# Effect of Corrosion on High-Strength Concrete with Steel Slag as Partial Replacement of Coarse Aggregate

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**Abstract.** The search for sustainable building materials has been prompted by the growing need for natural aggregates in concrete as well as the difficulties in disposing of industrial byproducts. Steel slag has physical properties similar to those of natural aggregates and can be used successfully in concrete. The durability performance of M70 grade high-strength concrete with steel slag added as a partial substitute for coarse aggregate at extra levels of 0%, 40%, 45%, 50%, and 55% is investigated in this study. The Rapid Chloride Permeability Test (RCPT) and Rapid Chloride Migration Test (RCMT) were used to assess the concrete's resistance to chloride ion penetration. According to experimental findings, the migration coefficient and chloride permeability consistently decreased as the amount of steel slag increased. The concrete with 55% steel slag had the lowest migration coefficient and charge passed, indicating better durability and resistance to chloride infiltration. The results imply that steel slag can serve as a sustainable and efficient replacement for natural coarse aggregate in high-strength concrete, enhancing durability and encouraging the advantageous use of industrial waste.
**Keywords:** High-strength concrete, Steel slag Durability, RCPT, RCMT, Chloride penetration.

## 1 Introduction

Concrete is used in construction resources worldwide owing to its versatility, strength, durability and ease of construction. Infrastructure have resulted in a substantial increase in the demand for natural aggregates, leading to depletion of natural resources and environmental factors. Consequently, considerable research efforts have been directed toward the use of trash and industrial byproducts materials as sustainable alternatives in concrete production. Among the various industrial wastes produced globally, steel slag has emerged as a capable material because of its favourable engineering properties and potential

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environmental benefits [1]. A byproduct of the steel production process is steel slag, when fluxing agents like lime and dolomite are used to remove impurities from molten steel.

For every unit mass of steel produced 15–20% of steel slag is created, which poses serious disposal and environmental management issues [2]. The material primarily consists of calcium silicates, calcium alumino ferrites, free lime, and compounds of iron, magnesium and manganese. Due to its high hardness, rough texture, and angular particle shape, steel slag exhibits characteristics comparable to those of conventional aggregates used in concrete. Previous investigations have reported that steel slag can effectively improve the engineering properties of concrete while concurrently promoting sustainable waste utilization [3-5].

High strength concrete (HSC) has gained considerable significance in modern construction because of its increased durability, decreased permeability and improved compressive strength. Such concrete is widely used in bridges, marine structures, critical infrastructure projects long-term performance is essential. Despite its advantages, Concrete with high strength is naturally fragile and possesses relatively less tensile strength, making it disposed to crack initiation and propagation under loading conditions [6]. To improve its toughness and crack resistance, fibers are often incorporated into concrete mixtures. Previous studies have verified that steel fiber reinforcement can significantly enhance bond strength, fatigue resistance, ductility, and post-outrageous behavior of concrete [4–8]. Furthermore, recent have highlighted the effectiveness of both natural and artificial fibers in improving the mechanical performance and durability characteristics of concrete composites.

Several investigators the feasibility of utilizing steel slag as additional for natural aggregates in concrete. Researchers demonstrated that steel slag may be effectively added to concrete while preserving acceptable engineering qualities and lessening the environmental impact of disposing of industrial waste. [1,2]. Chinnaraju et al. [9] observed satisfactory strength characteristics in concrete steel slag as coarse aggregate replacement. Similarly, Kothai and Malathy [10] reported that steel slag could effectively replace fine aggregates without adversely affecting concrete performance. Liu et al. [11] investigated the possibility of utilizing steel slag as both fine and coarse aggregate and reported improvements in density along with reduced water absorption. Subathra Devi and Gnanavel [12] further confirmed that concrete incorporating steel slag exhibits favorable mechanical and durability properties. Apart from improving mechanical performance, steel slag has also demonstrated considerable potential for enhancing the durability of concrete. Etinger et al. [13] reported improved properties of concrete containing steel slag aggregates. The rough surface texture and angular geometry of steel slag particles contribute to improved aggregate and a denser interfacial evolution zone, thereby reducing permeability and enhancing resistance to aggressive environmental conditions. These characteristics make steel slag a suitable material for producing durable concrete structures exposed to severe service environments.

The corrosion of embedded steel reinforcement brought on by chloride intrusion is one of the main reasons why reinforced concrete constructions deteriorate. Chloride ions penetrate concrete through pores and microcracks, finally reaching the reinforcing steel and initiating corrosion. This process results in cracking, spalling, harm of cross-section area of reinforcement, and reduction in structural service life. Therefore, evaluating the resistance of concrete to penetration of chloride is essential for assessing its long-term durability. Though studies have investigated the mechanical properties of steel slag concrete, comparatively limited research has focused on the chloride penetration of high strength concrete integrating steel slag aggregates [10–14].

The current study examines how the durability performance of M70 grade high-strength concrete is affected when steel slag is partially substituted for coarse aggregate. Steel slag was incorporated at replacement levels of 0%, 40%, 45%, 50%, and 55% by the weight of coarse aggregate. Concrete's ability to withstand chloride intrusion was assessed. The Rapid

Chloride Permeability Test (RCPT) in accordance with ASTM C1202 [14] and the Rapid Chloride Migration Test (RCMT). The study is to identify the optimum steel slag replacement level that improves resistance to chloride penetration while promoting the use of industrial waste in high-strength concrete. The conclusions of this investigation are expected to the development of durable and sustainable concrete for modern structural applications.

# 2 Materials and Methodology

## 2.1 Materials

### *2.1.1 Cement*

The study used OPC of 53 grade IS:12269 requirements. This type of cement is commonly used in experimental research due to its constant quality and adaptability for generating high-strength concrete.

### *2.1.2 Fine Aggregates*

These aggregates have particle sizes of less than 4.75 mm. They can be obtained naturally or manufactured artificially, but their grading must be consistent throughout the project to provide consistency in concrete qualities. For consistent performance. This experiment made use of locally accessible sand. It was classed as Zone-II in accordance with IS:383-1970, Table 4.

### *2.1.3 Coarse Aggregates*

Concrete requires coarse aggregates, which are particles retained on a 4.75 mm IS screen, in order to be strong and stable. Their shape, size and texture significantly influence the durability and mechanical performance of the mix. Aggregates were considered only as inert fillers, but current research highpoints their critical structural role. In this study, 20 mm crushed angular aggregates were selected to ensure adequate strength and good mesh behaviour.

### *2.1.4 Micro Silica*

Electric arc furnaces produce silica fume, also referred to as micro silica, as a byproduct, during the manufacture of silicon and ferrosilicon alloys. The outcome of engaging carbonaceous materials like coal, coke, or woodchips to carbothermically reduce high-purity quartz. Owing to its fine particle size and extremely high silica content, micro silica is recognized as a pozzolanic material that increases the concrete's density and durability.

### *2.1.5 Fly Ash*

Fly ash is produced as a fine powder when crushed coal is burned. The light particles are carried away with flue gases, while the heavier fraction that settles in the furnace bottom is called bottom ash. It is  a valuable supplementary cementitious material, conducive to both sustainability and performance in concrete.

### *2.1.6 Steel Slag Aggregates*

Steelmaking processes invariably produce slag as a co-product. These materials are suitable for usage as concrete aggregates. with the right processing, which will help with waste utilization and decrease reliance on natural resources.

## 2.2 Methodology

### *2.2.1 Mixing of Concrete*

The components of concrete are cement, sand, coarse aggregates, water, and irregularly chemical or mineral admixtures. It is used building globally, valued for its flexibility and strength. However, realizing durable concrete depends not only on the quality of ingredients but also on the correct execution of batching, mixing, transporting, placing, compacting, and finishing operations.

### *2.2.2 Importance of Mixing*

Proper mixing is vigorous to produce fresh concrete of uniform quality. During mixing, cement paste must coat each aggregate particle thoroughly to achieve homogeneity as shown in fig 1. Well-mixed concrete ensures the required workability in fresh state and superior performance in hardened state. Inadequate mixing, on the other hand, may lead to segregation, bleeding, and weak zones in the structure, ultimately compromising durability and following as per the figure 1.

**Fig. 1.** Mixing of Testing Materials

### *2.2.3 Rapid Chloride Penetration Test*

RCPT test Setup consists of desiccator, vacuum pump (1/4 HP), 500 ml water tank (separating funnel), Specimen of Diameter 10 cm and depth 5 cm.

**Fig. 2.** Desiccator

Before starting the test, conditioning of the specimen need to be don First, take the sample prepared inside the desiccator shown in the figure 2 and close the lid. A maximum of 6 samples can be kept in the desiccator, a separator can be used for keeping samples in the vertical direction. There are three valves connecting vacuum pump, desiccator, and water tank. After keeping the specimens inside the desiccator, all the valves need to be checked for vacuum direction. It means that the valve from the vacuum pump must be opened and so does the corresponding valve at the desiccator, during this process the water valve should be closed. Place the specimen in between acrylic cells and apply silica adhesive gel on all sides as shown in figure 3.

**Fig. 3.** Specimens under RCPT test

## 3 Results and Discussions

The resistance of chloride ion penetration of concrete samples containing different proportions of Steel slag as a partial natural aggregate replacement was assessed using the Rapid Chloride Permeability Test (RCPT) in the fig.4. The test determines the concrete permeability to chloride ions by calculating the total charge that was transferred (in coulombs) over a 6-hour period. The control sample (0% steel slag) showed the high charge passed, indicating a higher permeability to chloride ions, the charge passed through the concrete decreased consistently. At 50% and 55% replacement, the charge is below 1000 C, in fig 4 signifying very low permeability and good durability against chloride attack. At lower replacement levels, the permeability remains low but above 1000 C.

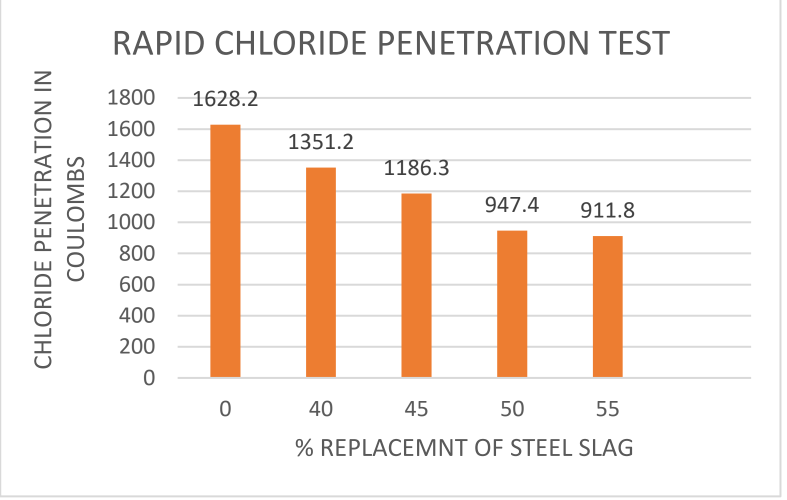


**Fig. 4.** RCPT values for various coarse aggregate % Replacement

The control sample (0% SS) exhibited the highest chloride migration coefficient of $5.9 \times 10^{-12}$ $m^2/s$, indicating the highest permeability. The RCMT readings gradually dropped as in fig.5 shown the fraction of steel slag replacement rose. The lowest RCMT value, $1.5 \times 10^{-12}$ $m^2/s$, was observed at 55% steel slag replacement, indicating the best resistance to chloride penetration in the fig. 5.

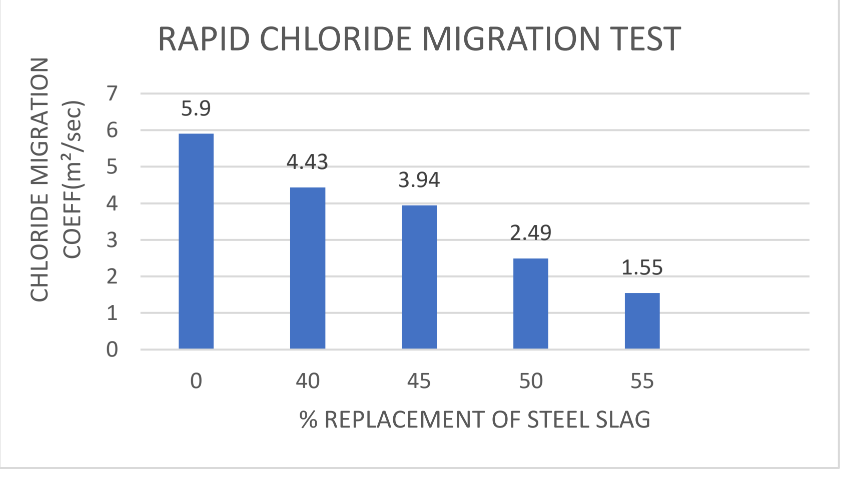


**Fig. 5.** RCMT values for various % Steel slag as a additional for coarse aggregate

## 4 Conclusions

The study investigates the partial substitution of coarse aggregate with steel slag, examining different parameters such as RCPT at replacement levels of 0%, 40%, 45%, 50%, and 55%. The outcomes from the experimental examination are summarized

1. The experimental investigation has shown to be a more effective method of disposing of steel slag.
2. According to the RCPT results, the charge passed through the 0% replacement is 1628.2C, for 40% replacement 1351.2C, for 45% replacement 1186.3C, for 50% replacement 947.4C, for 55% replacement 911.8 C. The chloride permeability rating for 0%, 40%, 45% is moderate and for 50%, 55% the permeability shown is low.
3. Overall, the 55% replacement was found to be more beneficial and effective in all the parameters.

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## References

1. M. Adeem, A.D. Pofale, Utilization of industrial waste slag as aggregate in concrete applications by adopting Taguchi's approach for optimization. Open J. Civ. Eng. **2**, 96–105 (2012)
2. A.I. Al-Negheismis, F.H. Al-Sugair, R.Z. Al-Zaid, Utilization of local steel making slag in concrete. J. Environ. Sci. Sustain. Soc. **1**, 39–55 (1996)
3. Y. Huang, G. Xu, H. Cheng, J. Wang, Y. Wan, H. Chen, An overview of utilization of steel slag. Procedia Environ. Sci. **16**, 791–801 (2012)
4. E. Baran, T. Akis, S. Yesilmen, Pull-out behaviour of prestressing strands in steel fibre reinforced concrete. Constr. Build. Mater. **28**, 362–371 (2012)
5. K.E. Caballero-Morrison, J.L. Bonet, J. Navarro-Gregori, J.R. Martí-Vargas, Behaviour of steel-fibre-reinforced normal-strength concrete slender columns under cyclic loading. Eng. Struct. **39**, 162–175 (2012)
6. L. Jiang, M. Bai, Y. Miao, Study of the performance of steel fibre reinforced concrete under water and salt freezing condition. Mater. Des. **44**, 267–273 (2013)
7. E. Genesis, M. Gesoğlu, S. Ipek, Effect of steel fibre addition and aspect ratio on bond strength of cold-bonded fly ash lightweight aggregate concrete. Constr. Build. Mater. **47**, 358–365 (2013)
8. H. Houari, B. Ghofrane, G. Debicki, Flexural fatigue performance of metal steel fibre reinforced mortar: Influence of fibre aspect ratio and type. Constr. Build. Mater. **5**8, 166–170 (2014)
9. K. Chinnaraju, V.R. Ramkumar, K. Lineesh, S. Nithya, V. Athish, Study on concrete using steel slag as coarse aggregate replacement and eco sand as fine aggregate replacement. Int. J. Res. Eng. Adv. Technol. **1**(3) (2013)
10. P.S. Kothai, R. Malathy, Utilization of steel slag in concrete as a partial replacement material for fine aggregates. Int. J. Innov. Res. Sci. Eng. Technol. **3**(4) (2014)

11. C. Liu, K. Zha, D. Chen, Possibility of concrete prepared with steel slag as fine and coarse aggregates: A preliminary study. Procedia Eng. **24**, 412–416 (2011)
12. V. Subathra Devi, B.K. Gnanavel, Properties of concrete manufactured using steel slag. Procedia Eng. **97**, 95–104 (2014)
13. I. Etinger, M. Jelić Rukavina, A. Mladenović, Improvement of post-fire properties of concrete with steel slag aggregate. Procedia Eng. **62**, 745–753 (2013)
14. ASTM International, ASTM C1202: Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration (ASTM International, West Conshohocken, PA, 2012)