A review on the effect of industrial waste in concrete

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This review study enlightens the effect of industrial waste such as bottom ash, copper slag, ferro chromium slag, GGBFS, steel slag, stainless steel slag as a substitute in concrete. The detailed study on its chemical composition and also the advantages and disadvantages of using the slag are discussed. The experimental work carried out with mix proportion, w/c ratio of these industrial wastes in concrete is elaborately tabulated.

INTRODUCTION

Industrial revolution brought many changes in human lifestyle with various industries giving employment to people. On the other hand, numerous amount of industrial solid waste is generated from the industrial sectors. The disposal of this solid waste is a tedious process causing various threats to the environment. Moreover, these by-products are the main cause for the increase in 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, as it will protect the environment, instead of dumping such wastes [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].

Concrete is the choice of material in construction industry due to its inherent properties of versatility, economy, durability and ease of construction [3]. Hence the use of industrial waste in concrete has become popular in the recent years.

INDUSTRIAL WASTE

Slag is produced in a very large amount in pyro metallurgical processes, and are huge sources of waste if not properly recycled and utilised. With rapid growth of industrialisation, the available land for land-filling of large quantity of metallurgical slags is reducing all over the world and correspondingly, the disposal cost becomes increasingly higher. The global warming effect and natural resource saving are the general environmental topics nowadays. In addition, the land filled with the waste materials has become a significant source of pollution of air, water and soil, and further adversely affects the human health, and the growth of plant and vegetation etc. From the viewpoint of preservation and protection of the global environment, slag recycling has attracted the attention of many scientists in recent years [4]. This paper highlights the use of industrial waste in concrete. The industrial waste such as bottom ash, copper slag, ferrochrome slag, GGBFS, steel slag, stainless steel slag are reviewed.

BOTTOM ASH

Furnace 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 tonne of ash is 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 [5]. BA has no pozzolanic property which makes it unsuitable to be used as a cement replacement material in concrete. However, BA was ground by ball mill for 6 hours to achieve optimum pozzolanic reaction of BA for cement replacement.

The chemical component in bottom ash are SiO_2, Al_2O_3, CaO, Fe_2O_3, MgO, Na_2O, K_2O, P_2O_5, TiO_2, MnO_2 & SO_3. The combination of SiO_2, $Al_2O_3$and Fe_2O_3 in BA is higher than Portland cement with CaO content more than 10%. The compressive strength, bulk density, flexural strength and thermal conductivity increased with increased BA content as replacement part of Portland cement replacement [6-12]. Bottom ash particles absorbed a smaller amount of cement paste and water due to its lower porosity and water absorption. Furthermore, fine bottom ash absorbed only a very small amount of cement paste and water during mixing and hence the w/c ratio for BA is more than the normal concrete [8]. Table 1 reflects the experimental work done on replacing the bottom ash in concrete.

COPPER SLAG

Copper slag (CS) is widely used in the sand blasting industry and it has been used in abrasive blast treatment and in the manufacture of abrasive tools, abrasive materials, cutting tools, tiles, glass, and roofing granules (13). The chemical composition of copper slag are SiO_2, Fe_2O_3, Fe_3O_4, CaO, MgO, Al_2O_3, Na_2O, K_2O, CuO, ZnO. The amount of SiO_2 and Fe_2O_3 is higher than in the cement. SiO_2 is about 25-40% and Fe_2O_3 is about 50-60% range. The results of compressive, split tensile strength test have

Table 1. Experiments on replacement of bottom ash as a substitute in concrete

S. no.	Author, country & year	Ref. no.	Material replace	Mix proportion	Experiments carried out
1	Y. Bai, F. Darcy, P. A. M. Basheer. UK 2005	6	Fine aggregates	BA 0, 30, 50, 70, 100% w/c ratio 0.45 & 0.55 slump 0-10mm, 30-60mm	Compressive strength, Drying shrinkage (up to 30% best suited)
2	P. Aggarwal, Y. Aggarwal, S. M. Gupta. India 2007	7	Fine aggregates	BA-0, 20, 30, 40, 50%	Compressive strength, Splitting tensile
3	Kou shi Cong, Poon Chi Sun. China 2009	8	Fine aggregates	BA-0, 25, 50, 75, 100% i, fixed w/c ratio-0.53 ii, slump-60-80mm	Compressive strength, Drying shrinkage, Chloride ion penetration
4	H.K.Kim, H.K.Lee. Korea 2011	9	Fine &coarse aggregate	BA-25, 50, 75, 100% in fine & coarse aggregates	Flow characteristics, density of concrete, compressive strength, flexural strength
5	W.Wongkeo et al. Thailand 2012	10	Cement	BA-0, 10, 20, 30%. Aluminium powder - 0.2% to produce aerated concrete	TRG, XRD, Bulk density, compressive strength, flexural strength, thermal conductivity
6	H.K.Kim, J.H.Jeon, H.K.Lee. South Korea 2012	11	Fine aggregates (mortar)	W/B ratios-50, 38, 30, 24 & 20%	Flow characteristics, compressive strength, dynamic modulus of elasticity, water absorption characteristics
7	Diana Bajare et al. Latvia 2013	12	Cement	20 & 40 % BA i. grinded for 4 min ii. grinded for 15 min	Compressive strength, water penetration, absorbtion, CO_2 emission

indicated that the strength of concrete increases with respect to the percentage of slag added by weight of fine aggregate up to 40% of additions and 15% for cement.

It was observed that a decrease in the absorption rate by capillary suction, absorption and carbonation depth in the copper slag concrete tested improved its durability. Copper slag concrete exhibits good durability characteristics, it can be used as an alternate to fine aggregate and also be utilised in cement as a raw material for making blended cements [13-19]. Table 2 shows the experimental work done on replacing the copper slag in concrete.

FERROCHROME SLAG

Huge quantity of waste material is thrown off during the manufacture of ferrochrome. In India, there is a generation of 1–1.2 metric tonnes of solid waste slag for each metric tonnes of ferrochrome product [23]. Major chemical Constituents are Cr_2O_3, Al_2O_3, SiO_2, MgO, CaO and Fe_2O_3. Al_2O_3& SiO_2 is more than as present in the cement. Cr_2O_3 is about 10%. It contains about 6–12% deleterious substances like chromium as chromium oxide and has the potentiality of releasing hazardous chromium compounds to the environment restricting its use and disposal [20-22]. Chromium is one of the most common toxic heavy metal found in the environment. It is found

Table 2. Experiments on replacement of copper slag as a substitute in concrete

S. no.	Author , country & year	Ref. no.	Material replace	Mix proportion	Experiments carried out
1	K. S. Al. Jabri. Oman 2006	13	Cement	A, 5% replacement for cement, B, 13.5% CS & 1.5% cement by pass dust CBPD & 85% cement	Compressive, Tensile, flexural Strength, Modulus of elasticity, compare effect of CS & CBPD
2	W. A. Moura, J. P. Gonclaves, M. B. Leitelima. Brazil 2007	14	Cement	W/C ratio: 0.4, 0.5, 0.6 With 20% cement replacement	Compressive Strength, Splitting tensile, absorption rate by capillary action, carbonation
3	M. Khanzali, A. Behnood. Iran 2009	15	Coarse aggregates	W/C ratio : 0.40, 0.35, 0.30 Silica fume 0, 6, 10%	Compressive strength, splitting tensile, rebound hammer
4	Wei Wu, Wei de zhang, Guo wei ma. Australia 2009	16	Fine aggregates	Six mixture 0, 20, 40, 60, 80, 100% of replacement	Compressive, splitting tensile & flexural strength, dynamic compressive strength
5	Wei Wu, Wei de zhang, Guowei ma. Singapore, 2010	17	Fine aggregates	Six mixture 0, 20, 40, 60, 80, 100% of replacement	Microstructure, dynamic mechanic properties using split hopkinson pressure bar
6	K. S. Al. Jabri. Oman 2011	1	Fine aggregates	0, 20, 40, 50, 60, 80, 100% of replacement	Strength and durability
7	D. Brindha, S. Nagan. Tamilnadu 2010	18	Fine aggregates & cement	0-60% - fine aggregates 0-20% - cement	Accelerated corrosion test, RCPT, ultrasonic pulse velocity, compressive & split tensile, acid attack
8	M. Najimi, J. Sobhani, A. R. Pourkhorshidi. Iran 2011	19	Cement	0, 5, 10, 15% Copper slag	Compressive strength, microstructure analysis, 61 & 120 days in sulphate attack condition

that residual chromium in the ferrochrome slag mostly remains immobilised as Cr(III) in highly stable spinel phases like Chromite or Magnesiochromite / Magnesium Aluminium Chromite and thereby inhibiting chromium release from slag matrix under ambient environmental conditions. At the same time, the slag samples contain negligibly too small amount of leachable Cr (VI) concentration to cause any significant pollution problem [23].

Ferrochrome slag in concrete slightly increases unit weight and slump values of concrete. Ferrochromium slag concrete slightly increases the compressive strength. Splitting tensile strength increases by addition of ferrochromium. Influence of ferrochromium slag on elasticity modulus is insignificant. Wear resistance of concrete significantly increases with the increase in contents of ferrochromium. Freeze–thaw resistance is enhanced by Ferrochromium slag [20-22]. Table 3 reflects the experimental work done on replacing the ferrochrome slag in concrete.

GGBFS

Blast furnace slag (BFS) is a by-product of pig iron production, a stage process in the production of steel; approximately 300 kg of slag are generated per ton of pig iron [29]. The GGBFS is a mineral admixture obtained from the iron and steel industries. It is used as partial replacement for cement in concrete, which results in low cement consumption and subsequently benefits the environment. When GGBFS is used as cement replacement, one improvement is the compressive strength is due to the fineness of the GGBFS and to the chemical hydration. GGBFS, which is latently hydraulic, undergoes hydration reactions in the presence of water and calcium hydroxide, $Ca(OH)_2$. This secondary pozzolanic reaction yields a denser microstructure because the $Ca(OH)_2$ is consumed and CSH paste is formed [27]. The chemical constituent is similar to cement composition with higher amount of Fe_2O_3, Al_2O_3& SiO_2.CaO content is about 30-40% [24-31].

GGBFS improves the mechanical properties of concrete, reduces the heat of hydration and decreases the permeability of concrete and the alkali aggregate reactivity. Disadvantages of blast furnace slag cement are the slower rate of strength gain especially at lower temperatures, longer curing period and carbonation. It was observed that the concretes containing 50% and above-replacement levels of slag showed sharply reduced values of the charge, irrespective of curing condition and testing age [24-31]. Table 4 list the experimental work done on replacing the GGBFS in concrete.

Table 3. Experiments on replacement of ferrochrome slag as a substitute in concrete

S. no.	Author, country & year	Ref. no.	Material replace	Mix proportion	Experiments carried out
1	J. Zelic, Croatia. 2005	20	Coarse aggregates	W/c 0.64 Cement - 350 kg/m^3 5 concrete type with aggregate size	Physical & mechanical properties of concrete pavements
2	Mehmet Yilmaz, BahaVuralKok. Turkey 2009	21	Coarse aggregates	Binders 50/70, 160/220, 160/220 + 3% SBS Styrene butadiene styrene	Stability, Stiffness modulus, moisture susceptibility
3	O. Gencel. Turkey 2012	22	Coarse aggregates	Fly ash 10, 20, 30% weight Ferrochromium slag 25, 50, 75%	Compressive, Splitting tensile, Elastic modulus, abrasion resistance, freeze and thaw, porosity, water absorption
4	C. R. Panda et al. India 2013	23	Fine and coarse aggregates	Fine and Coarse aggregates 0, 20, 40, 60, 80, 100%	Compressive strength, leaching character

STEEL SLAG

Steel slag is a solid waste from steel production. It can be categorised as carbon steel slag and stainless steel slag according to the type of steel, and as pre-treatment slag, basic oxygen furnace slag (BOFS), electrical arc furnace slag (EAFS), ladle refining slag (LFS) and casting residue according to the steel making process [32]. The chemical composition of steel slag is similar to the cement properties such as Iron oxides, SiO_2, CaO, Al_2O_3, MgO, MnO, SO_3 with rich iron oxides content.

Compressive strength of concrete with steel slag exhibits lower early strength but higher late strength than the pure cement concrete under the condition of constant 28 days. Increasing the steel slag content tends to increase the permeability to chloride ion of the concrete. A large steel slag replacement tends to significantly weaken the carbonation resistance of the concrete. Steel slag has a negative effect on the strength and durability of concrete and this negative effect of steel slag can be overcome by lowering the W/B ratio [33-37]. Table 5 indicates the experimental work done on replacing the steel slag in concrete.

Table 4. Experiments on replacement of GGBFS as a substitute in concrete

S. no.	Author, country & year	Ref. no.	Material replace	Mix proportion	Experiments carried out
1	Kyong Yun Yeau, Eun Eyumkim. Korea 2004	24	Cement	0, 25, 40, 55% GGBFS I. Type I cement II. Type V cement	Compressive Strength, RCPT, Accelerated chloride ion diffusion, accelerate steel corrosion test, half-cell potential test
2	H.Y.Wang. Taiwan 2008	25	Cement	W/B : 0.23, 0.47, 0.71 GGBFS - 5, 10, 20, 80 & 100% With different changes	Weight loss due to heating, compressive strength, elastic modulus, absorption capacity
3	O.Cakir. F.Asoz. Turkey 2008	26	Cement	0, 30, 60% - GGBFS Mortars at i. 20° ii.40°at standard conditions & 100% humidity	Compressive & flexural strength, UPV, Capillarity coefficient, volumetric absorption
4	S. E.Chidiac, D. K. Panesar. Canada 2008	27	Cement	W/B - 0.31, 0.38 GGBFS - 0-60% Binder - 270, 450 kg/m3	Comp strength, UPV, density, Non evaporable water content, freeze and thaw, scaling resistance
5	Erhanguneyisi, Mehmet Gesoglu. 2008	28	Cement	i, Wet curing ii, air curing (at 20 °) GGBFS-50-80% W/C:0.4	Compressive, Splitting tensile, absorption, Chloride permeability, accelerated corrosion cell
6	J.I.Escalante Garcia et al. Mexico 2009	29	Cement	Binder-230, 280, 330 kg/m^3 BFS-0, 30, 50, 70% Slump - 20+2cm BFS activated with sodium silicate, Na_2o : 4, 6 & 8	Compressive strength, micro structure
7	Mehmet gesoglu, Erhanguneyisi, Haticeoznuroz. Turkey 2012	30	Light weight aggregates	Light weight aggregates - 52.5% Normal coarse aggregates - 47.5%	Compressive strength, water absorption of light weight aggregates
8	M.Shariq, Jagdish Prasad, Amjad Masoed. India 2013	31	Cement	M10, M20, M30 UPV-3, 7, 28, 56, 90, 150, 180 GGBFS-20, 40, 60	UPV & compressive strength relations, Dynamic modulus of elasticity

Table 5. Experiments on replacement of steel slag as a substitute in concrete

S. no.	Author, country & year	Ref. no.	Type of industrial waste	Material Replace	Mix proportion	Experiments carried out
1	J. M. Manso. Spain 2006	33	EAF slag	Fine & coarse aggregates	Six mixes : cement -370kg/m^3 W/B-<0.6 Slump-60-90mm No admixtures	Durability of concrete, accelerated aging test, alkali aggregates reaction, chemical reaction test, freeze and thaw, wetting & drying test
2	Xiaolu Guo, Huishengshi. China 2013	34	Steel slag powder & GGBFS	Cement	i. 0, 10, 20, 30, 40, 50% - cement & steel slag ii. steel slag & GGBFS-50, 25 & 25, 20 & 30, 15 & 35, 10 & 40, 50	Morphology & mineral composition, Compressive strength, Hydration
3	Q.Wang et al. China 2013	35	Steel slag	Cement	W/B - 0.50 & 0.35 Comp strength - 47 & 73 MPa 0, 15, 30, 45% steel slag	Compressive strength, Drying shrinkage, permeability to chloride ion, carbonation
4	Viana.C.E et al. Brasil 2009	36	Welding slag	Fine aggregates	i. fine aggregates ii. acid SWF waste iii. neutral SWF iv. basic SWF	Compressive, tensile strength, after firing to 950° c, linear shrinkage, water absorption, apparent density
5	Ramesh et al. India 2013	37	Welding slag & furnace slag	Fine aggregates	5, 10, 15% slag with different slump value	Compressive strength

STAINLESS STEEL SLAG

Stainless steel slag is the by-product of making stainless steel from scrap iron. Approximately one ton of stainless steel waste is generated when producing three tons of stainless steel [39]. Stainless steel slags include EAF (Electric Arc Furnace), AOD (Argon Oxygen Decarburization) and LM (Ladle Metallurgy) slags. The last two types of slags are generated during the basic refining process step in stainless steelmaking [38]. It has been reported that chromium is the most harmful element in stainless waste. The leaching results of stainless steel slag from Italy, China and Taiwan could be concluded that the amounts of almost all the heavy metals recovered by the leaching test were lower than the detection limits. Therefore, the pollution risks posed by the heavy metals in the stainless steel slag were very low. Moreover, in most areas, the stainless slag can be treated simply as common and not hazardous waste [40].

Table 6. Experiments on replacement of stainless steel slag as a substitute in concrete

S. no.	Author, country & year	Ref. no.	Type of industrial waste	Material replace	Mix proportion	Experiments carried out
1	L. Kriskova et al. Belgium 2012	38	Stainless steel slag (LM & AOD)	Cement	LM & AOD slag, W/C ratio- 0.5 for OPC, 0.75 for slag	Particle size distribution, X-ray diffraction, compressive strength, SEM analysis
2	Y.NSheen et al. Taiwan 2013	39	Stainless steel slag (SSOS & SSRS)	Cement	SSOS & SSRS-0, 10, 20, 30, 40, 50%	Microstructure analysis, compressive strength
3	Y.N.Sheen et al. Taiwan 2014	40	Stainless steel slag SSOS	Coarse & fine aggregates	SSOS-0, 25, 50, 75, 100%	Compressive strength, UPV, surface resistance,

The chemical composition of steel slag are SiO_2, CaO, Al_2O_3, Fe_2O_3, FeO, MgO, Cr_2O_3, MnO, TiO_2, SO_3, Na_2O, K_2O, CaO/SiO_2 with 40-50% of CaO [37-39]. The stainless steel slag, because of its microstructural morphology, chemical composition and CaO–Al_2O_3–SiO_2 three-phase diagram analysis is nearly similar to B.F. slag. Then the stainless steel has both the cementation and pozzolanic reaction characteristics like B.F. slag to be the binder of concrete. This study shows the optimal cement replacement ratio of stainless steel slag is 30%, and SSRS is better than SSOS with regards to the engineering properties when the fineness is 4400 cm2/g [39]. This study shows that the optimal aggregate replacement ratio for SSOS is 100%. Therefore, stainless steel oxidizing slag may qualify as an aggregate for green concrete materials. This practice will reduce stainless steel slag wastes, and will contribute to recycling and environmental protection [40]. Table 6 displays the experimental work done on replacing the Stainless slag in concrete.

RESEARCH NEEDS

Recent and current research states the following :

1. Further efforts are needed to understand the long-term properties of high-strength concrete containing copper slag aggregate.
2. Study on the durability properties of ferrochromium slag in concrete.
3. Research needs on the long term durability tests on the Steel slag (Welding slag).
4. Stainless steel slag is the new emerging industrial waste product and hence additional research is needed for the mechanical properties and also the durability properties concern to this slag.

SUMMARY AND CONCLUSIONS

When the industrial wastes are used in concrete for building construction, economically it is beneficial since the material cost is reduced. The industrial waste has lot of chemicals in it, which reacts with cement and other ingredients which reduce the life of the concrete. Hence, durability studies are very essential even if it shows better mechanical properties.

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