Building blocks as infills: Current scenario and alternate materials

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Abstract: Currently, all nations have taken major initiatives in developing the infrastructures such as express highways, power projects, industrial structures, multi-storeyed residential flats etc., to meet the requirements of globalization. Concrete plays a key role and a large quantum of concrete is being utilized in every construction project. The use of such huge quantity of concrete will lead to several environmental impacts as well as economical issues. To reduce the environmental impact, the important thing is to diminish the use of the natural constituents of the concrete by effectively utilizing the abundantly available industrial by-products. And to reduce the economy, the major initiative is to minimize the quantity of cement and aggregates in concrete by partial substitution with suitable by-products and using lightweight technology. Hence this study is oriented towards designing a new mix for the production of foamed concrete, thereby producing a sustainable and greener concrete. Application of green concrete is an effective way to reduce environmental pollution and improve durability of concrete under severe conditions. Foamed concrete using quarry dust replacing the manufactured sand partially and with fly ash and GGBFS replacing cement partially is dealt in detail in this paper. It is observed that there is considerable increase in compressive strength with addition of quarry dust, fly ash and GGBFS.

Keywords: Foamed concrete, fly ash, GGBFS, quarry dust, sustainability, thermal conductivity, environmental impact

1. INTRODUCTION

Now-a-days, it is very difficult to procure bricks at a reasonable price because of the non availability of natural resources, especially soil. Also excavation of top soil may cause agricultural and environmental issues. Further, river sand is scarcely available for the production of concrete as well as hollow/solid concrete blocks. Hence researches are moving ahead for the advancement of alternate building blocks for the use of overwhelming construction activities. Foamed concrete (FC) is a versatile and lightweight building material, which can be adopted for the manufacture of building blocks. The objective of this study is to evaluate the practicability of using quarry dust (QD) as a partial substitute for the fine aggregate and to replace cement with ground granulated blast furnace slag (GGBFS) and fly ash (FA) partially in making FC. Due to the non availability of river sand, it has been replaced with manufactured sand (M sand) for this study. Quarry fine dust has been added at the rate of 20, 40, 60, 80 and 100 % by weight of fine aggregate. By the use of quarry fine dust, a large quantity of such industrial by-products can be very effectively utilized thereby reducing environmental pollution considerably. Also, the use of foamed concrete construction blocks for buildings, leads to the diminution of the total load of the whole construction leading to slender sections. Using quarry fine dust in place of manufactured sand, the cost of production also can be...
minimized.

In the current construction scenario, almost all the multi-storeyed structures are reinforced cement concrete framed structures. In these structures, depending upon the availability, country burnt bricks, laterite stones, hollow/solid concrete blocks are used as infills. But the unit weight of all these materials are very high of the order of 1900 kg/m$^3$ to 2300 kg/m$^3$, which obligate the designers to go for thicker sections to accommodate the heavy load. In addition to this, so many natural resources are being utilised for the production of such building units. Excavation of top soil may cause agricultural and environmental issues during the production of country burnt bricks and the burning of fuels may cause severe air pollution. Similar is the case for extracting laterite stones. Currently, the most commonly used infill materials are hollow/solid concrete blocks. All these blocks are made up of concrete, which consumes huge quantity of cement as well as other natural resources. Since Government has banned the excavation of river sand from river beds, there is scarcity of river sand everywhere. It can be learnt that about 25 % of the production of M sand is wasted as quarry fines, which are disposed as landfills causing lot of environmental issues.

Meanwhile, researches are moving ahead to reduce the weight of concrete to make it as light as it could be. Lightweight concrete is the best option for reducing the total weight of concrete. It is a peculiar type of concrete, where lightweight aggregates or stable foam is used as the ingredients. The concrete is termed as lightweight aggregate concrete if lightweight aggregates are added as ingredients and if stable foam is used, the concrete is known as lightweight foamed concrete. It is learned from the literatures that, foamed concrete of any density ranges between 300 and 1800 kg/m$^3$ having comparable compressive strength as that of normal concrete can be produced. Hence foamed concrete is a novel lightweight building material, which can be adopted for the advancement of building blocks. The key oddity of FC is the nonexistence of coarser particles. This paper discusses the possibility of addition of quarry dust replacing M sand and fly ash and GGBFS partially replacing cement.

FC of density upto 1800 kg/m$^3$ can be produced by adjusting the percentage volume of foam keeping a minimum of 20 %. A standard foam generator and a suitable foaming agent are the basic requirement for the production of stable foam, which consists of millions of equally distributed, consistently sized air bubbles or cells [1,2]. In a study on FC with fly ash, it has been observed that 67 % is the optimum quantity fly ash to be added for the replacement of cement without compromising compressive strength [3]. Further, studies on FC with filler materials, have been confirmed that a reduction in particle size of sand caused an improvement in strength [4]. Pulverised sand finer than 300 microns has been used as the fine aggregate for the above study. Thus for a given density, replacement of sand with fly ash resulted in higher strength. Also it is inferred that lower consistency of foamed concrete makes the density ratio, which is the ratio of fresh density to design density, higher than unity. It has also been reported that mixes made with fine sand of required consistency resulted in compressive strength higher than that of mix with coarse sand. This is ascribed to the uniform allocation of pores in foam concrete with fine sand [5,6].

Another study on surfactants suggest that, it plays the most important role during the formation of stable foam, which directly controls the properties of FC [7]. Creation of tiny enclosed air bubbles by reducing the surface tension of the solution is the key role of the stable foam [8,9]. Selection of surfactant and foam prediction parameters influences the properties of foam, which in turn affects the properties of foamed concrete [10]. Promising results were obtained during the experiment with GGBFS replacing 50 % of cement without compromising its properties [11]. For concrete designed for nuclear structures, up to 20 % GGBFS could be suitably used and the best overall performance of GGBFS has been reported for 30 % addition,[12,13].
At high replacement ratio, concrete made with GGBFS is found to have enhanced service life due to a mixture of dense pore structure and enhanced chloride binding capacity. It has been observed that, concrete containing considerable amount of GGBFS [ around 50%] can achieve high early-age strength at a water cement ratio of 0.35 [14]. Later, a study conducted on GGBFS concrete revealed that, better durability performance for chloride environment is obtained in high performance concrete containing GGBFS and fly ash compared to a control mix [15]. Also, it has been proved that GGBFS can be very effectively used for the production of geopolymer concrete[16]. Further, It has been reported that around 40 – 45 % of cement can be very effectively replaced by GGBFS for making concrete with similar strength as that of control mix [17].

The chemical compositions of quarry dust is found to be almost similar to that of cement. Since the size of quarry dust is very fine, it increases the strength of concrete [18]. Use of quarry dust also will lead to minimize the environmental pollution by the safe disposal of such an industrial waste. Hence it is concluded that for mass concreting works, the addition of substitute fine aggregate material like quarry dust along with waste plastic can be used to minimize the river sand depletion [19]. Also, it is learned that, due to the high fineness of quarry dust, it seems to be very effective in assuring very good cohesiveness to concrete. An investigation on the effect of quarry dust on self compacting concrete, reported that a higher dosage of super plasticizers are to be added to the concrete to achieve similar flow properties as that of normal concrete. Later, a study conducted on Rice Husk Ash (RHA) based concrete using quarry dust, it has been asserted that quarry dust can be used as a viable replacement material to sand to produce high strength RHA concrete. In a research work on micro fine quarry dust (MFQD) concrete, it is investigated that replacement of cement with MFQD up to 15 % has improved the strength of concrete. Later, a study on quarry dust as a substitute for fine aggregate and reported that 40 % replacement of fine aggregate by quarry dust has come out with excellent results [20]. Based on an overview conducted, it has been reported that 50 % of QD was used as a partial sand replacement in construction materials [21]. It was found that incorporating QD in concrete improves its flexural strength too. The flexural strength of concrete made with QD as fine aggregate is higher [about 4.3%] than conventional river sand concrete [22]. The average ratio of prism compressive strength to the cube compressive strength is marginally higher for concrete with 25% sand replacement compared with that of 0% replacement[23]. It is observed that use of a high volume of very fine quarry dust as filler in FC improved the compressive strength in comparison with the control foamed concrete prepared with 100% river sand [24]. It has been revealed that quarry dust and brick residue incorporated concrete can be very effectively utilised for heavy traffic pavement [25]. Quarry dust concrete has consistently produced higher compressive strength compared with sand mixes and it is concluded that addition of QD up to 30% improved the workability of the self-compacting concrete[26].

In all the studies mentioned above, use of quarry dust in normal concrete has been identified. Only few papers reported on foamed concrete with quarry dust. So a systematic study on FC entirely using M sand and also with quarry dust as a substitute for it is indeed inevitable. In view of all the studies conducted and reported above, it has been identified that no work has been reported on FC with the powder (mix of cement, fly ash and GGBFS together) sand ratio 1:3. Hence, it has been planned to conduct a comparative study of the performance of normal FC and foamed concrete with fly ash and GGBFS as substitutes for cement and quarry fine dust as a substitute for fine aggregate.

2. MATERIALS

Ordinary Portland cement, 53 grade with specific gravity 3.15 has been used as the major binder material. M sand [Zone II of IS: 383 (1970)], has been used as the fine aggregate, which has a specific gravity 2.53 and fineness modulus 2.34. Synthetic type foaming agent of specific gravity 1.07 and pH 6.7 in solution has been used for the study. Since foaming agent is a highly concentrated low dosage liquid, very small amount of it has been mixed with 35 times water as per the instruction of the
manufacturer to make the preformed solution. The stable foam produced using standard foam generator has a density of 78.5 kg/m$^3$. The specific gravity of class F fly ash used is 2.44. GGBFS of specific gravity 2.9 has also been used for the replacement of cement. Quarry dust of specific gravity 2.42 and of fineness modulus 2.07 has been used as a substitute for M sand. Mix was proportioned for making FC as per ASTM C796-797 [27].

2.1 Casting and testing of Specimen

With water powder [fly ash, GGBFS and cement mix] ratio of 0.65, various mixes in the proportion of 1:3 for expected densities of 1800 kg/m$^3$ and 1600 kg/m$^3$ with 20% and 30% foam volume have been prepared. The details of these mixes are shown in Table 1. Foam generator has been used for the production of stable foam and it was then mixed uniformly with the basemix using foam concrete mixer (FCM) as shown in Figures 1 and 2. FCM is a horizontal type of mixer with a mixing speed of 60 rpm. The density ratio [ratio of wet density to design density] has been checked during the production itself to verify whether it is nearly unity [28, 29, 30]. The prepared foamed concrete has been poured slowly into the cube moulds and levelled, since it doesn’t require any compaction. 100 mm sized cubes were cast for testing the properties dry density, compressive strength and water absorption. For the conduct of thermal conductivity test, 150 mm sized specimens were also prepared. The demoulded specimens were kept in water for sufficient curing. Thermal conductivity meter was used for the determination of thermal conductivity for which, the thermal probe was inserted into the holes drilled in the specimens as shown in Figure 3. The test results are presented in Table 2.

| Sl No | Mix ID | Water powder ratio | FA/ GGBFS/ QD | Sand powder ratio | Foam volume % | Percentage addition of FA/GGBFS/QD |
|-------|--------|--------------------|----------------|------------------|---------------|-----------------------------------|
| 1     | 0.65F$_2$20A | 0.65                | FA             | 3                | 20            | 0                                 |
| 2     | 0.65F$_2$20B | 0.65                | FA             | 3                | 20            | 0                                 |
| 3     | 0.65F$_2$20C | 0.65                | FA             | 3                | 20            | 40                                |
| 4     | 0.65F$_2$30A | 0.65                | FA             | 3                | 30            | 0                                 |
| 5     | 0.65F$_2$30B | 0.65                | FA             | 3                | 30            | 20                                |
| 6     | 0.65F$_2$30C | 0.65                | FA             | 3                | 30            | 40                                |
| 7     | 0.65G$_2$20A | 0.65                | GGBFS          | 3                | 20            | 0                                 |
| 8     | 0.65G$_2$20B | 0.65                | GGBFS          | 3                | 20            | 20                                |
| 9     | 0.65G$_2$20C | 0.65                | GGBFS          | 3                | 20            | 40                                |
| 10    | 0.65G$_2$30A | 0.65                | GGBFS          | 3                | 20            | 0                                 |
| 11    | 0.65G$_2$30B | 0.65                | GGBFS          | 3                | 20            | 20                                |
| 12    | 0.65G$_2$30C | 0.65                | GGBFS          | 3                | 20            | 40                                |
| 13    | 0.65Q$_2$20A | 0.65                | QD             | 3                | 20            | 0                                 |
| 14    | 0.65Q$_2$20B | 0.65                | QD             | 3                | 20            | 20                                |
| 15    | 0.65Q$_2$20C | 0.65                | QD             | 3                | 20            | 40                                |
| 16    | 0.65Q$_2$20D | 0.65                | QD             | 3                | 20            | 60                                |
| 17    | 0.65Q$_2$20E | 0.65                | QD             | 3                | 20            | 80                                |
| 18    | 0.65Q$_2$20F | 0.65                | QD             | 3                | 20            | 100                               |
| 19    | 0.65Q$_2$30A | 0.65                | QD             | 3                | 20            | 0                                 |
| 20    | 0.65Q$_2$30B | 0.65                | QD             | 3                | 20            | 20                                |
| 21    | 0.65Q$_2$30C | 0.65                | QD             | 3                | 20            | 40                                |
| 22    | 0.65Q$_2$30D | 0.65                | QD             | 3                | 20            | 60                                |
| 23    | 0.65Q$_2$30E | 0.65                | QD             | 3                | 20            | 80                                |
| 24    | 0.65Q$_3$30F | 0.65                | QD             | 3                | 20            | 100                               |
Figure 1. Foam concrete mixer

Figure 2. Stable foam produced using foam generator

Figure 3. Thermal conductivity test
3. RESULTS AND DISCUSSION

Table 2. Test results of FC specimens

| Sl No | Mix ID       | Compressive Strength in N/mm² | Dry Density in kg/m³ | Water Absorption in % | Thermal Conductivity in W/mK |
|-------|--------------|-------------------------------|----------------------|-----------------------|-----------------------------|
|       |              | 28 days                       |                      |                       |                             |
| 1     | 0.65F;20A   | 11.20                         | 1825                 | 2.25                  | 0.311                       |
| 2     | 0.65F;20B   | 11.73                         | 1791                 | 3.45                  | 0.292                       |
| 3     | 0.65F;20C   | 12.07                         | 1784                 | 4.23                  | 0.286                       |
| 4     | 0.65F;30A   | 7.67                          | 1568                 | 5.77                  | 0.275                       |
| 5     | 0.65F;30B   | 8.30                          | 1608                 | 6.26                  | 0.253                       |
| 6     | 0.65F;30C   | 8.97                          | 1642                 | 7.76                  | 0.213                       |
| 7     | 0.65G;20A   | 12.77                         | 1823                 | 1.95                  | 0.276                       |
| 8     | 0.65G;20B   | 13.53                         | 1757                 | 3.08                  | 0.234                       |
| 9     | 0.65G;20C   | 11.62                         | 1764                 | 3.98                  | 0.218                       |
| 10    | 0.65G;30A   | 8.42                          | 1602                 | 4.76                  | 0.187                       |
| 11    | 0.65G;30B   | 9.25                          | 1587                 | 5.96                  | 0.161                       |
| 12    | 0.65G;30C   | 7.51                          | 1594                 | 7.01                  | 0.147                       |
| 13    | 0.65Q;20A   | 6.78                          | 1796                 | 3.02                  | 0.379                       |
| 14    | 0.65Q;20B   | 7.23                          | 1804                 | 3.69                  | 0.354                       |
| 15    | 0.65Q;20C   | 8.15                          | 1812                 | 4.06                  | 0.341                       |
| 16    | 0.65Q;20D   | 11.29                         | 1778                 | 4.93                  | 0.328                       |
| 17    | 0.65Q;20E   | 10.83                         | 1759                 | 5.36                  | 0.304                       |
| 18    | 0.65Q;20F   | 9.78                          | 1812                 | 5.93                  | 0.287                       |
| 19    | 0.65Q;30A   | 6.23                          | 1623                 | 6.33                  | 0.261                       |
| 20    | 0.65Q;30B   | 7.02                          | 1648                 | 6.84                  | 0.246                       |
| 21    | 0.65Q;30C   | 8.28                          | 1575                 | 7.19                  | 0.230                       |
| 22    | 0.65Q;30D   | 9.57                          | 1593                 | 7.94                  | 0.217                       |
| 23    | 0.65Q;30E   | 9.33                          | 1602                 | 8.33                  | 0.201                       |
| 24    | 0.65Q;30F   | 9.02                          | 1623                 | 8.94                  | 0.184                       |

The results presented in Table 2 at a glance show that foamed concrete with 20 % foam volume and 20 % GGBFS gives the maximum compressive strength of 13.53 N/mm² at a dry density of 1757 kg/m³. Foamed Concrete with 20 % foam volume and 40 % fly ash gives the maximum compressive strength of 12.07 N/mm² at dry density of 1784 kg/m³ and FC with 20 % foam volume and 60 % quarry dust gives a maximum compressive strength of 11.29 N/mm² at a dry density of 1778 kg/m³. With these optimum values a set of FC with all these industrial byproducts in various proportions were prepared and the Mix ID details are presented in Table 3 and the test results are presented in Table 4.

Table 3. Mix ID details of FC with the addition of industrial by-products

| Mix ID   | W/P ratio | s/p ratio | Foam volume % | FA %  | GGBFS % | QD % |
|----------|-----------|-----------|---------------|-------|---------|------|
| 0.65M;20A| 0.65      | 3         | 20            | 10    | 10      | 20   |
| 0.65M;20B| 0.65      | 3         | 20            | 20    | 20      | 30   |
| 0.65M;20C| 0.65      | 3         | 20            | 30    | 30      | 40   |
| 0.65M;20D| 0.65      | 3         | 20            | 40    | 40      | 50   |
| 0.65M;20E| 0.65      | 3         | 20            | 40    | 40      | 60   |
| 0.65M;20F| 0.65      | 3         | 20            | 40    | 40      | 60   |
**Table 4. Test results of FC with all the by-products together**

| Sl No | Mix ID   | Compressive Strength in N/mm² 28 days | Dry Density in kg/m³ | Water Absorption in % | Thermal Conductivity in W/mK |
|-------|----------|--------------------------------------|----------------------|-----------------------|-----------------------------|
| 1     | 0.65M₂₀A| 5.63                                 | 1756                 | 4.25                  | 0.324                       |
| 2     | 0.65M₂₀B| 7.18                                 | 1812                 | 5.13                  | 0.306                       |
| 3     | 0.65M₂₀C| 9.77                                 | 1778                 | 5.78                  | 0.284                       |
| 4     | 0.65M₂₀D| 11.23                                | 1794                 | 6.21                  | 0.262                       |
| 5     | 0.65M₂₀E| 13.29                                | 1764                 | 6.52                  | 0.254                       |
| 6     | 0.65M₂₀F| 11.42                                | 1802                 | 7.01                  | 0.242                       |

Hence from the above test results, it is understood that the mix 0.65M₂₀E with 40 % FA, 30 % GGBFS and with 60 % QD is giving the maximum compressive strength of 13.29 N/mm² at a dry density of 1764 N/mm². The water absorption of it is 6.52 % with thermal conductivity of 0.254 W/mK. So it can be concluded that highly economical FC blocks with comparable compressive strength of the order of 13.29 N/mm² and with low thermal conductivity can be prepared at low density.

**4. CONCLUSIONS**

From the above experiments, the conclusions drawn are,

- Foamed concrete with 40 % fly ash, 30 % GGBFS and 60 % quarry dust is giving the maximum compressive strength.
- Water absorption is found to be steadily decreasing with respect to the addition of industrial by-products.
- The thermal conductivity values are found to be decreasing with respect to the addition of waste materials, so that the blocks can be very effectively used for thermal insulation purposes.
- Huge quantity of industrial by-products like fly ash, GGBFS and quarry dust can be successfully utilized for the manufacture of foamed concrete.
- Since industrial by-products are abundantly available and are very cheap, the cost of construction can be made more economical as well as the environmental issues related to dumping of these materials can be solved to a greater extent.
- Since the proportion 1:3 is selected and also cement being replaced with fly ash and GGBFS, cement content can be minimized thereby the concrete can be made more economical than normal foamed concrete/conventional concrete.
- With the help of suitable foaming agent and the industrial by-products, foamed concrete blocks of the required quality can be developed for all type of construction. The use of such lightweight blocks will reduce whole load coming over the structure, which in turn leads to lean sections, which helps in saving materials such as cement, steel and other finishing works too.
- The proportioning of foamed concrete with the various industrial by-products enables practicing civil engineers to design and develop blocks of required density and compressive strength to ensure sustainable and greener construction practices.

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