CARBON STORAGE THROUGH BIOMASS-BASED CONSTRUCTION

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Abstract

At the onset of increasing GHG emissions worldwide, it is becoming increasingly important to reduce fresh carbon emissions. New forms of building materials have been emerging, where natural fibres (biomass) are used in combination with zero emission or low emission pozzolans or binder materials such as lime, fly ash, furnace slag, etc. to reduce CO_2 emissions from manufacturing industry. One such building material uses Hemp and lime, and is called Lime Hemp Concrete (LHC). This research was focused on formulating LHC based on the literature reviewed, and; assessing the total carbon sequestration achieved by the formulated LHC mix from CHN Elemental analysis and X-Ray Diffractometer analysis. A stoichiometric analysis was conducted on the formulated LHC cube of dimensions 7cm x 7cm x 7cm to establish a projected carbon sequestration potential of 161.31 g of CO_2. At the age of 28 days, it was found that the cube had achieved a carbon sequestration of 105.39 g of CO_2. The project carbon sequestration potential for the LHC mix was 492.3 kg of CO_2 per m^3 of Lime Hemp Concrete and the achieved carbon sequestration was 307.26 kg of CO_2 per m^3 of LHC. Future work has been suggested in the paper for development of physical properties of the material such as mechanical strength. Life Cycle Assessment of an LHC wall with different mix designs also needs to be carried out to assess the net carbon emissions.

Keywords: *Hemp concrete, Biomass, Composite materials, Carbon sequestration, Sustainable materials*

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1. INTRODUCTION

Construction practices nowadays are heavily carbon intensive and emissions due to construction practices are significantly large. An environmentally conscious building design creates a healthy indoor environment while supporting a healthy outdoor environment. This design is practically unachievable by using present world conventional building methodologies and materials. So-called "modern" construction materials, though, help facilitate the construction of safe buildings the carbon footprint of such "modern" constructs is relatively very large and amount to unsustainable levels of carbon emissions that cause global warming. Total CO_2 emissions in the India amounted to about 2.3 Gigatonnes in the year 2014, out of which 4.4% of the emissions were made by the manufacture of cement alone amounting to 102 Megatonnes [1]. Globally, CO_2 emissions have stalled, but in contrast, India saw a 7.8% increase in the total CO_2 emissions since 2013 [1]. The cessation of the current alarm around carbon emissions would require a more "natural" approach. The answer to the environmental problems presented by the conventional carbon intensive building materials is what is relatively a new, yet a "traditional" building material that uses natural fibers (hemp, straw, animal hairs, bamboo…) and binder (lime, clay, mud, etc.,) called hemp concrete. Lime Hemp Concrete (LHC) or Hemp Concrete has displayed a lower ecological impact as opposed to other Portland cement based construction materials. An example of a hemp plant is shown in Fig. 1.

In a study conducted by K. Ip et al. [2], it was found that the LHC wall they studied had a total carbon sequestration of 275.7 kg of CO_{2e} for 1 m^3 of LHC. They also concluded that, for their manufacturing process, a functional unit of dimensions 1m x 1m x 0.3m sequestered 82.71kg of CO_2, thereby compensating for 46.43kg of manufacturing CO_2 emissions and also enabling a further storage of 36.08 kg of CO_2.

In a life cycle assessment study, it was found that 1 kg of hemp shivs sequester an equivalent of 2.1 kg of CO_2, and a functional unit of dimensions 1m x 1m x 0.3m was able to sequester 75.7 kg of CO_2, thereby amounting to 251.67 kg of CO_2 equivalent for 1 m^3 of LHC [3, 4]. The net emissions from transport, construction and manufacturing processes were found to be -35.5 kg of CO_2 equivalent [3, 4].

Fig 1 Hemp plant (Image courtesy of BOHECO)

2. SCOPE AND METHODOLOGY

This research aims to establish the total carbon sequestration achieved by the formulated LHC mix. For this purpose, the methodology adapted was to manufacture a test cube with accordance to a mix design derived from the studied literature [5 – 11]; carry out X-Ray Diffractometric (XRD) analyses and CHN Elemental Analyzer analyses.

A stoichiometric evaluation of the available binder content in the LHC mix is carried out to estimate the amount of carbon sequestration that can be achieved through carbonation reaction. A representative sample of the hemp shivs is taken by quarter-sampling technique and dried in a hot air oven for a period of 6 hours at 105 ^{O}C; and powdered for the CHN Elemental Analysis to establish the amount of carbon stocks present in the hemp component of LHC. The summation of the quantities of CO_2 consumed by Hemp and Lime binder gives us the total carbon sequestration achieved.

3. EXPERIMENTAL

The functional unit is a 7cm x 7cm x 7cm cube and had a wet density (at the time of casting) of 950.43 kg/m^3 and a dry density (after 28 days) of 567.05kg/m^3. It was made up of Hemp Shivs, 90% Hydrated Lime (binder) and water in the mass ratios of; Binder to Shiv (B/S) ratio – 2.15, water to binder (W/B) ratio – 1.3. Batch size, quantities and mass ratios are tabulated in Table 1. The cube was furthermore divided into 3 zones for the purpose of analysis, with the innermost zone being a small cube having volume of 2.69 x 10^{-4} m^3, middle zone being a hollow cube having a volume of 7.134 x 10^{-5} m^3 and the outermost zone being a hollow cube having a volume of 2.744 x 10^{-6} m^3. Fig. 2 shows the LHC block.

Table 1 Mass ratios and quantities of Hemp Shivs, Lime binder and Water

B/S Mass Ratio		**W/B Mass Ratio**
2.15		1.3
Hemp Shivs Weight (W_s) (g)	**Binder Weight (W_b) (g)**	**Water Weight (W_w) (g)**
80	172	223

Fig. 2 Lime Hemp concrete block

3.1 Estimation of Carbon Consumption through Carbonation

The carbonation of lime is governed by the following double replacement reaction:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O \quad (1)$$

The amount of lime binder available in the test cube at the time of casting is 117.9g.

Therefore, since the binder is 90% Hydrated lime and only lime undergoes carbonation in the given mixture, weight of hydrated lime is 106.11g.

Molar mass of calcium hydroxide and carbon dioxide are 74.093 g/mol and 44.01 g/mol, respectively.

By calculating the number of moles of calcium hydroxide present in the test cube, the number of moles of CO_2 required to carbonate the available $Ca(OH)_2$ can be estimated, which gives us the estimated carbon consumption through carbonation of the test cube.

Hence, the estimated carbon consumption through carbonation is 70.03g.

3.2 Determination of Carbon Consumed by Cube

At the age of 28 days, the cube was destroyed and samples from Zones 1, 2 and 3 were extracted for XRD analysis. The samples were ground into a fine powder before conducting analyses.

3.3 Determination of Percentage of Carbon in Hemp Shivs

To determine the amount of carbon dioxide present in the Hemp component of the mixture, it is necessary to determine the percentage of carbon that hemp shivs are constituted of. The quantity of carbon gives the quantity of carbon dioxide consumed by the hemp component. This carbon capture through photosynthesis is governed by the following equation:

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2 \qquad (2)$$

4. RESULTS AND DISCUSSION

4.1 X-Ray Diffractometer Analysis Results

The XRD Analysis revealed that, at the age of 28 days, in Zone 1, 27.93% of the binder was Calcite ($CaCO_3$) and 72.18% was portlandite ($Ca(OH)_2$) approximately. Whereas, Zone 2 and Zone 3 contained very small amounts of calcite, 5.13% and 5.66% respectively.

This data was used to calculate the quantities of the calcium carbonate present in the binder and the results are as follows:
Zone 1: 109.53 g
Zone 2: 29.05g
Zone 3: 1.12g

From the above-furnished information, the number of moles of calcium carbonate was calculated and applied in equation (1) to elicit the amount of carbon dioxide consumed. The resulting values are as follows:
Zone 1: 13.46g
Zone 2: 0.65g
Zone 3: negligible

The summation of the amount of carbon dioxide by the binder in each zone gives the total carbon dioxide consumed through carbonation of hydrated lime in LHC.

Therefore, the total CO_2 consumed by the binder at the age of 28 days is 14.11g.

4.2 CHN Elemental Analysis Results

The dried and powdered hemp shivs were carefully weighed and subjected to CHN Elemental analyses to determine the percent composition of carbon in them. Three samples were analysed and the results are as follows:
Sample 1: 45.25%
Sample 2: 45.78%
Sample 3: 45.24%
Average: 45.423%

The mass of hemp shivs in the test cube as found out using the mass ratios and wet weight is 54.84g.

From the CHN Elemental analysis results, it is established that mass of carbon present in the form of hemp shivs in the test cube is 24.91g.

Equation (2) shows that CO_2 reacts with H_2O to form $C_6H_{12}O_6$ and that for every atom of C in $C_6H_{12}O_6$ one mole of CO_2 is consumed. From (2) it can be determined that 91.28g of CO_2 was consumed by the hemp component of the LHC test cube.

4.3 Total Carbon Sequestration Achieved

The aforementioned results in 4.1 and 4.2 are summed to determine the total carbon sequestration achieved by the LHC test cube, which amounts to, 105.39g of CO_2.

However, the predicted total carbon sequestration was 161.31g of CO_2 for the test cube.

5. CONCLUSION

A Lime Hemp Concrete cube was made and its components were subjected to XRD analysis and CHN Elemental analysis. It was found in this research that, 1 m^3 of this particular mix of LHC has a carbon sequestration potential of up to 490.29kg of CO_{2e}, while, at the age of 28 days, the cube was able to sequester a total of 307.26 kg of CO_{2e}.

The LHC mix formulated for this research was much greater than the values published by other authors [2, 3, 4]. The possible reason for this being the use of 90% Hydrated Lime as binder instead of commercially available mixes that incorporate other materials such as Fly Ash, Slag, etc., that do not undergo any carbonation reactions.

The mechanical strength of the mix in the current study was negligible, indicating a need for research in this particular parameter. LCA exercises on different mix designs need to be conducted to establish a more statistical data on net carbon emissions of Lime Hemp Concrete.

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