

Study on Behaviour of Concrete Mix Replaceing Fine Aggregate With Steel Slag At Different Properties

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Abstract

This paper aims to study experimentally, the effect of partial replacement of fine aggregate by steel slag (ss), on the various strength and durability properties of concrete by using the mix designs .the optimum percentage of replacement of fine aggregate by steel slag is found. Workability of concrete gradually decreases, as the percentage of replacement increases which is found using slump test. Compressive strength, tensile strength, flexural strength and durability tests such as acid resistant's, using HCL,H₂SO₄ and rapid chloride penetration, are experimentally investigated.

The results indicate that for conventional concrete, partial replacement of concrete by steel slag improves the compressive, tensile, flexural strength. The mass loss in cubes after immersion in acids is found to be very low. Deflection in the RCC beams gradually increases, as the load on the beam increases, for the replacement. The degree of fluoride ion penetrability is assessed based on the limits given in ASTM C 1202. The viability of use of steel slag in concrete is found.

Waste management is one of the most common and challenging problems in the world. The steel making industry has generated substantially solid waste. Steel slag is a residue obtained in steel making operation. This paper deals with the implementation of steel slag as an effective replacement for sand. Steel slag ,which is consider as the solid waste pollutant, can be used for road construction ,clinker raw materials, filling materials etc. In this work, steel slag used as replacement for sand, which is also major component concrete mixture. This method can be implement for producing hallow blocks, solid blocks, paver blocks, concrete structures etc. Accordingly, advantages can be achieved by using steel slag instead of natural aggregates this will also encourage other researchers to find another field of using steel slag.

Keywords: Steel slag; replacement; durability; rapid chloride permeability.

I. INTRODUCTION

Concrete is the most widely used material on earth after water. Many aspects of our daily life depend directly or indirectly on concrete. Concrete is prepared by mixing various constituents like cement, aggregates, water, etc. which are economically available. Concrete is unique among major construction materials because it is designed specifically for particular civil engineering projects. Concrete is a composite material composed of granular materials like coarse aggregates embedded in a matrix and bound together with cement or binder which fills the space between the particles and glues them together.

Concrete plays a critical role in the design and construction of the nation's infrastructure. Almost three quarters of the volume of concrete is composed of aggregates. To meet the global demand of concrete in the future, it is becoming a more challenging task to find suitable alternatives to natural aggregates for preparing concrete.

The fine aggregates fraction is that passing the 4.75 mm sieve and retained on the 75 μ sieve. According to some estimates after the year 2010, the global concrete industry will require annually 8 to 12 billion metric tons of natural aggregates. "During the past 25 years, the production of crushed stone has increased at an average annual rate of about 3.3 percent. Production of sand and gravel has increased at an annual rate of less than 1 percent. Production of crushed stone, which is expected to increase by more than 20 percent, will be about 1.6 billion metric tons, while production of sand and gravel will be just under 1.1 billion metric tons, an increase of 14 percent. In essence the amount of crushed stone to be produced in the next 20 years will equal the quantity of all stone produced during the previous century i.e. about 36.5 billion metric tons."Therefore the use of alternative sources for natural aggregates is becoming increasingly important.

Steel slag:- Slag is a by-product generated during manufacturing of pig iron and steel. It is produced by action of various fluxes upon gangue materials

within the iron ore during the process of pig iron making in blast furnace and steel manufacturing in steel melting shop. Primarily, the slag consists of calcium, magnesium, manganese and aluminum silicates in various combinations. The cooling process of slag is responsible mainly for generating different types of slags required for various end-use consumers. Although, the chemical composition of slag may remain unchanged, physical properties vary widely with the changing process of cooling.

The blast furnace (BF) is charged with iron ore, fluxing agents (usually limestone and dolomite) and coke as fuel and the reducing agent in the production of iron. The iron ore is a mixture of iron oxides, silica, and alumina. From this and the added fluxing agents, alkaline earth carbonates, molten slag, and iron are formed. Oxygen in the preheated air blown into the furnace combines with the carbon of the coke to produce the needed heat and carbon monoxide. At the same time, the iron ore is reduced to iron, mainly through the dioxide. The oxides of calcium and magnesium combine with silica and alumina to form slag. The reaction of the carbon monoxide with the iron oxide yields carbon dioxide (CO₂) and metallic iron. The fluxing agents dissociate into calcium and magnesium oxides and carbon dioxide. The oxides of calcium and magnesium combine with silica and alumina to form slag

Production of steel calls for the removal of excess silicon by mineralization and of carbon by oxidation from pig or crude iron. Steel slag is a hard, dense material somewhat similar to air-cooled iron slag. It contains important amounts of free iron, giving it its high density and hardness, which make it particularly suitable as a road construction aggregate. Slag is transported to processing plants, where it undergoes crushing, grinding, and screening operations to meet various use specifications. Processed slag is either shipped to its buyer for immediate use or, in slack seasons, stored.

II. LITRATURE REVIEW

Compressive strength

- **Monshi and Asgarani (1999)** producing Portland cement from iron and steel slags after magnetic separation are mixed with limestone of six different compositions. Samples with higher lime saturation factor developed higher C₃S content and better mechanical properties. Blending 10% extra iron slag to a cement composed of 49% iron slag, 43% calcined lime, and 8% steel slag kept the compressive strength of concrete above standard values for type I ordinary Portland cement. From the six different mixtures of limestone, blast-furnace slag, and converter slag, samples M3, M5, and M6 showed relatively good mechanical
- properties. Cement M3 was blended with 10% iron slag as in the Portland blast furnace cement, and compressive strengths of 140.3, 193.8, 333.3 kg/cm² were obtained after 3, 7, and 28 days, respectively. The bare minimum compressive strength of concrete for type I Portland cement according to ASTM C150-86 for 3, 7, and 28 days are 12, 19, and 28 MPa, respectively (about 120, 190, and 280 kg/cm²).
- **Ameri et al. (2012)** used the steel slag from Zob-Ahan steel production factory in concrete. Here placed natural aggregates from the steel slag and performed compressive strength tests on samples containing slag ratios of 0, 25, 50, 75 and 100 % and cement contents of concrete 200, 300 and 350 kg/m³. According to his results, compressive strength improves with the increase in steel slag ratio up to 25% but after that increasing the steel slag ratio above 25% decreases compressive strength. The maximum compressive strength value occurs at 25% slag ratio.
- Split tensile strength:-**
- **Aldea et al. (2000)** studied the effects of curing conditions on properties of concrete by partial replacement of slag. He replaced 0% slag (control), 25% slag, 50% slag, and 75% slag with the cement. The specimen size 75 × 75 mm was used according to ASTM C 496-90. There is small effect of slag replacement up to 50% upon strength, whereas higher replacement results in a fall in compressive strength. The 25% and 50% slag replacement have a valuable effect compared to control, as tensile strength increases for all the curing types. The 50% slag replacement provides tensile strength to some extent higher to no slag replacement, whereas the 75% slag replacement reduces the tensile strength regardless of the curing type used
- Durability characteristics:-**
- **Veiga and Gastaldini (2012)** studied the sulfate resistance of a white Portland cement (WPC) containing 0%, 50% or 70% granulated blast-furnace slag as a partial cement replacement. The piece of the blended cements was monitored by exposing the prepared mortar specimens to a 5% Na₂SO₄ solution for two years according to ASTM C1012/04. He observed that the slag in the partial cement replacement benefits in both cements and an increase in its percentage increased sulfate resistance. For long-term exposure, all of the WPC blends showed a smaller amount of expansion than the corresponding blends with PC. After 24 months of exposure to a sodium sulfate solution, WPC established higher resistance to sodium sulfate attack than grey

Portland cement and this was maybe due to the lower CH content of the WPC hydrated paste. When the slag replacement level was higher, the expansion values were lower in ASTM C1012 test due to dilution effect and pozzolanic reactions that consume CH and density the matrix. All of the mortar mixtures containing white Portland cement exhibited enhanced resistance to sulfate attack than the corresponding grey Portland cement mortars. There could have been a balancing effect between the slag and the limestone used as filler in the WPC

III. MATERIALS AND PROPERTIES

The materials used in research are:-

1. Ordinary Portland cement (43 grade)
2. Fine aggregate (4.75 mm down)
3. Coarse aggregate (20 mm down)
4. Steel slag
5. Water
6. Admixtures

Cement:- Ordinary Portland cement of 43 grade (JP) was used in the experiment. The details of tests conducted on cement are described below

a) Specific gravity of cement:- Specific gravity of the cement is calculated by using density bottle method.

Cement specific gravity: **3.15**

b) Fineness test on cement:- Fineness test on cement can be calculated by sieve test or air permeability method, in commercial cement it is suggested that there should be about 25 to 30% of particles less than 7 microns in size.

Fineness of test cement: **92%**

c) Initial and final setting time on cement:- Initial and final setting time on cement is obtained by vicat's apparatus, for the initial setting time of the cement vicat's needle should penetrate to a depth of 33 to 35 mm from the top, for final setting time the vicat's needle should pierce through the paste more than 0.5mm. We need to calculate the initial and final setting time as per IS:4031 (Part 5) -1988.

Initial setting time of test cement: **90mins**

Final setting time of test cement: **3hrs 30mins (210 mins)**

d) Standard consistency test:- The standard consistency test of a cement paste is defined as that consistency which will permit vicat's plunger having the 10mm diameter and 50mm length to penetrate to a depth of 33 to 35 from the top of the mould. The basic aim to find out the water content required to produce a cement paste of standard consistency as specified by the IS: 4031(Part4)-1988.

Standard consistency of test cement : **33%**

Fine aggregate:- Aggregates smaller than 4.75mm and upto 0.075 mm are considered as fine aggregate.

The details of test conducted on fine aggregate are described below.

a) Specific gravity:- The specific gravity of fine aggregate is 2.64

b) Fineness modulus:- The standard definition of fineness modulus is as follows " An empirical factor obtained by adding the total percentages of a sample of the aggregate retained on each of a specified series of sieves, and dividing the sum by 100." Sieve analysis helps to determine the particle size distribution of the coarse and fine aggregates. This is done by sieving the aggregates as per IS: 2386 (Part1)-1963.

Properties of Fine aggregate

Properties	Test values
Specific gravity	2.64
Bulk density (gm/cc)	1.68
Fineness modulus	2.66

Coarse aggregate:- Aggregates greater than 4.75mm are considered as Coarse aggregate.

Properties of Coarse aggregate

Properties	Test values
Specific gravity	2.76
Bulk density (loose)(gm/cc)	1.38
Bulk density (compacted) (gm/cc)	1.53

Steel Slag:- The properties of Steel slag used in project are:

Properties of Steel slag:-

Properties	Test values
Specific gravity	2.72
Bulk density (loose)(gm/cc)	1.64
Bulk density (compacted) (gm/cc)	1.89

EXPERIMENTAL PROGRAMME

Tests for workability:-

Slump cone test:- Slump cone test is a very common test for determination of workability of concrete. This test was carried out for M25, before casting the specimens.

b) Compaction factor test:- This test is more accurate than slump cone test and this test is used to determine the workability of low water cement ratio

more accurately. This test is conducted as per IS:1199 -1959.

IV. RESULTS AND DISCUSSION

Slump cone test:-

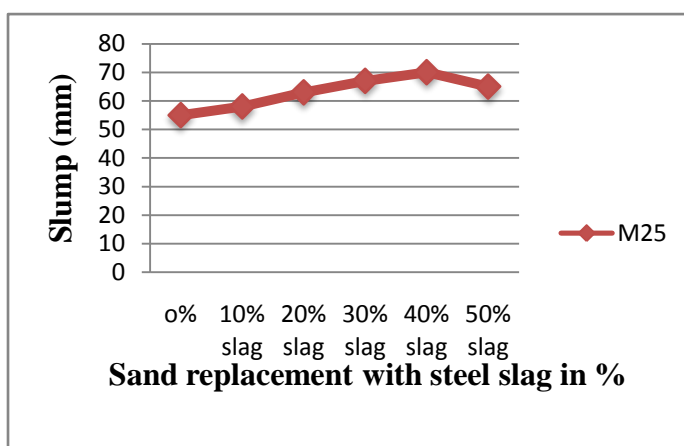
The Variation of slump with increase in percentage of steel slag 0%, 10%, 20%, 30%, 40%, 50% are

% of Steel Slag replacement	Average 7 Days compressive strength (N/mm ²)	Average 28 Days compressive strength (N/mm ²)
0%	20.36	32.07
10%	22.8	34.66
20%	23.16	36.10
30%	24.73	37.95
40%	26.8	40.79
50%	24.14	35.25

tabulated and the graph is plotted below.

Workability in terms of Slump Cone test

SI. No	Description	Slump (mm)
1	Plain concrete	55
2	Steel slag 10%	58
3	Steel slag 20%	63
4	Steel slag 30%	67
5	Steel slag 40%	70
6	Steel slag 50%	65



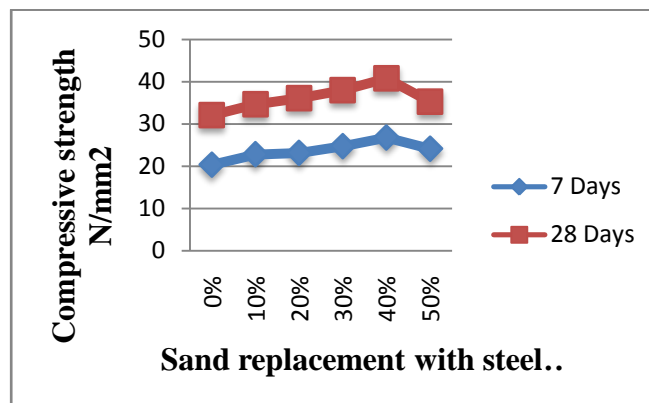
Variation of Slump

Description of result: From Fig The variation of slump for the partial replacement of Fine aggregate with Steel slag increased in the order of 55, 58, 63, 67, and 70mm for 0%, 10%, 20%, 30% and 40% proportions and decreased by 65 mm for 50% replacements respectively.

Compressive strength test:-

Concrete cubes of size 150mmx150mm were casted for 0%, 10%, 20%, 30%, 40%, 50% steel slag replacement. The compressive strength for M25 grade is tested for 7 and 28 days of curing and the results are tabulated and plotted below.

Compressive strength with different replacement percentages of Steel slag



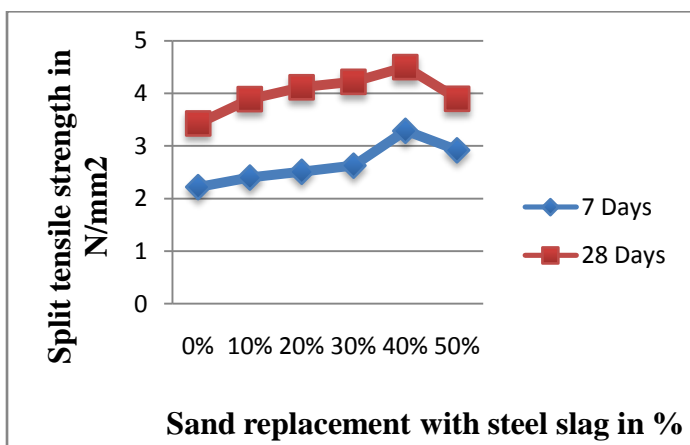
Compressive strength of concrete by partial replacement of sand with Steel slag

Description of result:

- From above graph The compressive strength of concrete is increased gradually from 0% to 30% and attained a maximum value at a replacement of 40% Steel slag in fine aggregate, while compared with controlled specimen.
- The compressive strength of concrete is decreased for 50% replacement of slag.
- However compressive strength of concrete for the partial replacement of Fine aggregate with Steel slag of 50% does not decrease by control mix.

Split tensile strength test:- Concrete cylinders of size 150mmx300mm were casted for 0%, 10%, 20%, 30%, 40%, 50% replacement of steel slag. The split tensile strength for M25 grade is tested for 7 and 28 days of curing and the results are tabulated and plotted below.

Split Tensile strength with different replacement percentages of Steel slag



Split Tensile strength of concrete by partial replacement of sand with Steel slag

Description of result:

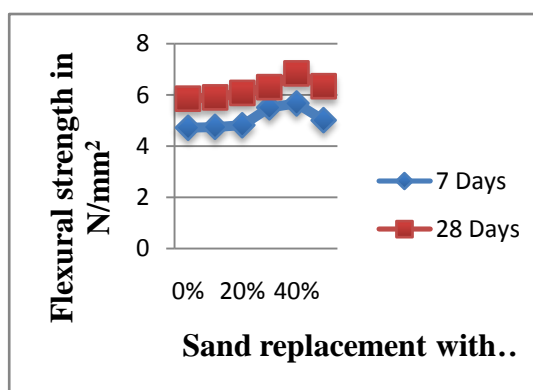
- From above the Graph The Split tensile strength of concrete is increased gradually from 0% to 30% and attained a maximum value at a replacement of 40% Steel slag in fine aggregate, while compared with controlled specimen.
- The Split tensile strength of concrete is decreased for 50% replacement of slag.
- However Split tensile strength of concrete for the partial replacement of Fine aggregate with Steel slag of 50% does not decrease by control mix.

Flexural strength test:- Concrete prisms of size 500mmx100mmx100mm were casted for 0%, 10%, 20%, 30%, 40%, 50% replacement of steel slag. The Flexural strength for M25 grade is tested for 7 and 28 days of curing and the results are tabulated and plotted below.

Flexural strength with different replacement percentages of Steel slag

% of Steel Slag replacement	Average 7 Days Flexural strength (N/mm ²)	Average 28 Days Flexural strength (N/mm ²)
0%	4.72	5.85
10%	4.75	5.90
20%	4.82	6.08
30%	5.51	6.3
40%	5.67	6.84
50%	5.01	6.34

% of Steel Slag replacement	Average 7 Days Split tensile strength (N/mm ²)	Average 28 Days Split tensile strength (N/mm ²)
0%	2.22	3.43
10%	2.4	3.89
20%	2.51	4.12
30%	2.63	4.22
40%	3.29	4.5
50%	2.92	3.9



Flexural strength of concrete by partial replacement of sand with Steel slag

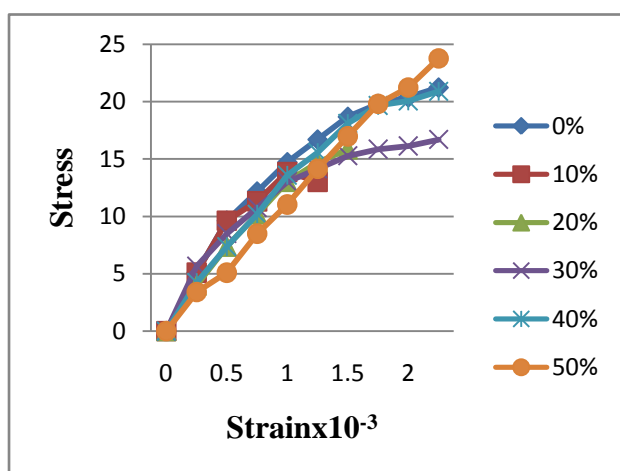
Description of result:-

- From above graph The Flexural strength of concrete is increased gradually from 0% to 30% and attained a maximum value at a replacement of 40% Steel slag in fine aggregate, while compared with controlled specimen.
- The Flexural strength of concrete is decreased for 50% replacement of slag.
- However Flexural strength of concrete for the partial replacement of Fine aggregate with Steel slag of 50% does not decrease by control mix.

Stress – Strain Curve:- A typical stress and strain of concrete in compression are tabulated and plotted below. The relation is fairly linear in the initial stages but subsequently becomes non linear reaching a maximum value before concrete fails. The curve is usually obtained by testing a cylinder with a height-to-lateral dimension ratio of at least 2, the test being conducted under uniform rate of strain. If a uniform rate of strain is adopted, it will not be possible to obtain the descending portion of stress and strain curve beyond the maximum stress.

% of Steel Slag replacement	28 Days Compressive strength		56 Days Compressive strength	
	Control 28 days	Immersed 0.5%HCL	Control 28days	Immersed 0.5% HCL
	32.07	46.3	32.07	43.9
	0%	42.09	34.66	39.4
20%	10 %	39.91	36.10	35.06
30%	37.95	39	37.95	34.22
40%	40.79	45.56	40.79	43.31
50%	35.25	34	35.25	30.04

Below graph shows the stress-strain behavior of concrete for 0% to 50% steel slag replacement.

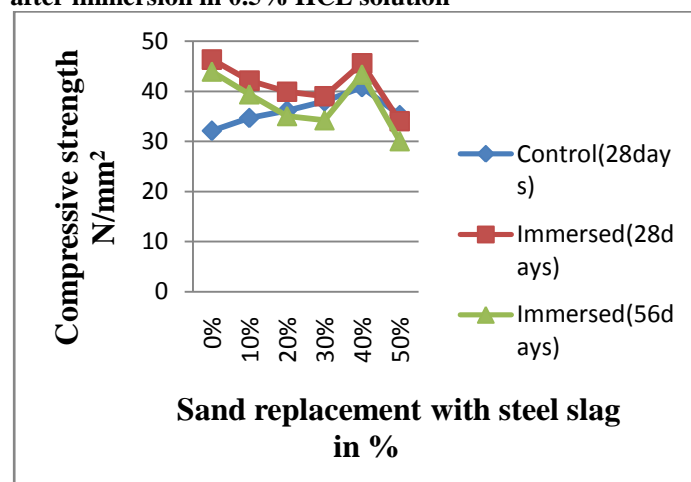


Stress-Strain curve of concrete for various percentages of Steel slag

Description of result:-

- The stress and strain increases gradually with increase in load upto the breaking point. From Fig it has been observed that the stress-strain curve for 0% conventional concrete and 40% Steel slag replaced concrete is similar
- Effects of HCL acid on 0% (normal) concrete and steel slag concrete- Durability studies:-** Concrete cubes of size 150mmx150mm were casted for 0%, 10%, 20%, 30%, 40%, 50% steel slag replacement. The cubes were casted and cured in water for 28 days and exposed to HCL of 0.5% and 1% concentrations. Cubes are immersed in solution after 28 days curing, and are tested for compressive strength after a further period of 28 and 56 days. The results are tabulated below and the graphs are plotted.

Compressive strength of concrete cubes after immersion in 0.5% HCL solution



Compressive strength of concrete cubes after immersion in 0.5% HCL

Description of result:-

- From Fig , it is observed that the compressive strength of concrete is decreasing when compared to control mix after immersing the cubes in 0.5%HCL solution
- However there is an increase in strength for the 40% replacement of Steel slag but slightly less than the strength compared to conventional concrete 0%.
- By observing the results of compressive strength of 0.5%HCL solution for 28 and 56 days it is observed that the strength loss will be much larger if the concrete is immersed in the solution for a longer period of time. So 40% slag is optimum from the consideration of resistance to sulphate

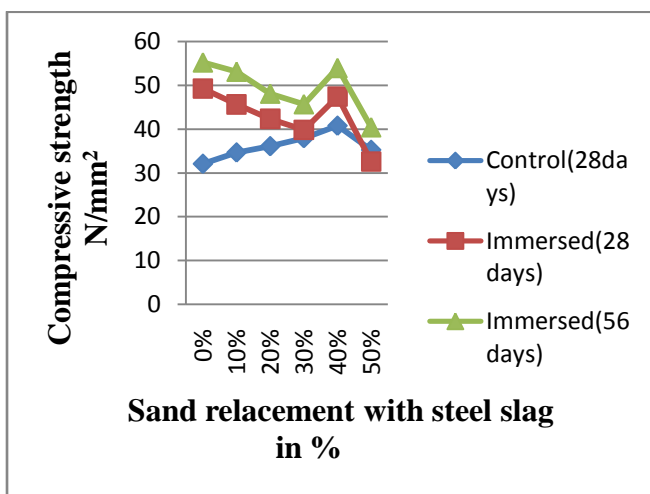
attack as observed from the experimental results.

Resistance to sulphate attack of concrete (mgso₄)
-Durability studies:- Concrete cubes of size 150mmx150mm were casted for 0%, 10%, 20%, 30%, 40%, 50% steel slag replacement. The cubes were casted and cured in water for 28 days. Magnesium sulphate (MgSO₄) solution of 50g/l and Sodium sulphate (Na₂SO₄) solution of 50g/l is used to evaluate sulphate resistance of concrete. Cubes are immersed in solution after 28 days curing, and are tested for compressive strength after a further period of 28 and 56 days. The cubes are tested for compressive strength and any reduction or change is noted. The compressive strength test results on immersed cubes specimens are tabulated belows.

- However there is an increase in strength for the 40% replacement of Steel slag but slightly less than the strength compared to conventional concrete 0%.
- By observing the results of compressive strength of MgSO₄ (50g/l) solution for 28 and 56 days it is observed that the strength loss will be much larger if the concrete is

immersed in the solution for a longer period of time. So 40% slag is optimum from the consideration of resistance to sulphate attack as observed from the experimental results.

% of Steel Slag replacement	28 Days Compressive strength		56 Days Compressive strength	
	Control 28 days	Immersed MgSO ₄	Control 28days	Immersed MgSO ₄
0%	32.07	49.23	32.07	55.2
10%	34.66	45.62	34.66	53.09
20%	36.10	42.33	36.10	48.09
30%	37.95	39.84	37.95	45.68
40%	40.79	47.42	40.79	53.93
50%	35.25	32.6	35.25	40.42



Compressive strength of concrete cubes after immersion in 50gm/litre of MgSo₄ solution
Description of result:-

- From Fig it is observed that the Compressive strength of concrete is decreasing when compared to control mix after immersing the cubes in MgSO₄ (50g/l) solution.

V. CONCLUSIONS

Based on the analysis of experimental results and discussions there upon the following conclusions are made.

- The compressive strength, flexural strength and split tensile strength of normal concrete and concrete with Steel slag as partial replacements are compared and observed that the strength of the normal concrete is slightly lower than the Steel slag replaced concrete.
- The compressive strength increases with increase in percentage of steel slag upto 40% by weight of fine aggregate. The enhancement in compressive strength is about 32% for 7 days curing and 27.2% for 28 days curing.
- The split tensile strength increases with increase in percentage of steel slag upto 40% by weight of fine aggregate. The enhancement in split tensile strength is about 48.2% for 7 days curing and 31.2% for 28 days curing.
- The Flexural strength increases with increase in percentage of steel slag upto

40% by weight of fine aggregate. The enhancement in split tensile strength is about 20.12% for 7 days curing and 17% for 28 days curing.

- From the results of compressive strength, split tensile strength, flexural strength of 7 and 28 days curing, 40% replacement of fine aggregate by steel slag is the optimum percentage of replacement of M25 grade concrete.
- From the Stress-Strain curve (Graph) 40% Steel slag replaced for M25 concrete is similar to that of M25 conventional concrete.
- The compressive strength of concrete is decreased compared to the control mix (0%) for all the percentage replacements of Steel slag but however there is an increase in strength for 40% replacement of Steel slag but slightly less than the strength compared to conventional concrete (0%) for 0.5% and 1% of HCL and $MgSO_4(50g/l)$, $Na_2SO_4(50g/l)$ at the ages of 28 and 56 days of strength.
- The following benefits can be obtained by using Steel slag :- (i)Cost reduction
(ii) Utilization of waste material is possible in construction by using Steel slag as a partial replacement material for fine aggregate in concrete.

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