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Biochar Enriched Concrete for Carbon Sequestration

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Abstract: In upcoming years , a lot of construction is going to happen leading to more cement consumption and more GHG's emissions by default as an embodied carbon. Reduction of cement consumption is possible by partially repacing it with biochar which is a by-product of pyrolysis of biomass or adding it as an additive in cement mortar and concrete for carbon sequestration. Biochar is effective in carbon sequestration activity and results in high water and carbon dioxide holding capacity. Increase in biochar lead to increase in carbon sequestration . As pozzolanic activity lead to strength gaining characteristics and durability of concrete, this study focusses on investigating pozzolanic activity of biochar. Biomass considered in this study were walnut shells and pretreatment was done with 0.1 N HCl and and pozzolanic activity is checked by chapelle test by observing $Ca(OH)_2$ fixation during the titration. It was observed that increase in temperature or Normality of HCl in pretreatment does not enhance pozzolanic activity of biochar . Hence pretreatment with 0.1 N HCl at room temperature for an hour is sufficient to enhance the pozzolanic activity of biochar with much high carbon dioxide sorption as compared to usual concrete without compromising with the strength of concrete. This study reclaims the potential use of biochar in concrete is reliable for carbon sequestration.
Keywords: Biochar, Carbon Sequestration, Pozzolanic Activity, Embodied carbon ,Cement Replacement.

I. INTRODUCTION

Building industry's emissions currently account for 40 percent of total global annual CO2 emissions. Out of which the third is attributable to embodied carbon. The anticipated growth and urbanization of the global population will lead to growth of construction of new housings and other infrastructure in upcoming years. India holds second rank in production of cement for the construction work. While 8 % of world's GHG's emissions are due to cement production as in the production of cement large amount of Carbon dioxide is released into the atmosphere known as Embodied carbon. Anything we will do to reduce the amount of cement in your concrete mix will have a significant impact on the overall embodied carbon of the concrete. Hence, Biochar is used as an partial replacement of cement in concrete to reduce the amount of cement in your concrete mix, also post combustion carbon sequestration is possible resulting in toes towards going net zero emissions where concrete will act as a carbon sink. Previously various literatures were addressed explaining different enrichments in concrete as a repacement of cement like Metakaolin [1][2] ,Fly ash [3][4], Bottom Ash [5], Rice husk Ash [1], Silica Fume [6][7], Palm oil Fuel Ash [8][9] Bagasse Ash [10] etc. Pyrolysis and Gasification of biomass are most used method by which the Biochar is formed. Materials like food waste, Poltry waste [11], Agricultural waste etc. can be considered as Biomass .

In recent times Biochar has been used for enhancing soil properties. Though The importance of biochar is mainly on Carbon sequestration Activity. This paper Focusses on use of walnut shell Biochar as partial replacement of cement . This study deals with the walnut biochar in cement concrete as a partial replacement of cement for carbon sequestration .Building material acting as a carbon sink can be a better solution to reduce GHG's emissions and reduction in Embodied carbon by default. Biochar is a material proved to be having high water as well as carbon holding capacity which leads to internal curing action and Carbon sequestration. Still there will always be a scrutiny regarding the strength of cement mortar or concrete when there will be the talk of replacement of cement. As strength property is known to be depended on pozzolanic activity of that material which can be enhanced by 0.1 N HCl Pre-treatment. [11] Increase in normality and Temperature are considered in this study to check its effect on pozzolanic activity of Biochar.

II. MATERIALS AND METHODS

A. Biochar Production

Walnut shells are generally utilized for deflashing and cleaning parts,also as low-cost adsorbent materials in an anaerobic filter medium of a De-centralized wastewater treatment system [12] but still there are no much effective ways for utilization of walnut shells.

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In this study Walnut shells are collected from market and converted to biochar by pyrolysis process at a controlled temperature in the range of 400˚C to 450˚C.Biochar is then Grounded manually to the size less than 180 microns.

Fig.1 Walnut shell Biochar Production

B. Pre-treatment

To enhance the pozzolanic activity of Biochar pretreatment was done with 0.1 N HCl [11]. Walnut shell biomass is immersed in HCl solution for 1 hour at room temperature and at 100 ˚C . Pretreatment is done with increasing normality of HCl i.e at 0.1 N, 0.5N, and 1 N respectively. After Pretreatment, biomass is washed with distilled water and kept for oven drying.Then this biomass is converted to Biochar with the help of muffle furnace as pyrolysis unit.

Fig.2 Walnut shell pretreatment before Biochar Production

C. Pozzolanic Activity measurement

Chapelle test is used in this study (N.F P18-513) which is a french test for pozzolanic activity measurement . 250 ml deionised water with 1 gm of biochar and 2 gm of calcium oxide powder is added to it and kept for continuous stirring for the period of 16 hours at 90˚C by keeping it in hot stirring plate. Slurry was allowed to cool after 16 hours and then 250 ml of 0.7 M sucrose was added to it with stirring for 15 minutes and followed by filtration and suspension. Few drops of phenolphthalein is added to 25 ml of filtrate and and followed by titration with 0.1 N HCl. Titration results define pozzolanic activity measurement .

$$Ca(OH)_2 \text{ fixed in mg} = 2\,\frac{(V_b - V_m)}{V_b}\,\frac{74}{56} * 1000$$

Where, *Vm* is the volume of 0.1 N HCl solution required for sample with biochar and *Vb* is the volume of 0.1 N HCl solution required for sample without biochar. [13]

D. Carbon sequestration Testing

Mortar cubes with 2%, 4%, 6% amendments are used in the study. (as per Is 4031) for the measurement of Carbon sequestration i.e percentage sorption of carbon diaoxide. And concrete cubes with 5%, 10% and 15% amendment of biochar are considered to check compressive strength of concrete (M20 grade).

properties of cement (used in the study)

1) grade - OPC 43 (Ultratech)
2) Specific gravity of Cement = 3.13
3) Fineness - 6%
4) Standard consistency - 32%

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5) Initial setting time - 175 min.
6) Final setting time - 310 min.

E. Test Results for walnut shell Biochar

1. Size - 150 microns down-size.
2. pH- 9.02
3. Specific gravity - 2.31

Fig.3 Mortar cubes and concrete cube preparation with walnut shell biochar enrichment.

F. Carbon sequestration study

For carbon sequestration study , Airtight chamber is prepared with 8mm thick transparent Acrylic sheets having two rooms (Room 1 and Room 2). To check if it is air tight, after preparing a closed chamber it is submerged into water and checked for water entry and that area is sealed with M-seal and checked again.

After preparing a Airtight chamber , 7.5 cm x 7.5 cm openings are made in both rooms for the entry of cubes , candles into the rooms. MQ 135 SENSORS [14]are attached on the top of the chamber by fixing Arduino Uno and LED assembly at top and sensors fixed upside down into rooms into the holes made on airtight chamber . holes with sensors are again filled with sealing coates to refrain air entry or exit of co2 from chamber . Double candle with single specimen per room is considered for carbon sequestration study.

Fig.4 Carbon sequestration study chamber with MQ 135 sensors

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III. RESULTS AND DISCUSSION

A. *Pozzolanic Activity*

The calcium hydroxide formed during titration in mg gives the measurement of the pozzolanic activity.

Table 1. Pozzolanic activity observations

Biochar Description	Trial No.	Vb in ml	Vm in ml	$Ca(OH)_2$ Fixed in mg.	Average In mg.
Untreated Biochar	Trial 1	18.2	16.80	203.29	214.58
	Trial 2	18.6	17.15	206.03	
	Trial 3	18.35	16.70	234.44	
	Vb value is not measured again as no difference in method is observed , hence average of upper 3 trials (I.e 18.40 ml) is considered ahead as Vb for further calculations of treated biochar .				
Treated Biochar 0.1 N HCl R. T - 60 MIN	Trial 1	18.4	15.40	430.90	440.47
	Trial 2	18.4	15.15	466.80	
	Trial 3	18.4	15.45	423.72	
Treated Biochar 0.1 N HCl 100˚C - 60 MIN	Trial 1	18.4	15.60	402.17	428.50
	Trial 2	18.4	15.05	481.17	
	Trial 3	18.4	15.60	402.17	
Treated Biochar 0.5 N HCl R.T - 60 MIN	Trial 1	18.4	15.10	473.99	418.93
	Trial 2	18.4	16.00	344.72	
	Trial 3	18.4	15.35	438.08	
Treated Biochar 0.5 N HCl 100˚C - 60 MIN	Trial 1	18.4	15.20	459.63	423.72
	Trial 2	18.4	14.95	495.54	
	Trial 3	18.4	16.20	315.99	
Treated Biochar 1 N HCl R.T - 60 MIN	Trial 1	18.4	15.30	445.26	394.99
	Trial 2	18.4	15.90	359.08	
	Trial 3	18.4	15.75	380.63	
Treated Biochar 1 N HCl 100˚C - 60 MIN	Trial 1	18.4	16.00	344.72	438.08
	Trial 2	18.4	14.95	495.54	
	Trial 3	18.4	15.10	473.99	

It shows that increase in temperature or Normality of HCl in pretreatment does not enhance pozzolanic activity of biochar and results are obtained to be unclear in inference. But untreated biochar shows $Ca(OH)_2$ formation of 214.58 mg. Where Treated bichar with 0.1 N HCl at room temperature for an hour shows $Ca(OH)_2$ formation of 440.47 mg which is almost more than double. Hence pretreatment with 0.1 N HCl at room temperature for an hour is sufficient to enhance the pozzolanic activity of biochar.

B. *Carbon Sequestration*

Results of sorption of carbon dioxide by mortar specimen enriched with walnut shell biochar with double candle , single specimen setup as shows below in table 2.

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Table 2 Carbon Sequestration observations

	Trials	Initial concentration of CO_2 (PPM)	Peak concentration of CO_2 (PPM)	Final Concentration of CO_2 (PPM)	Percentage Sorption of CO_2 (%)	Average Percentage Sorption of CO_2 (%)
Control specimen (No Biochar)	Spec. 1	410	574	560	8.53	8.32
	Spec. 2	412	572	558	8.75	
	Spec. 3	410	579	566	7.69	
Cement + 2% biochar	Spec. 1	411	573	548	15.43	16.40
	Spec. 2	418	565	539	17.68	
	Spec. 3	410	590	561	16.11	
Cement + 4% biochar	Spec. 1	417	567	527	26.67	29.07
	Spec. 2	425	584	534	31.44	
	Spec. 3	419	577	531	29.11	
Cement + 6% biochar	Spec. 1	422	569	507	42.17	40.99
	Spec. 2	407	578	511	39.18	
	Spec. 3	418	591	519	41.62	

Carbon sequestration of mortar cube with biochar (pretreated with 0.1 N HCl at room temperature for an hour) is obtained to be double to five times more than mortar cube without biochar. Carbon sequestration is observed to be increasing with increase in percentage biochar. It shows that with wanut shell biochar Carbon sequestration increases with increase in biochar.

Table 3. Compressive strength Test results on biochar enriched concrete (M20 grade)

Specimen Specification	Trials	Load (KN)	Area of cube (mm2)	28 days compressive strength N/mm2	Average Compressive strength in N/mm2
Control Specimen (No Biochar)	Spec. 1	476	22500	21.15	20.66
	Spec. 2	462	22500	20.53	
	Spec. 3	457	22500	20.31	
Cement + 5% biochar	Spec. 1	482	22500	21.42	21.22
	Spec. 2	471	22500	20.93	
	Spec. 3	480	22500	21.33	
Cement + 10% biochar	Spec. 1	493	22500	21.91	21.98
	Spec. 2	500	22500	22.22	
	Spec. 3	491	22500	21.82	
Cement + 15% biochar	Spec. 1	503	22500	22.35	22.54
	Spec. 2	507	22500	22.53	
	Spec. 3	512	22500	22.75	

Table shows that pretreated walnut shell biochar enrichment in concrete does not compromise with strength of concrete actually it is observed to be increasing strength instead.

IV. CONCLUSION

The entire study where walnut shell biochar has been used as an replacement in concrete and mortar is reasonable to increase in pozzolanic activity with pretreatment . Also it is liable to carbon sequestration t as increase in pretreated biochar increasing the carbon sequestration without compromising with strength of the concrete. This study concludes that pretreated walnut shell biochar can make building a carbon sink and it is reliable for reduction of cement consumption and to lay hand in pollution combat From cement industry.

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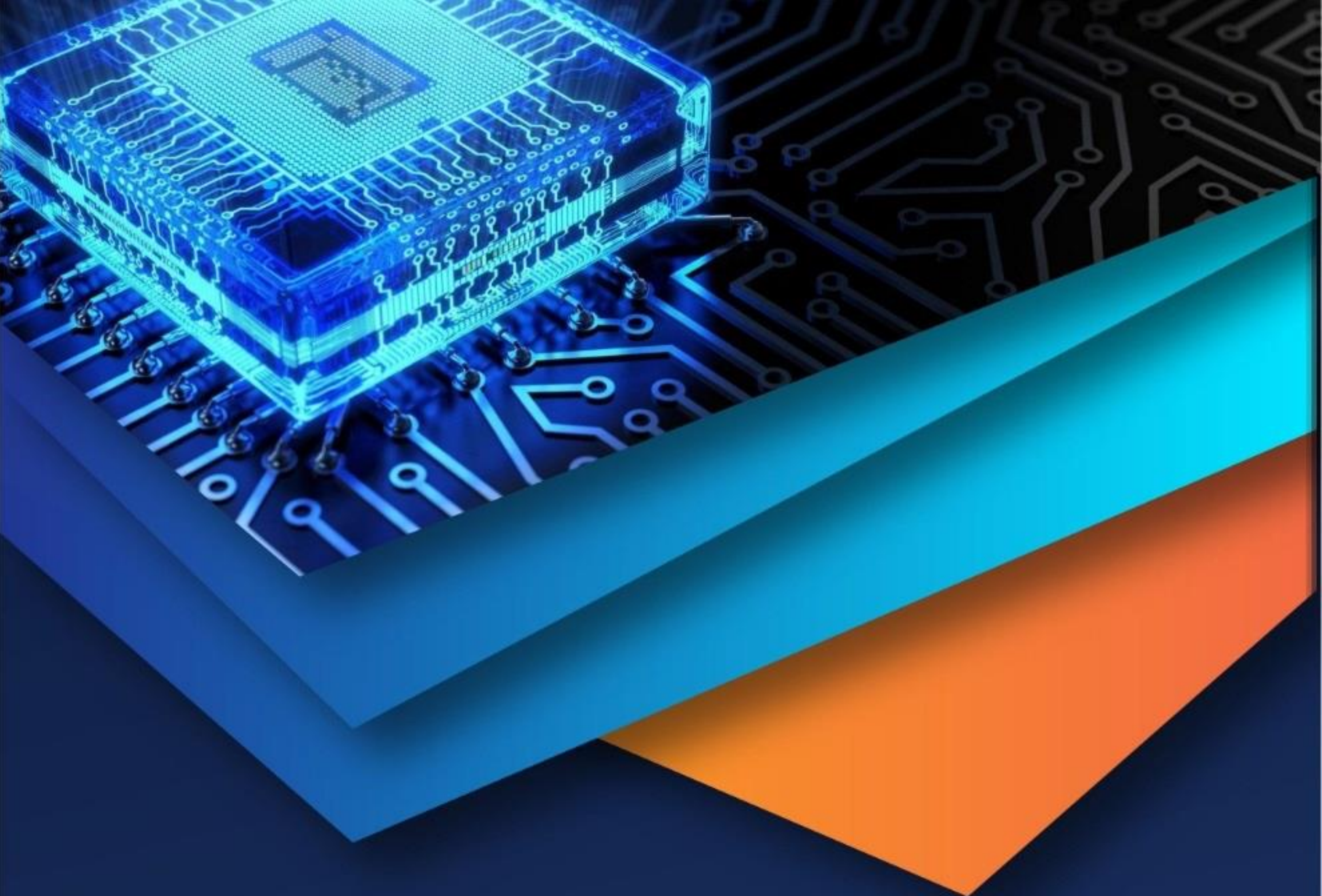

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