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Engineering properties of concrete with partial utilization of used foundry sand

Thiruvenkitam Manoharan [a,*], Dhamothiran Laksmanan [b], Kaliyannan Mylsamy [c], Pandian Sivakumar [d], Anirbid Sircar [d]

[a] Department of Mechatronics, RVS Technical Campus, Coimbatore 641402, India
[b] Faculty of Engineering, Karpagam Academy of Higher Education, Coimbatore 641021, India
[c] Department of Mechanical Engineering, Dr. N.G.P. Institute of Technology, Coimbatore 641 048, India
[d] School of Petroleum Technology, Pandit Deendayal Petroleum University, Gandhinagar 382007, India

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ABSTRACT

Solid wastes generated from manufacturing industries are increasing at an alarming rate and it is consistently increasing. One such industrial solid waste is Used Foundry Sand (UFS). On the other hand, fine aggregates involved in the concrete are generally river sand, which is scarce, high cost and excavation of the river sand that promote environmental degradation. So, there is an urge to find some alternative solution to dispose UFS and to limit the use of river sand. In this research work, river sand was partially replaced by UFS. The percentage replacements were 0, 5, 10, 15, 20 and 25 wt% respectively. Experimental investigations were carried out to evaluate the mechanical, durability and microstructural properties of M20 concrete at the age of 7, 28 and 91 day. XRD (X-ray Diffraction), EDX (Energy Dispersive X-ray) and optical-microscopic imaging analysis were performed to identify the presence of various compounds and micro cracks in the concrete with UFS. Comparative studies on control mix against trial mix were carried out. It was found that compression strength, flexural strength and modulus of elasticity were approximately constant up to 20 wt% UFS and decreased with further addition. Whereas, split tensile strength was increased after 20 wt% addition but it affects the other properties of concrete. The durability test results showed that the resistance of concrete against abrasion and rapid chloride permeability of the concrete mixture containing UFS up to 20 wt% were almost similar to the values of control mix. The findings suggest that UFS can effectively replace river sand. However, it is recommended that the replacement should not exceed 20 wt%.

1. Introduction

The use of concrete in the development of architecture and constructions is an integral part of modern human civilization. The key constituents of modern concrete are cement, river sand and aggregate which play significant roles in mix design. Since the consumption of river sand is high in the rapid infrastructure growth, the demand for the same is also very high in developing countries. Replacing river sand, either partially or fully, is being investigated as an approach to tackle this problem. Replacement of this component is a key challenge to address the negative effect of this substitution, which is mainly related to strength development in concrete (Neramitkornburi et al., 2015). Waste materials like recycled demolition materials, slag, foamed recycled glass, calcium carbide residue, UFS, fly ash, etc. are already being used as supplementary cementitious materials and have been studied in recent decades (Arulrajah et al., 2015; Phetchuay et al., 2014; Rahman et al., 2015). Among these materials, the use of UFS has not been researched considerably and it still remains an unexplored area in terms of its use as a supplement for river sand (Arulrajah et al., 2017). Therefore, studies on the potential use of these replacements are ultimately important.

UFS from ferrous and non-ferrous metal casting industries are mostly discarded as land filling material or dumped in open baron lands (Saraswati et al., 2013; Md et al., 2013; Amritkar et al., 2015). In contrast several countries have facing the problem in the supply of river sand to meet the increasing construction requirements (Bahoria et al., 2013; Prabhu et al., 2015). UFS creates nuisance to the public by the means of air and water pollution. Because of increased urbanization, scarcity of lands for disposal, stringent government rules and regulations, awareness of the public,

* Corresponding author.
E-mail address: manoharanpark@gmail.com (T. Manoharan).

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increased transportation cost makes it very difficult for conventional disposal of foundry sand. It is an alarming issue for the sustainability of the metal casting industries and environment. So it is very crucial to find out the solution to utilize the used foundry sand and to reduce the sand extraction from the river bed. There are different types of binders were used in the foundry industry to bind the sand particles. The widely used binders were clay bonded sand and chemically bonded sand. In this research work, UFS in the form of chemically bonded sand (sodium silicate) was used for the experimental investigations.

A few researchers had investigated the fresh and hardened properties of concrete containing clay bonded UFS to know the possibility of replacement of river sand in concrete. They concluded that, it is possible to replace the fine aggregate but the amounts of replacements were varied (Singh and Siddique, 2012a, 2012b; Siddique et al., 2009). This is due to the type and amount of binder used in the molding sand which influences the physical properties to a great extent.

The potential applications of UFS can be subdivided into three main categories namely, recycling, geotechnical and soil-based applications. Among the above, geotechnical applications have the huge scope for utilizing enormous quantity of UFS coming out from the foundries. The benefit of replacing UFS in concrete helps to reduce environmental and economic impacts (Prabhu et al., 2015; Singh and Siddique, 2012a). This promotes the sustainability of the foundry industries.

This research paper discuss the experimental results conducted for the evaluation of fresh concrete properties, mechanical properties (compressive strength, splitting tensile strength, flexural strength and modulus of elasticity), durability properties (ultrasonic pulse velocity, rapid chloride permeability, water absorption and abrasion resistance) and micro-structural analysis, after partially replacing natural fine aggregate by UFS.

2. Materials and methods

2.1. Cement

Portland pozzolana cement 53 Grade of Ultratech brand single lot was used throughout the investigation. The cement used was fresh and without any lumps. The physical and chemical properties satisfy the requirements of IS: 8112-1989.

2.2. Aggregates

Natural river sand with 4.75 mm maximum size and machine crushed granite blue metal of 20 mm maximum size from the local crusher industry were used as fine and coarse aggregate respectively. Both aggregates were free from impurities such as dust, clay particles, organic matter etc, and tested as per IS: 383-1970. The physical properties of UFS, fine and coarse aggregates were given in Table 1.

Table 1
Physical properties of UFS, fine and coarse aggregates.

Parameters	UFS	Fine aggregate	Coarse aggregate
Moisture content (%)	0.60	0.33	0.55
Bulk density (kg m^{-3})	1811	1710	1640
Specific gravity	2.36	2.62	2.76
Fineness modulus	2.37	2.60	7.12
Water absorption (%)	0.90	1.13	0.70
Clay and friable particles (%)	1.4	–	–
Material finer than 150 μm (%)	1.1	3.9	Nil

2.3. Used foundry sand

Sample of the used chemically bonded foundry sand (sodium silicate) was collected in bags from local foundry located in Coimbatore, Tamilnadu. UFS was washed with fresh water for three times to remove the fines and clay particles. Then it was dried in sunlight for two days and used in concrete mixtures. The physical properties and particle size of the UFS used in this experimental work were given in Tables 1 and 2 respectively.

2.4. Water

Locally available potable water free from oils, acids, alkalis, salts and organic materials were used for mixing and curing.

2.5. Mix proportions

Concrete mixes were prepared in power driven roller mixer of capacity 0.76 cum, six different concrete mix proportions were made, in this first was the control mix and the other five mixes contained UFS. Fine aggregate was replaced with UFS by weight percentage. The fine aggregates replaced were 5, 10, 15, 20 and 25 wt%. The obtained mix-proportions were 1:1.53:3.13 with water cement ratio 0.5 as per the IS: 10262-1982 and were given in Table 3.

2.6. Sizes of the specimens used for evaluating the test results

All the specimens used in the experimental work were recommended by IS: 516-1959, cubical molds of size 150 × 150 mm were used for finding compressive strength and ultrasonic pulse velocity. Cylindrical moulds of 150 mm dia and 300 mm length, concrete specimens were prepared for the determinations of split tensile strength and modulus of elasticity. Beams having a size of 100 × 100 × 500 mm were prepared to evaluate the flexural strength of the concrete. The cylinders (100 mm diameter and 200 mm length) were cast for rapid chloride penetration resistance test.

The number of concrete samples tested for each test was three specimens from each batch-mix. However, the individual result variation of a set of specimen should not be more than 15% of the average. If more, the test result of the sample was not considered and the test was repeated. The mean value obtained from these specimens was used to evaluate mix design.

2.7. Microstructure analysis

The micro structural and chemical compositions of the samples were examined by using the JEOL JSM6360LV SEM and EDX instrument. XRD peak intensities were used to determine the chemical combination and phase present in the system. This was done by using SHIMADZU XRD-6000. Optical image data of the surface measures the absorption and scattering properties of the structure under investigation. High-definition digital camera was employed to capture the images of 1 μm resolution, which were instantly transferred to a computer for digital image processing.

3. Results and discussions

3.1. Fresh concrete properties

Fresh concrete properties such as slump, compaction factor, fresh concrete density, air content and temperature were determined according to the Indian Standard Specification IS: 1199-1959. The results were presented in Table 4.