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Self Compacting Concrete Using Steel Slag as a Partial Replacement to Fine Aggregates

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ABSTRACT- Concrete is the most widely used material in the building sector. Every year, hundreds of millions of cubic meters of concrete are utilized in India alone. Concrete is composed up of coarse and fine particles that have been cemented together using binding material. The typical concrete process in the construction industry is unsustainable since it consumes large amounts of natural resources such as sand, stone, and millions of tons of cement each year, which is harmful to the environment. Aggregate accounts for 70-80% of the volume of concrete and has a considerable impact on its various properties. Even industrialized countries have suffered aggregate supply constraints as a result of the significant growth in concrete demand across the world. As a result, research is needed to identify an environmentally benign and readily available alternative to the usage of component elements in concrete. Slag is a by-product of the steel industry, created by impurities in the metals or ores being processed during smelting, welding, and other metallurgical and combustion operations. Slag is generally made up of mixed oxides of elements including silicon, Sulphur, phosphorus, and aluminium ash, as well as byproducts of their interactions with furnace linings and fluxing materials like limestone. According to estimates, around one thousand million tonnes of slag is created as solid waste in India alone, necessitating study into how to use this large byproduct of the steel industry, which is not recyclable, as one of the elements in concrete manufacturing. Steel slag in construction protects natural aggregates while also using slag waste from steel mills, resulting in a higher reduction in environmental pollution.
The use of steel slag as a partial substitute for fine aggregate in different concrete mixes where varying percentages of cement have been replaced by fly ash and metakaolin is recommended in this study. The effect of increasing the proportion of steel slag on various parameters was researched and compared, as were tests on compressive strength, tensile strength, and water absorption.

KEYWORDS- Glass powder with calcium nitrate Abbreviations OPC (ordinary Portland cement), PCC (pozalana Portland cement), CTM (compression testing machine), LW (light weight), CSA (cross sectional area), CSS (Compressive strength of concrete)

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I. INTRODUCTION

A. Steel Slag Formation Processes and Its Types

Blast Furnace Slag

It is created in a blast furnace by melting iron ore or iron pellets, coke, and a flux (either limestone or dolomite). When the metallurgical smelting process is over, the lime in the flux is chemically mixed with the ore's aluminates and silicates, as well as coke ash, to generate blast furnace slag, a non-metallic product. BF slag may be chilled in a variety of methods when cooling and hardening from its molten state, resulting in a variety of BF slag products

- ***Blast Furnace:***

Combustion material and ore are delivered from the top of the chamber, while air is delivered from the bottom. This forces the chemical reaction to occur throughout the ore rather than just at the surface.

- ***Granulated slag:***

Granulated slag is rapidly cooled with enormous amounts of water to generate sand-like granules, which are then crushed into GGBS (Ground Granulated Blast Furnace Slag) or Type S slag cement. It can also be combined with Portland cement clinker to generate Type 1S cement. as shown in figure 1.

Figure 1: Granulated slag

In recent years, our society's rising awareness of environmental problems has resulted in increased slag consumption. Members of different enterprises working together weathering

- **Electric Furnace Slag**

It's made in a basic oxygen furnace (BOF) or an electric arc furnace (EAF). The principal metals used to create steel in each process are hot iron (BOF) and/or scrap metal furnace (EAF). The principal metals used to create steel in each process are hot iron (BOF) and/or scrap metal (EAF).

To serve as a fluxing agent, lime is injected. Steel furnace slag, also known as steel slag, is formed when lime reacts with silicates, aluminum oxides, magnesium oxides, manganese oxides, and ferrites. The molten slag is poured out of the furnace. Steel slag is treated to eliminate any free metals and sized into products after cooling from its molten condition.

- **Basic Oxygen Furnace (BOF):**

Oxygen is blown into the furnace vessel through a water-cooled shown figure 2.

Figure 2: Oxygen Furnace

B. Chemical Composition of Slags

together to find new slag product prospects are becoming more urbanized. Table 1 shows the usual chemistry of BFS, BOS, and EAF Slags following precise conditioning and weathering

Table 1.: Slag Chemical Composition (Revision 2, 2002) (A Guide to the Use of Iron and Steel Slag in Roads)

Constituents of oxides	**Symbol**	**BFS Slag (%)**	**BOS Slag (%)**	**EAF Slag (%)**
Calcium oxide	Cao	42	41	36
Free Lime	-	0	0-3	0-2
Silicon Oxide	Sio2	36	13	15
Iron Oxide	Fe2o3	0.65	21	30
Magnesium Oxide	MgO	7.0	10	7.8
Manganese Oxide	MnO	0.65	6	5.9
Aluminum Oxide	Al2O3	15	4	5.7
Titanium Oxide	TiO2	1	1	0.65
Potassium Oxide	K2O	0.45	0.03	0.2
Chromium Oxide	Cr2O3	<0.005	0.1	1
Vanadium Oxide	V2O5	<.05	1.4	0.3
Sulphur	S	<.6	0.08	0.2

- **Slag Cement**

Ready-mix concrete, precast concrete, masonry, soil cement, concrete wallboard, floor levelling compounds, and high temperature resistant building goods all contain slag cement. Improved workability and finish ability, strong compressive and flexural strengths, and resistance to harsh chemicals are all observable benefits in concrete as shown in figure 3
Figure 3 slag cement

- **Uses of Steel Slags**

Steel slag hot mix asphalt aggregate ensures a long-lasting surface.
The Indianapolis Motor Speedway in Indianapolis, Indiana, employed steel slag coarse aggregate SMA pavement for its new surface in 2005, which was designed for strength and longevity. Steel slag was chosen by DOT and many other users because of its extended life, tenacity, and outstanding friction qualities. No regular pavement can resist the horizontal shear pressures created by automobiles speeding through the corners at Indianapolis at 200 miles per hour Steel slag, on the other hand, can, which is why it was chosen as the coarse aggregate for the pavement by the track administrators. When Colorado state transportation officials intended to resurface picturesque I-70 through Glenwood Canyon, they picked steel slag coarse aggregate because they desired a long-lasting, stable, resilient, and high-friction surface. The steep rise and descent through the mountains around Glenwood Canyon can withstand the heavy truck traffic that clogs the I-70 corridor. Outside the largest stone quarry in Illinois, near Chicago, only steel slag SMA pavement can resist the truck traffic. The steel slag SMA pavement installed at the junction of Williams and Margaret Streets has been dubbed "the world's strongest intersection" by the Asphalt Institute. Choose steel slag as the aggregate for your next access road, parking area, driveway, or parking lot. Steel slag is a sustainable renewable recyclable resource.

- **Need for This Project Work**

To investigate the possible use of GLASS POWDER as partial replacement of SAND with CALCIUM NITRITE as accelerating admixture.

II. OBJECTIVES

In this project, a proportion of fine aggregate was replaced by steel slag in concrete with a partial replacement of cement by fly ash and metakaolin, and numerous experimental tests were conducted to achieve the following goals.:

- To investigate the influence on concrete compressive and tensile strength when steel slag is used as a partial substitute for fine aggregates at various percentages.
- To see how the addition of metakaolin to the aforesaid combination affects strength.
- To see how the use of steel slag as a fine aggregate substitute in a concrete mix affects capillary rise and water absorption.
- Conduct a comparison analysis of various test findings in order to determine the optimal quantity of various components in a mix.

III. LITRERATURE REVIEW

- **Manso and Gonzalez** [1] The durability of concrete built with EAF slag as an aggregate was investigated, and the findings revealed that it was satisfactory. The concrete mixes made with conditioned EAF slag had good fresh and hardened qualities, as well as acceptable behavior in harsh environments. The compressive strength was found to be comparable to that of ordinary concrete. The durability was marginally inferior than that of traditional concrete. The concrete had 21 good physical and mechanical qualities, but the findings suggested that the gradation and crushing procedure needed special attention. The findings revealed that the high porosity of EAF slag aggregates had an impact on concrete resistance to freezing and thawing, but that field improvements might be achieved by using air entraining admixtures.

- **Manso, Polanco et al** [2] reiterated that the mechanical strength and durability of steel slag aggregate concrete may be increased by using correct mix proportions. He did two durability tests: Autoclave and accelerated ageing tests The autoclave test detects the presence of expansive compounds, free lime, or magnesia in Portland cement, whereas the accelerated ageing test follows ASTM D-4792 After testing, the compressive strength was found to have enhanced. He carried out chemical reactivity tests to see how slag particles and other concrete components would react. Three samples were held in a wet environment for 28 days and then frozen and thawed 25 times for the freeze-thaw test. They are then soaked in water at 4°C for 6 hours before being frozen for 18 hours at -17°C. Variations in weights and compressive strength were recorded, and the findings revealed that slag concrete from an electric arc furnace had higher strength and less water penetration. He also noted that the application of air entraining admixtures improved freeze-thaw resistance and slag concrete durability.

- **Manso et al,** [3] conducted a leaching test to see whether concrete may affect the environment. Steel slag, for example, requires a thorough examination of its possible toxicity. The steel slag contains a number of hazardous heavy metals and salts. Before employing EAF slag as a filler material, a leaching test is necessary. The presence of sulphates, fluorides, and total chromium in leached water from crushed slag aggregates was determined. The findings revealed that crushed slag with a lower particle size had a greater concentration.

- ***Takashi et al.*** [4] Steel slag aggregate concrete was tested for freeze-thaw resistance. Steel slag aggregates, recycled aggregates, and crushed stones were used to make concrete examples that were compared. Steel slag aggregates utilized in the study varied in size from 15-

20mm. Every 5 hours, the samples were subjected to -18°C to 5°C in water. Steel slag aggregates concrete had superior freezing and thawing resilience than recycled aggregates and was almost as good as crushed stone, according to the findings. The results also revealed that as cement concentration rose, compressive strength and resistance to freezing and thawing improved.

IV. MATERIALS AND METHODOLOGY

A. Testing

The current chapter presents the findings of several tests performed on the concrete material. An experimental program was established to evaluate the influence of steel slag on compressive strength, split tensile strength, and water absorption in order to meet the study's objectives.

B. Materials

The characteristics of concrete materials are determined in a laboratory according to industry standards. Cement, fine aggregates, fly ash, steel slag coarse aggregates, Metakaolin, and water were among the components employed in this investigation. This section reports and discusses the results of experiments done to assess the physical characteristics of materials. In general, the materials are compliant with the requirements of the applicable Indian Standard Codes. The following properties were present in the materials utilized.

C. Portland Cement

Concrete's characteristics are determined by the quantity and quality of its constituents. Because cement is the most active component of concrete and has the highest unit cost, its selection and use are critical for achieving the most cost-effective balance of qualities for any given concrete combination. "Hydraulic cement (cement that not only hardens by reacting with water but also forms a water-resistant product) produced by pulverizing clinkers consisting primarily of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulphate as an inter ground addition," according to ASTM C 150 Clinkers are sintered material nodules (diameters 0.2-1.0 inch [5-25 mm]) that form when a raw mixture of a predefined composition is heated to a high temperature. Portland cement is one of the lowest-cost materials commonly employed throughout the previous century because to the low cost and broad availability of limestone, shales, and other naturally occurring components as shown table 2.

Table 2 Properties of OPC 43 Grade Concrete

Characteristic Properties	**Codal Requirements IS:8112-1989(Part 1)**	**Observed value**
Fineness (m^2/kg)	230 min	350
Standard consistency (%)	---------------	34
Initial Setting time (min)	30 Min	64 min
Final setting time(min)	600 Max	280
Specific gravity	--------------	3.15

D. Aggregates

Aggregates are a granular building material. Sand, gravel, and crushed rock are the most prevalent natural mineral aggregates. Aggregates are made from natural sources like as quarries and gravel pits, as well as sea-dredged materials in some nations (marine aggregates) as shown in table 3 and its sieve analysis distribution is shown in Figure 4.

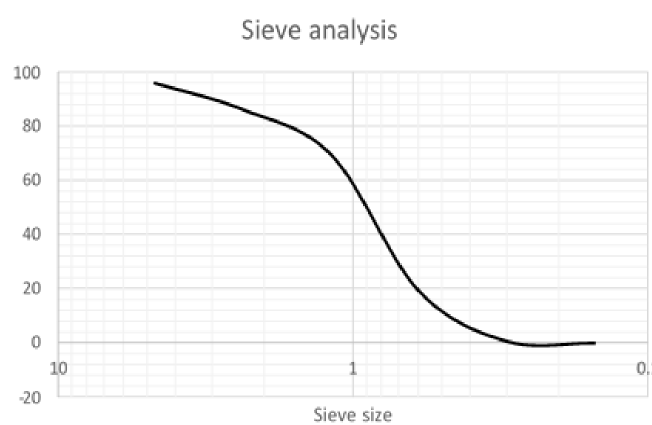

Figure 4: Sieve analysis

Table 3: Aggregate distribution

Wt. retained	% retained	% passing	Cumulative retained
34	3.4	97.5	3.5
143	15.3	83.6	17.6
229	23.8	60.5	41.5
218	22.6	39.2	62.8
310	31.9	7.5	93.8
58	5.8	1.8	99.6
15	1.5		

E. Metakaolin

Metakaolin is a pozzolanic additive/product with a variety of unique properties. Metakaolin comes in a wide range of colours and characteristics. The binding the purity of free lime determines its potential. Some of them can also improve responsiveness. Metakaolin is a useful additive for use in concrete and cement. Metakaolin typically replaces 8 percent to 20% (by weight) of Portland cement. This type of concrete has good technical qualities. The pozzolanic response begins quickly and lasts for 7 to 28 days.

F. Mix Proportions

Table 5 shows the proportions utilized in the overall mix, as well as proportions for distinct samples acquired by replacing fine aggregate with steel slag by a percentage is shown in table 4.

Table 4 Basic mix proportions of concrete

Water (Kg)	Cement /binder (Kg)	Fine aggregates (Kg)	Coarse aggregates (Kg)
198	495	760	940

Table 5: Sample Mix Proportions of Concrete

S. No.	Mix	Binder		Fine aggregate		Metakaolin (% by weight of cement)
		Portland cement (%)	Fly ash (%)	Steel Slag (%)	Aggregates (%)	
1.	M1	80	30	-	100	-
2.	M2	80	30	30	65	-
3.	M3	80	30	45	58	-
4.	M4	80	20	35	65	10
5.	M5	80	20	35	55	10

G. Fly Ash

Fly ash is a fine glass powder that is collected from the fumes produced by burning coal when power is produced. Silica, alumina, and iron make up the bulk of these micron-sized earth elements. A microscope reveals the distinction between fly ash and Portland cement. Because fly ash particles are virtually completely spherical, they may flow and blend readily in mixes. One of the features that makes fly ash a suitable additive for concrete is this ability. Fly ash is very similar to volcanic ash, which was used to make the first known hydraulic cements around 2,300 years ago

H. Steel slag

Steel slag was obtained from the Jalandhar Iron and Steel Industry for this project. As depicted in the illustration, it is black in colour. Table 3.3 shows the sieve analysis of steel slag.

V. RESULTS AND DISCUSSION

The objective of this research was to look at the strength, water permeability, and durability of concrete with various amounts of Steel Slag. The following properties were analyzed:

A. *Compressive strength*
B. Splitting tensile strength
C. Capillary suction Test
D. Water Absorption Test

Discussion of the test findings acquired from the experimental program.

A. Compressive Strength

The compressive strength shown in Figure 5 of concrete was tested using test pieces of 150 x 150 x 150 mm. Steel slag as a partial substitute for fine aggregate (sand) and fly ash as a partial replacement for coarse aggregate (cement) Cement was formed into cubes and cylinders to be tested later. To manufacture concrete in this study, cement and fly ash were mixed dry to a uniform colour, then fine and coarse aggregate were added and mixed with the cement and fly ash mixture. The water and admixture were then added, and the entire material was combined as shown in table 6.

Figure 6 also graphically depicts the cube strength of concrete mix results. When 25% steel slag is added, the compressive strength increases initially, but then decreases as the steel slag percentage increases to 50%. Also, when Metakaolin is combined with 25% steel slag, compressive strength improves, but it then declines as the amount of steel slag in the concrete expands.

Figure 5: Compressive strength test

Table 6: CSS Mix of concrete specimen size 100x100x100

MIX	CSS (MPA)			AVG. CSS (MPA)		
	7 days	28 days	56 days	7 days	28 days	56 days
M1	19.6	28.5	38.6	15.5	34.6	38.65
	20	38.4.	41.8			
M2	22.7	37.3	42.5	23.65	34.5	42.65
	24.8	33.2	43.6			
M3	22.6	38.6	42.3	22	34.85	41.8
	21.3	31.4	41.5			
M4	23	38.6	43.6	23.2	39.65	46.5
	27.3	41.6	48.4			
M5	31	34.5	44.5	18	37.55	43.65
	19	38.6	43			

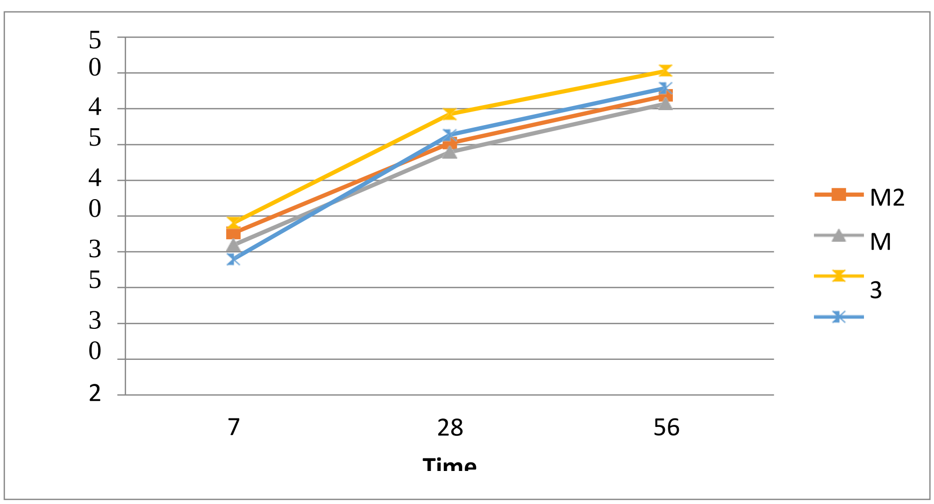

Figure 6: Graph 3 Compressive Strength of Concrete

B. Split Tensile Strength Test

At the ages of 7, 28, and 56 days, split tensile strength tests were performed. Table 7 shows the outcomes of the tests.

C. Coarse Aggregates

Mix Proportions

- Water cement ratio - 0.5
- Mix ratios - 1: 1.5: 3
- Grade of concrete - M20

D. Batching

The measurement of materials for making concrete is known as batching. Strictly speaking, weigh batching is the correct method of measuring the materials as compared to volume batching. The weigh batching was adopted in the project so as to facilitate accuracy, flexibility and simplicity. The concrete mix used in the project is nominal mix M20.The ingredients are therefore mixed inthe ratio of 1: 1.5: 3, with constant water cement ratio of 0.5.

- Nominal mix= M-20 (1:1.5:3)

Table 7: Split tensile strength

MIX	CSS (MPA)			AVG. CSS (MPA)		
	7 days	28 days	56 days	7 days	28 days	56 days
M1	3.56	3.46	3.95	2.4	3.66	4.44
	2.85	3.78	4.95			
M2	2.56	3.82	4.60	2.3	3.86	4.60
	2.50	3.75	4.50			
M3	2.51	3.78	4.20	2.42	3.63	4.45
	2.40	3.59	4.60			
M4	2.70	3.98	4.99	2.70	3.36	4.65
	2.72	4.04	4.72			
M5	2.62	3.98	4.77	2.15	3.85	4.45
	2.66	4.25	4.65			

In Figure 8, the split tensile strength of concrete mix is also graphically shown. The split tensile findings follow a similar pattern to compressive strength, with a gain in value as the proportion of slag replacement increases until 25%, then a loss in strength when slag is added 50%. It also rises when Metakaolin is added as shown in Figure 7.

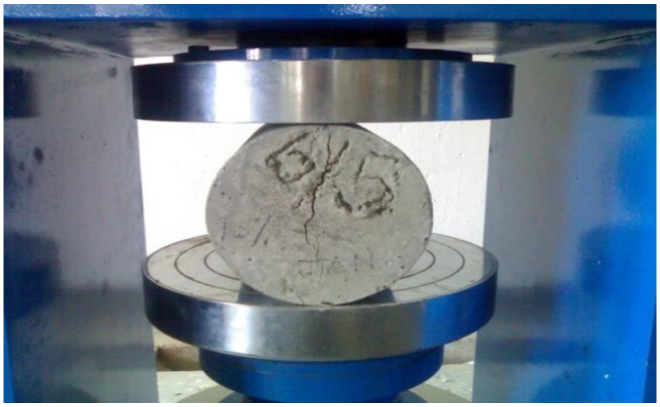

Fig 7 Split Tensile Strength Test

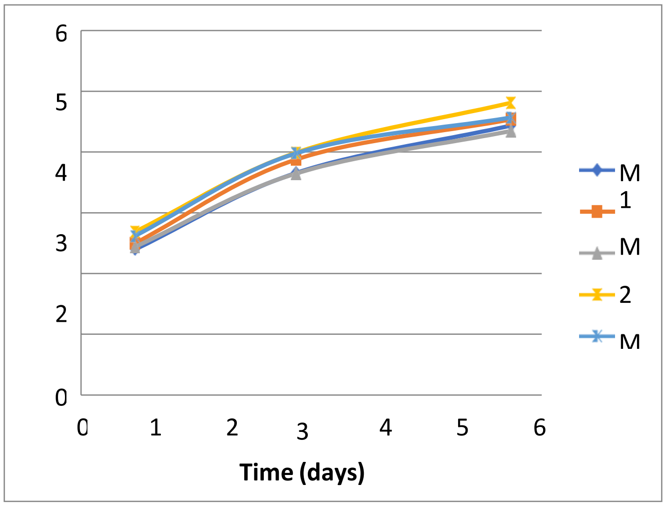

Figure 8: Split Tensile Strength of Concrete

E. Capillary Suction (Sorptivity) Test Results

The rate of flow of a waterfront through a porous material under capillary action is known as sorptivity. The lower the sorptivity rating, the more the concrete's resistance to water absorption. Several variables contribute to the decline in sorptivity. To begin with, as water enters the pores, it meets smaller pores, lowering the sorption rate. Secondly, even though the capillary pores create a strong linked network throughout the concrete, water particle penetration may be delayed because the air-water contact in the pore space is stable. This section analyzes the findings of capillary suction experiments performed on concrete specimens of various mixes cured at various ages.

Typical plots of cumulative water absorption against the square root of time for all concrete mixes at 28 and 56 days of curing are presented. Each plot represents the three specimens that were examined for each concrete mix. The tests performed on the three specimens at a given curing period produce similar slopes, especially in the early stages of the test, i.e. after about 6 hours, the connection between cumulative water absorption and the square root of time of exposure begins to vary from linearity. The capillary suction time test (CST) gives data on fluid/formation interactions, specifically the ability of a fluid or mud to filter through a permeable formation and alter reservoir material. The capillary suction time test (CST) is particularly effective for recording the effects of different salt concentrations (e.g. KCl) on the clay samples' swelling potential. Swelling clay in unconventional reservoirs has the potential to reduce frac-length and completion efficacy. A decrease in drainage area or fast mending fractures can significantly decrease a well's production. Five different chromatographic papers were examined, including the standard Whatman No. 17 chromatographic paper. Four distinct types of sludge were used in the testing, including a synthetic sludge generated expressly for benchmarking. A stirrer was also included to tackle the problem of test inconsistency (e.g., significant CST variability), which was especially problematic for heavy sludge kinds. The findings revealed that numerous alternative papers, which are less expensive than standard paper, may be used to reliably estimate CST values and that test repeatability can be improved in many circumstances and for several types of sludge. The implementation of the rectangular funnel resulted in a significant increase in test reproducibility.

Figure 9: Capillary Suction Test Sample

At 28 days, graph 5 illustrates cumulative water absorption with test time for concrete mixtures. Mix 4 had the lowest absorption (mm) value, followed by Mix 5 and Mix 3, while Mix 2 had the greatest absorption (mm) values of all the mixes after 28 days of curing at 28 days of curing, the lowest values of absorption (mm) recorded with Mix were 3.68 mm, whereas the maximum values of absorption (mm) found with Mix 2 were 7.7 mm. Furthermore, after 28 days of curing, the absorption (mm) value for Mix 1 is 7.31 mm. Sample mixtures exhibit a similar trend after 56 days of curing, as illustrated in figure 6.

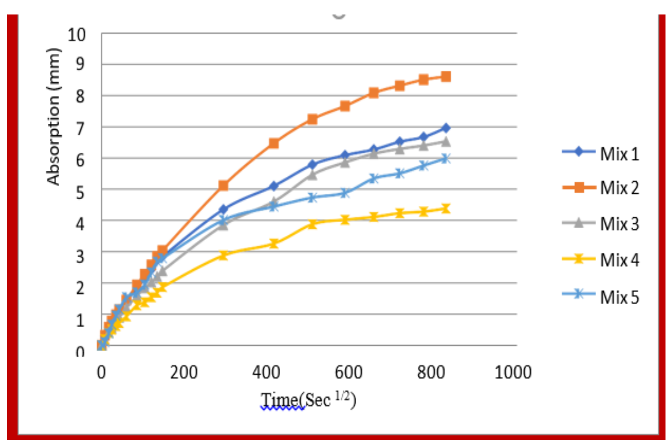

Figure 10: Capillary suction test graph at 56 days

F. Water Absorption

Water ingress owing to capillary suction of unsaturated concrete put in water with no head of water is measured by both sorptivity and water absorption. The flow in sorptivity is one-dimensional, but the flow in water absorption is three-dimensional. Tables 8 show the percentage water absorption of various blends after 28 and 56 days of curing.

Table 8: Water Absorption Test Results

Mix	% Water Absorption (28 Days)	% Water Absorption (56 Days)
M1	3.72	3.04
M2	3.82	3.20
M3	4.80	4.23
M4	3.82	3.16
M5	4.79	4.09

VI. CONCLUSION

The effects of substituting fine aggregates with steel slag, cement with fly ash, and Metakaolin in concrete mixes were investigated in this study, and the following results were drawn:

- Concrete's compressive and tensile strength enhanced as the amount of steel slag used to substitute fine aggregates increased (25 percent cement was replaced by fly ash).
- A concrete mix with 30% steel slag replaced fine aggregate showed the optimum compressive and tensile strength. In terms of strength, the 30% replacement outperformed the 40% replacement (25 percent cement was replaced by fly ash)
- Adding 10% metakoalin to a steel slag concrete as a replacement for cement resulted in an improvement in concrete strength, since metakoalin and fly ash make a strong adhesive contact.
- . Capillary rise and water absorption rose as steel slag concentration increased, but dropped as metakoalin was added to a concrete mix.
- Experimental results revealed that a concrete sample with 15% and 10% cement replacement by fly ash and metakoalin, respectively, and 40% fine aggregate replacement by steel slag outperformed all other mixtures.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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