Properties of Aerated Hempcrete as a potential sustainable Building Material

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Abstract Aerated concrete is lightweight concrete commercially available as aerocon blocks for the construction of infill walls. The compressive strength of these blocks varies from 4 to 6 MPa. This paper discusses the properties of aerated concrete by the use of mineral admixtures like fly ash, construction and demolition waste (C&D Waste) and hemp fibres. In order to reduce CO₂ emissions, save energy and conserve natural resources, there is a need for reducing the production and consumption of concrete products. This paper manifests the investigations carried out to study the feasibility of using aerated Hemp concrete Blocks in Urban Housing. Industrial Hemp fibers have been identified to potentially absorb carbon. Hence the use of processed Hemp hurd can be used to develop concrete blocks. The aeration process and the complete elimination of coarse aggregates make the blocks light-weight and energy absorbing. In addition, the partial replacement of Cement with Fly Ash and sand with pulverized Construction and Demolition waste is also employed here, thereby providing a cost-efficient, energy-efficient and moreover, recyclable model. The properties of concrete containing these replacements were examined and it was concluded that this beneficial, high-silica content crop can be effectively utilized as a building material, without sacrificing the strength and performance of the concrete. Improvement in engineering properties of this aerated hemp block is also investigated in this paper.

Keywords strength, aeration, ANOVA analysis, predicted
1. Introduction
The concrete industry is currently consuming natural aggregates at a rate of approximately 8 billion tones every year. It is also estimated that 40% of the total CO$_2$ emissions is due to the construction industries. Cement is an important constituent in concrete. The manufacture of cement releases a large amount of carbon dioxide and also consumes a large amount of energy. Hence, the need to find an alternative material to cement has become imperative. The use of Fly Ash does not emit CO$_2$ and is one of the possibilities to replace cement thus providing a productive use of industrial waste. Similarly sustainability in construction can be achieved only if agricultural products are used in construction practices. India is an agricultural country and the past construction practices have used many agricultural products as building material like jute, bamboo, sisal and coir fibres [1-3]. In this project an attempt is made to use hemp fibres in concrete. The hemp fibres are situated in the bast of the hemp plant, and have a high tensile strength. Inside the stem of the hemp plant is its woody core, the shive. Researchers have worked on Natural fibre reinforced concrete to study the influence of fibre type, geometry, aspect ratio, mix design, curing methods on the strength of concrete composite [4-7]. It has been reported that hemp fibres have high tensile strength and are durable in alkaline environment [8-10]. These properties make hemp fibre a good reinforcement material.

Lightweight in concrete can be accomplished by the aeration process by using air entraining admixtures like aluminium powder and hydrogen peroxide. The concrete is very light in weight due to the entrapped air and makes the block lighter due to pore formation. It also provides great thermal resistance, durability and cost reduction (upto 20%) as well. This paper discusses the strength properties of aerated hemp fibre reinforced concrete which is made using construction demolition (C&D) waste as replacement for sand and fly ash as replacement for cement. This allows mitigation of scarcity problems of natural aggregates and consumes very less energy and cost.

2. Materials and Methodology
The basic properties like bulk density, specific gravity and sieve analysis of the raw materials were done. Aluminium powder has been used as the aerating agent in this work. Lime powder is also used in order to facilitate the aeration process. The chemical reaction between calcium and Al$_2$O$_3$ results in the liberation of hydrogen gas thereby facilitating the formation of isolated air voids. The base mix was chosen from the previous works of the authors by adding lime powder as 30% by weight of cement and aluminium powder as 0.35% by weight of cement [11]. The casting of specimen and tests for the same were carried out in order to obtain the best proportion of Construction and Demolition waste (C&D waste). Similarly, the orientation of the hemp fibres in the concrete mould (random mix and perpendicular to the direction of application of the load) was also checked through compression testing of cubes after 7 days of water curing. Finally, the mix containing the appropriate replacement percentage and the best orientation was tested for compression and flexure. The aspect ratio of the fibres was 100. The target wet density of aerated concrete achieved is 1085-1128 kg/m$^3$.

Table 1 Properties of hemp fiber and the chemical constituents are as follows.

| PARAMETER        | Compressive strength | Tensile strength | Bending strength | Impact strength |
|------------------|----------------------|-----------------|-----------------|----------------|
| VALUE            | 31.5 MPa             | 6.89 MPa        | 0.0021 MPa      | 8.21 J/m$^2$   |

As there are variable parameters involved in the making of aerated concrete some Experimental trials were designed using design expert software considering fly ash (F) for cement replacement, C & D waste for sand replacement and also hemp fibres were used to improve the properties of aerated concrete. Using the combinations of the designed trial mix, for each trial specimens were cast to be tested for compressive, flexural and tensile strength. Compression test was done on cubes of size
150mm×150mm×150mm, casted for each replacements of fine aggregate. The cubes were demoulded after 24 hours and were subjected to water curing. Three cubes were tested for compressive strength at every 7, 14 and 28 days of curing and average compressive strengths were noted respectively. Similarly, flexural test is done after casting beam moulds of size 100mmx100mmx 500mm and tested. The tests results were conducted according to ASTM C39 and IS 516. Split tensile strength was done on cylinders of size 10 cm diameter and 20 cm height. The experimental results were entered in the software and validated using ANOVA analysis.

3. Results and Discussions

Response surface Methodology of central composite design was used for ANOVA analysis. The graphs are drawn considering the interaction effect of two factors. Compressive strength is found to increase as shown in fig 1, with increase in fly ash and C&D waste replacement with cement and sand respectively. Increase in hemp fibre content reduced the compressive strength from 14.72 to 12.22 MPa as given in fig 2. Fibre factors (fibre content and fibre aspect-ratio) have a significant relationship with the mechanical and physical properties of cementitious materials [12-14]. However, the interaction between fibre and matrix becomes complicated when fibres are introduced into the concrete rather than the mortar matrix, because they are not separated by a fine grained material which can move easily between them, but by particles which will often be of a larger size than the average fibre spacing if the fibres are uniformly distributed [15].

![Fig 1 Response surface graph for Compressive strength](image-url)
Fig 2 Response surface graph for Compressive strength

Fig 3 Response surface graph for flexural strength
Flexural strength is found to increase as shown in fig 3, with increase in fly ash and C&D waste replacement with cement and sand respectively. Increase in hemp fibre content increased the flexural strength from 2.56 to 3.12 MPa as given in fig 4.

Tensile strength is found to increase as shown in fig 5, with increase in fly ash and C&D waste replacement with cement and sand respectively. Increase in hemp fibre content increased the flexural strength from 2.36 to 2.59 MPa as given in fig 6.
Fig 6 Response surface graph for tensile strength

Fig 7 Compressive strength for 7 days, 14 days, and 28 days

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With the gradual increase in replacements of C&D waste (25%, 37.5% and 50%) for fine aggregates in the concrete, 7 days curing results showed that 50% replacement showed less distortion in the compressive strength. A decrease in compressive strength was observed with increase in the percentage of hemp fibers added to the concrete. Hence, fiber addition of 0.1% by weight of cement is recommended. The final compressive strength and flexural strength values after 28 days were found to be appreciable and this shows that the replacement of the fine aggregates with the construction and demolition waste up to 50% does not affect the strength parameters of concrete.

4. Multiple Optimizations

The optimised proportion of the three factors was finally obtained from the software as follows. Trials were made for the optimised proportion and tests were conducted to verify the confirmation of the predicted values. The optimised values and confirmatory test results are given in Table 2 and 3.

| Fly ash F (%) | C & D Waste (%) | Hemp fibres (%) |
|---------------|-----------------|-----------------|
| 17.59         | 45.25           | 0.10            |

| Compressive strength (MPa) | Flexural strength (MPa) | Tensile strength (MPa) |
|----------------------------|-------------------------|------------------------|
| Predicted                  | 14.82                   | 3.36                   | 2.85                   |
| Observed                   | 13.85                   | 3.12                   | 2.79                   |
4. Conclusion
The properties of aerated hempcrete with C&D waste and fly ash are summarised as follows:

1. The use of C&D waste finds a potential replacement for sand in the production of aerated hempcrete.
2. The strength properties of these blocks were much superior to the conventional aerocon blocks.
3. Hemp fibres which are organic natural fibres can be used as a building material for the various exceptional properties it possess.

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