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# Influence of type of binder on high-performance sintered fly ash lightweight aggregate concrete

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## HIGHLIGHTS

- The influence of SCMs on the mechanical properties of LWACs is marginal.
- It is possible to develop concrete up to 80 MPa by using SFA aggregates.
- The durability properties improved significantly by the inclusion of SCMs.
- The high strength LWACs exhibited negligible rate of carbonation and corrosion.

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## ABSTRACT

Concrete industry consumes natural resources in a massive manner. As the demand for concrete is growing, one of the effective ways to minimize the harmful effect of concrete is to improve its structural efficiency and durability performance. In the current study, the possibility of making high performance structural lightweight aggregate concrete using sintered flyash aggregate was investigated. The study also identifies the influence of silica fume and metakaolin on the performance of the lightweight aggregate concrete. The mechanical properties, such as compressive strength, splitting tensile, elastic modulus and drying shrinkage, and the durability properties like surface resistivity, chloride migration, carbonation rate and corrosion rate were investigated. All the developed concretes attain the strength required to qualify them as high strength concretes. The results demonstrate that the improvements in mechanical properties are marginal by the inclusion of silica fume and metakaolin, whereas significant enhancement to durability was observed. The carbonation results indicates that carbonation is no longer a concern for the developed concretes. It was also noticed that the mechanical and durability properties enhanced with age of curing.



## 1. Introduction

Structural lightweight aggregate concrete is a vital and versatile material in modern construction practices. The inclusion of lightweight aggregate (LWA) in structural concrete provides a weight reduction of 25%–35% without sacrificing the strength [1]. In recent decades the demand of high strength lightweight aggregate concrete has been increased in areas like multi storey buildings, long span bridges, offshore oil platforms and precast structural components [2,3]. In offshore floating structures, great efficiencies are achieved by the adoption of lightweight materials. A reduction of 25% in weight of reinforced concrete will result in a 50% reduction in load when it is under submerged condition [4]. This indicates that the use of high strength lightweight aggregate concrete provides prodigious benefit in the construction of offshore structures. Earlier research in the development of high strength lightweight concrete facilitated lightweight concrete to be used for unique applications where high strength and high durability are desired [5]. Though some European and North American codes provide certain guidelines towards the structural application of lightweight aggregate concrete (LWAC), most of the mechanical and durability characteristics are poorly categorized [6]. This may be due to lack of available data in this research area; since most of the structural lightweight aggregate concrete research is concentrated on expanded clay, shale and slate. Also, the properties of the concrete are significantly governed by the type of aggregate and moisture state of the aggregate that has been used [7,8].

In general, the strength of LWA can be related to the resulting concrete strength and is often referred to as the 'ceiling strength'. A relationship between the type of aggregate, density and strength of concrete, and its field of utilization is established by Dolby [9].

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According to the relation only artificially produced LWA is suitable to develop structural concretes. Sintered fly ash lightweight aggregate is one of such potential materials to make concrete lighter than the conventional aggregate concrete [10]. Sintered fly ash lightweight aggregates were produced by sintering the mixture of fly ash, semi plastic clay as binder and coke breeze at a certain proportion and sintering them at a temperature between 1200 °C and 1300 °C in a Laboratory Chain Grate Sintering System by the Down Draft Sintering Technique [11]. Reducing the self-weight of the concrete without sacrificing the strength is one such initiative to improve the structural efficiency of the concrete. To develop high strength concrete, inclusion of high end pozzolanic materials like metakaolin (MK) and silica fume (SF) is essential. According to earlier studies, it was found that 10 to 15% replacement levels are the optimum dosage for metakaolin and silica fume to enhance the matured properties of the concrete [12–14]. Adoption of lower water-binder ratio and suitable pozzolanic material will create a stronger paste within the concrete matrix. However, the strength and stiffness of the lightweight aggregates are usually inferior to normal aggregates, making it difficult to use them in the development of high strength concrete. The concept of particle packing may help to overcome this drawback to a certain extent. Earlier studies proved that proper aggregate packing is highly effective in the development of high performance concretes [15,16].

To avoid the workability issues associated with LWA, it is widely adopted to use saturated LWAs during the concrete production. Studies have shown that the use of saturated LWA makes the concrete performance similar to normal aggregate concrete, whereas the use of dry LWA improves the concrete performance superior to saturated LWA as well as the normal aggregates [8]. Most of the existing researches are based on the saturated aggregates only; this also causes to underestimate the actual potential of LWACs. Only limited research is available to classify the matured properties of the sintered fly ash aggregate concretes. It is believed that the inclusion of porous aggregate may exhibit inferior restraint against the shrinkage of the paste occurred in the concrete, due to lower stiffness [17]. Also, earlier studies reported inferior shrinkage properties in high strength concrete produced with sintered fly ash aggregate [18].

The present investigation is an attempt to develop high strength high performance lightweight concrete using sintered fly ash aggregate in a more reliable method and also to investigate the influence of metakaolin and silica fume on the mechanical and durability properties of the developed concretes. In this study metakaolin and silica fume were replaced at 10% and 15% by weight of the ordinary portland cement to investigate the relative effectiveness of metakaolin and silica fume on the development and performance of the concretes. For this purpose, two groups of concrete mixtures having water-binder ratios 0.25 and 0.35 were employed and the mechanical and durability characteristics of the developed concretes were assessed through various experimental investigation at different ages. This study will envisage the potential use of sintered fly ash aggregate on the development of high-performance concretes.

## 2. Experimental program

### 2.1. Materials

Ordinary Portland cement (53 grade) confirming to IS: 12269 [19] was used as the primary binding material. Metakaolin and silica fume were used as supplementary cementitious materials (SCMs). The physical and chemical properties of all the binders and chemical properties of LWA used in the present investigation are mentioned in Table 1.

Well graded river sand was used as fine aggregate. Three different size fractions of sintered fly ash aggregates 2–4, 4–8 and 8–12 mm, were used as coarse aggregates. All the coarse aggregates confirming with the requirements provided by ASTM C 330. The sintered fly ash aggregates are rounded in shape and possess a rough surface texture. The average individual aggregate crushing strength is found to be 9.5 MPa in accordance with the procedure given by Kockal and Ozturan [20]. The physical properties of the aggregates that are used in the present study has been mentioned in Table 2. Commercially available polycarboxylate ether based superplasticizer is employed to achieve the desired workabilities.

### 2.2. Mix proportioning

The water-binder ratios adopted in this investigation are 0.35 and 0.25. The free water content is fixed at 170 kg/m$^3$ for both the mixes. To compensate the water absorption by the aggregate that takes place during mixing, extra water is added according to the method proposed by the authors elsewhere [21]. Different aggregate fractions were combined in accordance with the combined aggregate grading as recommended by the DIN 1045 [22]. Standard curve DIN 'A' is adopted in the present study as the reference grading curve. Actual and standard DIN 'A' curve along with different aggregate fractions is presented in Fig. 1. The detailed mix composition formulated for the current experimental investigation is presented in Table 3. The optimum dosage of the superplasticizer (SP) was determined by conducting trials in order to achieve the designed slump of 100 ± 10 mm. In the mix designation letters 'C' stands for control mix and, 'M'and 'S' indicates mix which contains metakaolin and silica fume, respectively. The numbers 10 and 15 indicate percentage replacement of SCM by mass of cement. The numbers 25 and 35 indicate water-binder ratio 0.25 and 0.35, respectively. For example mix designation M 1025 indicates that the mix contain water-binder ratio 0.25 and 10% metakaolin as SCM.

### 2.3. Experimental methods

The experimental program was formulated in such a way that the mechanical properties were assessed by compressive strength, splitting tensile strength, modulus of elasticity and drying shrinkage. The durability properties were assessed by the surface resistivity, chloride migration coefficient, carbonation resistance and the rebar corrosion rate.

The mechanical properties were determined according to the guidelines provided by ASTM. The mechanical properties and the corresponding codes can be described as follows; compressive strength (ASTM C 39), splitting tensile strength (ASTM C 496), static modulus of elasticity (ASTM C 469) and drying shrinkage (ASTM C 157). Compressive strength and splitting tensile strength tests were conducted on an automatic compression testing machine having a capacity of 3000 kN. To determine the static modulus of elasticity, closed loop testing machine (Controls Advantest-9) unit was used. The axial deformation corresponding to the applied load was measured using symmetricaly placed three extensometers.

To determine the ionic conductivity of the concrete, surface resistivity has been conducted using the Wenner four probe apparatus on a cylindrical sample. Chloride migration is another important permeation characteristic exhibited by the concrete. Chloride migration coefficient of the concrete was determined using rapid chloride migration test conducted on disc specimen in accordance with NT Build 492 [23]. To govern the carbonation resistance the cylindrical specimens splitted during splitting tensile strength test were exposed to the atmospheric condition to simulate the real carbonation condition as proposed by the Comité Euro-International du Béton–Féderation Internationale de la Precontrainte [24] for