A Study on Mechanical and Durability Properties of Structural Concrete using Pumice and Sintered fly ash Aggregates

M. Sai Yaswitha Reddy*, V.K. Visweswara Rao and M. Srinivasula Reddy

Department of Civil Engineering, G. Pulla Reddy Engineering College (Autonomous), Kurnool, A.P, India.

*Email: saiyaswithareddy.m@gmail.com

Abstract. Lightweight aggregates has low density, high permeability than the conventional coarse aggregate. Most commonly available lightweight aggregate (LWA) are Pumice aggregate (PA), which is a natural aggregate, sintered fly ash aggregate (SFA), which is made by sintered processing the fly ash obtained as a by-product of coal based Thermal power plants. Among the many artificial aggregates, SFA is used as a replacement to coarse aggregate to produce lightweight aggregate concrete. This paper presents an experimental study of structural lightweight aggregate concrete (SLWAC) using combination of PA and SFA as a partial replacement for coarse aggregates. In this, the mechanical and durability properties of SLWAC using different percentages i.e., 25%, 50%, 75% and 100% of PA and the rest natural coarse aggregate, fully replacement of coarse aggregate with 50% PA and 50% SFA, are evaluated by conducting comprehensive series of tests on strength and permeability parameters. The test results showed better strength and adequate density, at coarse aggregate replacement with 50% PA and 50% SFA, to be accepted as SLWAC as per ASTM standards. When the coarse aggregate is completely replaced by pumice aggregate alone, the strength achieved is poor and is suitable for non-structural members. In this study, the mixes are designed for M25 grade concrete and the results are then compared with M25 grade of conventional concrete (CC).

1. Introduction

Concrete is a conglomeration of cement, water, fine and coarse aggregates. Concrete is the most widely used construction material in the construction industry because of its robustness, aesthetic and mouldability properties. The performance of the concrete developed largely depends on the properties of the ingredients used. In general, conventional concrete (CC) produced using natural coarse aggregate have densities in the range of 2400-2500 kg/m³. It is well known that the density of the concrete plays an important role in defining the size of the structural members. Reducing the size of the structural members is very beneficial in reducing the dead weight. This can be achieved by replacing natural coarse aggregate with LWAs, as the coarse aggregate has a major hold in defining the concrete density. Moreover, the vast majority of conventional concrete producers utilize crushed stone as coarse aggregate and its use in concrete has triggered disparity naturally. Astonishing exploitation of natural rock masses has been creating havoc and is leading to land sliding, avalanches,
etc. The influence of this on the environment has made to think toward unnaturally formed aggregates as an alternative to the natural rock aggregates and also to some of other natural sources. About 50% of concrete is filled with coarse aggregate, so instead of using conventional aggregate, usage of LWAs helps in not only avoiding destruction of natural rocks but also contributes to the reduction in overall density of concrete. Nowadays, a wide range of LWAs are available. Pumice aggregate (PA), natural resource, and Sintered fly ash aggregate (SFA), from artificial resource, have been used as a replacement of normal coarse aggregate in this study.

PA is a natural LWA formed due to the rapid cooling of liquid volcanic matter exploded. As the volcanic matter is exploded from the earth crust, it is rich in siliceous content [1]. Pumice is a very light rocky material whose cell structure consists of air pockets or air voids, the air voids forms when the gases contained in the liquid magma escapes during the cooling of magma leaving tiny air voids. The air voids are not inter-connected and the cell structure is stretched out and the cells are inter-connected to a great extent. PA has been used all across the World as a coarse aggregate in the production of LWA [2]. The major drawback with using PA as a coarse aggregate in making concrete is that, its mechanical strength properties are not sufficient enough to be used for structural purposes and can be used for specific purposes only by utilizing PA in making permeable concrete [3]. Even though, the permeable concrete with a very high permeability is useful for some applications like permeable pavements, thermal barriers, sound insulator, its incompetence in taking large loads makes its less useful for structural purposes [4]. Moreover, the water preservation behavior of PA is essentially high than typical coarse aggregate and found to have an impact on the consistency of trials during mixing and fresh concrete properties testing, which can be addressed by pre-soaking them before mixing in the concrete [5-6]. The strength properties of PA based lightweight concrete can be improved by adding SFA to the PA based lightweight concrete, by taking a cue from the research report of several researchers, where they reported that structural lightweight concrete can be developed using SFA as a replacement to coarse aggregate [7].

Utilization of SFA has several advantages apart from the improvement in the strength properties alone. It also helps in increased utilization of fly ash, an industrial by-product of coal based thermal power plants [8-9]. If fly ash is not properly disposed off, it can cause severe environmental pollution. India, China and USA being the top users of coal for power plants and their contribution to fly ash generation is also high. SFA LWA is found to be a very useful product both as a substitute to the natural coarse aggregate and to increase the utilization of fly ash for useful means, which otherwise would have been dumped futilely. SFA LWA is generally made by first mixing fly ash, clay and coke breeze in various proportions at a specified degree and sintering them at a temperature about 1200-1300 °C. The sintering technique used is mainly Downdraft Sintering Technique [10]. Decreasing the self-weight of the concrete without compromising on its usefulness as a structural material becomes an essential viability of the concrete. SFA is one of such potential materials to make concrete lighter than CC [11]. High strength lightweight cement can likewise be delivered by totally supplanting the CA with sintered fly ash aggregates. In this paper, M25 grade SLWAC by supplanting CA with PA in various percentages (25%, 50%, 75%, 100%), SFA by half substitution of CA and a mix of both lightweight aggregates, have been created and their mechanical properties (compressive strength, splitting tensile strength) and durability properties (water absorption test) are examined and analyzed. To stay away from the water absorption issues related with LWA, it is recommended to use submerged LWAs during the concrete creation.

The main objectives of this study is to determine whether pumice stone and sintered fly ash aggregate concrete can be used as structural lightweight aggregate concrete (SLWAC), also to develop the mix design for producing M25 grade concrete using pumice (PA) and sintered fly ash aggregate (SFA) and then comparing the mechanical properties and durability properties of structural concrete with conventional/normal concrete (CC/NC).
2. Experimental Program

The test specimens have been prepared by using material as Cement (OPC 53 grade), coarse aggregate of size 12.5mm passing, pumice aggregate and Sintered Flyash Aggregate of size 10mm, 4.75mm passing river sand as fine aggregate and Water.

2.1 General

Structural concrete (SC) has been prepared with pumice and sintered fly ash aggregates and tested for compressive strength, split tensile strength and water absorption according to ASTM C642-13 [12].

2.2 Specimen Specifications

100mm x 100mm x 100 mm size cubes have been casted and subjected for testing the compressive strength. 100 mm diameter and 200 mm height cylinders, have been prepared for testing the splitting tensile strength. 100mm x 100mm x 100 mm dimensions cubes have been casted for estimating percentage of water absorption and this testing has been carried out after curing 28 days.

2.3 Properties of Material

Ordinary Portland Cement (OPC), sand (as fine aggregate), pumice aggregate (coarse aggregate), sintered fly ash (Coarse aggregate), Potable water have been used for casting cubes and cylinders in M25 mix design.

2.3.1. Cement. Ordinary Portland cement (BrilaA1 cement) 53 grade, confirming to IS:12269-1987 [13] has been used. Physical properties of Ordinary Portland Cement are given below in Table 1.

| Property          | Test Results |
|-------------------|--------------|
| Consistency of cement | 32%          |
| Specific gravity   | 3.14         |
| Initial setting time | 24 mins     |
| Final setting time  | 268 mins     |

2.3.2. Coarse Aggregate. Coarse aggregate of 10mm size was used for this investigation, aggregate taken from the local quarry confirming to IS:383:1970 [14]. The specific gravity of CA is 2.77 and bulk density is 1752.6 Kg/m³.

2.3.3. Pumice Aggregate. The properties of pumice aggregate are shown in Table 2 and Figure 1 depicts the pumice used in the present study.

| Physical Properties | Test Results |
|---------------------|--------------|
| Maximum size        | 10mm         |
| Fineness modulus    | 2.705        |
| Specific gravity    | 1.05         |
| Bulk density        | 724 Kg/m³    |
| Water absorption    | 18.81%       |

2.3.4. Sintered Flyash Aggregate. Sintered Flyash Aggregate of size 10mm, 4.75mm passing has been used for preparing Structural concrete (SC) in M25 mix design.
2.3.4. Sintered fly ash aggregate. The properties of sintered fly ash aggregate are shown in Table 3 and the figure 2 depicts the SFA used in the present study.

| Physical Properties       | Test Results          |
|---------------------------|-----------------------|
| Maximum size              | 10mm                  |
| Fineness modulus          | 2.275                 |
| Specific gravity          | 1.785                 |
| Bulk density              | 903.6 Kg/m$^3$        |
| Water absorption          | 17%                   |

Figure 2. Sintered fly ash aggregate

2.3.5. River sand as Fine Aggregate. The locally existing sand confining to zone II was used in accordance with IS: 383-1970 [14]. The specific gravity, bulk density of this fine aggregate are 2.5, 1285 Kg/m$^3$ respectively and the fineness modulus of sand is 3.085.

3. Mix design for SLWAC

Nadesan and Dinakar (2016) [11] have proposed a new mix design specification for SLWAC. Using the concept of mix design for SLWAC proposed by Nadesan and Dinakar, a mix design for M25 has been developed, also by using natural coarse aggregate normal concrete (NC) is developed. Compression strength, Splitting tensile strength and Water absorption analysis have been carried out for various samples.

3.1 Mix Proportions for Developed Concrete

The following four are the different mixes for M25 grade with water/cement ratio 0.65, the target mean strength of M25 grade concrete is 31.6 N/mm$^2$ (IS 10262-2009) and their designations and proportions are shown in table 4. The different mixes are normal/conventional concrete (NC/CC), pumice aggregate concrete with different replacements (P$_{25\%}$, P$_{50\%}$, P$_{75\%}$, P$_{100\%}$), sintered fly ash aggregate concrete (S$_{50\%}$), combination of pumice and sintered fly ash aggregate (PS$_{50\%}$).

| Designation | Cement | Fine aggregate | Coarse aggregate | Pumice aggregate | Sintered flyash aggregate | Water |
|-------------|--------|----------------|------------------|-----------------|---------------------------|-------|
| NC          | 276.9  | 801            | 1084.73          | 0               | 0                         | 180   |
| P$_{25\%}$  | 276.9  | 801            | 813.55           | 102.795         | 0                         | 180   |
| P$_{50\%}$  | 276.9  | 801            | 542.36           | 205.59          | 0                         | 180   |
| P$_{75\%}$  | 276.9  | 801            | 271.18           | 308.38          | 0                         | 180   |
| P$_{100\%}$ | 276.9  | 801            | 0                | 411.18          | 0                         | 180   |
| S$_{50\%}$  | 276.9  | 801            | 542.36           | 0               | 349.5                     | 180   |
| PS$_{50\%}$ | 276.9  | 801            | 0                | 205.59          | 349.5                     | 180   |
4. Results and Discussion

4.1 Density
The air dry and oven-dry densities of all the SLWAC and CC have been estimated and given in Table 5. When CA is replaced with PA (at 75%, 100%), SFA (at 50%) light weight concrete can be achieved.

| Designation | Air dry density | Oven dry density |
|-------------|-----------------|-----------------|
| NC          | 2686            | 2665            |
| P25%        | 2476            | 2461.33         |
| P50%        | 2354            | 2320            |
| P75%        | 2016            | 1973.33         |
| P100%       | 1825            | 1786.66         |
| S50%        | 2400            | 2360            |
| PS50%       | 2033            | 1985            |

4.2 Compressive Strength
The least compressive strength necessary for structural lightweight concrete has been 17 MPa as per ASTMC-330 [15] standards. For this test the specimens of size 100 mm x 100 mm x 100 mm are cast, cured for 28 days. The compressive strength is the ratio of the maximum load to the surface area of the concrete cube. Three cubes were tested for each mix ratio & the average of three specimens is taken as the compressive strength. By using 25% pumice aggregate a decrease in compressive strength is noticed, about 60% of compressive strength has been decreased on further increase of percentage of pumice aggregate (by 75% & 100%). Compressive strength of NC for 28 days is outraged the target mean strength, this may depend on different factors like size of aggregate, water-cement ratio, cement strength. The compressive strength of different concrete mixtures are shown in Table 6 and maximum compressive strength of concretes for P50%, S50% and PS50% are compared with normal concrete in figure 3.

| Designation | Compressive strength (MPa) |
|-------------|-----------------------------|
| NC          | 50.67                       |
| P25%        | 24.67                       |
| P50%        | 34.33                       |
| P75%        | 18.67                       |
| P100%       | 16.00                       |
| S50%        | 40.33                       |
| PS50%       | 27.00                       |

Figure 3. Compressive strength for P50%, S50% and PS50%
4.3 Splitting Tensile strength
The minimum tensile-strength required for structural grade concrete is 2MPa for LWC according to ASTM C-330 [15]. For this test the specimens of size 100 mm diameter (D), 200 mm length (L) are cast, cured for 28 days. The splitting tensile strength of specimens for different mixes were tested on universal testing machine and are tabulated in Table 7 and maximum compressive strength of concretes for P 50%, S 50% and PS 50% are compared with normal concrete in Figure 4.

| Designation | Splitting tensile strength (MPa) |
|-------------|----------------------------------|
| NC          | 4.290                            |
| P 25%       | 2.864                            |
| P 50%       | 3.342                            |
| P 75%       | 2.546                            |
| P 100%      | 2.228                            |
| S 50%       | 3.978                            |
| PS 50%      | 3.024                            |

Figure 4. Splitting tensile strength at 28 days

4.4 Water Absorption
The water absorption test was performed according to ASTM C642-13 [12] which also includes the estimation of density, absorption and percentage of voids in hardened concrete. Test is conducted on three mix specimens (P 50%, S 50% and PS 50%) and compared with M25 grade CC and showed in Table 8.

| Designation | Weight of sample after oven dry (g) | Weight of surface dry sample after immersion (g) | Water absorption (in %) |
|-------------|-------------------------------------|-----------------------------------------------|------------------------|
| NC          | 2513                                | 2590                                          | 3.06                   |
| P 50%       | 1996                                | 2130                                          | 6.71                   |
| S 50%       | 2173                                | 2296                                          | 5.66                   |
| PS 50%      | 1800                                | 1946                                          | 8.11                   |

5. Conclusion
Based on the results and analysis the following conclusion are made. The compressive strength of pumice aggregate and sintered fly ash aggregate concrete at 50% replacement of CA is more comparable with target mean strength of normal concrete. On further increase in percentage of PA
instead of CA, a decrease in strength was noticed. Structural lightweight aggregate concrete can be achieved by using both PA & SFA. The results obtained for splitting tensile strength of 100 x 100 x 100 mm samples of SLWAC satisfies the requirements of structural applications according to ASTM C330. It has been observed that M25 grade with SLWACs has higher water absorption compared to standard aggregate concrete/NC.

References
[1] Bonewitz R, Rocks and minerals. 2nd edition, DK Publishing: London (2012).
[2] Khandaker M. Anwar Hossain, Properties of Volcanic Pumice Based Cement and Lightweight Concrete, Cement and concrete research 34 (2004).
[3] J. Rex, B. Kameshwari, Studies on Pumice Lightweight Aggregate Concrete with Quarry Dust Using Mathematical Modeling Aid of ACO Techniques", Advances in Materials Science and Engineering (2016) Article ID 9583757.
[4] Shadi Saadeh, Avinash Ralla, Yazan Al-Zubi, Rongzong Wu, John Harvey, Application of fully permeable pavements as a sustainable approach for mitigation of stormwater runoff, International Journal of Transportation Science and Technology 8(4) (2019).
[5] Nihat Kabay, Fevziye Aköz, Effect of prewetting methods on some fresh and hardened properties of concrete with pumice aggregate, Cement and Concrete Composites 34(4) (2012).
[6] C.W. Tang, Effect of presoaking degree of lightweight aggregate on the properties of lightweight aggregate concrete, Computers and Concrete 19 (2017).
[7] J.P. Behera, B.D. Nayak, H.S. Ray, B. Sarangi, Lightweight concrete with sintered fly ash aggregate: a study on partial replacement to normal granite aggregate, IE (I) Journal (85) (2004).
[8] R. Manikandan, K. Ramamurthy, Physical characteristics of sintered fly ash aggregate containing clay binders. Journal of Material Cycles and Waste Management Volume 14 (2012).
[9] Manu S. Nadesan, P. Dinakar, Structural Concrete using Sintered Flyash Lightweight Aggregate: A review, Construction and Building materials (2017).
[10] H.E. Exner, E. Arzt, Sintering Processes in Physical Metallurgy, Fourth Edition, Elsevier (1996).
[11] Manu S. Nadesan, P. Dinakar, Influence of Type Binder on High-performance Sintered Flyash Lightweight Aggregate Concrete, Construction and Building materials (2018).
[12] ASTM C642-13, Standard Test Method for Density, Absorption, and Voids in Hardened Concrete, ASTM International, West Conshohocken, PA, 2013, www.astm.org
[13] IS 12269: Standard specification for 53 grade ordinary Portland cement, BIS New Delhi, India (1987).
[14] IS 383: Standard specification for Coarse and Fine Aggregates from Natural Sources for Concrete, BIS New Delhi, India (1970).
[15] ASTM C 330: Standard Specification for Lightweight Aggregates for Structural Concretes, ASTM International, United States (2014).