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Properties of Industrial Slag as Fine Aggregate in Concrete

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Abstract

The main objective of this paper is to use the industrial waste such as bottom ash and Weld Slag (WS) as the partial replacement for fine aggregates in concrete. This paper presents the chemical analysis and strength properties of industrial solid waste such as bottom ash, weld slag 1 (WS 1) and weld slag 2 (WS 2). Their chemical compositions were identified by X-ray powder diffraction (XRD) analysis. The qualitative and quantitative elemental analysis of the bottom ash and weld slag was recognized by energy dispersive X-ray analysis and their morphology were studied by Scanning Electron Microscope (SEM). The compressive strength of concrete with 10% replacement of fine aggregate to the industrial waste shows higher strength than the normal concrete and hence this industrial waste can be used as fine aggregate in concrete.

Keywords: industrial waste, bottom ash, weld slag, XRD analysis, EDS analysis, compressive strength

1. Introduction

Rapid industrialization throws numerous amount of industrial solid waste. The disposal of this solid waste is a tedious process causing various threats to the environment. Moreover, these industrial waste are the main cause for the evaporation of CO_2 and other harmful gases which cause global warming and the destruction of the ozone layer which protects the planet earth from harmful cosmic rays. Researchers are more interested in using the industrial waste and by-products as substitute materials in concrete and construction, which in itself is a better alternative to dumping such waste as it will protect the environment [1]. Industrial wastes can be divided into two types: industrial by-products and recycled wastes. The first type includes coal ash, various slags from metal industries, industrial sludge, waste from industries like pulp and paper mills, mine tailings, food and agriculture, and leather. The second type includes different plastic and rubber wastes [2].

Bottom ash (BA) is a waste material from coal-fired thermal power plants. In India over 75% of the total installed power generation is coal based. High ash contents varying from 30% to 50% are generated during the power generation. More than 110 million tonnes of ash are generated every year. Presently, 65,000 acres of land are occupied by ash ponds. It has been observed that disposal of ash may lead to arsenic and lead pollution [3].

Submerged-arc welding is a well-established process capable of producing quality welds in a wide range of thicknesses in ferrous, stainless steels and even some non-ferrous metals. The process consists of an arc that is formed when an electric current passes continuously between a welding wire and the work piece. The arc, the tip of the welding wire, and the weld joint is fully

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covered by a layer of a powdered flux, which protects the welding operation from atmospheric contamination, prevents flash and glare, and makes it so that smoke and fumes are virtually non-existent. During the welding process, the flux is partially melted, resulting in a liquid protective slag layer that is solidified during the sequence, generating a waste material known as submerged-arc welding slag [4]. This slag is normally thrown away as a waste. This poses the problem of storage, disposal, and environmental pollution and needs landfill space apart from exhaustion of non-renewable resources. These slag can be reused in making the concrete. This paper highlights the use of industrial waste such as bottom ash and weld slag in concrete.

2. Literature Review

2.1. Bottom ash

In 2005, Y.Bai, Darcy and P.A.M.Basheer of UK, experimentally investigated the replacement of Furnace Bottom Ash (FBA) with fine aggregates. The experimental work was carried out in two series – Series A and Series B. For both series, the natural sand was replaced with the FBA sand at replacement level of 0%, 30%, 50%, 70% and 100% by mass, and the cement content was fixed at 382 kg/m^3. Series A was designed at fixed water–cement ratios (W/C) of 0.45 and 0.55 and Series B was designed at controlled slump in the slump range of 0–10 mm and 30–60 mm and concluded that 30% of the natural sand can be beneficially replaced with the FBA sand to produce concrete in the compressive strength range from 40 to 60 N/mm^2 without affecting both the permeation and drying shrinkage properties of the structural concrete [5].

Experimental investigations were carried out by replacing the sand with bottom ash by weight. The proportions of fine aggregate replaced ranged from 20% to 50%. The compressive strength, splitting tensile strength and flexural strength tests were performed at 7, 28, 56, 90 days. The mixture contains 30% and 40% bottom ash at 90 days, attains the compressive strength equivalent to 108% and 105% of the compressive strength of normal concrete at 28 days and attains the flexural strength in the range of 113-118% at 90 days of flexural strength of normal concrete at 28 days. Bottom ash concrete attains splitting tensile strength in the range of 121-126% at 90 days of splitting tensile strength of normal concrete at 28 days [6].

Experimental Investigation was done on the concrete mixes in which natural river sand was replaced by the Crushed Fine Stone (CFS), Furnace Bottom Ash (FBA) and Fine Recycled Aggregates (FRA) at replacement levels of 0%, 25%, 50%, 75% and 100% by mass and the cement content were fixed at 386 kg/m^2. In Series I, the concrete mixes were designed at fixed water–cement ratio of 0.53. In Series II, the concrete mixes were designed to have a near constant slump in the range of 60 to 80 mm. For the mixtures, prepared with the same slump range and with the use of a lower free W/C ratio, the FBA concrete had the highest compressive strength values. At a fixed slump value, the resistance to chloride-ion penetration of FBA concrete was higher than that of the control concrete [7].

The experimental study was conducted to evaluate the feasibility of utilizing bottom ash as fine and coarse aggregates in high-strength concrete with compressive strength in a range of 60–80 MPa. Dosages of water, silica fume, and superplastisizer were fixed as 187 kg/m^3, 143 kg/m^3 and 14 kg/m^3 for all specimens, respectively, constituting weight proportions of 30.8%, 20%, and 2.5% of cement in the control specimen. Fine and coarse bottom ash replaced with normal sand and gravel varying in percentages (25%, 50%, 75%, and 100%). The effect of fine and coarse bottom ash on the flow characteristics and density of concrete mixture was investigated and also mechanical properties, such as compressive strengths and modulus of elasticity and flexural strength of high-strength, lightweight concrete with bottom ash being evaluated [8].

Research was done on replacing cement with Bottom Ash (BA). Binder/sand/calcium hydroxide ratio of 55:40:5% by weight were used in this design. The water to solid ratio was used at 0.29. BA was used to replace part of Portland cement at

10%, 20% and 30% by weight and aluminium powder was added at 0.2% by weight of solid. The results of this study show that BA can be effectively used as a cement replacement to produce autoclaved aerated concrete up to 30% BA. The compressive strength and flexural strength can be increased up to 22–23%. [9]

Experimental research was carried out on replacing cement with Coal Combustion Bottom Ash (CCBA). Four different mixtures with CCBA were prepared, two of them with CCBA ground for 4 minutes and another two with CCBA ground for 15 minutes, replacing with 20 and 40% of the cement mass. The ground CCBA can effectively replace cement up to 20% of its total amount without reducing the compressive strength of concrete and its strength class. By replacing 20% of cement with CCBA, compressive strength of concrete is equivalent to the reference mix of concrete. Replacing 40% of cement with CCBA the compressive strength of concrete reduces significantly [10].

2.2. Weld slag

In 2009, Viana, C. E., Dias, D. P., Holanda, J. N. F., Paranhos, R. P. R. investigated that Slag of Welding Flux (SWF) waste has originated in the Submerged Arc Welding (SAW) that can be used as an alternative raw material for manufacturing of clay bricks. Four mortar samples were formulated: 1) reference mortar made with conventional fine aggregate 2) acid SWF mortar 3) neutral SWF mortar and 4) basic SWF mortar. In these three cases, natural sand was totally replaced by the corresponding SWF waste. It was demonstrated that the technological properties of the bricks incorporated with up to 10 weight. % of SWF waste replacing clay are compatible with those specified for ceramic bricks [11].

In 2013, Ramesh et al., investigated the compressive strength of furnace and weld slag as a replacement of fine aggregates in concrete. The compressive strength on the seventh day of concrete cubes increases from 10% to 15% replacement of sand by WS and the compressive strength on the 28th day of concrete cubes increases from 5% to 15% of replacement of sand by WS than the reference material and concluded that 5% of WS and 10% FS replacement with fine aggregates is very effective for practical purpose [12].

3. Materials

The following materials are used in the experiment:

(1) Cement: The cement used was an Ordinary Portland Cement (OPC) of 53 grade conforming to IS 12269-1987 specifications.

(2) Coarse aggregate: Coarse aggregate was used with 12mm nominal size conforming to IS: 383-1970 Specifications.

(3) Water: Potable water comprising to IS 456:2000 Specifications.

(4) Fine aggregate: River sand conforming to Zone II conforming to IS: 383-1970.

(5) Weld Slag (WS): The Weld slag was obtained from the local industries and ground to the required fineness in P&P Metalloys Pvt Ltd, Perumbalur district, Tamilnadu to meet the IS: 383-1970 Specifications.

(6) Bottom ash: Bottom ash was obtained from the Neyveli Lignite Power Plant, Tamilnadu.

3.1 Mix Proportion and Preparation of specimen

Three mixes were prepared using bottom ash and weld slag with 10% replacement of fine aggregates. Required quantities of cement, fine aggregate and coarse aggregate were first mixed thoroughly in 40 litre concrete Pan Mixer for a period of 2 minutes, and then water was added along with industrial slag. Control mix was prepared as per Indian standard specifications IS:

10262-2009 for 7 and 28 days. M35 grade concrete was adopted and the mixtures were cast in cube moulds of size 100mm×100mm×100mm. Afterwards the specimens were demoulded and kept in the room temperature for 7days and 28 days and tested under compression. The compressive strength test was carried out as per the IS516:1959 Specifications.

Table 1 Material properties for concrete mix

Properties	Coarse aggregates	Fine aggregates	Bottom ash	Weld slag 1	Weld slag 2
Specific gravity	2.64	2.65	2.66	2.9	2.7
Fineness Modulus	6.88	2.71	2.00	2.54	2.54

4. Results and Discussion

4.1 Material Properties

The physical nature of the bottom ash, weld slag 1 and weld slag 2 are shown in Fig 1a, Fig 1b and Fig 1c.

(a) Bottom ash

(b) Weld slag 1

(c) Weld slag 2

Fig. 1 Industrial waste

4.2 Gradation curve of fine aggregate, bottom ash and weld slag

Fine aggregate, bottom ash and weld slag were graded in the sieves 10mm, 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm and 0.15mm, cumulative passing in each sieve was noted and then the fineness modulus was calculated. Gradation curve was obtained with the sieve size in X-axis and cumulative passing in Y-axis shown in Fig. 2. Bottom ash has a particle size between 0.3 to 0.6mm at about 93.12%, weld slag has particles of about 70 to 75% in size 0.3 to 0.6mm and fine aggregate with size 0.3 to 0.6mm at about 65 to 70%.

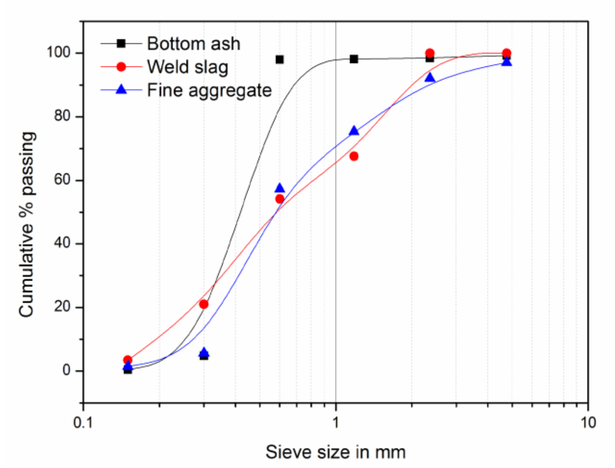


Fig. 2 Gradation curve of fine aggregate, bottom ash and weld slag

4.3 XRD Analysis

The material properties for concrete mix are listed in the Table 1. The chemical composition of the industrial slag was identified by X-Ray diffraction. The prepared samples were exposed to X-ray with the 2θ angle varying between 10° and 80° with Cu radiation. The applied voltage and current were 40 kV and 30 mA, respectively. The chemical composition of the bottom ash, weld slag 1 and weld slag 2 are listed in Table 2, Table 3 and Table 4. The XRD curve is listed in Fig. 3, Fig. 4 and Fig. 5. The XRD curves show that calcium and silica are predominant in bottom ash whereas Calcium, Magnesium and Chromium Silicide are predominant in WS.

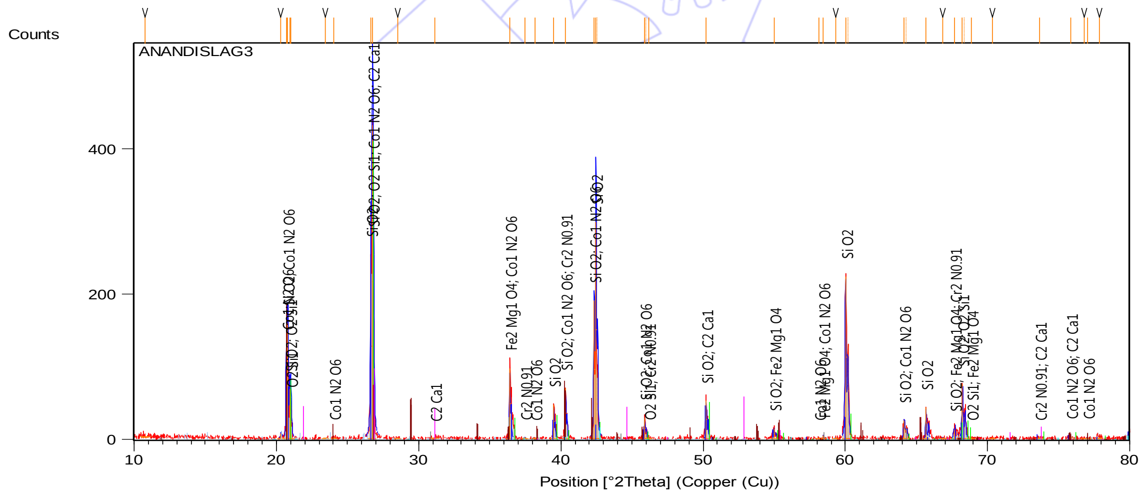


Fig. 3 XRD of Bottom ash

Table 2 Chemical composition of Bottom ash

S. No	Compound Name	Chemical Formula
1	Silicon Oxide	$Si\ O_2$
2	Quartz low	$O_2\ Si$
3	Magnesioferrite	$Fe_2\ Mg\ O_4$
4	Cobalt Dinitrate	$Co\ N_2\ O_6$
5	Chromium Nitride	Cr_2
6	Calcium Duo-dicarbide	$C_2\ Ca$

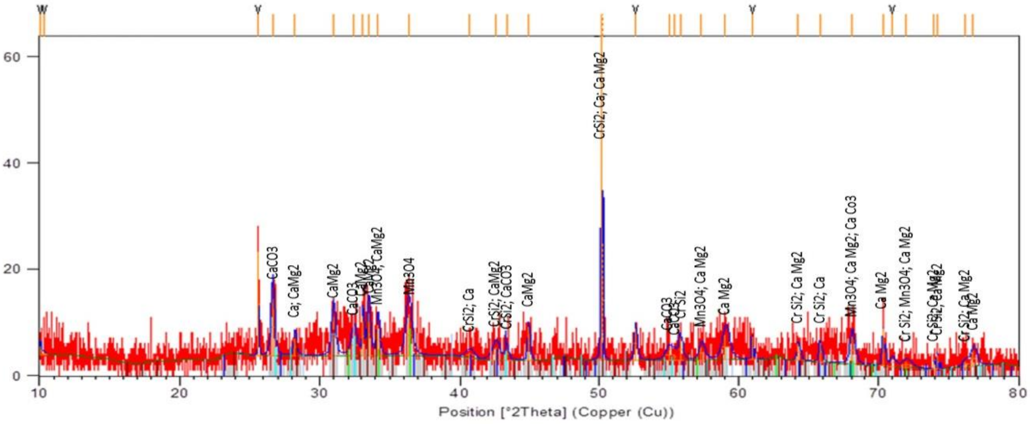


Fig. 4 XRD of Weld Slag 1

Table 3 Chemical composition of weld slag 1

S. No	Compound Name	Chemical Formula
1	Calcium Carbonate	$CaCO_3$
2	Manganese oxide	Mn_3O_4
3	Calcium	Ca
4	Calcium Magnesium	Ca Mg_2
5	Chromium Silicide	$CrSi_2$

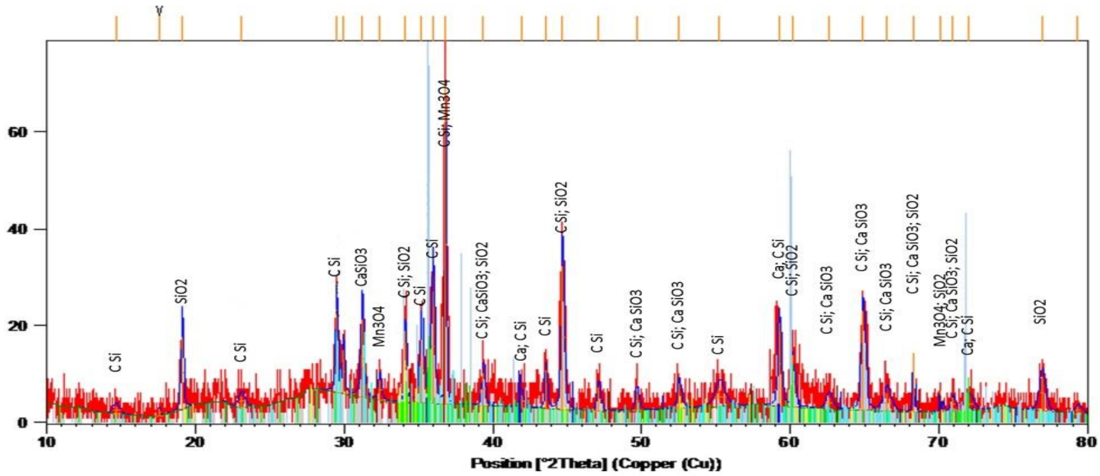


Fig. 5 XRD of Weld Slag 2

Table 4 Chemical composition of weld slag 2

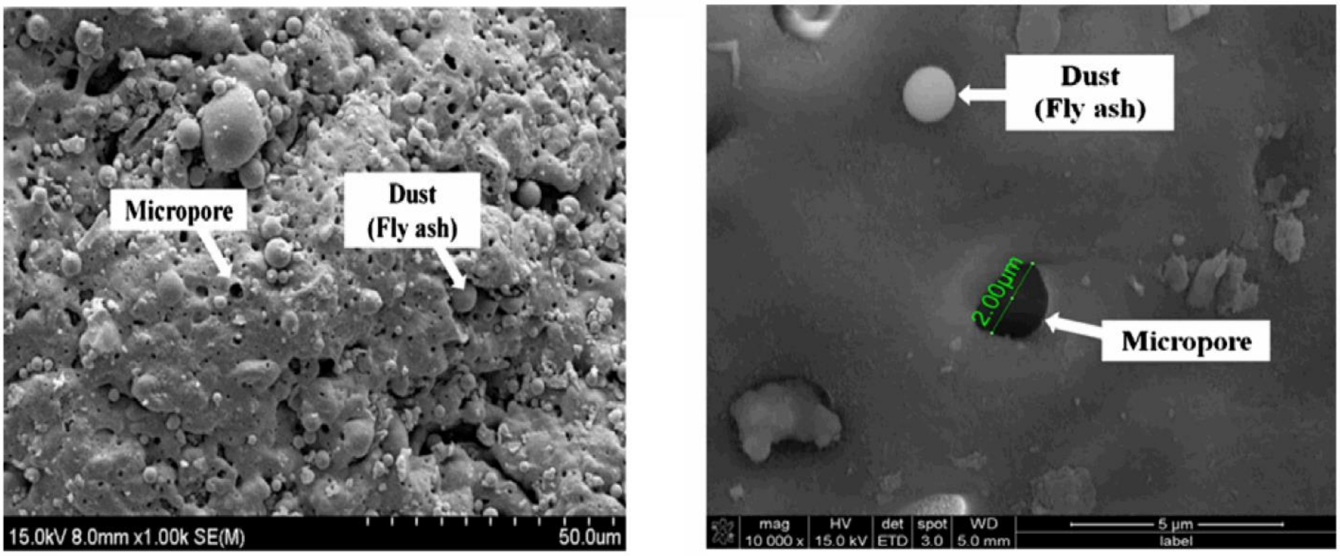
S. No	Compound Name	Chemical Formula
1	Calcium	Ca
2	Moissanite	C Si
3	Wollastonite	$CaSiO_3$
4	Manganese oxide	Mn_3O_4
5	Silica	SiO_2

4.4 EDS Analysis

According to the results of EDS analysis of WS 2 and bottom ash, comparatively large particles could be particles of Silica and Manganese oxide. The atomic weight of silica is 41.92% and manganese is 40.9%. The calcium content constitutes about 17.18%. The EDS analysis for WS 1 consists mostly of $CaCO_3$ particles in larger amount.

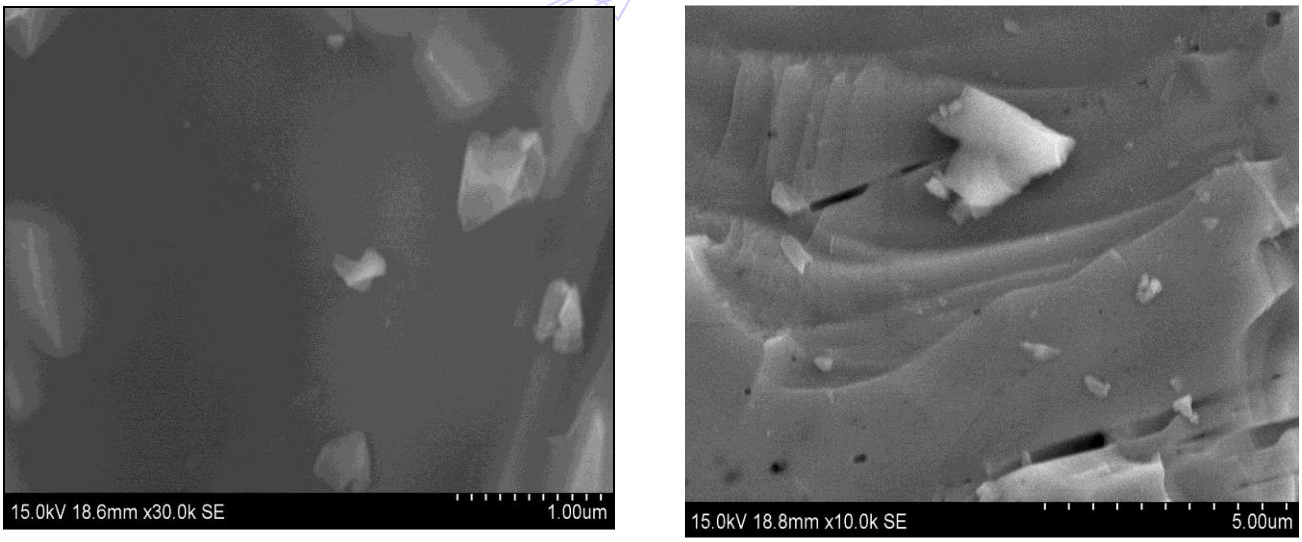
4.5 SEM Analysis

Water in cement paste can be absorbed into pores on the surface of bottom ash because there is some amount of nano size pores smaller than cement, as presented in Fig. 6(a) and 6(b) [8]. Fig. 7(a) and 7(b) indicate WS 1 have sharp edge shaped grains and consists of small micro pores. A closer examination of the WS 2 particle morphology shown in Fig. 8(a) and Fig. 8(b) reveals that the particles have irregularly shaped grains and are closely packed.



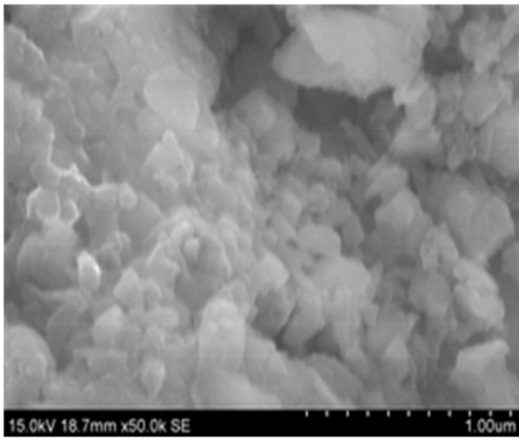
(a) 50 μm level (b) 5 μm level [8]

Fig. 6 SEM images of bottom ash

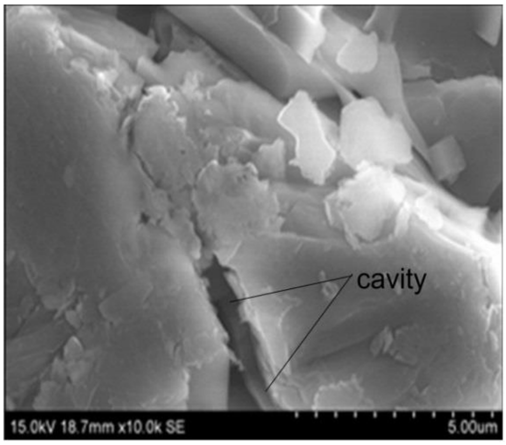


(a) 1μm (b) 5μm

Fig. 7 SEM images of weld slag 1



(a) 1μm



(b) 5μm

Fig. 8 SEM images of weld slag 2

4.5 Compressive strength

Compressive strength for 10% replacement of fine aggregates with bottom ash and welding slag were tested on a compressive testing machine with 3000KN capacity under a constant loading rate of 140 kg/cm^2/min for 7 days and 28 days and shown in Fig. 9. The strength was then compared with the reference mix of 7 days and 28 days. The compressive strength increases with the addition of bottom ash and WS 2, whereas WS 1 addition reduces the 28th day strength.

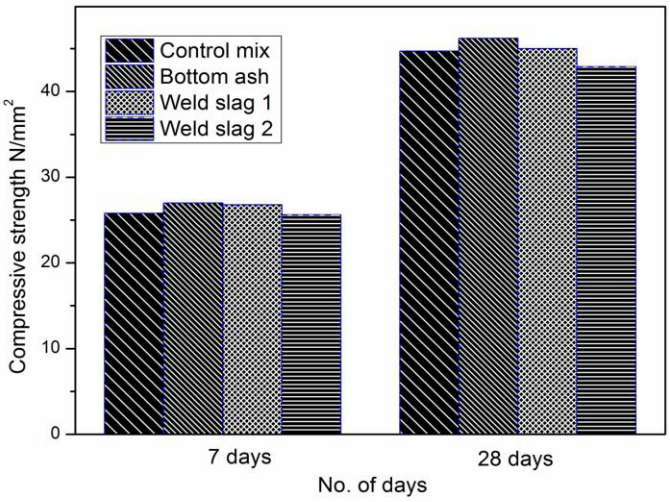


Fig. 9 Compressive strength of bottom ash and weld slag

5. Conclusions

In this work, the properties of indurstial wastes as aggregats in concrete have been studied. The following points can be summarized:

(1) The compressive strength of concrete by replacing 10% bottom ash at 7 days increases about 1.2N/mm^2 and at 28 days increases about 1.5N/mm^2.

(2) The compressive strength of concrete by replacing 10% WS 1 at 7 days is same as the control mixture, but at 28 days compressive strength decreases about 1.8 N/mm^2.

(3) The compressive strength of concrete by replacing 10% WS 2 at 7 days increases about 1N/mm^2 and at 28 days increases to about 0.3N/mm^2.

(4) The enhancement of strength in bottom ash and WS 2 is due to the presence of calcium and silica.

(5) The WS 1 achieves early compressive strength later the strength is decreased due to the presence of chromium.

(6) The weld slag and bottom ash are rich in oxygen and hence they can be used in concrete as a binder or fine aggregates which makes the concrete as more economical.

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