Journal of Building Design and Environment Vol 2 Issue 2 2023
DOI: 10.37155/2811–0730–0201–13

ORIGINAL RESEARCH ARTICLE

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Thermo-Physical study of Biochar Mixture into The Cement Based Material for Thermal Comfort

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Received: September 6, 2023; **Accepted:** December 6, 2023; **Published Online:** December 18, 2023

Citation: Kumar A, Pippal A, Agarwal R, Kumar R, Srinivasaraonaik B, Athar H, Kushwah S. Thermo-Physical study of Biochar Mixture into The Cement Based Material for Thermal Comfort. *Journal of Building Design and Environment*, 2023;2(2):21478. https://doi.org/10.37155/2811-0730-0201-13

Abstract: The cement-based materials have significant thermal properties which play a potential role in heat dissipation into the buildings. To improve thermal properties, particularly thermal conductivity, advanced materials such as phase change materials, vacuum insulation panels, and highly porous materials are employed. In this study, a biochar mixture was introduced in cementitious materials for thermal property enhancement. The biochar was prepared from the mixture of 10 wt% rice husk and 90 wt% sawdust in the absence of oxygen with the aid of muffle furnace at a temperature of 550 ℃ for 2 hours at a rate of 10 ℃ /min. The biochar dosages such as 3 wt%, 5 wt%, and 10 wt% were added with the replacement of cement in a cement paste. After 7 and 28 d, porosity, flexural strength, compressive strength, density, water absorption, and thermal conductivity were determined. The mechanical properties of samples were increased with 3 wt% biochar replacement with the cement and then decreased with 5 wt% and 10 wt%. The thermal conductivity of samples was decreased by 19–26.4% and 20.16–8.5% at 7 and 28 d respectively. The substitution of 3 wt% of biochar performed well in comparison to the control sample. Reduction of thermal conductivity of biochar-incorporated cementitious materials may be beneficial in situations where heat resistance is required due to its porous nature.
Keywords: Biochar; Thermal conductivity; Thermal comfort; Thermal properties; Mechanical properties

1. Introduction

Cement is one of the most frequently used building materials in the world. The cement industries play a major role in carbon emissions, making up about 8% of total carbon dioxide emissions[1]. In all over India, 2.3 metric tonnes of cement are used by per person per year[2]. In 2021, the industries of cement manufacturing are emitting 149

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million metric tonnes of carbon dioxide (CO_2). Carbon dioxide (CO_2) is a main source of climate change and carbon emission, it traps heat in Earth's atmosphere, which is affecting humans as well as the environment[2]. Reducing CO_2 emissions from cement is a significant challenge, as cement factories are one of the primary generators of CO_2 during the chemical transformation of limestone into clinker. Various supplementary materials such as silica fume, biochar[3] Fly ash, free lime, slag, and so forth are utilized for the reduction of cement demand. Furthermore, the emergence of novel binders, including Geo-polymers and calcium sulfo-aluminate cement, offers a greener alternative material with less CO_2 emission compared to Ordinary Portland cement (OPC)[4]. Biochar is a residue obtained by the pyrolysis of the biomass at a moderate temperature (550 ℃) with the minimum amount of oxygen. It is one of the most economical and affordable methods for the preparation of biochar[5]. Biochar can speed up the carbonation process due to its improved pore structure, and great chemical stability[6]. The pores structure of biochar contributes to its less thermal conductivity enhancing the insulation properties of building materials[5]. Biochar also enhances the mechanical characteristics of cement by speeding up the process of hydration[7, 8]. It was projected that the fracture resistance and bending capacity of the biochar-based cement composite may be increased because particles might absorb cracking force in the cementitious composite [9, 10].

Javed *et al*.[7] added different types of biochar such as bagasse biochar, coconut husk biochar, peanut husk biochar, rice husk biochar, and wheat husk biochar (1-5 wt%) in cement paste and mortar. The carbon dioxide adsorption capabilities were determined between 1.25-1.72 mmol/g. Gupta and Kashani[11] replaced 3 wt% biochar in cementitious materials. They have observed mechanical strength increment in mortar due to extra hydration nucleation sites. Aneja *et al*.[12] found that the flexural strength results of the concrete mix with 2% and 4% were better than those of the control concrete mixes owing to a reduction in permeability of 17.3% at 4 wt% of biochar. Haque *et al*.[13] added biochar in cement-based materials and determined the electrical conductivity of the sample. They have observed electrical conductivity raised by 12.6% in the cement substitution of 2 wt% of biochar at 28 d. D. Ali *et al*.[14] blended biochar (0 to 5 wt%) in pure cement paste and determined thermal conductivity. After 28 d, the thermal conductivity of cement paste was found to decrease by 28% when cement substitution was up to 5%. Mishra *et al*.[15] observed that the heat of hydration moderately increased when 1 wt% biochar was added to cement paste as compared to ordinary Portland cement (OPC) paste, however with 1.5 wt% biochar heat of hydration decreased. Roychand *et al*.[16] enumerated 10 wt% of biochar into cement composite materials. They have observed an 11% drop in compressive strength after 28 d.

Many researchers and experts have analyzed the thermal mechanical and physical properties of rice husks and sawdust biochar in cement material. However, there is no study on the combination of rice husk and sawdust biochar in cementitious material. Therefore, this study aims to study and compare the mechanical, thermal, and physical properties of rice husk and sawdust biochar with the individual rice husk and sawdust biochar. The obtained results are compared with the existing literature as discussed in **Table 1**.

Table 1. Comparison of existing literature data.

S.No.	Biochar	Replacement By Cement Wt	Effects By Replacement of Biochar	Reference
1.	Rice husk	Up to 8 wt% addition.	Slightly improved	Aneja *et al*.[12]
2.	Sawdust	Up to 5 wt% addition.	Increased compressive strength in concrete specimen.	Dixit *et al*.[24]
3.	Waste wood	Up to 8 wt% addition.	Increment by 8.4% for 2 wt% to 3 wt% addition.	Tan *et al*.[25]
4.	Rice husk waste and sugarcane bagasse	Up to 20 wt% replacement	Compressive strength is higher when 5 wt% cement replacement by bagasse biochar.	Asadi *et al*.[26]
5.	Weed tree	2 wt% addition	Slightly increased	Mo *et al*.[27]
6.	Bamboo chips	Up to 4 wt%	With a 1 wt% cement replacement, an increase of up to 20%.	Liu *et al*. [28]

Continuation Table:

S.No.	Biochar	Replacement By Cement Wt	Effects By Replacement of Biochar	Reference
7.	Waste synthetic eucalypts plywood boards	Up to 10 % replacement	After 28 d, it gave proper enhancement of compressive strength by 6.5 wt% replacement.	Qin *et al*.[29]
8.	Dewatered sludge	Up to 2 wt% replacement	Increasement by 5.8%	Chen *et al*.[30]
9.	Bagasse, wheat husk, peanut husk, coconut husk	Up to 5 wt% replacement	With 2 wt% cement replacement by bagasse biochar, an increase 18%.	Javed *et al*.[7]
10.	Rice Husk	Up to 7 wt% replacement	With 5% RHBC Foamed concrete strength increased to 11.3 MPa form 5.2 MPa	Song *et al*.[31]
11.	90 wt% Sawdust +10 wt% Rice husk	Up to 10 wt%	Thermal conductivity decreased by 29% and compressive strength increased by 3.36%	Present study

2. Materials and Method

2.1. Materials

Rice husk (RH), Sawdust (SD), and Ordinary Portland Cement 43(OPC 43) were collected from the local area of Roorkee, Uttarakhand, India. Ordinary Portland Cement of grade 43(OPC 43) was purchased from Roorkee's local market, Uttarakhand, India. The physical properties of raw materials are provided in **Table 2**.

Table 2. Physical properties of raw materials.

Properties	Rice husk biochar (RHB)	Sawdust biochar (SB)	90% RHB+10% SB	OPC 43
Density (kg/m^3)	115	135	179	3176
Blain finess (m^2/kg)	--	--	--	374
Mean particle size (µm)	---	---	12.67	23.32
pH	7.81	8.77	10.52	--
Yield (%)	32%	45%	50%	--
Water absorption	201%	218%	221%	--

2.2 Preparation of biochar

450g of sawdust biomass (SWD) and 50g of rice husk biomass (RHK) were pyrolyzed at 550 ℃ at the rate of 10 ℃ /min for 2 hours in the muffle furnace without oxygen in a pressurized condition[14]. A grinder mixer was used to crush biochar into very fine particles.

2.3. Preparation of biochar-based cement paste cubes

Ordinary Portland cement (OPC) is replaced by 3%, 5%, and 10 wt% of biochar with a water-to-binder ratio of 0.35 (**Table 3**). A mold size (25 mm × 25 mm × 25 mm) was used for making the cement paste cube **Figure 1** (a). After 24 hours, cubes were de-molded and placed in normal conditions in water for 7 d and 28 d **Figure 1** (b).

(a)

(b)

Figure 1. Cement cube casting (a) mould (b) Testing samples.

Table 3. Mix the proportion of raw materials.

W/C : 0.35	
Cement (%)	**Biochar (%)**
100	0
97	3
95	5
90	10

2.4. Compressive strength of biochar-based cement samples

After 7 and 28 d, samples were cleaned with cotton cloth. A UTM (Universal Testing Machine) was used to calculate the compressive strength of the specimen with an accuracy of 1.0%. Compressive strength is calculated by the forces applied to the cross-sectional area of the cubes. Compressive strength is calculated by the following equation (1)[14]

$$Compressive\ strength = \frac{d \times 3.15 \times 10}{BD} \qquad (1)$$

Where B and D are the width and depth of the cube, d represents the division in the deflection gauge.

2.5. Flexural strength of biochar-based cement samples

After 7 d and 28 d, samples were cleaned with cotton cloth. A UTM was used to determine the flexural strength of the specimen. Flexural strength is calculated by the following equation (2)[17]

$$Flexural\ strength = \frac{(3 \times p \times l)}{2BD^2} \qquad (2)$$

Where p is the load, l represents the net length of the cube, B and D are represent the width and depth of the cube.

2.6 Water absorption of biochar-based cement samples

The cubes were removed from the water after 7 and 28 d, the cured specimens were placed in an oven and dried at a certain temperature (100-110 ℃) for 24 hours. After 24 hrs, the specimens were removed from the oven, measured the dry weight (A) of each specimen. All the specimens were placed in water for the next 24 hours. After 24 hours take the specimens out of the water, and each specimen surface was cleaned with dry cotton cloths. Determined the wet weight (A) of each specimen.

Water absorption of the specimens was calculated by the following equation (3)[14]

$$Water\ absorption\ (\%) = \frac{\mathrm{A} - \mathrm{B}}{\mathrm{B}} \times 100 \qquad (3)$$

2.7 Density

The cubes are removed from the water after 7 and 28 d. Determined mass of the dry cubes(B) and also determine the volume of the cubes (V). After that, the density of the cubes is calculated by using the equation (4)[18]

$$Density = \frac{B(\mathrm{Kg})}{V(\mathrm{m}^3)} \qquad (4)$$

2.8 Porosity of biochar-based cement samples

The dry specimens were placed in Acetone for 24 hours. Determined the wet weight (A) of the samples (acetone soaked by the specimens). After 24 hours, take out the samples from the Acetone and placed them in oven to be dried at 50 ℃ for 24 hours. Determine dry wt (B) of the samples. The porosity of the cubes is determined by the following equation (5)[18]

$$Porosity(\%) = \frac{\mathrm{B}}{\mathrm{A}} \times 100 \qquad (5)$$

2.9 Thermal conductivity

A sophisticated C-therm TCI thermal conductivity analyser was used to calculate the thermal conductivity of biochar-based cement paste. The smooth and plane surface of the cubes were placed on thermal conductivity sensor and kept certain weight on it for proper contact with sensor. The voltage drop across the sensor is altered with help of existing software contained in the instrument. Thermal conductivity is determined corresponding the voltage drop and current.

3. Results and Discussions

3.1 Compressive strength of biochar-based cement samples

The compressive strength of biochar incorporated samples after 7 d and 28 d represented in **Figure 2**. The 7 d compressive strengths of the 3 wt% and 5 wt% increased by 16.27% and 28.55% whereas of 10 wt% decreased by 46.94% as compared to the control. After 28 d, the compressive strengths of biochar-based cement paste cubes having 3 wt% biochar increased by 3.25% however with 5 and 10 wt% biochar decreased by 51.35% and 68.08%, respectively as compared to control specimen. It means that biochar has promoted to strength up to 3 wt% due to extra hydration nucleation site. Moreover, the increase in compressive strength can also be attributed to the higher amount of C-S-H formation in biochar cement mixtures containing 3 wt% biochar. A strong association between C-S-H composition and strength improvement was not found due to the fact that further addition of biochar decreases the compressive strength of the biochar-based cement matrix.

3.2 Flexural strength of biochar-based cement samples

The flexural strength of biochar incorporated samples after 7 d and 28 d presented in **Figure 3**. The flexural strengths after 7 d increased by 13.33 % of 3 wt% and decreased by 7.44% of 5 wt%, and 25.92% of 10 wt% as compared to the control. Further, after 28 d, with 3 wt% biochar 40% of increment was observed whereas, with 5 and 10 wt% biochar flexural strength decreased by 5.5% and 20.8% respectively as compared to the control specimen. The increase is due to the biochar particles being well dispersed in the cementitious material. Further addition of biochar in cement matrix system decreases flexural strength due to agglomeration and biochar was not well dispersed. A higher amount of biomass biochar-based cement paste leads to reduced flexural strength, which is caused by increasing unfilled pores, which increased the low compacted matrix. Further, biochar works as a poor filler in the voids in the cement matrix, and does not resist the bending force[19-21].

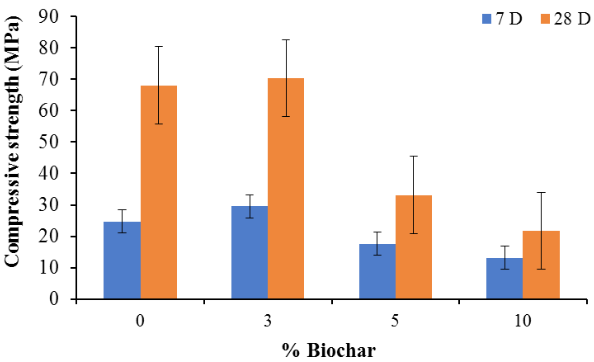

Figure 2. Compressive strength of biochar-based cement samples after 7 and 28 d.

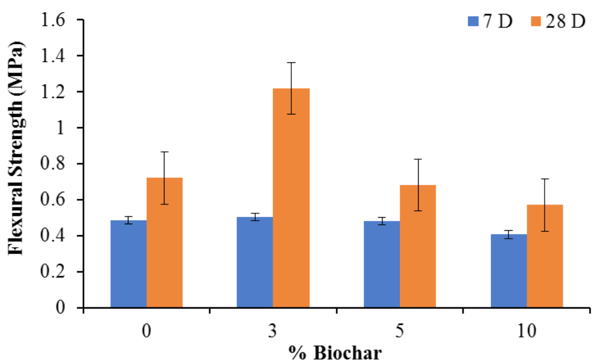

Figure 3. Flexural strength of biochar-based cement samples after 7 and 28 d.

3.3 Water absorption of biochar-based cement samples

After 7, 28 d, the water absorption of cement paste containing biochar was assessed in accordance with ASTM C642-97[18] as shown in **Figure 4**. In the case of 3%, 5%, and 10 wt% of biochar after 7 d there was a significant increase in water absorption by 6.0%, 13.28%, and 36.42% respectively as compared to the control specimen. After 28 d, as the amount of biochar increased there is a significant increase in water absorption by 31.56%, 47.78%, and 61.70% respectively. This is due to cement is being replaced by biochar in cement paste cubes because of significant bonding between the materials.

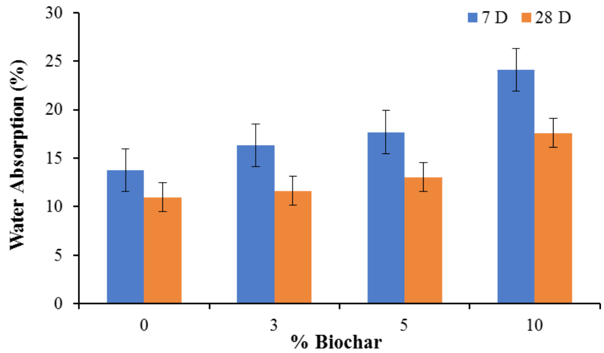

Figure 4. Water absorption of biochar-based cement samples after 7 and 28 d.

3.4 Density of biochar-based cement samples

Density of the cement paste containing biochar (SDB and RHB) was determined as per ASTM C642-97[18] after 7 d in **Figure 5**. As biochar % increases in cement paste, density of the biochar-based cement paste is reduced. In cases of 3%, 5%, and 10 wt% of biochar, there is a significant decrease in density by 3.2%, 7.8%, and 12.44% respectively. After 28 d, 3%, 5%, and 10 wt% of biochar, there is a significant decrease in density by 3.5%, 4.8%, and 10.6%. The density of the biochar-based cement paste is reduced compared to the control specimen due to the porosity of the biochar increases as the amount of biochar increase.

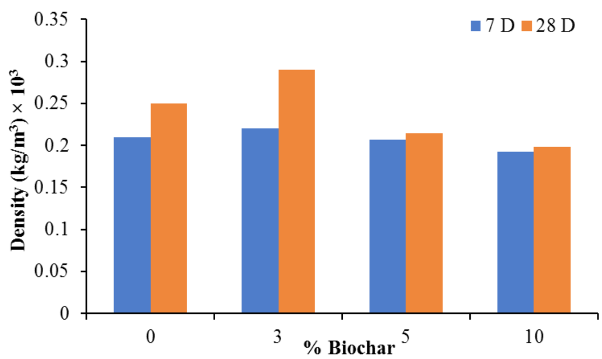

Figure 5. Density of biochar-based cement samples after 7 and 28 d.

3.5 Porosity of biochar-based cement samples

The porosity of the cement paste containing biochar (SDB and RHB) was determined as per ASTM C642-97[18] after 7 d and 28 d, as shown in **Figure 6**. As biochar % increases in cement paste cubes, the porosity of the biochar-based cement paste cubes increases. In cases of 3%, 5%, and 10 wt% of biomass biochar, there is a significant increase in porosity by 11.65%, 13.06%., and 17.06% respectively. After 28 d, 3%, 5%, and 10 wt% of biomass biochar, there is a significant increase in porosity by 12.45%, 13.45%, and 17.61% when compared to the control specimen. The increase and decrease in porosity is due to cement is being substituted by biochar and effective pores of biochar and cement in cement paste cubes because of the binding effect.

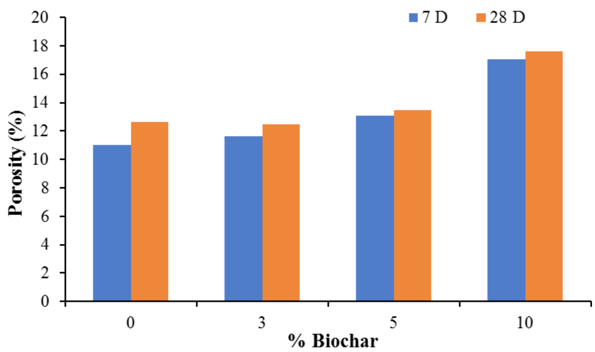

Figure 6. Porosity of biochar-based cement samples after 7 and 28 d.

3.6 Thermal conductivity biochar-based cement samples

After 7 and 28 d, thermal conductivity of cement paste containing biochar was determined as mentioned in the section 2.9[22]. As the amount of biochar increased, the thermal conductivity of biochar-based cement paste cube samples decreased by 10.5% for 3 wt%, by 26.01%, for 5 wt% and by 34% for 10 wt% at 7 d. When compared with the control specimen after 28 d the thermal conductivity decreased by 20.16 for 3 wt%, 25.2% for 5 wt% and 28.57 for 10 wt% (**Figure 7**). The high porosity of biochar materials had a substantial impact on the thermal bridge inside the biochar-based cement composite, which also decreased the thermal conductivity of the biochar-based cement composite[23]. Moreover, the thermal conductivity of biochar-based cement paste is decreased due to the significantly impacted by the high porosity of biochar materials. Decremental thermal conductivity of samples may impact on various building envelope such as mortar as plaster, concrete as roof etc. Further studies are to be experimented for real application on buildings.

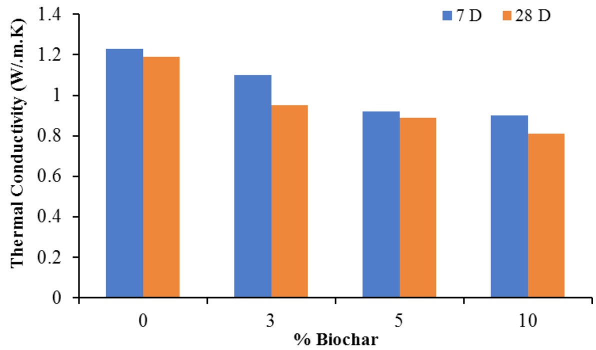

Figure 7. Thermal conductivity of biochar-based cement samples after 7 and 28 d.

4. Conclusion

This study was investigated for the impact of biochar mixture of SDB and RHB replacement with cement paste on improving the thermal properties, mechanical and physical. As the biomass biochar increase in biochar-based cement paste cubes up to the 3 wt% the compressive strength of the biochar-based cement composite is increased 16.27% and after 28 d, it increased by 3.25%, is higher when compared to control. The percentage of flexural strength decreased 13.33%, 7.44%, and 25.92% when compared to the control specimen in 7 d, and after 28 d, were 40% of 3 wt% increases when compared to control specimen but 5.5% of 5 wt%, and 20.8% of 10 wt% decreased. As biochar rises in cement-composite paste, water absorption increases by 6.0%, 13.28%, and 36.42% in 7 d, and after 28 d, it absorbs more water by 31.56%, 47.78%, and 61.70%. Percentage of density is significantly decrease in 7 d and 28 d 3.2%, 7.8%, and 12.44%, 3.5%, 4.8%, and 10.6%. The percentage of porosity is significantly increase in 7 d and 28 d 5.6%, 15.84%, and 37.59%, 1.58%, 5.9%, and 25.84% in matching to 3%, 5%, and 10 wt%. Thermal conductivity of cement paste containing biochar decreased continuously after 28 d when compared to the control specimen.

Conflict of Interest

There is no conflict of interest among the authors.

Acknowledgement

The authors would like to acknowledge the Director, CSIR-Central Building Research Institute, Roorkee, Uttarakhand, India for providing the funding for this research (Project No. OLP-02216).

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