APPLICATION OF FGC BLOCKS FOR SUSTAINABLE INFRASTRUCTURE DEVELOPMENT

Guru Kumar M S
P.G Student, Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur – 603203

Balasubramanian M
Assistant Professor, Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur – 603203

Arul Jeya Kumar A
Associate Professor, Department of Mechanical Engineering, SRM Institute of Science and Technology, Kattankulathur – 603203

E-mail: balasubml@srmist.edu.in

Abstract. The use of conventional materials in building construction results in increased emission of carbon dioxide and consumption of more energy. The replacement of sustainable materials with conventional materials can help in reducing the overall energy consumed while making it more eco-friendly. The aim of the study is to replace the cement used in manufacturing of concrete blocks with sustainable and waste materials such as fly ash, ground granulated blast furnace slag and calcined clay. The compressive strength of these blocks were slightly lesser than the conventional blocks while satisfying the standards’ minimum criteria. The blocks showed 50% reduced thermal conductivity and 35% reduced carbon emission, which suggests that these blocks could be an excellent replacement for conventional materials since it increases the thermal comfort of the building while reducing the environmental impact.

1. Introduction
The construction industry is one of the largest industry in world economy. It contributes around 6% to 9% of the overall gross domestic product of developing nations. Thus, the number of buildings being constructed and repaired are increasing day by day. The use of conventional building materials are generally practiced everywhere since it provides the customers or clients a sense of security and safety. However, the various components of construction materials take up huge amounts of energy for their manufacturing and usage making buildings as one of the largest consumers of energy [1]. The construction industry consumes about 40% of energy globally while contributing 25% of carbon dioxide emissions [2].

These values are not safe for the environment since it has many harmful effects. The consumption of energy leads to burning of fossil fuel leading to its depletion. The emission of carbon dioxide affects the environment creating many health conditions for all living organisms. This could be reduced by the
replacement of the conventional materials causing it with other materials, which has a much less harmful effect. The use of waste materials and by-products of many manufacturing processes are already being used in the research for finding more sustainable materials that could be used in the construction process. Cement is considered one of the biggest contributors of energy consumption and carbon emission. This could be reduced by the partial or complete replacement of cement used in any form in the construction with other materials. 

The majority of the building is comprised of the walling material. The conventional walling material such as solid concrete blocks, fired bricks use up a lot of cement in the form of manufacturing and plastering respectively. In many tropical regions such as India, these are the most commonly used walling material. The usage of cement in these materials could be curbed by replacing it with eco-friendly materials such as fly ash, ground granulated blast furnace slag (GGBS) etc. This research aims in the manufacturing of a new wall material, called as FGC blocks. The FGC blocks stands for “Fly ash - Ground granulated blast furnace slag - Calcined clay” Blocks. It is named in such a way because it is manufactured by the complete replacement of cement used conventional solid concrete block, with cementitious binding materials fly ash, GGBS and calcined clay in various proportions. These materials are used since they are by-products or waste materials in other manufacturing processes, which are generally dumped in landfills. Hence by using the materials the volume of landfills are reduced while the sustainability of the blocks are increased making them more environment friendly.

2. Materials and Methodology
The materials used for the preparation of the conventional concrete blocks were produced locally conforming to Indian Standards. The coarse aggregate were 6mm chips conforming to IS 383:1970 [3]. The fine aggregate used was manufactured sand passing through 4.75 mm sieve satisfying IS 383:1970 and 53 grade Ordinary Portland cement conforming to IS 12269:2013 [4]. The manufacturing of FGC blocks, which is done by using both coarse and fine aggregate similar to conventional concrete blocks, but by completely replacing the cement with binding materials such as ground granulated blast furnace slag, fly ash and calcined clay in various proportions. Mixing and curing of both the concrete blocks were done using potable water conforming to IS 456:2000 [5].

2.1. Fly ash
Fly ash is produced as a byproduct in coal burning. There are two major types of fly ash namely Class C and F based on the quantity of calcium, aluminum, silica and iron content present in it [6]. Adding fly ash in the matrix of concrete can help in reducing the drying shrinkage and sorptivity while being very economical on comparison with cement. It can also increase the workability of the mixture when proportioned properly. It demands less water, hence helping in reducing the segregation and bleeding while increasing the cohesiveness. The addition of fly ash might reduce the early strength of the concrete but can help in increasing the strength long term [7].

2.2. GGBS
Ground granulated blast furnace slag is a by-product obtained in the process of smelting of steel and iron in a blast furnace from iron ore. The slag obtained is through the quenching of the molten slag of iron in water forming a substance that is granular and glassy. It is then allowed to dry and is powdered finely [8]. GGBS has been used as a cementitious material for more than 120 years and its chemical composition varies with respect to the raw materials’ composition and the process of production. Its major constituents are lime, silica, alumina similar to the oxides which form Portland cement but in
different proportions [9], [10]. GGBS contains lower lime and higher alumina content on comparison with cement, which helps in reducing the heat of hydration and increase in temperature while increasing the long-term strength of the concrete.

2.3. Calcined clay
Calcined clay is ultrafine soft material obtained by the calcination of clay particles. It is usually processed in a kiln by burning clay at higher temperatures. The increase in temperature gradually removes the moisture at around 100 °C and at around 500 to 600 °C, complete dehydroxilation occurs. The addition of calcined clay in concrete can help in increasing the strength and durability properties of concrete. It can also increase the initial strength of the concrete due to the effect of accelerated cement hydration [11], [12].

2.4. Mix Design
The design was calculated for M4 grade of concrete for both conventional concrete block and FGC blocks as per the guideline of IS 10262:2009 [13]. The M4 grade of concrete blocks were chosen conforming to IS 2185:2005 standards [14]. The blocks were prepared with coarse and fine aggregate, and cement was completely replaced with various binding materials such as ground granulated blast furnace slag, fly ash and calcined clay in various proportions. The fly ash content was kept constant at 50% replacement of cement while GGBS was added in increasing content from 10% to 40% and calcined clay the remaining percentage of cement. The 4 mixes considered along with the percentage of cementitious material replacement has been provided in Table 1.

| Mix Number | Fly Ash | GGBS | Calcined Clay |
|------------|---------|------|---------------|
| M1         | 50%     | 40%  | 10%           |
| M2         | 50%     | 30%  | 20%           |
| M3         | 50%     | 20%  | 30%           |
| M4         | 50%     | 10%  | 40%           |

2.5. Block preparation and Testing
The conventional concrete blocks were casted for determining the compressive strength and thermal conductivity. The conventional or control concrete blocks and the FGC blocks were casted of dimension 400x200x100 mm size. It was cast using hydraulic concrete block press with the capacity of producing 300 blocks per hour. It consists of a steel mould capable of casting 10 blocks at a time, which is first compacted by vibration using a motor after which it is tamped 8 to 10 times with the steel hammer present in the machine operated hydraulically. The casted blocks are allowed to stay on the ground for 2 days with wet curing. After 2 days, the blocks are removed from the ground, stacked up, and cured for 28 days.

Mixes M1, M2, M3 and M4 were casted in the same fashion with complete replacement of cement with the above said materials in the proportions. It was noted that post casting, mixes M2, M3 and M4 failed to hold together pertaining to the increased percentage of calcined clay. It was because calcined clay is of extremely low weight and high volume, which resulted in failure of bonding with the other components of the block matrix. Mix M1 on the other hand, showed no failure and held still similar to the conventional block with 100% cement. This is because only 10% use of calcined clay as replacement for cement.

The compressive strength was determined for the blocks after curing for 14 days and 28 days using Universal Testing Machine conforming to IS 516-1959 [15]. The thermal conductivity was measured using Hot Disk Thermal Analyzer using a Kapton Sensor in which single sided testing was adopted.
3. Results and Discussions

3.1. Density

The density of conventional concrete blocks and M1 mix of FGC blocks were compared as shown in Figure 1. The density of the material determines its homogeneity, void ratio based on its materials used. Lower the density of the material, lower the dead load in the building and lower the thermal conductivity. The minimum density to be satisfied for a conventional solid concrete block is 1800 kg/m$^3$ and higher as per IS 2185:2015.

![Figure 1. Density of concrete blocks.](image)

The density of the FGC blocks were 18% lesser on comparison with the conventional blocks while it satisfies the minimum criteria for a conventional solid concrete block of 1800 kg/m$^3$ by IS 2185:2015. This suggests that the replacement of cement with these binding materials help in reducing the overall weight of the block thus reducing its density.

3.2. Compressive Strength

The compressive strength of the conventional solid concrete block as well as FGC block of mix M1 was compared for 14 day and 28-day test as shown in Table 2. The minimum compressive strength to be obtained by the blocks are 3.2 N/mm$^2$ as per IS 2185:2015.

| Specimen set | 14 day Compressive strength (N/mm$^2$) | 28 day Compressive strength (N/mm$^2$) |
|--------------|----------------------------------------|----------------------------------------|
|              | Conventional Concrete block | FGC Blocks | Conventional Concrete block | FGC Blocks |
| Set 1        | 3.53 | 3.22 | 4.54 | 4.12 |
| Set 2        | 3.71 | 3.17 | 4.47 | 4.08 |
| Set 3        | 3.65 | 3.35 | 4.45 | 4.21 |

The table shows that the compressive strength of the FGC blocks are a bit lesser compared to the conventional concrete block. This occurs due to complete replacement of cement yet it satisfies the minimum compressive strength to be attained by the conventional solid concrete block as per IS 2185:2005 of 3.2 N/mm$^2$ for M4 grade of concrete blocks.
3.3. Thermal Conductivity
The thermal conductivity of the building wall material determines the indoor thermal comfort of its occupants. The less the thermal conductivity, the less the heat transfer occurs inside the building during higher temperatures and better the insulation during colder times. The thermal conductivity of the material is dependent on various factors such as its density, voids present in it, the material composition and its thermal properties etc. The thermal conductivity of the materials were determined using a Hot Disk Thermal Analyzer apparatus as shown in Figure 2. The apparatus uses a transient plane source method, which is used for identifying the thermal conductivity, thermal diffusivity as well as the specific heat of the material. A Kapton sensor is used, which has a nickel coil, which generates heat energy when placed on the material. Single sided testing was employed where the one face of the sensor was placed on the material while the other face of the sensor was covered using an insulating material of known parameters thus helping in determining the thermal conductivity of the material as shown in Figure 3. A constant heating power of 100 mW was applied on the material for a period of 20 seconds after which the thermal conductivity values were observed. The test was repeated for five times to ensure an average value of thermal conductivity and the results are shown in Figure 4.

It was observed that the thermal conductivity of FGC blocks are almost 50% less when compared with the conventional concrete block. This can be attributed to the complete replacement of cement with finer, lighter materials, which helped in reducing the overall density of the material, making it more thermally efficient than the conventional material.
Figure 4. Thermal conductivity of wall materials.

This suggests that on application of these blocks in the building, the indoor air temperature will be reduced since the walls conduct less heat energy due to solar radiation during the daytime. This can improve the thermal comfort index of the occupants in the building. It can also help in reducing the electricity consumption of the building since the HVAC systems require less cooling load to be applied for the building. Thus using these blocks in the building envelope can help creating a more sustainable infrastructure on comparison with conventional materials.

3.4. Sustainability Analysis
The sustainability analysis of a material can be found by determining the overall carbon emitted by the material. This is usually calculated for ‘cradle to gate’, which is from the manufacturing of the raw materials to the transporting of materials to the site. The carbon emission was calculated for the conventional concrete block and the FGC blocks by using the ICE database for determining the carbon emission and the results are shown below in Figure 5.
Figure 5. Embodied carbon of wall materials.

The embodied carbon of the materials are represented in terms of m$^3$ of the material content. It has been observed that the embodied carbon of the FGC blocks are around 35% lesser when compared to the conventional solid concrete blocks. This reduction in embodied carbon of the material can be attributed to the inclusion of waste materials and by-products in the FGC block matrix as binding materials while the conventional concrete blocks use cement which as the sole binding material which has higher carbon emission during its production process. This reduction in carbon emission makes FGC blocks more significantly sustainable and an eco-friendly alternative to conventional concrete blocks.

4. Conclusion
The complete replacement of cement with other binding materials that are usually thrown away as waste showed positive results in all forms of testing. The replacement of cement helps in reducing the overall carbon emission of the material. The use of fly ash, GGBS and calcined clay as binding materials in the manufacturing of FGC blocks on comparison with conventional concrete blocks resulted in

- Reduction of density by 18% thus reducing the overall dead load of the building when used.
- Reduction in compressive strength by 8% but satisfying the minimum compressive strength criteria as per IS 2185:2015.
- Reduction in thermal conductivity by 50% thus improving thermal comfort of the occupants of the building.
- Reduction in the carbon emission by 35%, which makes it more environment friendly.

Therefore, the use of waste materials as binding agents in the manufacturing of FGC blocks not only satisfies the mechanical requirements, but also can help in increasing the thermal comfort inside the building by reducing the indoor air temperature due to the external wall conduction gains. It also helps in reducing the overall carbon dioxide emitted, thus making it a more sustainable and eco-friendly material.

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