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Retraction

Retracted: Investigation on Durability Behavior of Fiber Reinforced Concrete with Steel Slag/Bacteria beneath Diverse Exposure Conditions

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] M. Kumar M, V. L. Sivakumar, S. Devi V, N. Nagabhooshanam, and S. Thanappan, "Investigation on Durability Behavior of Fiber Reinforced Concrete with Steel Slag/Bacteria beneath Diverse Exposure Conditions," *Advances in Materials Science and Engineering*, vol. 2022, Article ID 4900241, 10 pages, 2022.

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Research Article

Investigation on Durability Behavior of Fiber Reinforced Concrete with Steel Slag/Bacteria beneath Diverse Exposure Conditions

Madhan Kumar M,[1,2] Vidhya Lakshmi Sivakumar,[1] Subathra Devi V,[3] N. Nagabhooshanam,[4] and Subash Thanappan[5]

[1]*Department of Civil Engineering, Saveetha School of Engineering, SIMATS, Chennai, Tamilnadu, India*
[2]*Department of Civil Engineering, Saveetha Engineering College, Chennai, Tamilnadu, India*
[3]*Director CIRA Technology Pvt. Ltd., Chennai 602105, Tamilnadu, India*
[4]*Department of Mechanical Engineering, Aditya Engineering College (A), Aditya Nagar, A D B Road, Surampalem, Andhra Pradesh, India*
[5]*Department of Civil Engineering, Ambo University, Ambo, Ethiopia*

Correspondence should be addressed to Subash Thanappan; subash.thanappan@ambou.edu.et

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One of society's most perplexing concerns is trash management. Among them is steel slag, which is obtained from steel mills and is used in the building industry as a partial substitution ingredient in concrete. To ensure that the concrete lasts the desired service life without deteriorating, bacteria (*Bacillus subtilis*) are introduced to ensure that the construction performs as planned. The research is focused on the M30 grade concrete mix specified in the Indian Standard Code. Concrete specimens containing fiber, steel slag, and bacteria are subjected to a variety of environmental conditions, including extreme, extremely severe, severe, moderate, and mild. The ultrasonic pulse velocity, sorptivity, water absorption, rapid chloride penetration, and acid resistance characteristics of the fiber-reinforced bacterial concrete are compared to those of regular concrete specimens.

1. Introduction

The 30 million tonnes of steel slag waste have been generated from the steel manufacturing industry every year in India. Utilizing this waste as a useful product in construction industry will reduce the over mining of natural resources. A single way of application can give the solutions for two problems such as waste management and depletion of natural resources. Steel slags are available in various sizes that can be used as substitute materials for fine and coarse aggregates in concrete. The properties of the steel slag such as size, shape, density, specific gravity, color, and appearance are compared to the conventional aggregates. Among all the properties, the water absorption of steel slag is slightly more than the normal coarse aggregates as, the micropores of the steel slag absorb greater portion of water from its surface [1]. The by-product of steel manufacturing plant is called steel slag and is used as a boosting material in clayey soil to improve the SBC of the soil [2]. Steel slag can be added as a basic ingredient material in concrete as well as a supplement material in cement for binding [3]. The depth of penetration of water in steel slag aggregate is higher in coarse form and lower in fine form while using in concrete. The same can be rectified by immersing the aggregate in water before using it into concrete [4]. The steel slag aggregate concrete having high resistivity to various imposed loads to avoid surface cracking in such a way that the particle binding in it [5]. Other than Blast Furnace Slag, the ferrous slag produced from the steel extraction producing major pollution element to the environment especially which leads leachate. Only

Blast Furnace and other nonferrous slags can be used for construction [6]. Utilization of steel slag in various construction activities and other raw materials-related products are reducing the management of waste due to slag and generating new job opportunities [7]. Some of the localized failure in conventional concrete can be reduced by replacing conventional aggregate with steel slag aggregate, since these aggregates having high resistivity to failures [8]. Replacing the steel slag and ceramic waste aggregates with optimized percentage can be improving the durability property of concrete compare than the conventional concrete, the percentage of replacement [1]. The self-healing property of the concrete can be improved by mixing the *Bacillus subtilis* with conventional concrete as liquid form with concentration 0.7×10^7 cells/ml. These are the lab-cultured bacteria with incubated at 30°C for 7 days [9]. Replacement of microsilica % in cement with *B. subtilis* giving good improvement in self-compacting property of the concrete, in addition to it improving the strength and durability of the concrete [10]. The replacement of 50% of conventional fine and coarse aggregate in concrete with addition of 1.5% of steel fiber increasing the workability and strength of the concrete by 30% when compared to the control concrete mix [11]. The performance of steel slag in very severe condition is good. Hence, it can be used for various practical applications in constructions where the atmospheric conditions are severe to very severe [12]. *B. subtilis* bacteria observing the moisture from the concrete and generating the calcium carbonate precipitation as a by-product which healing the surface and internal crack on the concrete by itself [13]. Steel slag aggregate can be used in concrete as economical and sustainable alternative material in concrete at different percentages to get the better strength in compression and tension [14]. Concrete specimen with and without cold joints subjected to continuous drying, wetting, freezing and thawing effects up to 900°C, and tested for weight losses of sample resulting the good strength on both the types of concrete [15]. Ultrasonic wave passes through the specimen of stones used for construction to test the physical properties with economical NDT method, The detailed internal structure and strength of stones from various locations are identified easily based on the receiving side velocity [16]. Ceramic waste materials are crushed and used as a waste powder in cement and their crystalline structure with porosity tested, the durability of the mortar specimen tested based on the chloride and sulphate attack [17]. The lab-cultured *B. subtills* bacteria were used in fly ash concrete, the calcium precipitation was examined and evidenced using SEM analysis. The final result shows effective in minimizing sorptivity in concrete specimen in the presence of FA [18]. The ceramic waste powder replaced as a waste particle in cement mortar and their microstructure was analyzed using scanning electron microscopy, after 90 days the compressive strength result shows 40% replacement gave better performance [19]. The optimization technique used in this project can be found out by the exact percentage of substitution of steel slag in concrete. In which we could convert the waste materials in to useful products with new opportunities of jobs. Here an attempt was made with steel slag as a replacement material for coarse aggregate and various durability properties under various exposure conditions are investigated. The suitable mix with optimal performance in various durability conditions was identified.

2. Manufacturing Materials and Methods

The basic ingredients for manufacturing the concrete as aggregates are crushed stone and river sand. They are selected based on their properties such crushing strength, impact value, specific gravity, water absorption, according to the Indian Standard Code 383–1996. The values of the abovementioned properties are compared with the standard values also. The main thing observed from the comparative study of properties of materials is absorbing the water by steel slag aggregate, which is 3%. But the value of water absorption of normal aggregates is 1–2%. The 53 grade Ordinary Portland Cement (OPC) is used as a binding material in concrete manufacturing process and is tested based on the IS code BIS 1489 Part–1. The basic properties of steel fiber used in this research have been listed in Table 1 such as density, aspect ratio, length, and diameter. As well as the shape of the fiber is zig-zig one to get the better binding with the basic ingredients of concrete. The liquid form of lab-cultured *B. subtilis* bacteria is used as a healing material in concrete. The hardened concrete properties such as characteristic compressive strength, split tensile strength, and flexural strength has been tested as per the IS Code 456–2000.

2.1. Properties of Materials

2.1.1. Steel Slag and Coarse Aggregate. The basic properties of normal and steel slag aggregate have been compared and listed in Table 1 with the specific properties required for concrete manufacturing process. A grade steel slag coarse aggregate was used as a replacement material in concrete with the different trial replacement such as 30, 40, 50, and 60%. Based on the previous study related to this research, the optimum value of replacement of steel slag as coarse aggregate is 50%. The detailed particle size distribution analysis for the steel slag aggregates also done, and the results shown in particle size distribution curve Figure 1.

2.1.2. Steel Fiber. In this research, zig-zag shaped steel fibers with 30 mm length and 0.5 mm diameter have been used as a reinforcement material to improve the tensile strength of the concrete. According to the literature review, 3% of the steel fiber by weight was used in every mold. The dispersion of the fiber was checked using wash out test and the uniformity of the fiber dispersion were observed. The properties of fiber have been listed in Table 2.

2.1.3. Bacteria. *B.subtilis* bacteria from the bacillus group was widely used in this research as a healing agent. *B.subtilis* is a bacterium having rod shape and the outer core of it can withstand in extreme conditions of environment.

Table 1: Properties of steel slag and normal coarse aggregate.

Properties	Normal coarse aggregate	Steel slag	Standard values
Impact value in J/m^2	9	25	<45
Cursing strength in N/mm^2	36	62	<45
Attrition (%)	5	4	<2
Specific gravity	2.8	3.5	2.5–2.7
Water absorption (%)	1–2	3	0.1–2.0

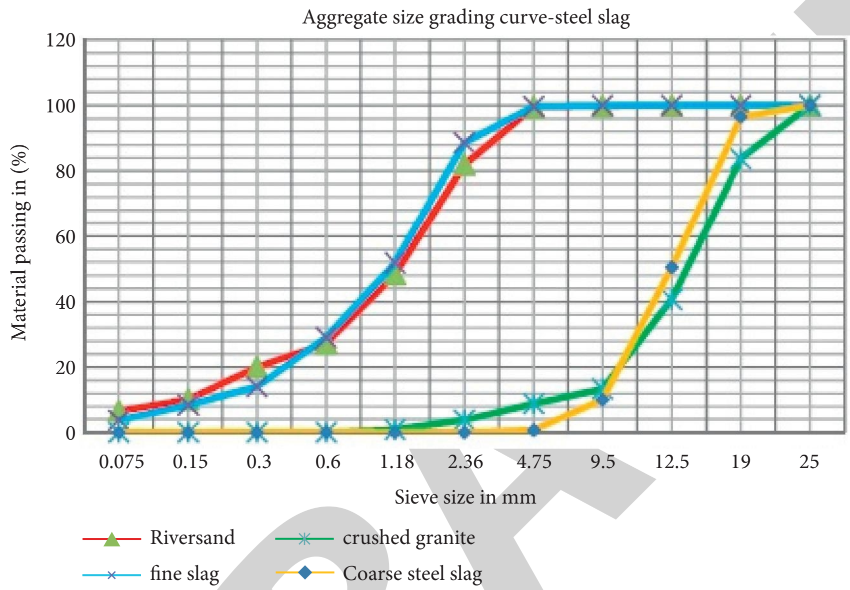


Figure 1: Particle size distribution of steel slag with normal aggregate.

Table 2: Properties of steel fiber.

Properties	Description
Diameter (mm)	0.5
Length (mm)	30
Aspect ratio	60
Ultimate tensile strength (Mpa)	900
Elastic modulus (Gpa)	210
Density	7850 (kg/m^3)
Shape	Zig-zag

(1) Preservation of Bacteria before Culturing. The *B. subtilis* bacteria were preserved in Luria Bertani Agar Medium and Luria Bertani Broth Medium. It forms irregular dry white colonies on nutrient media, and then they are incubated at the temperature of 30°C in a BOD incubator.

(2) Culturing of Bacteria. The bacteria are capable enough to produce the calcium carbonate on media with calcium course (Calcium Lactate). According to the supplier's recommendations, the *B. subtilis* were cultured in both agar and liquid media. The Petri dishes, flasks, and nutrient medium were sterilized before adding the bacterial strains, then the media is prepared according to the specifications provided below and cooled to room temperature (25°C). Then the culture was incubated at 30°C in the BOD incubator. The detailed list of preparation of media for *B. subtilis* is listed in Table 3.

2.2. Mix Design. The quantity of the materials can be derived exactly to achieve the required strength and durability of concrete by using mix design. There are different methods of mix design such as ACI method, BIS method, and DOI method. In this research, BIS method of mix design were used based on the IS code 10262–2009. The mix design was derived for M30 grade concrete in this research to achieve the effective quantity of material. Based on the mix design, the resulting mix ratio is 1 : 1.97 : 3.24 with water cement ratio of 0.54 to get target compressive strength. To test the various durability of concrete, the following two specimens were made for both conventional concrete and steel slag replaced fiber reinforced bacterial concrete. The standard dimensions for the cube is $150 \times 150 \times 150$ mm, and the cylinder is 100 mm dia with 150 mm depth. In this research, the optimum percentage of the replacement of steel slag as coarse aggregate is 50%, which is optimized with the trial mix of replacement of steel slag as coarse aggregate starting from 30% up to 60% with 10% increment. The cubes and cylinders are casted with 50% replacement of steel slag as coarse aggregate in addition to its 30 ml *B. subtilis* and 3% of steel fiber by weight to each cube. As per previous research, the quantity of bacteria added to the concrete is limited to 30 ml, if the quantity increased more than that precipitation of calcium exceeding the allowable limit in concrete, which caused the over deposition of the products on the surface. As well as increasing the percentage of the fiber more than 3%

Table 3: Preparation of media for *B. subtilis*.

Luria Bertani agar		Broth (LBB) medium, Miller (M1151/M1245)	
Compounds	Quantity	Compounds	Quantity
Casein enzymic hydrolysate	10.0 g	Casein enzymic hydrolysate	10.0 g
Yeast extract	5.0 g	Yeast extract	5.0 g
Sodium chloride	10.0 g	Sodium chloride	10.0 g
Distilled water	100 ml	Distilled water	100 ml
Agar	15.0 g		

resulting in the increase of self-weight of the concrete. After 24 hours, the specimens are demolded and cured in next 28 days. The designation for the specimens to test durability properties are follows. AA_{Mild}, $AA_{Moderate}$, AA_{Severe}, $AA_{Very\ Severe}$, $AA_{Extreme}$ and BB_{Mild}, $BB_{Moderate}$, BB_{Severe}, $BB_{Very\ Severe}$, $BB_{Extreme}$. Where AA represents Conventional Concrete and BB steel slag replaced fiber reinforced bacterial concrete.

2.3. Exposure Conditions. According to Indian Standard Code 456–2000 (Clause 8.2.2.1 and 35.3.2) the concrete durability conditions were tested based on the following five exposure conditions such as extreme, very severe, severe, moderate, and mild. The concrete specimens were placed directly to atmosphere for mild exposure conditions. Specimens were placed under the water, in order to meet the moderate exposure conditions. In case of severe exposure conditions, the concrete specimens was under continuous wetting and drying conditions. The specimens are buried under the subsoil to check the exposure conditions under very severe. For extreme exposure conditions, the specimens directly placed in chemicals or acids. Figure 2 shows the above mentioned five exposure conditions of concrete specimens.

3. Fresh Concrete Properties

3.1. Workability. This research deals with the concrete mix of 1 : 1.97 : 3.24 and water cement ratio of 0.54. According to this mix, the concrete cubes were casted for all the tests as well as the workability of the fresh mix are good with true slump value. In this research, steel slag used as a partial replaced coarse aggregate and the workability of steel slag concrete also less. In order to increase the workability, the steel slag is immersed in water before use.

3.2. Hardened Concrete Properties. The hardened concrete properties tested such as compressive strength, flexural strength, and split tensile strength. The abovementioned tests have been done for the 7 days and 28 days cured specimens with three trials to get the optimum value and suitable percentage of substitution of steel slag. In addition to that the below-listed hardened concrete tests were done to test the durability properties in the steel slag concrete with different exposure conditions such as extreme, very severe, severe, moderate, and mild.

3.3. Ultrasonic Pulse Velocity Test (UPV). In the given concrete specimen of size 150 × 150 × 150 mm, the ultrasonic waves were passed through it with the help of transmitter and received on other side. If, the received ultrasonic pulse velocity value is 4.5 and more than that; the quality of the concrete is in excellent condition. If the value lies between 3 and 4.5, then the quality of the concrete is good. In case of the value less than 3, then the quality of the concrete is doubtful. These are the derived parameters as per the IS 13311 (Part–1)–1992 with the unit of measurement of mm/s. The pulse velocity can be calculated with the ratio of distance traveled by time taken. The detailed experimental set up of Ultrasonic Pulse Velocity test method as shown in Figure 3.

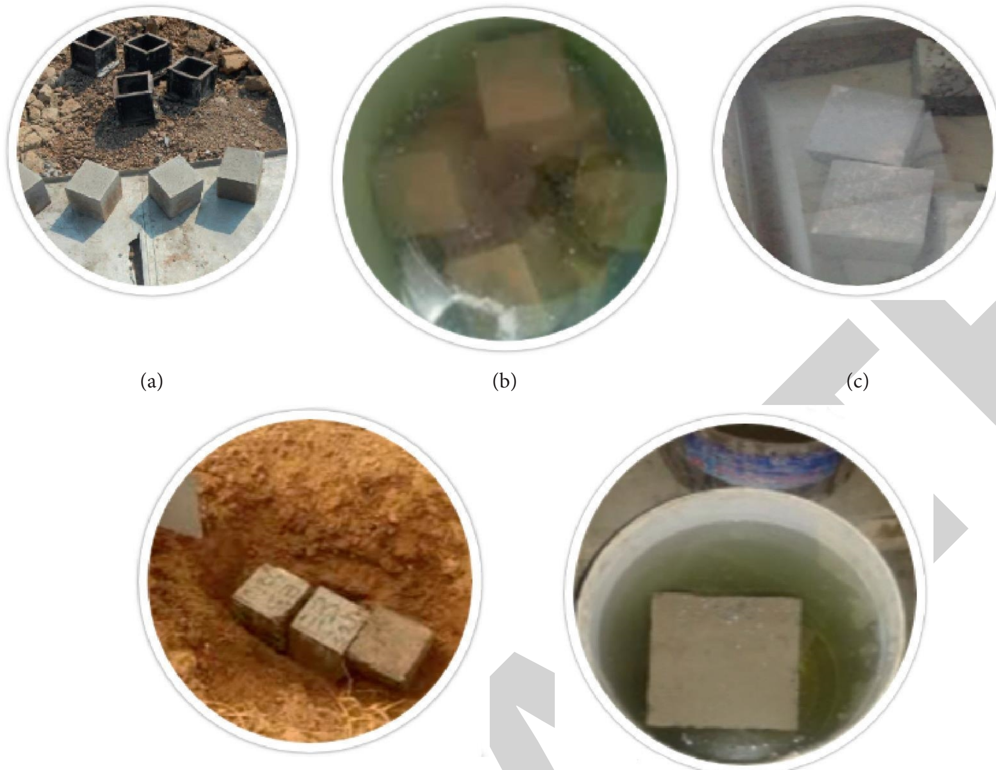
3.4. Rapid Chloride Penetration Test (RCPT). The RCPT used to find the amount of chloride penetration into the concrete specimen by passing the electric current through the concrete specimen with 100 mm diameter and 50 mm thick with 6 hours as per ASTM C 1202 as show in Figure 4. In this test throughout the time period 60 V of electricity will be maintained. In which the two leads, one submerged with sodium chloride solution of 3% and another end immersed with sodium hydroxide solution with 0.3 N. The amount of electric charge passed through the specimen will be calculated based on the formula given below in Coulombs (Q) in (1).

$$Q = \frac{900}{100}\left(I_0 + 2I_{30} + 2I_{60} \ldots + 2I_{360}\right). \tag{1}$$

3.5. Acid Resistance Test

3.5.1. Acid Attack-Hydrochloric Acid (Hcl). In order to check the acid resistance of steel slag concrete, the specimens are immersed in hydrochloric acid. A total of 28 days water-cured specimens of size 150 × 150 × 150 mm are immersed in the solution for the period of 90 days and the specimen weights will be compared based on the weight loss before and after immersed in the acid. Figure 5 shows the specimen immersed in Hcl.

3.5.2. Acid Attack-Sulfuric Acid (H_2SO_4). The concrete specimens of extreme exposure conditions can be tested by immersing in acid solutions for a particular period and measuring the weight of the compared specimens in which 0.1 normality sulfuric acid will be used in a container to immerse the concrete cube specimen for the period of



(a) (b) (c) (d) (e)

Figure 2: (a) Mild. (b) Moderate. (c) Severe. (d) Very severe. (e) Extreme conditions.

Figure 3: UPV test.

Figure 4: RCPT.

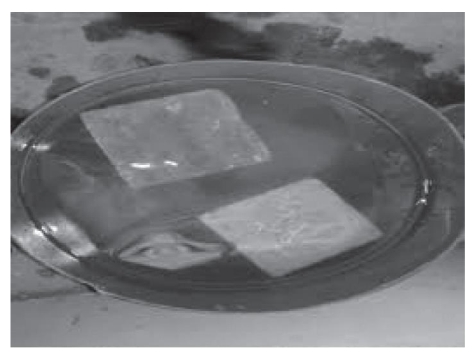


Figure 5: Specimen immersed in Hcl.

90 days. The weight loss of the concrete cube before and after immersion in acid is found and analyzed based on IS 456 : 2000, Clause 8.2. Figure 6 shows the specimen immersed in H_2SO_4.

3.6. Sorptivity Test. The water absorbing rate of the concrete specimen is determined by Sorptivity test. This test is used to analyze the internal voids and micropores in concrete. The specimen used for this test is a cylindrical specimen with the dimensions of 50 mm diameter and 100 mm height. ASTM C 1585–4 standards are the criteria used to conduct the Sorptivity test. The specimen needs to be prepared at 110°C for a period of one day, then 24 hours cooling in a room temperature, and then placed in the test setup. In order to

Figure 6: Specimen immersed in H_2SO_4.

maintain the unidirectional water flow, the specimen coated with water proofer on its circumference. The water will be absorbed by capillary action and its weight gain measured every half an hour. The Sorptivity is calculated based on the formula as in (2) given below and also shown in Figure 7:

$$K = \frac{W}{(A \cdot x \cdot ml/mm2/\sqrt{\min})}, \quad (2)$$

where W = weight of water absorbed (ml), A = cross sectional area of specimen (mm2), t = time in minutes, k = Sorptivity coefficient.

4. Results and Discussion

4.1. Ultrasonic Pulse Velocity Test. Based on the test conducted for the specimens of various exposure conditions in both conventional and steel slag replaced fiber-reinforced bacterial concrete, the test results are shown in Figure 8. Ultrasonic waves are passed through 150 mm side cube and the velocity is calculated using the time taken for the ultrasonic waves to travel a particular distance. Quality of concrete depends on the velocity of ultrasonic waves. When the velocity is less than 3, the concrete is categorized as poor; between 3 and 4.5, it is good; and greater than 4.5, it is excellent. According to the test results, the steel slag replaced fiber-reinforced concrete having the value of UPV between 3 and 4.5, and categorized as good; meanwhile, the value is greater than the conventional concrete. It shows that the internal structure and durability of the steel slag fiber-reinforced bacterial concrete is better than the conventional concrete in all exposure conditions. The test result shows that the concrete can withstand and perform well in the application of high acidity area. So the fiber-reinforced bacterial steel slag concrete can be utilized to construct the chemical industries, other plants related to acid applications and the area where the atmosphere and geotechnical conditions are acidic in nature. In extreme exposure conditions, steel slag fiber-reinforced bacterial concrete performs better than the conventional concrete.

4.2. Rapid Chloride Penetration Test. Electric current has been passed via the specimen placed in the Rapid Chloride Penetration Test (RCPT) setup to determine the amount of penetrability of chloride content through the specimen. When the value of electric charge is 100 coulombs, the amount of chloride penetrability will be negligible. The penetrability of chloride is low, when the value of electric charge passed through the specimen is between 1000 and 2000 as per the codal provision. The chloride ion penetrability for both normal concrete and fiber-reinforced steel slag concrete is less than 2000 coulomb for all the exposure conditions, which is shown in Figure 9. The steel slag fiber-reinforced concrete specimen with very severe exposure conditions resisting 7.5% better than the other exposure conditioned specimens and conventional concrete specimen.

4.3. Acid Resistance Test

4.3.1. Acid Attack-Hydrochloric Acid (HCl). We know that, the concrete is alkaline in nature. The alkalinity in concrete is producing better strength while binding with the aggregates. In order to find the resistivity to acid solutions, the specimens are immersed in hydrochloric acid and sulfuric acid and weighted according to Indian Standard Code. The $150 \times 150 \times 150$ mm size specimen has been immersed in HCl acid of 0.1 N for the duration of 90 days. The attack of the acid to the specimen can be observed by the weight loss percentage. The percentage of the various weight loss of SS concrete and conventional concrete are shown in Figure 10. From the test results, the concrete is performing well in hydro chloric acid than the sulfuric acid. The graph shows that the steel slag concrete with moderate, very severe, and extreme exposure conditions are good in acid attack of HCl acid than the other two exposure conditions. The result shows SS fiber-reinforced concrete having 70% more acid attack resistivity than the conventional concrete under all exposure conditions.

4.3.2. Acid Attack-Sulfuric Acid (H_2SO_4). According to IS 456–2000, the standard cube of size $150 \times 150 \times 150$ mm is used in this test. The different exposure conditioned cubes are immersed in the acid container with 0.1 N for the duration of 90 days. The weight reduction of concrete cube specimens takes place while performing the test. The loss of weight of concrete specimens are shown in Figure 11 under various exposure conditions. According to the test results, moderate and very severe exposure conditioned specimens have less weight loss percentage, which is less than 3% compared to the other exposure conditions. The result shows that steel slag fiber-reinforced concrete having very good resistivity to sulfuric acid compared to conventional concrete, which is 65% more resistant to losing weight than the conventional concrete.

4.4. Sorptivity Test. The test results of coefficient of Sorptivity to the steel slag fiber-reinforced concrete with conventional concrete are shown in Figure 12. The graph shows the capillary action in the steel slag concrete is lesser than the normal concrete in which steel slag concrete with severe and

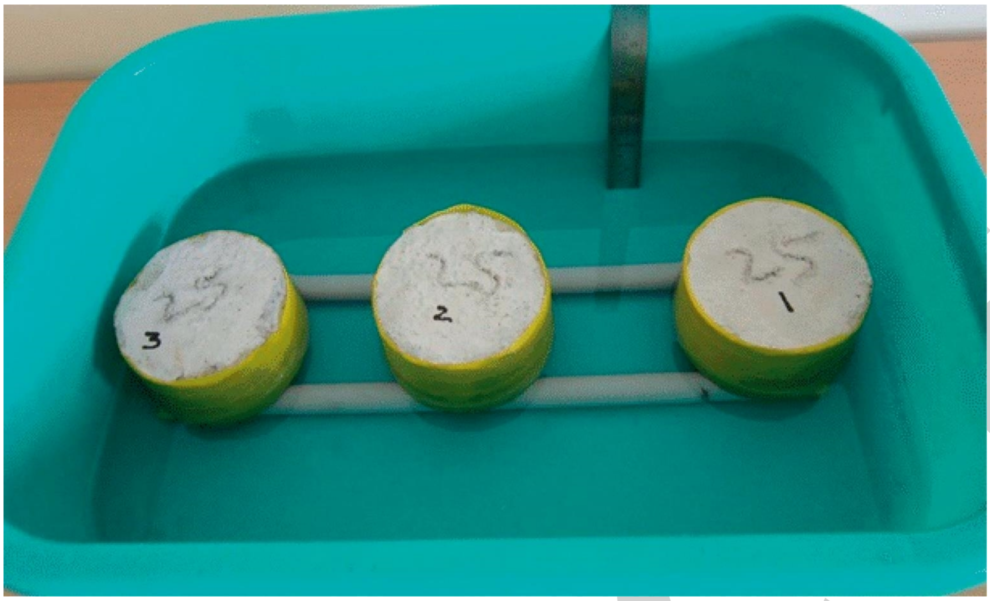


Figure 7: Sorptivity test.

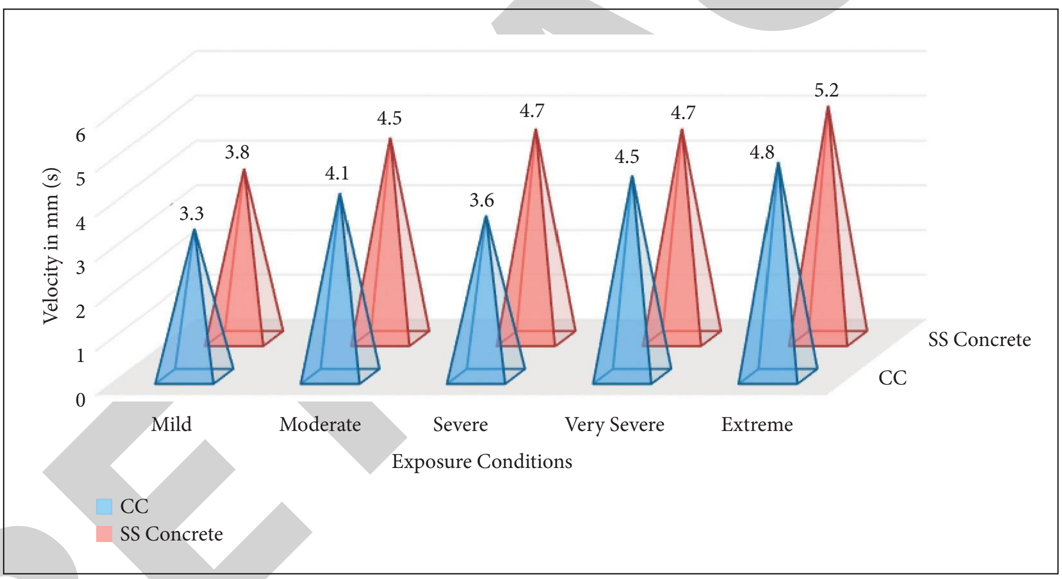


Figure 8: UPV of CC and steel slag concrete for different exposure conditions.

extreme exposure conditions are performing better than the other exposure conditions. The lesser value of coefficient of Sorptivity shows the lower percentage of capillary action and porosity. The presence of zig-zag–shaped fibers with replacement of steel slag decreases the porosity in the concrete, which results in the reduction of capillary action in steel slag concrete and improving the resistance of flow of water through itself. The materials inside the concrete mix are packed well with a lesser number of pores than the conventional concrete. According to the test results, the value of coefficient of sorptivity is 10.67% less in steel slag fiber-reinforced concrete than the normal concrete. This shows the capillary action of SS concrete is better than the normal concrete.

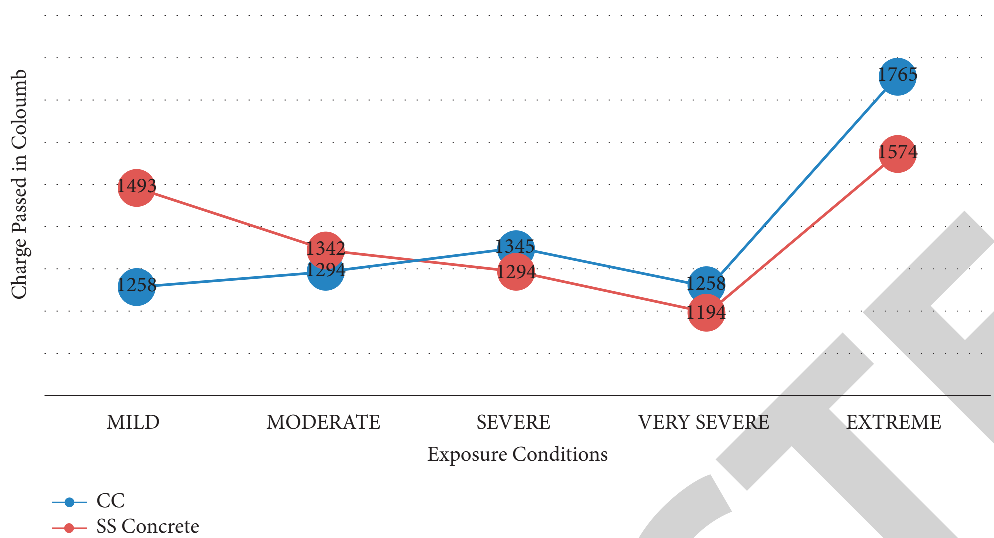


FIGURE 9: RCPT test results for CC and SS concrete.

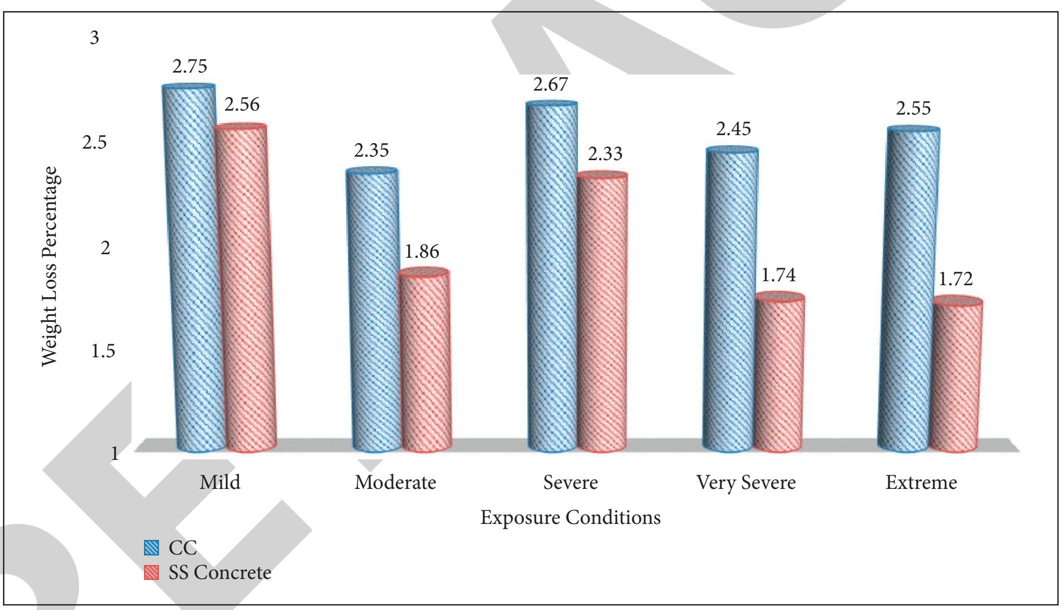


FIGURE 10: Comparison of weight loss percentage of CC and SS concrete in HCl acid attack.

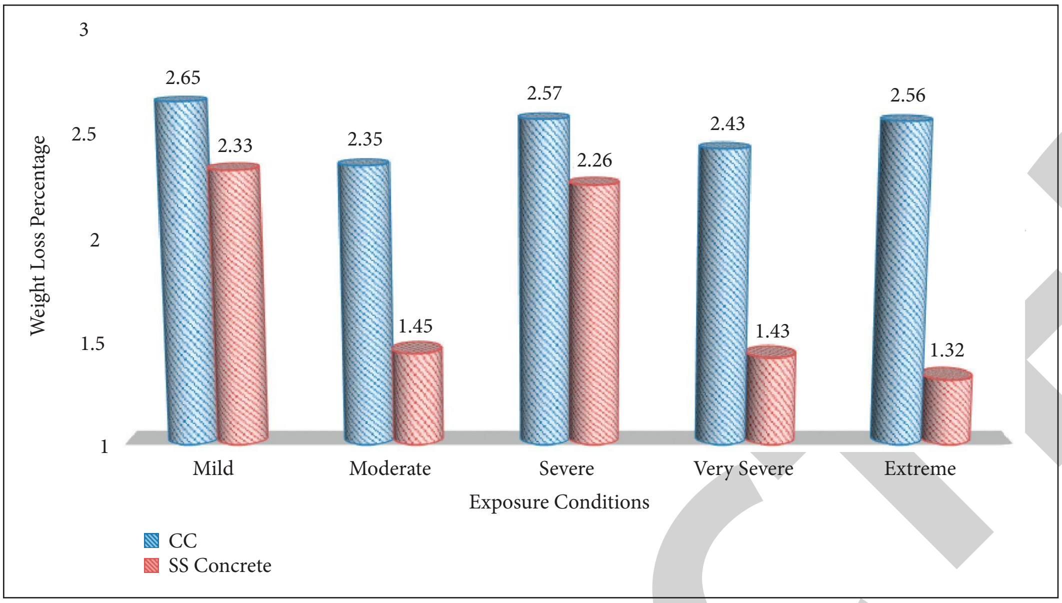


FIGURE 11: Comparison of weight loss percentage of CC and SS concrete in H_2SO_4 acid attack.

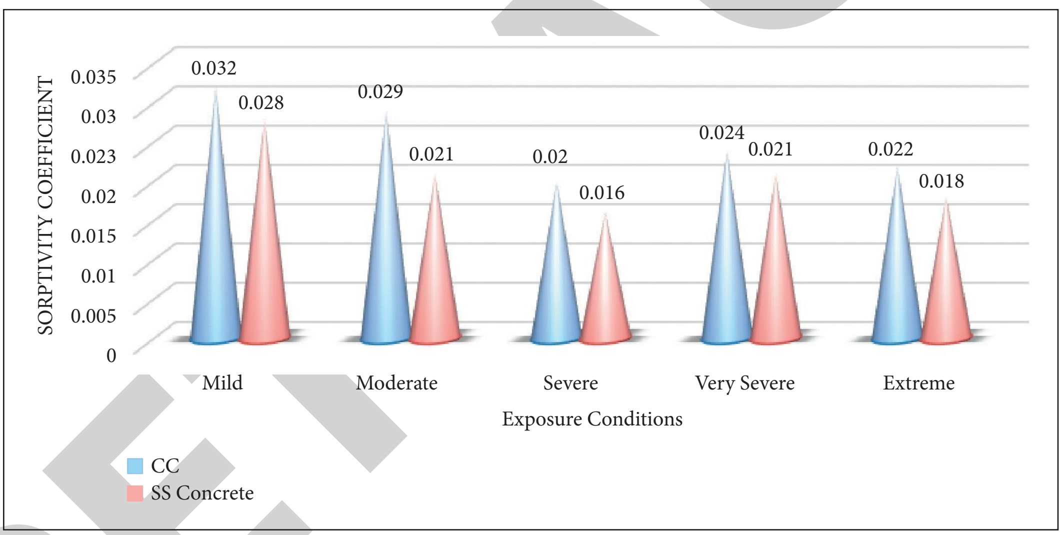


FIGURE 12: Sorptivity coefficient for CC and SS concrete.

5. Conclusion

The analysis of durability properties of M30 grade concrete with partial replacement of steel slag as coarse aggregate (50% replacement of coarse aggregate), steel fiber, and bacteria under various exposure conditions has been done. The finding from the experimental analysis listed as follows:

(i) Steel slag having greater water absorption property than conventional aggregate, it can be negligible before mixing into concrete by saturating the steel slag aggregates.

(ii) Steel slag concrete with extreme exposure conditions having better durability than conventional concrete. The UPV test shows the velocity of SSC at extreme exposure is having around 95% at the receiving side. It results in the good quality when compared to other conditions with less than 90% receiving velocity.

(iii) The percentage of rate of penetration of chloride through the concrete mass is very less in SS concrete, with very severe exposure condition with less than 4%. On the other hand, both conventional and other exposure conditioned SS concrete have the penetrability of more than 5%.

(iv) In the acid attack test, SS concrete with very severe and extreme exposure conditions has 65–70% more resisting capacity in both the acids (HCl & H_2SO_4) than the conventional concrete.

(v) According to the Sorptivity test result, the coefficient of Sorptivity is 10% less in SS concrete with severe and extreme conditions, than the other exposure conditions. The amount of flow of water through the concrete is less; so SS concrete with fiber and bacteria is highly suitable in the exposure conditions of severe, very severe, and extreme. Hence, it is suitable for the construction of chemical industries, coastal structures, and other civil engineering structures with extreme exposure conditions.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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