Eco-Efficiency and Performance Evaluation of M20 Grade Concrete with Partial Replacement of Cement by Steel Slag

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A thesis submitted to the Department of Civil Engineering in partial fulfillment for the degree of Bachelor of Science in Civil Engineering

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DECLARATION

We the undersigned hereby declare that the work and all resources presented in this thesis titled " **Eco-Efficiency and Performance Evaluation of M20 Grade Concrete with Partial Replacement of Cement by Steel Slag"** are the result of our original efforts and have not been submitted either in whole or in part for academic credit at any university, college or institution.

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Dedicate

To

"Our Beloved Parents & Teachers"

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ABSTRACT

Cement is the main material in concrete that helps everything stick together. However, it is also one of the biggest sources of carbon dioxide (CO_2), which is harmful to the environment. Because of this, researchers are trying to replace cement with more eco-friendly materials. In this study, waste slag from a steel cutting house called Venus sign limited was used as a partial replacement for cement. A well-established scientific explanation in Civil Engineering and Materials Science is known as the "Pozzolanic Reaction. Initial tests showed that this slag can behave like a pozzolanic material, which means it can help in strength development.

The slag was first ground into fine particles that could pass through a #100 sieve. Concrete samples were then prepared by replacing 10%, 20%, and 30% of cement with slag, using water–cement ratios of 0.40 and 0.45. Compressive strength tests were conducted at 7 and 28 days. The results showed that when 10% slag was used, the strength slightly decreased compared to normal concrete. However, when 20% and 30% slag were used, the strength decreased further.

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CHAPTER 1

INTRODUCTION

1.1General

Sustainable development has gained more importance in recent times than before. To maintain the balance of natural resources, engineers and scientists are focusing on recycling materials and exploring effective ways to utilize waste materials in construction and other fields. Concrete has been one of the most essential construction materials used by humans for centuries. It is highly adaptable and ranks as the second most widely used material in the world after water. Where approximately 30-33 billion tones of concrete are used every year (According to ACI). The production process of concrete is highly energy-intensive and is responsible for more than 7-8% of human-caused carbon dioxide emissions—of which cement plays the major role. Concrete

finds its applications from the houses we live in to the roads & bridges we travel. Concrete is a combination of cement, sand, coarse aggregates and water. To meet the growing demand for concrete, efforts are being made to boost the production of cement and natural aggregates. However, producing cement consumes a large amount of energy and emits harmful gases into the environment. . Similarly, the query sites, from where the natural aggregates and the raw material for cement are acquired, are not only polluting our environment but also causing depletion of our natural resources.

In our modern society, everyone is looking for an economical solution that can utilize our industrial waste so that our environmental burden are reduced and our natural resources are protected from depletion. Serious efforts are being made in all over the world to find out the suitable substitution of constitutions of concrete [1-3]. The emphasis on the utilization of industrial waste in concrete provides a very environmental-friendly solution [4]. Proper disposal of these materials requires significant effort, and even then, they continue to pose a burden on the environment. Their incorporation into concrete would be highly beneficial. It would not only be cost-effective but also reduce the demand for cement, thereby helping to protect the environment. In addition, using industrial waste in this way would provide a safe and effective method of disposal.

In this study, we deeply investigated the waste materials generated from various local industries located around Moghbazar. During our visits to Venus Sign Limited, Green Sign Limited, and other nearby cutting house facilities situated in Charulata Bazar in the surrounding area of Moghbazar, we observed that these industries are facing a significant landfill shortage problem. At present, the industrial slag produced by these facilities is being disposed of in an unplanned manner, which not only contributes to landfill scarcity but also creates serious environmental hazards. Therefore, we selected this locally generated industrial waste slag as a case study for its potential application in concrete production.

Figure 1.1: Steel Slag

1.2 Objectives of the Study:

- To investigate the compressive strength of steel slag concrete.
- To evaluate the effect of steel slag on CO_2 emission reduction.
- To determine the eco-efficiency of concrete with steel slag replacement.
- To identify the optimum slag replacement percentage for sustainable concrete production

CHAPTER 2

LITERATURE REVIEW

2.1 Research Background

Steel slag is an industrial by-product that is produced during the manufacturing and cutting process of steel or iron plates. Steel slag mainly contains calcium oxide, silica, iron oxide, magnesium oxide, and alumina. Due to its high strength, hardness, and durability, steel slag is widely used in road construction, asphalt mixtures, and concrete production as a partial replacement for natural aggregates or cementitious materials.

2.1.1 History of Using Steel Slag with Concrete

The use of steel slag in concrete began with the rapid growth of the steel industry during the late nineteenth and early twentieth centuries. Initially, steel slag was considered a waste material and was dumped in landfills. Later, researchers and engineers discovered that steel slag possessed strong mechanical properties and could be effectively used as construction material. In the early stages, steel slag was mainly used in road bases and railway ballast because of its hardness and abrasion resistance. By the mid-twentieth century, studies conducted in Europe, the United States, and Japan showed that processed steel slag could be used as coarse and fine aggregate in concrete production. Researchers found that steel slag improved the compressive strength, density, and durability of concrete while reducing the demand for natural aggregates. During the 1970s and 1980s, environmental concerns and the need for sustainable construction materials increased interest in recycling industrial by-products such as steel slag. Modern research has further demonstrated that steel slag concrete provides better resistance to wear, impact, and chemical attack compared to conventional concrete. Today, steel slag is widely used in sustainable and high-performance concrete technology because it helps reduce industrial waste, conserve natural resources, and lower environmental pollution associated with construction materials.

2.2 Studies on Carbon Emission Assessment & Mix Concrete with Steel Slag

2.2.1 "Comparison of Properties of Steel Slag and Crushed Limestone Aggregate Concretes"

Authors: M. Maslehuddin et al. (2003) Saudi Arabia.

This study compared concrete made with steel slag aggregate and conventional limestone aggregate. The researchers found that steel slag concrete showed higher density, improved durability, and satisfactory compressive strength. The study concluded that steel slag can effectively replace conventional aggregate in concrete production while supporting sustainable construction.

2.2.2 "Sustainable Cleaner Production of Concrete with High Volume Steel Slag"

Authors: P. R. Prem et al. (2018) Chennai, India.

This research investigated the use of high-volume steel slag in concrete mixtures. The study reported that partial replacement of cement with steel slag reduced environmental impact and carbon emissions while maintaining acceptable compressive strength. The authors emphasized the importance of sustainable concrete technology for eco-friendly construction.

2.2.3 "Steel Slag—Its Production, Processing, Characteristics, and Cementitious Properties"

Author: C. Shi (2004) China.

This paper reviewed the physical and chemical properties of steel slag and its application in cement and concrete. The study explained that steel slag possesses cementitious characteristics and can improve concrete performance when properly processed and utilized.

2.2.4 “Use of Low CaO Unprocessed Steel Slag in Concrete as Fine Aggregate”

Authors: H. Qasrawi et al. (2009) Jordan.

The researchers examined the use of untreated steel slag as fine aggregate in concrete. Results showed that steel slag improved compressive strength and abrasion resistance. The study also highlighted that steel slag can reduce the demand for natural sand and minimize industrial waste disposal.

2.2.5 “Durability of Concrete Made with EAF Slag as Aggregate”

Authors: J. M. Manso et al. (2006) Spain.

This research focused on the durability performance of concrete containing Electric Arc Furnace (EAF) steel slag aggregate. The findings revealed that steel slag concrete had good resistance against chemical attack and long-term environmental exposure, making it suitable for durable infrastructure applications.

2.2.6 “Carbonation Behavior of Steel Slag and Its Application in Carbon Dioxide Sequestration”

Authors: Q. Wang et al. (2013) China.

This study investigated the carbonation behavior of steel slag and its ability to absorb carbon dioxide. The researchers found that steel slag can contribute to CO_2 sequestration, which helps reduce greenhouse gas emissions and supports environmentally sustainable construction materials.

CHAPTER 3

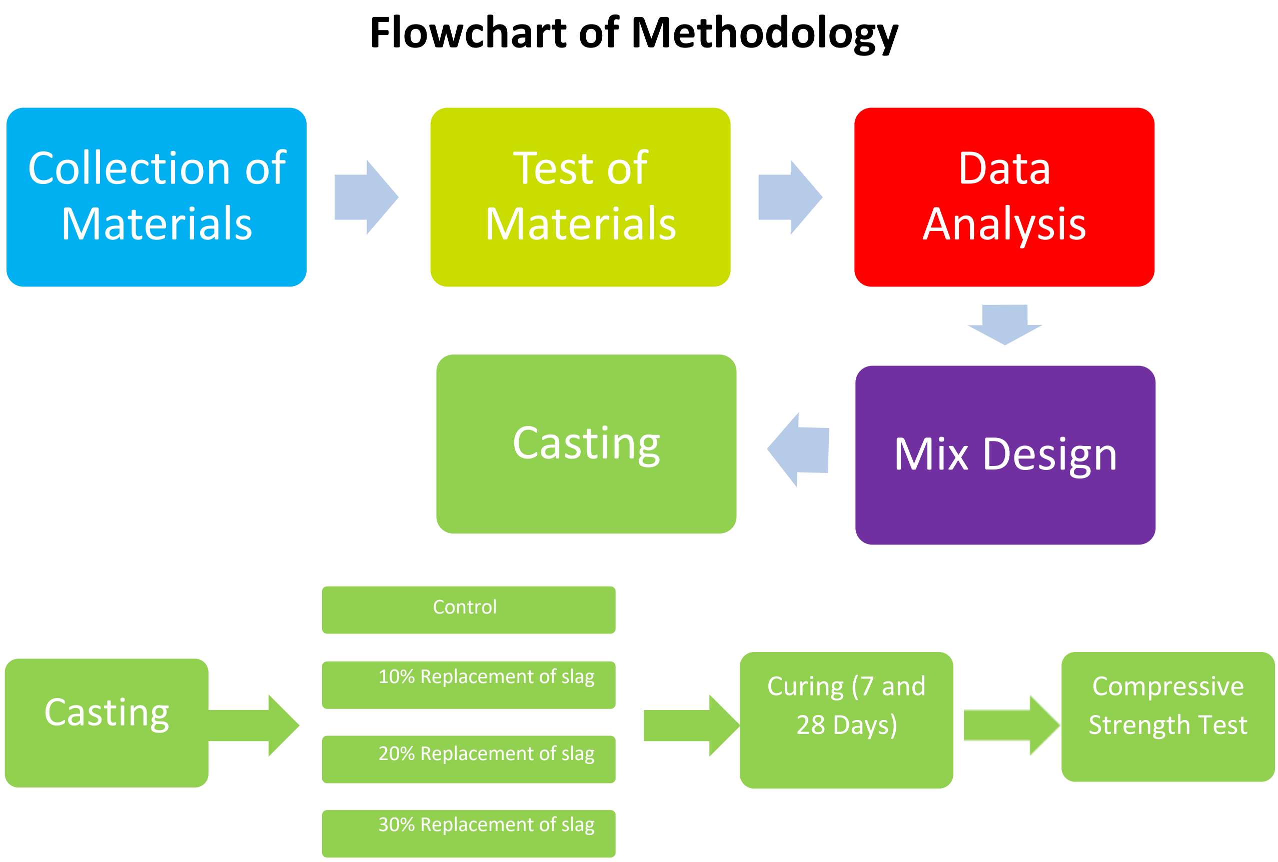
METHODOLOGY

3.1 Introduction

First, we completed the required concrete mix design. Then, we collected the materials needed to produce the concrete. Our work mainly focuses on studying the effect of steel slag on the strength properties of concrete with partially replaced cement. In this study, steel slag was used as a partial replacement for cement.

3.2 Methodology Overview

In our work, the materials were first collected. Then all the materials were taken to the laboratory and tested. All the materials used in our study are cement, sand, stone, steel slag as a percentage as replacement cement, water etc.



3.3 Collection of Materials

We have collected coarse aggregate and fine aggregate from Gabtali. Collected steel slag from the Venus Sign Limited Factory. We collected OPC cement from

3.4 Mix Design

A smooth platform was selected. Our mixing ratio was 1:1.5:3. First, the coarse aggregate was spread evenly on the platform according to the specified measurements. Then the fine aggregate was spread over the coarse aggregate according to the specified measurements. After that, the cement, used as a binding material, was spread evenly over the pre-applied aggregates in the specified quantity. Then, a portion of partially recycled steel slag was added over the cement. All the ingredients were then properly mixed until the mixture became uniform in color. Once the mixture was properly mixed, concrete mortar was prepared using potable water.

3.5 Water Cement Ratio

As per the mix design, the water–cement ratios are fixed at 0.4 and 0.45. For example, if the water–cement ratio is 0.4 and we use 10 kg of cement in a concrete mix, we will use 4 liters of water. Similarly, for a water–cement ratio of 0.45, if we use 10 kg of cement in a concrete mix, we will use 4.5 liters of water.

The water-cement ratio (w/c ratio) is the ratio of the weight of water to the weight of cement used in a concrete mix. It is one of the most important factors affecting the strength, durability, and workability of concrete. Mathematically:

Water-Cement Ratio = weight of Water / Weight of Cement

A lower water-cement ratio generally produces higher strength and more durable concrete because less water leaves fewer pores after hardening. However, if the water content is too low, the concrete becomes difficult to mix and place properly. On the other hand, a higher water-cement ratio increases workability but reduces strength and durability due to excessive voids formed after evaporation of water.

For normal concrete, the water-cement ratio usually ranges from 0.40 to 0.60 depending on the required strength and exposure conditions. According to

Abram's law, the compressive strength of concrete decreases as the water-cement ratio increases

3.5.1 Typical Water-Cement Ratios

- **0.40 – 0.45:** High strength concrete
- **0.45 – 0.55:** Normal reinforced concrete
- **0.55 – 0.60:** Mass concrete or low strength work

3.6 Cement

Cement is an essential material used in concrete because it acts as a binding agent that holds sand, gravel, and other aggregates together to form a strong and durable structure. When mixed with water, cement undergoes a chemical reaction called hydration, which hardens the mixture and develops the strength needed for construction works. Cement is an integral part of urban infrastructure. It is used to make concrete as well as mortar and to secure the infrastructure by binding the building blocks. Also cement concrete is widely used in bridges, roads, dams, pavements, tunnels, and water-retaining structures due to its high compressive strength and long service life. One of the major benefits of cement in concrete is its durability, as properly cured concrete can resist weathering, moisture, fire, and chemical attack. Cement also provides good workability, allowing concrete to be molded into different shapes and designs before hardening. In addition, cement concrete is economical and requires relatively low maintenance compared to many other construction materials. Modern construction also uses supplementary materials such as fly ash and slag cement with cement to improve the strength, sustainability, and durability of concrete. Hydraulic limes, natural cements, and artificial cements mainly gain their strength from the presence of belite. Since belite develops strength at a slow rate, these materials harden gradually over time. These cements were produced at temperatures below 1,250 °C (2,280 °F), which prevented the formation of alite. It is the compound that responsible for the early strength development in modern cement.

3.6.1 Raw Materials of Cement and Their Functions

Cement is manufactured from several important raw materials that contribute to its strength, durability, setting properties, and overall performance. The main raw material used in cement production is limestone, which contains calcium carbonate ($CaCO_3$). Limestone provides calcium oxide (CaO) after heating in the kiln, and this compound is mainly responsible for the strength and hardness of cement. Clay or shale is another essential material, supplying silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). Silica helps in increasing the strength and durability of cement by forming strong silicate compounds, while alumina assists in the setting process and lowers the clinkering temperature during manufacturing. Iron oxide acts as a flux material in the kiln and contributes to the hardness and color of cement. Gypsum ($CaSO_4 \cdot 2H_2O$) is added during the final grinding stage to control the setting time of cement and prevent flash setting, allowing sufficient time for mixing and placing concrete. Small amounts of magnesia (MgO) are also present, which help improve hardness and strength, although excessive amounts may cause unsoundness and expansion. Alkalis such as sodium oxide (Na_2O) and potassium oxide (K_2O) participate in chemical reactions during production, but excessive alkali content may lead to efflorescence in concrete structures. Therefore, each raw material used in cement manufacturing performs a specific function that helps achieve the required strength, durability, workability, and stability of cement in construction works.

Figure 3.1: Cement

Table 3.1: Chemical Composition of Ordinary Portland Cement

Ingredient	Percentage
Lime (CaO)	62
Silica (SiO2)	22
Alumina (Al2O2)	5
Calcium Sulphate (CaSO4)	4
Iron Oxide (Fe2O3)	3
Magnesia (MgO)	2
Sulphur (S)	1
Alkali	1
Total	100

3.6.2 Properties of Good Cement

The quality of cement greatly affects the performance of concrete and mortar. Good cement must have proper strength, fineness, soundness, durability, and suitable setting characteristics. These properties ensure safe, durable, and high-quality construction works in civil engineering. Cement must have those Properties:

- **Strength:** A good cement should provide high compressive strength after hardening. It must be capable of bearing structural loads without failure.
- **Proper Setting Time:** Cement should not set too quickly or too slowly.
- **Initial setting time:** should be sufficient for mixing, transporting, and placing concrete.
- **Final setting time:** should allow the concrete to harden within a reasonable period.

- **Soundness:** Good cement should retain its volume after setting and hardening. It should not expand excessively, as this may cause cracks in concrete.
- **Fineness:** Cement particles should be sufficiently fine. Fine cement increases the surface area for hydration, improves strength development, produces smoother concrete surfaces.
- **Good Plasticity and Workability:** When mixed with water, cement paste should be smooth and workable so that it can be easily placed and compacted.
- **Uniform Color:** High-quality cement usually has a uniform grey color with a slight greenish shade, indicating proper composition and burning.
- **Freedom from Lumps:** Good cement should be free from hard lumps. Lumps indicate absorption of moisture and partial hydration, which reduces cement quality.
- **Adequate Heat of Hydration:** Cement should generate a moderate amount of heat during hydration. Excessive heat may cause thermal cracking, especially in mass concrete structures.
- **Durability:** Good cement should resist weathering, chemical attack, moisture, and environmental effects to ensure long service life of structures.
- **Proper Chemical Composition:** The chemical constituents of cement should be in correct proportions to ensure strength, durability, and soundness.

3.7 Sand

Sand is technically classified as granular material resulting from the natural disintegration of rocks or the crushing of hard stones. In concrete, sand primarily fills the voids between coarse aggregates such as gravel or crushed stone, resulting in a dense and well-compacted mixture. This reduction of voids not only improves the density of concrete but also enhances its compressive strength and durability. Sand improves the workability of fresh concrete by making the mix more cohesive and easier to handle, place, and finish without segregation. In addition, it helps in reducing the amount of cement paste required, which makes concrete more economical while still maintaining required strength. By providing proper particle distribution, sand contributes to better bonding between cement paste and aggregates, which further increases the structural stability of hardened concrete. It also helps control shrinkage and cracking by minimizing excess cement content, which is more susceptible to drying shrinkage. Sand also helps distribute cement evenly throughout the concrete mix and reduces the amount of cement paste required, which lowers construction costs. In concrete construction, sand is widely used for making foundations, floors, pavements, bridges, buildings, and other structural elements because it contributes to the overall stability and uniformity of the concrete mixture. Different types of sand, such as river sand and manufactured sand, are commonly used depending on construction requirements and material availability.

3.7.1 Properties of Sand

In concrete, possesses several important properties that determine its suitability and performance. One of the most important properties is particle size and grading; well-graded sand contains a good distribution of different particle sizes, which helps in achieving dense packing, reducing voids, and improving concrete strength. The shape of sand particles also matters, as rounded particles (like river sand) improve workability, while angular particles (like crushed sand) improve interlocking and strength. Cleanliness is another key property, as sand should be free from clay, silt, organic matter, and other impurities that can weaken the bond between cement and aggregates. The strength of sand particles should be high enough to resist crushing under load, ensuring durability of concrete. Moisture content is also significant because it affects water-cement ratio and workability during mixing. In addition, good quality sand should be chemically inert, meaning it should not react with cement or other materials in concrete. Good sand should have proper bulk density to ensure proper mixing proportions and reduce voids in concrete. Durability and hardness are also important, as sand must withstand weathering and mechanical stresses over time without breaking down. These properties collectively ensure that sand contributes effectively to the strength, durability, and workability of concrete.

3.7.2 Sieve Analysis for Sand

Sieve analysis is a laboratory test to determine the particle size distribution (gradation) of sand. It helps to identify how coarse or fine the sand is and whether it is suitable for use in concrete, mortar, or other construction works. In this test, a dried sample of sand is passed through a stack of standard sieves arranged in descending order of mesh size (largest opening at the top and smallest at the bottom). The sand retained on each sieve is measured and expressed as a percentage of the total sample. From this data, a gradation curve is plotted, which shows the distribution of particle sizes. Sieve analysis is important because well-graded sand improves the strength, workability, and durability of concrete by ensuring proper particle packing and reducing voids. It is commonly carried out according to standards such as ASTM C136 and IS 2386.

Sieve numbers refer to standard sieve sizes used in sieve analysis to classify sand particles. Sieve sizes are #4, #8, #16, #30, #50, #100, #200/pan.

Figure3.3: Sieve Analysis for sand

3.7.3 Fineness Modulus (F.M) of Sand

Fineness Modulus is an empirical value that indicates the average particle size of sand. It is calculated from sieve analysis results. It gives an idea about whether the sand is fine, medium, or coarse.

Mathematically:

F.M= (Cumulative Percentage Retained on Standard Sieve) /100

F.M helps in selecting suitable sand for concrete mix design, controls workability and strength of concrete and ensures proper grading of fine aggregates.

3.7.4 Typical F.M values for sand:

- **Fine sand:** 2.2 – 2.6
- **Medium sand:** 2.6 – 2.9
- **Coarse sand:** 2.9 – 3.2

3.8 Aggregate

Aggregates are one of the most important materials used in concrete production. They consist of granular materials such as sand, gravel, crushed stone, and recycled concrete materials. According to Concrete Network, aggregates occupy nearly 60–80% of the total volume of concrete, making them the backbone of concrete structures. Fine aggregates usually include natural sand or crushed sand smaller than 4.75 mm, while coarse aggregates include gravel and crushed stones larger than 4.75 mm. Aggregates are widely used in construction works such as foundations, beams, columns, slabs, bridges, highways, dams, airport pavements, and railway sleepers. The selection of proper aggregate is essential because it greatly influences the strength, durability, and workability of concrete. One of the major uses of aggregate in concrete is to provide bulk and reduce the overall cost of construction. Cement is expensive compared to aggregates, so using suitable aggregates decreases cement consumption and makes concrete economical. Portland Cement Association explains that aggregates also improve the dimensional stability of concrete and reduce shrinkage and cracking during drying. In decorative concrete works, exposed and colored aggregates are used to enhance appearance, while lightweight aggregates are used in high-rise buildings to reduce dead load. Heavyweight aggregates are commonly used in structures requiring radiation shielding, such as nuclear plants and hospitals. Aggregates provide many benefits to concrete in both fresh and hardened states. Properly graded aggregates improve the workability and finishing quality of fresh concrete. Rounded aggregates increase workability because they reduce internal friction, whereas angular aggregates improve interlocking and bonding within the concrete mass. Aggregates also help reduce permeability, which protects concrete from water penetration and chemical attack. According to research from Penn State University, good-quality aggregates improve resistance to abrasion, weathering, and freeze-thaw cycles, thereby increasing the durability and service life of structures. In addition, aggregates improve thermal resistance and fire resistance, making concrete more stable under varying environmental conditions.

Figure 3.4: Stone

3.8.1 Strength of Aggregate

The strength of concrete is highly dependent on the properties of aggregates. Strong, hard, and durable aggregates increase the compressive strength of concrete because they can resist crushing under heavy loads. Aggregate size, shape, texture, and grading significantly influence concrete strength. Well-graded aggregates produce denser concrete with fewer voids, which improves both strength and durability. Clean aggregates provide better bonding with cement paste, while dirty or clay-coated aggregates weaken the bond and reduce concrete performance. Crushed stone aggregates generally provide higher strength than rounded gravel because of better mechanical interlocking. Furthermore, aggregates with low water absorption help maintain the proper water-cement ratio, which is critical for achieving high-strength concrete.

3.8.2 Coarse aggregate sieve analysis

Then coarse aggregate sieve analysis was completed by NO.100, NO.50, NO.30, NO.16, NO.8, NO.4,3/8in, 3/4in, 3/2in, and 3in sieves. For particle size fine aggregates, and coarse aggregate, the sieve analysis method was used according to ASTM C136.

3.9 Materials Ratio

We completed the concrete mix design for 2900 psi -strength concrete using the volume-basis method. The ratio of the different ingredients in the concrete was 1:1.5:3. The proportions of the different ingredients were measured according to this concrete mixing ratio.

3.10 Casting Cylinder

4×8-inch cylindrical specimens were used. Each mold was filled with concrete in three layers. While filling the molds, each layer was tamped 25 times using a 5/8-inch steel tamping rod. The remaining concrete in the mixing pan was occasionally stirred and scraped together to prevent the materials from separating. The molds were filled completely, and the tops were smoothed evenly. Finally, the molds were labeled with the date and the percentage of partially replaced recycled steel slag.

Figure 3.5: Measurement of Slag, Cement, Stone & Sand

Figure 3.6: Mixing Process

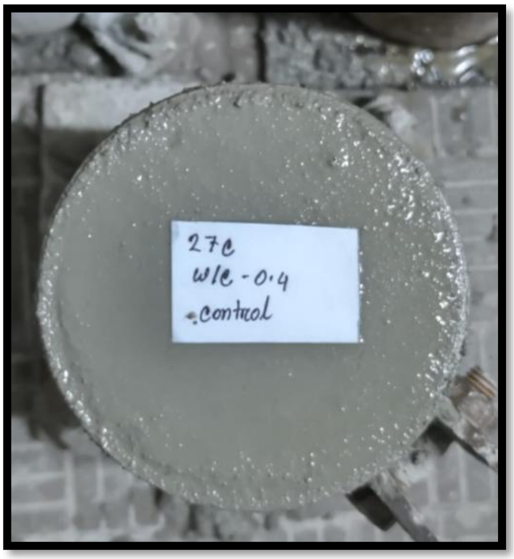


Figure 3.7: Mold Filling with Concrete and Tamping

Figure 3.8: After Leveling and Marking

Figure 3.9: After Leveling and Marking

Figure 3.10: After De-molding of Specimens

3.11 Curing for Specified Time

After removing the cylinders from the molds, the cylinders were numbered according to the date and the percentage of partially replaced recycled steel slag. Then, the numbered cylinders were kept completely submerged in water for 7 and 28 days.

Figure 3.11: Water Tank

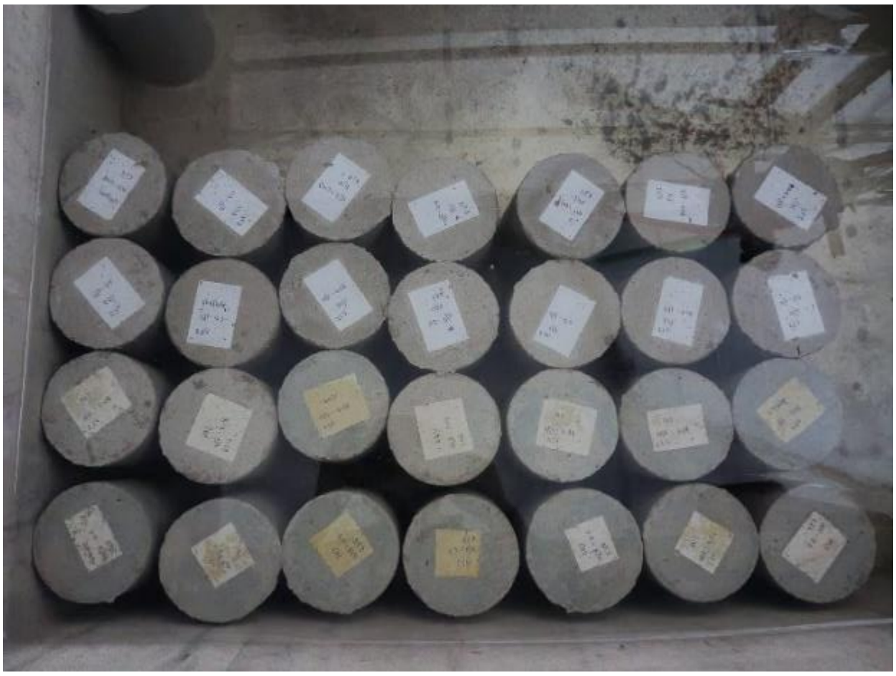


Figure 3.12: Curing Process

3.12 Compressive Strength Test of Cylinder

After 7 and 28 days, the cylinders were lifted out of the water. Then, they were kept for one day to air dry. After that, the compressive strength of the concrete cylinders was tested at zero degrees Celsius without any partially replaced aggregate. Finally, the compressive strength test was conducted on the concrete cylinders containing partially replaced steel slag.

Figure 3.13: Preparation for Compressive strength

Figure 3.14: Measuring cylinder's Dia by Vernier Caliper

Figure 3.15: UTM Load

Figure 3.16: UTM Load Application

Figure 3.17: Compressive Fracture of Cylinder after 28 Days

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the finding of the compressive strength test of cylinder with varying percentage of cement and partially replaced recycled slag.

4.1 Sieve Analysis for Fine Aggregate

Sieve Aperture (No.)	Sieve Size in mm	Retained	Retained (%)	Cumulative Retained (%)	Cumulative Passing (%)	FM
4	4.75	0	0	0	100	2.951
8	2.36	0	0	0	100	
16	1.18	358	35.8	35.8	64.2	
30	0.60	318	31.8	67.6	32.4	
50	0.30	254	25.4	93	7	
100	0.15	57	5.7	98.7	1.3	
Pan		13	1.3		0	
Total		1000		295.1		

Table 4.1: Sieve Analysis of Fine Aggregate

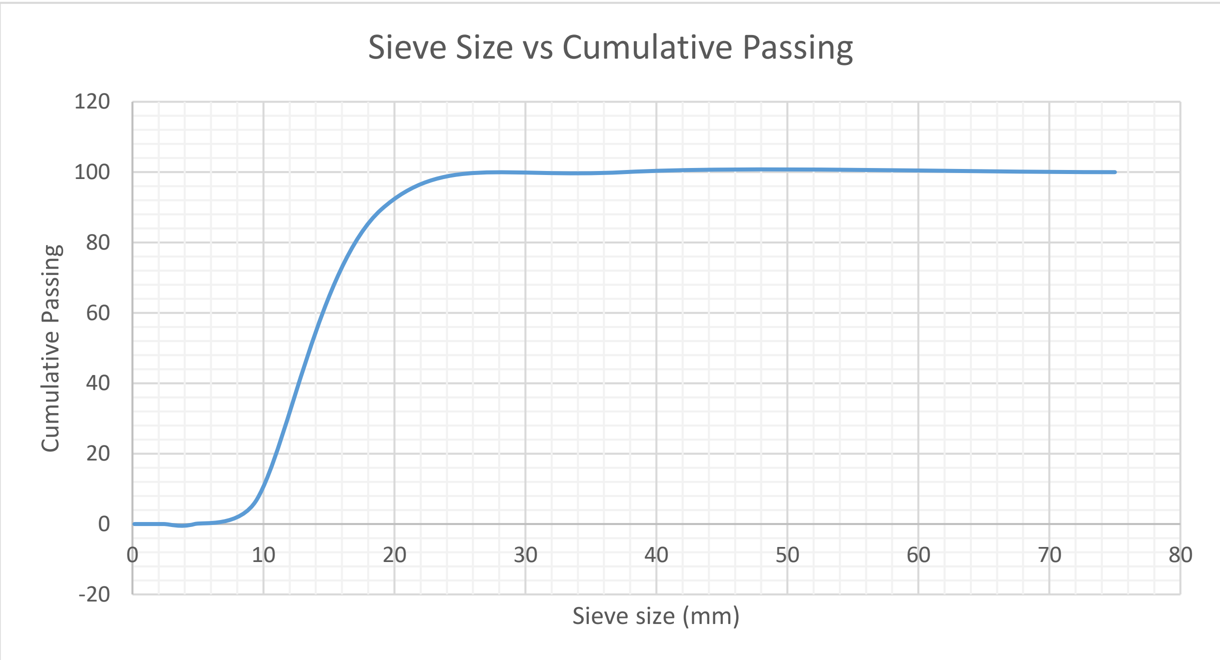


Table 4.2: Sieve Analysis of Coarse Aggregate

Sieve aperture	Sieve Opening (mm)	Retaining (gm)	Retained (%)	Cumulative Retained (%)	Cumulative Passing (%)	FM
3”	75	0	0	0	100	7.036
3/2”	37.5	0	0	0	100	
3/4”	19	106	10.6	10.6	89.4	
3/8”	9.5	824	82.4	93	7	
#4	4.75	70	7	100	0	
#8	2.36	0	0	100	0	
#16	1.18	0	0	100	0	
#30	0.6	0	0	100	0	
#50	0.3	0	0	100	0	
#100	0.15	0	0	100	0	
Pan		0	0			
Total				703.6		

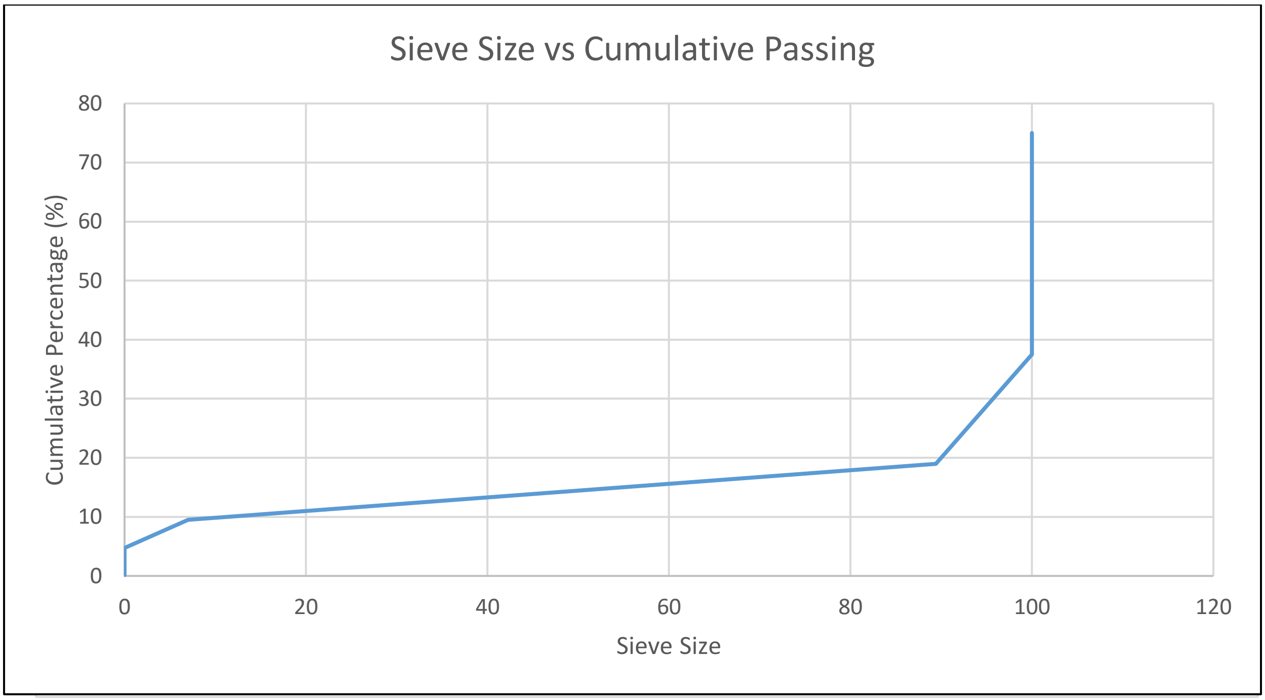


Table 4.3: Result of 7 days compressive strength

Water cement ratio	Slag (%)	Dia (mm)	Hight(mm)	Weight (gm)	Area (sq in)	Load (KN)	Compressive strength (psi)	Average Compressive strength(psi)
0.4	0	103.2	205	4110	12.97	160	2774.17	2814.98
		101.1	206	4115	12.44	159.2	2876.16	
		102.5	206	4000	12.79	159	2794.62	
	10	102	206	3965	12.67	110	1952.38	1990.31
		103.5	206	3910	13.04	117	2016.87	
		103	206	3855	12.92	115	2001.69	
	20	102.8	206	3800	12.86	70	1223.16	1156.23
		102	206	3745	12.67	65	1153.68	
		102.4	206	3690	12.77	62	1091.85	
	30	103.5	206	3635	13.04	60	1034.29	1051.21
		103	204	3580	12.92	60	1044.36	
		103.2	205	3525	12.97	62	1074.99	

Table 4.4: Result of 28 days compressive strength

Water cement ratio	Slag	Dia (mm)	Hight(mm)	Weight (gm)	Area (sq in)	Load (KN)	Compressive strength (psi)	Average Compressive strength(psi)
0.4	0%	102.1	205	4152	12.69	275	4871.40	4823.45
		101.8	206	4150	12.62	273	4864.52	
		103.0	205	4140	12.92	272	4734.43	
	10%	103.2	206	4254	12.97	260	4508.03	4535.07
		102.2	205	4130	12.72	245	4331.49	
		101.5	205	4145	12.54	265	4749.92	
	20%	103.6	207	4270	13.07	175	3010.87	3013.12
		102.2	207	4159	12.72	170	3005.52	
		102.8	206	4212	12.86	173	3022.96	
	30%	103.0	205	4188	12.92	165	2871.99	2970.80
		102.8	207	4033	12.86	177	3092.86	
		103.2	206	4025	12.97	170	2947.56	

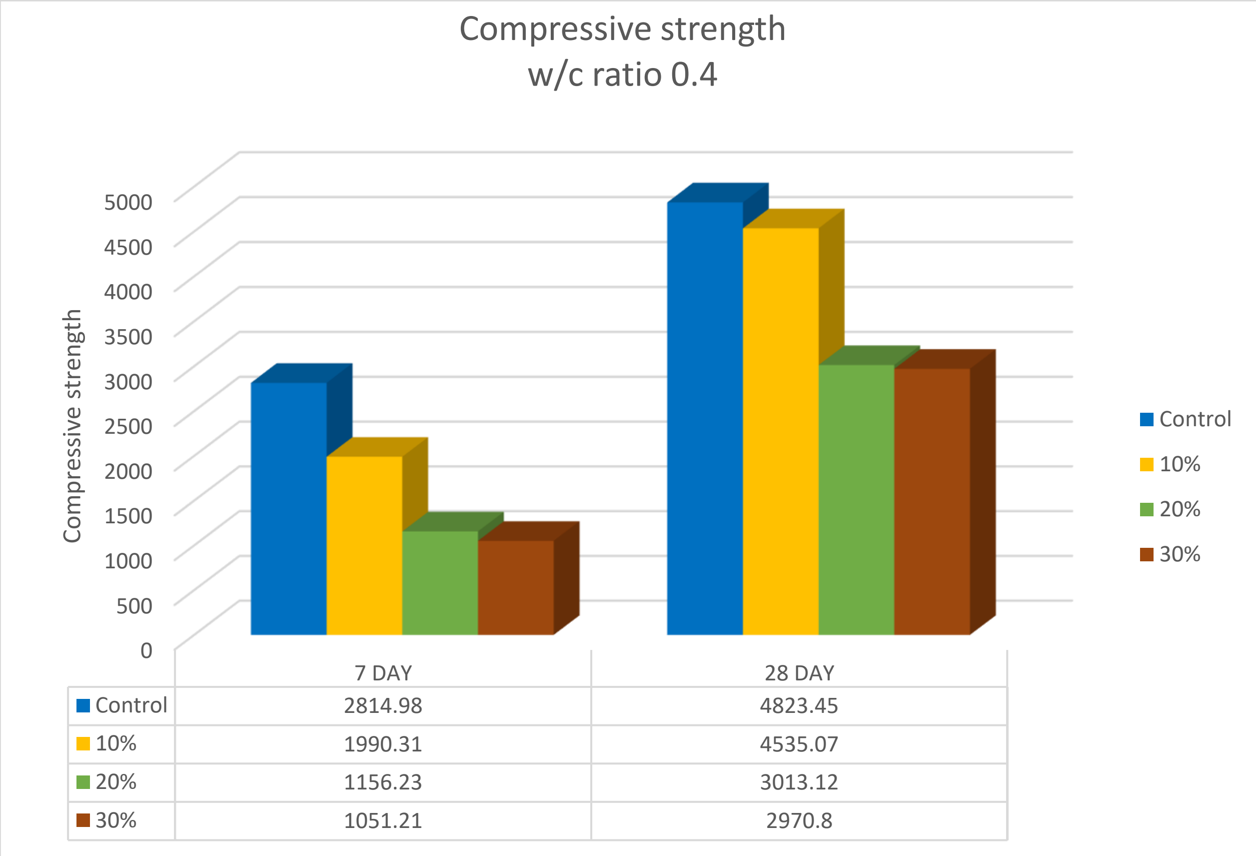
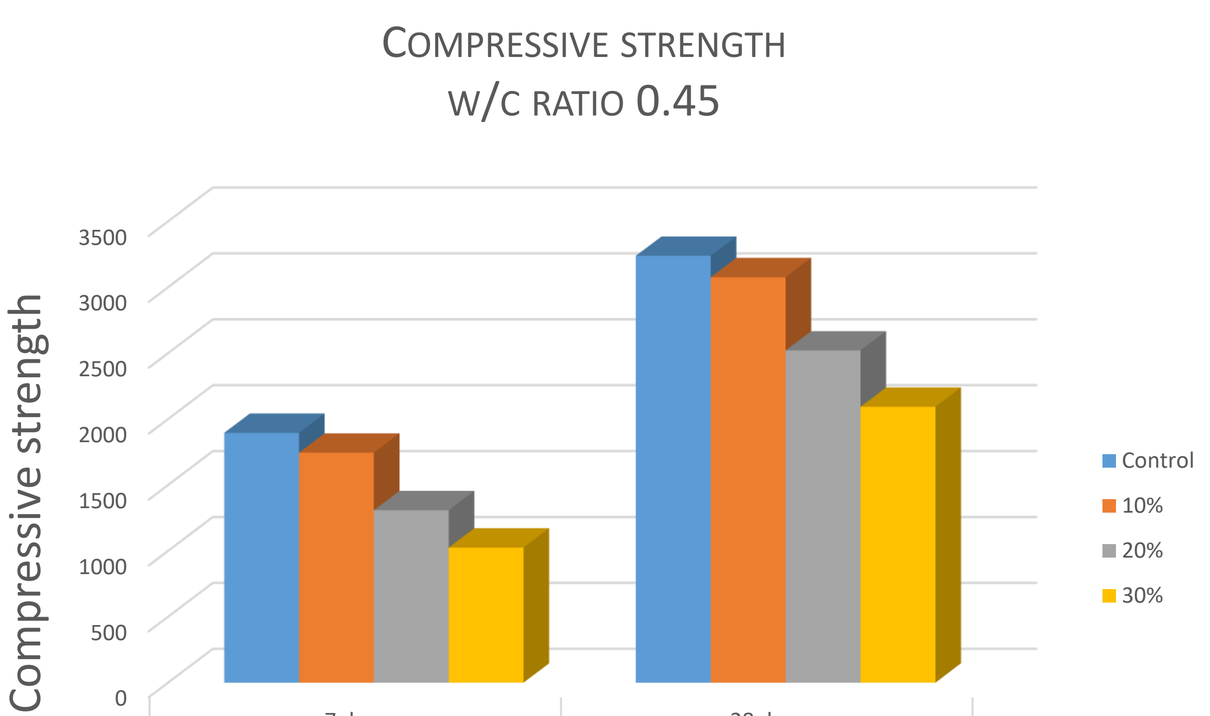


Table 4.5: Result of 7 days compressive

Water cement ratio	Slag	Dia (mm)	Hight(mm)	Weight (gm)	Area (sq in)	Load (KN)	Compressive strength (psi)	Average Compressive strength(psi)
0.45	0%	100.0	206	3936	12.17	107	1975.86	1895.31
		102.0	205	4000	12.67	105	1863.64	
		101.0	205	3955	12.42	102	1846.42	
	10%	103.2	206	4167	12.97	103	1785.87	1744.66
		102.5	205	4060	12.79	95	1669.74	
		101.9	206	4050	12.64	100	1778.38	
	20%	102.5	205	4111	12.79	70	1230.33	1308.50
		102.1	206	4178	12.69	77	1363.99	
		102.0	205	4160	12.67	75	1331.17	
	30%	101.5	206	4145	12.54	58	1039.61	1025.03
		103.2	206	4204	12.97	57	0988.30	
		102.0	205	4160	12.67	59	1047.19	

Table 4.6: Result of 28 days compressive

Water cement ratio	Slag	Dia (mm)	Hight(mm)	Weight (gm)	Area (sq in)	Load (KN)	Compressive strength (psi)	Average Compressive strength(psi)
0.45	0%	102.2	206	4033	12.72	182	3217.68	3238.43
		101.5	205	4000	12.54	186	3333.91	
		102.5	206	4020	12.79	180	3163.72	
	10%	102.5	205	4085	12.79	177	3110.99	3075.92
		102.0	206	4116	12.67	170	3017.32	
		102.4	206	4050	12.77	176	3099.46	
	20%	101.9	206	4121	12.64	145	2578.65	2520.35
		102.5	206	4213	12.79	132	2320.06	
		102.0	206	4150	12.67	150	2662.34	
	30%	102.1	206	4160	12.69	105	1859.99	2093.26
		102.8	206	4217	12.86	132	2306.54	
		102.4	206	4190	12.77	120	2113.27	



	7 days	28 days
Control	1895.31	3238.43
10%	1744.66	3075.92
20%	1308.5	2520.35
30%	1025.03	2093.26

Carbon Dioxide Emission

Table 4.7: Carbon Emission for Control

Material	Emission Factor CO_2 /kg	Quantity of Material (kg)	Emission CO2 (kg)
Cement	0.9	0.763	0.6867
Sand	0.005	1.15	0.00575
Stone	0.005	2.29	0.01145
		Total	0.7039

Table 4.8: Carbon Emission for Use Of 10%

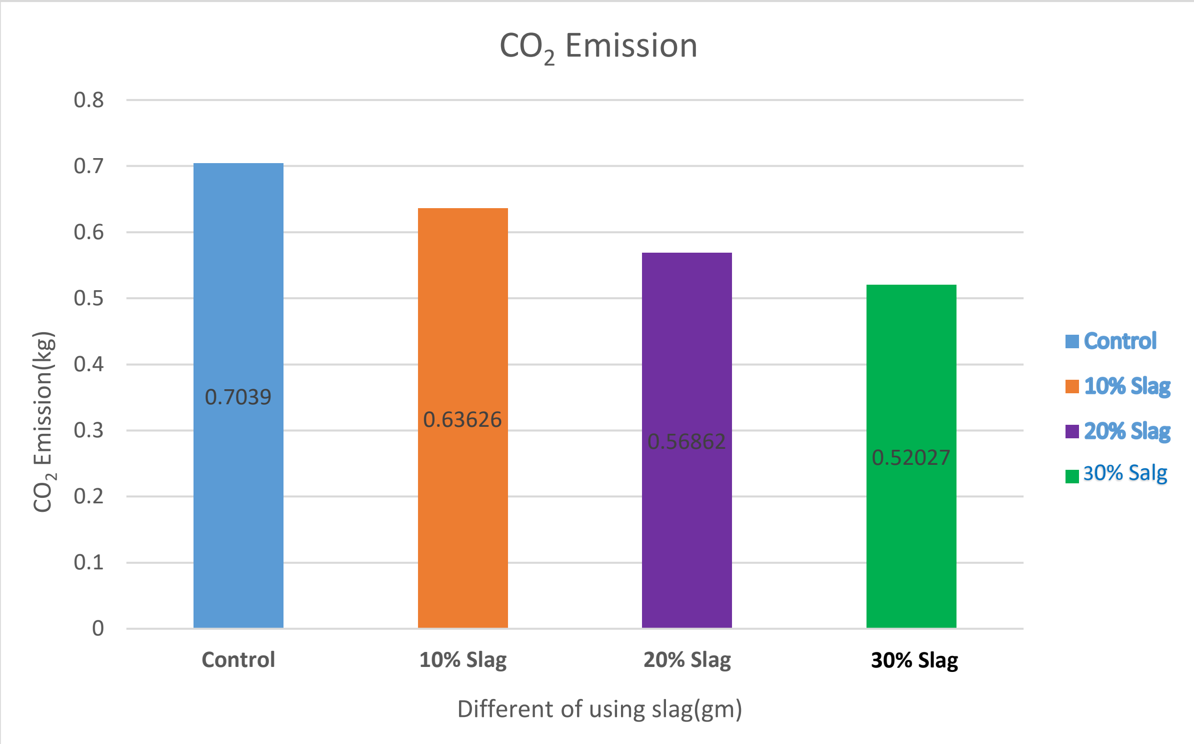
Material	**Emission Factor CO_2 /kg**	**Quantity of Material (kg)**	**Emission CO_2 (kg)**
Cement	0.9	0.687	0.6183
Slag	0.1	0.0076	0.00076
Sand	0.005	1.15	0.00575
Stone	0.005	2.29	0.01145
		Total	0.63626

Table 4.9: Carbon Emission for Use Of 20%

Material	**Emission Factor CO_2 /kg**	**Quantity of Material (kg)**	**Emission CO_2 (kg)**
Cement	0.9	0.611	0.5499
Slag	0.1	0.0152	0.00152
Sand	0.005	1.15	0.00575
Stone	0.005	2.29	0.01145
		Total	0.56862

Table 4.10: Carbon Emission for Use Of 30%

Material	**Emission Factor CO_2 /kg**	**Quantity of Material (kg)**	**Emission CO (kg)**
Cement	0.9	0.534	0.4806
Slag	0.1	0.229	0.0229
Sand	0.005	1.15	0.00575
Stone	0.005	2.29	0.01145
		Total	0.5207



Condition	Compressive Strength	Co2 Emission (Kg)	Eco Efficiency Index
0%	4823.45	0.7039	6852.464839
10%	4535.07	0.63626	7127.699368
20%	3013.12	0.56862	5299.004608
30%	2970.8	0.5207	5705.396582

Table 4.11: Eco Efficiency Index (EEI)

Compressive Strength Of Control (Psi)	Compressive Strength Different Condition (Psi)	Strength Retention (%)
4823.45	4535.07	94.02129181
	3013.12	62.46815039
	2970.8	61.59077009

Table 4.12: Strength Retention

Carbon Emission For Control (Kg)	Carbon Emission For Different Control (Kg)	Carbon Emission Reduce For Condition (10%,20%30) In Kg	Carbon Emission Reduce For Condition (10%,20%30%) In (%)
0.7039	0.63626	0.06764	9.609319506
	0.56862	0.13528	19.21863901
	0.5207	0.1832	26.02642421

Table 4.13: Carbon Emission Reduce

Compressive Strength Of Control (Psi)	Compressive Strength Different Condition (Psi)	Strength Retention (%)	Strength Loss %
4823.45	4535.07	94.02129181	5.978708186
	3013.12	62.46815039	37.53184961
	2970.8	61.59077009	38.40922991

Table 4.14: Strength Loss

Replacement slag %	Carbon emission reduce for condition (10%,20%,30%) in (%)	strength loss	SPF
0	0	0	0
10	9.6093	5.9787	1.607256
20	19.2186	37.5318	0.512062
30	26.02642	38.4092	0.677609

Table 4.15: sustainable performance factor (SPF)

CO_2 Emission

Table 4.16: Concrete use Globally Per Year (According to ACI)

Concrete use Globally Per Year (According to ACI)	**Material**	**Quantity (kg)**
$3x10^{13}$	Cement	$5.4545x10^{12}$
	Sand	$8.1818x10^{12}$
	Stone	$1.6363x10^{12}$

Table 4.17: Carbon Emission globally per year for control concrete

Material	Emission Factor CO_2 /kg	Quantity of Material (kg)	Emission CO2 (kg)
Cement	0.9	$5.4545x10^{12}$	$4.90905x10^{12}$
Sand	0.005	$8.1818x10^{12}$	$4.0909x10^{12}$
Stone	0.005	$1.6363x10^{12}$	$8.1815x10^{10}$
		Total	$5.0318x10^{12}$

Table 4.18: Difference carbon Emission globally per year between control and 10% steel slag replacement in concrete

Carbon Emission globally per year for control concrete	$5.0318x10^{12}$ kg	**Carbon emission reduction (%) =8.67**
Carbon Emission globally per year for 10% steel l slag	$4.595414x10^{12}$ kg	
Difference carbon Emission globally per year	$4.36386x10^{11}$ kg	
	436,386,000 tons	

Table 4.19: Carbon Emission globally per year for 10% steel l slag

Material	**Emission Factor CO_2 /kg**		**Quantity of Material (kg)**	**Emission CO_2 (kg)**
Cement	0.9		$4.90905x10^{12}$	$4.418145x10^{12}$
Slag	0.1		$5.4545x10^{11}$	$5.4545x10^{10}$
Sand	0.005		$8.1818x10^{12}$	$4.0909x10^{12}$
Stone	0.005		$1.6363x10^{12}$	$8.1815x10^{10}$
			Total	$4.595414x10^{12}$

4.2 DISCUSSION

The experimental results of this study indicate that recycled steel slag can be effectively used as a partial replacement for cement in concrete, although its performance depends on the replacement percentage and water–cement ratio. The sieve analysis confirmed that both fine and coarse aggregates were well graded and suitable for concrete production. The compressive strength test showed that the control mix achieved the highest strength, while strength gradually decreased with increasing slag content. At a water–cement ratio of 0.40, the 10% slag replacement mix retained about 94% of the control strength, indicating only a minor reduction in structural performance, whereas 20% and 30% replacements caused significant strength loss due to reduced cement hydration and weaker bonding within the concrete matrix. Similar trends were observed for the 0.45 water–cement ratio mixes, where overall strength values were lower because higher water content increased porosity in the hardened concrete. Despite the reduction in compressive strength, steel slag replacement significantly decreased CO_2 emissions, with carbon emission reductions of approximately 9.61%, 19.22%, and 26.03% for 10%, 20%, and 30% slag replacement respectively. The eco-efficiency analysis further revealed that the 10% slag replacement mix achieved the highest Eco-Efficiency Index, providing the best balance between strength and environmental sustainability. The Sustainable Performance Factor (SPF) value greater than 1 indicates acceptable and sustainable performance of the concrete mix. Therefore, the findings suggest that approximately 10% recycled steel slag can be safely used as a sustainable cement replacement material without significantly compromising the structural performance of concrete while contributing to environmental protection through reduced carbon emissions.

CHAPTER 5

Conclusion

This study concludes that recycled steel slag can be used as a partial replacement for cement in concrete to improve environmental sustainability. The compressive strength decreased with increasing slag content, but the 10% replacement mix showed acceptable strength with only minor reduction compared to the control mix. Higher replacement levels (20% and 30%) caused significant strength loss. The use of steel slag also reduced CO_2 emissions and improved eco-efficiency. The Sustainable Performance Factor (SPF) value greater than 1 confirmed acceptable sustainable performance. Therefore, about 10% recycled steel slag is recommended as an effective and sustainable cement replacement material in concrete production.

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