Mechanical Properties of Concrete with Sintered Fly Ash Aggregate as Substitute of Natural Fine Aggregate

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Abstract. Attempts have been made from time long to develop construction materials which should be strong, durable and simultaneously of light weight. In an attempt to reduce the self-weight of the structural concrete, light weight aggregates are being used and implemented. Fly ash is a waste material of coal based thermal power plants. Presently, fly ash is being used in construction industries in different ways. Sintered fly ash aggregates when used as a substitute for natural aggregates benefits the preservation of natural aggregates as well as the utilization of fly ash which poses a great environmental problem for its disposal. Simultaneously, it also reduces the cost of concrete. In the present investigation, sintered fly ash light weight aggregates have been used as a partial replacement of natural sand as fine aggregate in concrete. Varying percentages of natural fine aggregate have been replaced by sintered fly ash light weight aggregates. Experimental investigations have been carried out to study the mechanical properties related to the strength of concrete, namely, compressive strength, tensile strength, split tensile strength and flexural strength with sintered fly ash aggregate as fine aggregate substitute in concrete. In all mixes, silica fume have been used in conjunction with the binder material consisting of ordinary Portland cement.

1. Introduction
Concrete is one of the most resourceful and adaptable construction materials possessing superior qualities in terms of chemical and mechanical characteristics. It has found its application in almost all types of constructions. Presently, in the construction industry throughout the world, most of the concrete prepared is with natural fine aggregate as a major constituent. Its extensive usage results in geological and environmental imbalance and simultaneously, the naturally available sand gets depleted causing a great catastrophe for future generations. Accordingly, use of construction material for eco-friendly and sustainable development has become a great challenge for construction engineers. Keeping in view of the growing need of qualitative construction materials, substantial development has been made in this domain keeping in pace with the growing technology. In this context, there has been a wide range of explorations throughout the globe to come up with superior quality materials for construction which must guarantee in terms of strength and performance level. For sustainable development, it has become mandate to use industrial wastes as alternative construction materials. This not only saves the original materials for future generations but also their successful use eliminates the problem of their disposal. Now in one hand to save the natural materials and use the wastes as their potential substitute and on the
other hand to make the structure light weight, it has become vital for preparing artificial construction materials from industrial and agricultural sources. In a developing nation like India, construction activities are going on at a very big scale. This has necessitated a large sum of structural materials involving a large sum of construction cost. In this scenario, it is necessary to substitute these commonly used construction materials by appropriate novel materials which should be cost effective and eco-friendly. To the answer for the strain and demand for water-course fine aggregates, researches are being conducted and attempts have been made to utilize quarry dust, polyvinyl waste, plastic waste etc. as substitute for natural river sand as fine aggregate in concrete. The bending performance of concrete is found to be increasing by using polyvinyl wastes as a part substitute of sand [1]. Singh and Siddique [2] studied the effect of iron slag as partial replacement of fine aggregate in concrete and checked its durability and observed that up to 40% replacement of iron slag against NFA gives high strength to concrete. Structural low density concrete necessity can be met by pumice lightweight aggregates in concrete as fine and coarse aggregate substitute, in respect of strength and durability parameters [3]. Siddique [4] investigated the effects of flyash as a fine aggregate substitute in concrete and noteworthy development has been observed in concrete strength. Arumugan et al. [5] used pond ash as an effective alternative material for fine aggregate in concrete. Use of bottom ash as a material in concrete to be used as fine aggregate substitute n 10-40% enhances its compression and tension resistance as well as resistance to abrasion. However, the freeze-thaw resistance gets lowered [6]. Singh and Siddique [7] used coal bottom ash as fine aggregate in concrete. Enhanced strength was observed in concretes containing bottom ash. Fly ash, an industrial by-product from coal firing thermal power plants with current annual generation of approximately 300 million tons can be used in cement-based materials due to its very good pozzolanic properties. There are different ways of using fly ash in concrete industry. It can be used as partial replacement of cement or use of fly ash aggregate in replacement of natural aggregate. Fly ash light weight aggregates produced by sintering at high temperature and by pelletization has proved to be a successful construction material as substitute for natural coarse aggregates [8-10]. From the detailed review of the literature, it is observed that materials like pellets, coconut shell, volcanic pumice light weight aggregate, periwinkle shell etc. can be used as replacement of natural coarse aggregate. In the concrete industry these materials can be used as light weight aggregate. However, it is apparent that no specific study has been reported in the literature regarding utilization of sintered fly ash aggregate for replacement of fine aggregate. This presents wide scope for future investigation in this direction.

2. Experimental Setup
This section provide the details of materials used for the present experimental work, their properties, mixing and casting procedure for assessing different properties of concrete containing various percentage of sintered fly ash aggregates as fine aggregate substitute.

2.1. Materials Used
For the present experimental investigations, following materials are used:
- Ordinary Portland cement (OPC-43 grade)
- Natural fine aggregate
- Sintered fly ash aggregate
- Water
- Natural coarse aggregate (20mm down)
- Silica fume

The properties of the materials are mentioned below.

2.1.1. Cement
OPC 43 grade cement is used having physical characteristics represented in Table 1.
Table 1. Physical characteristics of cement

| Properties        | Results |
|-------------------|---------|
| Specific gravity  | 3.15    |
| Initial setting time | 40 min |
| Final setting time | 230 min |
| Normal Consistency | 34%     |

2.1.2. Aggregates

Water course sand available locally and satisfying the criteria of zone-II is used as fine aggregates for making of the concrete specimens. Similarly, Natural Coarse Aggregate (NCA) consists of broken granite rock of particle size ranging between 4.75 mm to 20 mm. Alternatively, Sintered fly ash aggregate used was acquired from Indian Metals and Ferro Alloys (IMFA), situated in Cuttack, Odisha, India. Since the flyash lightweight aggregates are used as fine aggregate substitute in the present study, maximum size of aggregates is limited to 4.75 mm. The characteristics of the fine and coarse aggregates used in the present study are mentioned in Table 2.

Table 2. Characteristics of aggregates

| Properties        | Fine Aggregate | Coarse Aggregate | Flyash Aggregate |
|-------------------|----------------|------------------|------------------|
| Bulk density (kg/m$^3$) | 1650           | 1732             | 1430             |
| Specific gravity  | 2.70           | 2.75             | 1.58             |
| Fineness modulus  | 2.84           | 7.8              | -                |
| Water absorption (%) | 0.81           | 0.22             | 11.5             |

2.2. Mix Design and Casting

For the present experimental investigation, volume proportion is considered for mix proportioning. Following IS: 10262-2009 stipulations, concrete mix for M30 grade was designed to achieve a target strength of 38.25 N/mm$^2$. Here OPC 43 grade cement was used as cementitious material. Accordingly, for 1 m$^3$ of concrete, the ingredient materials are 438 kg of cement, natural fine aggregate 610 kg, natural coarse aggregate 1206 kg and 197 liter of water. Different mixes were subsequently prepared keeping in view of the mix proportions so obtained but natural fine aggregates being replaced by fly ash light weight aggregates in 10, 20, 30, 40, 50 and 100 percent by weight. In all the mixes, silica fume was
added as supplementary cementitous material at the rate of 20% by weight of cement. The materials were properly mixed following standard procedure in a pan mixer and were cast into different moulds for further testing as shown in Figure 2. After 24 hours of casting, the specimens were placed inside water for curing. The various mechanical properties were tested after 7, 28 and 56 days of curing. The mix identity corresponding to different mix proportions are given in Table 3.

![Figure 2. Casting of Samples](image)

Table 3. Mix identity designation for concrete specimens

| Concrete mix Proportion | Mix identity       |
|-------------------------|--------------------|
| C80%+NFA100%+SF0%+SI20% | NA100SF0SI20       |
| C80%+NFA90%+SF10%+SI20% | NA90SF10SI20       |
| C80%+NFA80%+SF20%+SI20% | NA80SF20SI20       |
| C80%+NFA70%+SF30%+SI20% | NA70SF30SI20       |
| C80%+NFA60%+SF40%+SI20% | NA60SF40SI20       |
| C80%+NFA50%+SF50%+SI20% | NA50SF50SI20       |
| C80%+NFA0%+SF100%+SI20% | NA0SF100SI20       |

C-Cement, NFA -Natural fine aggregate, SF - Sintered fly aggregate, SI - Silica fume

3. Results and Discussion
For the present investigation, to assess the properties of flyash aggregates as a potential material for replacement of natural fine aggregates, tests were carried out to determine their hardened properties after 7, 28 and 56 days of curing. For this, strength of concrete in compression, flexure and splitting tension are evaluated following experimental procedures laid by Indian Standard specifications. The results pertaining to various tests are mentioned in the subsequent sections and discussions are made.

3.1. Compressive strength
Compressive strength of 150 mm cubic samples is found by examining in a compression testing machine after the samples were cured for specified period. The outcomes corresponding to the strength of cubes containing various proportions of fly ash light weight aggregates as a substitute of natural fine aggregates are presented in Figure 3.
Figure 3. Compressive strength of Cube specimens

From Figure 3 it is obvious that the cube compressive strength of concrete with different percentage of fly ash light weight aggregate are in very good agreement with that of natural fine aggregate. The minimum strength corresponds to 30% replacement. However, this one also is having strength at par with the controlled specimen containing natural fine aggregate. Even at 100% replacement, the strength is found to be higher than that corresponding to NFA concrete. It may be noted here that even though the mix is intended for M30 grade, the strength of concrete is quite higher than the target strength. This may be due to the addition of silica fume which further enhances the formation of C-S-H gel.

3.2. Splitting tensile strength

The tensile strength corresponding to splitting of concrete was determined by examining samples of cylindrical shape of 100 mm diameter and 200 mm high in a compression testing machine following Bureau of Indian Standards guidelines. The consequences are shown in Figure 4.

Figure 4. Split tensile strength of cylindrical specimens

The results reveal that the split tensile strength of concrete with different percentage of fly ash light weight aggregate are in very good agreement with that of natural fine aggregate. The maximum strength
corresponds to 20% replacement while, minimum strength corresponds to 40% replacement. Even at 100% replacement, the strength is found to be higher than controlled concrete specimen.

3.3. Strength in flexure
The strength of concrete in flexure was evaluated on prism samples of 100 mm square in cross section and 500 mm long the outcomes are represented in terms of modulus of rupture. The procedure laid down by BIS was followed to derive the flexural strength in a flexure testing machine. The results corresponding to test are presented in Figure 5.

The graph corresponding to experimental result shows that the strength of concrete in flexure with different percentage of fly ash light weight aggregate also follow the same trend, the strength being in very good agreement with that of controlled specimen with natural fine aggregate. The minimum strength corresponds to 20% replacement.

4. Conclusions
From the above experimental investigations made in the present work, these are the subsequent inferences which can be drawn. Fly ash light weight aggregate concrete shows very good mechanical properties in respect of strength corresponding to cube compression, splitting tension and flexure as compared to natural fine aggregate. At complete replacement, the strength in compression shows an increase of 45.6%, 28.4% and 21% after a curing period of 7, 28 and 56 days. Similarly, the strength corresponding to splitting tension exhibits an enhancement of 1.5%, 4.26% and 4.62% after curing period of 7, 28 and 56 days. The strength in flexure of concrete with full replacement shows respectively 26%, 18.6% and 12.3% increase after 7, 28 and 56 days of curing with respect to controlled specimen. Thus it can be fruitfully used as a prospective substitute for natural fine aggregate. However, since it absorbs more water, it is suitable for interior work rather than exterior structural units. Sintered fly ash aggregates when used as a substitute for natural aggregates benefits the preservation of the natural resources as well as the utilization of fly ash which poses a great environmental problem for its disposal. Simultaneously, it also reduces the cost of concrete. However, micro-structural study like XRD, SEM etc. needs to be carried out to ascertain the actual behaviour.

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