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Reuse and Recycle of Steel Industry By-Products in Construction Materials – A Review

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Abstract
This review paper collates and compiles the available published literature on usage of two by-products of steel industry- Ground Granular Blast Furnace Slag (GGBFS) and Ground Granulated Blast Furnace Slag Sand (GGBFSS) in concrete production. Replacement of binder material, fine aggregate and coarse aggregates in concrete making partially or fully is well established and leads to the sustainable development and reduces the material cost. GGBFS and GGBFSS bears similar properties as that of cement and natural fine aggregate/M-sand respectively. Replacement of cement with alternative binding materials reduces the carbon foot-print. Substitution of conventional materials of concrete with GGBFS and GGBFSS at different replacement levels enhances the mechanical strength, workability and durability of concrete.

Keywords: GGBFS, GGBFSS, workability, Mechanical strength, Durability, Sustainability

Introduction

Table 1: Acronyms used for ease of reading

Acronym	Expansion
AC	Asphalt Cement / Concrete
BFS	Blast Furnace Slag
BOF	Basic Oxygen Furnace
BOFS	Basic Oxygen Furnace Slag
BOP	Basic Oxygen Process
DTA	Differential Thermal Analysis
EAF	Electric Arc Furnace
FRSCC	Fiber Reinforced Self Compacting Concrete
GGBFS	Ground Granulated Blast Furnace Slag
GGBFSS	Ground Granulated Blast Furnace Slag Sand
GPC	Geo-Polymer Concrete
OPC	Ordinary Portland Cement
PSC	Portland Slag Cement
RO	Reactive Oxygen
SCC	Self-Compacting Concrete
SEM	Scanning Electron Microscopy
SMA	Stone Mastic Asphalt
SS	Slag Sand
SSA	Steel Slag Aggregate
TG	Thermo Gravimetry
XRD	X-ray Diffraction

Concrete is one of the vital product used in the construction industry. About 25 billion tons of concrete is used every year in the entire world. With the high demand and supply, the raw materials used in concrete production were mined on larger scale resulting in depletion of natural resources like fine and coarse aggregates. Further, higher production of cement has led to exploitation of natural resources and environmental pollution. Generally, OPC is used as a binder material in concrete production. To manufacture a ton of OPC, an equal amount of CO_2 with other gases are released into the atmosphere. Every year, about 5% increase in total global CO_2 emission was through cement manufacturing alone.

The embodied energy of concrete can be reduced without decreasing the performance or increasing the cost, through usage of alternative or supplementary material having similar properties of cement, natural fine and coarse aggregate. To manoeuvre exploitation and green house effects caused by the concrete, by-products generated from different iron ore industries such as GGBFS and GGBFSS resembling the properties of cement and natural fine aggregate can be used as alternative materials in concrete production, leading to technological, economic and environmental benefits. This also results in achieving global sustainable development and lowest possible environmental impact.

As a by-product, steel slag makes up a portion of 15-20% of iron output in integrated steel mills. In China, it is being deposited in slag storing yards and likewise, in Jordan Steel slag generated from three major steel-manufacturing factories is being dumped randomly in open areas, causing serious environmental problems.

An attempt is being made in this review paper to collate and compile the research findings from the literature pertaining to GGBFS and GGBFSS. The different types of slag- steel furnace slag, basic oxygen furnace slag, electric arc furnace slag etc and the effect of slag and slag sand on workability, compressive strength and durability when used alone and in combination is discussed in a sequential manner under different headings.

GGBFS - Origin

GGBFS is a by-product of iron manufacturing industry. Major steel plants in India generates 7760561 MT of GGBFS per annum. Iron ore, coke and limestone fed into the blast furnace at a temperature of 15000˚C to 16000˚C produces molten slag that floats above the molten iron. The molten slag is water-quenched rapidly after the molten iron is trapped off. This results in the formation of a glassy granulate which consists of siliceous (SiO_2: 30%-40%), aluminous (Al_2O_3: 3%-8%), Lime (CaO: 40%) and other residues (10%-20%). This glassy granulate is dried, ground to coarse grain size particle and powder form and designated as GGBFSS and GGBFS respectively.

Mechanically activated GBFS in the range of 50–95% was used to replace clinker in portland slag cement (PSC) by Sanjay Kumar., et., al. [1]. The slag and clinker were activated separately using attrition mill and mixed to prepare cement formulations. Use of activated slag resulted in a remarkable increase in strength vis-à-vis commercial slag cement. Both 1-day and 28-day strength were found to increase with increase in slag content up to 70%. The strength of the sample containing 80–85% slag was comparable to the commercial cement used as a reference. It was observed that mechanical activation of slag was more critical from the point of strength development. The hydrated cement samples were characterised using powder XRD, SEM, EDS, TG and DTA. It was established that microstructural changes resulting from enhanced reactivity of slag and densification were related with the improvement in cement strength.

Global Scenario

Usually, the mechanical strength will be accomplished with microstructural assessment to visualize the morphological changes that occurs in the solidified matrix after hydration.

Mineralogical studies on Ladle slag (SS) coming out of a BOF or an EAF was carried out by Shi,

C. J. [2]. Air-cooled ladle slag had a large portion of fine particles due to the conversion of b-C_2S to g-C_2S during the cooling process. XRD analyses of samples passing 100, 200 and 325 mesh indicated the major mineral in ladle slag fines was g-C_2S, which did not exhibit cementitious property in water. But ladle slag fines revealed significant cementitious property in the presence of an alkaline activator. The authors opined that with finer ladle slag exhibited better cementitious property compared to coarse particles.

Q. Wang and P. Y. Yan [3]. investigated the hydration properties of BOF steel slag, the most common steel slag in China. Steel slag was ground separately to 458m^2/kg and 506m^2/kg. Different hydration conditions were set by changing the temperature and pH value. Hydration exothermic rate was measured within 4days. Non-evaporable water content, hydration products and hardened paste morphologies were investigated at the end of 1, 3, 7, 28 and 90 days. The results indicated that hydration process of steel slag was on par with cement. Nevertheless, hydration rate was much lower than cement. The hydration rate of steel slag at the early age could be accelerated by raising the fineness of particles, curing temperature and alkalinity of solution. However, raise in the pH value of the solution or curing temperature did not yield good results for the later hydration of steel slag. CSH gel and $Ca(OH)_2$ were the main hydration products of steel slag. A part of C_3S and C_2S crystal in steel slag had very low activity and un-hydrated even after 90 days. RO phase was almost inert. The interface between the particles of RO phase and CSH gel was a weak region in the system.

Q. Wang., et., al. [4] investigated the cementitious properties of steel slag in which the cementitious phase was composed of silicate and aluminate. The large particles of these phases made little contribution to the cementitious properties. To improve the cementitious properties of steel slag, following three guidelines were suggested.

1. The RO phase (CaO–FeO–MnO–MgO solid solution), Fe_3O_4, C_2F and f-CaO made no contribution to the cementitious properties of steel slag. Steel slag with more cementitious phase and less RO phase can be obtained by removing some large particles and correspondingly, the large particles can be used as fine aggregates for concrete.
2. To improve the cementitious property, add regulating agent high in CaO and SiO_2 during manufacturing process of steel slag to increase the cementitious phase to inert phase ratio. The regulating agent should be selected to adapt to the specific steel slag and the alkalinity should be increased as high as possible, on the premise that the f-CaO content do not increase.
3. The cooling rate should be enhanced to improve the hydration activity of the cementitious phase at early ages and grindability of steel slag.

Many researchers have used GGBFS as fine and coarse aggregates on bench scale studies. Compared to natural fine aggregate, GGBFS has high impact and crushing value and possess rough surface texture. These properties make it a good aggregate for unbound and bituminous bound mixtures.

Qiang wang., et.,al. [5]. investigated the effect of different steel slags on the fluidity of paste and workability of concrete. The results indicated that steel slag did not improve the workability of concrete as that of GGBS. Some steel slags had negative effects on the compatibility of cement-superplasicizer system by accelerating the fluidity loss of paste, but the negative effects can be weakened by adding superplasiticizer content to the saturation dosage. Concrete containing steel slag can yield good workability through addition of superplasiticizer.

Perviz Ahmedzade & Burak Sengoz [6]. investigated the influence of steel slag as a coarse aggregate on the properties of hot mix asphalt. Four different asphalt mixtures containing two types of asphalt cement (AC-5; AC-10, limestone; steel slag) as coarse aggregate were used to prepare Marshall Specimens, to determine optimum bitumen content. Mechanical characteristics of all mixtures were evaluated by Marshall Stability, indirect tensile stiffness modulus, creep stiffness, indirect tensile strength tests. The electrical sensitivity of the specimens was investigated as per ASTM D257-91. As coarse aggregate, SS improved the mechanical properties of asphalt mixtures and volume resistivity values demonstrated that the electrical conductivity of steel slag mixtures were better than that of limestone mixtures.

Chinese researchers are greatly dealing on the development of application fields for BOFS since many years. Lots of new application and properties have been found, but few of them in asphalt mixture of road construction engineering. Yongjie Xue., et., al. [7]. explored the feasibility of using BOFS as aggregate in asphalt pavement focusing BOFS's physical and micro-properties and steel slag asphalt materials and pavement performances. For the first part of research work, the mechanochemistry and physical changes of the steel slag was studied by performing XRD, SEM, TG and mercury porosimeter analysis. In the second part, BOF steel slag was used as raw material, and design steel slag SMA mixture. By using traditional rutting test, soak wheel track and modified Lottman test, the high temperature stability and water resistance ability were tested. Single axes compression test and indirect tensile test were performed to evaluate the low temperature crack resistance performance and fatigue characteristic. Simultaneously, steel slag SMA pavement which was paved successfully was observed. A follow-up study to evaluate the performance of the experimental pavement confirmed that the experimental pavement was comparable with conventional asphalt pavement, even superior to the later in some aspects. All the test results and analyses validated the opinion that using BOF slag in asphalt concrete is feasible. Authors suggested that treated and tested steel slag should be used in a more extensive range, especially in asphalt mixture paving projects in such an abundant steel slag resource region.

Shaopeng Wu., et., al. [8]. explored the feasibility of using steel slag as aggregates in stone mastic asphalt (SMA) mixtures, and properties of such asphalt mixtures were evaluated. XRD, SEM, and MIP were employed to study the compositions, structure and morphology of aggregates. Volume properties and pavement performances of SMA mixture with steel slag were evaluated and compared with basalt as aggregates. Results indicated that volume properties of SMA mixture with steel slag satisfied the related specifications and expansion rate was below 1% after 7 days. Compared to basalt, high temperature property and the resistance to low temperature cracking of SMA mixture were improved by using steel slag. In-service SMA pavement with steel slag presented excellent performance on roughness and British Pendulum Number (BPN) coefficient of surface.

Ibrahim Asi., et.,al. [9]. intended to study the effectiveness of using SSA in improving the engineering properties of locally produced AC mixes. The toxicity, chemical and physical properties of the steel slag was evaluated and then 0%, 25%, 50%, 75%, and 100% of the limestone coarse aggregate in the AC mixes was replaced by SSA. The effectiveness of the SSA was judged by the improvement in indirect tensile strength, resilient modulus, rutting resistance, fatigue life, creep modulus, and stripping resistance of the AC samples. Research study results showed that replacing limestone coarse aggregate by SSA up to 75% improved the mechanical properties of the AC mixes. The optimal replacement level was 25%.

S. A. Tarawneh., et., al. [10]. evaluated the physical, mechanical properties and characteristics of steel slag aggregate concrete and compared with the typical crushed limestone aggregate concrete. SS was used as an aggregate replacement in conventional concrete mixes. Steel slag which mainly consists of calcium carbonate is produced during the oxidation process in steel industry. Steel slag was selected due to its almost similar characteristics as that of conventional aggregates and easily available by-product of the steel industry. Results showed that slag aggregate has better abrasion factor and impact value than conventional aggregate. Thorough investigation of the results indicated increase in compressive strength of 7 days were much more than that of age 28 days for all types of aggregate replacement. This indicates that the added slag could work as accelerator at early age while at 28 days age, the effect is reduced. The fine slag replacement scores the highest effect.

K. A. Olonade., et., al. [11]. investigated the feasibility of using SS as a substitute for FA in concrete. SS from a dump site was collected, crushed and sieved between No. 4 and 200 sieves. SS was characterized using XRF and XRD techniques. Concrete of mix ratio 1:2:4 was batched by weight with slag replacement levels of 0 to 100% of FA at 25% interval and the concrete cubes and beams cast were cured for 7, 14, 28 and 56 days. Water demand, compressive strength and flexural strength of the concrete were determined. Results indicated that SS contained high amorphous silica (42.40%) and ferric oxides (31.90%) with traces of crystalline particles. The water-cement ratio reduced from 0.62 to 0.50 as slag proportion increased from 0% to 100% at slump range of 60±10 mm. The strength of SS concrete increased with increase in SS proportion. The study suggested that FA could be replaced with slag up to 50% of weight to produce structural concrete.

This section deals with research work on utilizing GGBFS as a binder material and exploratory work carried out by researchers to investigate the effect of deleterious materials and impurities of steel slag in casting slag concrete.

Hasan Alanyali., et., al. [12]. used BOF slag as a clinker additive in cement. The study revealed that the concrete produced using BOF slag up to 30% by mass were within the compressive strength values of Grade-325 and Grade-425 steel making slag cement. Mainly steel slag takes a physical filling effect at early ages and has a notable negative effect on the early-age strength of mortar.

Qjang Wang., et., al. [13]. suggested the ways to improve the cementitious properties of steel slag. The results showed that the cementitious phase of steel slag was composed of silicate and aluminate, but the large particles made a very small contribution to the cementitious properties of steel slag. RO phase (CaO–FeO–MnO–MgO solid solution), Fe_3O_4, C_2F and f-CaO made no contribution to the cementitious properties. By removing the large particles, steel slag bearing more cementitious phase can be obtained by reducing the RO phase This RO phase enhances the cementitious properties of steel slag. The large particles can be used as fine aggregates for concrete. Adding regulating agent with high CaO and SiO_2 during manufacturing process of steel slag to increase the cementitious phase to inert phase ratio was another way to improve its cementitious properties. The regulating agent should be selected to adapt to the specific steel slag and the alkalinity should be increased to higher value on the assumption that the f-CaO content do not increase. The cooling rate should be enhanced to improve the hydration activity of the cementitious phase at the early ages and the grindability of steel slag.

Yan Shi., et., al. [14]. investigated the pozzolanic activity of the superfine SS with different particle sizes prepared by a superheated steam powdered jet mill. The results showed that the f-CaO content decreased with the decrease in particle size of steel slag. The normal consistency for water, setting time, and soundness of the cement paste with superfine SS remained within the acceptable ranges of the national standard. A decrease in the particle size of superfine SS can accelerate the hydration reaction of blended cement resulting in higher mortar strength. The activity index of superfine SS (D50 = 2.52 μm) can reach up to 95.0% which is much higher than that of ordinary steel slag powder (D50 = 13.3 μm). For blended cement with 10%, weight ratio of superfine SS (D50 = 5.10 μm) as a replacement, cement mortar exhibited higher compressive strength at 28 days than that of control. When the replacement weight ratio of superfine SS was above 10%, the strength of cement mortar gradually decreased. Microstructure analysis confirmed that there were more hydration products yield in cement paste with superfine SS than that of ordinary steel slag powder, which was consistent with mechanical strength results.

P. E. Tsakiridis., et., al. [15]. investigated the viability of adding steel slag in the raw meal to produce Portland cement clinker. Two raw meal samples were prepared, a reference sample ($(PC)_{Ref}$) with ordinary raw materials, and another with 10.5% steel slag ($(PC)_{S/S}$). Both the raw meals were sintered at 1450 °C. The chemical, mineralogical and the microscopic examination showed that use of steel slag did not affect the mineralogical characteristics of Portland cement clinker. Both clinkers were tested for grindability, setting times, compressive strengths and soundness. The hydration products were subjected to XRD analyses at the end of 2, 7, 28 and 90 days. The physico-mechanical test results showed that the addition of steel slag did not affect the quality of produced cement at the end of aforesaid curing periods.

The usage of BOP slag from Kardemir Iron and Steel Plant, Karabuk Turkey as an additive into cement was explored by Altun I & Yilmaz Ismail [16]. The Slag was ground to 4000 and 4700 cm^2/g levels, and added in the ratios 15, 30 and 45 wt.%. Volume expansion, setting time, compressive strength and bending strength tests were measured in accordance with Turkish standards. Due to impurities of the slag, 2 and 7-day compressive strengths decreased with increase in amount of Mn, but this decrease was lower in the 28-day compressive strength for 30% slag addition. It was concluded that the physical and mechanical properties of the slag concrete were acceptable in the Turkish Standards Institute (TSI).

S. Kourounis., et., al. [17]. investigated the properties and hydration of blended cements with steelmaking slag. Three cements containing up to 45% w/w steel slag were tested. The steel slag of fraction “0–5 mm” was used, due to high content in calcium silicate phases. Initial and final setting time, standard consistency, flow of normal mortar, autoclave expansion and compressive strength at 2, 7, 28 and 90 days was measured. The hydrated products were identified by X-ray diffraction and non-evaporable water by Temperature Grade analysis (TGA). The microstructure of the hardened cement pastes and its morphological characteristics by scanning electron microscopy. It was concluded that slag used in the production of composite cements of the strength classes 42.5 and 32.5 of EN 197-1. The slag cements presented satisfactory physical properties. The steel slag slowed down the hydration of the blended cements, due to the morphology of C_2S contained and its low content in calcium silicates.

Steel Slag has less effect on the permeability of concrete at lower w/b ratio. GGBFSS has small influence on the carbonation of concrete with constant 28-day compressive strength, if less than 3-day initial standard curing is ensured. Steel slag has not been extensively used as a replacement to cement. Theoretically, it has the following drawbacks.

- Highly variable mineral composition
- Low reactive calcium silicate compounds in the steel slag results in poor cementing properties
- Free calcium and magnesium oxide contents are high which causes volume expansion problems and
- Steel slag has higher density compared to other binders

Oner A and Akyuz S [18]. conducted a laboratory investigation on optimum level of GGBS on the compressive strength of concrete. GGBS was added according to the partial replacement method in all the mixtures. A total of 32 mixtures were prepared in four groups according to the binder content. Eight mixes were prepared as reference with 175, 210, 245 and 280 kg/m^3 of cement to calculate the Bolomey and Feret coefficients (KB, KF). For each group 175, 210, 245 and 280 kg/m^3, dosages were determined as initial dosages, which were obtained by removing 30 percent of the cement content of control concretes with 250, 300, 350, and 400 kg/m^3 dosages. Test concretes were obtained by adding GGBS in an amount equivalent to approximately 0%, 15%, 30%, 50%, 70%, 90% and 110% of cement content. All specimens were moist cured for 7, 14, 28, 63, 119, 180 and 365 days and subjected to compressive strength testing. The test results proved that the compressive strength of concrete mixtures containing GGBS increased with increase in the amount of GGBS increase. After an optimum point, at around 55% of the total binder content, the addition of GGBS did not improve the compressive strength. This was attributed to the presence of unreacted GGBS, acting as a filler material in the paste.

P.J. Wainwright and N. Rey [19]. performed Bleed tests on concretes in which cement was replaced up to 85% with GGBS obtained from different sources (in accordance with ASTM C232-92). The time at which the bleed test started was varied from 30 to 120 min to simulate site conditions. The addition of slag up to 55% increased the bleed capacity by 30% (compared to the ordinary Portland cement mix) but had little effect on bleed rate. Increasing the slag content to 85% had no significant effect on bleeding. The source of slag was also found to have little effect on the bleeding. The comparison was made with results from 10 years ago suggest that the present-day slags had a less marked effect on bleeding. Probably, because it was ground finer. Delaying the start of the bleed test from 30 to 120 min reduced the bleed capacity of OPC mix by more than 55% compared with 32% for the slag mixes. The reduction in bleed rate at about 45% was similar for all mixes.

Blast-furnace slags cooled at different rates were used to study the effect of fineness, mixing method and content of slag on the strength development of blended slag mortar by Chao-Lung Hwang & Chao-Yin Lin. [20]. activator and curing temperature were used to activate the early strength. The microstructure of blended slag paste was also investigated in this study to explain the strengthened effect.

The strength development of slag cement has a great consideration for the scheduling of formwork removal, prestressing operations, and other practical aspects of slag cement usage. The prediction of slag concrete strength, using the Feret's model was studied by introducing the concept of the equivalent binder by A. Bougara et., al. [21]. this led to define an efficiency coefficient of slag which distinguishes the latter with the regard to the cement. This obtained coefficient characterizes well the slag and lets to predict the slag concrete strength from strength values of a normal concrete made without slag for a given age and replacement rate. At 90 days curing age, the test results showed that for 15% replacement, the slag was activated completely and gave 67% of efficiency more than the cement. For higher replacement rate, the efficiency of the slag decreased and become like that of cement for 50% replacement.

BFS and NP have been widely used as a partial replacement for cement in concrete construction due to its merits including cost reduction and improvement of the ultimate mechanical and durability properties. Walid Deboucha., et., al. [22]. research emphasized on the effect of substituting cement with Blast furnace slag and natural pozzolana up to 40 % on compressive strength and capillary water absorption of concrete. The compressive strength was determined on prisms at the curing ages of 7, 28, and 90 days. Cylindrical specimens were employed for capillary water absorption test after 28 days of curing. The results showed that it was possible to obtain the same or better strength grades by replacing cement with BFS up to 30% in concrete. However, the use of NP content reduced the compressive strength. Lower capillary water absorption for BFS and NP substitution was observed.

Guo Xiaolu., et., al. [23]. carried out investigation on the workability and durability of sustainable concrete made with steel slag powder. The mechanism of chemically activated steel slag powder was studied and results showed that when steel slag powder was added to concrete, the slumps through the same time and the dry shrinkages were lower. The initial and final setting times were slightly retarded and the abrasion resistance was better. The chemically activated steel slag powder could improve compressive strength, resistance to chloride permeation and water permeation, as well as carbonization resistance. The hydrated products of cement paste with GGBFS alone and with a combined admixture of GGBFS-steel slag powder were analysed by XRD. XRD patterns indicated that the activators enhanced the formation of calcium silicate hydrate(C-S-H) gel and ettringite (AFt). This research study contributes to sustainable disposal of wastes and has the potential to provide several important environmental benefits.

Alexander S. Brand and Ebenezer O. F [24]. collated the findings from the literature to express the variability in material properties and to explain the source(s) of the variability on steel furnace slag (SFS), electric arc furnace (EAF) slag, basic oxygen furnace (BOF) slag, ladle metallurgy furnace (LMF) slag, and argon oxygen decarburization (AOD) slag. It can significantly affect the composite properties, when used as an aggregate or as a supplementary cementitious material in bound applications, such as concretes, mortars, alkali-activated materials, and stabilized soils. It was found that SFS composition and properties can be highly variable, including different compositions on the exterior and interior of a given SFS particle, which can affect bonding conditions and be one source of variability on composite properties. A suite of tests was proposed to better assess a given SFS stock for potential use in bound applications; at a minimum, the SFS should be evaluated for free CaO content, expansion potential, mineralogical composition, cementitious composite mechanical properties, and chemical composition with secondary tests, including cementitious composite durability properties, microstructural characterization, and free MgO content.

Sabet Divsholi., et., at. [25]. investigated the durability properties and microstructure of Ground granulated blast furnace slag cement concrete. More than 200 samples with varying water–

cementitious material ratios and replacement percentages of GGBS were cast. The compressive strength, electrical resistivity, chloride permeability and carbonation tests were conducted. The moisture loss and microstructure of concrete were studied. The partial replacement of PC with GGBS produced considerable improvement on various properties of concrete. The partial replacement of PC with GGBS improved the pore structure of concrete. The electrical resistivity of the concrete was increased and the total coulombs passed during rapid chloride permeability test were significantly reduced. The rate of carbonation for the samples with 30 and 50 % GGBS replacement increased, however longer period of water curing for GGBS blended cement concrete reduced the carbonation rate and reduce the concern of increased carbonation rate. On top of ecological reasons such as reduced CO_2 footprint and consumption of GGBS, the GGBS is a viable pozzolanic material for everyday construction purposes considering the improvement in fresh concrete properties, mechanical properties and durability properties.

Juan Lizarazo-Marriaga., et., al. [26]. investigated the effect of steel slag and Portland cement in the rate of hydration and strength of blast furnace slag pastes on the compressive strength and the hydration mechanisms of GGBS pastes. The compressive strength, mineralogical changes due to hydration, setting times, alkalinity of the raw materials and pore solution, and the volume stability were measured on binary and ternary mixes. It was concluded that the steel slag can be used as an activator of GGBS and the optimum composition of those materials was determined with a proposed parameter called "slag index". The properties measured in blended OPC-GGBS-BOS mixes showed encouraging results to be used industrially. The mechanisms of hydration of the blended slag mixes were discussed and a hydration model of the blended system GGBS-BOS was proposed.

Indian Scenario

Subathra Devi V and Gnanavel B. K. [27]. investigated the potentiality of Steel Slag as a partial replacement to coarse and fine aggregates and study the strength and durability properties for the mix design of M_{20} grade concrete. The optimum replacement percentage of fine and coarse aggregate was determined. Workability of concrete gradually declined with increase in the replacement percentage, which was revealed through slump test. Compressive strength, tensile strength, flexural strength and durability tests (acid resistance using Hcl and H_2SO_4 and Rapid chloride penetration) were investigated. The results indicated that for conventional concrete, the partial replacement of fine and coarse aggregates by steel slag improved the compressive, tensile and flexural strength. The mass loss in cubes after immersion in acids was found to be very low. Deflection in the RCC beams gradually increased with increase in load on the beam, for both the replacements. The degree of chloride ion penetrability was assessed as per ASTM C 1202.

Sanbir Manhas and Amir Moohmend [28]. examined the likelihood of using GGBS in bond concrete as a sand substitute. The level of GGBS substitution was 0, 5, 10%. 15% to normal sand for the standard w/c proportion of 0.4 was considered. The broadened work was finished with 100% supplanting's of normal sand with GGBS in the w/c proportions of 0.4 and 0.6. The flow qualities of different blends and their compressive qualities at different period were examined. A request for common sand in concrete is expanding step by step. We undertake this exploratory examination to research the impact of incomplete supplanting of bond with ground granulated impact heater slag (GGBS) in concrete containing quarry tidy as fine aggregate. GGBS is one of the side-effect of steel fabricating industries. On usage of the mechanical soil waste or auxiliary materials for the generation of bond and cement is energized in field of development since it adds to decreasing the utilization of characteristic assets. By supplanting the fine total to discover the quality, toughness also, erosion protection properties of cement. The infiltration of chloride particles by methods for awed voltage method in saline medium and gravimetric weight reduction method. The substitution of fine total by GGBS in the scope of 0% (without GGBS), 5%, 10% and 15%. Concrete blends were blended totally, tried and discover the compressive, flexural and split rigidity are contrasted and the customary cement.

Richa Poland., et., al. [29]. explored the current uses of SS in concrete and its possible use as cementitious material. Due to its huge production, haphazardus unscientific dumping and hazardous effects, there was a need to study its effect on concrete with higher replacement ratios. New methods need to be developed so that comparable 28 days strength could be achieved. Previous researchers had reported the loss of strength by high replacement of BOS steel slag alone, as replacement of OPC, but its use along with GGBS have shown very encouraging results in the studies conducted internationally. The compressive strength, the changes in mineralogy due to hydration, the setting times and the volume stability are discussed based on the available literature. There is a need to study the effect of these ternary mixes to know the optimum level of replacements.

The chemical composition of SS, OPC and GGBS used in this research work obtained from Bhilai Steel plant, India is represented in Table 2.

Table 2: Chemical composition of OPC, GGBS, and SS (Bhilai Steel Plant (BSP)

Sl. No.	COMPONENTS	OPC	GGBS	SS	SIGNIFICANCE
1	Lime(CaO)	60-67	35.73	45.98	Expanding agent to overcome contraction as cement slurry
2	Silica (SiO_2)	17-25	34.62	15.88	High pozzolanic activity
3	Alumina (Al_2O_3)	3-8	11.83	0.92	Improves mechanical properties
4	Iron oxide (Fe_2O_3)	0.5-6	2.73	17.04	Increases the hardness
5	Magnesia (MgO)	0.1-4	9.83	6.67	Reduces the burn-ability of raw materials
6	Sulphur trioxide (SO_3)	1-3	1.42	Absent	Increases the dry shrinkage
7	Soda (Na_2O) + potash (K_2O)	0.5-1.3	0.50	Absent	Accelerator for cement hydration
8	P_2O_5	Absent	Absent	1.80	Reduces the content of C_3S & early strength
9	MnO	Absent	Absent	1.32	--

(Source: Palod et al. [29])

The basic difference between SS and OPC is very high iron and low alumina content respectively.

Metallurgical slags (granulated and air-cooled) disposed as waste from the ferro-manganese and ferro-manganese–silicon alloys manufacturing plants was considered in this research work. Unlike blast furnace slags, it finds little use. Amit Rai., et., al. [30]. explored the possibility of using high and low MnO metallurgical slags. Low MnO granulated slag was used to make blended slag cement with OPC. Addition of slag lowered the compressive strength of blended cement compared to OPC. However, the composition of a 50:50 blend, ground to 3000 cm^2/g (Blaine), conformed to IS: 455-1989 for Portland slag cements, IS: 269-1989 for 33 grade OPC, with respect to standard consistency, setting times, soundness and compressive strength (22 MPa and 33 MPa at 7 & 28 days respectively) tests carried out as per IS: 4031-1988. X-Ray diffraction analysis indicated low MnO granulated slag was non-crystalline and the air-cooled slags were crystalline containing mainly quartz, MnO and Mn_2O_3. Chemical analysis of slag samples indicated low CaO and Fe_2O_3 contents and high SiO_2, Al_2O_3, MnO, MgO, Na_2O and K_2O, thus indicating pozzolanic reactions contributing to a great extent in the strength development of blended slag cement compositions. High MnO (>15%) and MgO (>8%) containing slags were considered unsuitable for blended cements because of its deleterious effects. Air-cooled lumpy slag was evaluated for use as aggregates in concrete. All the tests for aggregates (coarse and fine aggregates) of concrete from natural resources were carried out as per BIS codes. The material passed all the tests viz. crushing strength, impact value, abrasion, alkali aggregate soundness, excluding deleterious materials content. With slight modification this slag could be used for non-structural concrete. The results of the investigation provided a direction for profitable plans for making blended slag cements.

Ganesh babu K and Kumar V. [31]. assessed the 28-day cementitious efficiency of GGBS in concrete at the various replacement levels. The overall strength efficiency was found to be a combination of general efficiency factor, depending on the age and a percentage efficiency factor, based on replacement percentage. This evaluation made it possible to design GGBS concretes for a desired strength at any given replacement percentage.

CH. Rajesh., et., al. [32]. self-compacting concrete possess higher flow ability to settle without utilization of any mechanical vibration. The main motto of this study was to explore the mechanical properties of reinforced SCC using GGBS & limestone powder as mineral admixtures along with pond ash as substitution of fine aggregate. Cubes, cylinders and beams reinforced with 4mm bars were cast to find mechanical behaviour. The experimental work was done to observe the effects taking place during replacement of the GGBS, Limestone powder and pond ash on fresh and solidified properties of SCC. Pond ash by weight of fine aggregates, GGBS& limestone powder by weight of cement were replaced to attain self-compacting concrete properties to predict flow behaviour in various percentages such as 20%, 40% and 60% respectively. The super plasticizer by 1% weight of cement was used to increase the workability of SCC. This replacement proved to have some economic benefits as well as time effective techniques in concreting for the future.

In a experimental work carried out by Tadepalli Naga Srinu and Kallempudi Murali [33]. the cement was completely replaced with fly ash and GGBS at equal proportions incorporated with steel fibers of standard length 1mm, and diameter of 50mm aspect ratio of 50 the type of steel fibers used was crimpled form, to counter the stress produced to balance and make the concrete withstand with tension steel fibers were added maximum up to 2% taken by weight of binder i.e GGBS and low calciumbased fly ash supplied by local thermal plant. The maximum increase in strength was observed at 1.5% of incorporation of steel fibers. The addition of steel fibers had shown good increase in compressive, flexural and split tensile strength. The use of fly-ash and ggbs helped in reducing the air pollution by eliminating carbon-dioxide and carbon monoxide which is produced in manufacturing of cement.

R. Gopalakrishnan [34]. synthesized Geo polymer by mixing strong alkali solutions such as sodium hydroxide (NaOH), potassium hydroxide (KOH), sodium silicate and potassium silicate with alumina-silicate materials. The main constituents for preparing geo polymer concrete for this investigation was GGBS, fly ash (Class F), alkaline liquid, fine and coarse aggregates. Fly ash was rich in silicate and alumina, hence it reacts with alkaline solution to produce alumina silicate gel that binds the aggregate to produce a good concrete. GGBS was used mainly as it is having the latent hydraulic properties and fly ash was used since it is having the pozzolanic properties possessing the physical, chemical and mechanical properties of cement. The experimental investigation was on heat cured GGBS / Fly based alumina silicate concrete. The influence of concentration of molarity on compressive strength and effect of curing temperature were studied. It was concluded that higher concentration of molarity performed well in both the Fly ash and GGBS based geopolymer concrete. Compared to the fly ash, GGBS based geopolymer concrete performs well.

Ravi and N.K. Amudhavalli [35]. focused on the investigating characteristics of M50 grade concrete with partial replacement of cement with Ground Granulated Blast Furnace Slag (GGBS) and sand with the ROBO sand (crusher dust). The cubes and cylinders were tested for compressive strengths and split tensile strength. It was found that by the partial replacements of cement with GGBS and the sand with ROBO sand helped in improving the strength of the concrete substantially compared to nominal mix concrete. The compressive strength was studied at 7days, 28 days. Water reducing admixtures were used to increase the workability characteristics. For all levels of cement replacement concrete achieved superior performance in the fresh and mechanical tests compared with the reference mixture.

R. Christopher Daniel Raj., et., al. [36] used GGBS as replacement for cement. In this study, 60%, 70% and 80% of cement was replaced with GGBS in concrete and the mechanical properties were investigated. To improve early strength nano and micro silica were added to the concrete mix in two different proportion. In the first mix, 1% nano silica and 5% micro silica were added to concrete cubes to find the compressive strength of concrete. In the second mix, cubes, cylinders and flexural prisms were cast to investigate the compressive strength, split tensile strength and flexural strength of GGBS concrete respectively. The study revealed that 70% of GGBS could be replaced for cement in concrete with the addition of 3% nano silica (NS) and 10% micro silica (MS).

A.V. Pramod., et., al. [37]. discussed on the mechanical properties of M25 grade concrete made with recycled fine aggregate and mineral admixtures such as fly ash, GGBS and combination. By utilizing the recycled material and mineral admixtures, the pressure on the environment will be reduced to certain extent and this gives the direction towards making the concrete more sustainable and greener. Mechanical properties of M25 grade concrete such as compressive strength, split tensile strength and flexural strength of concrete were analysed and the results were compared with that of the normal concrete.

B. Sarath Chandra Kumar and K. Ramesh [38]. carried out research work to produce a carbon dioxide emission free cementious material. The geopolymer concrete is such a vital and promising one. In this study, geopolymer was prepared from GGBS and metakaolin from industry. The Alkaline liquids used in this study for the polymerization process were the solutions of sodium hydroxide (NaoH) and sodium silicate (Na_2Sio_3). A 8 Molarity and 10 Molarity solutions was taken to prepare the mix. The cube compressive strength was calculated for different mixes. The cube specimens were of size 150 mm x 150 mm x 150 mm. Ambient curing of concrete at room temperature was adopted. In total, 180 cubes were cast for compressive strength at age of 28 days respectively. The test data indicate that on exposure to 5% Sodium Sulphate, Sulphuric Acid and Sodium Chloride, the losses in weight, and strength of geopolymer concrete (GPC) were significantly much less than those for cement concrete. Thus, the geopolymer concrete is considered to be an environmentally pollution free construction material.

K. Chandra Padmakar and B. Sarath Chandra Kumar [39]. studied the strength and durability properties of Metakaolin and Ground Granulated Blast Furnace Slag (GGBS) based Geopolymer Concrete mixes at various proportions. Methods/Statistical Analysis: In this study, Geopolymer showed great potential and did not need the presence of Portland cement as a binder. Geopolymer concrete was prepared by using an alkaline solution of the suitable chemical composition. The ratio of the mixture was 2.5 and the concentration of sodium hydroxide was 10M. The geopolymer concrete specimens were tested for different types of strengths for 3, 7, and 28 days and cured at ambient temperature. This study helped in gaining knowledge about the morphological composition of concrete which might result in path-breaking trends in the construction industry.

P. Malleswara Rao and K. Hamantha Raja [40]. investigated the properties of metakiolin and GGBS based geopolymer concrete. Methods/Statistical Analysis: In this connection, Geopolymer was the binder inorganic polymer. Geopolymer concrete will be introduced as an alternative concrete which did not use any cement in its mixture and used Metakaolin and GGBS as alternative cement. NaOH and Na_2SiO_3 were used as activator solution. Geopolymer concrete was prepared using the solution of sodium silicate mixed with sodium hydroxide. The fixed ratio of sodium silicate to sodium hydroxide is 2.5 and the concentration of sodium hydroxide is 8M. The geo polymer concrete specimens were tested for compressive strength for 28 days and cured at ambient temperature.

V. Keerthy and Y. Himath Kumar [41]. managed to investigate the quality properties of geopolymer concrete. The primary point of this anticipate is to utilize ground granulated impact heater slag and fly fiery remains set up of common Portland concrete, keeping in mind the end goal to decrease carbon dioxide emanation. Method: From this, we can look at the properties of geopolymer concrete with bond concrete. The fixings utilized are GGBS and Fly cinder. Sodium hydroxide and sodium silicate are utilized as basic activators. The molarity of sodium hydroxide is 8M and 10M. The proportion of soluble activators is 1:2. Calcium silicate is framed when GGBS gets responded with sodium hydroxide and sodium silicate. This calcium silicate goes about as a cover for coarse total and fine total. The response is said to be exothermic since the warmth is developed when calcium silicate is framed. Henceforth, the underlying warmth is not required to begin the polymerization procedure. The fly fiery remains and GGBS are supplanted in 5 distinctive extents (100% GGBS, 75% GGBS &25% Fly cider, half GGBS &50% Fly slag, 25% GGBS&75% Fly powder,). The samples were cured at room temperature and tested at 7 and 28 days. The test incorporated compressive quality, split elasticity and flexure quality to contrast the outcomes and bond concrete.

The primary object of N. Durga Prasad and Y. Himath Kumar [42]. was to observe the mechanical properties of geopolymer concrete with GGBS and FLYASH. Sodium hydroxide and Sodium Silicate (NAOH and Na_2SiO_3) area unit used as basic activators. The molarity of Sodium hydroxide is 10M and 12M.The ratio of basic activators are1:2. Having similar properties to cement concrete and attaining equal strength, the geopolymer concrete reduces greenhouse emission. The proportions used were 100% GGBS, 75% GGBS & 25% fly ash, 50% GGBS & 50% fly ash, 25% GGBS & 75% fly ash. The ambient natural process at space temperature is completed for an amount of seven and twenty eight days. The mechanical properties were identified by compressive, flexural, split tensile strength tests through which the results were compared for 10 M and 12 M.

S. Kavitha and T. Felix Kala [43]. made an attempt to investigate the effect of Eco-bamboo fibers on the strength behavior of FRSCC partially replacing cement with GGBS and Alccofine. An innovative natural plant bamboo fiber where more atmospheric CO2 could potentially be sequestered and it is extracted by using mechanical method was used in this study and cement being costly, replaced by waste material GGBS, ALLCOFINE is added to produce high strength and performance concrete. A mix proportion of SCC was arrived by using trial and error method and w/c ratio was maintained constant for all the mixes. The bamboo fibres of 1% (l/d ratio=40 which already evaluated by experiment) of 4.9mm length to the weight of cement are added to the SCC which cement is partially replaced by 30% GGBS and 10% of Alcofine. The outcome of using bamboo fibers in the compressive strength, split tensile strength and the flexural behavior were studied. The addition of bamboo fibers also made the concrete very resistive in flexure and maximum improvement in 28 days strength was observed to be 6.1 N/mm2, hence addition of bamboo fiber content increases the flexural strength in SCC also with the replacement of GGBS and alccofine.

In the study conducted by N. Lokeshwaran., et., al. [44]. self-compacting concretes were considered using GGBS by replacing Portland cement with 10%, 20%, 30%, 40% and 50% by weight. The rheological and mechanical properties of SCG (GGBS incorporated SCC) were found to be increased compared to conventional concrete. Six reinforced concrete beams (SCGB) of shear span to depth ratio (a/d) 2 were tested for flexural capacity and ductile behaviour. The experimental cracking moment of SCGB beams were found to be more than the theoretical cracking moment enhancing its flexural resistance. Also, SCGB beams with higher percentage of GGBS exhibited higher ductility. The outcomes revealed that use of GGBS in SCC enables higher performance with economy and sustainability.

Prakash Kini and Sridevi H [45]. investigated the response of the adsorbent GGBS against phosphorus removal from human urine through batch adsorption experiment. It is necessary to treat human urine at the source, a major contributor of phosphorus in domestic wastewater to reduce adverse effects on aquatic life due to high nutrient manifestation with water bodies. Human urine sample required for the study were collected from ten young to middle aged persons and diluted with 50% tap water to mimic the flushing system in the source separated toilets. Batch adsorption experiments for various GGBS dosage and contact time were studied with necessary pH corrections. The results showed the phosphorus removal efficiency of more than 90% at the dosage of 700g/L and the contact time of 120min. The required pH range to achieve this efficiency was found to be 6-9, a normal pH range of fresh and stored urine as well. The final pH value of diluted human urine was reached around 8.70 from the initial value of 6.28 during the storage period due to urea hydrolysis. This upsurge in pH will evade the necessity of pH correction by artificial means to improve the phosphorus removal efficiency.

GPC is a hardened cementation paste made from GGBS and alkaline solution. N. Veerendra Babu., et., al. [46]. observed the effect of GGBS based on GPC and by replacing of 100% GGBS with OPC. The molarity of sodium hydroxide is 6, 8, and 10molar respectively. The proportion of soluble activators is 1:2. Calcium silicate is framed when GGBS gets responded with sodium hydroxide and sodium silicate. A mix proportion for Geopolymer concrete was designed by assuming the unit weight of geopolymer concrete as 2400 kg/m3. To conduct the GPC with GGBS to analyse the progressions of properties like strength and durability.

Preetham Siddhartha Reddy., et., al. [47]. determined the fatigue behaviour of concrete using GGBS and Robosand. The work was done by replacing cement and fine aggregate with GGBS and Robosand which was tested under static loading on 28 days. From the result, it was observed that there was an increase in the fatigue strength of high-performance concrete compared to conventional concrete. The replacement of 50% of cement with GGBS gets maximum increase in compressive strength of 55.82 N/mm^2. The increase in the flexural strength was seen due to the increase in the percentage of Robosand and GGBS, the highest value of the flexural strength obtained was 21.790 N/mm^2.

D. Mani Deep and N. A. Jabez [48]. focused on investigating characteristics of M60 grade concrete with partial replacement of cement with GGBS and fly ash. GGBS replacing cement via 10%, 15%, 20% and fly ash replacing cement as 5% constant. The cubes, cylinders and prisms were tested for compressive strength, split tensile strength and flexural strength. Durability studies with sulphuric acid and hydrochloric acid were also conducted. The compressive strength and split tensile strength increased by replacement of cement with fly ash and GGBS (5%+15%) in acidic environment. The durability properties were improved with the replacement of GGBFS and Fly ash and optimum values obtained by replacing fly ash by 5% and GGBS by 15%. By replacement of GGBS the attack due to acid was reduced and it results in reduction of weight loss parameters. The RCPT test, it clearly showed that the addition of GGBS and Fly ash the chloride penetration was reduced.

Allen Frost James., et., al. [49]. aimed at exploring the effect of Human hair and GGBS replacements on different properties of concrete and finding the efficient and alternate way for disposing the solid wastes to reduce the pollution generated from these wastes. The research focused on both structural as well environmental implications of both human hair and GGBS. The different specimens consisting of both GGBS and human hair were cast and tested on CTM. The results of different samples were compared with the controlled. From research findings it was found that there was improvement in strength parameters of concrete with the incorporation of human hair along with GGBS. Strictly from the research it is observed that the maximum strength derived is at 1% human hair and 20% GGBS replacements. With the addition of both waste materials, there is reduction in dead load of the structure thus this exploration would turn out to be quite useful for those structures where emphasis is on using lightweight materials.

S. Sai Sandeep., et., al. [50]. concentrated on exploring qualities of GGBS and including metakaoline based Geopolymer mortar 3D shapes with M40 Grade mortar 3D square. The authors concentrated on researching qualities of Geopolymer mortar shapes with different relative of supplanting of bond with GGBS and including metakaoline.

R. Nithyanandham and G. Augustine Maniraj Pandian [51]. proposed to investigate the strength characteristics of pebble concrete with partial replacement of cement by GGBS. This research was an attempt to study experimentally the strength characteristics of Pebble aggregates in concrete. In this study, several specimens were cast and tested to understand the strength characteristics of pebble aggregates.

K. Nagendra Reddy., et., al. [52]. used GGBS and metakaolin to produce alkali activated slag mortar with the effect of alkaline activator concentration. Alkali activated slag mortar was accelerated using alkaline solution of sodium silicate mixed with sodium hydroxide. The fixed ratio of sodium silicate to sodium hydroxide is 2.5:1 and the concentration of sodium hydroxide was taken as 10M. Substitution of mineral admixture also influenced strength performance of AAS mortars. The use of alkaline activation system is the best method to prepare industrial by-product concrete. Moreover, alkali activated product itself gains superior properties which lead to the system become the most interesting method to produce sustainable concrete.

V. Vinod., et., al. [53]. studied the strength properties of concrete by partially replacing cement with GGBS. Concrete cubes were prepared by replacing the cement with GGBS in four different proportions (5%, 10%, 15% and 20%). The cubes cast with the above proportions were tested for the compressive strength and the values obtained were compared with those of control specimens at the end of 7, 14 and 28day curing periods.

Kuldeep R. Dabhekar., et., al. [54]. carried out an experimental laboratory investigation of concrete on partial replacement of GGBS with cement. Cementitious waste material GGBFS was utilized in concrete with replacement at different percentage of cement to compare compressive strength and UPV value of GGBFS concrete at different percentage and at different age of concrete. To improve workability of GGBFS concrete, the Visco Flux 2203 super plasticizer was used after testing the properties of GGBFS to make better workability of concrete. The number of samples was tested under different percentage of GGBFS and cement combination with M40 grade of concrete. This was the second phase of the research in this study the comparison was between normal concrete of grade M40 with replacement of GGBFS as a cementitious waste material partially as per the above-mentioned percentage of replacements. The result of compressive strength was acceptable as comparing normal M40 grade of concrete if the curing age was more than 28 days but at the early age of all the replacement samples were having lower strength as comparing the normal concrete strength.

R. Nagesh Kumar., et., al. [55]. carried out experimental study on the properties of SCC. PC replaced with GGBS and coarse aggregate replaced with broken tiles, in 10%, 20%, 30%, 40% is and 50% proportioning ratios. The influence of mineral admixture and inert aggregate on the workability, compressive strength, split tensile strength and flexural strengths of SCC were examined for M30 grade SCC. The test results showed the optimum IS proportion for this grade was found at 30% and the green SCC were within IS acceptable limits.

Amir Moohmend and Sandeep Salhotra [56]. in review study, the addition of PET fibre in concrete at different length and width and PET in concrete 0.5%, to 3% ratio mix in concrete. GGBS also replaces the cement at 30%, 40% and 50%. According IS code various mix design is used for this type of mix, mainly 43, 53 grades of cement were used as most of research. Cubes, beams and cylinder examined for 7, 28 and 56 days to the mechanical property of concrete in which compression test, split tensile test and flexural test were shown at hard concrete and compaction checked at fresh concrete. As observed from the various literature results, the strength of GGBS and PET fibre concrete decreased as increased in length and percentage of fibre. But PET fibre with GGBS took time to gain strength, but mostly it showed fair results.

High Strength concrete is widely used for construction of high-rise structures, bridges and so on. But using HSC cost us more. Alternately we can use some admixtures which can increase strength indirectly. M Prathap Kumar., et., al. [57]. used GGBS, Fly ash and SP-430 Super plasticizers. On conducting different trail mixes, it was as certained that by using 10% of fly ash, 30% of GGBS & 60% of Cement leads to 10.3% raise in compressive strength for 28 days and 30.8 % for 180 days.

High seismicity in geographical region requires the use of high-level steel reinforcement in construction. The use of SCC appeared as a solution to improve the filling up of zones which are not very accessible to conventional method of concrete compaction. But use of the Self-compacting concrete is uneconomical. K Suresh., et., al. [58]. tried to make it economical by replacing cement with other by products. In this research, replaced cement with GGBS and Silica fume. By conducting trail mixes with those products to know that the strength increased for the mix of 20% GGBS and 4.23 % of Silica fume and after that it declined.

V. Nagendra., et., al. [59]. presented the effect of GGBS and Nano-Silica (NS) as mineral admixtures in concrete, with specific size of particle passing through particular size of sieves along with varying dosages. The experimental work was carried out in two stages. In the first stage, the GGBS effect was studied as replacement to cement in various proportions of 10, 20, 30 and 40% and the size of particles for each replacement is varying from 20μm to 250 μm. At first stage, the results showed that, at 20% replacement of cement, the strength is optimum for particle size of 20 μm. In the second stage, the effective dosage of nanosilica along with GGBS was studied. In second stage, the 20% of GGBS was taken as constant and the nanosilica was varied in the proportion of 2, 4 and 6%. From all the results, it was noticed that GGBS addition with nanosilica for concrete has the maximum strength yield at 4%NS and 20% GGBS replacement for 20μm particle size.

P. Uday Kumar and B. Sarath Chandra Kumar [60]. focused on investigating characteristics of GGBS and adding metakaoline based Geopolymer Concrete with M40 Grade Concrete. This leads to examine the admixtures to improve the performance of the concrete. It also focused on investigating characteristics of Geopolymer concrete with various proportional of replacement of cement with GGBS and adding metakaoline. The reinforcement was designed considering a balance section for the expected characteristic strength. All the specimens were tested by using two-point loading. The load deflection characteristics of the RPCC beams and RGPC beams are almost similar. The cracking moment was marginally lower for RGPC beams compared to ROPC beams. The cracking patterns and failure modes observed for RGPC beams were found to be similar to the ROPC beams. The total number of the flexural cracks developed was almost same for all the beams. The beams failed initially by yielding of the tensile steel followed by the crushing of concrete in the compression face.

M. Vijaya Sekhar Reddy and M. Seshalalitha [61]. evaluated the strength properties of high-performance concrete using GGBS and Robosand. The mechanical properties of M_{60} HPC concrete with partial replacement of Cement by GGBS and fine aggregate by Robo sand (crusher dust) with the addition of superplasticizer was evaluated. In M_{60} grade of concrete as the water-cement ratio of 0.25 was insufficient to provide the good workability, hence superplasticizer is necessary for the development of HPC. It is observed that the maximum compressive strength achieved in M_{60} grade of concrete is 65.3MPa with 40% replacement of cement by GGBS and 15% replacement of Fine aggregate by Robosand. From the experimental results the Robosand can be used as an alternative material for the fine aggregate and GGBS can be partially replaced with the cement.

P. Muthupriya [62]. investigated the characteristics of M75 concrete with partial replacement of cement with GGBS and glass fibre. Ten mixes were studied with GGBS & Glass Fibre using a water binder ratio of 0.26 and super plasticizer CONPLAST SP-430. The cubes and cylinders were tested for both compressive and tensile strengths GGBS can enhance the durability aspects of HPC compared to control mix. Among the mixes, the mix with replacement level as 7.5% GGBS and 0.3% glass fibre was better with respect to strength and durability. It was found that, by the partial replacement of cement with GGBS and glass fibre helped in improving the strength of the concrete substantially compared to normal mix concrete.

V. S. Tamilarasan., et., al. [63]. took up the workability studies on concrete with GGBS as a replacement material for cement with and without superplasticiser. Concrete grades of M_{20} and M_{25} have been taken for the work. The mixes were designated using IS code method. GGBS replacement adopted was 0% to 100% in steps of 5%. Slump test, Compaction factor test, Vee Bee Consistometer and flow test were conducted. The degree of workability of concrete was improved with the addition of GGBS in concrete up to 45% replacement level for M_{20} grade concrete and degree of workability of concrete was improved up to 50% replacement for M_{25} grade concrete. From the results obtained it is known that M_{25} grade concrete has better workability compared to M_{20} grade concrete. So GGBS cement used as a substitute for cement which will reduce the cost of cement in concrete and also reduce the consumption of cement.

B. Rajendra., et., al. [64]. studied the stabilization of black cotton soil using cement flyash and GGBS. The characteristics of Black cotton soils, with different proportions (10%, 20%, and 30%) of Cement, Fly-ash and GGBS one at a time and the evolution of their properties of Black cotton soil were studied. From the study GGBS gave less dry density than Cement and Fly-ash at any varied percentage but increased compared to normal black cotton soil.

S. P. Sangeetha and S. P. Joanna [65]. investigated the structural behaviour of reinforced concrete beam with various replacement levels of GGBS. Experimental investigation included testing of six reinforced concrete beams with and without GGBS. Portland cement was replaced with 30% and 40% GGBS. Glenium B233 was used as superplastisizer for the casting of beams to improve the workability. Two specimens were cast in each series. All the specimens were tested under two-point static loading. Data presented include the load-deflection characteristics, cracking behaviour and stress strain characteristics of the reinforced concrete beams with and without GGBS when tested at 28th days and 56th days. The investigation revealed that the flexural behaviours of reinforced GGBS concrete beams are comparable to that of reinforced concrete beams.

SUMMARY

The concepts relating to iron ore industry by-product's management are still emerging and undergoing continuous review and upgradation in India. Literature review has shown that there is enormous scope for such a detailed investigation to bring out an optimum usage of GGBFS & GGBFSS.

Using of SS in concrete manufacturing is a sustainable development. Improvements and results on usage of Slag and SS are discussed by addressing its beneficial effects and possible drawbacks in cement and concrete production. Utilizing Slag and SS at large-scale due to huge scale production, which if dumped causes serious environmental problems. In this regard, the construction industry can play an important role. Slag and SS usage as aggregates in cement and concrete production or as supplementary cementitious material which has an important environmental impact also higher long-term strength and improved long-term durability can be achieved. Also workability of concrete using Slag and SS should be studied in detail. In the present situation, Slag and SS has not yet reached a high level of utilization in India. Possible reason is non availability of reliable data on its properties. More studies should be conducted with locally available material to overcome the difficulties encountered. However, high levels of utilization of Slag and SS in some developed countries has given encouraging results, gives hope for the future. Volume instability due to free CaO and MgO are obstacles in increasing the level of usage, but can be solved by using it along with GGBS as combined admixture. Another difficulty is the water absorption capacity of Slag and SS aggregates as compared with natural aggregate. Therefore, investigations should be conducted in the future for potential uses of Slag and SS in concrete.

Research Gaps

The following research gaps has been identified in this review paper.

1. Mechanical strengths of GGBFS and GGBFSS mortar and concrete cured for short and long durations.
2. Durability studies Acid and alkali attacks on mortar and structural concrete.
3. Behaviour of GGBFS and GGBFSS with mortar and structural concrete exposed different environmental conditions (Freezing and Thawing).
4. Micro structural analysis (XRD, EDX, FTIR, SEM, TGA) of GGBFS, GGBFSS mortar, concrete and acid alkali attacked concrete.

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