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Effects of foundry sand as a fine aggregate in concrete production

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HIGHLIGHTS

- Foundry sand (FS) reused as a substitute material for fine aggregate in concrete.
- The physical and chemical characterization of the FS was studied.
- FS substituted in five different substitution rates (10%, 20%, 30%, 40% and 50%).
- Destructive and non-destructive tests were performed on all concrete mixtures.
- 20% Substitution is established as an optimum proportion of FS in concrete making.

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ABSTRACT

This paper presents the results of experiments carried out to evaluate the utilization of foundry sand (FS) as a substitute material for fine aggregate in concrete production. The physical and chemical characteristics of the FS were also addressed. FS obtained from the aluminium casting industry was used as a substitute for fine aggregate in five different substitution rates (10%, 20%, 30%, 40% and 50%). Several tests, including density, slump cone, split tensile strength, flexural strength; ultrasonic pulse velocity (UPV) and compressive strength tests were performed to understand the effects of FS on the behavior of concrete. The grain size distribution analysis of FS revealed that 8% of FS were less than 75 μm, and the water absorption of FS was about 1.13%. The test results revealed that the strength properties of the concrete mixtures containing FS up to 20% was relatively close to the strength value of the CM, and the average decrease in strength was only 2.1%. The decrease in the strength is attributed to the fineness of the FS and the presence of dust, clay and wood flour in the FS. From the test results obtained it was concluded that a substitution rate of up to 20% can be effectively used in good concrete production without affecting the concrete standards, and a substitution rate beyond 20% is not beneficial.

1. Introduction

Concrete is the most widely used construction material in the construction industry, and offers a number of advantages, including good mechanical and durability properties, low cost, and high rigidity. Over the past several decades, the demand for concrete has been increasing rapidly due to growth in infrastructure development. River sand is one of the main ingredients in concrete production, and it is used as a fine aggregate. The heavy demand for concrete has resulted in the over-exploitation of river sand in the river bed, and this has led to a range of harmful consequences, including increased river bed depth, water table lowering and the intrusion of salinity into rivers. The restriction in the extraction of sand from the river increases the price of sand and has severely affected the stability of the construction industry [1]. As such, finding an alternative material to river sand has become imperative. Over the past several decades, an enormous amount of research [1–10] has been carried on the use of industrial waste as a substitute/replacement material for fine aggregate. The research findings revealed that the substitution of an alternative material in concrete could improve both the mechanical and durability properties, and the practice led to the sustainable concrete development.

Foundry sand (FS) is a by-product from the metal alloys casting industry with high silica content. Silica sand is bonded with clay or chemicals, and is used for the material casting process. Foundries recycle the sand many times, and when the sand is no longer recyclable, it is disposed of; this is called foundry sand [11]. About 15% of sand used by foundries is ultimately disposed of, amounting to millions of tons. In India, many foundries dump this waste in nearby vacant areas (Fig. 1), which creates an

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Fig. 1. Foundry industry dumping solid waste along Madurai to Coimbatore highway in Tamilnadu, India.

environmental problem. With increased restrictions on disposal in nearby areas, industries are constrained to find alternative ways to reuse waste. Past few decades, FS have been utilized in highway applications [11–13], but the amount of waste re-utilized in this way is still negligible. For this reason, there is a need to utilize FS in other ways become very imperative. Recently, research has been carried out on the utilization of FS in concrete and concrete related products. Siddique et al. [11] evaluated the mechanical properties of concrete containing FS. Fine aggregate was replaced by foundry sand in three different percentages (10%, 20%, and 30%). A marginal increase in the strength properties was observed with the substitution of FS and it was suggested that FS, can be effectively used in concrete making. The findings of Bakis et al. [14] showed that fine aggregate replaced with 10% of FS was suitable for asphalt concrete mixtures. Kraus et al. [15] conducted an investigation to evaluate the feasibility of the use of FS in self consolidating concrete (SCC). It was concluded that it is viable to produce economical SCC by using FS in addition, and further research is needed to determine the optimum FS proportion. Siddique et al. [16] made an attempt to study the mechanical, durability and micro-structural properties of concrete made with FS. The results showed that concrete mixtures with foundry sand showed good resistance to carbonation and rapid chloride penetration. The mechanical properties of the concrete improved with the substitution of FS, and it was recommended that FS be used in concrete production without affecting the mechanical and durability properties. In another study, Singh and Siddique [17] studied the abrasion resistance and strength properties of concrete containing waste foundry sand (WFS). The feasibility of the re-use of FS in ready-mixed concrete (RMC) production was examined by Basar and Nuran Deveci Aksoy [18]. The test results indicated that partial replacement of FS decreased the strength of the concrete and increased the water demand of the concrete mixture. While a great deal of research has been carried out on the re-use of FS in civil engineering applications, there has been limited research on the use of FS in concrete production, and more research is needed to determine the optimum replacement of FS in concrete production. In addition, environmental pollution created by dumping of FS, in the surrounding of Coimbatore, in Tamilnadu, India should be minimized. In order to resolve the both issues, experimental investigation was carried out on the re-utilization of FS obtained from an aluminium casting industry, Coimbatore, in Tamilnadu, India, as a replacement for fine aggregate in concrete production, at different substitution rates. Based on the test results obtained, the optimum proportion of FS in concrete production was established. Furthermore, the obtained test results were verified using the expressions recommended in design standards.

2. Experimental program

2.1. Materials

Ordinary/commercial Portland cement was used in this study as a binding material. The specific gravity of the cement was tested according to IS 2720(Part 3):1963 [19], and was found to be about 3.14. The natural river sand passing through 4.75 mm was used as fine aggregate. Locally available blue metal jelly having a size of 20 mm was used as coarse aggregate. Blue metal jelly is the blue-gray hard stone, bluish in color, which is widely used as a coarse aggregate in concrete production in South India. The specific gravity [20] of the sand and the coarse aggregate was about 2.48 and 2.67. Sieve analysis was carried out on both fine and coarse aggregate, according to IS 2386(1):1963 [21]. Foundry sand (FS) obtained from an aluminium casting industry, Coimbatore, in Tamilnadu, India was used in this study. The physical and chemical properties of the FS were tested according to Indian standards. The specific gravity and density [20] of the FS were about 2.24 and 1576 kg/m^3, respectively. The water absorption [22] of the FS was about 1.13%, which is higher than that of normal sand due to the presence of ashes and wood particles. Sieve analysis was carried out to understand the grain size distribution of the FS and it was observed that 8% of FS were less than 75 μm, which shows that the FS is fine material. The sieve analysis results of FS and river sand is presented in Table 1. The chemical properties of the FS were tested according to IS 4032:1985 [23], and the results showed that FS contains about 87.48% silica (SiO_2) and 4.93% alumina (Al_2O_3). The results of a chemical analysis indicated that the FS is a very suitable material for concrete production.

2.2. Concrete

According to IS 10262 [24], the concrete mix proportions were designed to achieve the strength of M25. The concrete mix proportion was 1:1.53:2.86. A constant water cement ratio (*W*/*C*) was followed for all mixtures and the value was about 0.44. Among the six mixtures, five mixtures were prepared by replacing 10%, 20%, 30%, 40% and 50% of natural sand with FS, and the one remaining mixture was a control mixture (CM) without FS. The detailed formulations of the proportions of six mixtures are given in Table 2.

2.3. Specimen preparation

The concrete mixtures were prepared with and without FS substitution. The FS substitution rate ranged between 10% and 50%, in increments of 10%. The FS used in this study was washed by fresh water more than four times to remove ash and clay particles. The FS was then dried in sunlight for two days and then used in concrete mixtures. For all mixtures, aggregates such as cement, natural sand, coarse aggregate and FS were weighed in a dry condition and were then mixed together in a laboratory batch mixer, in order to avoid aggregate and water loss. Fresh concrete properties such as workability of the concrete were measured using the slump cone test. In addition, the unit weight of the concrete was also examined. To determine the compressive strength and tensile strength of the concrete, cubes and cylinders having a size of 150 × 150 × 150 mm and 150 × 300 mm was prepared. Beams having a size of 100 × 100 × 500 mm were also prepared to evaluate the flexural strength of the concrete. All specimens such as cubes, cylinders and beams were filled with concrete in three layers, and each layer of the concrete was effectively compacted using a table vibrator. After casting of all specimens, the specimens were covered with a plastic sheet in order to avoid moisture loss. After that, specimens were kept at room temperature for 24 h, and thereafter were demoulded and transferred to the curing tank until their testing dates. After the required curing days, the cubes were tested in a compression testing machine (CTM) having a capacity of 2000 kN at the ages of 7, 28, 90 and 180 days. The cylinders and beams were tested in the CTM and flexural testing machine respectively at the age of 28, 90 and 180 days to evaluate the tensile and flexural strength of the concrete. All specimens were tested according to the Indian standards [25]. To simplify the discussion of the mixtures, names were given to the mixtures, such as CM, FS 10%, FS 20%, FS 30%, FS 40% and FS 50%. For example, the name FS 20% indicated that the concrete mixture contained 20% of foundry sand.

Table 1
Sieve analysis results of river sand and foundry sand aggregates.

Foundry sand (FS)		Natural sand	
Sieve size	% of Passing	Sieve size	% of Passing
4.75 mm	100	4.75 mm	100
2.36 mm	100	2.36 mm	91.42
1.18 mm	94.12	1.18 mm	52.64
600 μm	83.63	600 μm	24.18
300 μm	36.24	300 μm	9.84
150 μm	16.12	150 μm	6.18
75 μm	11.86	75 μm	3.24