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ORIGINAL ARTICLE

Effect of zeolite and bamboo biochar as CO_2 absorbant in concrete

Srinivasan Revathi[1*], Dobson Alice Elizabeth Tania[1], Sutharson Ancy Shadin[1] and Jegatheesan Keerthana[1]

Abstract

Carbon dioxide (CO_2) is one of the major air pollutants that enter the atmosphere. There is a large release of carbon dioxide into the atmosphere as a result of burning fossil fuels in the cement manufacturing industries and many other industries, as well as emissions from gridlock. This increase in CO_2 concentration in the atmosphere leads to various ill effects and global warming. To reduce the CO_2 level in the atmosphere, efforts were made to prepare concrete that can absorb CO_2 by addition of zeolite and bamboo biochar. These materials were chosen because zeolite and bamboo biochar have large pore volume and large specific surface area and so they can absorb more CO_2. Zeolite is having more oxygen content and bamboo biochar is having more carbon content which helps in CO_2 absorption. In this work, Zeolite is substituted for fine aggregate in the varying ratios of 25% and 50% and bamboo biochar is substituted for cement in the ratios of 0.5%, 1% and 1.5%. The strength properties and CO_2 absorbing capacities of various zeolite and bamboo biochar concrete ratios were compared and it was found that concrete with 50% zeolite and 1% bamboo biochar (ZB_5) was the optimal mix. The optimal mix was found based on compressive strength, split tensile strength, water absorption, impact strength, amount of CO_2 absorption and depth of CO_2 penetration in concrete. This optimal mix has a compressive strength of 38.49 MPa which is 7.48% higher than conventional concrete and also has a split tensile strength of 4.39 MPa which is 15% higher than conventional concrete. It was also found that the optimal mix absorbed 1.2 g of CO_2 per day and that the depth of CO_2 penetration was 15 mm when the concrete cube was kept in the carbonation chamber for 7 days. This study provided necessary information on the addition of zeolite and bamboo biochar in the concrete which enhances both strength properties and CO_2 absorption. This study is important because now-a-days the current CO_2 emission in the atmosphere is mainly due to several man-made activities. This ZB concrete provides a solution to reduce the amount of CO_2 in the atmosphere and can be used in the concrete pavements, sewer pipelines, parapet walls and the environments with higher CO_2 concentration and emission.

Highlights

- Zeolite and bamboo biochar mixed concrete can be utilized to lower CO_2 levels in the atmosphere. Because zeolite has a large pore volume and specific surface area, it absorbs more CO_2.
- Increase in amount of zeolite increases the strength of concrete and CO_2 absorption but an increase in the amount of bamboo biochar by more than 1% reduces the strength of concrete but increases CO_2 absorption.

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*Correspondence:
Srinivasan Revathi
srevathi@mepcoeng.ac.in
Full list of author information is available at the end of the article

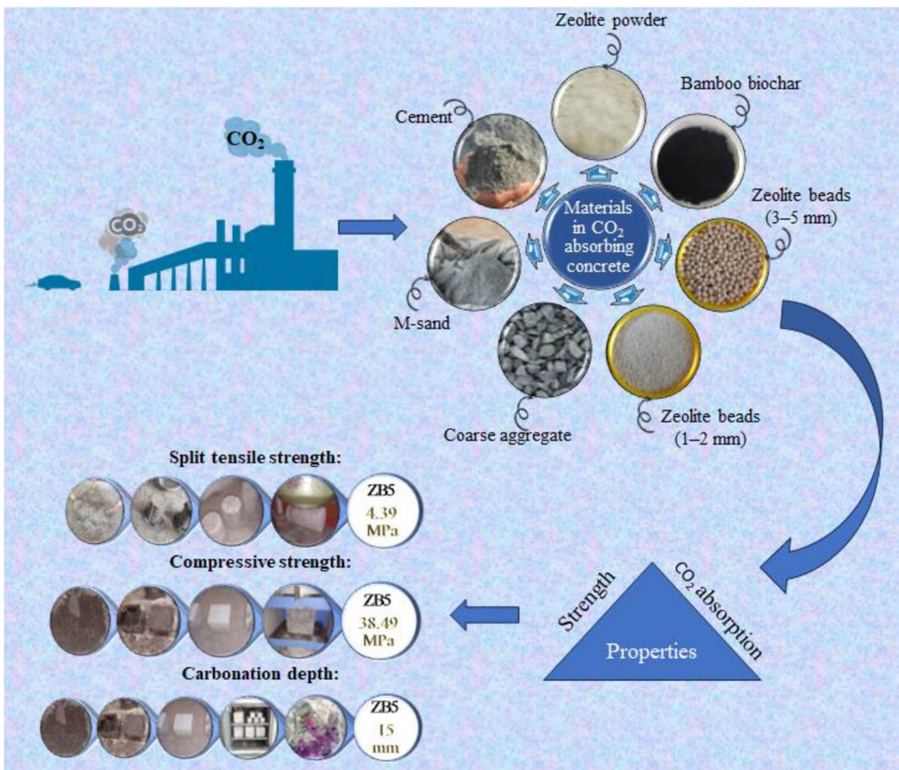
• The concrete containing 50% zeolite and 1% bamboo biochar gives the best results in carbonation depth, compressive strength, tensile strength and impact strength than conventional concrete. It has the highest amount of CO_2absorption of 1.2 g/day and a carbonation depth of 15 mm in 7 days.

• Bamboo biochar, zeolite powder and manufactured zeolite beads incorporated concrete showed increased strength and increased CO_2 absorption. Zeolite is an important supplement that boosts mechanical power and aids in CO_2 absorption.

• ZB concrete gives carbon-neutral construction environment and leads to sustainability.

Keywords CO_2 absorption, Zeolite beads, Zeolite powder, Bamboo biochar, Concrete, Sustainable environment

Graphical Abstract



1 Introduction

The demand for personal vehicles rises as population density does. This increases the amount of carbon dioxide and other harmful gas emissions from vehicles, which pollute the atmosphere. Carbon dioxide (CO_2) emission is regarded as the most significant issue among all greenhouse gas emissions (Abeydeera et al. 2019). The impact of greenhouse gas emissions on global warming has attracted a lot of attention. Because of its enormous emission level, CO_2 makes up more than 60% of greenhouse gases that cause global warming. The need for development grows together with population growth. As a result, more cement-based building materials are produced, which increases atmospheric carbon dioxide emissions. The primary greenhouse gas, carbon dioxide, retains heat in the atmosphere and plays a role in climatic change. It is urgently necessary to recover carbon dioxide, reduce carbon dioxide emissions, recycle carbon dioxide, and effectively use carbon dioxide. In this aspect, zeolites, which are crystalline alumina silicates with regular pores and hollows will be useful. Zeolite is available on a huge scale industrially as well as organically. They possess extraordinary qualities, such as molecular sieves, ion exchange, a sizable surface area, and catalytic action, which distinguish them as a sought-after component for many industrial applications. The volatile SiO_2 and Al_2O_3

concentration of zeolite is largely responsible for its pozzolanic characteristics. This substance combines with calcium hydroxide ($CaOH_2$) to create calcium silicate hydrate (CSH) gel during the hydration of cement. As a result, concrete gains an improved microstructure and becomes impermeable. Current research uses bamboo biochar as a natural additive in concrete to absorb atmospheric CO_2 and act as an eco-friendly adsorbant material. When biomass is heated in a sealed container with absence of air, it gives a carbon-rich substance known as biochar. This article examines concrete's ability to absorb CO_2 when zeolite and bamboo biochar were added by carbonation.

Rajnivas et al. (2020) enhanced that the use of zeolite had improved the level of carbon sequestration. Zeolite can be found used in concrete because its water absorption is within the permissible range. They said that the zeolite in concrete serves as a carbon sink and can absorb carbon dioxide, a significant air pollutant. Sedlmajer et al. (2015) informed that zeolite is a silicate substance and is completely compatible with other elements of concrete. The necessity for a higher water content in the mixture, which is evident in the composition of concrete must be considered in the given structure of the zeolite. Concrete built with zeolite can absorb CO_2 without emitting any of it. Mengal et al. (2018) informed that ordinary concrete releases a significant amount of CO_2 into the atmosphere. The zeolite in a bottle with a six-inch diameter and a 12-in. height may absorb 1 to 14 g of CO_2 in 5 days. This asset retains its sturdiness and longevity. As a result, it can be utilized anywhere without a problem. Sudarsono et al. (2022) found that the compressive strength of regular concrete 36 days after placement was 39.31 MPa, whereas the strength of 15% zeolite concrete was 38.65 MPa and the strength of 25% zeolite concrete was 28.23 MPa. Aman et al. (2022) stated that using sustainable concrete lessens the harmful effects of concrete production on the environment. In tests, as an additional cementitious material, biochar has been examined for its ability to have high compressive strength, tensile strength and flexural strength. The production of biochar and its use as a carbon-sequestering medium would produce a carbon-negative environment and be lucrative. As biochar made from agricultural waste, it has no negative environmental effects compared to agro-waste ashes. Akinyemi and Adesina (2020) showed that there was significant potential in using biochar from agricultural wastes. For cementitious composites, biochar can be used as a sustainbale admixture by considering factors such as source, production method and its dosage. By doing this, it will be possible to significantly reduce greenhouse emissions, which will lessen the influence of cement-based material manufacturing on climatic changes. It encourages us to learn that if less than 1% of biochar by weight of concrete is used in concrete components, it is feasible and conceivable for the modified concrete to store roughly 0.5 Gt (Giga tonnes) of CO_2 annually. This is presumptively equivalent to 20% of the total annual CO_2 emissions produced by cement-based businesses. Therefore, this material must be used to lower the hazardous level of CO_2 in the atmosphere, to which the construction and building sector contributes significantly. Wang et al. (2020) reported that the addition of biochar as a green additive encouraged the production of hydration products due to its influence on regulating moisture but did not speed up or slow down the hydration process. As a result, the composites' compressive strength rose after the addition of 1% by weight of biochar. Unfortunately, mechanical strength was adversely affected by the porousness and brittleness of biochar as well as the high dosage (5% by weight). Investigations are conducted into the compressive strength and fracture toughness of biochar mortar that uses biochar dosages of 0.2–4 wt% to replace cement, as well as comparisons to a control mortar devoid of bamboo biochar. According to Liu et al. (2022) the primary oxidation chemicals in the bamboo biochar have been determined by XRF and XRD measurements, to match ASTM C618–19 (2019) standards for class N-pozzolan, which is used to build concrete. Moreover, the non-crystal silica in bamboo charcoal can be used in the hydration process. As a result, when utilized to create mortar or concrete, the bamboo charcoal particles present can have a cementitious effect. The main goal was to calculate the test results for replacing some of the cement and fine particles in concrete's fresh and hardened qualities with zeolite and UFS (Ragavi Nalina et al. 2020). Bamboo charcoal is employed as the test's raw material (Ji et al. 2022) Using a pestle and mortar, dried charcoal powder is physically combined with KOH in a 1:1 ratio. The charcoal adsorbant's capacity to collect CO_2 would be improved by changing the surface texture. Biochar, which resembles charcoal, was produced when organic materials break down at high temperatures without oxygen (Nithyalakshmi et al. 2022). Biochar has a relatively low heat conductivity because carbon makes up the majority of its composition. Revathi et al. (2022) stated that the rate of CO_2 emission keeps rising daily, and in order to reduce this, potato peels, lime, seaweeds and potassium hydroxide were used in the casting of CO_2 absorbent paver blocks. Haamidh and Prabavathy (2016) proposed that to effectively adsorb a considerable amount of CO_2 at the surfaces of the concrete cubes, zeolite plasters were applied and sand can be completely replaced in the mortar. Zhang et al. (2022) stated that due to its affordability and environmental friendliness, biochar makes for an appealing adsorbant for Direct Air Capture.

Zhu et al. (2023) explained the interaction mechanisms between biochar and cement matrix based on chemical compositions and physical properties by using BSEM, EDX, FEM. They derived biochar (0-5 mm) from wood waste. They concluded that wall effect is occurred at side-edge of biochar by Ca rich layer which consists of C-S-H gel which helps in bonding and also air bubbles exchanged from internal pores at top edge of biochar which leads to mechanical strength. The biochar is having porous nature and having good compatibility with cement. Zhang et al. (2022) informed that biochar could be applied to carbon neutral construction materials and it leads to sustainable environment. Gupta et al. (2020) produced biochar from the wastes and used it as admixtures in cementitious construction materials. They informed that adding biochar improves the compressive strength, toughness and reduction in permeability and also leads to sustainability. Because of having high carbon content and specific surface area, biochar leads to strength development in mortar.

Kua and Tan (2023) prepared dry and pre-soaked biochar by soaking biochar in water for 24 hours and using it in mortar. They have tested the mortar cubes for compressive strength, flexural strength, water sorptivity and carbon efficiency. They have used biochar as 2% replacement for sand. They concluded that dry biochar with internal carbonation gives more strength than pre-soaked biochar. Souradeep Gupta and Pang (2017) used polycarboxylate-based superplasticiser at percentages by weight of cement and superabsorbent polymer (SAP) as potassium polyacrylate based commercial product at 0.6% in the mortar with 0.2 and 0.5% polypropylene fibers (PP). By using both SAP and PP, there is improvement in strength and reduction in permeability. Praneeth et al. (2020) used biochar at percentages of 2%, 4%, 6%, and 8% of total weight of cement fly ash blocks. They observed that 4% and 6% addition of biochar is giving highest strength based on the grade of concrete. Gupta et al. (2022) studied the effect of particle size and porosity of biochar at 2% by weight of cement on cement mortar. They informed that adding coarser biochar reduces the strength, but after blending, the finer biochar improves packing density and increases in strength. Yang and Wang (2021) used biochar at percentages of 2 and 5 in cement mortar with accerlated carbonation curing and normal curing. They concluded that the degree of carbonation of biochar and compressive strength had increased with increase in biochar. Kua et al. (2018) used biochar produced from mixed wood sawdust and checked its ability to capture direct air in indoor. The main factor for carbon capture is pyrolysis temperature. Gupta and Kua (2020) analysed the effect of rice husk biochar in cenosphere modified mortar and its addition did not have major influence on compressive strength of mortar. But they suggested that rice husk biochar was a good alternative material for silica fume in light weight mortar.

Previous researchers used both natural and chemical compounds for CO_2 absorption in low grade of concrete. They used several biochar which was prepared from locally available wastes for both strength improvement and carbondioxide absorption. All the researchers are trying to add biochar in the cement mortar, but in this research, it is used in concrete so that the performance in M35 grade of concrete was studied. Based on the review, it is found that biochar is a perfect material for binding with cement, so it can be used in concrete. Previous researches used CO_2 absorbing materials in low grade concrete, which showed low CO_2 absorption. This work concentrates on M35 grade of concrete by using zeolite and bamboo biochar as CO_2 absorbing materials. The concrete was made to absorb more CO_2 to make the environment sustainable. In this study, the optimal ratios of zeolite and bamboo biochar that can absorb high CO_2 without reduction in strength were found.

In addition, biochar made from bamboo was not used as CO_2 absorbing material in concrete in previous researches. However this research work concentrated on using only the natural materials for effective absorption of CO_2 in concrete of grade M35 and bamboo biochar was used as CO_2 absorbing material. In this research work, zeolite beads of two sizes and zeolite powder were replaced for fine aggregate and bamboo biochar was replaced for cement at small percentages to the weight of cement. This zeolite and bamboo biochar incorporated concrete were cast at various ratios and their comparison was made and their optimal mix was found. This zeolite and bamboo biochar incorporated concrete can be used in paver blocks since carbondioxide emission are higher on roads and in commercial buildings and if the temperature rises above 750°C it can act as a fire extinguisher by releasing the CO_2 absorbed. This study is important as it focuses on using natural material to reduce the concentration of CO_2 in the atmosphere, which is a pressing issue currently.

2 Material characterization

2.1 Cement, fine aggregate and coarse aggregate

Cement that complied with IS: 12269–2013 and OPC53 was utilised in this study. The initial setting time for cement was 45 minutes, while the final setting time was 560 minutes. Cement had a specific gravity of 3.16. The chemical composition of cement used were lime and silica in amounts of 62% and 22% and alumina, calcium

Fig. 1 Zeolite beads(1–2 mm), Zeolite beads(3–5 mm), Zeolite powder, bamboo biochar

sulphate, iron oxide, magnesia and sulphur trioxide in amounts of 5%, 4%, 3%, 2% and 1%. Fine aggregate conformed with IS 383–1970 (1970) Zone-II requirements. The mass density was 1.43 g/cm^3. It had a specific gravity of 2.65 and the fineness modulus of the sand was 0.525. The coarse aggregate used had a nominal size of 20 mm and was well graded according to IS: 383–(1970). It was acquired from a nearby crushing unit. The mass density was 1.52 g/cc, and the specific gravity was 2.74.

2.2 Zeolite beads (1–2 mm and 3–5 mm) and zeolite powder

Concrete's tetrahedral zeolite structure contributes to the formation of microstructure and improves its toughened qualities. Zeolite was used instead of 25% and 50% of M-Sand in the concrete. The zeolite beads are crysitalline zeolites having a three dimensional sodium alumina-silicate framework with interconnected cavities. These cavities absorb more CO_2 than zeolite powder. These beads are costly because of their preparation. So, zeolite beads varying from 1 mm to 5 mm and zeolite powder shown in Fig. 1 were mixed in the ratio of 1:4 and used in the concrete. The mixture of zeolite beads and zeolite powder had pH of 8 and specific gravity of 2.8, which is similar to that of fine aggregate. The chemical composition of zeolite powder used included silica and alumina in amounts of 72.96% and 11.93%, and calcium oxide, iron oxide and magnesia in amounts of 2.77%, 1.20% and 1.04%. It also had trace amounts of manganese oxide and titanium dioxide.

2.3 Bamboo biochar

Bamboo biochar (BBC), as shown in Fig. 1, is more cost-effective and environmentally benign than cement that was used to absorb CO_2. In the amounts of 0.5, 1, and 1.5% bamboo biochar was used to substitute cement. The colour of bamboo biochar was black and it had a specific gravity of 2.59. The chemical composition of bamboo biochar used here included potassium oxide, silica and calcium oxide in amounts of 39.30%, 22.20% and 10.70%, and iron oxide, magnesia and manganese oxide in amounts of 3.37%, 3.25% and 1.59%. It also had trace amounts of alumina.

2.4 Super plasticizer

In order to make the concrete mix more workable (IS 9103 (1999)), polycarboxylate superplasticizers (PCE) was added along with an extra 0.5-wt% of the cement in this study. The colour of PCE was reddish brown and it had a pH of 6. It gave good workability to the concrete. The slump cone test revealed the workability value as 3.7.

3 Experimental work

The concrete mix of M35 grade (IS 10262 (2009)) was adopted as it is the grade required for mild traffic. This grade of concrete is designed as per IS 456 (2000). 150 mm × 150 mm × 150 mm cubes and 300 mm × 500 mm cylinders of varying mixes of zeolite and bamboo biochar as shown in Tables 1 and 2, were prepared and cured. The cubes and cylinders were then subjected to compressive strength test, split tensile strength test, carbonation depth test, titration test, water absorption and impact test at the end of 7 days and 28 days of curing.

A. Compressive strength test:

Compression testing equipment with a capacity of 200 tons was used to determine the compressive strength of concrete cubes as per IS 516 (1959). Before the operation began, the machine's bearing surface grimed and other impurities had been thoroughly cleaned off. A continuous load was applied until the specimen could bear it, but once it exceeded its limit, it could no longer sustain itself and eventually fell apart. The applied pressure had been continuously observed. The highest load

Table 1 Description of all concrete mixes

Descriptions	Symbols
Control Mix	CS
25% zeolite and 0.5% Bamboo biochar	ZB_1
25% zeolite and 1% Bamboo biochar	ZB_2
25% zeolite and 1.5% Bamboo biochar	ZB_3
50% zeolite and 0.5% Bamboo biochar	ZB_4
50% zeolite and 1% Bamboo biochar	ZB_5
50% zeolite and 1.5% Bamboo biochar	ZB_6

Table 2 Mix design of all mixes (kg/m^3)

Specimen	Cement	BBC	Fine aggregate	Zeolite beads	Zeolite powder	Coarse aggregate	Water
Mix 1 (CS)	446	–	618	–	–	1136	200
Mix 2 (ZB_1)	443.77	2.23	463.5	38.625	115.875	1136	200
Mix 3 (ZB_2)	441.54	4.46	463.5	38.625	115.875	1136	200
Mix 4 (ZB_3)	439.31	6.69	463.5	38.625	115.875	1136	200
Mix 5 (ZB_4)	443.77	2.23	309	77.25	231.75	1136	200
Mix 6 (ZB_5)	441.54	4.46	309	77.25	231.75	1136	200
Mix 7 (ZB_6)	439.31	6.69	309	77.25	231.75	1136	200

took by the specimens was noted. The 7th and 28th day compressive strength test was taken for the specimen.

B. Split tensile test:

Universal testing machine with a capacity of 100 tons was used to find out the split tensile strength of the concrete cylinders as per IS 5816 (1999). The concrete cylinders of all types were kept in universal testing machine and tested for split tensile strength test. The 7th and 28th day split tensile strength was tested for the cylinders of all the ratios.

2P/LD determines the split tensile strength, where P stands for failed load, L stands for cylinder's length, and D stands for diameter.

C. Water absorption test:

According to ASTM C140-11a (2011), a water absorption test was conducted. The test specimens were submerged in water for 24 to 28 hours at a temperature of 60 to 80 °F (15.6 to 26.7 °C) so that the upper surfaces of the specimens were at least 6 in. (152 mm) below the water's surface. At least 18 in. of space must be kept between each specimen. The samples were weighed as they were suspended from a metal wire and completely submerged in water, and the immersed weight (Wi) was noted. The wire mesh of 3/8 in. (9.5 mm) was placed in, any apparent surface water was removed with a damp cloth, and left to drain for 60 ± 5 seconds before being weighed and recorded as Ws (saturated weight). The desiccated specimens' weight was recorded as Wd after being dried in a ventilated oven at 212 to 239 °F (100 to 115 °C) for at least 24 hours (oven-dry weight).

$$\text{Proportion of water absorbed} = \frac{W_s - W_d}{W_d} \times 100\% \quad (1)$$

where W_d refers weight of specimen after oven-drying (kg) and W_s refers to sample's saturated weight (kg).

D. Impact Test:

Figure 2 indicated that an impact test was conducted to evaluate the impact strength. Impact testing is a method used to assess how well a material can withstand

Fig. 2 Impact test apparatus and test specimen

deformation in the event of an abrupt shock or impulse load. This impact test is suggested in the ACI 544-2R (1999) method. It is a qualitative method to study the resistance of concrete subjected to sudden impact load. It indirectly represents the toughness of the concrete specimen (Ali et al. 2023). Here, the specimens were broken using this method using a known weight of 4.5 kg dropped from a known height of 45 cm. A 64 mm steel ball placed in the centre of the disc served as the conduit through which the force from the hammer was transferred to the specimen. Before testing, discs were taken out of the water tank and allowed to dry in the air for a while. For each set of characteristics, the impact resistance of three samples was assessed. By using this procedure, the number of blows up to which the samples withstood (till the first crack) was found out and the impact load was calculated using the following equation.

$$\text{Impact strength} = \frac{n \times wgh}{1000} \quad (2)$$

where w stands for the weight of disk (kg), g stands for acceleration due to gravity (m/s^2), h stands for the height of drop (m), n means the number of blows. The impact strength is in N-m.

E. Titration method for calculating amount of CO_2:

After 28 days of curing, the concrete cubes were placed in an air-tight chamber which is perfectly sealed by using M-seal fast curing epoxy compound adhesive where CO_2 gas was produced by hydrochloric acid and sodium carbonate as shown in Fig. 3. This process produces 44 g of CO_2, sodium chloride salt, and water. The CO_2 gas produced was passed into an air-tight chamber. The concrete cube was kept in a closed chamber in presence of CO_2 for 1 day. After 24 hours, the remaining unabsorbed CO_2 was passed into a round-bottomed flask containing excess NaOH (sodium hydroxide) solution where CO_2 was absorbed by NaOH and got converted into an equivalent amount of sodium carbonate. Contact of CO_2 with NaOH in a closed environment provided the required time for NaOH to absorb CO_2. The resulting mixture had excess sodium hydroxide and sodium carbonate and was then titrated against HCl until the first colorless phenolphthalein end point where the NaOH got neutralized and the sodium carbonate got converted to sodium bicarbonate. The titration was continued against HCl until the methyl orange endpoint where the sodium bicarbonate got converted to CO_2 and water. This titration process is shown in Fig. 4. The difference between

Fig. 3 Titration set-up and titration process

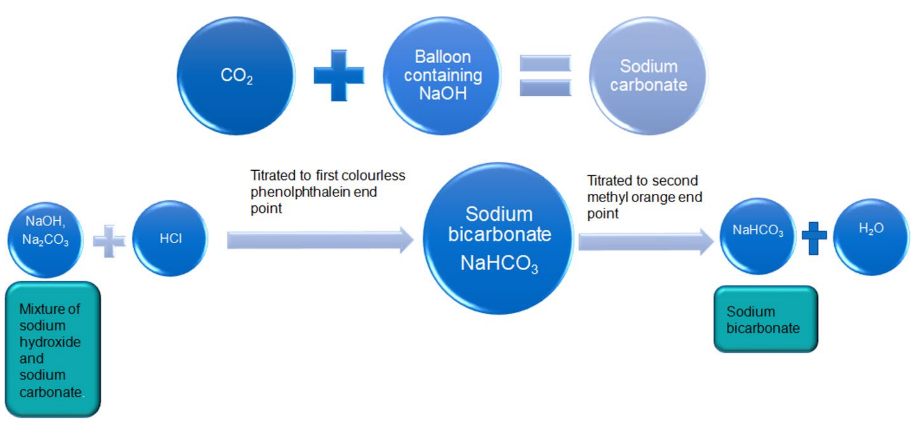


Fig. 4 Flow chart showing process of titration method

the two endpoints was used to calculate the CO_2 which was unabsorbed by the concrete cube.

$$\text{Amount of } CO_2\ (g) = \text{Volume of titrant (l)} \times \text{Molarity of standard acid (mol/l)} \times \text{Molecular weight of } CO_2\ (g/mol) \quad (3)$$

F. Carbonation depth:

After 28 days curing, the cubes were kept in a carbonation chamber for 3 days. During carbonation, the important parameters which need to be considered are atmospheric pressure in air-tight chamber and also its humidity and temperature between inside and outside. Based on these parameters, concentration of CO_2 in the chamber may vary. For constant flow, these parameters play a major role. The gradual and continual process of carbonation produces calcium carbonate when carbon dioxide in the atmosphere combines with calcium hydroxide in concrete. This process only happens in the presence of moisture and reduces the alkalinity of concrete. In this study, the concentration of CO_2 in the chamber is maintained at 4%, relative humidity was maintained at 20% and temperature was maintained at 40 °C. After carbonation, the specimens were then split into two halves and a pH indicator solution of phenolphthalein is sprayed on the inner face of the cross-sectioned cubes. Colorless places indicated the absorption of CO_2 and the depth of CO_2 absorption is measured from the outer edge (ISO 1920-12 (2015)). The same procedure was repeated for cubes kept for 7 days in the carbonation chamber.

4 Results

A. Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDX)

SEM analysis is a powerful analytical technique that enables the creation of high-resolution pictures and high-magnification analysis on a variety of materials. EDX is the X-ray emission from an object passing through an electron beam. SEM-EDX is a non-destructive qualitative and quantitative analysis of elemental composition inside the sample. The SEM for zeolite beads of 1-2 mm was examined in 2 μm, shown in Fig. 5a. The EDX for zeolite beads of (1-2 mm) explained that the elements present inside were O, Al, Si, Mg, Ca, Na and K, which had 64.43%, 20.31%, 12.27%, 2.06%, 0.92%, 5.23% and 2.03% of atom, respectively. The SEM for zeolite beads of 3-5 mm was examined in 2 μm, shown in Fig. 5b. The EDX for zeolite beads of 3-5 mm explained that the elements present inside were O, Al, Si, Mg, Ca, Na and K, which had 50.06%, 29.32%, 8.95%, 5.02%, 0.71%, 12.30% and 0.8% of atom, respectively as shown in Table 3. The SEM for bamboo biochar (BBC) was examined in 10 μm, shown in Fig. 5c. The EDX for BBC explained that the elements present inside were O, Al, Si, Mg, Ca, Na and K, which had 7.04%, 31.02%, 0.39%, 4.06%, 1.25%, 9.70% and 0.37% of atom, respectively, as shown in Table 3. These samples were tested in SEM Facility Consultancy on Characterization of Nanomaterials, the Gandhigram Rural Institute, Gandhigram, Tamil Nadu. From the tests, it was shown that zeolite beads are having more oxygen content which enables the zeolite beads to absorb more CO_2 and bamboo biochar is having more carbon content which is activated carbon having more porous surface area that absorbs more CO_2.

B. Compressive strength test:

The casted cube specimens were kept inside the compression testing machine. Figure 6 compares the compressive strength values for all the types of specimens. Results in 7 days demonstrated that the zeolite BBC blend had greater strength than the control mix. Comparing ZB_1, ZB_2, and ZB_3, it is clear that ZB_2 had the greatest compressive strength of 27.37 MPa which was found to be 3% higher than control mix. The strength of the concrete cube diminished with ZB_3 because 1.5% of the cement was replaced by BBC, reducing the concrete cube's ability to bind inside the concrete cube as CSH gel formation is reduced. Among ZB_4, ZB_5, and ZB_6, ZB_5 had the highest compressive strength of 27.64 MPa, which was found to be 4.1% higher than that of the conventional concrete. The compressive strength of ZB_6 was lower than that of ZB_4 and ZB_5 due to the same reason as stated for ZB_3. The same trend could be observed in 28-day compressive strength results. Thus, it could be concluded that ZB5 had the highest 7-day and 28-day compressive strength. The percentage increase in the 28 days compressive strength was found to be 7.48% greater than that of the conventional mix. As a result, it could be concluded that zeolite addition will improve the compressive strength when adding at 50% replacement as shown in Fig. 6.

C. Split tensile test:

The casted cylinder specimens were kept inside the universal testing machine. The tensile strength for both 7th and 28th day strength results were displayed in Fig. 7. For 7 days with a ratio of 25% zeolite and 1% BBC, ZB_2 had the greatest tensile strength of 3.31 MPa and was found to

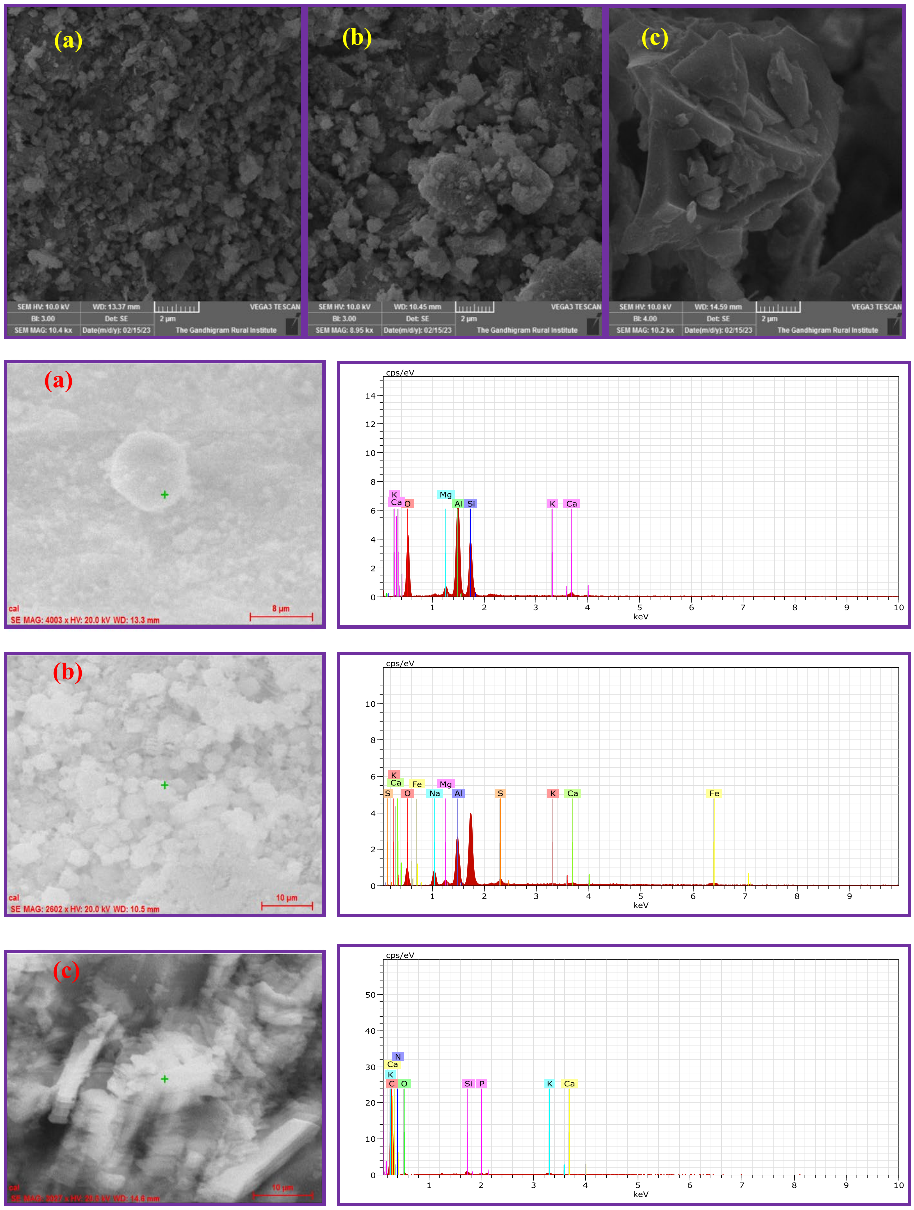


Fig. 5 SEM and EDX analysis of (a) Zeolite Beads(1-2 mm) (b) Zeolite Beads(3-5 mm) (c) Bamboo Biochar

be 4% higher than the control mix among ZB_1, ZB_2, and ZB_3. With a ratio of 50% zeolite and 1% BBC, ZB_5 had the greatest tensile strength of 3.33 MPa when compared to ZB_4, ZB_5, and ZB_6. The 7-day results revealed that ZB_5 had the greatest split tensile strength (3.33 MPa) of all the samples, and had 4.72% higher than conventional concrete. In 28 days, with a ratio of 25% zeolite and 1% BBC, ZB_2 had the maximum tensile strength of 4.33 MPa among ZB_1, ZB_2, and ZB_3. With a ratio of 50% zeolite and 1% BBC, ZB_5 had the highest tensile strength of 4.39 MPa when compared to ZB_4, ZB_5, and ZB_6. ZB_5 had the highest split tensile strength (4.39 MPa) of all the samples, and had 15% greater strength than the control mix. It was evident that ZB_5 had the maximum tensile strength of 4.39 MPa for the 28-day split tensile test. The split tensile strength for zeolite BBC concrete was found to be higher than conventional concrete as shown in Fig. 7.

It is evident from the aforementioned compression and split tensile tests that ZB_2 and ZB_5 zeolite BBC concrete had the greatest strength and water absorption was

Table 3 Percentage of atom present in zeolite beads (1-2 mm), zeolite beads (1-2 mm), bamboo biochar

Element	Zeolite beads (1-2 mm) atom (%)	Zeolite beads (1-2 mm) atom (%)	Bamboo biochar atom (%)
C	–	–	92.03
O	64.43	50.06	7.04
Al	20.31	29.32	31.02
Si	12.27	8.95	0.39
Mg	2.06	5.02	4.06
Ca	0.92	0.71	1.25
Na	5.23	12.30	9.70
K	2.03	0.8	0.37

consistent. So, based on the above tests, it is evident that ZB_2 and ZB_5 were better in strength behaviour because of 1% addition of bamboo biochar. More than 1% bamboo biochar leads to decrease in strength behaviour.

D. Water absorption test:

Figure 8 demonstrates that zeolite BBC concrete's water absorption was slightly higher than that of conventional concrete but it stayed within the permitted range of 10%. ZB_2 and ZB_3 had the least water absorption of 4.42% and 4.32% when compared to ZB_1 with water absorption of 4.72%, and ZB_4 and ZB_5 had the lowest water absorption of 4.02% and 5.2% compared to ZB_6 that had water absorption of 5.81% as shown in Fig. 8. This shows that increase in zeolite and bamboo biochar content increases

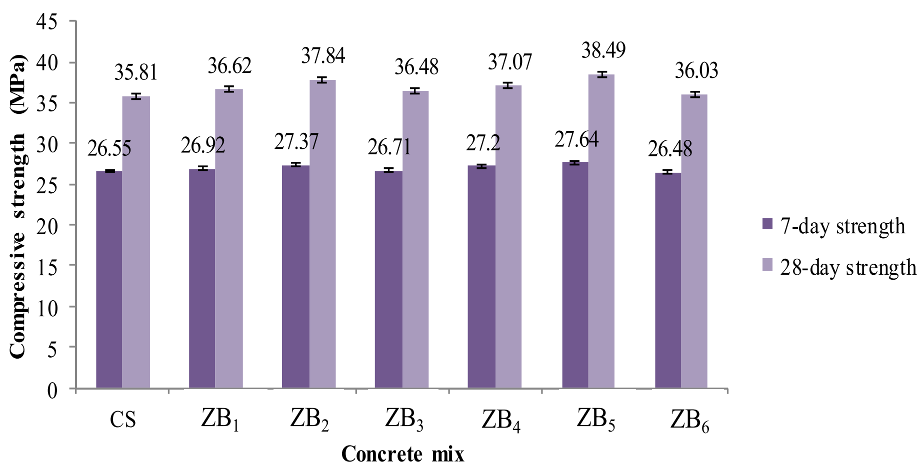


Fig. 6 Compressive strength test results

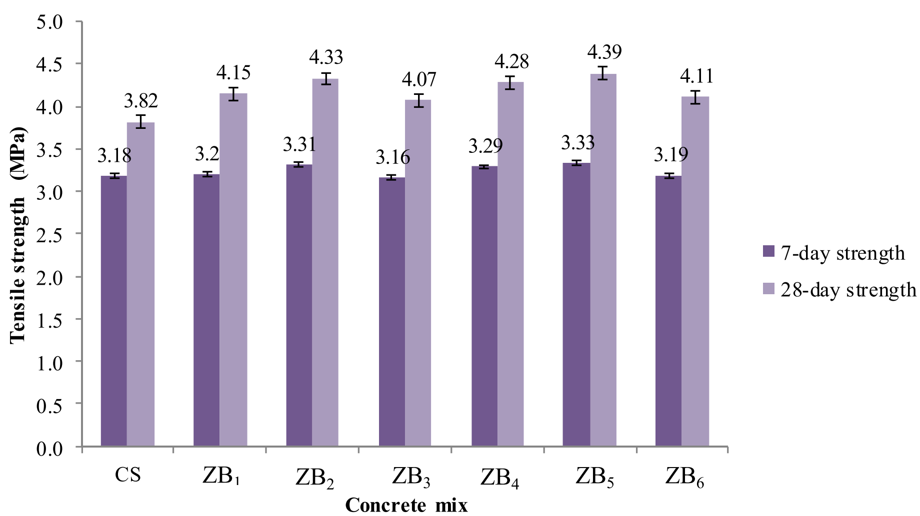


Fig. 7 Split tensile strength test results

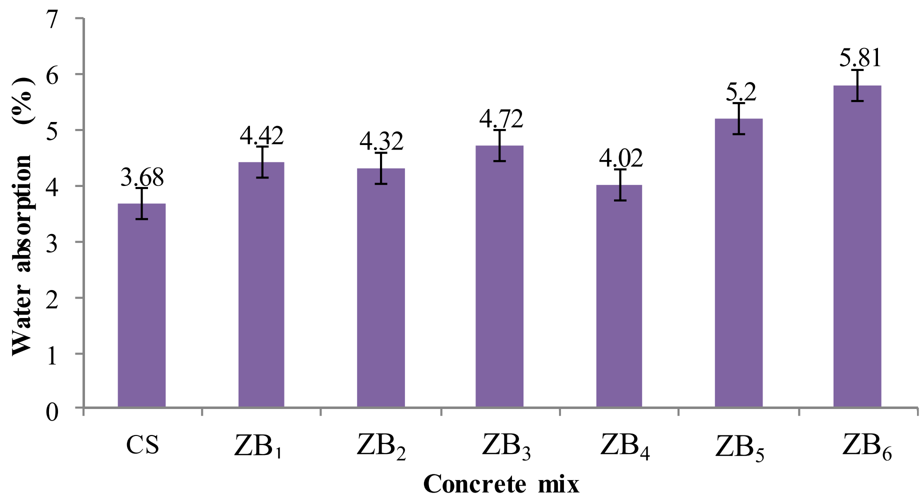


Fig. 8 Water Absorption test results

the water absorption. When adding zeolite at 50% and bamboo biochar at 0.5%, the pores were getting reduced because of trapped air due to its dense packing and its water absorption which was less compared to all other specimens. This mechanism is explained by Zhuang et al. (2022) that the trapped air inside the concrete distributes inside the pores during mixing, curing and drying. This effect happened in ZB_4 concrete so that water absorption reduced. Compared to all the specimens, control specimen which had lower water absorption than zeolite bamboo biochar concrete. It implies that the addition of zeolite and bamboo biochar creates large pores and large specific area which absorbs more water so that water absorption is more for ZB concrete.

E. Impact test:

The impact test equipment for concrete is shown in Fig. 2. The test specimen used in this experiment has been depicted. The Control mix and optimal amounts of the zeolite BBC concrete ZB_2 and ZB_5 have undergone an impact test. Zeolite BBC concrete was found to have a higher impact strength than regular concrete. According to Fig. 9, ZB_5 has the greatest impact strength of any type of concrete. The impact strength of concrete depends on various paramters such as compressive and tensile strength of cementitious matrix, type and size of aggregate used (Esaker et al. 2023). While adding zeolite and bamboo biochar, the structure of cementitious matrix was improved because of the dense pack particle size distribution of zeolite beads of different sizes and bamboo biochar. Because of its dense packing, ZB_5 got the impact strength of 30 J which was higher than ZB_2. The impact strength histogram for the control mix and zeolite BBC mix was shown in Fig. 9.

F. Titration method for calculating amount of CO_2:

In Fig. 3, the titration setup was depicted. Titration were performed for 1 day, and the process had been

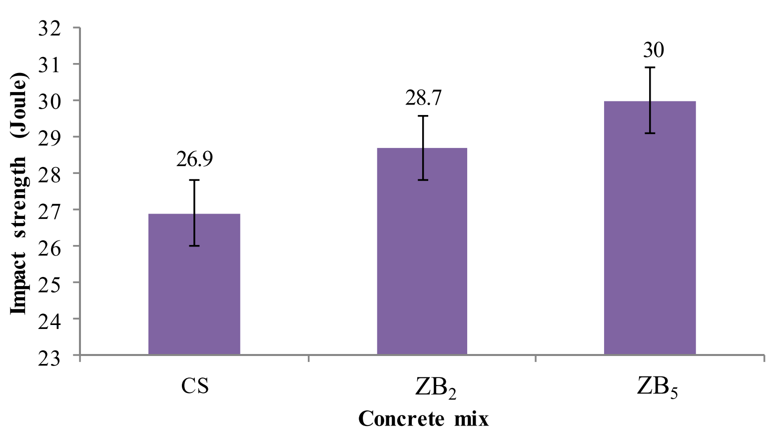


Fig. 9 Impact strength test results

carried for all the specimens. The control mixture and the zeolite BBC concrete ZB_1, ZB_2, ZB_3, ZB_4, ZB_5 and ZB_6 levels were titrated to find out the amount of CO_2 absorbed by the specimens. First, the process was carried out for CS and the result was found to be 0 (g/day). Then the process was carried out for ZB_1, ZB_2, ZB_3, ZB_4, ZB_5 and ZB_6. It could be observed that all ZB concretes had a higher CO_2 absorption potential compared to the conventional mix. Among the six ZB concrete mixes, ZB_5 and ZB_6 absorbed the greatest amount of CO_2. As both ZB_5 and ZB_6 had the same absorption of CO_2, ZB_5 had been taken into account because it had the best split tensile strength, compressive strength,and impact strength. It was evident that ZB_5 absorbed more CO_2 than the other proportions of concrete. The absorption of ZB_5 was discovered to be higher than that of ZB_2. The concrete's ability to absorb CO_2 was depicted in Fig. 10.

G. Carbonation depth:

A 3-day and 7-day carbonation depth test has been performed for all the specimens. The concrete blocks were placed inside the carbonation chamber for the designated number of days, then they were tested using a phenolphthalein indicator. The Control mix and zeolite BBC mix were kept for 3 days inside the carbonation chamber. For 3 days, the CO_2 was absorbed to the depth of 4 mm for ZB_1, 5 mm for ZB_2 and ZB_3, 8 mm for ZB_4 and ZB_5 whereas ZB_6 had the greatest depth of 9 mm among the concrete cubes. The other samples of the control mix and zeolite BBC were kept inside the carbonation chamber for 7 days and the outcomes for the 7 days were 13 mm for ZB_1, 14 mm for ZB_2 and ZB_3, 15 mm for ZB_4 and ZB_5 and 16 mm for ZB_6, which were the maximum of all. These outcomes for carbonation depth test is shown in Fig. 11. It demonstrates that among the others, ZB_6 had the greatest complexity. In both for the 3-day and 7-day tests, ZB_6 had the highest carbonation depth of among all the concrete cubes. This is due to greater addition of bamboo biochar as it is having more carbon and oxygen content. Although ZB_6 had the greatest carbonation depth, ZB_5 might be preferable because it had the highest compressive strength and split tensile strength.

5 Analysis of results

Based on the above test results of compressive strength, tensile strength, water absorption test, impact strength and carbonation tests, it can be seen that ZB_5 had greater contribution towards strength and carbondioxide absorption. From the SEM image of zeolite which is shown in Fig. 5, zeolite has large pore volume and high specific area which make it suitable for absorbing more CO_2 into it. Also, zeolite beads are having more oxygen content, as stated from the EDX results. It has the capacity to absorb more CO_2 from the atmosphere and more aluminium content which improves the strength of concrete. Bamboo biochar has a crystalline structure which is having pores in it observed from the SEM image which is shown in Fig. 5. It also has more carbon content from the EDX result and increases hardness, thereby increasing the compressive, tensile strength and impact strength of concrete. This biochar is having certain amount of carbon and oxygen which also helps in absorbing carbondioxide and because of its fineness, it improves packing density of concrete. Also, some air bubbles are exchanged from internal pores, which leads to mechanical strength as observed by Zhu et al. (2023). Compared with other specimens, there was more water absorption is more for ZB_5 and ZB_6 because they had higher amount of zeolite and bamboo biochar which have more pores in them, making them suitable for absorbing more water.

From the compressive strength results shown in Figs. 6 and 7, compared to ZB_1 and ZB_3, ZB_2 is having more compressive strength, and compared to ZB_4 and ZB_6, ZB_5 is having more compressive strength. From these

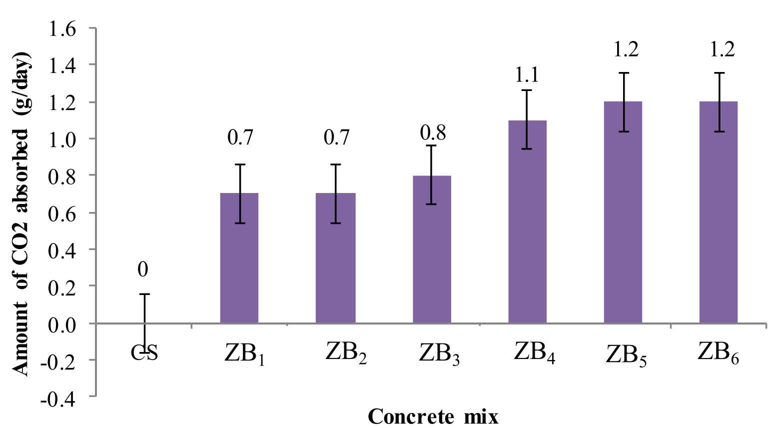


Fig. 10 Titration test results

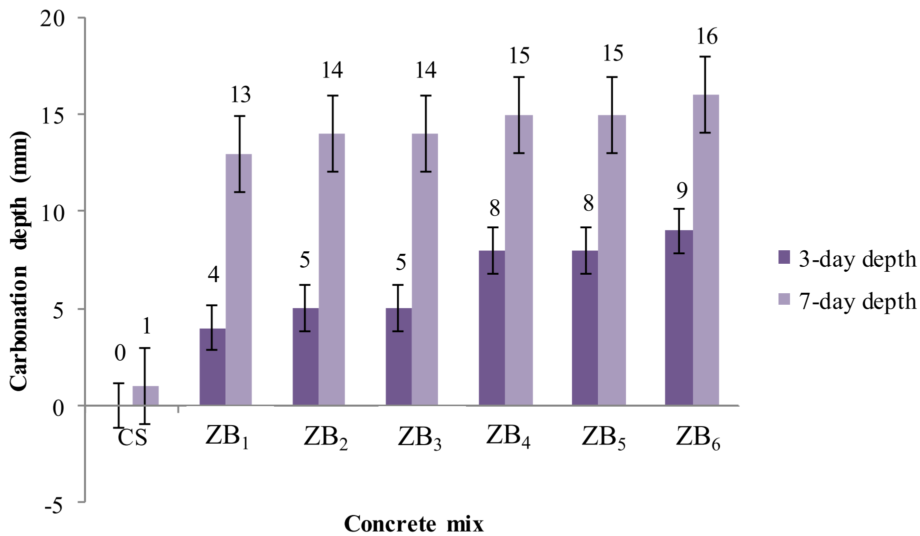


Fig. 11 Carbonation depth test results

results, it can be concluded that adding 1% of bamboo biochar improves the strength of concrete, while replacing more than 1% of cement with BBC which increases the brittleness and so reduces the strength of concrete. This behaviour is due to the increase in carbon content while adding more than 1% of BBC. Comparing ZB_2 and ZB_5, ZB_5 had more compressive strength, which states that adding zeolite of 50% improves the strength than 25%. So, increasing the percentage of zeolite increases the compressive strength of concrete. Also, the increase in zeolite from 25% to 50% increases the strength of concrete.

From the tensile strength results shown in Fig. 7, it is concluded that its behaviour was the same as that of compressive strength test. Adding more than 1% of bamboo biochar reduces the strength and increase in zeolite increases tensile strength too. Based on these results, impact test was only conducted for ZB_2 and ZB_5. From the results shown in Fig. 9, it is concluded that ZB_5 had more impact strength because of an increased addition of bamboo biochar compared to ZB_2, which improved its hardness and dense packing. Based on titration test and carbonation depth test, it is shown in Figs. 10 and 11 that ZB_5 and ZB_6 had more carbondioxide absorption than other specimens because it is having more zeolite and bamboo biochar as it is having large specific area and more oxygen and aluminium content than other specimens. But with respect to the strength behaviour ZB_5 gave better strength in compression, tension and impact. Adding more than 1% of bamboo biochar reduces the strength of concrete as it becomes brittle. So, from this analysis, it is concluded that adding 50% of zeolite and 1% of bamboo biochar will be the best proportion for concrete to be applied in more carbondioxide environments. It leads to carbon-neutral and sustainable environment.

6 Conclusion

This paper discusses the suitability of adding zeolite and bamboo biochar in various percentages in the concrete for improving its strength and mainly CO_2 absorption in carbon-rich environments. This study examined the mechanical properties and CO_2 absorption capacities of ZB concrete. This ZB concrete improves the strength and CO_2 absorption of concrete. In ZB concrete, zeolite beads and zeolite powder were partially replaced with 25% and 50% of fine aggregate and bamboo biochar was partially replaced with 0.5%, 1% and 1.5% of cement. The results found that when BBC was used in place of cement to a greater extent than 1%, the compressive strength decreases as the increase in BBC content increases the brittle nature of concrete. Increase in zeolite addition leads to increase in compressive strength as zeolite has a higher composition of aluminium and silica. The microporous structure of zeolite is well seen through SEM analysis and this porous structure helps in higher CO_2 absorption. Comparing ZB_1, ZB_2 and ZB_3, ZB_2 had the highest compressive strength of 37.84 MPa. Comparing ZB_4, ZB_5, and ZB_6, ZB_5 had the greatest compressive strength of 38.49 MPa which is 7.48% higher than conventional concrete which proves that BBC optimal percentage is 1%. The Split Tensile strength for ZB_5 was 4.39 MPa which is higher than all the other mix ratios of zeolite BBC concrete and was 15% greater than conventional concrete. Water absorption for zeolite BBC concrete for all the mix ratios of zeolite and BBC was within the limit. In that, ZB5 had a water absorption of 5.2% which was below the permissible limit. Impact strength for ZB_5 was 30 J which was 10% higher than the control specimen which proves that it is having more toughness than conventional concrete. Although ZB_6 had the greatest carbonation depth of 16 mm, ZB_5 having carbonation depth of 15 mm may be preferable because it had the highest compressive strength and split tensile strength test results, making it suitable to be used in the structures where strength is the leading parameter. Finally, this paper concludes that ZB_5 mix with 50% zeolite with partial replacement of fine aggregate and 1% BBC with partial replacement of cement is recommended and is found to be the optimal mix in strength and CO_2 absorption prespective, because it has the higher compressive strength, split tensile strength, impact strength and water absorption within the limit and has the highest amount of CO_2 absorption of 1.2 g/day and a carbonation depth of 15 mm in 7 days.

6.1 Future perspectives and recommendations

This paper focuses on the mechanical properties and CO_2 absorption behaviour of ZB concrete and it is also for M35 grade of concrete. The durability properties of ZB concrete, long term CO_2 absorption capacity, different curing condition, addition of other kinds of biochar with different grades of concrete, mortar, paints and paver blocks will be the future perspective of this study. In addition, mixing of pre-soaked biochar at 300 °C and 500 °C into the mortar gave greater compressive strength than the control mix and it also increased the internal curing efficiency as suggested by Gupta and Kua (2018). So, ZB concrete can be prepared with pre-soaking of bamboo biochar and pre-soaking effect of that concrete can be studied further.

Abbreviations

CO_2	Carbondioxide
PCE	Poly Carboxylate Ether
CSH	Calcium Silicate Hydrate
BBC	Bamboo Biochar
CS	Control Specimen
ZB1	Specimen having 25% zeolite and 0.5% bamboo biochar
ZB2	Specimen having 25% zeolite and 1% bamboo biochar
ZB3	Specimen having 25% zeolite and 1.5% bamboo biochar
ZB4	Specimen having 50% zeolite and 0.5% bamboo biochar
ZB5	Specimen having 50% zeolite and 1% bamboo biochar
ZB1	Specimen having 50% zeolite and 1.5% bamboo biochar
NaOH	Sodium hydroxide
SEM	Scanning Electron Microscopy
EDX	Energy dispersive x-ray spectroscopy

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Authors' contributions
All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Revathi.S, Alice Elizabeth Tania.D and Ancy Shadin.S. The first draft of the manuscript was written by Revathi.S and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

Competing interests
The authors declare that there is no competing interest.

Author details
[1]Department of Civil Engineering, Mepco Schlenk Engineering College, Sivakasi, Tamil Nadu 626005, India.

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