

Enhancing PVCC beam performance through PVA fiber and basalt fabric in sustainable construction: ductility, strength, and energy absorption improvements

P. Prasanthni¹ , B. Priya², T. Palanisamy³, G. Dineshkumar⁴

¹K. S. R. College of Engineering, Tiruchengode, Namakkal, Tamilnadu-637215, India.

²Nandha Engineering College, Erode, Tamilnadu, India.

³National Institute of Technology, Surathkal, Karnataka, India.

⁴Vaagdevi College of Engineering, Warangal, Telangana, India.

e-mail: prasanthni@ksrce.ac.in, pri_erd@yahoo.com, tpalanisamicivil@nitk.edu.in, gdkcivil@gmail.com

ABSTRACT

This study evaluates the performance of PVCC (Polyvinyl Alcohol Cementitious Composite) layered beams (BP1 to BP5), basalt fiber fabric-wrapped beams (BB1 and BB2), and a control beam (B0). Results show that specimen BP3, with 1.2% PVA fiber in PVCC layered beam, and BB2, with basalt fiber fabric wrapped at the bottom up to the neutral axis, exhibit superior performance. BP3 delays first crack initiation, increases the ultimate load-carrying capacity by 19.87%, and achieves a remarkable 54.57% increase in maximum ductility compared to B0. BP3 also demonstrates 54.54% higher stiffness and notable energy absorption. Similarly, BB2 outperforms BB1 and B0 in first crack load, ultimate load carrying capacity, ductility, stiffness, energy absorption, and energy index. BB2 exhibits 2.10 times increase in ductility compared to B0. Incorporating PVA fiber in PVCC layered beams and basalt fiber fabric wrapping offers better improvements in crack resistance, load capacity, ductility, stiffness, and energy absorption, contributing to innovative and sustainable beam design in construction.

Keywords: PVCC layered beams; Basalt beams; Ductility enhancement; Sustainable beam design.

1. INTRODUCTION

Different techniques for the strengthening and repair of structural elements such as beams and columns as made in recent research. Major repairs will need for most of the reinforced concrete structures shortly to avoid partial or total collapse during earthquakes. And also, to reduce the considerable deformation of the structural elements in the structure, new composites or technique is needed [1]. Strengthening existing structures is the biggest challenge that civil engineers are facing these days [2]. For strengthening the reinforced concrete structural members, a new technique through fiber cementitious composites and external wrapping with fiber fabric was proposed in this study. The advantages of using fiber cementitious composites and wrapping increase the flexural, shear, axial load carrying capacity, and seismic behavior of the reinforced concrete structures [3].

BROWN *et al.* [4] in their work reported that the weakening of concrete structures due to steel corrosion is a significant concern since repairing these structures has shown to be a costly process. They also stated that reinforcing the concrete structures with fibers is one of the possible ways and there is an increasing worldwide interest in utilizing fiber-reinforced concrete structures for civil infrastructure applications [5]. SEN and REDDY [6] reported that the materials chosen for structural up gradation must, in addition to functional efficiency and increasing or improving the various properties of the structures, should fulfill some criterion, for the cause of sustainability and better quality [7]. DOMKE *et al.* [8] have reported that considerable efforts have been taken worldwide to utilize local natural waste and by-products materials as supplementary cementing materials to improve the properties of cement concrete [9]. LEPECH and LI [10] deal with the importance of sustainability of the environment in which the structure is being built in making infrastructure design and maintenance decisions. A preliminary case study is being done on the green material design framework [11]. To improve the sustainability of the structure, a new cement-based composite is required, and it is being analyzed by application in the green material design framework. A large number of substitutes including industrial wastes were used to gauge their

properties with ECC. Among them, green foundry sand, fly ash, and cement kiln dust show a greater tendency to replace certain raw materials within ECC composites [12]. The addition of green foundry sand reduces the tensile strain capacity of ECC. By Re-engineering the fiber-matrix interface, the multiple cracking behavior and strain hardening capacity is being restored. The result of this paper indicates the application of Micromechanics and sustainable infrastructure design performance. AHMED and MIHASHI [13] discuss the various properties of PVA fiber-reinforced cementitious composites. The test is being done for different hybrids of PVA fibers of varying lengths. The composite containing finer lightweight sand has higher ultimate strength than that of a composite containing coarser lightweight sand [14]. The lightweight hybrid PVA fiber-reinforced cementitious composite has a higher strain hardening capacity. The result shows that the ultimate load of lightweight hybrid fiber is lower than that of natural silica, but the c_{mod} at peak load is higher than normal silica sand. KENDALL *et al.* [15] deal with the life cycle of structures utilizing ECC composites. The sustainability of a material can be evaluated based on the life cycle of the structure. The life cycle can be assessed by proposing a framework [16]. This framework is applied to ECC used as a link slab in bridge decks. This modeling shows various waste materials used to retain adequate durability process. In bridge deck construction and rehabilitation works, it generates a greater life cycle of the structure. KIM *et al.* [17] deal with the study of wet mixtures suitable for the shotcreting process in the fresh state. This can be developed by creating micromechanics and rheological design. Due to the controlled rheology of the fiber matrix and dispersion of fibers, the spray ability and pumpability of ECC are enabled [18]. The result shows that an ECC having pump ability and spray ability properties at fresh and strain-hardened states has been developed by rheological and micromechanical design [19]. Fiber composite strengthening in concrete has many advantages. The usage of fiber composite strengthening materials has higher ultimate strength compared to normal composite materials. Moreover, the irregularities in the shape of the concrete surface can be taken up by these fiber composite materials. The steel plate used in concrete has to be pre-bent to the required radius since the material can follow a curved profile. Similarly, the material fibers and resins are durable, and it requires little maintenance if it is correctly specified [20–23].

This work aims to find out the alternative composites/techniques by the evaluation of its characteristics in reinforced concrete structures. In this work, a new composite named Polyvinyl Alcohol Cementitious Composites (PVCC) was developed and it is provided at the bottom of the beam at the cover zone instead of cover thickness with various dosage levels of Polyvinyl Alcohol (PVA) fiber addition, and also new wrapping technique using natural-based basalt fiber fabric was used in this work to strengthen the beams. This natural-based basalt fiber fabric was bonded externally by epoxy resin at the bottom alone and bottom with side faces of the beam up to the neutral axis. The developed PVCC was registered for a patent in the name of “PVA Concrete Composite panel”.

2. MATERIALS AND SAMPLE PREPARATION

Ordinary Portland Cement (OPC) of Grade 53 was used. The cement used for this study conforming to IS 12269–1987 [24]. Testing was carried out on cement samples by IS: 4031 [25]. Fly ash used for this work was attained from Mettur Thermal Power Station, Tamilnadu. The vital role of adding class F fly ash is to supply additional fines for compaction [26]. Naturally available river sand with a fraction passing through 4.75 mm sieve and retained on the 600 μ m sieve was used for casting specimens and sand passing through 4.75 mm and retained on 200 μ m sieve was used for casting Polyvinyl Alcohol Cementitious Composites with a specific gravity of 2.70 [27–29]. Crushed blue granite coarse aggregates of particle size 20 mm were used for the present investigation, and it is confirmed as per IS 383–1970 [30] with a specific gravity of 2.68 [31]. Available tap water in the laboratory was used for mixing and curing the specimens as well. Polyvinyl Alcohol fiber purchased from Spinning King Limited, Gujarat was used in this research work. Basalt fiber fabric was formed by melting the Basalt rock at high temperature (1450°C) and rapidly drawn it into a continuous fiber, and it was made as fabric. It is commonly known as Basalt Fiber Fabric [32]. Basalt fiber fabric of 320 grams per meter square was purchased from Arrow Textile Technical Limited, Mumbai. The developed PVCC was provided in the bottom of the beam at cover zone instead of cover thickness during casting of specimens. The PVCC layered beam was cast by providing PVCC layer with a various dosage level of PVA fiber such as 0.40%, 0.80%, 1.20%, 1.60%, and 2% by volume of the composite [33].

3. EXPERIMENTAL STUDY

Totally eight numbers of the test specimen were cast for the study of the structural behavior of PVCC layered, and basalt fiber fabric wrapping reinforced concrete rectangular beams [34]. Among all the eight beams, out of which one is taken as a control beam. The five beams were cast as PVCC layered beams by providing a PVCC layer in the bottom of the beam at the cover zone instead of cover thickness with a various dosage level of PVA fiber such as 0.4%, 0.8%, 1.2%, 1.6%, and 2% by volume of the composite and other two beams were wrapped

with basalt fiber fabric after casting which is provided at the bottom alone and bottom with side faces of the beam up to neutral axis [35].

3.1. Preparation of beam specimen

The design of beam was carried out using Limit state method using IS 456:2000 [36] and detailing were made as per IS 13920:1993 [37]. The beam with 2 nos. of 20 mm diameter bar and 2 nos. of 16 mm diameter bar is used as tension and compression reinforcement [38]. As per IS 13920:1993, the transverse reinforcement is provided with 8 mm diameter bar at 50 mm c/c from both the end at a length of 300 mm and rest of the length is provided with 100 mm c/c [39]. The detailing figure of the rectangular beam is shown in Figure 1. By using the concrete mixer, the mixing is done, and the beams were kept for 28 days curing [40]. The plywood sheet mould is used for making beam specimens with the size of 170 mm $\times$ 250 mm $\times$ 1400 mm [41]. The typical representation of Control, PVCC layered, and Basalt Fiber Fabric Wrapped Rectangular Beam [42]. The typical representation of Control, PVCC layered, and Basalt Fiber Fabric Wrapped Rectangular Beam is shown in Figure 2. The developed PVCC was provided in the bottom of the beam at the cover zone instead of cover thickness during the casting of specimens. By providing PVCC layer at the cover zone may assist the tension face concrete to arrest tension cracks. To evaluate the structural behavior of the wrapped RC Rectangular beam, the natural-based basalt fiber fabric wrapping was provided at bottom alone and bottom with side faces of the beam up to the neutral axis [43]. These wrapping may assist the tension face of concrete to arrest tension cracks and also assist side faces of concrete to arrest shear cracks.

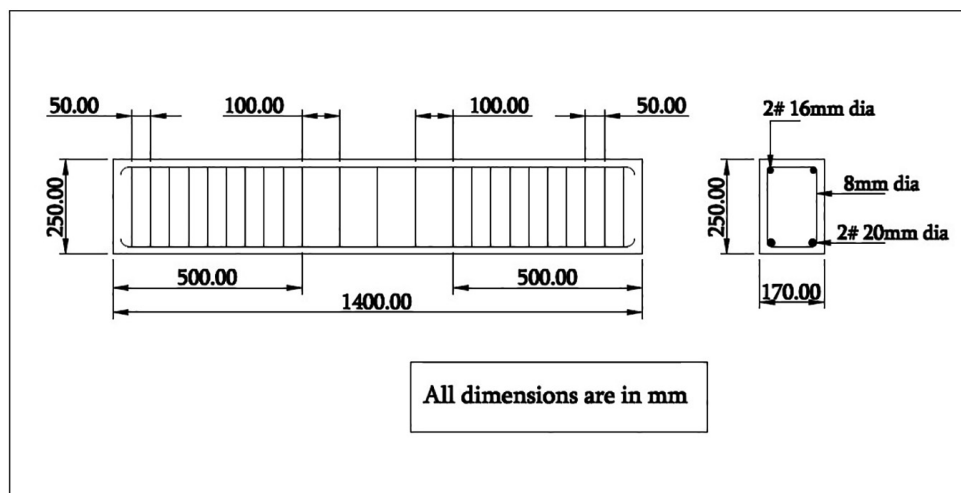


Figure 1: Detailing of reinforced concrete beam.

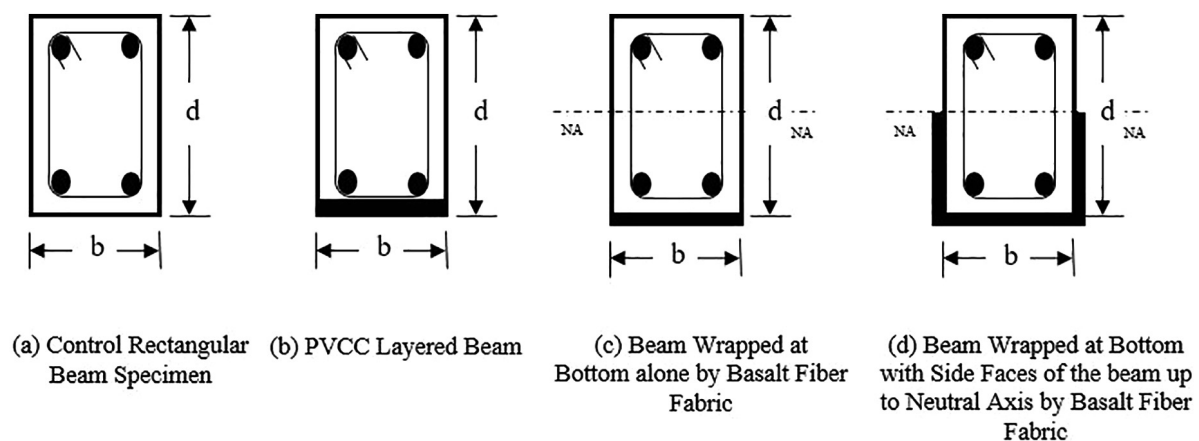


Figure 2: Control, PVCC layered, and basalt fiber fabric wrapped rectangular beam.



Figure 3: (a) Experimental test setup of beam specimen. (b) Failure pattern of control B0 beam specimen. (c) Failure pattern of PVCC layered BP3 beam specimen. (d) Failure pattern of basalt fiber fabric wrapped BB1 beam specimen. (e) basalt fiber fabric wrapped beam specimen.

3.2. Experimental test setup for beam specimen

The test was carried out in 100 T loading frame. The testing beam was rested on the two simply supported rollers. By using hand operated hydraulic jack, the load was gradually applied to the specimen. The load is applied at an increment of 10 kN up to the failure of the specimen. To measure the deflection, the LVDT was used at mid-span and 1/3 distance from the end support [44, 45]. Figure 3(a) shows the experimental test setup of beam specimen. Figure 3(b), 3(c), 3(d) shows the failure pattern of control B0, PVCC layered beam specimen (BP3) and Basalt fiber fabric wrapped beam specimen (BB1). Figure 3(d) shows the experimental test setup Basalt fiber fabric beam specimen (BB2).

4. TEST RESULTS AND DISCUSSION

In this section, structural evaluation of PVCC layered reinforced concrete beam under static loading are discussed. The results and discussion section include two parts. The first part deals with the structural behavior of PVCC layered reinforced concrete beam and second part deals with the structural behavior of the basalt fiber fabric wrapped reinforced concrete beam [46]. It is noticed that all the beams have failed in a flexural mode [47]. The first crack load, ultimate load carrying capacity, load deflection curve, ductility factor, stiffness, energy absorption capacity and energy index are presented and discussed in the following section.

4.1. PVCC layered reinforced concrete beam

4.1.1. First crack load

For PVCC layered, the first crack load of control reinforced concrete beam (B0) and PVCC layered reinforced concrete beams (BP1 to BP5) are shown in Figure 4. For the control specimen (B0) the first crack was initiated at 80 kN and it is occurred at the bottom face of the beam. With the addition of 0.4%, PVA fiber in PVCC layered concrete beam (BP1) shows the first crack at the load level of 84 kN. For the specimen BP2 and BP3 with PVA fiber addition of 0.8% and 1.2% in PVCC layered beam, there is an increase in the first crack load, and it is found as 88 kN and 92 kN, respectively. The first crack was noticed soon for the specimen BP4 and BP5 when compared with BP3 specimen, and it is found as 86 kN and 82 kN with 1.6% and 2% addition of PVA fiber in PVCC layered concrete beam, respectively.

4.1.2. Ultimate load carrying capacity

The ultimate load carrying capacity for control reinforced concrete beam (B0) and PVCC layered reinforced concrete beams (BP1–BP5) are shown in Figure 5. The ultimate load for the control specimen was found to be 113 kN. The ultimate load for control beam was attained at the load level of 113 kN. With the addition of 0.4% and 0.8% PVA fiber in PVCC layered beam obtains the ultimate load of 125 kN and 132 kN, respectively for the specimen BP1 and BP2. The specimen BP3 with the addition of 1.2% of PVA fiber in PVCC layered beam reaches the ultimate load of 141 kN. The ultimate load carrying capacity of BP4 and BP5 specimen with the addition of 1.6% and 2% of PVA fiber in PVCC layered beam shows a slight decrease in load level and it is noted as 137 kN and 122 kN, respectively. Figure 6 shows the comparison of first crack and ultimate load of

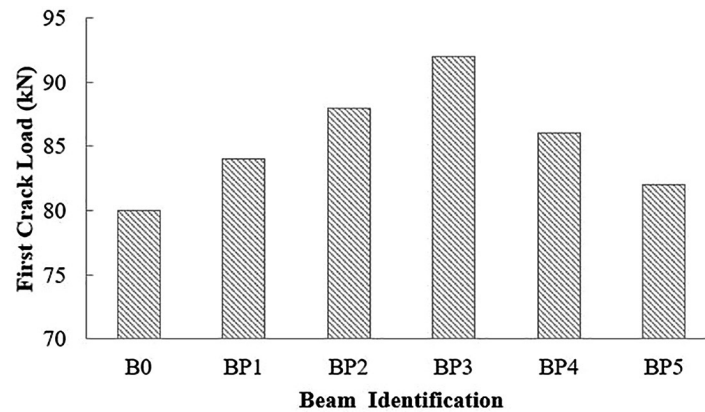


Figure 4: First crack load of control and PVCC layered beams.

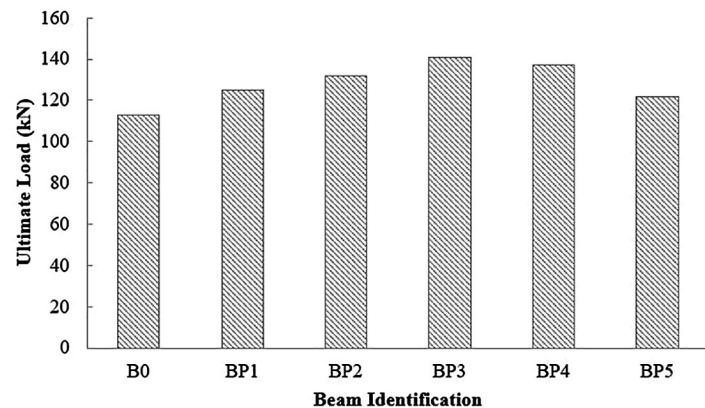


Figure 5: Ultimate load carrying capacity of control and PVCC layered beams.

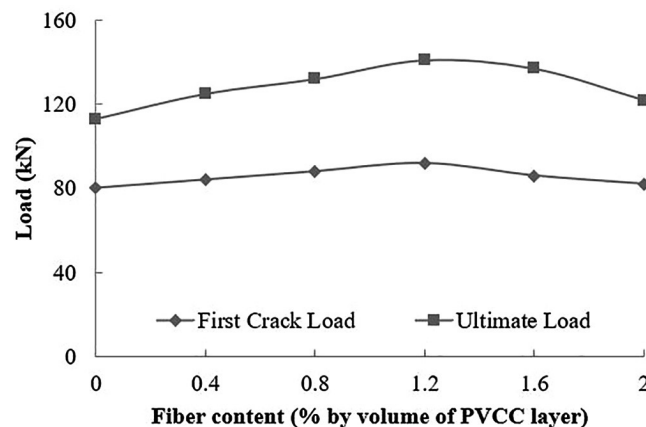


Figure 6: Comparison of first crack load and ultimate load carrying capacity of control and PVCC layered beams.

control and PVCC layered beam. The optimum dosage level of addition of PVA fiber in PVCC layered beam was derived as 1.2%. Beyond this dosage level the cement mortar become less due to increasing fiber content. Due to bonding problem the strength may tend to decrease beyond this limit.

4.1.3. Load deflection behavior

For control reinforced concrete beam (B0) and PVCC layered reinforced concrete rectangular beam (BP1 to BP5), the load deflection behaviors were drawn and it is shown in Figure 7. The specimen BP3 carries more load and resist more deflection due to existence of the optimum fiber content in the PVCC layered mixtures when compared with all other PVCC layered reinforced concrete beams. While increasing the load, multiple cracks have been developed and propagated without splitting of beam. Whenever PVCC layered beam specimen subjected to formation and propagation of cracks, there is a change in slope of the load deflection curve. The first crack was initiated at the bottom of the beam at a load of 80 kN for control beam specimen B0, and the related deflection is noted as 2.38 mm. At the load of 113 kN, the beam specimen B0 reaches the ultimate load and, the corresponding deflection is recorded as 6.4 mm. At the load of 84 kN, the first crack with the corresponding deflection of 1.98 mm. The specimen BP1 obtained the ultimate load of 125 kN with a deflection of 4.44 mm. For the beam specimen BP2, the first crack and ultimate load are recorded as 88 kN and 132 kN and its deflection is noted as 1.62 mm and 4.72 mm. The first crack was developed at 92 kN and the ultimate load is found to be 141 kN for the PVCC layered beam specimen BP3. Deflection of 1.27 mm was noted for first crack load and 5.14 mm was noted for ultimate load. The first crack load and the ultimate load for the PVCC layered beam specimen (BP4) was noticed at 86 kN and 137 kN. The corresponding deflection for the first crack and ultimate load was recorded as 1.21 mm and 4.52 mm.

The first crack was observed at the load of 82 kN and the deflection was marked as 1.88 mm for the PVCC layered beam specimen (BP5). The ultimate load tends to decrease gradually, when compared to other PVCC layered mixtures and it reaches the load level of 122 kN with deflection of 4.33 mm. Comparison of load-deflection curves for control and PVCC layered beams are shown in Figure 7. Beam BP1 to BP5 showed better performance when compared to control beam B0. The mode of failure observed for the all the specimen BP0 to BP5 is a flexural failure.

4.1.4. Ductility behavior

In this investigation ductility factor was calculated by maximum deflection to the yield deflection. The ductility value of 2.68 was calculated for the control beam specimen (B0). With the addition of 0.4% of PVA fiber in PVCC layered beam specimen (BP1) increases the ductility value of 1.37 times and addition of 0.8% PVA fiber in PVCC layered beam (BP2) increases the ductility value of 1.76 times when compared with the control beam specimen (B0). Figure 8 displays the ductility factor value for the control and PVCC stacked beams. By adding 1.2% PVA fiber to the PVCC layered beam, the ductility value of 5.90 was achieved, which is a 2.20-fold increase over the control beam specimen (B0). With 1.6% and 2% of PVA fiber added, the PVCC layered beam specimens BP4 and BP5 had ductility values of 4.96 and 4.38, respectively. These values are lower than those of the BP3 specimen but greater than those of the control specimen (B0).

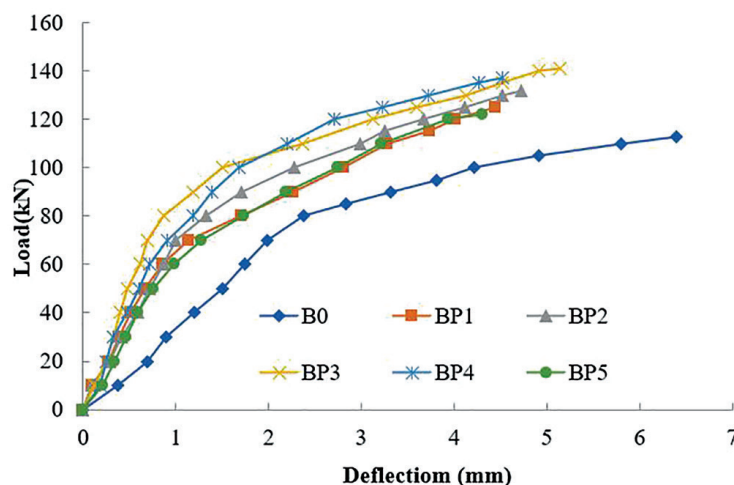


Figure 7: Comparisons between load deflection curves of control and PVCC layered beam.

4.1.5. Stiffness

The stiffness value for control and PVCC layered reinforced concrete beams is shown in Figure 9. The slope of the tangent drawn to load deflection curve gives the stiffness of the beam. The stiffness value increases 1.32 times and 1.46 times when compared to control specimen (B0) with the addition of 0.4% and 0.8% PVA fiber in PVCC layered beam specimen BP1 and BP2. By comparing to control specimen (B0), the addition of 1.2% PVA fiber in PVCC layered beam (BP3) shows greater stiffness value which was 2.22 times higher. The stiffness value for the beam specimen BP4 and BP5 with the addition of 1.6% and 2% PVA fiber in PVCC layered mixtures slightly reduced when compared to BP3 beam specimen but it gets increased 1.98 times and 1.37 times when compared with control specimen (B0).

4.1.6. Energy absorption

Energy absorption capacity of the beam was calculated by the area of the curve under the specimen during loading. Whenever, a structure is subjected to loading some energy is absorbed by the specimen. The structural safety under strong earthquake motion may be evaluated by the comparison between the input energy of structures imparted by earthquake and energy absorption capacity. Energy absorption capacity is used in earthquake design of structures. The energy absorption capacity for control and PVCC layered reinforced concrete beams are shown in Figure 10. For control beam specimen (B0) the energy absorption was calculated as 356.08 kN mm. The energy absorption value gained around 1.04 and 1.20 times with the addition of 0.4% and 0.8% PVA fiber in PVCC layered beam BP1 and BP2 when compare to control concrete beam (B0). The beam BP3 with the addition of 1.2% PVA fiber in PVCC layered mixture gives higher energy absorption when equating with control concrete beam (B0). The energy absorption capacity decreases with the addition of 1.6% and 2% of PVA fiber in PVCC layered beam BP4 and BP5, when compared with the specimen (BP3). In PVCC layered beam the higher energy absorbed by BP3 beam with 1.2% addition of PVA fiber in PVCC layered mixture which is 1.49 times more than control concrete specimen.

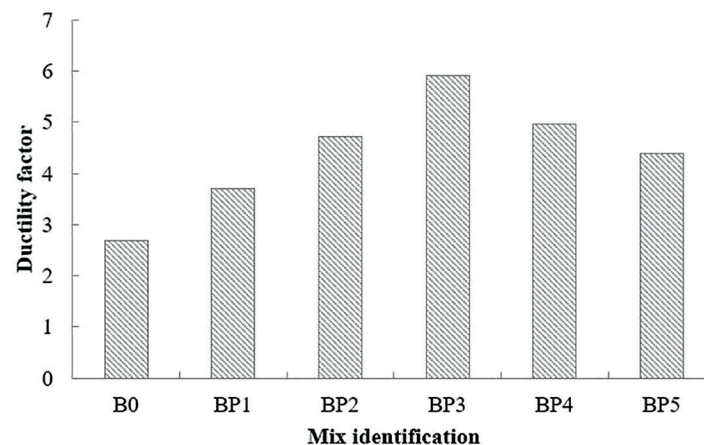


Figure 8: Ductility factor of control and PVCC layered beams.

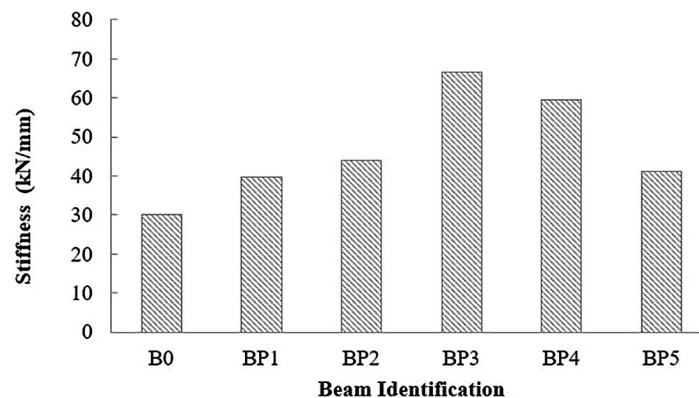


Figure 9: Stiffness of control and PVCC layered beams.

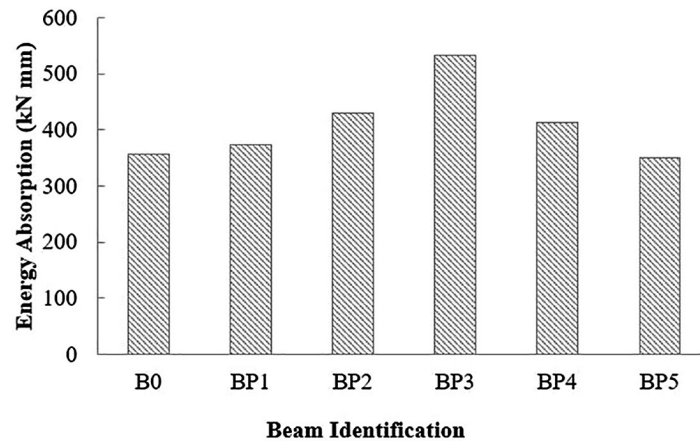


Figure 10: Energy absorption of control and PVCC layered beams.

4.1.7. Energy index

The ratio of total energy absorbed by the specimen up to ultimate load and energy absorbed by the specimen till the first crack gives energy index of the specimen. The energy index for control beam specimen and PVCC layered beam specimen are illustrated in Figure 11. For the control concrete beam (B0) energy index value found as 3.66. With the addition of 0.4% and 0.8% of PVA fiber in PVCC layered beam increases 1.01 and 1.38 times when compared with a control concrete beam (B0). At 1.2% PVA fiber addition in PVCC layered beam (BP3) gives 1.53 times higher energy index value when compared to control concrete beam (B0). The beam specimens BP4 and BP5 show a slight decrease in energy index value when compare with BP3 beam specimen, but it increases 1.23 and 1.02 times when compared with control concrete beam specimen (B0). When compared with control and other PVCC layered beam specimens, the beam BP3 with 1.2% PVA fiber addition gives maximum energy index value.

4.2. Basalt fiber fabric wrapping of reinforced concrete rectangular beam

4.2.1. First crack load

For control concrete beam the first crack load was witnessed at 80 kN. The first crack was observed at the load of 85 and 96 kN for basalt fiber fabric wrapping at bottom alone (BB1) and bottom with side faces of the beam up to neutral axis (BB2), respectively. Figure 12 shows the first crack load of control concrete beam (B0) and basalt fiber fabric wrapped beams BB1 and BB2. The first crack was noticed at flexural zone of the beam.

4.2.2. Ultimate load carrying capacity

The ultimate load carrying capacity for control reinforced concrete beam (B0) and basalt fiber fabric wrapped beams BB1 and BB2 are shown in Figure 13. The ultimate load was recorded at 148 kN for basalt fiber fabric wrapping at the bottom alone (BB1) and basalt fiber fabric wrapping at the bottom with side faces of the beam up to neutral axis (BB2) was witnessed as 160 kN. The ultimate load for basalt fiber wrapping at bottom alone (BB1) and bottom with side faces of the beam up to neutral axis (BB2) showed 1.06 and 1.2 times, respectively more than control concrete beam (B0). The comparison between the first crack and the ultimate load for basalt fiber fabric-wrapped reinforced concrete beams is shown in Figure 14.

4.2.3. Load deflection behavior

The load deflection behavior for control concrete beam specimen (B0) is shown in Figure 15. The first crack load and corresponding deflection were noted as 80 kN and 2.38 mm for the specimen (B0). The load carrying capacity was increased to 113 kN with deflection of 6.4 mm. For beam specimen (BB1) with basalt fiber fabric wrapping at bottom alone shown the first crack load of 85 kN and ultimate load of 148 kN and their corresponding deflection registered was 1.02 and 4.72 mm. The load deflection for basalt fiber fabric wrapping at bottom alone is shown in Figure 15. The first crack and ultimate load formed at the load level of 96 kN and 160 kN with the deflection of 1.24 mm and 4.15 mm, respectively for the basalt fiber fabric wrapping at bottom with side faces of the beam upto neutral axis (BB2). Comparison of load-deflection behavior of control beam (B0), basalt fiber

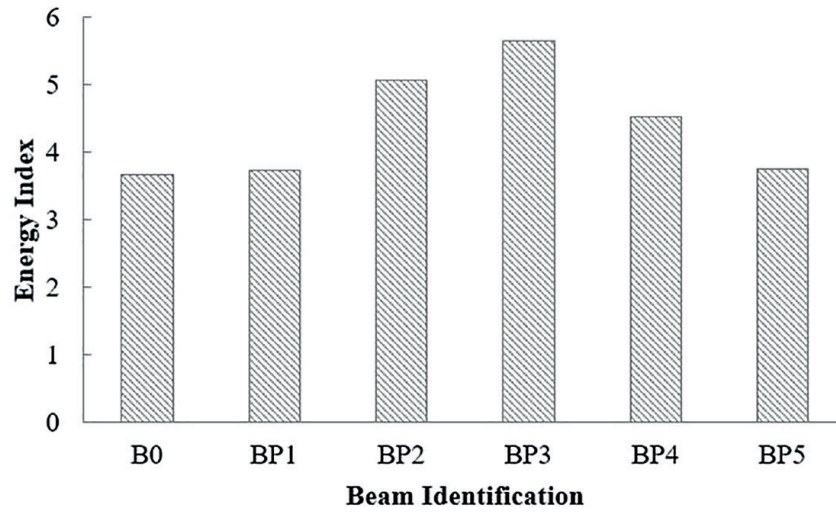


Figure 11: Energy index of control and PVCC layered beams.

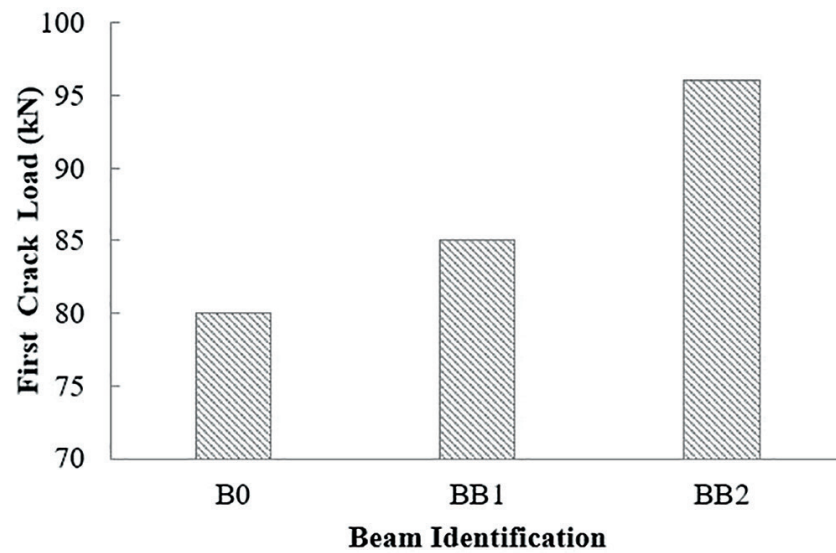


Figure 12: First crack load of control and basalt fiber fabric wrapped beams.

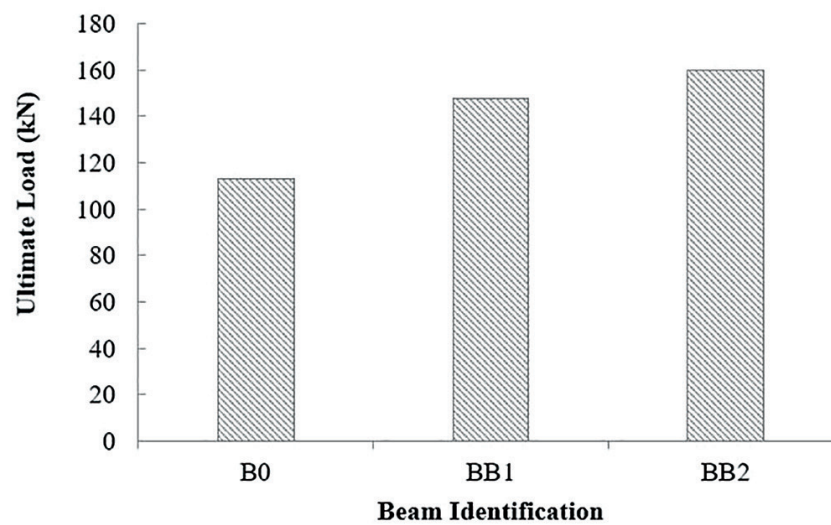


Figure 13: Ultimate load carrying capacity of control and basalt fiber fabric wrapped beams.

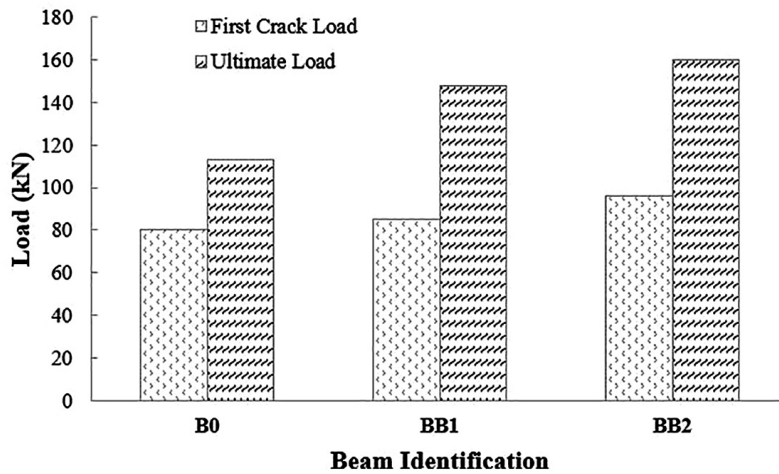


Figure 14: Comparison of first crack load and ultimate load carrying capacity of control and basalt fiber fabric wrapped beams.

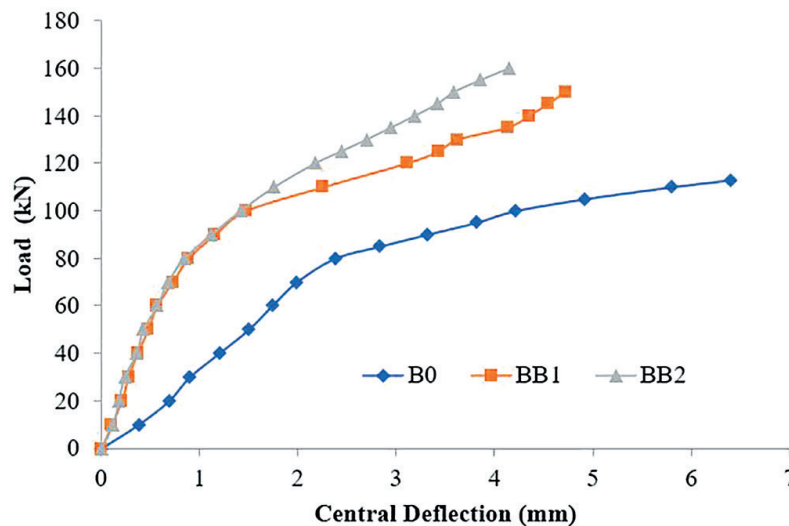


Figure 15: Comparisons of load deflection curves between control and basalt fiber fabric wrapped beams.

fabric wrapped beam at bottom alone (BB1) and basalt fiber fabric wrapped at bottom with side faces of the beam up to neutral axis (BB2) are presented in Figure 15.

4.2.4. Ductility behavior

The ductility factor for the specimen B0, BB1, and BB2 is shown in Figure 16. The ductility value for the beam with basalt fiber fabric wrapping of the beam at bottom alone (BB1) is 1.53 times more than control specimen B0. In same while the ductility value for specimen wrapped with basalt fiber fabric at the bottom with side faces up to neutral axis (BB2) is 5.94 which is 2.10 times more than control specimen. The ductility of the member get increased for the specimens wrapped with basalt fiber fabric wrapping at bottom alone and at the bottom with side faces up to neutral axis compared to control specimen.

4.2.5. Stiffness

The stiffness value was calculated for the control and basalt fiber wrapped specimens from the load deflection curve and it is shown in Figure 17. For the control concrete the stiffness was calculated as 30 kN/mm. The stiffness value obtained for BB1 and BB2 is 45.03 kN/mm and 68.24 kN/mm respectively, which is about 1.50 and 2.27 times more when compared to control concrete beam (B0).

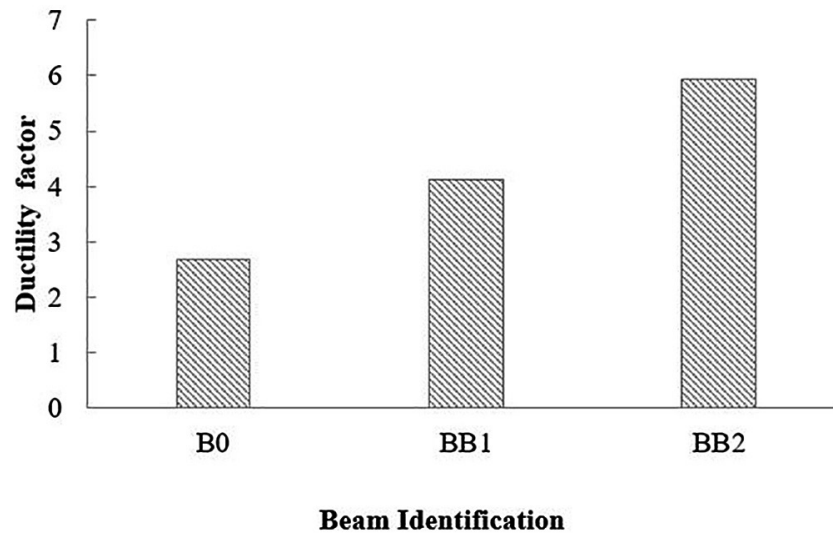


Figure 16: Ductility factor value for control and basalt fiber fabric beams.

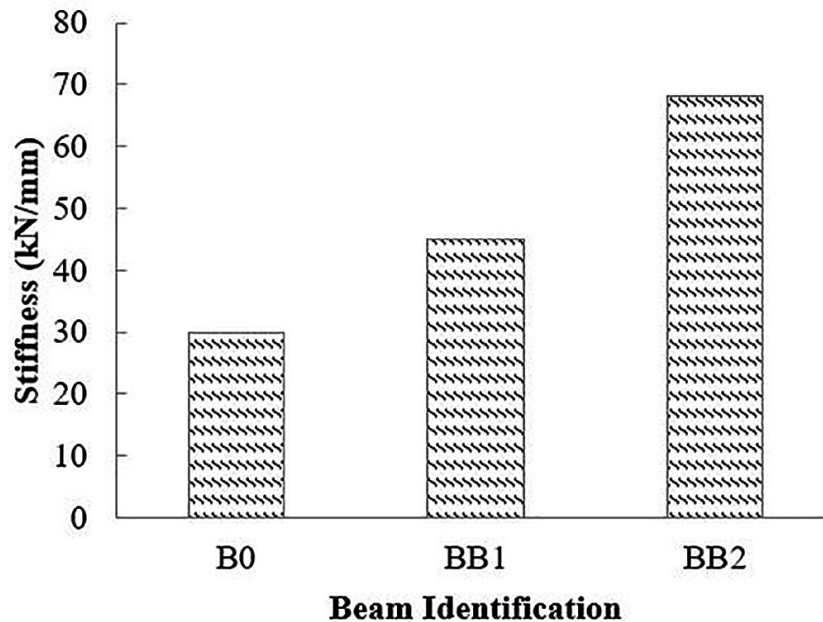


Figure 17: Stiffness of control and basalt fiber fabric beams.

4.2.6. Energy absorption

The beams with basalt fiber fabric wrapping at bottom alone (BB1) and bottom with side faces of the beam up to neutral axis (BB2) show maximum energy absorption value which is 1.25 and 1.71 times higher value than with control concrete beam (B0). The beam BB2 results in maximum energy absorption when equating with control beam (B0) and basalt fiber fabric wrapping at bottom alone (BB1). For control and basalt fiber wrapping beams, the energy absorption value is shown in Figure 18.

4.2.7. Energy index

The energy index value for control and basalt fiber fabric wrapped beam is shown in Figure 19. For control concrete, the energy index was calculated as 3.66. The basalt fiber fabric wrapping at the bottom alone (BB1) gives energy index value of 4.54 and the beam with basalt fiber fabric wrapping at bottom with side faces up to neutral an axis (BB2) tends energy index value as 6.12, which is 1.24 and 1.67 times greater when compared to control concrete beam (B0).

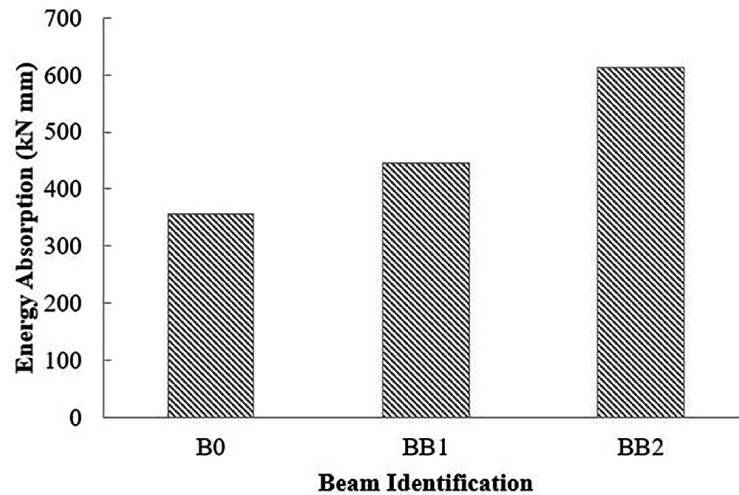


Figure 18: Energy absorption of control and basalt fiber fabric beams.

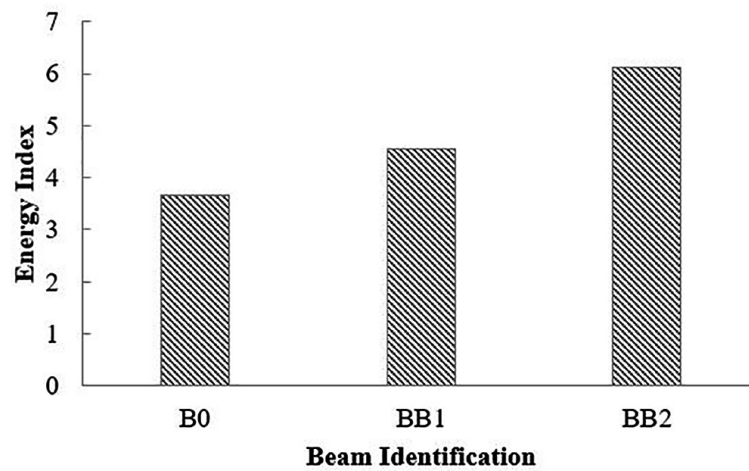


Figure 19: Energy index of control and basalt fiber fabric beams.

4.3. Analytical modeling

The analytical study was carried out to investigate the behavior and strength of PVCC layered and Basalt Fiber Fabric Reinforced Concrete beam by developing a numerical model based on finite element method using ANSYS. The analysis is performed to correlate this result with the experimental test result of the specimen. The concrete was modeled by using the Solid 65 element and steel by Link 8 element. After the solid model is constructed, it is meshed to form the finite element model. The material properties such as Poisson ratio, Young's modulus, Density and Tensile strength were adopted while modeling the specimen. The boundary conditions used for beam are simply supported condition. The type of analysis done for the entire beam is linear analysis. Figure 20 shows the finite element modeling of control, PVCC layered and basalt fiber fabric wrapped beams. The loads were applied on the rectangular beam, with an increment load of 10 kN. Then the deflection and corresponding load were taken from the solution process. Figure 21 to 22 shows the deflection diagram for control, PVCC layered and basalt fiber fabric wrapped beam, respectively. The comparison of the ultimate load with experimental test results and analytical test results is shown in Table 1. The analytical ultimate load of the control specimen B0 has a 7.07% difference when compared to the experimental result. For the specimen, BP3, BB1, and BB2 the difference between the two results is about 4.2%, 4.05%, and 2.5%, respectively. The experimental results show higher values than analytical values which are less than 7%. The comparison in deflection of experimental test results with analytical test results are shown in Table 1. The difference of 9.84% is obtained for B0 specimen. For BP3, BB1 and BB2 specimens the difference obtained were 9.33%, 8.4% and 11.08%, respectively. The analytical deflection values and experimental deflection result shows the difference less than 11.08%.

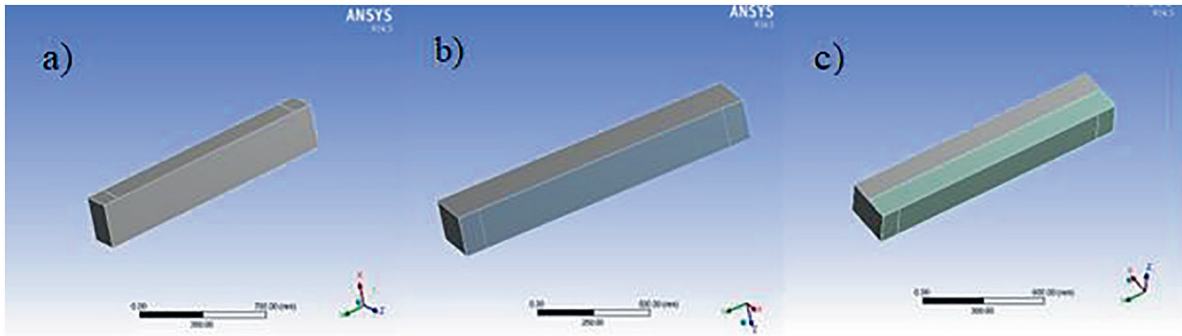


Figure 20: Finite element model of beam (a) control beam (b) PVCC layered beam and (c) basalt fiber fabric of beam at bottom with side faces up to neutral axis.

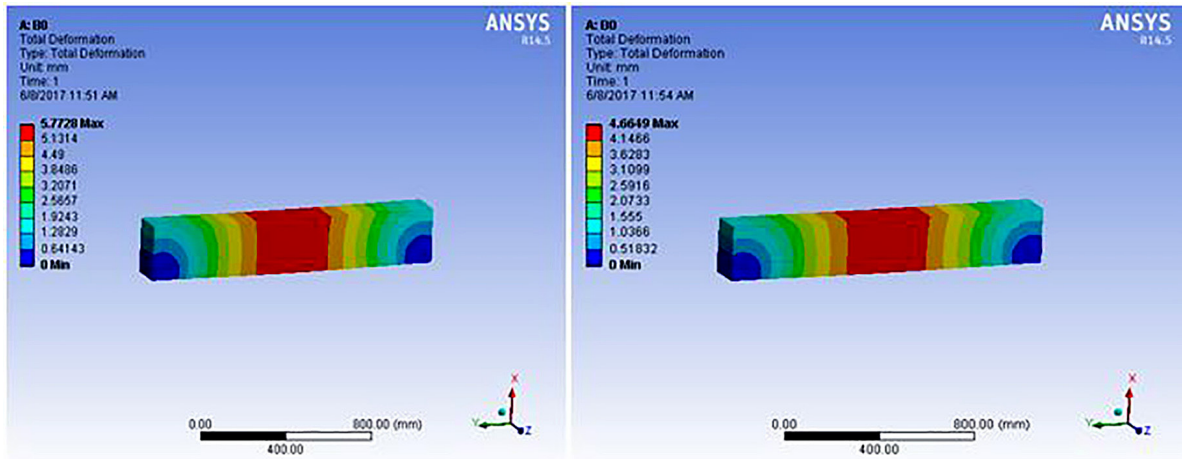


Figure 21: Deflection diagram for control concrete beam and PVCC layered beam specimen (BP3).

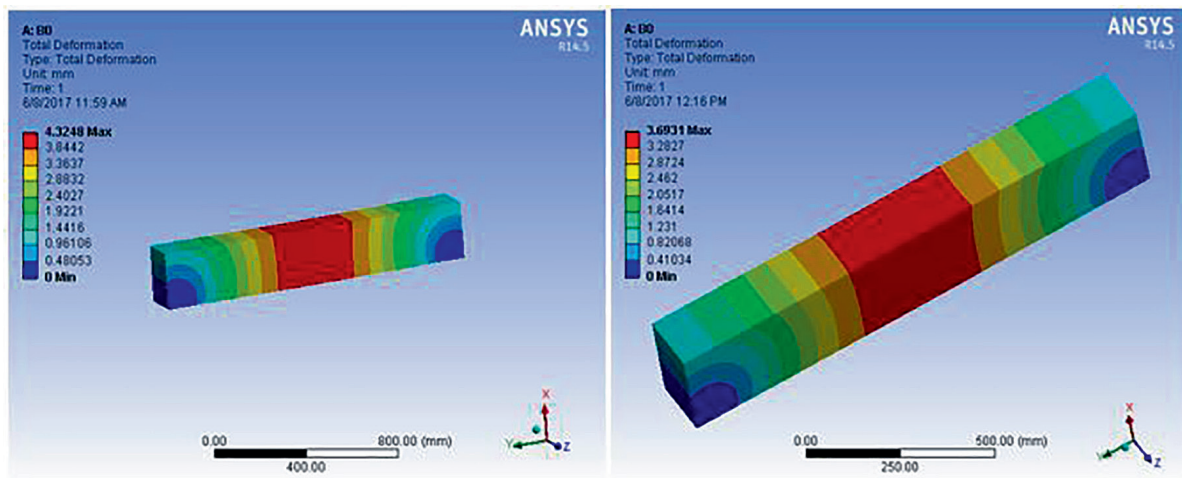


Figure 22: Deflection diagram for basalt fiber fabric beam wrapped at bottom and bottom with side faces up to neutral axis.

Table 1: Comparison of ultimate load and deflection with experimental and analytical modeling results.

S. NO.	BEAM IDENTIFICATION	ULTIMATE LOAD (kN)		DIFFERENCE (%)	DEFLECTION (mm)		DIFFERENCE (%)
		EXPERIMENTAL	ANALYTICAL		EXPERIMENTAL	ANALYTICAL	
1	B0	113	105	7.07	6.4	5.77	9.84
2	BP3	141	135	4.20	5.14	4.66	9.33
3	BB1	148	142	4.05	4.72	4.32	8.40
4	BB2	160	156	2.50	4.15	3.69	11.08

5. CONCLUSION

From the evaluation of structural behavior of Polyvinyl Alcohol Cementitious Composite layered and basalt fiber fabric wrapped beam, the following conclusions were arrived:

By evaluating the test results of all PVCC layered beam (BP1 to BP5), basalt fiber fabric wrapped beam (BB1 & BB2) with control beam (B0), the specimen BP3 and BB2 showed better performance than all other specimens. The initiation of first crack was prolonged for the beam specimen BP3 with addition of 1.2% PVA fiber in PVCC layered beam.

For the specimen BP3 with the addition of 1.2% of PVA fiber in PVCC layered beam the ultimate load carrying capacity increases by 19.87% when compared with control beam specimen B0. The maximum ductility was obtained by the addition of 1.2% PVA fiber in PVCC layered beam which is increased by 54.57% when compared to control beam specimen (B0).

The specimen BP3 with the addition of 1.2% PVA fiber in PVCC layered beam shows greater stiffness value and it is 54.54% higher than control beam specimen B0. There is a notable energy absorption capacity and energy index value is seen for all PVCC beam when compared to control concrete specimen B0.

For the specimen BP3 the energy absorption capacity is increased by 33.08% and energy index is increased by 34.99% when compared to control beam specimen B0. For basalt fiber fabric wrapped beam, the BB2 specimen in which the basalt fiber fabric wrapped at bottom with side face of the beam up to neutral axis performed well when compared to BB1 and B0 specimen.

The first crack load and ultimate load carrying capacity for the basalt fiber fabric wrapped at the bottom with side face of the beam up to neutral axis (BB2) was increased than BB1 and B0 specimen. The ductility value for the specimen BB2 in which the basalt fiber fabric wrapped at the bottom with side face of the beam up to neutral axis is increased by 2.10 times than control specimen B0. The stiffness, energy absorption and energy index value of basalt fiber fabric wrapped at the bottom with side face of the beam up to neutral axis shown noticeable development when compared to BB1 and B0 specimen.

6. ACKNOWLEDGMENT

The authors would like to extend their heartfelt appreciation to the KSR College of Engineering for their invaluable support in providing the necessary infrastructural facilities.

7. BIBLIOGRAPHY

- [1] PARGHI, A., ALAM, M.S., "A review on the application of sprayed-FRP composites for strengthening of concrete and masonry structures in the construction sector", *Composite Structures*, v. 187, pp. 518–534, 2018. doi: <http://dx.doi.org/10.1016/j.compstruct.2017.11.085>.
- [2] SADRMOHTAZI, A., KHABAZNIA, M., TAHMOURESI, B., "Effect of organic and inorganic matrix on the behavior of FRP-wrapped concrete cylinders", *Journal of Rehabilitation in Civil Engineering*, v. 4, n. 2, pp. 52–66, 2016.
- [3] ALJARRAH, M.T., ABDELAL, N.R., "Improvement of the mode I interlaminar fracture toughness of carbon fiber composite reinforced with electrospun nylon nanofiber", *Composites. Part B, Engineering*, v. 165, pp. 379–385, 2019. <http://dx.doi.org/10.1016/j.compositesb.2019.01.065>.
- [4] BROWN, R., SHUKLA, A., NATARAJAN, K.R. *Fiber reinforcement of concrete structures*. University of Rhode Island Transportation Center (URITC). USA. Project No. 536101, pp. 1–51, 2002.
- [5] KUMAR, A.P., MANEIAH, D., SANKAR, L.P., "Improving the energy-absorbing properties of hybrid aluminum-composite tubes using nanofillers for crashworthiness applications", *Proceedings of the*

- Institution of Mechanical Engineers. Part C, Journal of Mechanical Engineering Science*, v. 235, n. 8, pp. 1443–1454, 2021. <http://dx.doi.org/10.1177/0954406220942267>.
- [6] SEN, T., REDDY, J., “Finite element simulation of retrofitting of RCC beam using coir fiber composite (natural fiber)”, *International Journal of Innovation, Management and Technology*, v. 2, n. 2, pp. 175–179, 2011.
- [7] PRAVEEN KUMAR, A., “Experimental analysis on the axial crushing and energy absorption characteristics of novel hybrid aluminium/composite-capped cylindrical tubular structures”, *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, v. 233, n. 11, pp. 2234–2252, 2019. doi: <http://dx.doi.org/10.1177/1464420719843157>.
- [8] DOMKE, P.V., DESHMUKH, S.D., KENE, S.D., *et al.*, “Study of various characteristic of concrete with rice husk ash as a partial replacement of cement with natural fibers (Coir)”, *International Journal of Engineering Research and Applications*, v. 1, n. 3, pp. 554–562, 2011.
- [9] KUMAR, A.P., SHUNMUGASUNDARAM, M., SIVASANKAR, S., *et al.*, “Static axial crushing response on the energy absorption capability of hybrid Kenaf/Glass fabric cylindrical tubes”, *Materials Today: Proceedings*, v. 27, pp. 783–787, 2020. doi: <http://dx.doi.org/10.1016/j.matpr.2019.12.246>.
- [10] LEPECH, M.D., LI, V.C., “Application of ECC for bridge deck link slabs”, *Materials and Structures*, v. 42, n. 9, pp. 1185–1195, 2009. doi: <http://dx.doi.org/10.1617/s11527-009-9544-5>.
- [11] HAINCOVÁ, E., HÁJKOVÁ, P., “Effect of boric acid content in aluminosilicate matrix on mechanical properties of carbon prepreg composites”, *Materials (Basel)*, v. 13, n. 23, pp. 5409, 2020. doi: <http://dx.doi.org/10.3390/ma13235409>. PubMed PMID: 33261181.
- [12] KARBHARI, V.M., WANG, D., GAO, Y., “Processing and performance of bridge deck subcomponents using two schemes of resin infusion”, *Composite Structures*, v. 51, n. 3, pp. 257–271, 2001. doi: [http://dx.doi.org/10.1016/S0263-8223\(00\)00136-7](http://dx.doi.org/10.1016/S0263-8223(00)00136-7).
- [13] AHMED, S.F.U., MIHASHI, H., “Strain hardening behavior of lightweight hybrid polyvinyl alcohol (PVA) fiber reinforced cement composites”, *Materials and Structures*, v. 44, n. 6, pp. 1179–1191, 2011. doi: <http://dx.doi.org/10.1617/s11527-010-9691-8>.
- [14] IBRAHIM, A., ALSHAREEF, N., HATEM, M., *et al.*, “Experimental investigation of flexural and shear behaviors of reinforced concrete beam containing fine plastic waste aggregates”, *Structures*, v. 43, n. 2, pp. 834–846, 2022. doi: <http://dx.doi.org/10.1016/j.istruc.2022.07.019>.
- [15] KENDALL, A., KEOLEIAN, G.A., LEPECH, M.D., “Materials design for sustainability through life cycle modeling of engineered cementitious composites”, *Materials and Structures*, v. 41, n. 6, pp. 1117–1131, 2008. doi: <http://dx.doi.org/10.1617/s11527-007-9310-5>.
- [16] SALEH, H.M., BONDOUK, I.I., SALAMA, E., *et al.*, “Asphaltene or polyvinylchloride waste blended with cement to produce a sustainable material used in nuclear safety”, *Sustainability (Basel)*, v. 14, n. 6, pp. 3525, 2022. doi: <http://dx.doi.org/10.3390/su14063525>.
- [17] KIM, Y.Y., KONG, H.J., LI, V., “Design of engineered cementitious composite suitable for wet-mixture shotcreting”, *ACI Materials Journal*, v. 100, n. 6, pp. 511–518, 2003.
- [18] GUPTA, P.K., VERMA, V.K., “Study of concrete-filled unplasticized poly-vinyl chloride tubes in marine environment”, *Proceedings of the Institution of Mechanical Engineers, Part M, Journal of Engineering for the Maritime Environment*, v. 230, n. 2, pp. 229–240, 2016. doi: <https://doi.org/10.1177/14750902145604>.
- [19] ZONG, G., HAO, X., HAO, J., *et al.*, “High-strength, lightweight, co-extruded wood flour-polyvinyl chloride/lumber composites: Effects of wood content in shell layer on mechanical properties, creep resistance, and dimensional stability”, *Journal of Cleaner Production*, v. 244, pp. 244, 2020. doi: <http://dx.doi.org/10.1016/j.jclepro.2019.118860>.
- [20] VELUMANI, M., MOHANRAJ, R., KRISHNASAMY, R., *et al.*, “Durability evaluation of cactus-infused M25 grade concrete as a bio-admixture”, *Periodica Polytechnica. Civil Engineering*, v. 67, n. 4, pp. 1066–1079, 2023. doi: <http://dx.doi.org/10.3311/PPci.22050>.
- [21] KUMAR, S., MUKHOPADHYAY, T., WASEEM, S.A., *et al.*, “Effect of platen restraint on stress-strain behavior of concrete under uniaxial compression: a comparative study”, *Strength of Materials*, v. 48, n. 4, pp. 592–602, 2016. doi: <http://dx.doi.org/10.1007/s11223-016-9802-z>.
- [22] MOHANRAJ, R., VIDHYA, K., “Evaluation of compressive strength of Euphorbia tortilis cactus infused M25 concrete by using ABAQUS under static load”, *Materials Letters*, v. 356, p. 135600, 2023. doi: <http://dx.doi.org/10.1016/j.matlet.2023.135600>.

- [23] PAN, Z., WU, C., LIU, J., *et al.*, “Study on mechanical properties of cost-effective polyvinyl alcohol engineered cementitious composites (PVA-ECC)”, *Construction & Building Materials*, v. 78, pp. 397–404, 2015. doi: <http://dx.doi.org/10.1016/j.conbuildmat.2014.12.071>.
- [24] IS: 4031. Methods of physical tests for hydraulic cement. Bureau of Indian Standards (BIS), New Delhi, India, 1988.
- [25] IS: 8112. Ordinary Portland cement, 43 grade—specification. Bureau of Indian Standards. 2013.
- [26] MOHANRAJ, R., SENTHILKUMAR, S., PADMAPOORANI, P., “Mechanical properties of RC beams with AFRP sheets under a sustained load”, *Materiali in Tehnologije*, v. 56, n. 4, pp. 365–372, 2022. doi: <http://dx.doi.org/10.17222/mit.2022.481>.
- [27] SHANMUGASUNDARAM, S., MOHANRAJ, R., SENTHILKUMAR, S., *et al.*, “Torsional performance of reinforced concrete beam with carbon fiber and aramid fiber laminates”, *Revista de la Construcción. Journal of Construction*, v. 21, n. 2, pp. 329–337, 2022. doi: <http://dx.doi.org/10.7764/RDLC.21.2.329>.
- [28] KHAN, M.K.I., ZHANG, Y.X., LEE, C.K., “Mechanical properties of high-strength steel–polyvinyl alcohol hybrid fibre engineered cementitious composites”, *Journal of Structural Integrity and Maintenance*, v. 6, n. 1, pp. 47–57, 2021. doi: <http://dx.doi.org/10.1080/24705314.2020.1823558>.
- [29] MENG, D., HUANG, T., ZHANG, Y.X., *et al.*, “Mechanical behaviour of a polyvinyl alcohol fibre reinforced engineered cementitious composite (PVA-ECC) using local ingredients”, *Construction & Building Materials*, v. 141, pp. 259–270, 2017. doi: <http://dx.doi.org/10.1016/j.conbuildmat.2017.02.158>.
- [30] IS: 383. Specification for Coarse and Fine aggregate from natural sources for concrete. New Delhi, India, 1970.
- [31] LOGANATHAN, P., MOHANRAJ, R., SENTHILKUMAR, S., *et al.*, “Mechanical performance of ETC RC beam with U-framed AFRP laminates under a static load condition”, *Revista de la Construcción. Journal of Construction*, v. 21, n. 3, pp. 678–691, 2022. doi: <http://dx.doi.org/10.7764/RDLC.21.3.678>.
- [32] RAJESH, A.A., SENTHILKUMAR, S., SARGUNAN, K., *et al.*, “Interpolation and extrapolation of flexural strength of rubber crumbs and coal ash with graphene oxide concrete”, *Matéria (Rio de Janeiro)*, v. 28, n. 4, pp. e20230179, 2023. doi: <http://dx.doi.org/10.1590/1517-7076-rmat-2023-0179>.
- [33] SUN, M., CHEN, Y., ZHU, J., *et al.*, “Effect of modified polyvinyl alcohol fibers on the mechanical behavior of engineered cementitious composites”, *Materials (Basel)*, v. 12, n. 1, pp. 37, 2018. doi: <http://dx.doi.org/10.3390/ma12010037>. PMID:30583548.
- [34] PRASANTHNI, P., PALANISAMY, T., “Mechanical Characteristics and structural behavior of engineered cementitious composites using polyvinyl alcohol fiber”, *Asian Journal of Research in Social Sciences and Humanities*, v. 6, n. 7, pp. 749–761, 2016. doi: <http://dx.doi.org/10.5958/2249-7315.2016.00460.3>.
- [35] RAJU, S., DHARMAR, B., “Mechanical properties of concrete with copper slag and fly ash by DT and NDT”, *Periodica Polytechnica. Civil Engineering*, v. 60, n. 3, pp. 313–322, 2016. doi: <http://dx.doi.org/10.3311/PPci.7904>.
- [36] IS: 456. Plain and reinforced concrete-code of practice. New Delhi: Bureau of Indian Standards. New Delhi, India. 2000.
- [37] IS: 13920. Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces: Code of Practice. New Delhi, India. 1993.
- [38] PATTUSAMY, L., RAJENDRAN, M., SHANMUGAMOORTHY, S., *et al.*, “Confinement effectiveness of 2900psi concrete using the extract of Euphorbia tortilis cactus as a natural additive”, *Matéria (Rio de Janeiro)*, v. 28, n. 1, pp. e20220233, 2023. doi: <http://dx.doi.org/10.1590/1517-7076-rmat-2022-0233>.
- [39] MOHANRAJ, R., SENTHILKUMAR, S., GOEL, P., *et al.*, “A state-of-the-art review of Euphorbia Tortilis cactus as a bio-additive for sustainable construction materials”, *Materials Today: Proceedings*, Apr. 2023. In Press. doi: <http://dx.doi.org/10.1016/j.matpr.2023.03.762>.
- [40] RAVIKUMAR, K., PALANICHAMY, S., SINGARAM, C.J., *et al.*, “Crushing performance of pultruded GFRP angle section with various connections and joints on lattice towers”, *Matéria (Rio de Janeiro)*, v. 28, n. 1, pp. e20230003, 2023. doi: <http://dx.doi.org/10.1590/1517-7076-rmat-2023-0003>.
- [41] ALEX RAJESH, A., SENTHILKUMAR, S., SAMSON, S., “Optimal proportional combinations of rubber crumbs and steel slag for enhanced concrete split tensile strength”, *Matéria (Rio de Janeiro)*, v. 28, n. 4, pp. e20230206, 2023. doi: <http://dx.doi.org/10.1590/1517-7076-rmat-2023-0206>.

- [42] PRASANTHNI, P., PRIYA, B., DINESHKUMAR, G., *et al.*, “Mechanical properties of coal ash concrete in the presence of graphene oxide”, *International Journal of Coal Preparation and Utilization*, pp. 1–11, 2023. doi: <http://dx.doi.org/10.1080/19392699.2023.2284991>.
- [43] PALANISAMY, G., KUMARASAMY, V., “Rehabilitation of damaged RC exterior beam-column joint using various configurations of CFRP laminates subjected to cyclic excitations”, *Matéria (Rio de Janeiro)*, v. 28, n. 2, pp. e20230110, 2023. doi: <http://dx.doi.org/10.1590/1517-7076-rmat-2023-0110>.
- [44] KRISHNARAJA, A.R., ANANDAKUMAR, S., JEGAN, M., *et al.*, “Study on impact of fiber hybridization in material properties of engineered cementitious composites”, *Matéria (Rio de Janeiro)*, v. 24, n. 2, pp. e12347, 2019. doi: <http://dx.doi.org/10.1590/s1517-707620190002.0662>.
- [45] KRISHNARAJA, A.R., KANDASAMY, S., “Flexural performance of hybrid engineered cementitious composite layered reinforced concrete beams”, *Periodica Polytechnica Civil Engineering*, v. 62, n. 4, pp. 921–929, 2018. doi: <http://dx.doi.org/10.3311/PPci.11748>.
- [46] WANG, Z.B., HAN, S., SUN, P., *et al.*, “Mechanical properties of polyvinyl alcohol-basalt hybrid fiber engineered cementitious composites with impact of elevated temperatures”, *Journal of Central South University*, v. 28, n. 5, pp. 1459–1475, 2021. doi: <http://dx.doi.org/10.1007/s11771-021-4710-1>.
- [47] Wang, Z., Wang, P., Zhu, F., “Synergy effect of hybrid steel-polyvinyl alcohol fibers in engineered cementitious composites: fiber distribution and mechanical performance”, *Journal of Building Engineering*, v. 62, pp. 105348, 2022. doi: <http://dx.doi.org/10.1016/j.jobbe.2022.105348>.