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Strength, durability, and micro-structural properties of concrete made with used-foundry sand (UFS)

Rafat Siddique [a,*], Yogesh Aggarwal [b], Paratibha Aggarwal [b], El-Hadj Kadri [c], Rachid Bennacer [d]

[a] Civil Engineering Department, Thapar University, Patiala 147004, India
[b] Civil Engineering Department, National Institute of Technology, Kurukshetra, India
[c] Department of Civil Engineering, University of Cergy Pontoise, Neuville-sur-Oise, 95031 Cergy-Pontoise, France
[d] Civil Engineering, LMT-Ecole Normale Supérieure – Cachan, 61 av. du président Wilson, F-94235 Cachan Cedex, France

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ABSTRACT

This paper presents the design of concrete mixes made with used-foundry (UFS) sand as partial replacement of fine aggregates. Various mechanical properties are evaluated (compressive strength, and split-tensile strength). Durability of the concrete regarding resistance to chloride penetration, and carbonation is also evaluated. Test results indicate that industrial by-products can produce concrete with sufficient strength and durability to replace normal concrete. Compressive strength, and split-tensile strength, was determined at 28, 90 and 365 days along with carbonation and rapid chloride penetration resistance at 90 and 365 days. Comparative strength development of foundry sand mixes in relation to the control mix i.e. mix without foundry sand was observed. The maximum carbonation depth in natural environment, for mixes containing foundry sand never exceeded 2.5 mm at 90 days and 5 mm at 365 days. The RCPT values, as per ASTM C 1202-97, were less than 750 coulombs at 90 days and 500 coulombs at 365 days which comes under very low category. Thereby, indicating effective use of foundry sand as an alternate material, as partial replacement of fine aggregates in concrete. Micro-structural investigations of control mix and mixes with various percentages of foundry sand were also performed using XRD and SEM techniques. The micro-structural investigations shed some light on the nature of variation in strength at the different replacements of fine aggregates with foundry sand, in concrete.

1. Introduction

Concrete is the most widely used man-made product in the world, and is second only to water as the world's most utilized substance. Slightly more than a ton of concrete is produced each year for every human being on the planet, some six billion tons a year. Concrete is an affordable and reliable material that is applied throughout the infrastructure of a nation's construction, industrial, transportation, defense, utility, and residential sectors.

Fundamentally, concrete is economical, strong, and durable. Although concrete technology across the industry continues to rise to the demands of a changing marketplace, the industry recognizes that considerable improvements are essential in productivity, product performance, energy efficiency, and environmental performance. The industry will need to face and overcome a number of institutional, competitive, and technical challenges. One of the major challenges, with the environmental awareness and scarcity of space for landfilling, is the wastes/byproduct utilization as an alternative to disposal. Throughout the industrial sector, including the concrete industry, the cost of environmental compliance is high. Introduction of use of industrial by-products such as foundry sand, fly ash, bottom ash, and slag can result in significant improvements in overall industry energy efficiency and environmental performance.

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 in a foundry. When the sand can no longer be reused in the foundry, it is removed from the foundry and is termed as foundry sand. Used-foundry sand can be reused in various applications as an alternative to sending it to landfill, and reuse options are well established in England, Europe and North America. Reuse options include cement manufacture, asphalt, concrete, bricks and free-flow fill for certain construction applications. Some of these alternatives are starting to be adopted in India, but is still in early stage. Overseas examples show that it is not only better for the environment but is profitable for the foundry to use the sand alternatively. These foundries have significantly reduced the volume of waste sand

* Corresponding author. Tel.: +91 175 239 3207; fax: +91 175 236 4498.
E-mail address: siddique_66@yahoo.com (R. Siddique).

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going to landfill and actually offset the total cost of transporting the sand 'in' and 'out'.

The objectives of this study are to investigate the effect of use of foundry sand 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 microstructural analysis with XRD and SEM. Application of used-foundry sand in concrete will lead to diversion of large amounts of used-foundry sand from land filling to manufacturing of concrete.

3. Experimental methods

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

3.1. Materials and mix proportions

Portland Pozzolana Cement (53 MPa) conforming to Indian standard specifications IS: 1489-1991 was used. Consistency was 27%, specific gravity was 3.56 and fineness as per specific surface of cement was 354 m^2/kg. Locally available natural sand with 4.75 mm maximum size was used as fine aggregate. It fulfilled the requirements of ASTM C 33-02a and crushed stone with 20 mm maximum size was used as coarse aggregate. The properties of fine aggregates and coarse aggregates were found to conform to IS: 383-1970 with specific gravity of sand as 2.63 and coarse aggregate as 2.77. Unit weight of sand and coarse aggregate was 1890 and 1650 kg/m^3, respectively. Fineness modulus was observed to be 3.03 for sand and 6.74 for coarse aggregates. Locally available foundry sand was used as partial replacement of fine aggregates (regular sand). Foundry sand with specific gravity 2.61, unit weight 1638 kg/m^3 and fineness modulus 1.78 was used. The foundry sand showed lower fineness modulus and bulk density than the regular sand. As per the particle size distribution of the foundry sand, the size corresponding to 50% of passing (d_{50}) was around 33 μm and average diameter of foundry sand particle was observed to be 28.8 μm. Table 1 gives the chemical composition of foundry sand. A polycarboxylic ether based superplasticizer of CICO brand complying with ASTM C-494 type F, IS: 9103 – 1999 and IS: 2645-2003 was used.

Seven mix proportions were prepared. First was control mix (without foundry sand), and the other six mixes contained foundry sand. Fine aggregate (sand) was replaced with 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 2. The control mix without foundry sand was proportioned as per Indian standard specifications IS: 10262-1982, to obtain a 28-day cube compressive strength of 36 MPa. Hand mixing was done for the all the concrete mixes.

Table 1
Chemical properties of foundry sand.

Constituents	% by weight (used in present study)	Requirements as per American foundry men's society, 1991
Loss on ignition	2.15	5.15% (max)
Silica (SiO_2)	78.81	87.9%
Iron oxide (Fe_2O_3)	4.83	0.94%
Alumina (Al_2O_3)	6.32	4.70%
Calcium oxide (CaO)	1.88	0.14% (min)
Magnesium oxide (MgO)	1.95	0.3%
Sulphate	0.05	0.09%
Chloride	0.04	–

3.2. 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. The results are presented in Table 2. The 150 mm concrete cubes and 150 × 300 mm cylinders were cast for compressive strength, and 150 × 300 mm cylinders for split-tensile 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), cylinders (150 mm × 300 mm), and split-tensile strength of cylinders (150 mm × 300 mm) at 28, 90, and 365 days, as per IS: 516-1959.

The cylinders (100 mm × 200 mm) were cast for rapid chloride penetration resistance test and were sliced 2-in. (51-mm) thick of 4-in. (102-mm) nominal diameter. Rapid chloride penetration resistance test (according to ASTM C 1202-97) 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 2-in. (51-mm) thick slices of 4-in. (102-mm) 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 cylinders (150 mm × 300 mm) were cast for carbonation test. Carbonation test of depth of color less region using phenolphthalein indicator was determined using the cylinders (150 mm × 300 mm) as per RILEM CPC-18 [11]. After casting, test specimens were covered with plastic sheets and left in casting room for 24 h at room temperature and demolded and cured in water for 28 days. After that, specimens were air cured (open environment) for the required age say till 90-days or 365-days, and then were split. The freshly split surface was cleaned and sprayed with a phenolphthalein pH indicator. The indicator was a phenolphthalein 1% ethanol solution (1 g phenolphthalein and 90 ml ethanol (95.0 V/V%) diluted in water to 100 ml. The average depth 'Xp' of the colorless phenolphthalein region was measured from three points, perpendicular to the two edges of the split face, immediately after spraying the indicator.

X-ray diffraction analysis (XRD) was done on Philips PW 1140/09. Diffractometer operated at 35 kV, using Cu kα radiation and Ni filler. The samples for X-ray diffraction analysis were prepared in powdered form. The concrete sample was taken from the inner core of the matrix. X-ray diffraction is a non-destructive technique used to determine the elements present in any particular substance. X-ray diffraction is based on the fact that, in a mixture, the measured intensity of a diffraction peak is directly proportional to the content of the substance producing it (Soroka

Table 2
Mix proportions of concrete mixes containing UFS.

Mix no.	CM	F10	F20	F30	F40	F50	F60
Cement (kg/m^3)	350	350	350	350	350	350	350
Foundry sand (%)	0	10	20	30	40	50	60
Foundry sand (kg/m^3)	0	60.5	121.0	181.5	242.0	302.5	363.0
Water (kg/m^3)	175	175	175	175	179.24	185.6	196.2
W/C	0.5	0.5	0.5	0.5	0.512	0.53	0.56
Sand SSD (kg/m^3)	605	544.5	484.0	423.5	363.0	302.5	242.0
Coarse aggregate(kg/m^3)	1260	1260	1260	1260	1260	1260	1260
Superplasticizer(kg/m^3)	1.75	1.75	1.75	1.75	1.75	1.75	1.75
Slump (mm)	30	30	30	30	30	30	20
Compaction factor	0.83	0.88	0.84	0.85	0.81	0.81	0.78
Vee-bee consistometer (sec)	5.98	4.40	4.98	4.97	5.65	5.34	6.25
Air temperature (°C)	23	26	27	20	22	22	34
Concrete temperature (°C)	25	29	27	23	24	24	28
Fresh concrete density (kg/m^3)	2437.7	2414.0	2419.2	2426.8	2420.1	2416.1	2402.2
pH value							
90-days	11.70	11.73	11.75	11.75	11.72	11.72	11.90
365-days	11.80	11.75	11.91	11.57	11.60	11.40	11.42