
# Various Uses of Blast Furnace Slag and Steel Slag in Concrete and Mortar: Review


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**ABSTRACT**

This paper presents a review to study the ideas of previous researches on using slag as a concrete material to get rid of the damage caused by it as a result of its accumulation in nature. The research also includes the types of slag and its production methods.

Slag is a non-metallic product resulting from the iron smelting process. It is considered an industrial waste that is harmful to the environment. Recently, many researchers have shed light on the use of these wastes in the field of construction in order to reduce their damage to the environment as well as take advantage of the properties that it's give to concrete to produce environmentally friendly concrete and also reduce the cost of producing building materials. The methods of using slag in the concrete differed. Some researchers used it as coarse aggregate and fine aggregate, and some used it as a cementitious material because it contains the same oxides as cement. The use of slag in concrete and mortar has given good results, and it has been concluded by looking at previous studies that the best percentage for using slag as coarse aggregate ranges from 30% to 40%, fine aggregate ranges from 20% to 30%, and cementitious materials up to 6%. The use of slag in concrete had a good effect on some properties of concrete, including compressive strength, split tensile strength, flexural strength, setting time, absorption, chloride penetration, and porosity.



**Keywords:** Types of Slag, Blast Furnace Slag, Steel Slag, Slag in concrete.


## 1. Introduction

The negative consequences of industrial waste are one of the most pressing issues facing our environment. Slag is one of these industrial waste materials. In recent years, a lot of studies have been done on how to solve environmental problems through is reducing industrial waste. The feasibility of employing industrial wastes such as fly ash, blast furnace slag, silica fume, cement kiln dust, and other wastes as material replacements in the construction process to produce environmentally friendly concrete has been investigated.

Slag is a non-metallic substance consisting mainly of a mixture of silica, alumina, lime, magnesia, and iron oxide. Slag varies according to the raw materials produced for it, the method of production, and the type of furnace. Usually, the slag produced from blast furnaces is called blast furnace slag. It contains several types divided according to the method of cooling, such as air-cooled slag, expanded slag, granulated blast furnace slag, and pelletized blast furnace slag, while the slag is produced from electric furnaces is called steel slag, and this type is produced from scrap smelting. The electric furnace helps with the possibility of rapid melting and maintaining heat. However, some disadvantages were noted to using this furnace, including the difficulty of controlling the electrical parameters of the electrode, which leads to arc breaking and excessive consumption of energy and the electrode, thus increasing the cost. The amount of slag production is estimated at approximately (0.3-1) ton for each ton of iron [1]. The method of treating slag varies according to the purposes for which it is used, in addition to the development of the countries producing it. The method of cooling and treating it also varies according to the raw materials used. The slag resulting from the process of smelting iron ores in blast furnaces is called blast furnace slag. As for the slag resulting from smelting iron used as scrap in electric arc furnaces and other furnaces, it is called steel slag [1]. The main difference between blast furnace slag (BFS) and steel slag (SS) is the iron concentration. FeO level in BFS is roughly 0.70%, but total iron content in SS ranges from 16% to 25%. Also, the chemical composition of slag affects the properties of concrete. For example, the strength decreases when the ratio of $SiO_2$ is low.

Manufactured gravels can use slag waste from iron and steel mills to produce lightweight aggregates. It is also possible to use slag as a cement, portland slag cement commonly constitutes between 30 and 45 percent of the cementing material in the mix. Some furnace slag concretes have a slag component of 70 percent or more of the cementitious material [2].

## 2. Aim of Research

The aim of this research was to identify the slag material and its types, and to review the previous literature on how to use slag in concrete and knowing the appropriate proportions for the use of this substance.

## 3. Types of Slag

There are different types of slag classified depending on the source as follows [3].

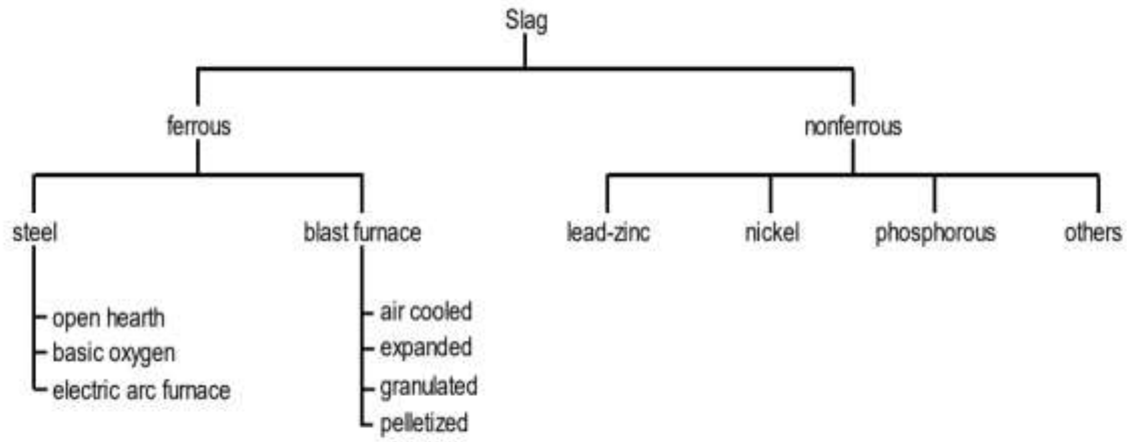



**Fig.1 Types of slag depending on the source [3]**

Blast furnace slag (BFS) is categorized based on how the molten slag is treated once it is removed from the oven. The types of BFS are as the following [3].

- Air-Cooled Blast Furnace Slag (ACBFS) is the material resulting from the hardening of molten BFS under normal weather conditions. The molten BFS is often dumped into a fossa, and jets of water are usually sprayed onto the surface of slag to accelerate cooling and facilitate expedited eviction of the material so as not to discourage the smelting process.

- Expanded slag or foamed slag: this type results from the treatment of molten slag with restrained quantities of water (lower than that required for granulation). Expanded slags are higher cellular and vesicular than the first type (ACBFS), and lighter in unit weight.
- Granulated Blast Furnace Slag (GBFS): Slag is created by rapidly quenching molten slag with water to production a granular, glassy product. When crushed to very soft, cement sized particles, this material has cementitious properties that make it a advisable material for partial replacement or supplement to portland cement. Because the grain size of GGBS is smaller than that of typical Portland cement, its strength is poor at first, but it gradually improves with time. High compressive strength, low heat of hydration, chemical resistance, superior workability, good durability, and cost-effectiveness describe the ideal GGBFS replacement as cementation material [4].
- Pelletized blast furnace slag: this type produced when the molten slag is cooled and solidified with air and water quenched in a spinning drum, resulting in the formation of particles, rather than a strong mass. By controlling the process, the pellets can be made more crystalline, which is better for aggregate use, or more glassy, which is extra suitable in cementitious applications.

## 4. Slag Production

The blast furnace is continually charged from the crest with $Fe_2O_3$ (ore, sinter, pellets), smelting stone (dolomite or limestone), and fuel in the manufacturing of iron (coke, typically). The blast furnace produces two products: molten iron that gathers in the undermost of the oven (hearth) and liquid material blast-furnace slag (BFS) that floats on the pool of molten metal. At a temperature of around 1500 °C, both kinds are regularly tapped from the furnace [5].

Air-cooled slag and granulated slag are the two types of BFS, as shown in Fig. 2. The former is made by cooling molten slag in open pits or yards, while the latter is made by rapidly cooling molten slag with a water jet; the former resembles crushed stone, while the latter resembles sand [6].

Air-cooled slag is usually used as coarse aggregate, while water-cooled slag (Granulated slag) is used as an aggregate for e.g., road construction and can be mixed with clinker and calcium sulphate to use as a binder for mortar, cement, grout, and concrete [7].

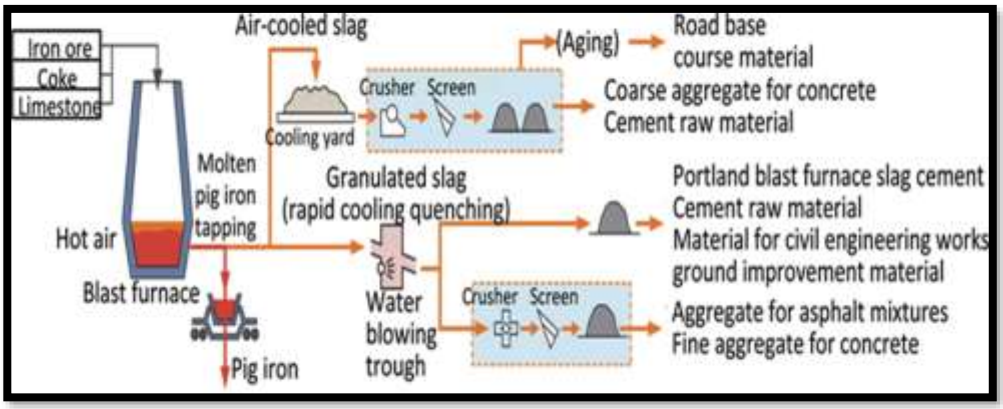



**Fig.2 Production flow of the blast furnace slag (BFS) [6]**

There is another type of furnace that produces slag called electric arc furnace (EAF), as shown in Fig. 3. The designed EAF can be used to smelt metal and slag. This EAF enables rapid melting with good heat preservation; however, some disadvantages have been observed in the designed EAF-induced smelting, namely, the electrical parameters of the electrode cannot be controlled simply, which leads to arc breaking, excessive electrode consumption, long time for smelting, high power consumption, and increased cost of single furnace smelting [8].

(EAF) slag, a by-product of steelmaking recovered back of the oxidizing process, is useful when employed as coarse aggregate in bituminous mixtures and hydraulic concrete. Concrete made with (EAF) oxidizing slag as an aggregate shows good physical and mechanical properties [9].

The usage of (EAF) slag aggregates can reduce the durability of concrete while increasing linear expansion [10].

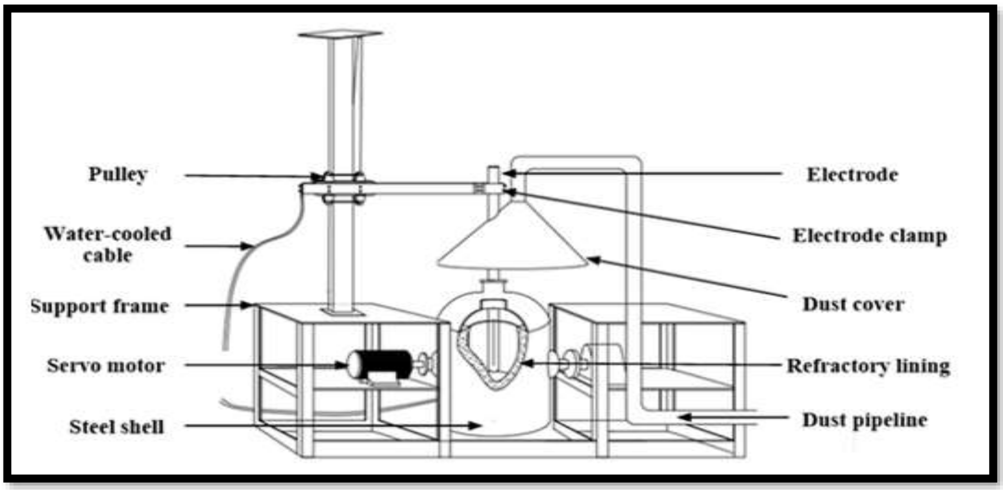



**Fig. 3 Schematic diagram for Electric Arc Furnace (EAF) [8]**

## 5. Steel Slag (SS) and Iron Slag (IS)

The slag produced at BF during pig iron manufacturing is called blast furnace slag or Iron Slag (IS). While the slag produced in the steel melting shop is called as steel slag (SS), see Fig. 4. Steel slag has the potential to be used as a raw mix component in the manufacturing of cement clinker up to 10%. Steel slag can also replace granulated blast furnace slag in the production of slag cement by up to 10%. Steel is made by oxidizing iron to remove extra silicon and carbon. Limestone and coke are used in the process. Steel slag has greater iron content and physical properties that are comparable to air-cooled iron slag. The main distinction between BF slag and steel slag is the iron concentration. FeO level in BF slag is roughly 0.70%, but total iron content in SS ranges from 16% to 25% [11].


**Fig. 4 Blast Furnace slag (Iron Slag) and Steel Slag.**

## 6. Physical and Chemical Requirements of BFS

The physical and chemical requirements of blast furnace slag BFS according to [12] are shown in the Tables (1) and (2):

**Table 1: Physical requirements (ASTM C 989-95, 1995) [12].**

| **Item** | | |
|---|---|---|
| Amount retained when wet screened on a 45 μm (sieve no. 325), max% | | 20 |
| Specific surface by air permeability, Method C 204 shall be determined and reported although no limits are required. | | --- |
| Air content of slag mortar, Max. % | | 12 |
| | **Average of last five consecutive samples** | **Any individual sample** |
| **Slag activity index, min,%** | | |
| **7 days index** | | |
| Grade 80 | --- | --- |
| Grade 100 | 75 | 70 |
| Grade 120 | 95 | 90 |
| **28 day index** | | |
| Grade 80 | 75 | 70 |
| Grade 100 | 95 | 90 |
| Grade 120 | 115 | 110 |

**Table 2: Chemical requirements (ASTM C 989-95, 1995) [12].**

| | |
|---|---|
| **Sulfide sulfur (S), Max.%** | 2.5 |
| **Sulfate ion reported as $SO_3$, Max.%** | 4.0 |

## 7. Effect of Slag on the Properties of Concrete and Mortar

The current studies focused on the use of industrial waste as alternatives to building materials used in the formation of concrete. The slag in the concrete is used as an additive material of different shapes such as a replacement to cement, replacement to aggregate, and filler material. Ground Granulated Blast Furnace Slag (GGBS) has some disadvantages on the concrete such as lower initial strength and higher dry shrinkage [13]. While many studies provided good results about the effect of slag on some properties of concrete, as shown below:

### 7.1 Compressive Strength

Compressive strength is one of the most important properties of concrete. The use of slag leads to a change in the compressive strength for the better, but in certain proportions. The adding of slag in various amounts improves the compressive strength of concrete by up to 6% of its weight. But when the slag percentage is more than 6%, the compressive strength decreases [14]. Slag concrete has a similar performance to conventional concrete and has a higher compressive strength.

(Liu, et al., 2011) [15] they used steel slag by 100% as gravel and sand. The compressive strength reached 59.6 MPa, while the compressive strength of conventional concrete was 45.4 MPa. Later, (Sezer and Gulderen, 2015) [16] used the same idea by using steel slag in some mixtures by 100% as fine aggregate and in other mixtures by 100% as coarse aggregate. Also, they used the steel slag by 100% as fine and coarse aggregate in the same mixture, but they did not give any results on the strength of this mixture due to segregation and they concluded that it is the best resistance obtained from the mixture in which steel slag was used as coarse aggregate, where the compressive strength increased by 2.2%, 7%, 2%, and 3.4% at ages 3, 7, 28, and 90 days, respectively. However, it is possible to use slag with fly ash as a partial substitute for cement. The addition of blast furnace slag by 9% with 40% of fly ash significantly improves the compressive strength, as the compressive strength increased by 33% when compared with conventional concrete (Ali and Abdullah, 2014) [4].

(Alberici, et al., 2016) [17] noted that the use of steel slag as a fine aggregate gives good results in terms of compressive strength, they use steel slag (SS) as partial replacement of sand by 0%, 10%, 20%, 30%, and 40%. After testing, it was observed that the compressive strength increased when using steel slag compared to the reference model, Where the compressive strength of the reference model was 37.6 MPa, and this value increased in the replacement ratio of 10 %, 20%, 30%, and 40%, reaching 39.98 MPa, 41.48 MPa, 45.1 MPa and 42.5 MPa, respectively. It was concluded that the best replacement rate is 30%. Adding steel slag as a fine aggregate to concrete can improve its dynamic and static compressive strength; the compressive strength subjected to impact loading increases at first, then decreases as the steel slag content increases, similarly under monotonic compression (Guo, et al., 2018) [18]. The chemical properties of the slag have an effect on the blends and their strength, the strength decreases when the ratio of $SiO_2$ is low. Ground Granulated Blast Furnace Slag GGBFS outperforms regular concrete because it contains twice as much of that compound, improving its strength even when compared to normal concrete (Parron-Rubio, et al., 2019) [19].

## 7.2 Split Tensile Strength

The split tensile strength improves as the amount of steel slag in the fine aggregate increases up to 30% by weight. For M25 grade concrete, the increase in split tensile strength is around 16.7% after 28 days of curing, and for M30 grade concrete, the increase is about 15.6 percent after 28 days of curing (Gupta and Saxena, 2017) [20]. As for as, when replaced the cement by 20% with slag type GGBFS, the split tensile strength also increases (Jeya, et al., 2020) [21].

## 7.3 Flexural Strength

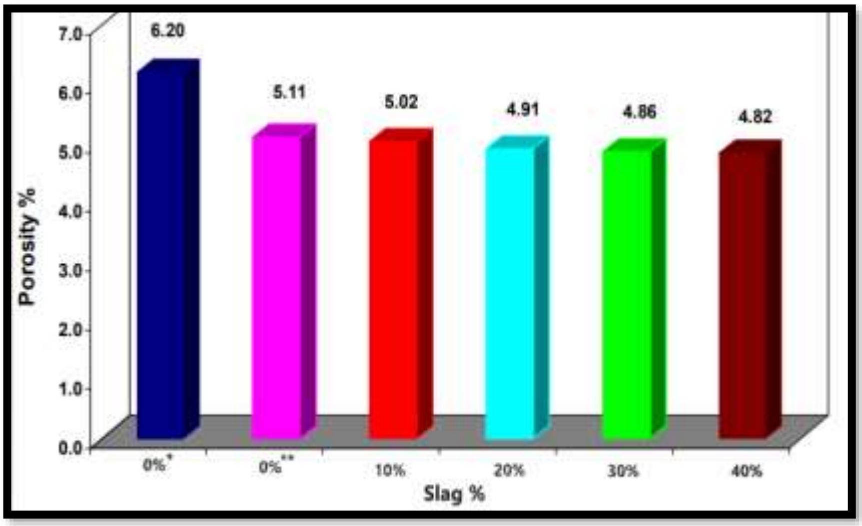
In terms of flexural strength, (Liu, et al., 2011) [15] noted that using steel slag as fine aggregate and coarse aggregate gives slightly lower flexural resistance when compared with the reference mixture, where the flexural strength decreased by 2.1% at 28 days than the reference mixture. While (Ali and Abdullah, 2014) [4] noted that the use of BF slag by 9% with 40% of fly ash as a partial substitute for cement increases the flexural strength by 33.34% when compared with the reference mixture, but it decreases when slag and fly ash are increased than these percentages. However, (Gupta and Saxena, 2017) [20] noted that the flexural strength rises by replacing 30% by weight of fine aggregate with amount of steel slag. The increase in flexural strength test is approximately 36.7 percent for M25 grade concrete and 24.7 percent for M30 grade concrete after 28 days of curing. Thus, it was concluded that the optimal percentage of slag as a partial substitute for fine aggregate is 30%.

## 7.4 Workability

(Salman, et al., 2017) [22] conclude that the workability of mortar mixes was reduced by adding of steel slag. Because the slag added as a cementitious material is very fine, therefore, its surface area will be larger. This results in reduced workability**.** This leads to an increase in the water requirement. To avoid a decrease in the resistance of the mixture due to the increase in the amount of water, a superplasticizer can be used to obtain the required workability.

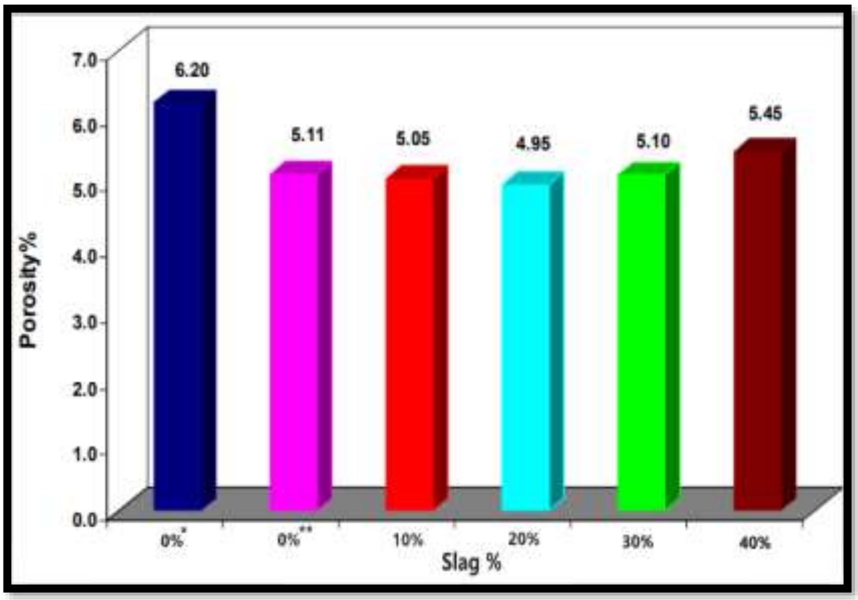
## 7.5 Porosity

When the slag is ground to a high fineness, it is suitable for use as a filler or as a substitute for cement. Where the slag fills the gaps, which leads to reducing the porosity. That is provided by (Kazem, et al., 2011) [23] when they used slag as a substitute for cement and sand in different proportions. The slag reduces the porosity, and the best result was when replacing cement with slag by 40%, the result was 4.82%, see Fig. 5, and it reached 4.95% when replacing slag with sand by 20%, see Fig. 6.




*Without superplasticizer , **with superplasticizer

**Fig. 5 Effect of Slag as a Partial Substance of cement on Porosity, (Kazem, et al., 2011) [23].**




*Without superplasticizer , **with superplasticizer

**Fig. 6 Effect of Slag as a Partial Substance of Sand on Porosity, (Kazem, et al., 2011) [23].**

### 7.6 Setting Time

Many factors influence the setting time of concrete, including temperature and the water/cement ratio. The setting time with GGBS will be significantly longer, potentially by thirty minutes. The effect will be more evident at high quantities of GGBS and/or low temperatures. An extended setting time benefits the concrete by keeping it workable for longer and contracting the risk of cold joints. This is especially beneficial in hot weather (Suresh and Nagaraju, 2015) [24].

### 7.7 Early Age Temperature Rise

The reduction involved in the hardening and setting of concrete generates powerful heat and can produce large temperature rises, especially in thick section pours. This can result in thermal cracking. Replacing cement with Ground Granulated Blast Furnace Slag GGBS lowers the temperature rise and helps to avoid thermal cracking in early age. The higher the percentage of GGBS, the lower will be the rate at which heat is improved and the smaller the largest temperature rise, see Fig. 7 (Suresh and Nagaraju, 2015) [24].

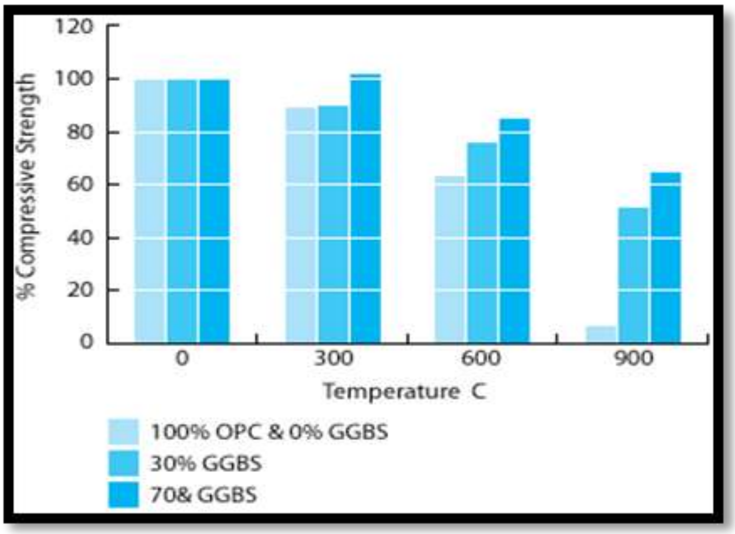



**Fig.7 Compressive Strength Variation to Temperature, (Suresh and Nagaraju, 2015) [24].**

### 7.8 Absorption

Absorption is directly proportional to the percentage of slag added. This is what (Kazem, et al., 2011) [23] noticed when they used two groups, in the first group used slag with a percentage of 10%, 20%, 30%, and 40% by weight of cement instead of cement and the second group is to replace the slag with a ratio of 10%, 20%, 30%, and 40% by weight of cement instead of sand. For the surface absorption, it decreased in all samples compared to the reference mixture. The decrease in absorption is due to the Pozzolanic interaction that occurs between $Ca(OH)_2$ and C.S.F Eventually, compound C-S-H is formed, and thus the density of the transition zone increases, this interaction also helps to close large gaps (Jihad, 2012) [14].

### 7.9 Chloride Ion Penetration

Constructions in the marine environment are exposed to attack by sulfates and chlorides, and this causes them many damages. The slag helps reduce the penetration of chloride ions into the concrete. (Bhat and Tengli, 2019) [25] Check the effectiveness of the slag in the marine environment, the idea of their research was to make a comparison between concrete samples exposed to chloride ion and using different percentages of GGBS as a partial substitute for cement. Eight mixtures were examined replacement ratios of 0%, 10%, 20%, 30%, 40%, 50%, 60%, and 70%. They noticed that the highest value of chloride ion penetration into concrete was at 0% of GGBS and the lowest value at a replacement rate ranging from 30% to 50% of GGBS, see Fig. 8.

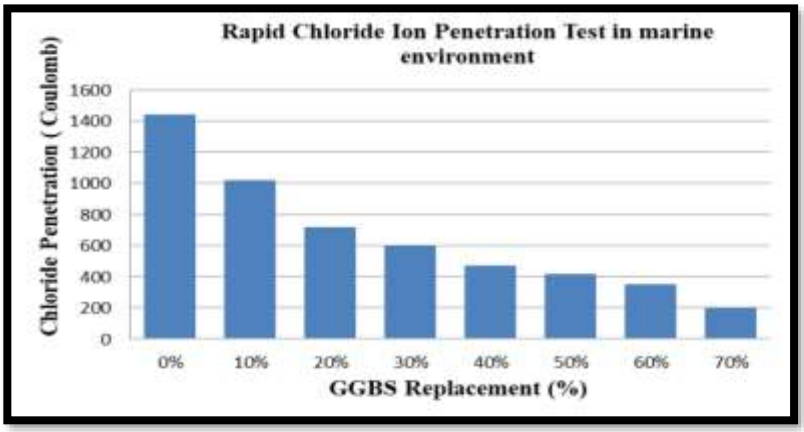



**Fig. 8 Chloride Ion Penetration in Marine Environment, (Bhat and Tengli, 2019) [25].**

## 8. Conclusions

- Ground slag is a suitable cementitious substitute for cement.
- Slag can be used as a partial substitute for sand or gravel, but they cannot be combined in the same mixture.
- When using slag as a cementitious material, it reduces absorption.
- The chemical composition of slag affects the properties of concrete, for example, the strength decreases when the ratio of $SiO_2$ is low.
- The use of slag in concrete reduces the penetration of chloride and also reduces the porosity by filling the large pores.
- The setting time with GGBS will be significantly longer, potentially by 30 minutes. This is useful to reduce the risk of cold joints, especially in hot weather.
- When slag is used as a cementitious material, its workability is reduced, so a superplasticizer can be used to obtain the desired consistency.
- Replacing portland cement with GGBS helps to avoid early age thermal cracking and reduces the temperature rise.
- The best replacement rate for coarse aggregate with slag ranges from 30% to 40%, while the best replacement rate for fine aggregate with slag ranges from 20% to 30%.
- Because the grain size of GGBS is smaller than that of typical Portland cement, its strength is poor at first, but it gradually improves with time.
- High compressive strength, superior workability, chemical resistance, low heat of hydration, good durability, and cost-effectiveness describe the ideal GGBFS replacement as cementation material.

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