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UTILIZATION OF SLAG IN THE PRODUCTION OF GREEN CONCRETE-REVIEW

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Abstract: Ordinary Portland cement (OPC) requires approximately 4.0 G Joule energy to produce one ton of CO2 emissions. In an endeavor to protect the environment, alkali-activated slag (AAS) can either completely replace OPC as a binder or be combined with ground granulated blast-furnace slag (GGBFS). In addition to being eco-friendly, this concrete allays worries about energy consumption, raw material costs, and production expenses associated with conventional concrete. The utilization of GGBFS and AAS in the concrete matrix is encouraged by their cementitious qualities. Because AAS is more pumpable, chemically stable, and resistant to harsh environments, it is receiving increased attention when used in conjunction with slag to generate OPC or when it is used in its whole instead of cement. This essay examines the chemistry, clean production, and source. This literature review also objects to provide reviews on the properties, hardening conditions, and behaviors of GGBFS and AAS -based concrete composites as well as to synopsize the research development trends to generate comprehensive insights into the potential applications of GGBFS and AAS concrete as raw building materials for making sustainable and greener concrete composites, towards industrializing ecofriendly buildings today.

***Index Terms* – Slag, Concrete.**

I. INTRODUCTION

Between 4 and 6% of the world's CO2 emissions from the building sector come from the manufacturing of cement. The calcination of calcium carbonate results in direct emissions, while the combustion of fossil fuels, the processing of minerals, and transportation all contribute indirectly to the carbon footprint of cement manufacturing. Huge efforts have been made to lower the carbon footprint connected to cement production in order to minimize environmental effects. One of these is cement replacement, in which ground granulated blast-furnace slag (GGBFS), pozzolanic material, is used in part place of cement to create blended cement. Germany created the first slag-based cement that was sold commercially in 1865. Presently, slag cement is used in more than 200 million tons per year worldwide. As iron is processed in steel plants to remove impurities from iron ore, metal slag is a ferrous slag, industrial waste, and by-product of the iron industry. In order to create GGBFS, the molten slag, a sintered metal product, is cooled under high water jet pressure. When mineral crystallization cannot happen in a timely manner, the slag travels through 80% to 90% of the glass phases. The production of steel is responsible for 13–20% of carbon emissions.

The sixteenth component of supplemental cementitious materials (SCM), which are used to produce high-performance concrete and can increase the strength and durability of concrete, is slag. The extremely fine powdered slag, with a bulk density of 1200 kg/m3 and a surface area of 400–600 m2/kg, can be combined with free lime to replace 40%–65% of the cement content overall. However, coarser slag powder can be substituted for aggregate in the concrete matrix. Slag has cementitious properties similar to OPC, while having a low hydration activity. Slag aids concrete manufacturing in a number of ways. It greatly lowers the cement's hydration heat, increases concrete's durability, long-term compressive strength, and adiabatic temperature rise. One type of slag that can substitute a high cement content in the manufacturing of concrete is GGBFS, however it may cost less in terms of mechanical strength. The larger particle size of GGBFS also has worse cementing qualities, which may lessen the binding of GGBFS particles to calcium silicate hydrate gels. Large volumes of steel slag may also cause coarser pore structures to form, which would be detrimental to the strength and durability of the concrete. However, a composite binder made of GGBFS was found to have enhanced concrete rheology, extended setting times, refined porosities, and produced enough compressive strength in earlier investigations.

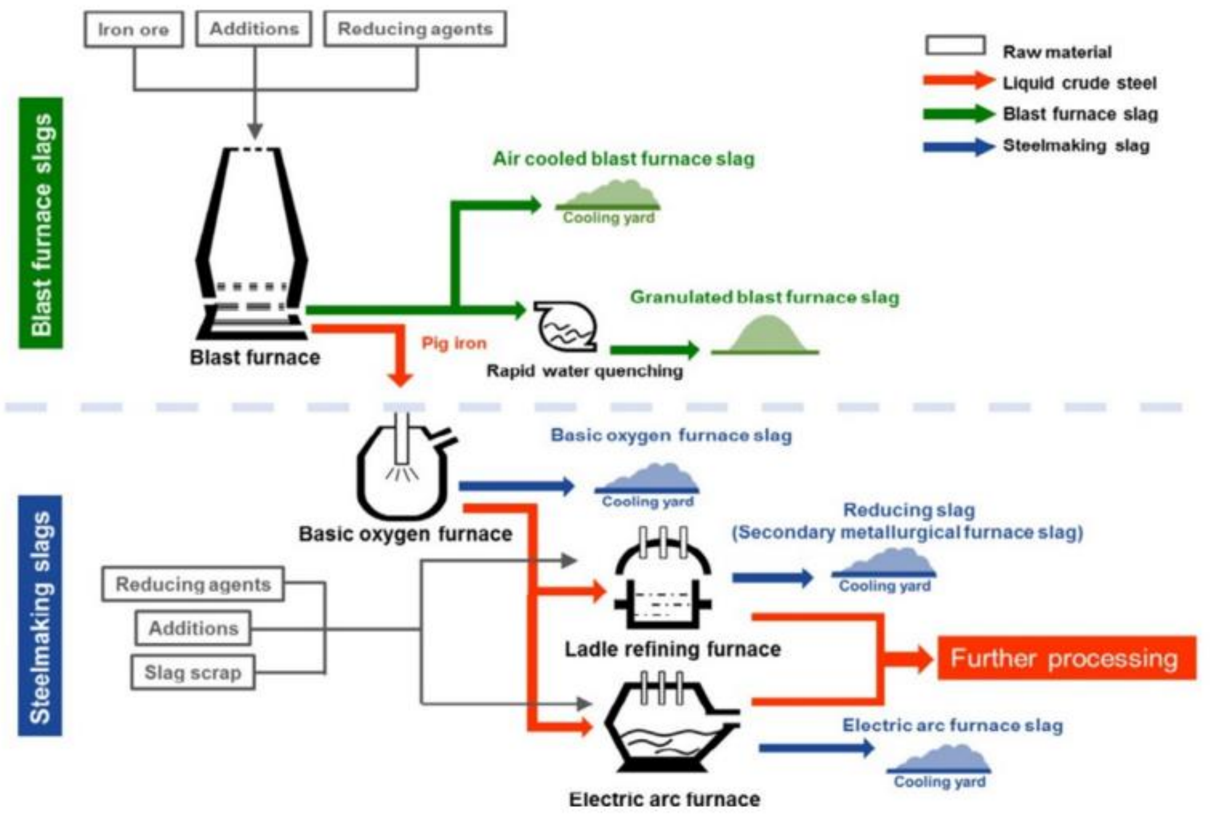

Figure 1. Source and Production of Slags.

Source of slag	Use of slag	Property	Uses
GGBFS	Air-cooled slag	Hydraulic property Non-reactive alkali-aggregate Low K_2O and Na_2O Heat insulator and noise attenuation effects when formed a fiber Component of fertilizer (CaO, SiO_2)	Material for road base As coarse aggregate in the construction sector Replacement for clay as cement clinker raw material The raw material for rock wool Calcium silicate fertilizer
	Granulated slag	Vigorous latent hydraulic reactivity when finely milled. Low Na_2O and K_2O Latent hydraulic property Weightless, high internal friction angle, high permeability of water Omits chlorides. Non-reactive alkali-aggregate Component of fertilizer (CaO, SiO_2)	The raw material for GGBFS Blending material for OPC Concrete admixtures The raw material for cement clinker (clay replacement) Material for civilian activities and material for the improvement of soil As a fine aggregate for concrete Calcium silicate fertilizer Improvement of soils
Steel-making slag	Rehabilitated slag, electric arc furnace slag	Hard wear-resistant Hydraulic property High internal friction angle Components of SiO_2, FeO, CaO Component of fertilizer (MgO, SiO_2, FeO, CaO)	Aggregate for asphalt concrete Base course material Material for civilian activities and material for the improvement of soil (sand compaction piles) Base material for cement clinker Used in the production of fertilizer and improvement of soil

Figure 1. Major Properties and Uses of Slag.

II. . CHEMICAL COMPOSITION AND REACTIONS

The basic materials used in the iron-making process determine the composition of the slag. The application of GGBFS as an AAS in construction has a lot of promise. According to GGBFS, the main chemical components of the relevant slag are silica (35%), calcium oxide (40%), alumina (13%), and magnesia (8%). The remaining trace elements consist of sulfur, iron, titanium, manganese, and alkaline metal oxides. The amount of glass suitable for blending with OPC typically ranges from 90% to 100%, and a lot depends on the slag's initial cooling temperature and cooling technique. Table 2 provides a summary of GGBFS's chemical makeup. When crushed into a fine powder, GGBFS exhibits cementitious properties, crystalline and glassy phases, and mildly alkaline properties. Its leachate is somewhat alkaline when used as a partial binder in a mineral additive or blended cement, but because of a small amount of self-contained sulfur, the concrete is not at risk of corroding. After that, the slags, or GGBFS, are activated and hydrated for use in AAS concrete.

Table 1. Chemical Composition of GGBFS

Chemical	OPC	GGBFS
SiO2	20.7	35.34

Al2O3	0.15	11.59
CaO	52.7	41.99
MgO	2.24	8.04
K2O	0.41	-
Fe2O3	5.63	0.35
Na2O	4.54	-
TiO2	0.86	-
P2O5	0.54	0.37
MnO	0.76	0.45
LOI	9.81	0.008

Activation and hydration reaction of AAS with GGBFS

GGBFS by itself provides only a minimal level of hydration. Sulfates and alkalis activate GGBFS, which then has a pore-inhibiting impact on OPC. This has been demonstrated in a study where it was claimed that upon contact with water, a Si-Al-O layer formed on the surfaces of a Canadian GGBFS [47]. This absorption of H+ ions by the Si-Al-O layer led to an increase in OH– ions and the pH value of the solution. This made it more difficult to break the Si-O and Al-O link, which led to the creation of C-A-S-H or C-A-H and C-S-H hydration compounds further on. Not much CS-H was generated, even after 150 days of moist curing. However, GGBFS-based concrete's small pores provide reduced permeability, greatly enhancing its durability. The PH, activator, and composition of the slag all have an impact on the hydration products of AAS with GGBFS. Regardless of the activator used, the primary hydration product is calcium silicate hydrate (CSH), which has a low C/S ratio and various degrees of crystallinity. The majority of earlier studies came to the conclusion that hydrotalcite and C-S-H gel were combined to form a thin crytal layer. Nevertheless, crystalline C-S-H might not be dominant in a high pH environment as there isn't a new crystalline peak with AAS of GGBFS.

Hydration process with GGBFS as partial cement replacement

It has been found that in an adiabatic environment, OPC concrete blended with 20 to 80% GGBFS took less time to reach peak hydration in terms of heat hydration. The quantity of GGBFS rose. In the meantime, the observed rates of plain concrete were typically lower than the normalized peak heat rates. This demonstrates unequivocally that heat generation has happened in GGBFS-based concrete from very early on. The study also revealed that when GGBFS and cement are combined, Ca(OH)2 is produced by its self-hydration. Once the Ca(OH)2 solution is saturated, GGBFS consumes the Ca(OH)2 again during a pozzolanic process. This indicates that the rate of reaction and the creation of a Ca(OH)2 saturated solution determine the number of Ca(OH)2 crystals. When the reaction rate is slower than the formation rate, more Ca(OH)2 crystals are generally produced, which can be seen through the height of the X-ray diffraction (XRD) peak [84]. The XRD peak reportedly peaked at a 40% OPC replacement rate with GGBFS and a 425 m2 /kg specific surface area [85]. When compared to an identical OPC, GGBFS generally performs better as a cementitious material, helping to attain higher compressive strength at both the early and long-term strengths. The activation of alkali activators, such NaOH, controls this.

III. Physical properties of GGBFS

As covered in the ensuing subsections, the particle shape and size distribution, specific gravity, bulk density, color, fineness, and hydration activity index of GGBFS have a substantial impact on their physical characteristics prior to activation. GGBFS is significantly lighter than OPC, with a bulk density that varies between 1000 and 1400 kg/m3. Its color is almost off-white. When the cement replacement rate is more than 50%, GGBFS concrete also has a white hue. The color may contribute to a building's pleasing visual impression, and using concrete based on GGBFS frequently relaxes the pigmentation restrictions. Although some have gone as high as 85%, a replacement rate of between 50% and 70% is excellent to get a light color painting. Additionally, the surface of GGBFS-concrete is smoother and free of defects. However, according to their cement mortar composite tests, if the GGBFS contains sulfur, it could give the concrete a blue or green tint. In summary, the color and efflorescence of the resulting concrete can be greatly affected by substituting GGBFS for cement. Conversely, the self-consolidating concrete's (SCC) workability is significantly impacted by the bulk density of GGBFS. The pozzolanic reaction creates morel C-S-H gels with GGBFS of aggregate sizes, which boost the paste's density and reduce micropores in it to create a more vigorous paste.

Table 2. Typical Physical properties of GGBFS

Property	Value
Color	Off-White
Specific Gravity	2.9
Bulk Density	1200–1300 kg/m3 (vibrated) 1000–1100 kg/m3 (loose)
Fineness	Greater than 350 m2 /kg

Distribution of particle size and specific gravity

The binder's distribution of particle size, or DPS, is a crucial physical characteristic that influences the binder service characteristics and is employed to attain the best possible performance in a more regulated concrete mixture. Regarding this, GGBFS is a highly cementitious substance that, when ground into a fine powder, has a high specific surface area, experiences an OPC-like hydration reaction, and shows less crystal formation. The specific gravity of GGBFS is approximately 2.9 on average, with a range of 2.85 to 2.95. The Particle Size Analyzer (PSA) laser is typically used to assess the DPS of GGBFS with a specific grinding time. Because of their comparatively larger reactive surface area, finer slags tend to increase the hydration heat.

Fineness and hydration activity index

When the specific surface area of GGBFS increases, so does the hydration activity and compressive strength of GGBFS-based concrete. However, a gray correlation analysis shows that it is not exceeded by 350 m2/kg. Although stronger particles are produced when coarser and finer particles are combined, increased fineness often improves fluidity. According to reports, a number of factors, including sorption, porosity, compressive strength, and resistance to chloride-ion penetration, were taken into account when examining the impact of nano-slag on high strength concrete. The high strength concrete with 10% ground nanoslag, according to the results, showed greater strength and durability. Furthermore, it is not advised to disperse ground nano slag at a ratio of less than 5, as this will not result in the desired strength.

IV. Effect on Compressive strength of Concrete

In order to support the applied structural and service loads during the hardened stage, GGBFS concrete must have a sufficient hardness. GGBFS's mechanical qualities need to be strengthened because it is primarily utilized as concrete and cement in building supplies. The modulus of elasticity, flexural strength, splitting tensile strength, and compressive strength are among the mechanical characteristics of GGBFS.

Because it contains less free lime and more C-S-H gel, GGBFS-based concrete essentially has a greater ultimate strength than OPC concrete. Within ten to twelve years, GGBFS-based concrete may continue to strengthen until it doubles the 28-day strength. In general, a concrete mix containing 50% GGBFS can produce a similar characteristic strength to that with an OPC content. Elevated GGBFS replacement level has the potential to boost cementitious content and quickly attain comparable 28-day strength. Over a specific time period, the creation of concrete strength may be somewhat impacted by the slag's origin. It has recorded an increase in strength of 8.6% and 19.5% at a GGBFS replacement rate of 50% and 65%, respectively, for an OPC concrete mixture, depending on the average efficiency function (k). Additionally, it has been proposed that the development of early strength in greener concretes can be accomplished with a specified water/cement content of 0.35 rather than 0.45 w/c ratio and a 1:1 mixing ratio of GGBFS to calcium aluminate. Additionally, it is discovered that the concrete containing 50% GGBFS has a reasonable late-age compressive strength, being much less at 7 days, closer to plain cement concrete at 28 days, and less than 3.6% at 90 days than plain cement concrete.

A year-long, comprehensive study on OPC concrete with FA and GGBFS was carried out. The findings showed that, in comparison to OPC concrete, a mixture of GGBFS and FA would produce early strength that was either acceptable or comparable while preserving long-term strength. According to Jos's study, early strength development at 20 and 90 days was lowest at an 80% replacement rate and highest at 40% and 60% replacement rate. It was revealed that the study's wet curing of GGBFS-based concrete with 20% and 40% substitution demonstrated higher compressive strength. The greatest compressive strength at a 15% replacement rate and the impact of GGBFS on high-performance concrete (HPC) up to 180 days are also documented.

V. Effect on Tensile & Flexural strength of Concrete

Two essential and significant characteristics of concrete are its splitting tensile strength and flexural strength. Two groups of the concrete specimen were used by the researcher; the first group was cured at 20 C +/- 3 C with a relative humidity of 20–35%, and the second group was cured at 42 C with a relative humidity of 20%. The outcomes demonstrated that the second batch of specimens had demonstrated remarkable flexural strength at a 40% cement replacement with GGBFS. This was explained by the SiO2 modifier's ability to react with Ca(OH)2 at high temperature. According to reports, 60% replacement is the ideal quantity to maintain flexural strength. Furthermore, at 40% replacement rate, the flexural strength was marginally decreased, and at 80% replacement rate, it was significantly lower.

Flexural fatigue in concrete based on GGBFS at 50% and 80% replacement rate was investigated by several studies. According to the study's findings, the fatigue period peaked at a 50% replacement rate and a stress level greater than 0.80. Three different HPCs' compressive strength performance is also studied at. 600 kg/m3 of OPC were found in the first series, 420 kg/m3 of OPC and 180 kg/m3 of GGBFS were found in the second series, and 60 kg/m3 of silica fume and 360 kg/m3 of OPC were found in the final series. The splitting tensile strength and compressive strength of every specimen containing GGBFS were significantly higher than those of OPC concrete.

Additionally, the impact of metakaolin (MK) and GGBFS on the flexural strength of concrete has been investigated, with results showing a significantly higher flexural strength at 70% OPC replacement with GGBFS. Additionally, they have noticed a slight decline in flexural strength at 40% GGBFS replacement and a larger decline at 70% replacement rate. The enhancement of the interfacial zone in the presence of both GGBFS and MK may be the cause of the improvement in flexural strength. After 90 days of curing, the flexural strength in the study was stronger even with a high replacement rate of 60%.

VI. Conclusion

It is well known that the industrial revolution and quick construction methods are to blame for the rise in demand for cement manufacture and a rise in global population. Because of these reasons, cement factories release CO2, which poses a serious ecological threat. The substantial amount of air pollution may exacerbate global warming. It is therefore crucial to look for other, environmentally friendly additional cementing materials. GGBFS is an engineering waste and by-product in the manufacturing of iron in a blast furnace. One of the "greenest" building materials is made by cooling molten iron slag and quenching hardened iron slag in water, resulting in a glassy granular material that is ground into a fine powder. Previous studies have mostly focused on the unique qualities of GGBFS concrete, namely its compressive strength, as opposed to its micro-fine morphological features. The majority of research also disregarded the impact of alkaline activator solutions, natural and artificial fibers, and GGBFS-based and AAS concrete matrix strength.

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