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AN EXPERIMENTAL INVESTIGATION OF THE PARTIAL SUBSTITUTION OF STEEL SLAG AS FINE AGGREGATE IN CONCRETE

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Graphical abstract

Abstract

The use of steel slag as aggregate in concrete is one environmentally friendly method to reduce the detrimental consequences of the depletion of natural mineral resources. The behavior of steel slag sand concrete (SSC) under compression is examined in this paper. A set of cube tests under compression are reported, with the results evaluated. The experiments used SSCs integrated with steel slag at volume substitutions of 0, 10, 20, 30, and 40% for fine aggregate. The findings indicate that concrete's compressive strengths can be raised by including steel slag as fine aggregate. The strength of compression of SSC first rises as the amount of steel slag increases when loading is applied. Compressive strength falls once the ideal percentage of steel slag is added. Water permeability, acid attack, and rapid chloride penetration test are conducted for the durability test. The addition of steel slag to concrete increases the material's ductility, durability, and resistance to cracking. To achieve enhanced performance for SSC under compression, 20% of steel slag should be used as fine aggregate.

Keywords: Steel slag (SS), workability, compressive strength, split tensile and flexural strength.

1.0 INTRODUCTION

Since there are fewer raw materials available today, sustainability has become the main focus in recent years. As a result, research has been done on the use of sustainable materials for social, economic, and environmental advantages that will improve our quality of life. Therefore, the greater difficulty for upcoming construction companies will be to provide the world's need for concrete while also figuring out a good substitute for natural aggregate in the preparation of high compressive strength materials in concrete. We also know that steel slag can be used to partially substitute natural materials in the production of asphalt concrete, replacing some of the natural aggregate used to form the base layer of roads, and their strength measures with steel slag from the IronWorks Company.

This is because More than 75% of the volume of concrete is composed of aggregates, and finding appropriate substitute materials for natural aggregates in the preparation of concrete is getting harder. River beds will decrease as a result of ongoing exploitation of natural rocks, creating an ecological and environmental imbalance. Additionally, natural aggregate will increase in price. To solve this issue and raise the standard of our living environment, we must use waste materials like steel slag in place of natural rock or aggregate in concrete [1]. For many years, river sand has been utilized as fine aggregates in the building sector to make concrete. These days, because of the rising demand for river sand and the developing 55 challenges associated with its mining, the timely completion and economic feasibility of many construction projects are deteriorating [2]. Because raw resources are becoming less common these days, sustainability has become the main focus in recent years.

Consequently, studies on the application of sustainable materials to enhance the quality of the environment, society, and economy have been conducted. The most used material in construction is concrete. Therefore, the larger task facing upcoming construction companies is to provide the world's need for concrete while also determining a suitable natural aggregate replacement to create high-compressive-strength concrete.

The continued mining of natural rocks will cause river beds to diminish, leading to an imbalance in the ecosystem and ecology. The cost of natural aggregate will also rise [1]. The building industry has always been supported in its development by traditional construction, which has occupied a key role. Due to the utilization of a large quantity of concrete in the building sector, shortcomings in the sand occur. Hence, there is a need in the construction industry to develop an alternative material to replace the sand. Currently, the building business needs to grow much like the manufacturing sector. Conventional construction has maintained its leading position throughout history, aiding in the growth of the building industry. [3].

2.0 RESEARCH SIGNIFICANCE

Even though a lot of study has been done globally, the fact that steel slag can also be used in place of some fine aggregate is not widely known in India. Experiments were carried out. The effects on the characteristics of both fresh and cured concrete of partially replacing fine aggregate with fine steel slag aggregate. Throughout the course of the investigation, the percentages of dried fine steel slag aggregate substituted for fine aggregate were maintained at 0%,10%,20%,30%, and 40%. All investigated attributes have a w/c ratio of 0.45, except the study looking into how w/c ratios affect compressive strength.

An experiment was conducted to examine the effects on the consistency, soundness, and setting qualities of cement paste when a portion of the fine aggregate was replaced with fine steel slag aggregate. X-ray diffraction (XRD) and scanning electron microscopy (SEM) were used to examine the microstructure of the mixes. The variation in the percentage of steel slag in concrete at different replacement levels was examined. One can assess the effects of a w/c ratio of 0.45 by examining the split tensile strength, flexural strength, and compressive strength of concrete. The key tests for durability were resistance to chloride ion penetration, water permeability, and acid attack. The flexural strength of the concrete beam was studied. In the modern world, industrial waste utilization and recycling are important concerns. A waste product from the production of high carbon ferrochromium alloy is ferrochrome slag. While steel slag has been extensively studied globally, its application as a fine aggregate in India remains underexplored. By investigating the mechanical and durability properties of concrete with varying percentages of steel slag replacement, this study provides critical insights into optimizing concrete mix designs for improved performance. The findings contribute to sustainable construction practices by demonstrating how steel slag enhances compressive strength, ductility, and resistance to environmental degradation.

Because of this, water-cooled ferrochrome slag was used in this study to partially replace fine aggregate in concrete, with the aim of analysing its impact on strength and carrying out leaching tests to ascertain the slag's suitability for use as fine aggregate in an environmental setting. [4]. We are also familiar with the application of steel slag, which is used in the production of concrete to partially substitute natural materials.

3.0 MATERIALS

3.1 Cement

To manufacture concrete, ordinary portland cement (OPC) is used. Together with the OPC's initial setting time (IST) and final setting time (FST), which are 35 and 310 minutes, respectively, and specific gravity of 3.10, Table 1 also shows additional physical and chemical properties of cement.

Table 1 Cement's Chemical and Physical Properties

Chemical composition	OPC	Physical Properties	OPC
SiO_2	20.26	Density (g/cm^3)	3.08
Al_2O_3	5.33	Fineness (m^2/kg)	3.12
Fe_2O_3	3.55	Specific gravity	3.10
CaO	60.30		
MgO	2.4		
SO_3	3.11		
LOI	3.50		

3.2 Steel slag

Table 2 displays the characterization, physical characteristics, and particle size distribution of the steel slag, while the fineness modulus of the fine steel slag aggregate is shown in Table 3. The steelmaking process and the furnaces used determine the chemical characteristics of steel slag. Research is being done on using steel slag as fine aggregate in concrete once it has been processed to the proper size. Steel slag aggregates include a significant proportion of free iron, which provides the composite a high density and improved hardness. This makes it appropriate for use in the building industry, especially as a synthetic aggregate source for road construction. Steel slag aggregates have been found to outperform regular aggregates in terms of improving sample compressive strength, flexural strength, and split-tensile strength when used in lieu of some fine aggregate.

Concrete that has steel slag aggregates added has a higher specific gravity. Slag aggregate concrete showed a lower water penetration depth in the durability test than the usual control concrete mix because the steel slag particles are impermeable.

Numerous studies and papers that have been published worldwide have made it evident that the type and source of the furnace used affects the chemical composition of the slag. Slag aggregates from electric arc furnaces (EAFs) are used as fine aggregate in concrete, either entirely or in part, has been the subject of extensive investigation.

3.3 Aggregate

The coarse aggregate of aggregate grading (No. 8) with nominal maximum sizes is 20 mm is utilized. The coarse aggregates have irregular shapes, sharp corners. Table 2 displays the physical characteristics of the artificial sand and steel slag aggregates that were received

Table 2 Physical Properties of Fine Aggregates and Fine Steel Aggregate

Test	Fine Steel Slag Aggregates	Artificial Sand
Specific gravity	3.22	2.72
Water Absorption	2.1%	1.66%
Sieve Analysis	Zone 2	Zone 2
	FM = 2.79	FM = 3.20

3.4 Concrete Mix Proportions

Concrete mix proportions are determined using IS: 10262-2019 for M40 grade of the concrete. The primary test parameters in this investigation are the steel slag content and concrete strength. Table 4 illustrates the total number of 5 mixing groups that are created, including two types of concrete: control concrete and composite concrete. Mix proportions are established using the 20 mm coarse aggregate used in the investigations. A water-to-binder ratio of 0.45 is selected for this experiment. The proportions of the chosen water binder ratios in the concrete design mix are shown. The fine steel slag aggregate replacement percentage is adjusted to range from 0% to 40% based on the fine aggregate weight. By measuring the cubes' compressive strength after seven and twenty-eight days, the ideal dosage of fine steel slag aggregate for partially substituting fine aggregate is established. To create a homogeneous mix, the materials of the concrete are completely mixed using a laboratory mixer equipped with tilting drum types. For compacting the cubes, a vibrating table Is used. [5].

For the split tensile test, twelve SSC and three normal concrete (NC) cylindrical specimens measuring 150 mm in diameter and 300 mm in height are ready. Three specimens are produced for each set of test parameters. In preparation for the RCPT test, five cylindrical specimens, one for each combination, with dimensions of 100 mm in diameter and 50 mm in height, were created. Using moulds, the cylindrical samples are formed. The samples are left in a moist curing chamber for a full day. Following unmoulding, the specimens are cured in room temperature for 28 days by daily misting with water. [6] The results show that concrete with steel slag aggregate exhibits numerous different diffraction peaks in its X-ray diffraction pattern.

4.0 METHODOLOGY

Using 53 Grade Ordinary Portland Cement (OPC), as specified by the makers, a number of laboratory trial mixes are cast to create fine steel slag concrete, and fine steel slag material is procured from Pune, Maharashtra, India to examine its qualities. The experiments are carried out at the MIT WPU Kothrud facility in Pune, Maharashtra, India.

4.1 Microstructure Analysis

The microstructural characteristics of the concrete samples that contained fine steel slag aggregate were examined using X-ray diffraction (XRD) and scanning electron microscopy (SEM) techniques. Concrete sample pieces were first dried in an oven set to 105°C for 24 hours to eliminate moisture before being subjected to SEM analysis. To avoid charging effects, the dried samples were subsequently placed on aluminum stubs using conductive adhesive and lightly covered with carbon or gold. High-resolution pictures were taken by directing an electron beam at the coated samples' surface while they were inside the SEM chamber under a strong vacuum. To examine the morphology, pore structure, and binding formation between the cement paste and steel slag aggregates, these pictures were captured at various magnifications.

Hardened concrete samples with different amounts of steel slag were ground into a fine powder and run through a 75-micron filter to guarantee uniform particle size for XRD examination. After being prepared, the powder was crushed to create a flat surface inside the XRD machine's sample holder. After that, the device exposed the sample to X-ray photons at various angles (2θ), resulting in diffraction patterns that showed the material's crystalline phases. The mineral composition of the concrete was determined by analyzing the observed diffraction peaks using common reference databases. Section 5.1 (Results and Discussion) presents the findings from the XRD and SEM studies.

Table 3 Fineness Modulus of Fine Steel Slag Aggregate.

Sieve No (ASTM)	Sieve Opening (mm)	Weight Retained (gm)	Cumulative Retained (gm)	Weight (%)	% Finer	F.M Value
No. 4	4.75	9.0	9.0	1.8	98.2	
No. 8	2.36	31.7	40.7	8.1	91.9	
No. 16	1.18	119.2	159.9	32.0	68.0	
No. 30	0.60	134.8	294.7	5.9	41.1	2.78
No. 50	0.30	106.3	401.0	80.2	19.8	
No. 100	0.15	83.3	484.3	96.9	3.10	
Cumulative Weight Retention (%) Total = 277.9						

The results show that concrete with steel slag aggregate exhibits numerous different diffraction peaks in its X-ray diffraction pattern.

4.2 Slump

In accordance with IS 1199:1959, the slump test was used to assess the workability of fresh concrete. The conventional slump cone utilized had dimensions of 200 mm for the base, 100 mm for the top, and 300 mm for the height. Three layers of concrete were poured into the cone on a level, non-absorbent surface, and each layer was tamped 25 times with a steel rod that was 16 mm in diameter. The top surface was leveled after filling, and the cone was steadily raised vertically. The slump value, which shows the consistency and workability of the mix, was calculated by measuring the height difference between the top of the cone and the displaced concrete.

4.3 Compressive Strength

To evaluate the strength growth of concrete, the compressive strength test was conducted following IS 516:1959 requirements. For every mix change, 150 mm × 150 mm × 150 mm cube specimens were made, and they were cured in water at 27 ± 2°C for seven and twenty-eight days. The cube surfaces were cleaned and put in a 2000 kN loading capacity Compression Testing Machine (CTM) before testing. The greatest load recorded was used to determine the concrete mix's compressive strength. The load was added gradually until failure, at a rate of 140 kg/cm² per minute.

The concrete's compressive strength is being studied when fine steel slag is partially substituted as a fine aggregate. In the experiment, one sieve range of fine steel slag aggregate passing through 4.75 mm is utilised to partially substitute fine aggregate (20% by weight).

4.4 Split Tensile Strength

The split tensile strength test was conducted following IS 5816:1999 to evaluate the tensile strength of concrete. Cylindrical specimens measuring 150 mm in diameter and 300 mm in height were cast and cured in water at 27 ± 2°C for 28 days. Before testing, the cylinders were wiped clean and placed horizontally between the compression platens of a Universal Testing Machine (UTM). A uniform load was applied along the vertical diameter at a constant rate until the specimen failed. The maximum load at failure was recorded, and the split tensile strength was calculated using the formula:

$$T = (2P) / (\pi DL)$$

where T is the tensile strength (MPa), P is the applied load (N), D is the diameter of the specimen (mm), and L is the length of the specimen (mm).

4.5 Flexural Strength

The flexural strength test was conducted as per IS 516:1959 to determine the ability of concrete to resist bending. Beam specimens of dimensions 150 mm × 150 mm × 700 mm were cast and cured for 28 days. The specimens were then placed on two support rollers in a three-point loading system, with a span of 400 mm. A uniformly increasing load was applied at the mid-span of the beam until failure occurred. The flexural strength was calculated using the equation:

$$F = (PL) / (bd^2)$$

where F is the flexural strength (MPa), P is the maximum applied load (N), L is the span length (mm), b is the width of the specimen (mm), and d is the depth of the specimen (mm).

4.6 Acid Attack Test

The acid attack test was conducted to evaluate the durability of concrete in acidic environments. Concrete cube specimens of 150 mm × 150 mm × 150 mm were cast and cured for 28 days before being immersed in a 5% hydrochloric acid (HCl) solution for another 28 days. After immersion, the specimens were removed, surface-dried, and their weight and compressive strength were recorded. The percentage reduction in weight and compressive strength was calculated to determine the concrete's resistance to acid deterioration.

4.7 Rapid Chloride Penetration Test (RCPT)

The RCPT test was conducted as per IS 14959 (Part 2):2001 to evaluate the concrete's resistance to chloride ion penetration. Cylindrical specimens of 100 mm diameter and 50 mm height were cast and cured for 28 days. The specimens were placed in a test setup where a 60V electrical potential was applied across two chambers containing sodium chloride (NaCl) and sodium hydroxide (NaOH) solutions. The total charge passed (in coulombs) over six hours was measured, categorizing the concrete's permeability level. Lower charge values indicate higher resistance to chloride penetration.

4.8 Water Permeability Test

The water permeability test was conducted as per IS 3085:1965 to assess the permeability of concrete. Cube specimens of 150 mm × 150 mm × 150 mm were cured for 28 days before being placed in a permeability test apparatus, where they were subjected to a constant 5-bar (0.5 MPa) water pressure for 72 hours. After the test, the specimens were split, and the depth of water penetration was measured to determine the permeability characteristics of concrete with different steel slag replacement levels. A lower penetration depth indicates better resistance to water ingress.

5.0 RESULTS AND DISCUSSION

5.1 Scanning electron microscope (SEM)

The concrete containing steel slag aggregate specimens containing fine steel slag aggregate are less porous and denser than the control specimens, according to SEM micrographs of the concrete samples. In the concrete using 20% fine steel slag aggregate, the capillary pores seen in the control concrete are essentially nonexistent. Concrete that contains up to 20% fine steel slag aggregate will have a denser microstructure, which will increase the material's durability.

5.2 Slump Test

According to IS 1199 part 2 2018 [7], to ascertain if fresh concrete is workable, a slump test is conducted before the sample is cast, as indicated in Figure 1. Based on the results of the slump test, the concrete mix generated a genuine slump value of 35 mm at the 0% replacement level. The decline diminishes with an increase in the replacement level percentage, from 0% to 40% at 10% intervals for both replacement percentages. It demonstrates that, on average, sand is finer than steel slag. Compared to crushed granite and river sand, steel slag has a greater capacity to absorb water in both fine and coarse aggregate. As steel slag has a higher water absorption capacity compared to natural fine aggregate, it retains more water when mixed with cement. At a constant water-to-cement ratio of 0.45, this results in less free water being available for the hydration process, potentially affecting the workability and overall strength development of the concrete. [8]

Figure 1 Slump cone test

Table 4 Proportion of M40 grade concrete mixtures

Water binder ratio	notes	Cement (kg/m³)	Fine steel slag aggregate (%)	Fine steel slag aggregate (kg/m³)	CA (kg/m³)	FA (kg/m³)	W (kg/m³)
0.45	Control mix	450	0	0	1030	660	198
0.45		450	10	66	1030	594	198
0.45		450	20	132	1030	528	198
0.45		450	30	198	1030	462	198
0.45		450	40	264	1030	396	198

5.3 Compression Test

The compressive strength of concrete increases with steel slag replacement up to 20% on the seventh day of curing, after which it begins to decline as the replacement level increases further. The experimental setup of the compression testing machine is presented in Figure 2, and the typical failure pattern of tested cubes is shown in Figure 3. The controlled mix design with 10% steel slag replacement in the aggregate has a compressive value of less than 27.2 MPa, whereas the design without any steel slag replacement has a value of 24 MPa. Furthermore, on the seventh day of curing, the compressive strength reached its maximum value at a replacement of 20%, with a value of 27.6 MPa. The regulated mix design, on the other hand, exhibited a compressive strength of greater than 20 MPa. The controlled mix design's compressive strength increased to 43.37 MPa on the 28th day of curing, surpassing that of the 7th day of curing. This demonstrates that the concrete's strength increases with a longer cure period. Additionally, on day 28, the 10%, 20%, and 30% steel slag replacement samples' compressive strengths are almost the same at 47.68, 40.28, and 44.62 MPa, respectively. All data shown in Figure 4.

However, as it is previously indicated, when 30% of steel slag is substituted on the seventh day of curing, the compressive strength starts to drop to 20.13 MPa, and the compressive strength drops at 30% of steel slag replacement. In conclusion, the highest compressive strength was achieved by replacing 20% of the steel slag with different percentages of fine aggregate. The increase in compressive strength up to 20% steel slag replacement is attributed to the enhanced interfacial bonding between the angular steel slag particles and the cement matrix, which improves load transfer and densifies the microstructure. However, at higher replacement levels (30% and 40%), the excessive steel slag content leads to increased voids, weaker cementitious bonding, and reduced compactness, ultimately lowering the compressive strength. All data are shown in Figure 4.

Figure 2 Compression testing machine

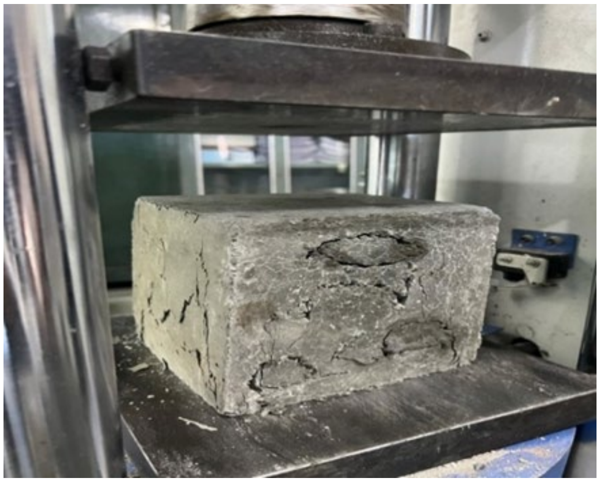

Figure 3 Crack occurred in Cube

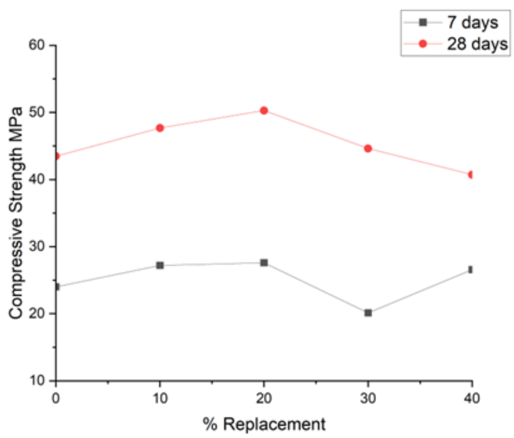

Figure 4 Compressive Strength Test

5.4 Split Tensile on Cylinder

The impact of substituting steel slag on the splitting tensile strength is ascertained. The experimental setup of the splitting tensile strength is presented in Figure 5. The typical failure pattern of tested Cylinder is shown in Figure 6. For all hardened concrete samples' splitting tensile strength test results at the 28-day curing age are shown in Figure 7. With FA values of 0%, 10%, 20%, 30%, and 40%, the splitting tensile strength of concrete are 3.05 MPa, 3.11 MPa, 3.55 MPa, 3.18 MPa, and 3.19 MPa, in that order. When steel slag is added to concrete mixes up to 30% of the total fine aggregate, the split tensile strength decreased by less than 5% when compared to the strength of the reference concrete mix so the strength of the cylinder is increase at 20%replecement of steel slag and decreases at 0% and 30%. The results of the split tensile strength test are presented in the graph Figure 5.

Figure 5 Compression testing machine

Figure 6 Crack occurred in cylinder

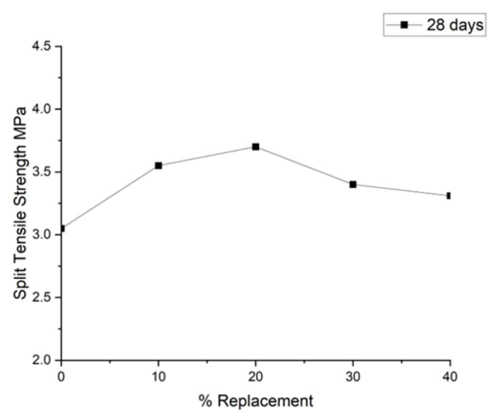

Figure 7 Split Tensile Strength Test

5.5 Flexural Strength

Concrete's flexural strength is determined by applying a steady load to beam specimens at a rate of 0.011 MPa/s using flexural testing equipment with a 1000 kN capacity. The experimental setup of the Universal Testing Machine is presented in Figure 8. The typical failure pattern of the tested beam is shown in

Figure 9. Comparable to the strength of compression. This decrease is discovered to be 18% of the control concrete. The 20% ratio of steel slag aggregate is determined to have the highest flexural strength across the different replacement ratios. At 28 days of curing, these improvements are measured at 9.8% of the flexural strength, respectively, and the results of the Flexural Strength test are presented in the graph in Figure 10.

The correlations between the measured properties are presented in the following figures: Figure 11 shows the relationship between flexural and compressive strength, Figure 12 shows the relationship between split tensile and compressive strength, and Figure 13 shows the relationship between split tensile and flexural strength.

Figure 8 Universal Testing Machine

Figure 9 Crack marked on beam

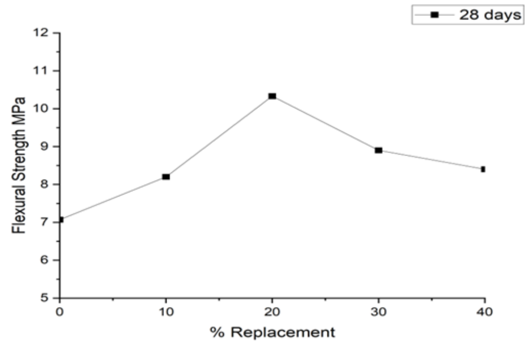

Figure 10 Flexural Strength Test

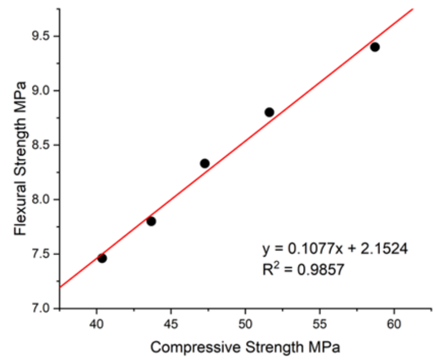

Figure 11 Equation of Flexural strength and compressive strength

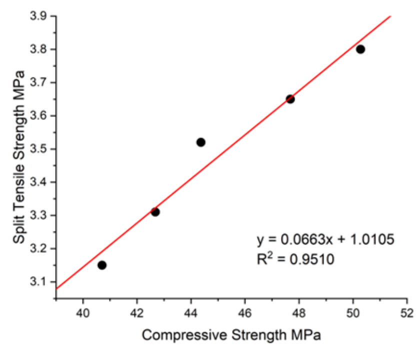

Figure 12 Equation of split tensile strength and compressive strength

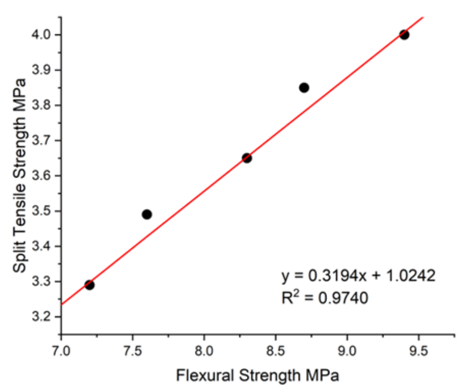

Figure 13 Equation of split tensile strength and flexural strength

5.6 Acid Attack test

A portion of the weight and compressive strength of 150 mm concrete cubes were lost after they were immersed in 5% HCl acid for 28 days. The results of the test showed how resistant steel slag-containing concrete is against acid attacks. When concrete formed with steel slag is lighter and has a lower compressive strength, ettringite (sulphate calcium sulfoaluminate) and calcium hydroxide around the small aggregate particles do not form. These processes thereby increase the concrete's ability to withstand acid attack. Relative to normal concrete, steel slag-containing concrete loses 4.01% of its weight and 2.11% of its compressive strength. The concrete cube containing steel slag is more resistant to the acid assault than the control concrete. the weight loss and strength percentages in the acid resistance test, as shown in Figure 14**.** [10]

Figure 14 Acid attack test

5.7 RCPT Test

The total charge passed during this period is calculated in coulombs using the trapezoidal rule. The experimental setup of the RCPT test is presented in Figure 15. According to [11], the penetrability of chloride ions is limited to low levels when charges fall between 1000 and 2000 coulombs, and moderate levels when charges fall between 2000 and 4000 coulombs. Whereas conventional concrete with 20% fine aggregate replacement concrete has poor penetrability, 20% fine aggregate replacement concrete has moderate penetrability. The creation of a calcium silicate hydrated gel during the primary cement hydration reaction is a prerequisite for the secondary hydration process, which is produced by pozzolanic materials including steel slag, fly ash, and silica fume. The following are the preliminary study findings. It produces low permeability concrete by densifying the microstructures of the cement. When pozzolanic ingredients are introduced, the permeability qualities of the concrete will diminish with age[12].

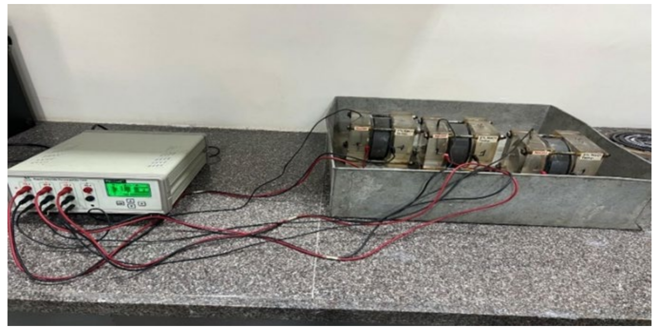

Figure 15 RCPT test

5.8 Water Permeability Test

The pores or voids that are present in concrete determine its permeability. Given that it is a blend of cement, sand, and coarse aggregate—all of which have pores and voids—it is porous. Because the materials in concrete are constantly interacting, when CO_2, SO_2, and Cl seep through the pores and react with the reinforcement, they can produce toxic substances like water, rust, and corrosion, which increase the volume of the reinforcement and weaken the structure by causing surface cracking and collapse. The three sample specimens, 150 by 150 by 150 mm concrete cubes, were cast after curing for 28 days to conduct the water permeability test as per DIN 1048, the German Standard.[13] At that point, after the test cell is assembled and equipped with the necessary components, the six cubes can be tested. A consistent water pressure of 5 N/mm2 or 5 bar was maintained for the course of the three-day (72-hour) test.

As indicated by the equation below, a system consisting of air compression coupled to a water tank via a valve is used to apply water pressure to the concrete cube. Up until the steady-state is reached, the water's fluctuating depth is recorded. As indicated in Figure 16, the test will be conducted at a temperature of 27 ± 2 °C. The formula for the coefficient of permeability (K) is

$K = D^2 P/2TH$

where,

D - Concrete penetration depth (mm),

P-Concrete porosity expressed as a proportion

T-Time in seconds,

H- pressure head of 1.5 meters.[27].

The water permeability results are summarized in Table 5.

Figure 16 Water permeability apparatus

Table 5 Water Permeability

Mix Proportion	Avg Penetration Depth (mm)	Permeability (cm/sec)
0%	12	2.7721×10^{-10}
10%	14	3.704×10^{-10}
20%	17.5	5.788×10^{-10}
30%	18.5	6.468×10^{-10}
40%	21	8.335×10^{-10}

5.9 SEM Test

By using scanning electron microscopy techniques, or SEM, it is possible to determine the micro-structural properties down to a 10-mm fragment. Despite being the most widely used basic material in the building industry, concrete has a very complicated and heterogeneous microstructure. The ferrochrome slag particles are characterised using SEM, and to examine the contact where the cement matrix and slag meet. It can be observed that because ferrochrome slag replaced traditional sand as fine aggregates, the microstructure changed. Round grains replaced irregular ones, there were fewer voids, and there are more microcracks in the 10FS, 20FS, and 30FS slag samples due to the presence of finer particles in the slag. The SEM picture of the concrete sample 40FS reveals greater voids and microcracks. The SEM picture of ferrochrome slag at 200 magnifications, which shows particles with sizes ranging from 1 mm to 200 mm, is shown in Figure 17(a). The SEM picture of ferrochrome slag at 1.0k magnification, which displays round and porous grains, is shown in Figure 17(b) and Figure 17(c)

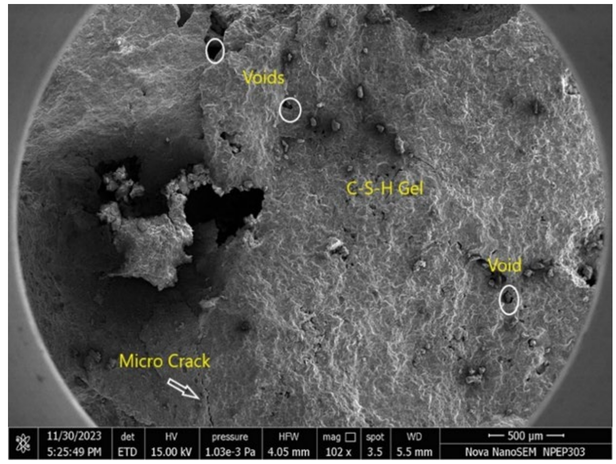

Figure 17(a) 20% ss SEM Test

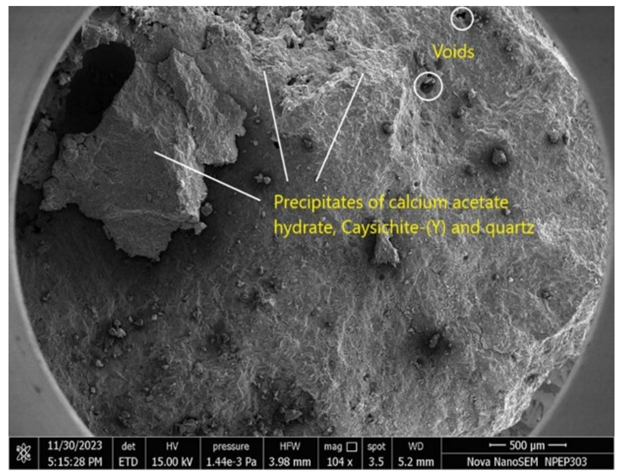

Figure 17(b) 30% ss SEM Test

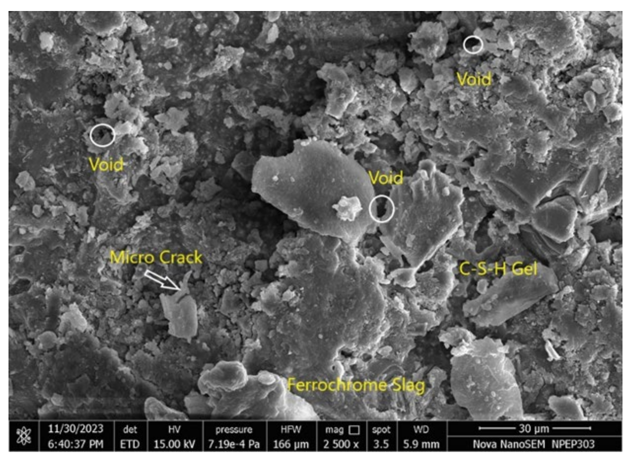

Figure 17(c) 40% ss SEM Test

5.10 XRD Test

XRD, or the X-ray diffraction pattern, is employed to investigate how the most damaged concrete's mineral phase forms (28 days after exposure to sulphate solution) as a result of sulphate solution erosion. An operation of this method is shown in Figures 18 and 19. These results show that concrete with steel slag aggregate exhibits a broad range of diffraction peaks in its X-ray diffraction pattern. Through a comparative analysis of their corresponding characteristic angles, it is determined that these diffraction peaks correspond to ettringite, calcium hydroxide crystal, gypsum, SiO2, albite, and calcium magnesium carbonate, in that order. When the concentration of the erosion solution is the same, the Ca(OH)2 diffraction peak of the steel slag fine aggregate concrete under different steel slag replacement ratios exhibits distinguishable changes; the NC group has the lowest value and the SSC-90 group has the greatest. This implies that, even at the same concentration of solution erosion, the amount of Ca(OH)2 in the sample increases when the steel slag substitution rate develops. This is because the active mineral components, such as C3S and C2S, will also react with a small quantity of f-CaO in steel slag during the long-term hydration process, resulting in the formation of C-S-H gel and Ca(OH)2. [15]

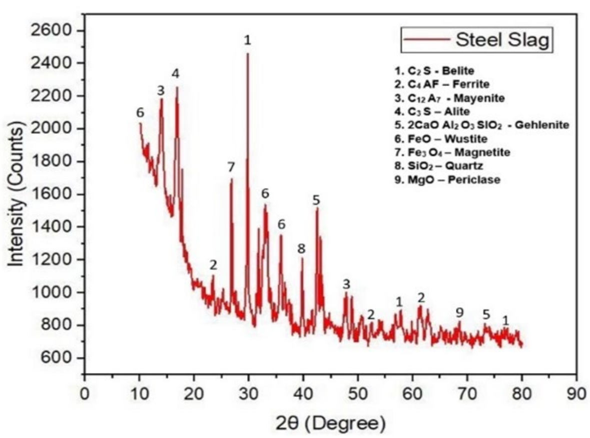

Figure 18 XRD Test Graph of steel slag

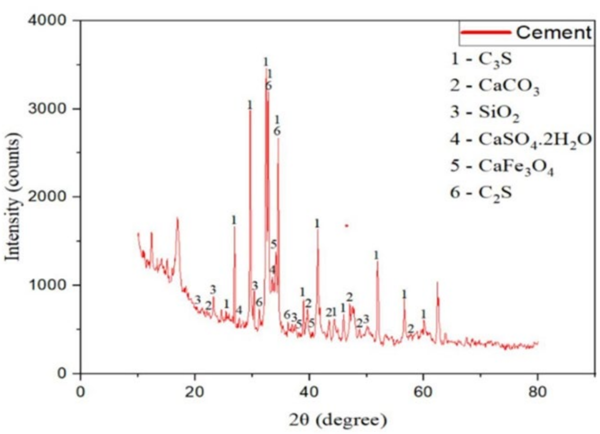

Figure 19 XRD Test Graph of cement

6.0 CONCLUSION

Examining the fine steel slag aggregate's strength and durability as a possible fine aggregate replacement is the aim of this study. The compressive, tensile, flexural, water permeability, rapid chloride penetration, and acid resistance to HCL of concrete with steel slag in the fine aggregate are all studied experimentally. It is observed that compressive strength of 20% replacement of the steel slag as a fine aggregate increases by 5.45%.

Flexural strength of the concrete increases by 46.11% for 28 days of the concrete of 20% replacement of steel slag.

Split tensile strength of the concrete increases by 21.31% for 20% replacement of steel slag.

In water permeability test shows the 27 ± 2 C temperature at which the test is to be performed. After being submerged in 5% HCl acid for 28 days, 150 mm cubes of concrete were found to have lost a percentage of their weight and compressive strength.

In acid attack test the percentage loss of weight is 4.01% and the percentage loss of compressive strength is 2.11% when comparing normal concrete and steel slag-containing concrete. Compared to the control concrete, the concrete cube containing steel slag is more resilient to the acid attack.

In the RCPT test With time, when pozzolanic chemicals are added, the concrete's permeability properties will decrease.

More research is necessary before combining steel slag with other byproducts in the formulation of the concrete mix.

More research is needed to determine why steel slag aggregate replaces fine aggregate in concrete mixes at a larger percentage.

A longer curing period is necessary to fully comprehend the behaviour of the concrete, and this may result in varied outcomes for steel slag concrete.

More research is needed to determine the percentage of weight loss in steel slag concrete caused by sulphate attack in durability tests like the sulphate attack test.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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