it on 250 µm sieve and retaining on 150 µm sieve. Its pictorial view is shown in Figure 3. For this work the sand was manually sieved. After manual sieving, retain of 150 µm sieve was taken for research work. The lab tests done on sand are given in Table 1 with their results.

Figure 3. Sand used in casting of ECC

Table 2. Properties of fine aggregates, coarse aggregates and sand

Lab Tests	Fine Aggregates	Coarse Aggregates	Sand
Specific gravity	2.69	2.66	2.66
Unit weight (kg/m3)	1597	1256	1381
Water Absorption	2%	0.25%	3-4%
Fineness Modulus	3.63	3.68	100% passing of 250µm

2.5. Polypropylene Fiber

Fibers in the concrete resist the cracking due to drying and plastic shrinkage. The function of PP fibers is to avoid the micro crack creations. Polypropylene (PP) fibers as shown in Figure 4 with length of 19 mm were mixed with the ECC.

Figure 4. Polypropylene Fiber

The fibers were used in different percentages. This was purchased from Matrixx Company (Duracrete), Karachi Pakistan. Polypropylene fibers do not absorb water, due to a hydrophobic surface, which prevents any chemical adhesion with the concrete matrix. Fibers bond in the concrete matrix through interfacial adhesion and mechanical anchoring.

2.6. Fly Ash

The Fly Ash used in the research work was Pozzocrete 40 type. It confirms to ASTM 618. It can be used as a component of cement with Portland clinker. The properties of fly ash are provided by the Matrixx Company is mentioned in Table 3. The use of fly ash in RCC construction is extremely successful. The fly ash reduces hydration without affecting the strength and it also increases the ultimate strength of concrete by providing better compaction ability of mixture. Beside several other paramount properties, it arrested the fine void spaces in mix which would otherwise be occupied by water or cement. Hence fly ash increases the strength of the composites.

2.7. Superplasticizer

This is the admixture utilize in concrete to enhance the rheological properties of green concrete. This admixture helps to disperse the mixture's constitutes uniformly. It is a form of additives in mix. The adhesion of fly ash increases the water demand in concrete and cause lesser flow ability of mixes. The addition of super plasticizer increase the slump. The super plasticizer were purchased from Sika Karachi.

Table 3. Properties of Fly Ash

Properties	Values	Standards
Compressive Strength	5,500 – 8,000	ASTM D695
Flexural Strength	6,000 – 8,000	ASTM D790
Tensile Strength at break (psi)	4,500 – 6,000	ASTM D638
Elongation at break (%)	100 – 600	ASTM D638
Water absorption	Negligible (0.01 – 0.03)	ASTM D570
Specific gravity	0.90 – 0.91	ASTM D792
Tensile Modulus (ksi)	165 – 225	ASTM D638
Compressive Modulus (ksi)	150 – 300	ASTM D695
Flexural Modulus (ksi @ 25^{o}C)	170 – 250	ASTM D790

3. Specimen Details and Mix Design

Mix proportion has important role in terms of strength and the better workability. Dr Victor c. Li, 2008, proposed a mix ratio of 1:0.8:1.2 (cement: sand: fly ash), for better hardened properties and rheological properties [2].

In this research, 90 cylinders were made from ECC, 45 cylinders from each mix i.e. at mix design ratio 1:1:1 and 1:0.8:1.2 (Cement: Sand: Fly Ash) on various percentages of fibers (i.e. 0%, 0.25%, 0.5%, 0.75% and 1%). Also 9 additional cylinders were cast from normal concrete (1:2:4 @ 0.5 w/c ratio) at 7, 14 and 28 days for reference purpose. The specimens were test in UTM. The further details is mentioned in table.

4. Experimental Program

The required quantities of materials i.e. cement, fine aggregates and coarse aggregates for normal concrete and cement, sand, fly ash and super plasticizers for ECC were mixed with the water to produce the mixtures. The mixer which was used in this research was a high shear mixer for the production of ECC. It is usually used for high mortar mixing. In this work, it was utilized for proper mixing of fiber so to have a homogenous form of mixture. The workability of PCC was found using slump cone test as 3 in. However, for the ECC it. It is so high that it can flow under its own weight on all the percentages of fibers. The workability was only visually observed i.e. in ECC the composite did not stand for a second and it started to flow under its own weight resulting in high flowable concrete.

For tensile strength testing, cylinders of dimensions 4 in. diameter x 8 in. height, having total volume of 100.6 in^3 were cast. The method adopted to determine the tensile strength of the specimen was indirect tensile or splitting tensile strength test. The Figure 5 shows the specimen under splitting tensile strength test. A diametric compressive load was applied along the length of the sample at a continuous rate until failure occurs. The loading induce tensile stresses on the plane containing the applied load, causing tensile failure of the sample, British Standard BS 1881: part 118:1993 and ASTM C78-94 formed the basis of this procedure. The Specimen are testing at the age of 7, 14 and 28 days of curing under the UTM. The machine applies compressive stress on the cubes due to the downward movement of the plated at a constant rate of 10 kN/Minute. The load applied at the failure of the cylinder was noted for every specimen. These should be brief and placed at the end of the text before the references.

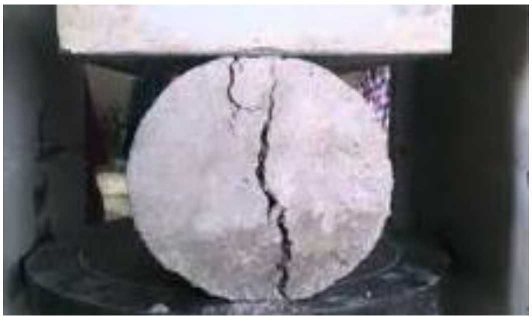


Figure 5. Cylinder in UTM under splitting tensile test setup

Table 4. Specimen Detailing

Material	Mix Ratios	w/c ratio	Curing period	% of fiber	No. of Cylinders
PCC	1:2:4	0.5	7 days	Nil	3
			14 days		3
			28 days		3
					Total 09
ECC	1:1:1	0.45	7 days	0%,	3
				0.25%	3
				0.5%	3
				0.75%	3
				1%	3
			14 days	0%	3
				0.25%	3
				0.5%	3
				0.75%	3
				1%	3
			28 days	0%	3
				0.25%	3
				0.5%	3
				0.75%	3
				1%	3
					Total 45
	1:0.8:1.2	0.45	7 days	0%	3
				0.25%	3
				0.5%	3
				0.75%	3
				1%	3
			14 days	0%	3
				0.25%	3
				0.5%	3
				0.75%	3
				1%	3
			28 days	0%	3
				0.25%	3
				0.5%	3
				0.75%	3
				1%	3
					Total 45

5. Result and Discussion

The cylindrical samples of PCC and ECC were tested in UTM, under splitting tensile strength test setup. The Figure 6 illustrates the splitting tensile strength results of PCC 1:2:4 with ECC 1:1:1 and 1:0.8:1.2 at 0% of PP fibers. Overall, the tensile strength of both mixes gradually increased from 7 to 28 days curing period. But, strength of concrete with ECC 1:0.8:1.2 is higher than PCC and ECC 1:1:1 by 28% and 19.6% respectively at 14 days. This strength is plummeted at 28th day by 6.6% as compared to ECC 1:1:1. Though, it is 42% and ECC 1:1:1 is 49.5% more than the PCC.

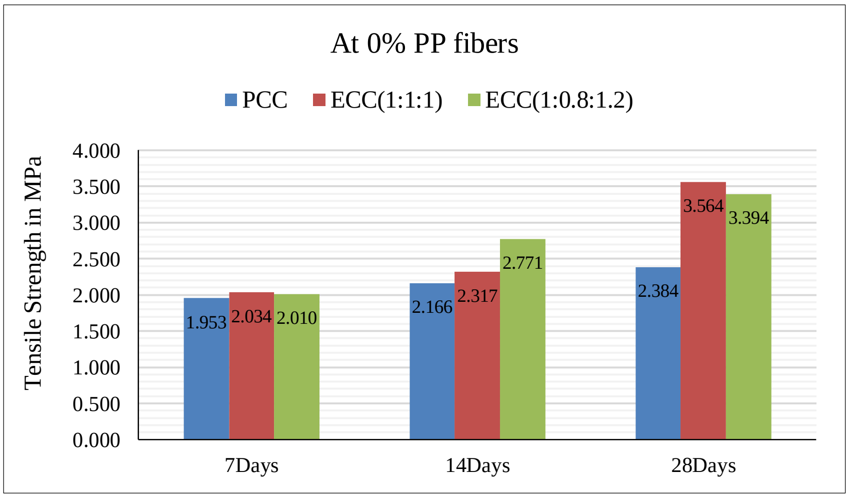


Figure 6. Tensile Strength of PCC (1:2:4), ECC (1:1:1) and ECC (1:0.8:1.2) @ 0% PP fibres

Further, Figure 7 depicts the information at 0.25% of PP fibers, generally, same trend was observed here as that of 0% PP fibers. As percentage of PP fibers in ECC 1:1:1 and ECC 1:0.8:1.2 increased by 0.25%, the ultimate strength enhanced throughout course of time and peaked at 4.435 and 3.555 MPa by 28th day, which is 86% and 49% more than PCC, respectively. However, strength observed at ECC 1:1:1 is 25% more than the ECC 1:0.8:1.2 at same age.

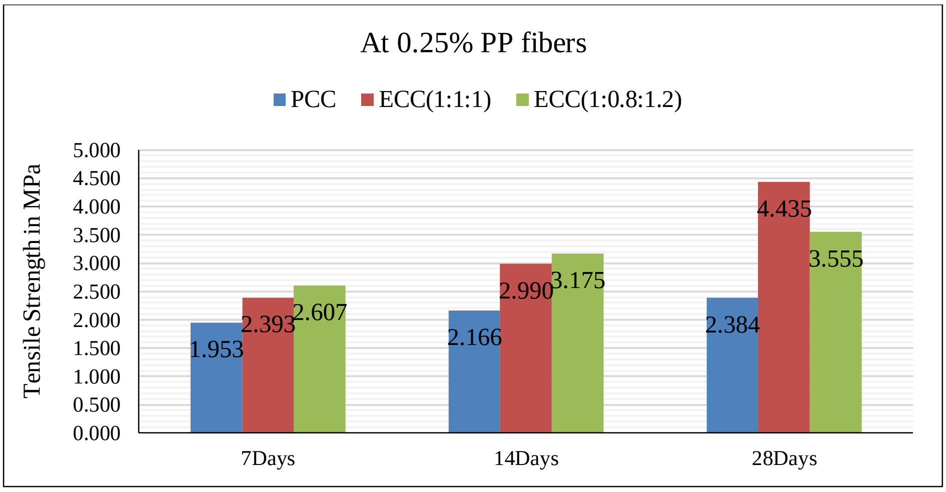


Figure 7. Tensile Strength of PCC (1:2:4), ECC (1:1:1) and ECC (1:0.8:1.2) @ 0.25% PP fibres

While Figure 8, shows strength results at 0.5% of PP fibers. Hence, exactly, the same trend as that of previous is repeated, again. It uniformly raised in both mixes, at all curing ages and achieved single maximum value of 5.040 MPa for ECC1:1:1 after 28 days and this value is 111.4% and 38% higher as compared to PCC and ECC 1:0.8:1.2 respectively. And it is 38% higher than the mix ECC1:0.8:1.2. In addition to this, minor cracks were appeared on the external surface of specimens during loading which were not observed in any of the specimens at 0.25% of fibers.

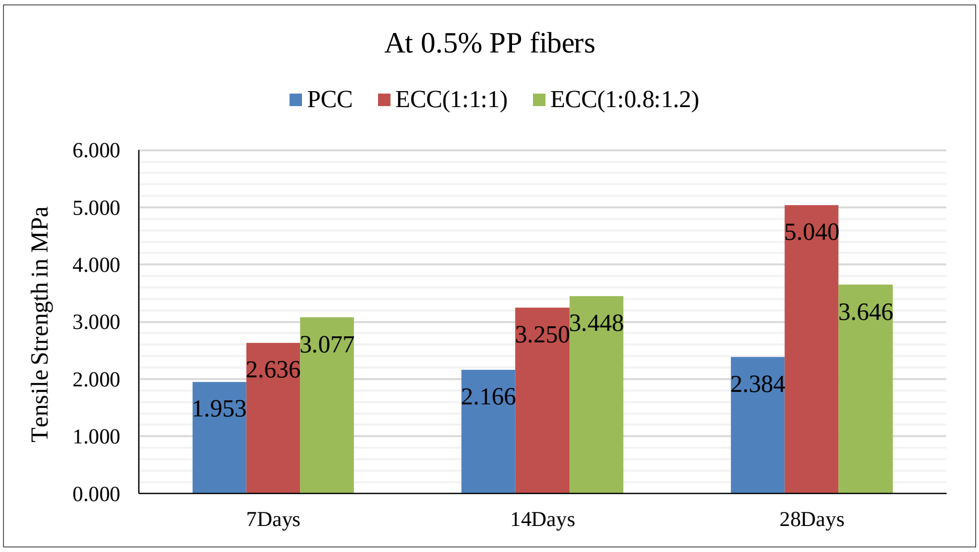


Figure 8. Tensile Strength of PCC (1:2:4), ECC (1:1:1) and ECC (1:0.8:1.2) @ 0.5% PP fibers

On the other hand, as proportion of fibers exceed 0.5%, the tensile strength slightly increased throughout. But, this strength values are lower as compare to strength at 0.25% and 0.5% PP fibers. However, Figure 9 and 10 reveals that it is almost levelled off at 3.45 MPa by 14 and 28 days curing ages in both ECC 1:1:1 and ECC 1:0.8:1.2 at 0.75% and only ECC1:1:1 at 1% proportions of fibers. Furthermore, strength become steady in both mixes at 28th day by approximately 4.2 MPa, which is 12% and 1.6 % more than ECC 1:0.8:1.2. Nonetheless, this decreased strength is still greater than the strength from PCC at all curing ages. The ultimate reason for this trend is non-uniform mixing of fibers in concrete. Lumps of fibers were generated during preparation of fresh concrete which resulted in suppressed strength.

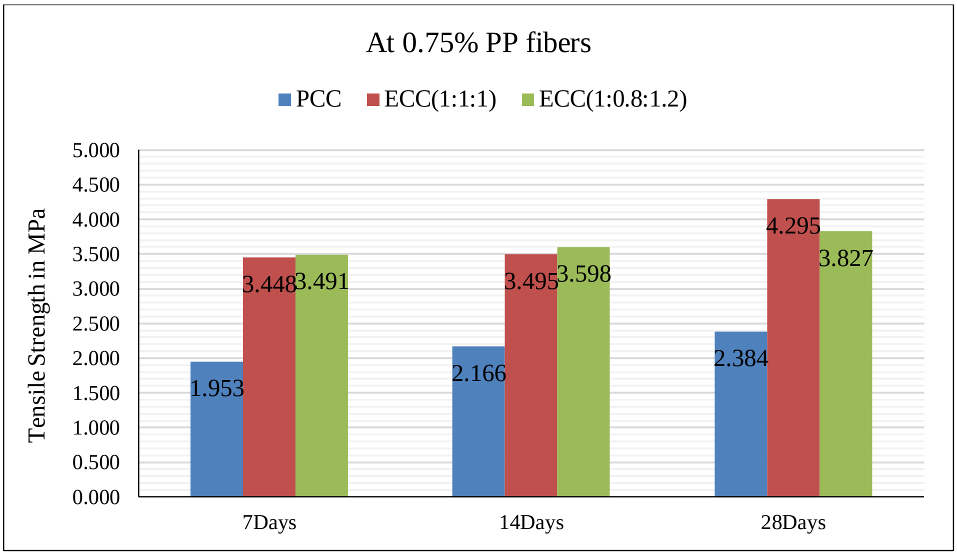


Figure 9. Tensile Strength of PCC (1:2:4), ECC (1:1:1) and ECC (1:0.8:1.2) @ 0.75% PP fibers

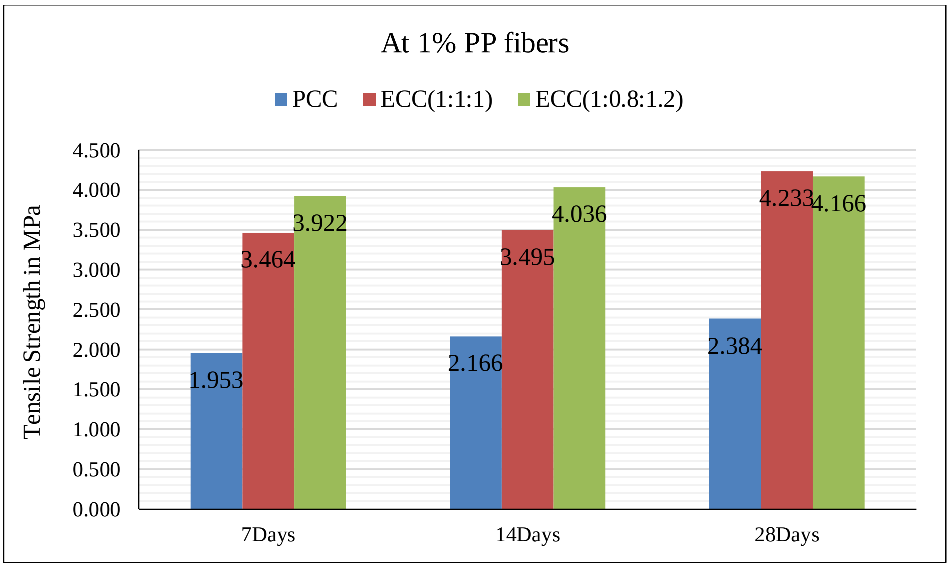


Figure 10. Tensile Strength of PCC (1:2:4), ECC (1:1:1) and ECC (1:0.8:1.2) @ 1% PP fibers

6. Conclusions

Based on results of experimental investigation conducted on PCC and ECC @ 1:1:1 and 1:0.8:1.2, the following conclusions are drawn:

- ECC 1:1:1 achieve highest indirect tensile strength at 0.5% PP fiber than normal concrete 1:2:4. The results shows an increment of 111.40% than PCC 1:2:4.
- Whereas, ECC 1:0.8:1.2 attains highest value of indirect tensile strength at 1%, which is linearly increasing from 0% to 1% that is indicating that it would further increase.
- Tensile strength in ECC 1:1:1 is increasing from (0% - 0.5%) of fibers by weight of cement and above 0.5% (such as, 0.75% and 1%) is decreasing as compared to other percentages (i.e. 0% - 0.5%).
- Tensile strength in ECC 1:0.8:1.2 is increasing from (0% - 1%) of fibers by weight of cement and it has not shown any decrement up to 1% PP fiber which is indicating that the indirect tensile strength would increase further at upper trails than 1%.
- Workability of fiber reinforced concrete is also an appreciable issue as satisfactory workability was observed with use of chemical admixture with dosage of 1%.
- ECC 1:0.8:1.2, even in this ratio the indirect tensile strength has linear increment, but as the workability is concerned that was being decreased as the fiber percentage was being increased.

It is recommended to do proper mixing of concrete for not only achieving good workability but to reduce the chances of improper distribution of fibers leading to the failure of concrete.

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