Biochar Amended Concrete for Carbon Sequestration

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Abstract. With the rapid increase in built-up areas around the world, and the emergence of new cities, there is a potential of sequestering carbon in civil infrastructures. Biochar is the by-product of the pyrolysis of biomass, which can be introduced to the cement mortar and the cement concrete, as a replacement of cement as well as an additive. Biochar is effective in the carbon sequestration activity and results in the high internal curing action due to the high-water absorptive capacity. As the percentage of biochar increases the amount of carbon dioxide adsorbed is also observed to increase. However, it is imperative that biochar addition should not compromise the strength characteristics of concrete. As a well-accepted fact, the pozzolanic activity plays large importance on the durability and the strength gain of concrete. The present study is aimed at investigating the pozzolanic activity of the biochar. Biochar specimens were subjected to different pre-treatments, and the corresponding changes in the pozzolanic activity were studied. The biomass used for the study was locally available coconut shells and the pre-treatment was done with the 0.1N HCl. The pozzolanic activity was checked by calculating the amount of Ca(OH)2 fixation during the titration. It was observed that treatments at higher temperatures have no significant effect on the pozzolanic activity. And this suggests that pre-treatment of biochar at room temperature is enough for enhanced pozzolanic activity. The study has reaffirmed the potential use of biochar in making sustainable concrete fit for carbon sequestration.

1. Introduction
Cement is the most broadly perceived material used in the construction industry. It has critical importance among the construction materials. In the production process of cement, the amount of carbon dioxide emission is more and thus it leads to many of the environmental impacts. India lies second in the production of cement for satisfying the needs of the construction work. Thus, there is a requirement of replacement of cement with a suitable material which will go with the different characteristics of cement. Various research papers were addressed on the characteristics of concrete after replacement of the cement with different industrial by-products such as silica fume [6][12], metakaolin [1][14], fly ash [6][7], bottom ash[13], rice husk ash[1], palm oil fuel ash[3][15]. Biochar is formed after the pyrolysis of biomass. The biomass may be any material such as food waste, agricultural waste, poultry waste etc.

The importance of biochar is mainly on carbon sequestrating activity. Now in the present time, the biochar is successfully used in the soil for enhancing the soil, and it also holds the carbon in soil and thus makes the soil more fertile. This paper focuses on the effective use of the coconut shell biochar in the replacement of the cement. The studies reveal that the biochar showed better carbon sequestration characteristics in concrete without compromising the strength requirements. As the emission of carbon dioxide is increasing in the present world, it has become a pertinent problem that requires special...
attention. So that the material that is used for the building construction should have a capacity of the carbon sequestration. This situation leads to the effective use of the biochar in the concrete as the replacement of cement. Biochar is a material that can hold water and carbon which in turn results in the internal curing action and carbon sequestration.

When a material is used for the partial replacement of cement it may not always assure the strength properties, therefore some sort of treatment is to be done prior to replacement. It was clear that the strength property depends on the pozzolanic activity of the material, which can be enhanced by the pre-treatment. The effective treatment is done by using the 0.1 N HCl [19], and higher normality does not influence the pozzolanic activity of the biochar. The increased pozzolanic activity leads to better strength characteristics. The possible use of biochar in concrete can cater to the growing need of disposal of biomass in addition to producing concrete with enhanced carbon sequestration property.

2. Materials and methods

2.1. Biochar production
Coconut shell, which is commonly available in Kerala, was used for this study. Though the coconut shells are used for different purposes such as fuel, craft and for purifying the water, the amount of coconut shells that are effectively utilised is minimal. The coconut shells were collected, cleaned, and converted to biochar by the pyrolysis process at controlled temperature. The temperature range was fixed at 600°C to 650°C. The prepared biochar was then ground into fine particles, having a size less than 180 microns.

2.2. Pre-treatment
In order to study the pozzolanic activity, biochar was pre-treated with 0.1N HCl [19]. The biomass ie., the coconut shells were immersed in the HCl solution at varying temperatures viz., at room temperature, at 100°C, 500°C and 800°C for different time intervals of 30 minute and 1 hour at each of these temperatures. After this treatment, the sample of treated biomass was washed with distilled water and it was then oven dried. Then it was turned into biochar using a small pyrolysis unit. Since it was evident from earlier studies that the normality of HCl had little effect on the enhancement of the pozzolanic activity [19] it was decided to carry out the pre-treatment with 0.1N HCl. The biochar was ground using mechanical grinders.

2.3. Pozzolanic activity measurement
Chapelle test is a French standard (NF P18-513) used for finding pozzolanic activity.25 ml of deionised water is used as a solvent, and in that 1g biochar and 2 g of calcium oxide powder were added. The solution was then kept for continuous stirring for a period of 16 hours at a temperature of 90°C by keeping it in a hot stirring plate. Then, after stirring it for 16 hr, the slurry was cooled and then 250 ml of 0.7 M sucrose was added to it, accompanied by stirring for 15 minute and followed by filtration of suspension. A few drops of 0.1% phenolphthalein were added to the 25 ml of the filtrate and followed by filtration with 0.1 N HCl. The pozzolanic activity is determined [19] using the titration results, as shown in equation (1):

$$Ca(OH)_2 \text{ fixed in mg} = \frac{2}{V_b} \left( V_b - V_m \right) \frac{74}{56} \times 1000$$ (1)

The terms $V_m$ and $V_b$ denote the volume of 0.1 N HCl solution required for blank samples with and without biochar, respectively. The calcium hydroxide formed during titration in mg gives the measurement of the pozzolanic activity.

2.4. Test for identifying carbon Sequestration
Biochar amended mortar cubes with different percentage of biochar were placed inside an airtight chamber. The setup is as shown in figure 1.

Burning candles were kept inside the containers to produce carbon dioxide within the containers. Mortar cubes prepared with different percentages of biochar were stacked in the container in order to check the possible sorption of carbon dioxide produced by the burning candles. MQ135 carbon dioxide sensors were fixed inside the container to monitor concentration of carbon dioxide. Containers were
properly sealed to ensure the measurement of carbon dioxide within the container. Mortar cubes with 1%, 2%, 5% amendments were used in the study. The studies were done with single and double burning candles. Table 1 and table 2 give the properties of cement and the biochar that were used for the experiment.

![Image](image1.png)

**Figure 1.** (a) Shows the experimental setup that was used for the identification of the carbon sequestration property (b) MQ135 carbon dioxide sensors.

| Particulars          | Values       |
|----------------------|--------------|
| Grade                | OPC 43       |
| Specific gravity     | 3.16         |
| Standard consistency | 32%          |
| Initial setting time | 116 min      |
| Fineness             | 5%           |

**Table 1. Properties of Cement.**

| Particulars          | Values       |
|----------------------|--------------|
| Size                 | 150 microns down-size |
| pH                   | 9            |
| Specific gravity     | 2.64         |

**Table 2. Test result for biochar.**

3. Results and discussion

3.1. Pozzolanic activity

Pozzolan is a broad class of siliceous or siliceous and aluminous materials which, in themselves, possess little or no cementitious value but which will, in finely divided form and in the presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. The pozzolanic activity has a great importance in the strength properties.

![Image](image2.png)

**Figure 2.** Variation of pozzolanic activity at different temperature.
Figure 2 shows the effect of pre-treatment at different temperatures and time conditions. The pre-treatment of the biomass followed by the pyrolysis process is shown to enhance the pozzolanic activity of the biochar produced.

It was observed that higher temperatures do not enhance the pozzolanic activity significantly. The untreated biochar shows Ca(OH)\textsubscript{2} formation of 208.7 mg whereas the pre-treated biochar exhibited almost double this value. This confirms that pozzolanic activity can be increased considerably with the use of biochar produced from pre-treated biomass. As mentioned, the pozzolanic activity has considerable importance in the strength properties; this points out that the strength characteristics can be ameliorated by the treatment of the biomass before pyrolysis and thereby carryout the pyrolysis under controlled temperature conditions. The increase in pozzolanic activity is due to the increase in the surface area and porosity of the biochar produced. Better pozzolanic activity was achieved by the pre-treatment of the biomass even at room temperature. However, it was found that the pozzolanic activity reduced with the increase in the pre-treatment temperature. Moreover, with the increase in the time of immersion there was no appreciable increase in the pozzolanic activity. Hence it can be stated that pre-treatment with 0.1N HCl acid at room temperature for 60 minutes was well enough to enhance the pozzolanic activity of biochar.

3.2. Carbon sequestration

Results of the possible sorption of carbon dioxide by biochar amended mortar specimens are tabulated in table 5. Then the percentage of sorption was calculated for each biochar percentage. The results are tabulated in table 3.

**Table 3. Percentage sorption of carbon dioxide in single candle, single specimen setup.**

| Control specimen (no biochar) | Cement + 1% biochar | Cement + 2% biochar | Cement + 5% biochar |
|-----------------------------|---------------------|---------------------|---------------------|
| Initial concentration of CO\textsubscript{2} (ppm) | 400 | 404 | 471 | 548 |
| Peak concentration of CO\textsubscript{2} (ppm) | 561 | 543 | 579 | 674 |
| Final concentration of CO\textsubscript{2} (ppm) | 539 | 516 | 530 | 579 |
| Percentage sorption of CO\textsubscript{2} (%) | 13.66 | 19.42 | 45.37 | 75.30 |

It is evident from the table that there was an increased percentage of sorption of carbon with the increasing biochar content in the cement mortar. The experiments with double candle (Table 4) also showed similar trend.

**Table 4. Percentage sorption of carbon dioxide in double candle, single specimen setup.**

| Control specimen (No biochar) | Cement + 1% biochar | Cement + 2% biochar | Cement + 5% biochar |
|-----------------------------|---------------------|---------------------|---------------------|
| Initial concentration of CO\textsubscript{2} (ppm) | 408 | 400 | 440 | 408 |
| Peak concentration of CO\textsubscript{2} (ppm) | 570 | 543 | 548 | 570 |
| Final concentration of CO\textsubscript{2} (ppm) | 557 | 521 | 516 | 530 |
| Percentage sorption of CO\textsubscript{2} (%) | 8.02 | 15.38 | 21.29 | 24.69 |

This points out that the biochar amended is increasing the carbon sequestration ability of cement mortar. This opens up the possible use of biochar in concrete and cement mortar for sequestering carbon and mitigating climate change. Further studies with biochar amended concrete have clearly brought up the fact that concrete prepared with pre-treated biochar had higher strength. The table 5 shows the compressive strength of concrete amended with biochar. M25 mix design was used, mix design was done with reference to IS 10262:2009.
Table 5. Compressive strength test results using treated biochar amended concrete.

| Specimen specification          | 7 days compressive strength (N/mm²) | 28 days compressive strength (N/mm²) |
|---------------------------------|------------------------------------|-------------------------------------|
| Control specimen (No biochar)   | 37.2                               | 44.7                                |
| Cement + 5% biochar             | 40.4                               | 53.5                                |
| Cement +10% biochar             | 38.6                               | 47.8                                |
| Cement + 15% biochar            | 33.6                               | 40.6                                |

These results categorically points that addition of biochar into concrete was not compromising on the strength of concrete.

4. Conclusions

From the experimental studies it is evident that the amendment of biochar prepared from pre-treated biomass produces mortar with better carbon sequestration ability which can be extensively used for improving the indoor air quality. The percentage of sorption increase with the increase of biochar. The strength of the biochar amended concrete is not compromised due to the pre-treatment which involves the simple procedure by treating with 0.1N HCl. The study has brought out clearly that the biochar produced from pre-treated biomass is a potential candidate for combating the pollution from cement industry and catering to the need to save the environment.

5. References

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