Feasible use of Recycled Foam Concrete in Cement Mortar

Evangeline Lalrinmawii¹, Santosini Sahu²*, Pradip Sarkar³ and Robin Davis⁴

¹M.Tech. Scholar, National Institute of Technology Rourkela, India-769 008
²Ph.D. Scholar, National Institute of Technology Rourkela, India-769 008
³Associate Professor, National Institute of Technology Rourkela, India-769 008
⁴Assistant Professor, National Institute of Technology Calicut, India-673 601

*santosinisahus762@gmail.com

Abstract. Lightweight foam concrete blocks have gained popularity over the last decade, particularly in the construction of interior infill walls. Consequently, the construction and demolition waste generated by such foam concrete blocks are increasing regularly. Recycling of these wastes and using them in cement mortar or concrete as partial replacement of conventional material can be an essential step towards the management of construction and demolition waste as well as conservation of natural resources leading to sustainability. The present study aims to assess the feasibility of recycled Autoclaved Aerated Concrete (AAC) and Cellular Lightweight Concrete (CLC) blocks as a possible replacement of sand and cement in the manufacturing of mortar. This study investigates various physical and mechanical properties of mortar in which sand and cement are partially replaced with material from recycled AAC and CLC block. Chemical analysis of demolished AAC and CLC block samples determined using X-Ray Fluorescence (XRF) analysis to find out the differences in composition between the conventional materials and replaced material. This study concludes that materials from recycled AAC and CLC block can be used in cement mortar as partial replacement of either cement or sand up to 15-20% without significant reduction of strength.

1. Introduction
Continuous urbanization and infrastructural development worldwide lead to a huge amount of construction and demolition waste generation. Growing usage of lightweight foam concrete blocks in recent times results in a considerable portion of the construction and demolition waste. Disposal of these wastes requires a huge open area for landfilling and creates other environmental issues. The use of waste foam concrete blocks in cement concrete or mortar provides a reasonable solution for problems related to waste management. In the present study, an attempt is made to partially replace sand and cement by materials recycled from demolished wastes of two popular forms of foam concrete blocks: AAC and CLC.

The quantity of natural sand in the cement mortar and concrete varies from 20 to 80%. Hence, the demand for natural sand is quite high, and the excessive use of this causes a severe threat to the environment and society. To encounter the present requisite, accessibility of good quality of sand is decreasing day-by-day [1]. The shortage of such natural resources has introduced the concept of the use of various substitute materials to replace the sand partially. Alternative materials such as fly ash, crushed brick, recycled alumina, pond ash, quarry dust, marble dust or limestone, waste foundry sand, waste plastic, etc. are previously used in concrete and mortar mixtures as a partial or full replacement of normal sand to check the feasibility [2-6].
Cement occupies 15 to 20% of the volume and is the most expensive component in concrete and mortar production [7]. The cement manufacturing industry is a major source of greenhouse gas emissions, causing environmental pollution. At this stage, the use of supplementary cementitious materials to replace a portion of the cement in concrete or mortar can be a promising idea. Many previous studies are carried out to investigate possible replacement materials for Portland cement (OPC). Some substitute materials have already been used as a replacement of OPC such as fly ash, rice husk ash, sugarcane ash, silica fume, limestone, and siliceous stone powder, etc. in past literature [8-13].

Recycling of the AAC and CLC blocks in construction work is not studied yet. Replacement of cement by demolished CLC and AAC block dust can be promising for both reducing CO2 emission and problems of waste management. Similarly, the replacement of sand by demolished CLC and AAC block dust can help to conserve natural resources. Therefore, the prime focus of the present study is identified as to explore the prospect of utilizing the demolished CLC and AAC dust as an alternative material for partial replacement of sand and OPC in cement mortar.

2. Material and experiments

2.1. Materials

As a part of experimental work, cement, sand, recycled AAC, and CLC powder are used to prepare the test specimens. Ordinary Portland cement of 43-grade and normal tap water are used throughout the study. The fine aggregate used in the experiment is natural river sand conforming to ASTM C144 [14]. The CLC and AAC powder used in this study for sand and cement replacement is recycled from waste CLC and AAC blocks. AAC aggregate (AAC-A) and CLC aggregate (CLC-A) finer than 4.75 mm is used as the replacement material for natural sand in the test specimen. Specific gravity and water absorption of sand, AAC-A, and CLC-A are evaluated experimentally as per relevant ASTM C128 [15] and reported in table 1. It can be observed from table 1 that the specific gravity values of AAC-A and CLC-A are lesser than that of sand. This is because AAC-A and CLC-A are obtained from lightweight foam concrete blocks, which contain 65-70% of fly ash. The more porous structure of AAC-A and CLC-A than sand is indicated by their higher water absorption rates. Table 1 also presents the fineness modulus, coefficient of curvature, and coefficient of uniformity for sand, AAC-A, and CLC-A obtained from sieve analysis. The fineness modulus data show that sand is coarser than AAC-A and CLC-A. The coefficient of uniformity and coefficient of curvature values show that the grading of all three samples is of similar nature. The particle size distribution curve for all three samples, including the ASTM C-144 [14] limits are shown in figure 1. It can be seen from the figure that AAC-A and CLC-A are within the permissible range to qualify as fine aggregate in cement mortar.

| Properties          | Sand | AAC-A | CLC-A |
|---------------------|------|-------|-------|
| Specific gravity    | 2.6  | 1.7   | 1.6   |
| Water absorption (%)| 0.8  | 8.7   | 13.2  |
| Fineness modulus    | 3.26 | 2.98  | 3.17  |
| Coefficient of uniformity | 3.25 | 2.94  | 3.53  |
| Coefficient of curvature | 0.78 | 0.92  | 0.88  |

AAC binder (AAC-B) and CLC binder (CLC-B) finer than 90μ is used as the replacement material for cement in the test specimen. Physical properties of AAC-B, CLC-B, and OPC are tested in the laboratory as per relevant ASTM standards [16-17], and reported in table 2. AAC and CLC block has fly ash as a chief constituent material, which results in the specific gravity of AAC-B and CLC-B much lower than that of OPC. In addition, these materials require more water than OPC to form a consistent paste because of the presence of high absorptive fly ash particles.
Figure 1. Particle size distribution of Sand, AAC-A, and CLC-A.

Table 2. Physical properties of OPC, AAC-B, and CLC-B.

| Properties   | AAC-B | CLC-B | OPC  |
|--------------|-------|-------|------|
| Specific gravity | 2.10  | 2.18  | 3.15 |
| Consistency (%) | 45    | 53    | 31   |

The microstructural analysis of AAC-B and CLC-B is carried out by X-Ray Fluorescence (XRF) analysis to evaluate their chemical composition and applicability as cementitious materials. The major oxide compositions of OPC, AAC-B, and CLC-B obtained with Zetium PANalytical XRF spectrometer are reported in table 3. It tends to be seen from table 3 that both AAC-B and CLC-B contain all the major oxide elements of OPC. However, the percentage of these oxides in AAC-B and CLC-B varies from OPC. The major difference is observed to be with the percentage of CaO, SiO$_2$, Al$_2$O$_3$, and MgO. CaO and MgO present in higher amounts while SiO$_2$ and Al$_2$O$_3$ in a lesser amount in OPC as compared to that of AAC-B and CLC-B. The XRF analysis result fortifies the feasible use of AAC-B and CLC-B as a partial cementitious material in cement mortar or concrete.

Table 3. Chemical composition (%) of OPC, AAC-B, and CLC-B.

| Oxide | OPC     | AAC-B  | CLC-B  |
|-------|---------|--------|--------|
| CaO   | 56.422  | 19.432 | 16.473 |
| SiO$_2$ | 20.495 | 40.016 | 44.531 |
| Al$_2$O$_3$ | 5.736 | 15.830 | 18.018 |
| MgO   | 4.526   | 0.737  | 0.760  |
| Fe$_2$O$_3$ | 3.218 | 4.133  | 3.379  |

2.2. Replacement of fine aggregate
The mortar cubes of 50 mm size are prepared with a water-to-binder (w/b) ratio of 0.485 and sand-to-cement ratio 2.75 as per ASTM C109 [18]. Cement mortars cubes are prepared with natural sand replaced separately by AAC-A and CLC-A. Sand replacement ratio considered in this study are 0% (natural sand only), 5%, 10%, 15%, 20%, 25% and 30% by weight. It is to be noted that OPC is used uniformly as a binder in all the mortar specimens considered here. The compressive strength and water absorption test of the cube specimen from different categories are tested after 28 days of curing.

2.3. Replacement of cement
AAC-B and CLC-B are used to replace OPC in cement mortar by 0% (OPC only), 5%, 10%, 15%, 20%, 25%, and 30% of weight. The proportions of materials for the standard mortar are kept uniform, as mentioned in the previous section. Natural sand is used as fine aggregate uniformly for all the mortar specimens considered here. The mortar cubes of 50 mm size are prepared according to ASTM C-109
(2016) for the compressive strength test. The compressive strength and water absorption of mortar cubes are tested after 28 days of curing as per the procedure outlined in relevant ASTM Standard.

3. Result and discussion

3.1. Replacement of fine aggregate
The effect of replacement of sand by different percentages of AAC-A and CLC-A on the mean compressive strength of cement mortar cubes are presented in figure 2. The test results illustrate that the replacement causes a reduction in mortar compressive strength. Sand replacement up to 15% with AAC-A and CLC-A cause a reduction in compressive strength of mortar cubes up to 20% when compared with controlled mortar specimens. Further increase in the replacement of sand is found to reduce the strength significantly. This reduction may be due to the low specific gravity, high water absorption of AAC-A and CLC-A as compared to that of sand and the presence of the foam-forming agent. A high volume of AAC-A and CLC-A particles led to the creation of pores in the mixes. It can be suggested from the above result that replacement of sand maximum up to 15% with AAC-A and CLC-A can be considered for waste utilization without significant loss in compressive strength.

The water absorption test results of AAC-A and CLC-A replaced cube specimen are shown in figures 3-4. From the test results, it is found that the water absorption rate increases as the AAC-A and CLC-A replacement increases. The water absorption rate of the mortar specimens containing 15% of AAC-A and CLC-A found to be increased by 30 to 40% as compared to the controlled mortar specimen. This high rate of absorption of replaced mortar specimen is because of the high water absorption of the AAC and CLC fines as compared to sand.

![Figure 2. Variation of 28-day compressive strength of sand replaced samples.](image)

3.2. Replacement of cement
The compressive strength of hardened mortar is presented in figure 5 for mortar cubes with cement replaced by AAC-B and CLC-B. It can be observed from figure 5 that the compressive strength of mortar cube decreases gradually as AAC-B replacement increases. However, this decrease is quite small (less than 10%) up to 15% replacement. Similarly, the compressive strength of mortar cube increases with the increase of CLC-B replacement up to 10%. Further increase of CLC-B replacement reduces the compressive strength. However, up to 20% of CLC replacement results in no reduction of compressive strength as compared to the control specimen.

The results of the water absorption test for AAC-B and CLC-B replaced mortar specimen are shown in figures 6-7. From the test results, it is found that the water absorption rate increases as the AAC-B and CLC-B replacement increases. An increase in water absorption rate in AAC-B replaced specimen is found to be much higher than that in CLC-B replaced specimen. This may be the reason behind the strength reduction in AAC-B replaced cube specimens. The water absorption rate is increased by 20% in 15% AAC-B replaced specimen, and about 6% in 15% CLC-B replaced mortar specimens.
4. Conclusions
In order to find an alternative application, which has a higher economic and environmental value, the feasibility of demolished AAC and CLC fines as a possible sand and cement replacement in the mortar preparation is investigated. The experimental result shows that the compressive strength decreases, and the water absorption rate increases with the increase of sand replacement. However, from the strength reduction rate of mortar cubes, it can be suggested that AAC-A and CLC-A can be used as recycled...
material up to 15% replacement of sand in mortar. The microstructural analysis of AAC-B and CLC-B confirms that AAC-B and CLC-B can also be used as cementitious materials. The strength and durability tests on mortar specimens replaced with AAC-B and CLC-B indicate that these materials can effectively replace cement usage in mortar up to 15%. Replacement of cement with CLC-B can even increase the compressive strength to some extent. The experimental investigation conducted in this study makes it clear that recycled foam concrete waste can be used as partial replacement of cement and sand ensuring a sustainable solution to waste management with the conservation of natural resources.

5. References

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