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Effects of water cooled ferrochrome slag as fine aggregate on the properties of concrete

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HIGHLIGHTS

- WCFS can be used for partial replacement of fine aggregate in concrete.
- The grain size of the WCFS is similar to virgin sand.
- Natural sand can be replaced up to 30% by the WCFS.
- Use of WCFS in concrete is considered important from the point of waste utilization.

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ABSTRACT

The present study aims to represent the outcomes of investigation carried out to assess the use of water cooled ferrochrome slag (WCFS) as an alternative to natural sand in concrete making. Various destructive tests such as compressive strength, splitting tensile strength, flexural strength and modulus of elasticity were conducted on various concrete samples containing 0–50% of the WCFS on replacement of equal weight of natural sand. Non-destructive test like ultrasonic pulse velocity (UPV) test was conducted to compare the results of destructive tests. Rapid chloride permeability test (RCPT), acid resistance and sulphate resistance tests were addressed to access the durability of concrete containing the WCFS. Optical micro structural study was conducted to examine the microstructure of concrete with the WCFS. The WCFS is found similar to natural sand. The results indicated that there is a little decrease in strength properties of concrete due to inclusion of the WCFS but can be used up to 30% with minor scarification of strength. This little scarification may not be considered important when compared with the advantages on reuse of industrial waste and thus conservation of natural resources. Inclusion of the WCFS up to 30% has almost no negative impact on durability of concrete.

1. Introduction

Excessive generation of industrial waste materials is one of the major aspects of environmental pollution [1]. Nearly 1–1.2 kg of solid waste material is produced from ferrochromium industry on production of each kg of ferrochrome. These waste materials are mainly ferrochrome ash, air cooled ferrochrome slag and water cooled ferrochrome slag. These materials contain residual chromium for which disposal as land fill may pollute the ground water due to leaching of chromium. In recent, it has been reported [2,3] on use of ferrochrome ash as a supplementary cementitious material and improvement of concrete properties due to its inclusion. Similarly air cooled ferrochrome slag has gained popularity as a coarse aggregate in concrete [4,5,6]. But reuse of water cooled ferrochrome slag is lagging behind. A little is reported [6] till date on a few properties of concrete with the WCFS. Various authors have been reported positively on use of industrial solid waste materials [7] such as waste foundry sand [8–12], steel slag [13], blast furnace slag [1], copper slag [14], coal bottom ash [15], imperial smelting furnace slag [16,17], fly ash [18] and ferrochrome slag [6] as substitute material for partial replacement of natural sand. This study aims to investigate the behavior of concrete containing the WCFS as a partial replacement material of natural sand.

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2. Literature review

Improvement in performance is reported on concrete made with non-ground blast furnace slag replacing 20% of natural sand [1]. Inclusion of waste foundry sand up to 15% as replacement of natural fine aggregate enhanced the density and impermeability with reduced chloride ion infiltration [10]. Rapid chloride permeability of M-20 and M-30 grade concrete decreased on inclusion of waste foundry sand up to 20% as partial replacement of virgin sand [11]. On replacement of natural sand with waste foundry sand and bottom coal ash in equal quantities, there is increase in Coulomb value on a chloride penetration test. But replacement of these materials up to 60% offered low chloride penetration [12]. The chloride penetration decreases when natural sand is replaced partially with steel slag as fine aggregate in concrete [13]. Utilization of copper slag up to 40% as fine aggregate in concrete replacing equal mass of natural sand, offered high strength parameters [14]. Inclusion of bottom ash in concrete as partial replacement of natural sand offered better dimensional stability and low chloride infiltration in comparison to reference concrete [15]. The pull-off strength is reported similar or more than the reference when imperial smelting furnace slag is used as fine aggregate in concrete [16]. Imperial smelting furnace slag retards the setting of Portland cement [17].

2.1. Research significance

Sustainable green concrete made with various industrial waste materials has gained popularity from the economic and ecological point of view. Till date a little is reported on production of concrete with waste materials of ferrochromium industry. Very less reports are available and there is gap of knowledge on various properties of concrete using WCFS as a substitute material of fine aggregate in the concrete. The present work is an effort to bridge the knowledge gap.

3. Experimental program

3.1. Materials

Portland slag cement (PSC) conforming to Indian standard, IS 455:1989 [19] used in the study. The specific gravity of PSC determined in accordance to IS 2720 (Part III/Section 1):1980 [20] and was found 2.96. The sand passing through 4.75 mm was used as fine aggregate. The specific gravity, fineness modulus and water absorption of the sand was found as 2.62, 2.33 and 1.01% respectively. Black hard crusher broken natural granite stone was used as coarse aggregate with maximum size of 20 mm and conformed to Indian standard specifications IS: 383-1970 [21]. The specific gravity, fineness modulus and water absorption of coarse aggregate were found as 2.64, 7.19 and 0.43% respectively. The WCFS was collected from Indian Metals & Ferro Alloys Limited and was used for partial replacement of natural sand. The grain size distribution for river sand and WCFS carried out as per IS: 383-1970 [21] and the results are presented in Table 1. Both traditional sand and WCFS have almost similar gradations. The density, fineness modulus and specific gravity of the WCFS were found 1411.82 kg/m^3, 2.69 and 2.52 respectively. The water absorption of the WCFS when tested in accordance with IS 2386 (Part III):1963 [22] was found 10.89%, which is higher than natural sand. The chemical analysis of the WCFS was analyzed as per IS 4032:1985 [23] and reported in Table 2. Drinking water confirming to the IS 456:2000 [24] with pH value of 7.0 ± 1 was used for concrete making. Polycarboxylate based superplasticizer confirming the requirements of IS 9103:1999 [25] was used for workability.

The physical and chemical examination established that the WCFS is a radically suitable substitution substance of natural sand in concrete making. The SEM analysis of the WCFS was conducted at 500X magnification using Jeol make JSM-6510 model scanning electron microscope. The scanning electron microscopy SEM image shows (Fig. 1) that the WCFS has spherical and porous texture. XRD of the WCFS was also conducted using in a powder X-ray diffractometer (Panalytical X'PERT-PRO) using Cu kα radiation. X-ray diffraction (XRD) of the WCFS as presented in Fig. 2 shows that chromite, forsterite, olivine, calcite, maghemite and chromferide are the main phases present in WCFS.

3.2. Methods

The design mix of M-30 grade concrete and the workability test of fresh concrete after 15 min of mixing was conducted as per IS 10262:1999 [26] and IS 1199:1959 [27] respectively. The mixing of concrete was done as per ASTM C 192:1998 [28]. The compressive strength, flexural strength and modulus of elasticity (MOE), tests were conducted at 28, 91 and 180 days as per IS 516:1959 [29]. The splitting tensile strength and ultrasonic pulse velocity tests were carried out as per IS 5816:1999 [30] and IS 1311:1992

Table 1
Sieve analysis of natural sand and WCFS.

Sieve size (mm)	Passing (%)		
	Natural sand	WCFS	Requirements (Zone-II) (IS:383-1970)
10.00	100.00	100.00	100
4.75	99.20	99.50	90–100
2.36	97.80	96.40	75–100
1.18	88.10	61.30	55–90
0.60	66.80	42.80	35–59
0.30	14.20	21.30	8–30
0.15	0.90	9.90	0–10

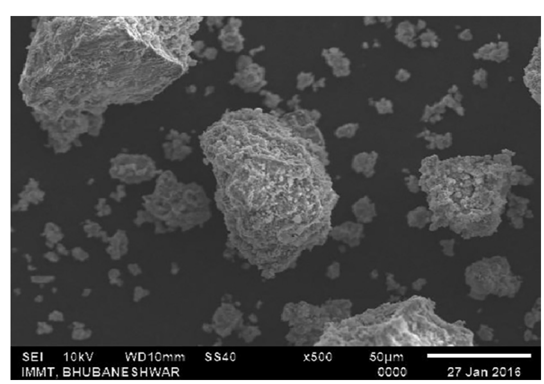

Fig. 1. SEM image of WCFS.

Table 2
Chemical composition of WCFS.

Constituent	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Cr	Cr (VI)	SO_3	Na_2O	K_2O	Mn_2O_3	TiO_2	SrO	LoI
Value (%)	26.98	23.69	5.63	4.75	24.06	9.358	0.003	0.68	0.103	0.47	0.812	0.66	0.012	1.79