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Testing and evaluation of PVCC nano layered reinforced concrete T-beam: Experimental study

ABSTRACT

This study examines the performance of reinforced concrete T-beams strengthened with PVCC nano layering and basalt fiber fabric wrapping. TP3, a PVCC nano-layered specimen with 1.2% PVA fibre, and TB2, a basalt fibre fabric-wrapped beam, outperform the other specimens. TP3 has a first fracture load of 112 kN and a maximum ultimate load of 165 kN, with 1.66 times the ductility and 1.51 times the stiffness of the control beam (T0). TP3 also has 1.61 times more energy absorption and the highest energy index, 1.46 times that of T0. TB2 can withstand a maximum ultimate load of 185 kN and has higher ductility, stiffness, energy absorption, and energy index than T0. The experimental results are validated by finite element analysis, which provides useful insights into strengthening procedures in structural engineering applications.

Keywords: *T-beam, PVCC nano layered beams, Basalt beams, Ductility enhancement*

1. INTRODUCTION

In recent studies, various methods for strengthening and repairing structural components including beams and columns have been developed [1]. In order to prevent complete or partial collapse during earthquakes, the majority of reinforced concrete structures will soon require major repairs [2-6]. Additionally, new materials or techniques are required to lessen the significant deformation of the structural components in the structure [7]. The largest difficulty currently facing civil engineers is strengthening old structures [8-10]. In this work, a novel method using fibre cementitious composites and external wrapping with fibre fabric was suggested for strengthening the reinforced concrete structural components [11]. The benefits of utilising fibre cementitious composites and wrapping boost the reinforced concrete structures flexural, shear, axial load-carrying capability, and seismic behaviour [12-15].

The uses of a super ductile FRCC for the repair and retrofit of concrete structures [16]. Research shows the strong and ductile structural performance, and strain-hardening of ECC have been developed using fracture mechanics and micromechanics and give immediate reaction because of rapid disintegration and become more intense in safety requirements [17-20]. The durability of ECC reinforced with Polyvinyl Alcohol (PVA) fiber by the micromechanics-based approach with a strain hardening capacity of 5% [21-23]. The water absorption and sorptivity properties of mechanically loaded Engineered Cementitious Composites (ECC). The ductile range of more than 3% with a minimum of 2% of fibre content by volume under uniaxial tensile loading single crack brittle fracture behaviour was observed in control concrete [24]. The water absorption and sorptivity level were determined from the microcracking behaviour in the ECC model [25]. The use of water-soluble silicon-based water repellents can easily inhibit the sorptivity level and reduces the absorption capacity of the resulting ECC mixture [26]. He concluded that the usage of water-repellent admixtures reduces the risk factor in ECC specimens. The long-term durability of concrete beams externally bonded with FRP sheets with the effect of severe environmental conditions and on the interfacial bond between the fiber and the concrete [27]. The concrete beams were strengthened by FRP sheets and resins with a different environment, the maximum capacity,

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stiffness, and ductility were acquired by load-deflection curves of the specimens kept at room temperature [28-29]. The problems made for Reinforced Concrete (RC) buildings such as weaker seismic design provisions, capacity design considerations, reinforcement detailing for ductile behaviour [30], and also for the excessive failure of beam-column joints for framed structures because of poor joint behaviour and inadequate shear reinforcement in the joint region [31]. So, the RC structural members strengthened with the help of a composite enclosure [32]. The behaviour of mechanical properties of concrete specimens, and RC piles have been done in retrofitting piles using basalt fibers by M30 [33]. The specimens were conventional, singly, and doubly wrapped with basalt fiber (woven-type) [34-36]. The performance of seismic strengthening of shear deficient joints of 3D Reinforced Concrete (RC) corner beam-column connections [37]. This technique was achieved by making the beam-column connections without any transverse reinforcement in their joint region by a coating of GFRP sheets and a steel cage [38]. The seismic behaviour was identified under cyclic loading patterns with the same axial loads on columns. Finally, the shear strengthening of joints was achieved by using GFRP sheets and estimates of the relation of the strut-and-tie model [39]. The strengthening behaviour of the circular and rectangular simply supported CFST beams using unidirectional CFRP nano layers with partially, fully and combined strengthening schemes with various nano layers and lengths [40]. The seismic performance of FRP-wrapped thin-walled steel tube confined full-scale circular cantilever columns under cyclic load and displacement wrapping with CFRP, GFRP, thin-walled steel tube and thinly walled tubular [41]. The yield moment, chord rotation at yielding, secant stiffness to yield point, flexure and cyclic shear resistance after the plastic hinge formed on rectangular RC columns wrapped with Fiber Reinforced Polymers (FRP). Totally two models are proposed for the ultimate chord rotation [42-45].

This study aims to investigate the development and structural behavior of Polyvinyl Alcohol Cementitious Composites (PVCC) with varying dosages of Polyvinyl Alcohol (PVA) fiber. The research focuses on the evaluation of the structural behavior of PVCC-nano layered T-beams. Additionally, the study examines the effectiveness of Basalt Fiber Fabric wrapping on the bottom and sides of the beam up to the neutral axis. The objective is to determine the optimal dosage of PVA fiber in PVCC and identify the most suitable wrapping technique. The performance characteristics of PVCC nano layered composites are compared with those of Basalt Fiber Fabric wrapping in T-beams. This research provides insights into improving the mechanical properties and structural performance of PVCC and explores innovative approaches for enhancing the strength and durability of T-beam structures.

2. MATERIALS AND METHODOLOGY

The cement used was Ordinary Portland Cement (OPC) of Grade 53 [46]. This study's cement complied with IS 12269 [47]. Cement sample testing was done using IS: 4031. Fly ash from the Mettur Thermal Power Station in Tamilnadu was used for this project [48]. Adding class F fly ash is essential for providing additional particles for compaction [49-50]. Sand from a locally accessible river that passed through a sieve of 4.75 mm and was retained on a 600-m sieve was used to cast specimens, while sand that passed through a sieve of 4.75 mm and was retained on a 200-m sieve was used to cast composites made of polyvinyl alcohol with a specific gravity of 2.70 [51-54]. For the current experiment, crushed blue granite coarse aggregates with a particle size of 20 mm and a specific gravity of 2.68 were used [55]. The specimens were also mixed and treated with tap water that was on hand in the lab [56]. This study employed polyvinyl alcohol fibre that was acquired from Spinning King Limited in Gujarat. Basalt fibre fabric was created by rapidly drawing melted basalt rock into a continuous fibre at a high temperature (1450°C) and then weaving it into the fabric [57]. It is frequently called Basalt Fibre Fabric. Arrow Textile Technical Limited in Mumbai supplied the basalt fibre fabric, which weighs 320 grams per square metre [58, 59]. The properties of Polyvinyl alcohol Fiber and Basalt Fiber are depicted in the table. 1.

Table 1. Properties of Polyvinyl Alcohol Fiber and Basalt Fiber

S. No.	Property	Polyvinyl alcohol Fiber Values	Basalt Fiber Values
1	Diameter (mm)	0.10	0.012
2	Chopped length (mm)	15	-
3	Aspect Ratio	15	-
4	Tensile strength (MPa)	1200	4150
5	Shape	Straight round	-

3. EXPERIMENTAL STUDY

A new strengthening method for reinforced concrete T-beam is proposed by incorporating a Polyvinyl Alcohol Cementitious Composite (PVCC) nano layer at the tensile faces instead of cover thickness and by giving external wrapping using basalt fiber fabric at the bottom alone and bottom with side faces of the T-beam up to neutral axis to investigate their flexural behavior [37]. The five test specimens were cast for T-beam with PVCC nano layer 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 is designated as TP1, TP2, TP3, TP4 and TP5 and two test specimens for basalt fiber fabric wrapped T - beam designated as TB1 and TB2, which is provided at the bottom alone and bottom with side faces of the beam up to neutral axis, respectively, with one control specimen T0. The T-beam test specimen was designed for a span of 1800 mm with a rectangular section of web dimensions 110 mm × 130 mm × 1800 mm and a flange size of 300 mm × 110 mm × 1800 mm. The mixing was done by using a concrete mixer and the T-beams were kept for 28 days curing. The reinforcement details of T-beam are shown in Figure 1. The placing of reinforcement in T-beam steel mould and casting of T-beam test specimen is shown in Figure 2. The typical representation of control, PVCC nano layered and basalt fiber fabric wrapped T-Beam is shown in Figure 3.

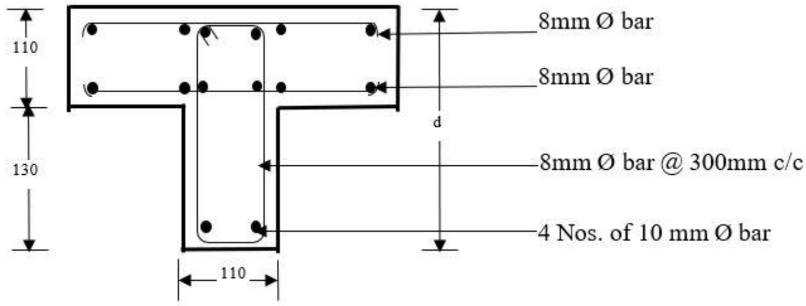

Figure 1. Reinforcement Details of T-Beam

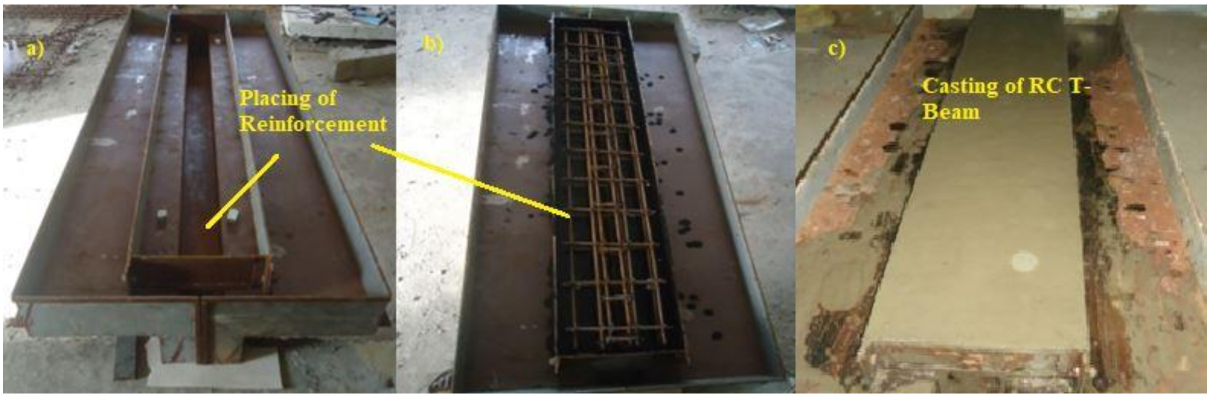

Figure 2. Placing of Reinforcement in T-Beam Steel Mould and Casting of Reinforced Concrete T-Beam

4. TEST RESULTS AND DISCUSSION

4.1. PVCC Nano layered Reinforced Concrete T-Beam

4.1.1. First crack load

The first crack load for control reinforced concrete T-beam (T0) and PVCC nano-layered reinforced concrete T-beams (TP1 to TP5) are shown in Figure 4. The first crack load for the control T-beam is attained at the load level of 95 kN. With the addition of 0.4% and 0.8%, PVA fiber in PVCC nano layered T-beam, the first crack load of TP1 and TP2 specimens was recorded as 98 kN and 102 kN. The specimen TP3 with the addition of 1.2% of PVA fiber in PVCC nanolayered T-beam prolonged the first crack up to 112 kN. The first crack load of TP4 and TP5 specimens with the addition of 1.6% and 2% of PVA fiber in PVCC nano layered T-beam is found as 90 kN and 85 kN, respectively. For all the beams the first crack was noticed at the bottom face of the beam at the flexural zone.

4.1.2. Ultimate load-carrying capacity

The ultimate load for the control T-beam specimen is found as 142 kN. The ultimate load-carrying capacity value of the control and PVCC nano-layered reinforced concrete T-beam is plotted in Figure 3. With the addition of 0.4%, PVA fiber in PVCC nanolayered concrete T-beam (TP1) shows ultimate load at the load level of 148 kN. For the specimen TP2 and TP3 with PVA fiber addition of 0.8% and 1.2% in PVCC nanolayered T-beam, there is an increase in the ultimate load, and it is found to be 154 kN and 165 kN, respectively. The ultimate load is slightly reduced to 158 kN and 144 kN with 1.6% and 2% respectively, the addition of PVA fiber in PVCC nanolayered concrete T-beam [57]. The comparison of the first crack load and ultimate load-carrying capacity of control and PVCC Nano layered T- Beams is shown in Figure 4.

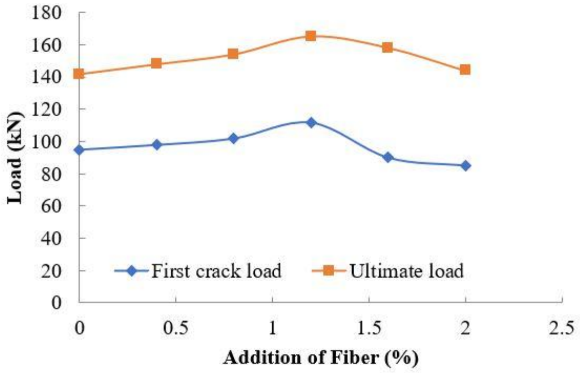

Figure 3. Comparison of First Crack Load and Ultimate Load Carrying Capacity of Control and PVCC Nano layered T- Beams

4.1.3. Load deflection behavior

The load-deflection behaviour of the control and PVCC nano-layered reinforced concrete T beam is plotted in Figure 4. While increasing the load, the central deflection also correspondingly increases. When the beam is subjected to the formation and propagation of cracks, there may be a change in the slope of the load-deflection curve. Also noted that all the PVCC nano-layered T-beam specimen fails in the flexural mode. For the control specimen, the deflection at the first crack initiation and at ultimate load carrying capacity was noted as 1.72 and 3.80 mm, respectively. The first crack is started at the bottom of the beam at a load of 98 kN for PVCC Nano layered beam specimen TP1, and the related deflection is noted as 2.32 mm. At the load of 148 kN, the beam specimen TP1 reaches the ultimate load, and the corresponding deflection is recorded as 4.2mm. For the specimen TP2 the corresponding deflection for the first crack and the ultimate load is noted as 2.24 and 4.91 mm [57].

For the T-beam specimen TP3, the first crack and ultimate load are recorded as 112 kN, and 165 kN and its deflections are noted as 1.89 mm and 5.42 mm. The first crack was developed at a load of 90 kN, and the ultimate load was found at 158 kN for the PVCC nano-layered T-beam specimen (TP4). The corresponding deflection for the first crack and ultimate load are witnessed as 1.39 mm and 5.92 mm. The ultimate load tends to decrease gradually for the specimen TP5 when compared to other PVCC nanolayered mixtures, and it reaches the load level of 144 kN and its deflection value is marked as 6.32 mm. The comparison of load-deflection curves for control and PVCC nano-layered T- beams are shown in Figure 4**.**

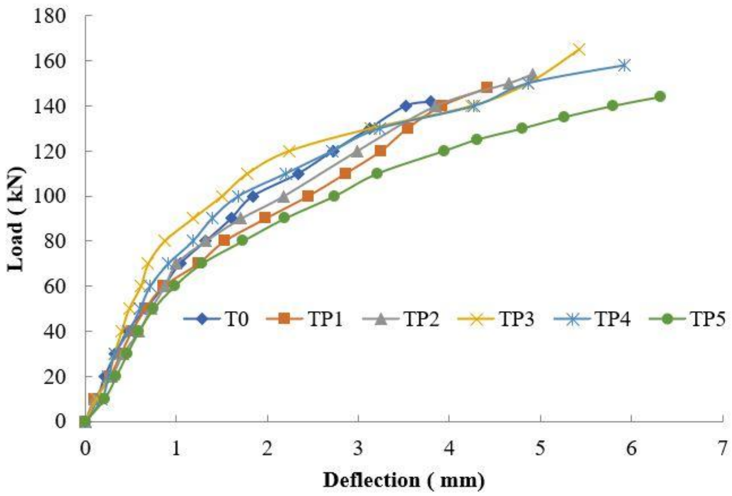

Figure 4. Comparison of Load Deflection Curves for Control and PVCC Nano layered T-Beams

4.1.4. Ductility behavior

The ductility value was calculated for control and PVCC nano layered T-beam and it is presented in Figure 5. The ductility value increases 1.03 times and 1.31 of control concrete T-beam specimen (T0) with the addition of 0.4% and 0.8% PVA fiber in PVCC nanolayered T-beam specimen. By comparing the control concrete specimen (T0), the ductility increases by 1.66 times with the addition of 1.2% PVA fiber [52]. The ductility value for the T-beam specimen TP4 and TP5 with the addition of 1.6% and 2% PVA fiber in PVCC nanolayered mixtures slightly reduced when compared to TP3 specimen, but it increased by 1.49 and 1.29 times more when compared to the control concrete [57].

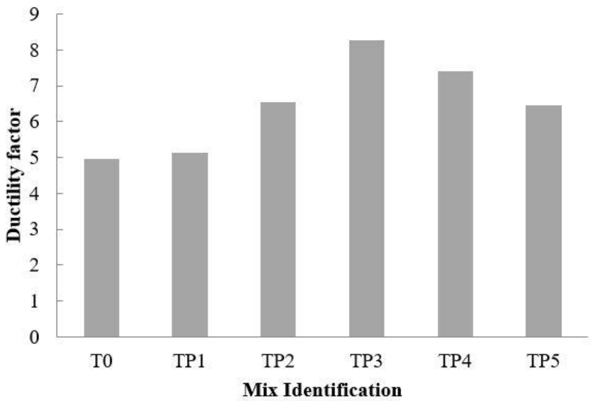

Figure 5. Ductility Factor of Control and PVCC Nano layered T-Beams

4.1.5. Stiffness

It was observed that the stiffness value was increased by 1.37, 1.76, and 2.20 times with the addition of 0.4%, 0.8%, and 1.2% of PVA fiber in PVCC nanolayered T-beam specimen when compared to control specimen T0. For specimens TP4 and TP5, the stiffness value gradually decreases when compared to TP3 and it is increased by 4.96 and 4.66 times when compared to control specimen T0. The stiffness value for control and PVCC nanolayered T-beam specimens are shown in Figure 6.

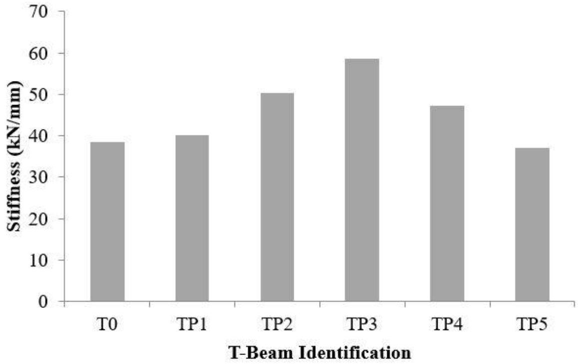

Figure 6. Stiffness of Control and PVCC Nano layered T-Beams

4.1.6. Energy absorption

The energy absorption capacity for control T-beam specimens and PVCC nano-layered T-beam specimens are plotted in Figure 7. The energy absorption value for the control concrete T-beam was found as 346.92(kN-mm). For the specimen TP1, TP2, TP3, TP4, and TP5 the energy absorption capacity was obtained as 399.15, 487.78, 560.75, 514.91, and 478.57 kN mm. Among all PVCC nanolayered T beam specimens, TP3 specimen with 1.2% addition of PVA fiber shows maximum energy absorption capacity value and it is 1.61 times more than the control concrete T beam specimen [37].

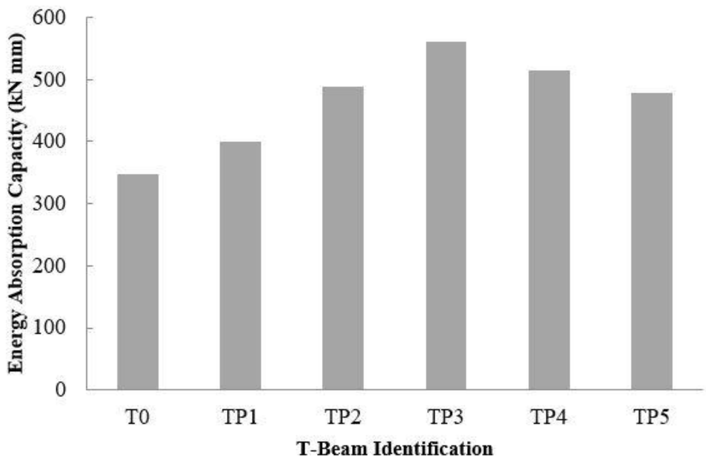

Figure 7. Energy Absorption of Control and PVCC Nano layered T- Beams

4.1.7. Energy index

For control concrete T-beam specimen (T0) the energy index is found as 3.65. The energy index value gained around 1.10 and 1.30 times with the addition of 0.4% and 0.8% PVA fiber in PVCC nanolayered T-beam TP1 and TP2 when compared to control concrete T-beam (T0). The T-beam TP3 with the addition of 1.2% PVA fiber in PVCC nano layered mixture gives a higher energy index which is 1.46 times when evaluating with control concrete. T-beam (T0). The energy index rises with the addition of 1.6% and 2% addition of PVA fiber in PVCC nanolayered T-beam TP4 and TP5 when compared with the control specimen (T0) [37]. The energy index for control T-beam and PVCC nano-layered T-beam specimen is shown in Figure 8.

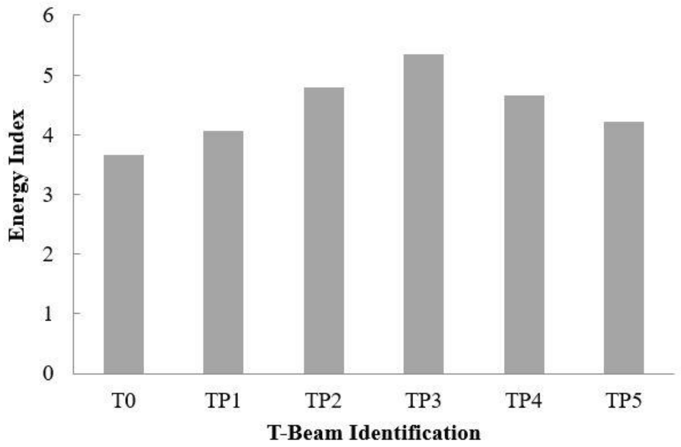

Figure 8. Energy Index of Control and PVCC Nano layered T-Beams

5. CONCLUSION

From the structural behavior of polyvinyl alcohol cementitious composite nanolayered and basalt fiber fabric wrapped T-beam, the following conclusions have arrived:

- By evaluating all T-beam specimens, the PVCC nano layered specimen TP3 and basalt fiber fabric wrapping at the bottom with side faces of the T-beam upto neutral axis TB2 shows improved performance characteristics compared to all other specimens. With PVA fiber addition of 1.2% in PVCC nanolayered T-beam for specimen TP3; the first crack load is prolonged to 112 kN and it reaches the maximum ultimate load of 165 kN which is more when compared with other specimens.
- The specimen TP3 with the addition of 1.2% PVA fiber in PVCC nano layered T-beam shows a greater ductility value which is 1.66 times higher compared to T0. The stiffness value of 58.56 kN/mm is obtained by the addition of 1.2% PVA fiber in PVCC nanolayered T-beam which gives an increment about 1.51 times when compared to the control T-beam specimen (T0).
- When compared with control and other PVCC nano layered T-beam specimens, the T-beam TP3 with 1.2% PVA fiber addition shows maximum energy absorption value. It gives 1.61 times higher energy absorption when compared with the control concrete T-beam (T0). In PVCC nano layered T-beam the higher energy index arrived by TP3 beam with 1.2% addition of PVA fiber in PVCC nano layered mixture which is 1.46 times more than the control concrete T-beam specimen.
- For basalt fiber fabric wrapping at the bottom with side faces of the T- beam up to the neutral axis (TB2) shows a maximum ultimate load of 185kN. The specimen with basalt fiber fabric wrapping at the bottom with side faces of the T-beam up to the neutral axis (TB2) shows the greatest ductility and stiffness value which is 1.68 and 1.53 times respectively, more when compared with control beam specimen T0. The basalt fiber fabric-wrapped beam TB2 shows 1.63- and 1.60-times higher energy absorption and energy index value when compared with control beam specimen T0. The experimental test result was validated using Finite Element analysis and it is found to be good.

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Data Availability

All data generated or analyzed during this study are included in this published article

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IZVOD

ISPITIVANJE I PROCENA PVCC NANO SLOJEVITOG ARMIRANOG BETONA T-GREDE: EKSPERIMENTALNA STUDIJA

Ova studija ispituje performanse armiranobetonskih T-greda ojačanih PVCC nano slojevima i omotačem od bazaltnih vlakana. TP3, PVCC nanoslojni uzorak sa 1,2% PVA vlakana i TB2, greda obmotana bazaltnim vlaknima, nadmašuju druge uzorke. TP3 ima prvo opterećenje loma od 112 kN i maksimalno opterećenje od 165 kN, sa 1,66 puta većom duktilnošću i 1,51 puta većom krutošću kontrolne grede (T0). TP3 takođe, ima 1,61 puta veću apsorpciju energije i najveći energetski indeks, 1,46 puta veći od T0. TB2 može da izdrži maksimalno maksimalno opterećenje od 185 kN i ima veću duktilnost , krutost, apsorpciju energije i energetski indeks od T0. Eksperimentalni rezultati su potvrđeni analizom konačnih elemenata, koja pruža koristan uvid u postupke ojačanja u primenama u građevinarstvu.

Ključne reči: T-greda, PVCC nano slojevite grede, Bazaltne grede, Povećanje duktilnosti

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