Foamcrete construction blocks using industrial wastes- A sustainable approach

Sajan K Jose\textsuperscript{1*}, Mini Soman\textsuperscript{1} and Sheela Evangeline Y\textsuperscript{1}

\textsuperscript{1} Department of Civil Engineering, College of Engineering Trivandrum, APJ Abdul Kalam Technological University, Kerala, India
\textsuperscript{*}E-mail: sajankjose@lbscek.ac.in

Abstract. There is a wide growth in construction industry in recent years, which is a very important area of concern for all the stakeholders. There is a wide-ranging diminution of natural resources, especially river sand. Also, the current statistics shows that for the production of one ton of cement, there is a discharge of one ton of carbon dioxide, which creates lot of environmental pollution. This has directed the investigators to find a more sustainable solution. Hence this study is oriented towards the development of a new building material in foamed concrete, in which natural river sand is completely substituted with manufactured sand, which is being substituted partially with quarry fine dust, which is an industrial by-product. The production of alternate building blocks using fly ash, GGBS and quarry dust can be very effectively used for the overwhelming construction processes. The consumption of industrial by-products in foamcrete, compensates the deficiency of natural resources, which solves the disposal of the above waste materials and safeguards the nature. With the use of this foamcrete blocks (density less than 1800 kg/m\textsuperscript{3}) as infills, slender sections can be designed for the framed construction works. Correspondingly, the thermal insulation properties of foamcrete blocks make it more acceptable in the present construction scenario. This is an attempt to focus the attention to discuss the utilization of industrial wastes in construction blocks. It has been observed that the construction blocks, made with these industrial wastes, have similar strength and other characteristics as that of conventional bricks. The maximum attained compressive strength is 13.29 N/mm\textsuperscript{2}.

Key words: Foamcrete, fly ash, GGBS, quarry dust, manufactured sand, thermal conductivity

1. INTRODUCTION

Brick is one of the most commonly adopted construction materials in construction engineering since ancient times. At present, hollow or solid concrete blocks are also used as in-fills in framed construction works. But, the abundant production of such building materials cause diminution of natural resources and create lot of conservational issues, which led the investigators to find a greener solution. There is a feasible solution found out by the researchers by the development of foamcrete. This study is an approach to modify the existing method of production of foamcrete to overcome the ill effects of brick production, with the usage of large quantities of industrial by-products. By effectively controlling the foam volume percentage, the production of several densities of foamcrete blocks in different varieties of 300 to 1800 kg/m\textsuperscript{3} is possible.

Kearsley and Wainright, (2001) \cite{1} investigated the consequence of substituting huge quantities of cement with different forms of fly ash. The study reported that, cement could be substituted with 67 % fly ash without any drop in compressive strength. Another research work conducted by the same authors \cite{2} examined the effect of increasing the levels of fly ash on the compressive strength of concrete and models were established to forecast the compressive strength. Kearsley and Mostert (2005) \cite{3}, revealed that foamcrete is having more sensitiveness to water than ordinary concrete. If water added is too less, it may cause quick disintegration of foam due to the deficiency of water for initial hydration. At the same time, if water added is too much, it may lead to segregation causing variation in density. Nambiar and Ramamurthy (2006, 2007) \cite{4,5} conducted studies on the impact of filler (fly ash and sand) on the properties of FC and it was inferred that a decrease in particle size of sand triggered an enhancement in strength. The above study has been conducted on foamed concrete with fly ash as a substitute for fine aggregate. Also, it has been observed that better consistency can be obtained with the abundant use of fine sand instead of coarse sand, which is accredited to the even dispersion of stomas in foamcrete with finer sand \cite{6}.

It has been noted that protein type foaming agent helps to produce minor secluded air fizzes than the artificial type foaming agent \cite{7,8}. Also, it has been reported that surfactant type and foam prediction parameters influence the properties of foam affecting the properties of foamed concrete \cite{9}. It has been identified that 50 % of cement
can be successfully replaced with GGBS in achieving promising results. [10, 11]. Again, it has been observed that up to 30 \% cement can be substituted with GGBS for the construction of nuclear structures [12,13].

Significantly, GGBS concrete at high substitution ratio improved the service lifespan due to a combination of impenetrable stoma edifice and improved chloride binding capacity. Also, it has been experimentally inferred that cement can be substituted with GGBS up to 50\% for the achievement of high early-age strength with w/c ratio up to 0.35 [14]. Further, a research done by Jang et al., 2017 [15] revealed that, high performance concrete containing GGBS and fly ash has come out with durable performance especially in the chloride environment. A study conducted by Hadi et. al. (2017) [16], verified that manufacture of geopolymer concrete is possible with the addition of GGBS. Also, it has been observed by Saranya et. al. that approximately 40 – 45 \% of cement can be very efficiently substituted by GGBS for producing concrete with comparable strength as that of control mix [17]. Further, it has been observed that GGBS along with palm oil fuel ash can come out with fruitful results, while making lightweight concrete [18].

It has been reported that 10 \% increase in strength can be achieved by the proper addition of quarry dust in concrete. [19]. Later, it has been identified that 50\% is the maximum possible amount of quarry dust that can be used to replace cement while making concrete [20]. It has also been observed that concrete resistance to sulphate attack was enhanced greatly by the addition of quarry dust in concrete, which makes the concrete a greener one thereby to reduce environment pollution and improve durability of concrete under severe conditions [21]. Later, a study conducted by Patel and Pitroda revealed that 40-70\% replacement is possible by means of quarry dust for getting better results and even more strength can be obtained by the addition of bacteria in concrete [22]. Further, it has been observed that reutilization of quarry dust from quarrying industry makes a justifiable tactic in order to conform with forthcoming requirements of conservational and concrete technology [23]. Again, it has been identified that the strength characteristics of both quarry dust and sand are same. The silica percentage present in quarry dust is above 80\% which gives high strength to concrete as in the case of sand. Thus, the environmental effects and waste can be significantly reduced [24]. Further, it has been identified that, very fine quarry dust decreases the compressive strength due to lack of grading and extreme flakiness. But there is increase in w/c ratio and slump value due to substitution of sand with quarry dust. Higher strength is achieved because of large voids present in quarry dust mortar than in sand mortar [25]. The particles are angular in shape, which creates better packing between the particles and reduce the porosity which in turn improves strength and durability characteristics [26]. It has been identified by Bahoria et. al. that for the application of mass concrete works, quarry dust can be very efficiently used along with waste plastics [27]. It has been observed that quarry dust requires more water to attain same slump when compared to control concrete. For mixes M20 and M25, quarry dust concrete with water cement ratio 0.65 showed same slump as that of control concrete with w/c 0.5 [28].

In view of the above studies, following observations are listed. 1) foamcrete blocks of low density with a reasonable compressive strength will be a feasible substitute for the existing in-fill materials, whose densities ranges between 1800 kg/m$^3$ and 2400 kg/m$^3$. 2) only few works are described on the feasibility of foamcrete as a building material as in-fills in framed construction. (3) feasibility of integrating huge quantities of industrial by-products viz; fly ash and GGBS for replacing cement, and quarry dust for substituting manufactured sand, for the production of building blocks will subsidize to a greener construction methodology. Accordingly, this study is intended to develop a design methodology for the manufacture of foamcrete, with all the three industrial by-products together. Hence, in this paper, it has been decided to conduct a study on foamcrete with fly ash and GGBS together replacing cement and with quarry fine dust substituting manufactured sand with water powder ratios 0.55 and 0.65.

2. EXPERIMENTAL INVESTIGATIONS

The experimental programme was intended to study the effect of waste materials viz. Fly ash, GGBS and quarry dust on the properties such as compressive strength, dry density, thermal conductivity and water absorption of foamcrete. In order to make the mix as economical as possible, the sand to powder (mixture of cement and the by-products together) ratio has been kept as 3 and 4. The foam requirement for densities of 1800 kg/m$^3$ and 1600 kg/m$^3$ have been arrived as per ASTM -C796-97 [29]. These two
densities are selected in such a way as to get compressive strength in the range of 5-8 N/mm\(^2\) which is line with that of existing bricks/ hollow/solid concrete blocks.

2.1 Materials

Ordinary Portland Cement of grade fifty-three having specific gravity 3.15 has been used for the preparation of foamcrete specimens. To avoid the use of river sand, which is costlier and since it is completely banned by the government, it has been decided to replace it fully with manufactured sand. 2.53 and 2.34 are the specific gravity and fineness modulus of manufactured sand. The foaming agent used is synthetic type, whose specific gravity and pH are 1.07 and 6.7 respectively. As specified by the manufacturer, the mixing of foaming agent with water was done in the proportion 1:35 before feeding into the foam generator. The produced stable foam was having a density of 78.5 kg/m\(^3\). The specific gravity of class F fly ash of 2.44 has been used to replace cement partially for this study. The specific gravity of GGBS taken for the study is 2.9. The specific gravity of quarry dust used is 2.42 and its fineness modulus is 1.86.

2.2. Moulding and testing of Specimen

Powder specified here is the mix of cement fly ash and GGBS. Various mixes of sand powder ratios 3 and 4 with selected water powder ratios 0.55 and 0.65 have been prepared for expected densities of 1800 kg/m\(^3\) and 1600 kg/m\(^3\). The various percentages of these industrial wastes used for the study and the mix ID (example) is presented in Table 1. Accordingly, mixes have been prepared and experiments have been conducted for the above-mentioned water powder ratios. The key goal of this study is to make a greener and cost-effective building material, which can substitute the existing building materials such as bricks/hollow/solid concrete blocks having densities in the range of 1800 to 2400 kg/m3. Hence the experiment has been restricted to only two densities in order to attain compressive strength in par with that of the existing one. Foamcrete mixer has been used for uniform mixing of the foamcrete by adding stable foam formed through the form generator. The ratio of wet density to design density known as density ratio has been checked every time during preparation of mix and found to be nearly unity [30]. Foamcrete being flowable in nature, it has been directly filled into the moulds without any compaction and was levelled accordingly by means of a sharp steel scale. The blocks were cast in all the available standard dimension as per IS 2185 (part 3)-1984 [31] for performing various tests. Nine numbers of blocks were made from each mix for these. Forty-eight mixes were prepared and 720 cubes were prepared and tested. The demoulded specimens were kept under water for curing. After that, they were oven dried for the attainment of constant weight, after which, they were cooled to room temperature. By properly inserting the thermal probe, of thermal conductivity meter, into the drilled hole on the specimens, the meter displayed the readings (thermal conductivity) automatically as shown in Figure 1.

Figure 1 Thermal conductivity meter
Table 1. Mix ID with the mixture proportion

| Sl. No | Mix ID   | Water powder ratio | Foam volume % | Addition of by industrial products (%) | Fly ash (F), GGBFS (G) and quarry dust (Q) |
|--------|----------|--------------------|---------------|----------------------------------------|--------------------------------------------|
| 0.55   | 0.65     | 20                 | 30            | 10                                     | 20                                         |
| 0.55   | 0.65     | 20                 | 30            | 10                                     | 20                                         |
| 0.55   | 0.65     | 20                 | 30            | 10                                     | 20                                         |
| 0.55   | 0.65     | 20                 | 30            | 10                                     | 20                                         |
| 0.55   | 0.65     | 20                 | 30            | 10                                     | 20                                         |
| 0.55   | 0.65     | 20                 | 30            | 10                                     | 20                                         |

3. RESULTS AND DISCUSSION

The outcome of the tests conducted are presented in Table 2 and 3. The graph showing compressive strength Vs percentage addition of quarry dust along with Fly ash and GGBS is presented in Figure 2. Also, the variation of thermal conductivity with respect to variation in compressive strength is presented in Figure 3. It can be understood that, there is considerable decrease in compressive strength and dry density in respect of increase in volume of foam, which can be accredited to the assimilation of foam fizzes ensuing in large vacuities, which in turn lead to the decrease in strength. Also, it can be seen that, there is an upsurge in compressive strength by the inclusion of fly ash, GGBS and quarry dust. The optimum value of compressive strength has been obtained for foamed concrete with 40% fly ash, 30% GGBS and 60% quarry dust. While adding GGBFS and fly ash into cement, it helps to produce a cementitious matrix, which is having a reasonable consistency. The substitution of cement by GGBS and fly ash provides advantages viz; the use of a waste material and the corresponding reduction in cement consumption leading to the lessening carbon dioxide emissions during production of cement. Furthermore, due to the pozzolanic reaction and filler features of slag, the density of microstructures in foamcrete is improved. Again, it is most interesting to note that there is marginal increase in compressive strength with respect to increase in the presence of water content, which is in distinction with that of normal concrete. This may be due to the requirement of lesser amount of foam at higher water powder ratio for achieving the similar target density. Suitable amount of water improves the uniformity and steadiness of the mixture and thus acts as a significant character in the manufacture of foamcrete of required density. It is observed that there is stable upsurge in water absorption with rise in volume of foam, fly ash content, GGBS and quarry dust together but, it is perceived to decrease slightly with upsurge in water powder ratio. Still, the percentage water absorption was much lower than the presently available blocks of corresponding strength. Thus, it is experimentally proved that, foamcrete of strength from 2.36 N/mm² to 13.29 N/mm² can be produced with 30 % and 20 % foam volume and with fly ash replacement up to 40% and GGBS substitution up to 30% for cement and quarry dust up to 60 % for substituting manufactured sand partially.
### Table 2. Test Results of foamcrete with industrial by-products for 1:3 mix and 1:4 mix with 20 % FV

| Sl. No | MIX ID     | Compressive strength (N/mm²) | Density (kg/m³) | Water absorption (%) | Thermal conductivity (W/mK) |
|-------|------------|-----------------------------|----------------|---------------------|----------------------------|
| 1     | 0.55M₂₀A   | 3.23                        | 1651           | 2.83                | 0.412                      |
| 2     | 0.55M₂₀B   | 5.61                        | 1809           | 3.23                | 0.368                      |
| 3     | 0.55M₂₀C   | 7.86                        | 1795           | 3.63                | 0.307                      |
| 4     | 0.55M₂₀D   | 9.23                        | 1717           | 3.97                | 0.253                      |
| 5     | 0.55M₂₀E   | 11.15                       | 1800           | 4.24                | 0.212                      |
| 6     | 0.55M₂₀F   | 10.26                       | 1712           | 4.98                | 0.182                      |
| 7     | 0.55M₂₀A   | 2.86                        | 1822           | 3.16                | 0.342                      |
| 8     | 0.55M₂₀B   | 3.98                        | 1808           | 3.54                | 0.301                      |
| 9     | 0.55M₂₀C   | 5.06                        | 1752           | 3.98                | 0.269                      |
| 10    | 0.55M₂₀D   | 6.13                        | 1788           | 4.35                | 0.246                      |
| 11    | 0.55M₂₀E   | 7.28                        | 1762           | 4.78                | 0.213                      |
| 12    | 0.55M₂₀F   | 5.96                        | 1803           | 5.13                | 0.197                      |
| 13    | 0.65M₂₀A   | 5.63                        | 1756           | 4.25                | 0.324                      |
| 14    | 0.65M₂₀B   | 7.18                        | 1812           | 5.13                | 0.306                      |
| 15    | 0.65M₂₀C   | 9.77                        | 1778           | 5.78                | 0.284                      |
| 16    | 0.65M₂₀D   | 11.23                       | 1794           | 6.21                | 0.262                      |
| 17    | 0.65M₂₀E   | 13.29                       | 1764           | 6.52                | 0.254                      |
| 18    | 0.65M₂₀F   | 11.42                       | 1802           | 7.01                | 0.242                      |
| 19    | 0.65M₂₀A   | 3.18                        | 1796           | 4.36                | 0.301                      |
| 20    | 0.65M₂₀B   | 4.73                        | 1784           | 5.27                | 0.274                      |
| 21    | 0.65M₂₀C   | 5.28                        | 1813           | 5.87                | 0.254                      |
| 22    | 0.65M₂₀D   | 6.39                        | 1821           | 6.34                | 0.232                      |
| 23    | 0.65M₂₀E   | 7.68                        | 1787           | 7.08                | 0.208                      |
| 24    | 0.65M₂₀F   | 6.23                        | 1793           | 7.26                | 0.196                      |

### Table 3. Test Results of FC with industrial by-products for 1:3 mix and 1:4 mix with 30 % FV

| Sl. No | MIX ID     | Compressive strength (N/mm²) | Density (kg/m³) | Water absorption (%) | Thermal conductivity (W/mK) |
|-------|------------|-----------------------------|----------------|---------------------|----------------------------|
| 1     | 0.55M₃₀A  | 2.36                        | 1642           | 3.16                | 0.443                      |
| 2     | 0.55M₃₀B  | 4.42                        | 1623           | 3.32                | 0.379                      |
| 3     | 0.55M₃₀C  | 6.73                        | 1578           | 3.68                | 0.346                      |
| 4     | 0.55M₃₀D  | 8.62                        | 1569           | 4.13                | 0.308                      |
| 5     | 0.55M₃₀E  | 9.87                        | 1598           | 4.37                | 0.292                      |
| 6     | 0.55M₃₀F  | 9.11                        | 1612           | 4.86                | 0.275                      |
| 7     | 0.55M₃₀A  | 2.12                        | 1623           | 3.27                | 0.413                      |
| 8     | 0.55M₃₀B  | 2.76                        | 1574           | 3.69                | 0.384                      |
| 9     | 0.55M₃₀C  | 3.63                        | 1586           | 4.11                | 0.351                      |
| 10    | 0.55M₃₀D  | 4.21                        | 1587           | 4.47                | 0.323                      |
| 11    | 0.55M₃₀E  | 4.72                        | 1598           | 4.89                | 0.284                      |
| 12    | 0.55M₃₀F  | 3.68                        | 1628           | 5.25                | 0.261                      |
| 13    | 0.65M₃₀A  | 4.18                        | 1624           | 3.57                | 0.396                      |
| 14    | 0.65M₃₀B  | 5.78                        | 1584           | 3.85                | 0.365                      |
| 15    | 0.65M₃₀C  | 7.83                        | 1603           | 4.23                | 0.302                      |
| 16    | 0.65M₃₀D  | 9.48                        | 1625           | 4.86                | 0.283                      |
| 17    | 0.65M₃₀E  | 11.25                       | 1582           | 5.23                | 0.264                      |
| 18    | 0.65M₃₀F  | 9.87                        | 1583           | 5.96                | 0.241                      |
| 19    | 0.65M₃₀A  | 2.77                        | 1604           | 4.25                | 0.378                      |
| 20    | 0.65M₃₀B  | 3.06                        | 1615           | 5.38                | 0.341                      |
Figure 2. Compressive strength Vs percentage addition of quarry dust

Figure 3. Compressive strength Vs Thermal conductivity of foamed concrete

4. COST ANALYSIS

An analysis has been carried out on the cost aspect of foamcrete, made up of these industrial by products, and normal concrete existing in the current construction industry. It has been understood
that the production cost of foamcrete is comparatively less than that of the existing concrete. The detailed
analysis is presented in Table 4

**Table 4. Comparison of production cost**

| Sl No | Description                  | Foamed concrete with Fly ash GGBFS and Quarry dust | Normal concrete |
|-------|------------------------------|---------------------------------------------------|-----------------|
|       |                              | Quantity (kg) | Rate (Rs) | Amount (Rs) | Quantity (kg) | Rate (Rs) | Amount (Rs) |
| 1     | Cement                       | 84            | 6.00      | 504.00      | 320            | 6.00      | 1920.00     |
| 2     | Manufactured sand            | 336           | 1.90      | 638.40      | 640            | 1.90      | 1216.00     |
|       | Fly ash                      | 112           | 3.70      | 414.40      |                |           |             |
| 3     | GGBFS                        | 84            | 5.20      | 436.80      |                |           |             |
|       | Quarry dust                  | 504           | 1.30      | 655.20      |                |           |             |
| 4     | 6mm aggregates               |               |           |             | 1280           | 2.20      | 2816.00     |
| 5     | Foaming agent                | 0.45 litre    | 100.00    | 45.00       |               |           |             |
| 6     | Labour                       | 0.25 nos.     | 750.00    | 187.50      | 0.25 nos.     | 750.00    | 187.50      |
| 7     | Total cost per cubic meter   |               |           |             | 2881.30        |           | 6139.50     |

5. CONCLUSIONS

Studies on foamcrete have been conducted on the effective utilisation of fly ash and GGBS together for
the substitution of cement and quarry dust for the replacement of fine aggregate. The conclusions drawn
are,

- Maximum compressive strength of foamcrete, made up of 40% fly ash, 30% GGBS and 60% quarry dust, obtained is 13.29 N/mm².
- It is observed that thermal conductivity of foamcrete is decreasing with reference to the inclusion
  of all the waste materials. The maximum reduction in in thermal conductivity is observed to be
  55.83% for 055M20F, ie mix with 40% fly ash and GGBS each and with 60% quarry dust in 1:3
  proportion with water powder ratio 0.55.
- Enormous volumes of waste materials viz; fly ash, GGBS and quarry dust can be efficaciously
  exploited for the production of foamcrete.
- The cost analysis clearly shows that, the copiously available industrial by-products, which are
  being very cheap, can be effectively utilised for reducing the production cost of foamed concrete.
considerably.

- The effective utilisation of all these industrial by-products can lead to a revolution in the construction industry, especially in terms of green revolution.
- Since the cement consumption in the proposed foamcrete is less in comparison with that of ordinary concrete, it will lead to the decrement of carbon foot print. Also, the cost of construction can be minimized.
- With the usage of such lightweight blocks, the total weight imposing over a structure can be reduced so that thin sections can be designed for beams, columns as well as foundations, which helps in savings of materials viz; cement, steel and other finishing materials, thus dropping the construction cost.
- The mix proportions of foamcrete, with all these industrial by-products, will give a novel information to the practicing civil engineers, in the design and development of blocks of targeted density and compressive strength, for guaranteeing an environmentally friendly building practice.

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