Experimental Investigation of Light Weight Concrete Using Sintered Fly Ash Aggregates

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Abstract. Light Weight Concrete (LWC) is popularly used in multi-story building frames, curtain walls, shell roofs, folded plates, prestressed or precast elements due to its lower dead load as compared to conventional concrete. Although it is less popular in practice because of its high-water absorption capacity, high cost, lack of standard specifications, and difficulty in consistent batches. This paper presents experimental study of right proportion of different size of Sintered Light Weight Aggregate (SLWA) and its influence on fresh and mechanical properties. LWC mixes were prepared with pre-soaked aggregates of different sizes 8-12mm and 4-8 mm. Their proportioning plays an important role in the density and strength of concrete. The aggregates were mixed in various proportions of 80:20, 60:40, 40:60, and 20:80, to study the fresh and harden properties of LWC. Results showed that LWC prepared with finer aggregate (4-8 mm) reduces the bulk density and enhances the mechanical properties.

Keywords. Lightweight concrete; sintered light weight aggregates; cellular structure

1. Introduction
Concrete is important construction material in development of infrastructure. It is second largest consumable material after water. In the preparation of concrete, for each ton of cement, 6-7 tons of aggregates are required [1] and extraction of such huge quantity of aggregates from earth to meet infrastructural requirement is posing serious threat on environment including depletion of natural resources.
Fly ash is industrial waste, by product of coal base thermal power plant. There are different modes of utilization of fly ash. In India, Fly ash is primarily used in cement and brick manufacturing which constitute around 36%. Figure 1 shows 22.4 % of fly ash is unutilized and disposed in landfills [2]. It contaminates ground water and makes land infertile causing serious environment threat.
Many researchers tried to use fly ash as raw material to make artificial aggregate as it is major contributor in volume of concrete. The physical properties of these aggregates depend upon type of fly ash, binder, manufacturing process and moisture content. Concrete is predominantly used as structural concrete so researchers tried to develop artificial aggregates having high strength yet low density, better thermal properties and low water absorption. Bijen et al. [3] used artificial aggregates made from pulverized fly ash with different manufacturing processes and compared light weight concrete properties. It was observed that sintering process improve strength by fusing the fly ash particles at point of contact [4]. Cerny et al. [4] applied ignition layer of coal to the batch of SLWAC to reduce quantity of ignition gas. He produced up to 56Mpa lightweight concrete with bulk density <2000 Kg/m$^3$. Some researchers compared cold bonded and sintered light weight aggregate concrete. They recorded compressive strength up to 39.94 MPa and flexural strength of 4.07 MPa with Sintered Light Weight Aggregate Concrete (SLWAC) [6]. Durability of concrete produced from SLWA was better than cold bonded aggregates and the performance was further improved by adding silica fume [7]. Arora et al. [3] compared natural weight aggregate concrete with sintered light weight aggregate concrete and concluded that the compressive strength, flexural strength and the modulus of elasticity were lower in SLWAC. Nadesan et al. [4] produced 70Mpa concrete with low water/cement ratio. It was very much clear from literature that light weight concrete can be used in structural members like beam, column and slabs. There are no standard Indian specifications available for making structural light weight aggregate concrete and so it is rarely used in India. The high-water absorption, high cost and lack of versatile procedure for designing, execution, testing and assessment are also responsible for limited use [10]. SLWA are having cellular structure so they absorb more water than normal weight aggregate. Previous research indicates that water absorption in SLWA is of 5 to 25 % whereas in normal weight aggregate it is less than 2% [11]. In natural aggregates, surface moisture is also part of mixing but in SLWA water is also absorbed in inner particles so that it is not available for hydration of cement. Rate of absorption is also critical in case of air dry SLWA as water is absorbed rapidly, so available water for hydration of cement is not uniform and creating inconsistency in the mixture [12].This issue can be minimized by using saturated aggregates. When aggregates are submerged in the water and used in saturated state, the mixing water is used only for paste formation. L. Kong et al. [3] used dry aggregates with additional water for better durability of SLWAC. G. Joseph et al. [4] concluded that no significant effect on
mechanical properties of SLWAC were found using pre-soaked or air-dried aggregates with additional water during mixing. Still, this is an area where less information is available. M. Nadesan et al. [3] correlated water absorption in paste with different water cement ratios and found that that for 0.45 w/c ratio, 11% of additional water is required to saturate SFA aggregates in concrete mix. Maximum size of aggregate also plays an important role in mechanical properties of SLWAC as previous research shows that as the size of the aggregate decreases, strength increases and unit weight also increases [12]. There are different sizes available for SFA aggregate like 8-12 mm, 4-8 mm or 2-4 mm. Previous research shows that DIN AB curve can be used for water cement ratio >0.45 and DIN A curve can be used for w/c ratio < 0.45 [15]. In the cases where only 8-12 mm and 4-8 mm size aggregates are available their researchers used 80% coarser material and 20 % finer material. Arora at el. used 65% and 35% of both the sizes in mix design of SLWAC. So still there is less research related to packing of different sizes SLWA and its impact on properties of concrete.

In this research, fresh and mechanical properties are compared of light weight concrete made from different proportion of sintered light weight aggregates of 8-12 mm and 4-8 mm and find out right proportion of SLWA that produces light weight concrete which is comparable in fresh and mechanical properties and having unit weight <2000 kg/m³.

2. Research Methodology

2.1. Raw Material

Lightweight concrete samples were prepared with SLWA as coarse aggregate, Natural River sand as fine aggregate and Ordinary Portland Cement (OPC) grade 43 as a binder. Sintered fly ash aggregates were the main component in LWC, as it reduces the density of concrete. Mainly SFA aggregates of size 8-12mm and 4-8 mm were procured from M/s Litagg Industries Pvt Ltd Ahmadabad and mixed in different proportioning shown in Figure 3. It mainly comprises 61% Silica, 14% Al₂O₃, 9 % of CaO, 8% Fe₂O₃, and small quantities of alkalis. Sieve size analysis of coarse aggregate (size 8-12 mm & 4-8 mm) and fine aggregate of Zone-III is shown in Figure 2. Physical characteristics of raw ingredients required for LWC are mentioned in Table 1.

![Figure 2. Gradation Curve of Aggregates](image-url)
Table 1. Physical properties of raw ingredients

| Property                        | Cement | Fine Aggregate | SFA Coarse Aggregate (8-12 mm) | SFA Coarse Aggregate (4-8 mm) |
|---------------------------------|--------|----------------|--------------------------------|--------------------------------|
| Consistency (%)                 | 27     | -              | -                              | -                              |
| Initial Setting Time (minute)   | 140    | -              | -                              | -                              |
| Final Setting Time (minute)     | 179    | -              | -                              | -                              |
| Specific Gravity                | 3.15   | 2.62           | 1.57                           | 1.53                           |
| Water Absorption (%)            | -      | 1              | 16                             | 16.5                           |
| Fineness Modulus                | -      | 2.67           |                                 |                                |
| Compressive Strength (MPa)      | 7 days | 42.8           | -                              | -                              |
|                                 | 28 days| 52.5           | -                              | -                              |
| Crushing Strength (MPa)         | -      | -              | 9.15                           | 9.62                           |

2.2. Mix Proportioning

The total number of four mixes were designed and prepared for grade M25 by Weight Method (Specific Gravity Pycnometer) as per ACI 211.2-98 [15]. Fresh and mechanical properties of LWC were inspected as per the guidelines of Indian Standards. The quantity of raw material for different mixes are reported in Table 2. The water cement ratio for each mix was fixed at 0.45.

Pre-soaking of aggregates is done with 11% water by the weight of SFA aggregates which can be seen in Fig 3. SFA aggregate of sizes 8-12 mm and 4-8 mm were used in varying proportions of 80:20(A80), 60:40(A60), 40:60(A40) and 20:80(A20). Other than SFA aggregate proportioning of all ingredients were kept fixed.

Table 2. Mix proportioning for various SLWAC

| Mix          | A80  | A60  | A40  | A20  |
|--------------|------|------|------|------|
| Cement (kg)  | 370  | 370  | 370  | 370  |
| Natural Sand (kg) | 684  | 684  | 684  | 684  |
### Water (kg)

|       | 166 | 166 | 166 | 166 |
|-------|-----|-----|-----|-----|

### SFA Aggregate (8-12 mm) (kg)

|       | 548 | 410 | 274 | 136 |
|-------|-----|-----|-----|-----|

### SFA Aggregate (4-8 mm) (kg)

|       | 136 | 274 | 410 | 548 |
|-------|-----|-----|-----|-----|

### Plasticizer (kg)

|       | 2.8 | 2.8 | 2.8 | 2.8 |
|-------|-----|-----|-----|-----|

### Plasticizer (kg)

|       | 2.8 | 2.8 | 2.8 | 2.8 |
|-------|-----|-----|-----|-----|

### Testing Program

Fresh properties of lightweight concrete were found as per the guidelines of IS 1199:1959 [17]. For all four mixes, there were three samples casted to inspect the mechanical properties (compressive, tensile, and flexural) under the guidelines of IS 516:1959 [18] and IS 5816:1999 [19]. Specimen size for the compressive, tensile, and flexural test were chosen as 100 mm x 100 mm x 100 mm, 150 mm x 150 mm x 150 mm, and 500 mm x 100 mm x 100 mm respectively. Water absorption and voids percentage of SLWC were examined on concrete cubes of 100 mm size as per ASTM C 642-13 [20]. Permeability was inspected on cube size 150 mm as per DIN 1048 [21].

### Results and Discussion

#### 3.1. Fresh State Properties

Most of the guidelines categorized structural light weight concrete having density < 2000 Kg/m3 [22]. During the fresh state, it was ensured that the concrete had adequate consistency and stability to avoid segregation or handling problems. The workability of fresh concrete for different mixes were measured in terms of compaction factor at a fixed dosage of super plasticizer (Auramix -300). It can be established from Figure 4 that the compaction factor is reducing gradually as we increase proportion of smaller SLWA. This reduction in workability may be due to non-uniform particle distribution of aggregates [9]. Higher workability can be achieved by increasing large spherical particles. The fresh density of all four mixes is compared with workability in the Figure 4. An increase in density decreases the workability, this increase in density is due to a higher proportion of small SLWA [22]. Result also shows that fresh density is increasing from Mix A₈₀ to A₂₀ and only A₈₀ is < 2000 Kg/m3 fulfilling the criteria of light weight concrete.

![Figure 4. Fresh properties of SLWAC](image)

#### 3.2. Harden State Properties

3.2.1. Mechanical Strength: Compressive strength of all four mixes were measured after 7, 14, and 28 days of curing at uniform loading of 140 kg/cm²/min. It is observed that compressive strength increases
with an increase of proportion of smaller SFA aggregates as shown in Figure 5. This gradual increment from A₈₀ to A₂₀ of compressive strength is due to the better water holding capacity of smaller SLWA. This absorbed water works as an internal reservoir within SLWA and cause internal curing.[9]

![Figure 5. Compressive Strength of SLWAC](image)

Tensile and flexural strengths for all four mix were examined after 28 days of curing. Figure 6 represents tensile and flexural strengths. The results shows that these strengths are slightly increasing as aligned to compressive strength results. Tensile strength of A₂₀ mix is 1.59% greater than A₈₀ mix, similarly flexural strength is 2.7% higher. Generally tensile strength is governed by tensile strength of aggregate, paste matrix and interfacial transition zone.[9] This increment of strength may be occurred due to more inherent curing by SLWA and improved interfacial transition zone. [9]

![Figure 6. Tensile and Flexural Strength](image)

3.2.2. Water absorption and Permeability
Harden concrete density is to be measured in term of bulk and apparent density to justify the lightweight concrete having density< 2000 Kg/m³ These densities are calculated by weighing concrete cubes at different conditions i.e., oven dry, saturated, saturated with boiled water, and submerged weight. Fig. 7 shows bulk and apparent densities of all four mixes. It can be concluded that lower the proportion of
large particles of SLWA, higher is the density of concrete [22]. Increasing fine SLWA reduces the percentage of pores in concrete thus increases density which can be observed from Figure 9. It is also in line with reduction of percentage of pores that establish decrease in permeability. As there are less voids so less water will seep through concrete that can be seen from Figure 8. This is verified by DIN permeability test on all four mixes. Permeability results are compared with percentage of pores in Figure 9, which shows the similar relationship. [22].
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4. Conclusion
Following conclusions can be drawn from various tests carried out and the analysis of fresh and mechanical properties of SLWAC made from different ratios of coarser and finer SLWA in mix design.

- Compaction factor of SLWAC is reducing while increasing proportion of fine SLWA, which indicates that mix is getting stiffer, can be due to filling of large voids by small size aggregates.
- Bulk and apparent densities increase from the ratio A₈₀ mix to A₂₀ which can be due to better packing and a smaller number of voids.
- From the ratios A₈₀ to A₂₀, overall size of the aggregate decreases in the mix resulting in more specific areas that causes more volume of pores. These pores are filled by finer material improving density.
- Compressive strength is increasing as coarser aggregates are reduced in mix. So, A₂₀ mix is giving more compressive strength as compare to A₈₀ and it is increased by 9%.
- Tensile and split strength is increasing but increment is not in the same ratio as in compressive strength.
- Water penetration in SLWAC is in decreasing order with increase of smaller SFA aggregates which can be correlated to volume of pores.

Overall conclusion can be made from above investigation that of smaller SLWA in LWC enhance the properties of concrete but simultaneously density also increases. In our study it crosses 2000 Kg/m³ after A₈₀ mix which defeats the sole purpose of light weight concrete. Phase changing materials can be used as an absorption agent for SLWA to enhance the properties of SLWAC [23]. However more studies are required for verification of performance characteristics.

References
[1]. Faundeen, J. L., Burley, T. E., Carlino, J., Govoni, D. L., Henkel, H. S., Holl, S., & Zolly, L. S. (2013). The United States geological survey science data lifecycle model. US Department of the Interior, US Geological Survey.
[2]. Yousuf, A., Manzoor, S. O., Youssouf, M., Malik, Z. A., & Khawaja, K. S. (2020). Fly ash: production and utilization in India—an overview. J Mater Environ Sci, 11(6), 911-921.

[3]. Van der Wegen, G. J. L., & Bijen, J. M. J. M. (1985). Properties of concrete made with three types of artificial PFA coarse aggregates. International Journal of Cement Composites and Lightweight Concrete, 7(3), 159-167.

[4]. K. Ramamurthy, K.I. Harikrishnan, Influence of binders on properties of sintered fly ash aggregate, Cem. Concr. Compos. 28 (2006) 33–38.

[5]. Cerny, V., Kocianova, M., & Drochytka, R. (2017). Possibilities of lightweight high strength concrete production from sintered fly ash aggregate. Procedia engineering, 195, 9-16.

[6]. Gomathi, P., & Sivakumar, A. (2015). Accelerated curing effects on the mechanical performance of cold bonded and sintered fly ash aggregate concrete. Construction and building Materials, 77, 276-287.

[7]. Güneyisi, E., Gesoğlu, M., Pürsünli, Ö., & Mermerdaş, K. (2013). Durability aspect of concretes composed of cold bonded and sintered fly ash lightweight aggregates. Composites Part B: Engineering, 53, 258-266.

[8]. Arora, V., & Ojha, P. (2015). Suitability of sintered fly ash light weight aggregate in structural concrete, National council for cement and building material, India

[9]. Nadesan, M. S., & Dinakar, P. (2017). Structural concrete using sintered flyash lightweight aggregate: A review. Construction and Building Materials, 154, 928-944.

[10]. Domagala, L. (2020). Size Effect in compressive strength tests of cored specimens of lightweight aggregate concrete. Materials, 13(5), 1187.

[11]. S. Chandra, L. Berntsson, Lightweight Aggregate Concrete: Science, Technology, and Applications, Noyes Publications, Norwich, New York USA, 2002

[12]. ACI Committee 213. (2003). Guide for structural lightweight-aggregate concrete. American Concrete Institute.

[13]. Kong, L., Hou, L., & Bao, X. (2015). Application of AC impedance technique in study of lightweight aggregate-paste interface. Construction and Building Materials, 82, 332-340.

[14]. Joseph, G., & Ramamurthy, K. (2009). Workability and strength behaviour of concrete with cold-bonded fly ash aggregate. Materials and structures, 42(2), 151-160.

[15]. Prestera, J. R., Boyle, M., Crocker, D. A., Chairman, S. B., Abdun-Nur, E. A., Barton, S. G., ... & Yuan, R. L. (1998). Standard Practice for Selecting Proportions for Structural Lightweight Concrete (ACI 211.2-98).

[16]. Nadesan, M. S., & Dinakar, P. (2017). Mix design and properties of fly ash waste lightweight aggregates in structural lightweight concrete. Case studies in construction materials, 7, 336-347.

[17]. IS 1199 (1959): Methods of sampling and analysis of concrete. Bureau of Indian Standards.

[18]. IS: 516. (1959). Method of tests for strength of concrete. Bureau of Indian Standards.

[19]. IS 5816 (1999): Method of Test Splitting Tensile Strength of Concrete. Bureau of Indian Standards.

[20]. ASTM, C. (2013). Standard test method for density, absorption, and voids in hardened concrete. C642-13.

[21]. DIN 1048. EN-Testing Concrete; Determination of Depth of Penetration of Water Under Pressure in Hardened Concrete.

[22]. Raj, N., Patil, S. G., & Bhattacharjee, B. (2014). Concrete mix design by packing density method. IOSR J. Mech. Civ. Eng, 11(2), 34-46.

[23]. Somani, P., & Gaur, A. (2020). Evaluation and reduction of temperature stresses in concrete pavement by using phase changing material. Materials Today: Proceedings, 32, 856-864.
[24]. Henkensiefken, R., Castro, J., Bentz, D., Nantung, T., & Weiss, J. (2009). Water absorption in internally cured mortar made with water-filled lightweight aggregate. *Cement and Concrete Research, 39*(10), 883-892.

[25]. Holm, T. A., & Bremner, T. W. (2000). State-of-the-art report on high-strength, high-durability structural low-density concrete for applications in severe marine environments.

[26]. Bogas, J. A., & Nogueira, R. (2014). Tensile strength of structural expanded clay lightweight concrete subjected to different curing conditions. *KSCE Journal of Civil Engineering, 18*(6), 1780-1791.

[27]. Neville, A. M. (1995). *Properties of concrete 4*. London: Longman.

[28]. Kockal, N. U., & Ozturan, T. (2011). Durability of lightweight concretes with lightweight fly ash aggregates. *Construction and Building Materials, 25*(3), 1430-1438.