Review on the Performance of Fibre and Industrial Slag in Concrete

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Abstract

This review paper discusses about the different types of fibre used in concrete at different periods with the mix parameter details. This review enlightens the effect of industrial waste such as Bottom ash, Copper slag, Ferrochromium slag, Ground granulated blast furnace slag (GGBFS), Steel slag, Stainless steel slag as a substitute in concrete. The elaborate study on its chemical composition and also the merits and demerits 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. The detail study reveals that more research work is required for the long term durability studies on the Copper slag, Ferro chromium slag, Steel slag and Stainless steel slag.

Keywords: *Copper slag, fibre, bottom ash, ferrochrome slag, GGBFS, steel slag, stainless steel slag, concrete, review*

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INTRODUCTION

Concrete is a unique construction material due to its flexibility, durability and economy. American Concrete Institute (ACI) defines High Performance concrete (HPC) as "Concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing and curing practices". The important quality of High performance concrete is the effective removal of voids in the concrete matrix, which prevents deterioration of concrete. Super-plasticizer is added in HPC to obtain a satisfactory workability of fresh concrete and the addition of admixtures such as fly ash, silica fume, Ground granulated blast furnace slag (GGBFS) reduces the water content ultimately increasing the strength[1]. Hence, Mehta and Aitcin suggested the term High performance concrete (HPC) for concrete mixtures that possess the following three properties: high-workability, high-strength, and high durability.

The term 'fibre reinforced concrete' is defined by the ACI in their ACI 116R Cement and Concrete Terminology document as concrete containing dispersed randomly oriented fibres. Inherently, concrete is brittle under tensile loading; it can be recalled that the definition of brittleness includes inverse proportionality to elongation at break in tensile testing[2]. Fibre reinforced concrete (FRC) is concrete made primarily of hydraulic cements, aggregate and discrete reinforcing fibres. Different types of fibres like steel fibres, glass fibres, synthetic fibres and natural fibres like asbestos fibres and vegetable fibres (Sisal and Jute) are used as reinforcement in concrete[3].

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 wastes as it will protect the environment[4]. 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[5].

This paper is focused on review of recent experimental and theoretical studies in the addition of fibre in concrete and replacing of industrial waste as a substitute in concrete. A detailed analysis of concrete with various industrial wastes such as bottom ash, copper slag, ferrochrome slag, GGBFS, Steel slag and Stainless steel slag are also discussed.

HIGH PERFORMANCE FIBRE REINFORCED CONCRETE

High performance fibre reinforced concrete (HPFRC) became very popular construction material in the recent decades in structural engineering. The addition of fibres improves the mechanical properties such as tensile strength, flexural strength, fracture toughness, resistance to fatigue, impact, wear, thermal shock and shrinkage behaviour of concrete which attracts designers for its durability[6]. The brittleness of high performance concrete can be reduced and also the sufficient ductility of concrete is ensured by the addition of fibres in concrete. On the other hand, workability of the concrete is reduced by adding fibres.

Concrete fibre composites have been found more economical for use in Airport and Highway Pavements, Bridge Decks, Erosion resistance Structures, slope stabilization, Refractory Concrete, Earthquake Resistance Structures and Explosive Resistance Structures[7]. Due to the increased application of HPFRC, many experimental studies are conducted to investigate its properties and durability. Utilising the industrial waste as a substitute in HPFRC is also becoming popular in recent years. HPFRC have strong impact in terms of minimizing crack density, crack width and resistance towards fire. Compressive strength, flexural strength, split tensile strength, flexural toughness, bonding strength of HPFRC is higher than the normal concrete. Durability of Polypropylene fibres shows better results than the steel, carbon, coconut fibres[6, 8–25]. Experiments done in recent years are listed in Table 1.

Table 1: *Experiments on Addition of Fibre in Concrete.*

S. No	Author Country, year	Ref. No.	Type of Fibre and Industrial waste	Mix parameters	Experimental work	Remarks
1	C. S. Poon, Z. H. Shui, L. Lam China, 2004	8	Steel fibre (SF) Polypropylene fibre (PP), Metakaolin, Silica fume (SS).	Plain concrete. 10% Metakaolin replaced for cement. 20% silica fume, without Fibres, with 1% SF, 0.22 PP, 1% SF + 0.22 PP, 0.11 PP.	Compressive Strength, Elastic modulus, Energy absorption capacity, for heated and unheated concrete.	Steel fibres show better result than PP fibres.

2	M. N. Abou, Zeid E. M., Fahmy, M. T. Massoud Canada, 2002	9	PP fibres and Silica fume.	PP- 0, 0.5, 1, 1.5%, silica fume for cement- 0, 10,1 5% and W/C- 0.35, 0.40, 0.50	Compressive Strength, Modulus of rupture, cracking pattern.	PP fibres have strong impact in terms of minimizing crack density, crack width.
3	M. C. Nataraj, T. S. Nagaraj, S. B. BasavaRaj India, 2005	10	Steel fibres.	PP fibres- 0, 0.1, 0.3, 0.5% by volume, aspect ratio- 40, Compaction factor- 0.81, 0.85, 0.8 Slump- 25, 15, 10, 6 mm.	Impact test, UPV test.	The addition of steel fibres improves the impact resistance of concrete.
4	Harun Thayildizi Turkey, 2008	11	Carbon fibres (CF) and silica fume.	CF- 0, 0.5, 1, 2% Silica fume: 0, 10, Temp- 400, 600, 800°C Scoria-lightweight aggregates.	Experimental and statistical analysis of compressive and flexural strength.	Anova analysis is used. Optimum compressive strength: 20°C, 10% Silica fume, 0.5% CF. Flexural strength: 20°C, 10% Silica fume, 1% CF.
5	P. Ramadoss, K. Nagamani India, 2008	12	Crimped steel fibres.	SF- 0, 0.5, 1 and 1.5% Aspect ratio-80 W/C- 0.25, 0.40	Flexural strength, Split Tension Strength, durability test, water absorption.	Fibre shows better durability (i.e.,) HPFRC is very much less permeable concrete.
6	Harun Thayildizi Turkey, 2008	13	PP fibres and Silica fume.	Silica fume- 0, 10% for cement. PP- 0, 0.5, 1 and 2% Temp- 400, 600 and 800°C Scoria-lightweight aggregates.	Experimental and statistical analysis of compressive and flexural strength.	Anova analysis Optimum compressive strength is at 20°C 10% SS, 1% PP fibres Flexural strength 20°C, 10% SS, 0.5% PP fibres.
7	Vaishnavi G. Ghospade India, 2010	14	Glass fibres and Silica fume.	SF- 0, 10, 20, 30% for cement Glass fibres- 0, 0.5, 1, 2%	Compressive and flexural strength, Split Tension Strength.	Optimum dosage is 1% glass fibre and 10% silica fume increase.
8	M.N. Soutos, T.T. Le, A.P. Lampropolelos UK, 2012	15	Steel and Synthetic fibres.	Steel fibres - Hooked end of 60 mm, Wavy profile- 60 and 50 mm Flattened ends. Dosage- 30, 40 and 50 kg/m^3 Synthetic fibres- 4.6 and 5.3 Kg/m^3	Compressive and flexural strength, flexural toughness, load deflection relationship	Steel fibres compressive strength increase is 4 to 5 N/mm^2 PP fibres- 2 to 3 N/mm^2 Steel fibres- flexural strength increase 0.4 to 0.6 N/mm^2
9	P. Ramadoss India, 2012	16	Steel fibres and Silica fume.	Steel fibres 0, 0.5, 1, 1.5% SF- 5, 10, 15%	Compressive and flexural strength, Split Tension Strength.	Multi-variate linear regression model is used.

10	Mehmet Gesoglu *et al.* Turkey, 2012	17	Steel fibres and SF-Mineral admixtures.	W/C- 0.35 and 0.55 Hooked end steel. Fibre length/aspect ratio- 60/80 and 30/40. Artificial coarse light weight aggregates- 90% Fly ash + 10% cement.	Compressive, tensile and bonding strength.	Addition of fibres increases the bonding and tensile strength. GLM-Anova is used.
11	E. Gungisi *et al.* Turkey, 2012	18	Hooked end steel fibres.	Aspect ratio- 55, 65 and 80 Volume fraction- 0.35, 0.7, 1, 1.5% fibres.	Bond strength.	Addition of fibres increases the bonding strength.
12	S. P. Yap *et al.* Malaysia, 2013	19	PP and nylon fibres.	Three different fibres- 0.25, 0.50 and 0.75% - PP1, PP2 and N1.	Hardened Density, Compressive and flexural strength, Split Tension Strength, modulus of elasticity, UPV, Post failure compressive strength.	Multi filament PP fibres- flexural and splitting tensile strength increase to 86%.
13	Majid Ali *et al.* Turkey, 2013	20	Coconut fibres.	1, 2, 3 and 5 by mass of cement. Fibre length- 2.5, 5 and 7.5 cm.	Compressive strength, Split Tension Strength, modulus of rupture, UPV, Post failure compressive strength, Flexural toughness, dynamic modulus of elasticity.	5% coconut fibres, 5 cm length shows best results. Lower dynamic and static modulus of elasticity.
14	Ahmet Cavdar Turkey, 2013	21	Co-polymer polypropylene fibres (CPP), HPP, AR-Aramid.	0, 0.3, 0.6, 0.9 and 1.2% fibres by volume Temp- 21, 100, 450, 650 and 850°C.	Petrographic investigations, polymeric fibre content.	Flexural strength of concrete with fibres increases at high temp compared to concrete without fibres.
15	Danyinggao *et al.* China, 2013	22	Steel and PP fibres and GGFBS.	GGBFS- 30, 40 and 50 Steel fibres- 0, 0.5, 1, 1.5 and 2% PP- 0, 0.6, 0.9 and 1.2 kg/m^3 Strength grade- C40, C60 and C80.	Fire performance of PP fibre and steel fibre reinforced concrete.	The addition of steel fibre and PP fibre improve the splitting strength of the concrete after being exposed to high temperature.

16	Diato Niu *et al.* China, 2013	23	Steel fibres.	Plain concrete and 0.5, 1, 1.5, 2% fibres and 3.5 NaCl solution W/C- 0.45.	Compressive and flexural strength, Split Tension Strength, freezing and thawing, microcosmic test.	Steel fibre reduces the rate of crack propagation and retard the performance deterioration of the concrete.
17	Peng Zhang, Qing Fu li China, 2013	24	PP fibres.	X and Y shaped PP fibres 00.06, 0.08, 0.10, 0.12% fibres.	Water impermeability test, Dry shrinkage, Carbonation test, Freezing and thawing.	Decrease in length of permeability, drying shrinkage, carbonation with increase in fibre content.
18	Serdar Aydin Bulant Baradan Turkey, 2013	6	Steel fibres.	6 and 13 mm steel fibres 0.5, 1, 1.5, 2% fibres by volume.	Compressive strength, Flexural toughness, Flexural toughness, Drying shrinkage, Workability.	Longer fibres show better mechanical properties.
19	N. Ganesan P. V. Indira M.V. Sabeena India, 2014	25	Steel and PP fibres.	Reinforcement bars-10,12,16, 20 mm diameter SF- 30 mm and PP- 12 mm.	Pull out test, Bond stress, and Bond slip behaviour.	Smaller diameter bars with HFRHPC shows better bond strength.

INDUSTRIAL WASTES

Slags are produced in a very large amount in pyro-metallurgical processes, and are huge sources of waste if not properly recycled and utilized. The enormous growth of Industries, the available land for land-filling of large quantity of metallurgical slags is reducing all over the world; therefore the disposal cost becomes increasingly higher. The global warming effect and natural resource saving are the general environmental topics nowadays. Land dumped with waste materials pollutes the air, water and soil which adversely affects the human and plant life. To preserve and protect the global environment, many researchers are interested in slag recycling in recent years[26]. 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 about 75% of the total installed power generation is coal based which generates huge ash contents varying about 30 to 50%. About 110 million tonne of ash is generated every year and recently 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. 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 and SO_3.The sum of SiO_2, Al_2O_3 and Fe_2O_3 in BA is higher than the Portland cement with CaO content more than 10% .The compressive strength, bulk density, flexural strength and thermal conductivity had increased with increased BA content as replacement part of Portland cement replacement. 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. Table 2 reflects the experimental work done on replacing the bottom ash in concrete[27–33].

Table 2: *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	27	Fine aggregates	BA- 0, 30, 50, 70, 100% W/C ratio 0.45 and 0.55. Slump- 0–10 mm, 30–60 mm	Compressive strength, Drying shrinkage (up to 30% best suited).
2	P. Aggarwal, Y. Aggarwal, S. M. Gupta. India, 2007	28	Fine aggregates	BA- 0, 20, 30, 40, 50%	Compressive Strength, Splitting tensile.
3	Kou shi Cong, Poon Chi Sun. China, 2009	29	Fine aggregates	BA- 0, 25, 50, 75, 100% Fixed W/C ratio- 0.53 Slump- 60–80 mm	Compressive strength, Drying shrinkage, Chloride ion penetration.
4	H. K. Kim, H. K. Lee. Korea, 2011	30	Fine and coarse aggregate	BA- 25, 50, 75, 100% in fine and coarse aggregates	Flow characteristics, density of concrete, compressive strength, flexural strength.
5	W. Wongkeo *et al*. Thailand, 2012	31	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	32	Fine aggregates (mortar)	W/B ratios- 50, 38, 30, 24 and 20%	Flow characteristics, compressive strength, dynamic modulus of elasticity, water absorption characteristics.
7	Diana Bajare *et al*. Latvia, 2013	33	Cement	20% BA grinded for 4 min And 40% BA grinded for 15 min	Compressive Strength, water penetration, absorbtion, CO_2 emission.

Copper Slag

Copper slag (CS) are the major by product in the manufacture of copper industries and it is used in the manufacture of abrasive tools, abrasive materials, cutting tools, tiles, glass, and roofing granules[34]. The chemical compositions 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 have 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% of cement about 50–60% range. The results of compressive, split tensile strength test. 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 utilized in cement as a raw material for making blended cements[4,34–40]. Table 3 shows the experimental work done on replacing the copper slag in concrete.

Table 3: *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	34	Cement	5% replacement for cement, 13.5% CS and 1.5% Cement by pass dust (CBPD) and 85% cement.	Compressive, Tensile, flexural Strength, Modulus of elasticity, compare effect of CS and CBPD.
2	W. A. Moura, J. P. Goncalves, M. B. Leitelima. Brazil, 2007	35	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	36	Coarse aggregates	W/C ratio: 0.40, 0.35, 0.30. Silica fumes 0, 6, and 10%.	Compressive Strength, Splitting tensile, Rebound hammer.
4	Wei Wu, Wei de zhang, Guowei ma. Australia, 2009	37	Fine aggregates	Six mixtures 0, 20, 40, 60, 80, 100% of replacement.	Compressive, Splitting tensile and flexural strength, Dynamic compressive strength.
5	Wei Wu, Wei de zhang, Guowei ma. Singapore, 2010	38	Fine aggregates	Six mixtures 0, 20, 40, 60, 80, 100% of replacement.	Microstructure, Dynamic mechanic properties using split Hopkinson pressure bar.
6	K. S. Al. Jabri. Oman, 2011	4	Fine aggregates	0, 20, 40, 50, 60, 80, 100% of replacement.	Strength and Durability.
7	D. Brindha, S. Nagan. Tamil Nadu, 2010	39	Fine aggregates and cement	Fine aggregates- 0–60%. Cement- 0–20%.	Accelerated corrosion test, RCPT, Ultrasonic pulse velocity, Compressive and split tensile, Acid attack.
8	M. Najimi, J.S obhani, A. R. Pourkhorshidi. Iran, 2011	40	Cement	0, 5, 10, 15% Copper slag.	Compressive Strength, Microstructure analysis, 61 and 120 days in sulphate attack condition.

Ferrochrome Slag

Huge quantity of waste material is disposed-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. Major chemical constituents are Cr_2O_3, Al_2O_3, SiO_2, MgO, CaO and Fe_2O_3. Al_2O_3 and SiO_2 is more than 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 since chromium is one of the most common toxic heavy metal found in the environment. Ferrochrome slag mostly remains immobilized as Cr (III) and the slag contains small amount of leachable Cr (VI) concentration which does not cause any significant pollution problem. 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[41–44]. Table 4 reflects the experimental work done on replacing the ferrochrome slag in concrete.

Table 4: *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	41	Coarse aggregates	W/c- 0.64 Cement- 350 kg/m^3 5 concrete type with aggregate size.	Physical and mechanical properties of concrete pavements.
2	Mehmet Yilmaz, Baha Vural Kok Turkey, 2009	42	Coarse aggregates	Binders- 50/70, 160/220, 160/220 + 3% SBS (Styrene butadiene styrene).	Stability, Stiffness modulus, moisture susceptibility.
3	O. Gencel Turkey, 2012	43	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	44	Fine and Coarse aggregates	Fine and Coarse aggregates-0, 20, 40, 60, 80,100%.	Compressive Strength, leaching character.

Ground granulated blast furnace slag

Blast furnace slag (BFS) is a by-product of pig iron production and approximately 300 kg of slag are generated per ton of pig iron. 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, the compressive strength enhances due to the fineness of the slag. GGBFS 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. The chemical constituent is similar to cement composition with higher amount of Fe_2O_3, Al_2O_3 and SiO_2.CaO content is about 30-40%. 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 irrespective of curing condition and testing age[45–52]. Table 5 list the experimental work done on replacing the GGBFS in concrete.

Steel Slag

Steel slag is a solid waste from the steel industries. There are different types of steel slag such as carbon steel slag, stainless steel slag, basic oxygen furnace slag (BOFS), electrical arc furnace slag (EAFS), ladle refining slag (LFS). 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.

Table 5: *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	45	Cement	0, 25, 40, 55% GGBFS Type I and Type V cement.	Compressive Strength, Rapid Chloride Penetration Test (RCPT), Accelerated chloride ion diffusion, accelerate steel corrosion test, half-cell potential test.
2	H. Y. Wang Taiwan, 2008	46	Cement	W/B: 0.23, 0.47, 0.71, GGBFS- 5, 10, 20, 80 and100%With different changes.	Weight loss due to heating, compressive strength, elastic modulus, absorption capacity.
3	O. Cakir, F. Asoz Turkey, 2008	47	Cement	0, 30, 60% -GGBFS, Mortars at 20°,40° at standard conditions and 100% humidity.	Compressive and Flexural Strength, Ultrasonic Pulse Velocity Test (UPV), Capillarity coefficient, volumetric absorption.
4	S. E. Chidiac, D. K. Panesar Canada 2008	48	Cement	W/B- 0.31, 0.38 GGBFS- 0–60% Binder- 270, 450 kg/m^3.	Comp strength, UPV, Density, Non evaporable water content, freeze and thaw, scaling resistance.
5	Erhanguneyisi, Mehmet Gesoglu 2008	49	Cement	Wet curing, 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	50	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 and 8.	Compressive strength, Micro-Structure.
7	Mehmet gesoglu, Erhanguneyisi, Haticeoznuroz. Turkey, 2012	51	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	52	Cement	M10, M20, M30 UPV - 3, 7, 28, 56, 90, 150, 180 GGBFS - 20, 40, 60.	UPV and Compressive strength relations, Dynamic mod of elasticity.

Compressive strength of concrete with steel slag exhibits lower early strength but higher strength at the later period. 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[53–57]. Table 6 indicates the experimental work done on replacing the steel slag in concrete.

Table 6: *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	53	EAF slag	Fine and coarse aggregates	Six mixes: cement - 370 kg/m^3 W/B- <0.6 Slump- 60–90 mm No admixtures.	Durability of concrete, accelerated aging test, alkali aggregates reaction, chemical reaction test, freeze and thaw, wetting and drying test.
2	Xiaolu Guo, Huishengshi. China, 2013	54	Steel slag powder and GGBFS	Cement	0, 10, 20, 30, 40, 50% -cement and steel slag. Steel slag and GGBFS- 50, 25 &25, 20&30, 15&35, 10&40, 50.	Morphology and mineral composition, Compressive strength, Hydration.
3	Q.Wang *et al*. China, 2013	55	Steel slag	Cement	W/B- 0.50 and 0.35 Comp strength- 47 and 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	56	Welding slag	Fine aggregates	Fine aggregates. Acid Slag of Welding Flux (SWF) waste. Neutral SWF Basic SWF.	Compressive, tensile strength, after firing to 950°C, linear shrinkage, water absorption, apparent density.
5	Ramesh *et al*. India, 2013	57	Welding slag and 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. 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 steel making. It has been reported that chromium is the most harmful element in stainless steel waste. The leaching results of stainless steel slag from Italy, China and Taiwan concluded that the presence of the heavy metals were lower than the detection limits and hence there is no pollution effect by the use of stainless steel slag. The chemical composition of steel slag are SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, Cr_2O_3, MnO, TiO_2, SO_3, Na_2O, K_2O with 40–50% of CaO. The stainless steel slag is very similar to Blast Furnace slag, because its microstructural morphology, chemical composition and CaO-Al_2O_3-SiO_2 three-phase diagram analysis is nearly Blast Furnace slag. Then the stainless steel slag has both the cementation and pozzolanic reaction characteristics like BF slag to be the binder of concrete. 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[58–60]. Table 7 displays the experimental work done on replacing the Stainless slag in concrete.

Table 7: *Experiments on Replacement of Stainless Steel Slag as a Substitute in Concrete.*

S. No.	Author Country And Year	Ref. No.	Type of Industrial Waste	Material Replace	Mix Proportion	Experiments Carried Out
1	L. Kriskova *et al.* Belgium, 2012	58	Stainless steel slag (LM and AOD)	Cement	LM and AOD slag, W/C ratio- 0.5 for OPC, 0.75 for slag	Particle size distribution, X-ray diffraction, compressive strength, Scanning Electron Microscopic (SEM) analysis.
2	Y. N. Sheen *et al.* Taiwan, 2013	59	Stainless steel slag, Stainless Steel Oxidising Slag (SSOS) and Stainelss Steel Reducing Slag (SSRS)	Cement	SSOS and SSRS- 0, 10, 20, 30, 40,50%	Microstructure analysis, compressive strength.
3	Y. N. Sheen *et al.* Taiwan, 2014	60	Stainless steel slag SSOS	Coarse and fine aggregates	SSOS- 0, 25, 50, 75,100%	Compressive strength, UPV, surface resistance.

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 (Weld 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 it shows better mechanical properties.

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