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Research Paper

Comparison of Compressive Strength and Flexural Capacity between Engineered Cementitious Composites (Bendable Concrete) and Conventional Concrete used in Bangladesh

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ABSTRACT

The Engineered Cementitious Composites (ECC) is made of the same ingredients as in regular concrete. The coarse aggregate is replaced with tiny Polyvinyl Alcohol fibres. This structure offers maximum flexibility and it is expected to cost less. It looks exactly like normal concrete, but under excessive strain, the ECC concrete allows, the specially coated network of fibre in the cement to slide within the cement, thus avoiding the inflexibility that causes brittleness and breakage. As this is a special type of concrete there are no defined codes for it, thus for these reasons, the parameters needed are to be obtained using trial and error method. During the composite preparation, sieve analysis was carried out. Composites were reinforced with Polyvinyl Alcohol (PVA) at the following ratios: 0 % (control), 0.5 %, 1 % and 1.5 %. The cylindrical specimens were subjected to compression and the slab specimens were subjected to flexural test using a Universal Testing Machine, while acquiring data with GOM Correlation Software. Test results reveal that fibre ratio 1% is most acceptable for attaining best compressive strength along with high flexural value. Even though 1% fibre content concrete in the flexural strength test showed 33% less strength of what 1.5% fibre content concrete gained, in the long run, for having the highest compressive strength value (almost 62% more than of 0% fibre content concrete and 15% more than of 1.5% fibre content concrete), 1% fibre content concrete is most suited for constructions.

1 Introduction

A new generation concrete named ECC (Engineering Cementitious Composite) is a strain-hardening concrete consists of polymer fibre. Normal concrete is vulnerable in tension but this material is capable of bending under loading, has a better tensile strength and has proved to be 50 times more flexible and 40 times lighter than conventional concrete [1]. This composite will contribute to safer, more durable, and sustainable concrete infrastructure that is cost-effective [1-3]. This concrete has the strain-hardening property but can be processed with conventional equipment. This concrete has strain

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capacity of about 3 to 5% as compared to 0.01% of conventional concrete [1-6]. ECC is a unique class of mortar-based high-performance fibre-reinforced cementitious composites featuring high tensile ductility and durability. It is prepared from the same basic materials of traditional concrete but high range water reducing (HRWR) agent is required to impart good workability [2, 5]. Flexural strength to the concrete is induced by the fibres admitted to the concrete. The concrete is produced with 2% of optimal volume of different fibres [2]. ECC flexes without fracturing, due to the interaction between fibres, sand and cement working in a matrix that binds everything together within the material. In addition to reinforcing the concrete with fibres, acts as ligaments to bond it more tightly. Due to this, instead of fracturing, the material undergoes a process called micro-cracking, wherein the energy of the tensile strain is diffused into a number of tiny cracks producing cracks of extremely small size, averaging less than 60 µm in width, roughly half the width of a human hair [7]. These micro-cracks heal themselves over time. Initially self-healing concrete costs roughly three times as much as conventional concrete. But its lower lifecycle cost is ascribed to lower repair frequency and lesser consumption of materials due to its higher ductility and durability which leads to savings in cost [4, 8, 9]. Further, this technology is being advanced by using Iron Ore Tailings (IOTs) to develop greener engineered cementitious composites (ECCs). Due to the high cement usage in ECC limits the material greenness and increases the material cost compared with normal concrete. The replacement of cement with IOTs results in 10–32% reduction in energy consumption and 29–63% reduction in carbon dioxide emissions in green ECC compared with typical ECC [10-13]

In the present study, using PVA fibre, ECC was created having fibre contents of 0% (control concrete), 0.5%, 1% and 1.5%. The specimens (both ECC and control) were made using river sand that is used to cast concrete in most places in Bangladesh. Before making concrete, the aggregates were investigated for absorption capacity, bulk specific gravity and size determination. Cylindrical concrete specimens were prepared and tested for obtaining compressive strength and slab specimens were prepared and tested for obtaining flexural capacity. Finally, a comparative study has been carried out between the test results of concrete containing fibre and control specimen.

2 Experimental Setup and Laboratory Procedures

2.1 Materials

CEM-I 52.5 N Grade Ordinary Portland Cement (OPC) was utilized for all the mixes. The normal consistency of the cement was measured 26.4% as per ASTM C187. The initial and final setting time was determined 189 min and 304 min, respectively according to ASTM C191. This cement consisted of 80-94% clinker content and 6-20% limestone (extender). Class F Fly-ash was used in the preparation of all the mixes. ECC is a special type of concrete where coarse aggregates are always avoided as these may affect the ductile properties of the matrix. Hence, only locally available river sand was used. The specific gravity and absorption capacity of aggregates were determined following ASTM C128. The physical properties of the aggregates and gradation of fine aggregates determined through sieve analysis is discussed in article 3.1.

Although various fibre types have been utilized in the production of ECC, Polyvinyl Alcohol (PVA) fibre was used for this research work. The PVA fibres used in the study was bought from Het Fulfilment Bedrijf BV, Cruquiuszoom, Netherlands. The dimensions of the PVA fibre used were 8 mm in length and 39 µm in diameter. The nominal tensile strength of the fibre was 1620 MPa and the density was 1300 kg/m^3. The properties of PVA Fibre acquired from the manufacturer are shown in Table 1. Fig 1 shows the PVA Fibre used in this study.

Fig. 1 – Polyvinyl Alcohol (PVA) Fibres used in the study

Table 1 - Mechanical and geometric properties of PVA fibre (RECS 15)

Fibre Type	Nominal Strength (MPa)	Apparent Strength (MPa)	Diameter (µm)	Length (mm)	Young Modulus (GPa)	Strain (%)	Specific Weight (kg/m^3)
PVA	1620	1092	39	8	42.8	6	1300

From the previous studies related to ECC, PVA fibres were found to be well-suited for a wide variety of applications because of their superior crack-fighting properties, high modulus of elasticity, excellent tensile and molecular bond strength and high resistance to alkali, UV, chemicals, fatigue and abrasion [6, 10, 12]. These studies also showed that, PVA fibres are unique in their ability to create a molecular bond with mortar and concrete that is 300% greater than other fibres [9]. PVA fibres are monofilament fibres that are available in three different deniers (diameter of the fibre) designated as 7, 15, and 100. The fibre lengths are 6.35 mm for (PVA-7), 7.94 mm for (PVA-15), and 12.7 mm (PVA-100). Due to the fine nature of these fibres and the fact that they disperse into monofilament fibres, they are less likely to be visible in the finished surface. How visible they are in relation to each other is directly proportionate to their various diameters (7 is least visible, 100 is most visible). Equally true, the smaller the fibre, the more fibres there are for any given unit of measure, the more likely they are to choke mixes at higher dosage rates. This is why the PVA-100 are dosed at higher rates in the more flowable mixes than of the PVA-15. As PVA-15 is a good middle ground between 7 and 100 (provides minimal visibility and good strength) we used this fibre throughout the experiment. Fibre to concrete ratio in ECC should be kept between 0.5 to 2.0% by weight. ECC uses a very small amount of fibre. Various study shows fibre to concrete ratio control the tensile, compressive and flexural strength in some extent [2, 4, 5]. Thus, to find the best ratio we experimented four different ratios of fibres. The fibre contents of 0%, 0.5%, 1.0%, 1.5% of the total weight of cementitious materials (cement and fly ash) were used to find the best mix design which not only provided the best strength but also most economical design too.

2.2 Test Specimens

For ECC, the water to cement ratio is crucial in determining the strength of the composite. A low water to cement ratio in PVA-ECC is expected to increase the strength of the mix along with promoting even fibre distribution and mixture consistency. However, bringing this ratio too low can also reduce the workability of the concrete. Research showed that the water to cementitious material (w/c) ratio 0.27 gives the best result [2]. It's recommended to keep this ratio in between 0.22-0.34, because water to cement ratio more than 0.34 might show more strain hardening behaviour and low strength. A water to cement ratio of 0.40 believed to achieve the best balance between strength and workability for us because of the replacement of silica sand with local river sand and most importantly because of discarding the use of HRWR (High Range Water Reducing Plasticizer). Chemical admixtures were to be used to obtain rheological properties that are more desirable to mix design, but considering the cost effectiveness and applying the use of locally available materials we dropped the HRWR. ECC is a mortar based composite lagging coarse type aggregate (stone or brick chips) and typically has around 2 to 3 times more cementitious material than conventional concrete [2]. The modified mix contains a cementitious content much higher than common concrete but is still within the limit specifications. We used a cementitious material to sand ratio of 2.2:0.8. The mix proportion of total four concrete mixes for both cylinder and slab specimens are summarized in Table 2.

The material should be mixed using a high-speed shear-action mixer so that the fibre is well dispersed. However, these mixers would not be representative of the large gravity-based drum mixers commonly found at concrete batch plants. So, in this research, a small shear mixer machine from Materials Laboratory of Ahsanullah University of Science & Technology was used for mixing of ECC. The mixing of the materials was done in several steps. Mixing procedure is shown in Table 3.

Table 2 - Proportion of concrete mixes

Cylinder Specimen ID	Slab Specimen ID	Fibre Percentage	Cement (kg/m^3)	Fly Ash (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Fibre (kg/m^3)
CF0 (control)	SF0 (Control)	0	583	700	513	467	---
CF0.5	SF0.5	0.5	583	700	513	467	6.415
CF1	SF1	1	583	700	513	467	12.83
CF1.5	SF1.5	1.5	583	700	513	467	19.245

Table 3 - Various mixing sequences that were evaluated in the mixing procedure

Mixing Sequence	Step 1	Step 2	Step 3
Aggregates	75% water + 100% sand	100% fly ash	100% Cement + 25%water
Mixing duration	0.5 minute	2 minutes	2 Min 30 Sec

After the mixing procedure was completed, the mixture was poured into the specific moulds to make the cylinder and slab specimens.

2.3 Test Setup

An experiment for compression test on cylindrical specimens and four points bending test on slab were performed at the Materials Laboratory of Ahsanullah University of Science & Technology. Compressive strength was tested according to ASTM C39 standard test method using moulded cylindrical specimens. Where as flexural strength test was performed as per ASTM C78 code. For compression test, cylindrical concrete specimens of 75 mm by 150 mm (height 150 mm, Dia. 75 mm) in size were made and for flexural strength test, slab concrete specimens of 350x100x25 mm in size were made.

The freshly consolidated concrete kept in the moulds were covered with damped clothes for one day. After one day of casting, the specimens were removed from the moulds and then kept under lime water for curing up to 90 days. 1,000kN capacity digital Universal Testing Machine (UTM) in Fig. 2(a) was used to apply load on the specimens at a rate of 3mm/min. The vertical displacement and axial load were recorded from the load cell of UTM as illustrated in Fig. 2(b). The test setup of flexural strength test and the test specimen during the failure are shown in Fig. 2(c) and Fig. 2(d) respectively.

(a) Digital universal testing machine (UTM)

(b) Test setup of compression test

(c) Test setup of flexural strength test

(d) Test specimen during of flexural strength test

Fig. 2 – Different phases of the experiments

3 Results and Discussion

3.1 Physical Properties of Aggregates and Sieve Analysis

The physical properties of the aggregates are summarized in Table 4. Gradation of fine aggregates determined through sieve analysis according to ASTM C136 is plotted in Fig. 3.

Table 4 - Physical properties of aggregates

Properties	Fine Aggregates
Bulk Specific Gravity (OD)	2.63
Bulk Specific Gravity (SSD)	2.74
Apparent Specific Gravity	2.94
Absorption Capacity (%)	4
Fineness Modulus	1.5
Unit Weight (kg/m^3)	1456.67

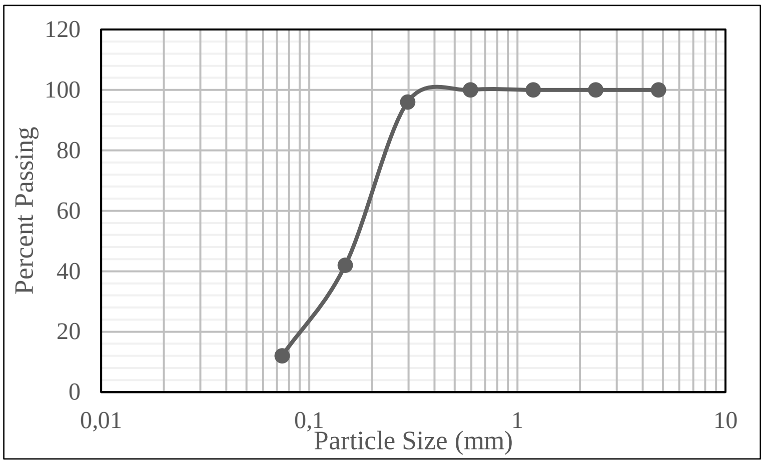


Fig. 3 – Gradation curve of fine aggregates

3.2 Compressive Strength Test

As it was observed in the previous works related to ECC, it is the type of concrete that gains strength even after 28th day of curing whereas conventional concrete doesn’t. That’s why the curing process was extended up to 90 days. The values of load from the UTM machine were recorded using a video recorder and then the video was processed for strain values using GOM Correlation Software. With the strain values acquired from the correlation software and the stress calculated from the values of load from, UTM, stress vs. strain graphs were plotted for every specimen and the results were analysed thoroughly. Fig. 4 presents the stress vs. axial and lateral strain responses of concrete cylinders made with and without PVA fibre after 28 days of curing and Fig. 5 presents the comparison after 90 days of curing. From Fig.4, it has been observed that concrete specimens with PVA fibre have comparatively higher compressive strength than that of control concrete. From Fig. 5, it has been observed that even after 28 days of curing, the specimens with PVA fibre gained strength and the control concrete stopped or gained very little strength. PVA fibre is the type of material that acts like a skeleton for the cementitious materials and helps the concrete gain strength over time. Fig. 6 presents the average compressive strength chart and Fig. 7 presents the relative comparison of compressive strength test values between the control specimen and concrete with different percentage of fibre on day 90. From Fig. 7, it has been clearly noticed that compressive strength values for specimens with PVA fibre content of 0.5%, 1%, 1.5% were increased by almost 20%, 60% and 40% respectively with respect to control concrete. It indicates that under compression, concrete with PVA fibre is stronger than that of control concrete.

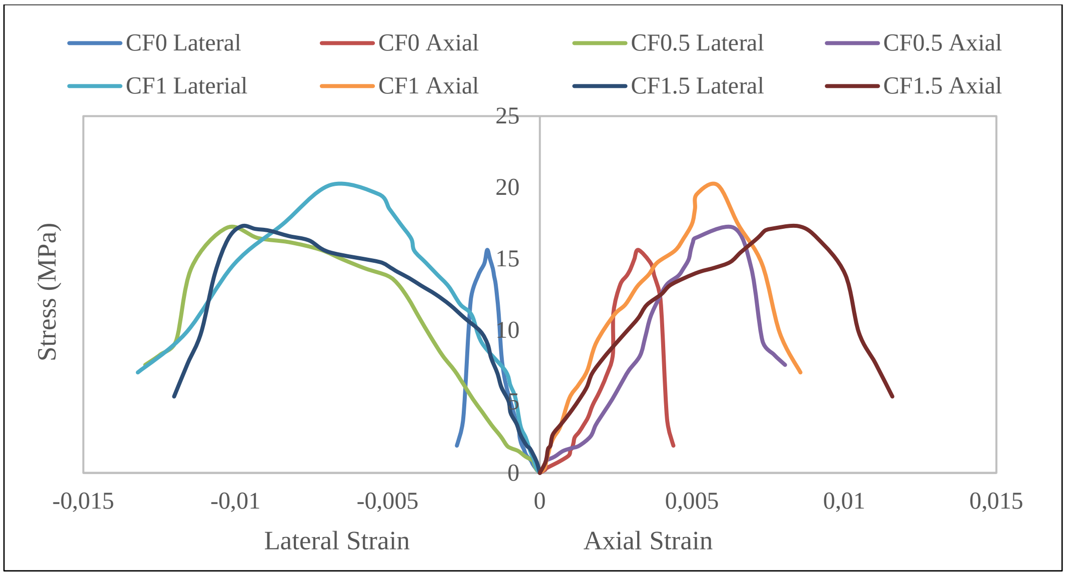


Fig. 4 – Stress vs Strain Combined Graph of Day 28 (Compressive Strength Test)

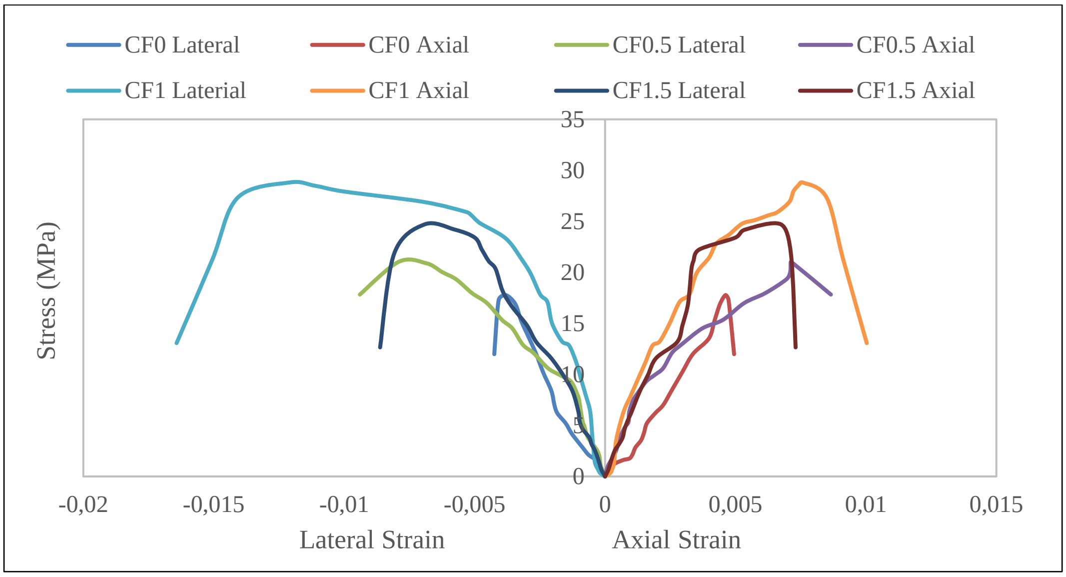


Fig. 5 – Stress vs Strain Combined Graph of Day 90 (Compressive Strength Test)

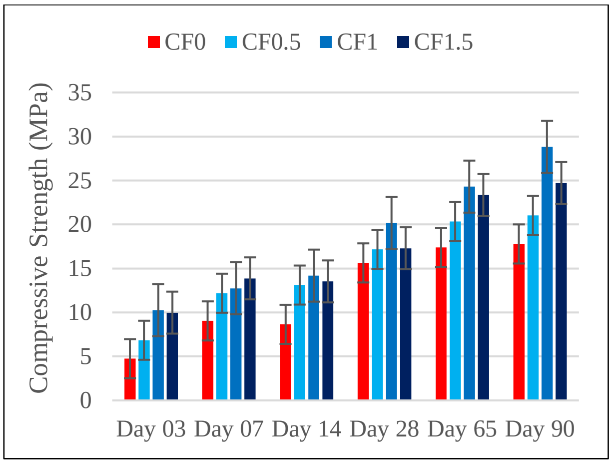


Fig. 6 – Average Compressive Strength Chart

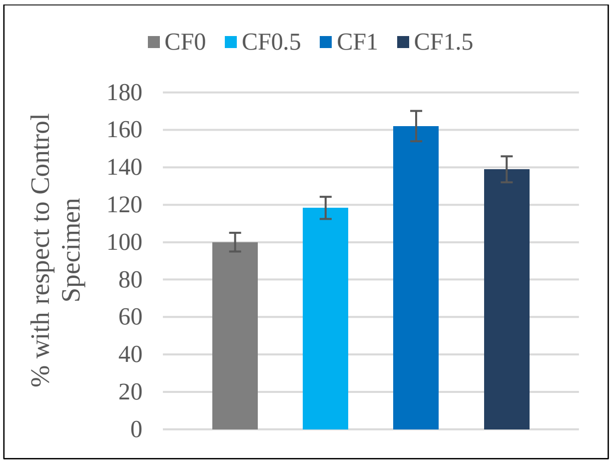


Fig. 7 – Comparison of Compressive Strength for test specimens on Day 90

3.3 Flexural Capacity Test

Curing for slab specimens were also extended up to 90 days due to the strength gaining of ECC. Flexural capacity is a very important property for the concrete as conventional concrete fails to bend when load is applied because of its vulnerability to tensile cracking. Using the UTM (Universal Testing Machine), flexural strength test was done on the slab specimens. A four-point load was applied to the specimens and bendability of the concrete was observed. Using the following formula and method shown in Fig. 8, the test was done.

$$\sigma = \frac{FL}{bd^2} \quad (1)$$

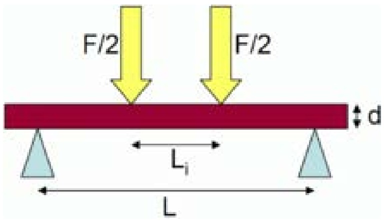


Fig. 8 – Beam under 4-point bending

Here, F is the load (force) at the fracture point, L is the length of the support (outer) span, b is width, and d is thickness of the slab specimen. L_i is 1/3 of L. Fig. 9 presents the average flexural strength chart and Fig. 10 presents the relative comparison of flexural strength test values between the control specimen and concrete with different percentage of fibre on day 90. From Fig. 10, it has been clearly noticed that flexural strength values for specimens with PVA fibre content of 0.5%, 1%, 1.5% were increased by almost 30%, 5% and 55% respectively with respect to control concrete. It indicates that under bending load, concrete with PVA fibre is stronger than that of control concrete.

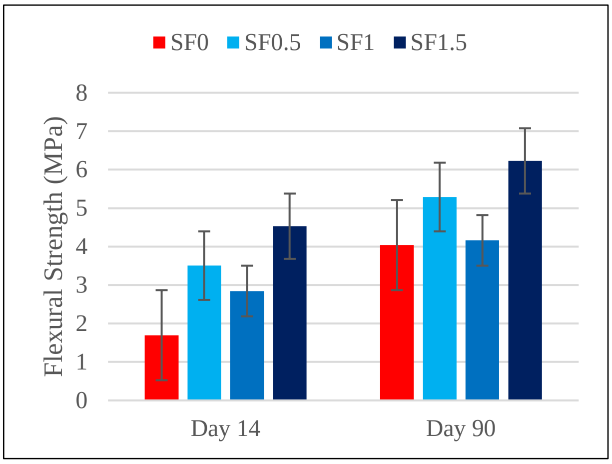


Fig. 9 – Average Flexural Strength Chart

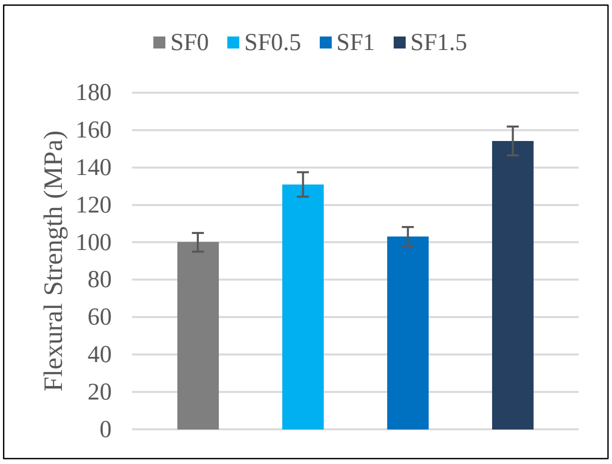
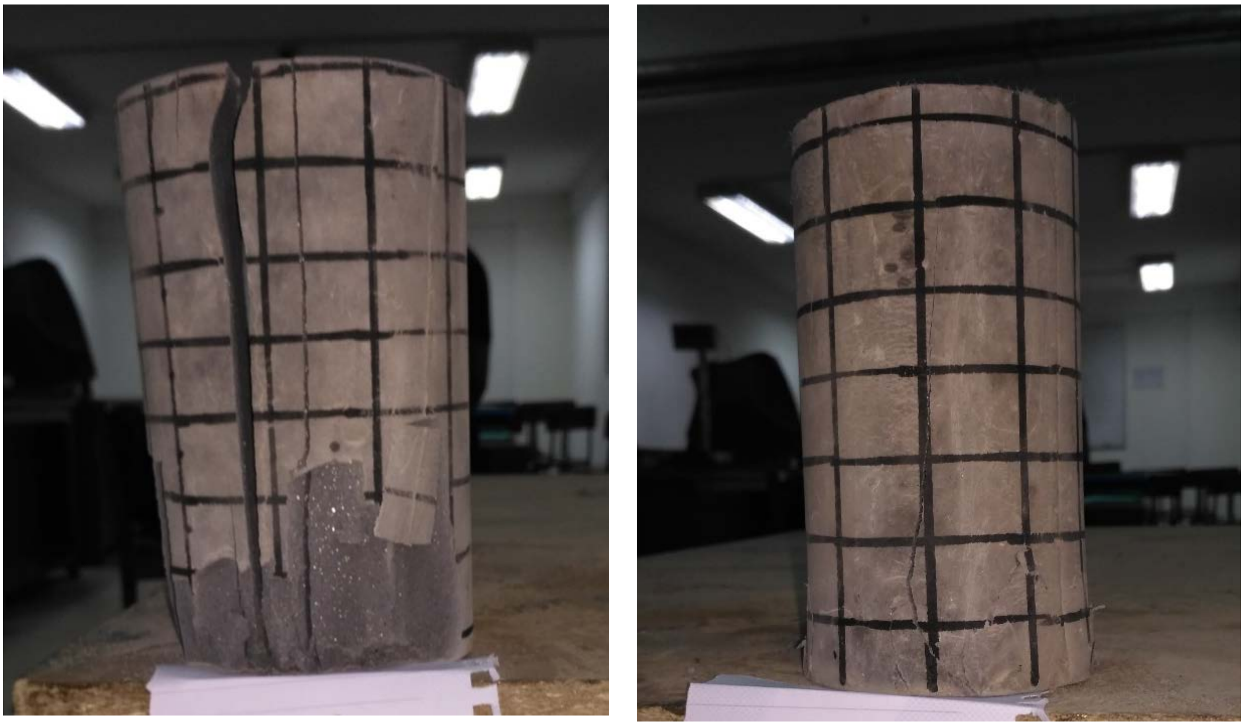


Fig. 10 – Comparison of Flexural Strength for test specimens on day 90

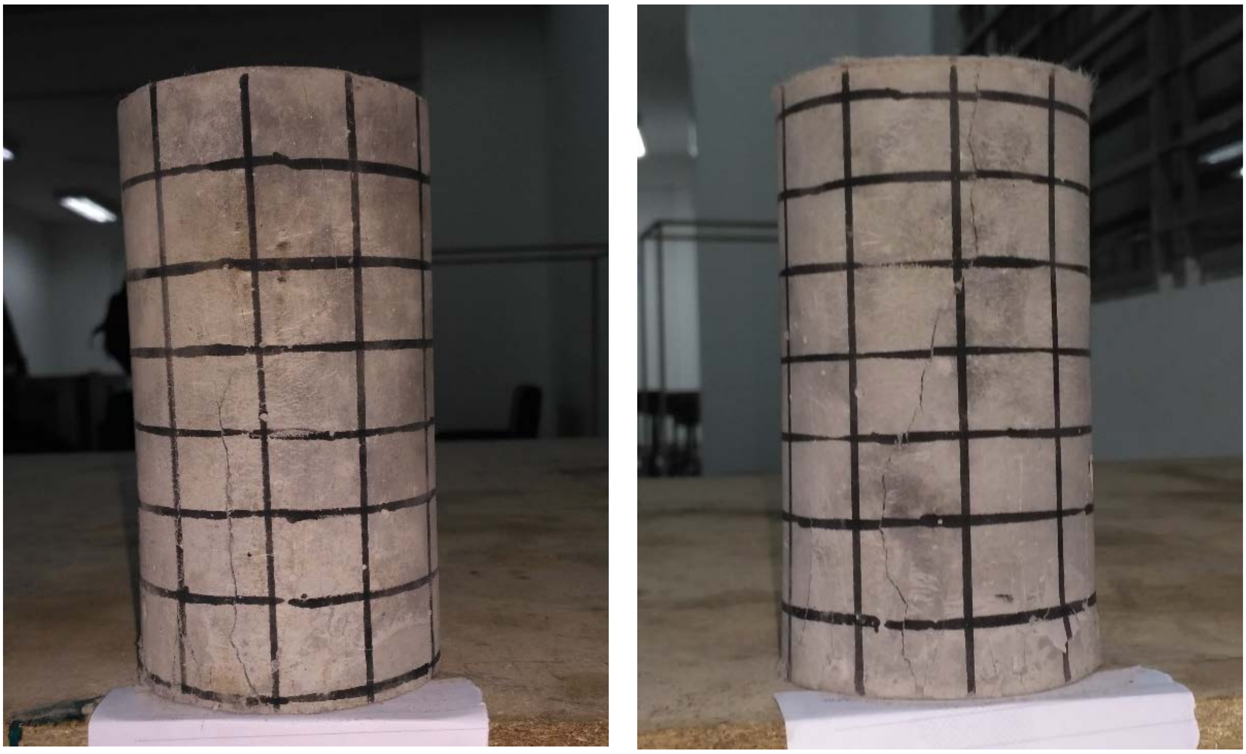
3.4 Failure Pattern

From Fig. 11, it is clearly evident that under compressive load, the failed control specimen shows more rupture tendency than concrete specimens with fibre. The specimen with fibre only showed micro-cracks while the control specimens completely raptured.

From Fig. 12, it has been noticed that under bending (four-point) load, the control test specimen was divided completely into two pieces right after it hit the highest load intake capacity. But the specimens with fibre did not split after reaching the highest load intake capacity, instead at first, they bended and then started to split. Also, it can be observed that the specimens with fibre content never completely split. This clearly indicates that concrete with fibre can withstand more load than of the control concrete.



(a) Control (b) 0.5% Fibre



(c) 1% Fibre (d) 1.5% Fibre

Fig.11 – Failure pattern of concrete specimens after compression test

(a)
Control

(b)
0.5% Fibre

(c)
1% Fibre

(d)
1.5% Fibre

Fig. 12 – Failure pattern of concrete specimens after four-point bending test

4 Conclusion

After completing the experiments and analysis, it can be seen that the compressive strength for 0.5% of PVA fibre was increased by almost10% to 60% of conventional concrete, for 1% of PVA fibre was increased by almost 30% to 115% of conventional concrete and for 1.5% of PVA fibre was increased by almost 10% to 110% of conventional concrete throughout the days of the curing of specimens. On the 90th day of curing, the specimens with 1% PVA fibre showed 62% increased compressive strength where 1.5% PVA fibre showed 40% increased compressive strength. The compressive strength of concrete was found to be maximum when the fibre content was 1.0%. As the fibre content was increased to 1.5%, there was about 15% drop in compressive strength because fibre ratio can cause balling effect and reduces workability. This can be compared to segregation in ordinary concrete, creating localization of fibre rather than a smooth homogeneous mixer.

Strain values for compressive specimens give us insights about the ductility, reinforcement direction, poison ratio, modules of elasticity comparison between the ordinary concrete and ECC. The change in strain capacity was negligible for conventional concrete causing sudden failure. Also, the slope of those curve observed to be pretty steep. For the 0.5% PVA fibre specimens, the strain capacity changed drastically and to a higher value. As the fibre content was increased, the strain capacity also increased and for 1.5% PVA fibre, it almost increased by 140% of conventional concrete. From the combined graphs, it was observed that the 0% PVA fibre specimens had the steepest curve where for 0.5%, 1% and 1.5% PVA fibre specimens, the curves were very gentle. They provided better strain value. After a long curing process, ultimate strength gained by the 1% PVA fibre specimen, observed to be the best ductile material.

Flexural slabs under four-point loading were analysed for load-displacement behaviour of concrete and ECC. ECC increased flexural capacity about 40% and most importantly the strain displacement capacity by 300%. Investigation showed that conventional concrete plays insignificant role in flexural strength while the flexural strength for 0.5% of PVA fibre was increased by almost 30% to 132% of conventional concrete, for 1% of PVA fibre was increased by almost 3% to 70% of conventional concrete and for 1.5% of PVA fibre was increased by almost 54% to 167% of conventional concrete throughout the days of the curing of specimens. The flexural strength of concrete was found to be maximum when the fibre content was 1.5%. For fibre content 1.0% specimens, the flexural strength was even lower than 0.5% fibre content specimen. The reason behind such error is making of non-homogenous mixture which was caused by the shear mixture machine and its rotation speed. The flexural strength was dropped by almost 21% when the fibre content was increased from 0.5% to 1.0%. Again, the flexural strength was gained by almost 33% when the fibre content was increased from 1.0% to 1.5%.

In the flexural capacity test, the displacement of 1% fibre content specimen is 44% down by the fibre content of 1.5% from mid-point. The displacement of mid-point of the specimen defines its bendability. The more the displacement is, the better is the bendability. From the observation, it can be concluded that the 1.5% PVA fibre ECC showed better bendability.

In the above comparisons the compression strength and flexural strength of the bendable concrete is comparatively higher than the conventional cylinders and slabs. The reason behind the higher strengths of bendable concrete is due to the presence of fibre as reinforcement. Whereas, the strength of conventional cylinders and slabs is comparatively low since it is not reinforced with any fibre.

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REFERENCES

[1]- S. Gadhiya, T.N. Patel, D. Shah, Bendable Concrete: A Review. Int. J. Struct. Civil Eng. Res. 4(1) (2015) 141-147.

[2]- V.C. Li, T. Kanda, Innovations Forum: Engineered Cementitious Composites for Structural Applications. J. Mater. Civil Eng. 10(2) (1998) 66-69. doi:10.1061/(asce)0899-1561(1998)10:2(66).

[3]- M.I.F. Alam, A. Rahman, M.R. Haque, Experimental Studies on Engineered Cementitious Composites (Bendable Concrete), B. Sc. Thesis, Ahsanullah University of Science and Technology, Dhaka, 2019.

[4]- M. Lepech, V.C. Li, Design and Field Demonstration of ECC Link Slabs for Jointless Bridge Decks. In: Proceedings of the third International Conference on Construction Materials: Performance, Innovations and Structural Implications, Vancouver, 2005, pp. 22-24.

[5]- M.D. Lepech, V.C. Li, Large-Scale Processing of Engineered Cementitious Composites. ACI Mater. J. 105(4) (2008) 358-366.

[6]- M.B. Mavani, Fresh/Mechanical/Durability Properties and Structural Performance of Engineered Cementitious Composite (ECC). M. Sc. Thesis, Ryerson University of Toronto, 2012.

[7]- K.B. Madhavi, M. Venugopal, V. Rajesh, K. Suresh, Experimental Study on Bendable Concrete. Int. J. Eng. Res. Tech. 5(10) (2016) 501-504. doi:10.17577/ijertv5is100400.

[8]- V.C. Li, E.H. Yang, Self-healing in Concrete Materials. In: van der Zwaag S. (eds) Self Healing Materials. Springer editions, 2007, pp. 161–193. doi:10.1007/978-1-4020-6250-6_8.

[9]- M.D. Lepech, V.C. Li, Long Term Durability Performance of Engineered Cementitious Composites. Restor. Build. Monuments 12(2) (2006) 119-132. doi:10.1515/rbm-2006-6038.

[10]- X. Huang, R. Ranade, V.C. Li, Feasibility Study of Developing Green ECC Using Iron Ore Tailings Powder as Cement Replacement. J. Mater. Civil Eng. 25(7) (2013) 923-31. doi:10.1061/(asce)mt.1943-5533.0000674

[11]- E.H. Yang, Y.Z. Yang, V. Li, Use of High Volumes of Fly Ash to Improve ECC Mechanical Properties and Material Greenness. ACI Mater. J. 104(6) (2007) 620-628.

[12]- V.C. Li, Tailoring ECC for Special Attributes: A Review. Int. J. Concrete Struct. Mater. 6(3) (2012) 135–144. doi:10.1007/s40069-012-0018-8.

[13]- Y. Zhu, Y. Yang, Y. Yao, Use of Slag to Improve Mechanical Properties of Engineered Cementitious Composites (ECCs) with High Volumes of Fly Ash. Const. Build. Mater. 36(2012) 1076–1081. doi:10.1016/j.conbuildmat.2012.04.031.