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Microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates

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HIGHLIGHTS

- Use of industrial by-products i.e. bottom ash and waste foundry sand in concrete.
- Microstructure analysis of concrete using XRD and SEM.
- Mechanical and durability properties of concrete using industrial by-products.

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ABSTRACT

The possibility of substituting natural fine aggregate with industrial by-products such as waste foundry sand and bottom ash offers technical, economic and environmental advantages which are of great importance in the present context of sustainability in the construction sector. The study investigated the effect of waste foundry sand and bottom ash in equal quantities as partial replacement of fine aggregates in various percentages (0–60%), on concrete properties such as mechanical (compressive strength, splitting tensile strength and flexural strength) and durability characteristics (rapid chloride penetration and deicing salt surface scaling) of the concrete along with microstructural analysis with XRD and SEM. The results showed that the water content increased gradually from 175 kg/m^3 in control mix (CM) to 238.63 kg/m^3 in FB60 mix to maintain the workability and the mechanical behavior of the concrete with fine aggregate replacements was comparable to that of conventional concrete except for FB60 mix. The compressive strength was observed to be in the range of 29–32 MPa, splitting tensile strength in the range of 1.8–2.46 MPa, and flexural strength in the range of 3.95–4.10 MPa on the replacement of fine aggregates from 10% to 50% at the interval of 10%. Furthermore, it was observed that the greatest increase in compressive, splitting tensile strength, and flexural strength compared to that of the conventional concrete was achieved by substituting 30% of the natural fine aggregates with industrial by-product aggregates. The inclusion of waste foundry sand and bottom ash as fine aggregate does not affect the strength properties negatively as the strength remains within limits except for 60% replacement. The morphology of the formations arising as a result of the hydration process was not observed to change in the concrete with varying percentages of waste foundry sand and bottom ash.

1. Introduction

High consumption of natural sources, high amount production of industrial wastes and environmental pollution are some of the factors which are responsible for obtaining new solutions for a sustainable development. A sustainable development can be achieved only if the resource efficiency increases. The resource efficiency increment is possible by the reduction in use of energy and materials. Thus, solution is utilization of industrial by-products or solid wastes such as fly ash (FA), bottom ash (BA), waste foundry sand (FS), slag, silica fume, and waste glass in producing concrete. These concrete technologies reduce the negative effects on economical and environmental problems of concrete industry by having low costs, high durability properties and environmental friendliness.

When coal is burned in a coal fired boiler, it leaves behind ash, some of which is removed from the bottom of the furnace known as bottom ash, and some of which is carried upward by the hot combustion gases of the furnace, and removed by collection devices (fly ash). Worldwide, coal-fired power generation presently accounts for roughly 38% of total electricity production. Coal use

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in some of the more developed countries is static or is in decline. Significant increases in coal-fired generation capacity are taking place in many of the developing nations and large capacity increases are planned. During coal-fired electric power generation three types of coal combustion products (CCPs) are obtained. These by-products; fly ash, bottom ash and boiler slag are the largest sources of industrial waste. Utilization of CCPs in construction industry is an important issue involving reduction in technical and economical problems of plants, besides reducing the amount of solid wastes, greenhouse gas emissions and conserving existing natural resources. Some authors have reported the use of bottom ash in concrete as partial replacement of portland cement [1–3] or as a partial replacement of fine aggregates [4–9].

A foundry produces metal castings by pouring molten metal into a preformed mold to yield the resulting hardened cast. The metal casts include iron and steel from the ferrous family and aluminum, copper, brass and bronze from non-ferrous family. Waste foundry sand is high quality silica sand with uniform physical characteristics. It is a by-product of ferrous and non-ferrous metal casting industries, where sand has been used for centuries as a molding material because of its thermal conductivity. Foundries successfully recycle and reuse the sand many times. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed as waste foundry sand. Several authors have reported the use of used-waste foundry sand in various civil engineering applications such as highway applications [10–17], leaching aspect of usage of foundry sand [18–21], controlled low strength materials [22–24], concrete and concrete related products like bricks, blocks and paving stones [25–29], asphalt concrete [30].

Coal-combustion bottom ash and used foundry sand are abundant by-products which appear to possess the potential, to partially replace regular sand as a fine aggregate in concrete mixtures, providing a recycling opportunity for them. If these recycled materials can be substituted for part of the cementitious and virgin aggregate materials in concrete mixtures without sacrificing, or even improving strength and durability, there are clear economic and environmental gains. One of the primary impediments to beneficial reuse of industrial by-products such as waste foundry sands and bottom ash is a lack of engineering data that designers can use to evaluate the efficacy and economy of using the by-product in place of the natural sand. The engineering properties and behavior of sands can be readily estimated from the literature for use in preliminary design. In contrast, there is a dearth of similar information for industrial by-products and there are insufficient data to confirm that industrial by-products, which appear similar to sands, also have comparable engineering properties. With emphasis now being placed on engineering for sustainable development, there is a pressing need to provide this practical information to designers. Fulfilling this need is the primary purpose of this study. The objective is to provide practical information, regarding the strength, durability and micro-structural properties of bottom ash and waste foundry sand as replacement of fine aggregates in concrete. Both waste foundry sand and bottom ash have been studied as aggregate replacement, separately. The value of the current research is the use of both together. The present experimental study was conceived following the general purpose of testing new sustainable building processes and modern production systems, aimed not only at saving natural raw materials and reducing energy consumption, but also to recycle industrial by-products. The objectives of this study are to investigate the effect of use of bottom ash and waste foundry sand in equal quantities as partial replacement of fine aggregates in various percentages (0–60%), on concrete properties such as mechanical and durability characteristics of the concrete along with micro-structural analysis with XRD and SEM.

2. Experimental program

The effect of using various percentages of bottom ash and waste foundry sand as partial replacement of the fine aggregate in concrete was investigated. Also, the effect of incorporating waste foundry sand and bottom ash, in concrete on the mechanical, durability properties and microstructure were evaluated.

2.1. Materials and mix proportions

Portland Pozzolana Cement (53 MPa) conforming to Indian standard specifications IS:1489-1991 [31] with consistency as 27%, specific gravity as 3.56 and fineness as 5%, was used. Locally available natural sand with 4.75 mm maximum size was used as fine aggregate, fulfilling the requirements of ASTM C 33-02a [32] and IS:383-1970 [33] along with crushed stone of 20 mm maximum size used as coarse aggregate. Locally available waste foundry sand was used as partial replacement of fine aggregates (regular sand). The waste foundry sand showed lower fineness modulus and bulk density than the regular sand. As per the particle size distribution of the waste foundry sand, the size corresponding to 50% of passing (d_{50}) was around 33 μm and average diameter of waste foundry sand particle was observed to be 28.8 μm. Coal bottom ash obtained from Panipat Thermal Power Station, Panipat, Haryana, was also used as partial replacement of fine aggregates. The properties of coal bottom ash conformed to IS:3812-2003. The particle size distribution of bottom ash was measured, which showed that, of the particles 100% were smaller than 56 μm and 38% were smaller than 31.3 μm with average diameter of the particle size distribution was 33.4 μm with standard mean deviation of 8.1 μm for bottom ash. Table 1 gives the chemical composition of waste foundry sand and bottom ash while Table 2 gives the physical properties of the aggregates used. A polycarboxylic ether based superplasticizer of CICO brand complying with ASTM C-494 type F [34], IS:9103-1999 [35] and IS:2645-2003 [36] was used.

Seven mix proportions were prepared. First was control mix (without bottom ash and waste foundry sand), and the other six mixes contained bottom ash and waste foundry sand in equal proportions. Fine aggregate (sand) was replaced with bottom ash and waste foundry sand by weight. The proportions of fine aggregate replaced ranged from 10% to 60% at the increment of 10%. Mix proportions are as given in Table 3. The control mix without waste foundry sand and bottom ash was proportioned as per Indian standard specifications IS:10262-1982 [37], to obtain a 28-day cube compressive strength of 36 MPa.

For these mix proportions, required quantities of materials were weighed. The mixing procedure adopted was as follows: First, the cement, waste foundry sand, and coal bottom ash were dry mixed till a uniform color was obtained without any clusters of cement, waste foundry sand and bottom ash particles. Weighed quantities of coarse aggregates and sand were then mixed in dry state, thoroughly until a homogeneous mix was obtained. Water was then added in three stages as 50% of total water to the dry mix of concrete in first stage; 40% of water and superplasticizer to the wet mix; Remaining 10% of water was sprinkled on the above mix and it was thoroughly mixed. All the moulds were properly oiled before casting the specimens. The casting immediately followed mixing, after carrying out the tests for fresh properties. The top surface of the specimens was scraped to remove excess material and achieve smooth finish. The specimens were removed from moulds after 24 h and cured in water till testing or as per requirement of the test.

2.2. Testing procedure

Fresh concrete properties such as slump flow, compaction factor, vee-bee consistometer were determined according to an Indian Standard specification IS:1199-1959 [38]. The results are presented in Table 3. The 150 mm concrete cubes were cast for compressive strength, cylinders of size 150 mm × 300 mm for splitting tensile strength and beams of size 100 × 100 × 500 mm for flexural strength. After required period of curing, the specimens were taken out of the curing tank and their surfaces were wiped off. The various tests performed were compressive strength test of cubes (150 mm side), splitting tensile strength of cylinders (150 mm × 300 mm), at 7, 28, 90, and 365 days and flexural strength of beams (100 × 100 × 500 mm) at 28, 90, and 365 days, as per IS:516-1959 [39].

The cylinders (100 mm × 200 mm) were cast for rapid chloride penetration resistance test and were sliced 51-mm (2-in.) thick of 102-mm (4-in.) nominal diameter. Rapid chloride penetration resistance test (according to ASTM C 1202-97 [40] covered the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. The test method consisted of monitoring the amount of electrical current passed through 51-mm (2-in.) thick slices of 102-mm (4-in.) nominal diameter cores or cylinders for a 6-h period. A potential difference of 60 V dc was maintained across the ends of the specimen, one of which was immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, was related to the resistance of the specimen to chloride ion penetration.

The test method (according to ASTM C 672 [41]) covers the determination of the resistance to scaling of a horizontal concrete surface exposed to freezing and