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# Durability Studies on Steel Slag Concrete and Comparison with Conventional Concrete

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*Abstract* - **This is an experimental project which deals with the studies on the durability of steel slag as replacement of coarse aggregate in concrete. This project outlines the method of preparation, testing procedure and salient results on the concrete that is manufactured using the waste products of steel industries. In this project, concrete of grade M40 was investigated. The raw materials for making concrete will be Ordinary Portland Cement (OPC), fine aggregate, coarse aggregate and steel slag. The percentage of cement, water and fine aggregate will be kept constant within the mixture, while the percentage of steel slag as the replacement of coarse aggregate 50%. Cubes measuring 150 mm x 150mm x 150 mm was casted to investigate the properties of concrete specimen after 28 days. This project proposes to evaluate the Durability properties of concrete made with steel slag. Tests like water absorption test, acid attack test, sulphate attack test, exposure conditions, fire resistance was conducted to test the durability of the concrete.**
*Keywords:* **Durability, Steel Slag Concrete, Conventional Concrete**

## I. INTRODUCTION

Concrete is most widely used construction materials in the world. It can be cast in diverse shapes. Concrete is the composite materials formed by the combination of cement, sand, coarse aggregate and water in a particular proportion in such a way that the concrete produced meets the needs its workability, strength, durability and economy. Global warming and environmental destruction have become the major issue in recent years. Use of more environment-friendly materials and industrial wastes in any industry in general and construction industry in particular, is of paramount importance.

A number of studies have been conducted concerning the protection of natural resources, prevention of environmental pollution and contribution to the economy by using the waste material. The two major by-products of the steel industry are slag and fly ash. In India the steel industry is producing about 12 million tons of steel slag annually. The cost effectiveness in construction will be achieved only if we thinking from every corner of construction materials. Concrete is the preferred and this largest building material used by the construction industry.

Coarse aggregate is one of the major ingredients of concrete. Maximum volume of concrete is placed by coarse aggregate. In this sense, coarse aggregate is to be replaced by any other innovative materials which partially resemble the characteristics, properties, composition of coarse aggregate to avoid these issues.

In this project, an attempt has made to overcome this problem by the limited use of steel slag in place of coarse aggregate. We are using induction furnace slag collected from Karpagam Steel Industries. This slag is waste product of mild steel grade $C_{25}$XMn, $C_{20}$A (according to IS 2830-2012). The raw material used for this type of steels is scrap (Sponge iron, Ferro Silicon, Ferro Manganese, Aluminum, etc.).

## II. METHODOLOGY

The material properties were determined after discussions and studying the literature reviews, followed by proportioning of different mixes for SSC. Material collection, Mix design and Casting the specimens were done . Tests like compression test, water absorption test, acid attack test, Sulphate attack test, exposure conditions, fire resistance was conducted to test the durability of the concrete. And later the results were compared with conventional concrete and cost analysis was done.

## III. PROPERTIES OF MATERIALS

TABLE I PROPERTY OF FINE AGGREGATE

| S. No. | Property of Fine aggregate | Values |
|---|---|---|
| 1 | Nominal maximum size | 4.75mm |
| 2 | Fineness modulus | 3.41 |
| 3 | Specific Gravity ($G_{FA}$) | 2.61 |
| 4 | Bulk density (Loose state) | 1447.47 kg/m$^3$ |
| 5 | Bulk density (Dense state) | 1669.79 kg/m$^3$ |

TABLE II PROPERTY OF CEMENT

| S. No. | Properties of cement | Values |
|---|---|---|
| 1 | Grade of cement | 53 |
| 2 | Specific Gravity ($G_C$) | 3.15 |
| 3 | Standard consistency | 29% |

TABLE III PROPERTY OF STEEL SLAG

| S. No. | Property of Steel Slag | Values |
|---|---|---|
| 1 | Nominal maximum size | 20mm |
| 2 | Finess modulus | 4.75 |
| 3 | Specific Gravity ($G_S$) | 2.23 |
| 4 | Impact value | 27.22% |
| 5 | Crushing value | 11.00% |
| 6 | Abrasion value | 13.62% |
| 7 | Bulk density (Loose state) | 1003.65 kg/m$^3$ |
| 8 | Bulk density (Dense state) | 1201.93 kg/m$^3$ |

TABLE IV PROPERTY OF STEEL SLAG

| S. No. | Property of Coarse aggregate | Values |
|---|---|---|
| 1 | Nominal maximum size | 20mm |
| 2 | Fineness modulus | 5.08 |
| 3 | Specific Gravity ($G_{CA}$) | 2.84 |
| 4 | Impact value | 20.64% |
| 5 | Crushing value | 16.14% |
| 6 | Abrasion value | 17.06% |
| 7 | Bulk density (Loose state) | 1501.64 kg/m$^3$ |
| 8 | Bulk density (Dense state) | 1756.73 kg/m$^3$ |

TABLE V CHEMICAL COMPOSITION OF STEEL SLAG AGGREGATE:

| S. No. | Chemicals | Percentage |
|---|---|---|
| 1 | Iron (Fe) | 25.05% |
| 2 | Silicon (Si) | 17.90% |
| 3 | Manganese (Mn) | 6.52% |
| 4 | Carbon (C) | 0.38% |
| 5 | Sulphur (S) | 0.19% |

TABLE VI COMPARISON OF THE PROPERTIES OF NCA AND SSA

| S. No. | Properties | NCA | SSA | IS Specification |
|---|---|---|---|---|
| 1 | Nominal maximum size | 20mm | 20mm | - |
| 2 | Fineness modulus | 5.08 | 4.75 | 5.5 – 8.0 |
| 3 | Specific Gravity ($G_S$) | 2.84 | 2.23 | 2.6 – 2.9 |
| 4 | Impact value | 20.64% | 27.22% | Less than 30% |
| 5 | Crushing value | 16.14% | 11.00% | Less than 30% |
| 6 | Abrasion value | 17.06% | 13.62% | Less than 30% |
| 7 | Bulk density (Loose state) | 1501.64 kg/m$^3$ | 1003.65 kg/m$^3$ | - |
| 8 | Bulk density (Dense state) | 1756.73 kg/m$^3$ | 1201.93 kg/m$^3$ | - |

## IV. MIX DESIGN

Mix design can be defined as the process of selecting suitable ingredients of concrete and determining their relative proportions with the objective of producing concrete of certain minimum strength as economically as possible. Concrete mixture proportioning refers to the process of determining the quantities of the ingredients necessary to produce concrete of adequate workability and meeting the strength and durability requirements for the exposure conditions to which it will be subjected.

Indian standard method institution has brought mix design procedure mainly based on the work done in national laboratories. This is covered in IS: 10262-2009. This method can be applied to the medium strength and high strength concrete. The scope of the IS 10262-2009 are following.

### *A. Mix proportion (per m$^3$)*

1. Cement =506.57 kg/m$^3$
2. FA = 631.57 kg/m$^3$
3. CA = 1170.14 kg/m$^3$
4. Water = 177.3 kg/m$^3$
5. Chemical Admixture = 10.1 kg/m$^3$

TABLE VII MIX DESIGN (FOR 1 M3 OF CONCRETE)

| Material | Cement | FA | CA | Water | Super plasticizer |
|---|---|---|---|---|---|
| Kg/m$^3$ | 506.57 | 631.57 | 1170.14 | 177.3 | 10.1 |
| Mix ratio | 1 | 1.25 | 2.32 | 0.35 | 0.02 |

TABLE VIII MIX RATIO FOR STEEL SLAG CONCRETE = 1: 1.25: 2.32

| Mix ID | Materials ($Kg/m^3$) | | | | | |
|---|---|---|---|---|---|---|
| | Cement | FA | CA | SSA | Water | Super Plasticizer |
| CC | 506.57 | 631.57 | 1170.14 | - | 177.3 | 10.1 |
| SSC | 506.57 | 631.57 | 585.07 | 585.07 | 177.3 | 10.1 |

## V. TESTS ON FRESH CONCRETE

### *A. Slump Test*

The test is carried out using a mould known as a slump cone or Abrams cone. The cone is placed on a hard non-absorbent surface .This cone is filled with fresh concrete in three stages ,each time it is tamped using a rod of standard dimensions. At the end of the third stage, concrete is struck off flush to the top of the mould. The mould is carefully lifted vertically upwards, so as not to disturb the concrete cone. Concrete subsides

TABLE IX RESULTS OF SLUMP TEST

| Mix | Conventional Concrete | Steel Slag Concrete |
|---|---|---|
| Slump(mm) | 105 | 85 |

## VI. TESTS ON HARDENED CONCRETE

This chapter describes about the preparation of specimen and tests on hardened concrete (compressive strength test) including durability tests.

### *A. Mould Details*

The moulds are of size 150 X 150 X 150 mm. They are made of mild steel plates and can be assembled or dissembled with the help of bolts and nuts, and beams moulds were used.

### *B. Specimen Details*

The experimental program was designed to study the mechanical properties of concrete with partial replacement of coarse cement by steel slag for M40 grade of concrete. The compressive strength of the cubes after 28 days. For the test specimens, 53 grade ordinary Portland cement, natural river sand and coarse aggregate, steel slags are being utilized. The maximum size of the coarse aggregate was limited to 20mm. A sieve analysis conforming to IS 383-1970 was carried out for both fine and coarse aggregate. The concrete mix proportions of M40 with the water cement ratio of 0.35 were used. The concrete mix design was proposed to achieve to compression strength of 40MPa after 28 days curing of the cubes.

## VII. COMPRESSION TEST

After the required period of curing, the specimen were taken out and allowed to dry for about 4 hours and then kept in the CTM of capacity 2000KN.

### *A. Results of Compression test*

TABLE X RESULTS OF COMPRESSION TEST

| S. No. | % of slag | Area ($mm^2$) | Load (KN) | Compressive strength ($N/mm^2$) | Average ($N/mm^2$) |
|---|---|---|---|---|---|
| 1 | 0 | 4900 | 230 | 46.94 | 42.86 |
| | | | 190 | 38.78 | |
| 2 | 25 | 4900 | 230 | 46.93 | 43.87 |
| | | | 200 | 40.81 | |
| 3 | 50 | 4900 | 240 | 48.97 | 45.915 |
| | | | 210 | 42.86 | |
| 4 | 75 | 4900 | 180 | 36.74 | 42.855 |
| | | | 240 | 48.97 | |
| 5 | 100 | 4900 | 170 | 34.69 | 39.795 |
| | | | 220 | 44.90 | |

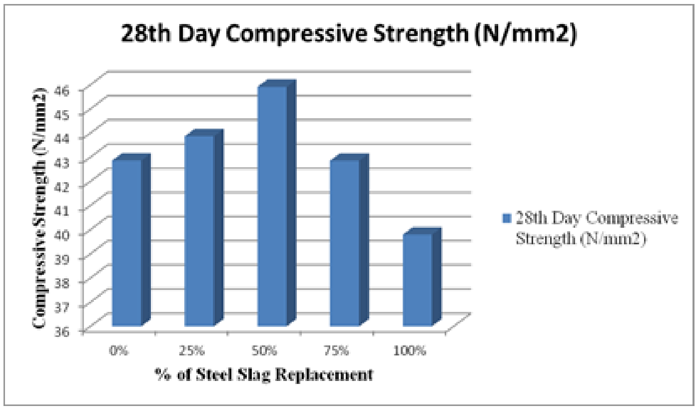


Fig. 1 Compressive strength Vs % of Steel slag replacement

TABLE XI UNIT WEIGHT OF CONCRETE

| S. No. | % of slag | Weight of Specimen(Kg) | Size of specimen (m) | Volume ($m^3$) | Unit weight ($Kg/m^3$) |
|---|---|---|---|---|---|
| 1 | 0 | 0.918 | 0.07 x 0.07 x 0.07 | $3.43 \times 10^{-4}$ | 2676.38 |
| 2 | 25 | 0.895 | 0.07 x 0.07 x 0.07 | $3.43 \times 10^{-4}$ | 2609.33 |
| 3 | 50 | 0.892 | 0.07 x 0.07 x 0.07 | $3.43 \times 10^{-4}$ | 2600.58 |
| 4 | 75 | 0.8915 | 0.07 x 0.07 x 0.07 | $3.43 \times 10^{-4}$ | 2600.57 |
| 5 | 100 | 0.886 | 0.07 x 0.07 x 0.07 | $3.43 \times 10^{-4}$ | 2583.09 |

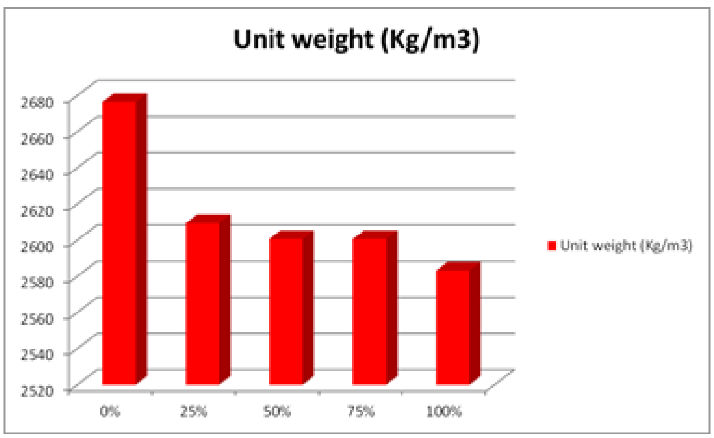


Fig. 2 Unit weight Vs % of Steel slag replacement

Optimum % of Replacement = 50%

*B. Durability Tests*

Concrete durability is one of the most important considerations in the design of new structures and when assessing the condition of existing structures. An understanding of concrete durability is fundamental to establishing the service life of new or existing structures. All concrete is likely to deteriorate to some extent, ensuring good durability is about minimizing the rate of deterioration.

The following durability tests were conducted in this project, and it will be described below,

1. Water absorption test
2. Acid attack test
3. Sulphate attack test
4. Exposure conditions
5. Fire resistance

*C. Water Absorption Test*

After the required period of curing, the specimens were taken out and allowed to dry for about 24 hours. The concrete specimens size was 150mm x 150mm x 150mm.

TABLE XII RESULTS OF WATER ABSORPTION TEST

| S. No. | Mix | Weight of saturated specimen (Kg) ($W_1$) | Weight of Oven-dried specimens (Kg) ($W_2$) | Water absorption at 7 days (%) | Average % |
|---|---|---|---|---|---|
| 1 | CC | 9.595 | 8.945 | 7.267 | 6.651 |
| 2 | | 8.925 | 8.417 | 6.035 | |
| 3 | SSC | 8.290 | 7.761 | 6.816 | 7.2735 |
| 4 | | 8.445 | 7.839 | 7.731 | |

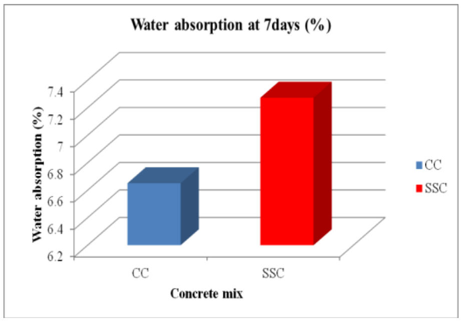


Fig. 3 Concrete mix Vs Water absorption

*Conclusion:* Water absorption of steel slag concrete was found to be 9.30 % higher than that conventional concrete.

*D. Acid Attack Test*

After the required period of curing, the specimens were taken out and allowed to dry for about 24 hours.. Then one container was prepared with 5 % of $H_2SO_4$ + 95 % of water. And the testing samples were immersed in the testing solution in 7 days. Durability of concrete against acid attack was calculated in terms of residual of residual compressive strength.

TABLE XIII COMPRESSIVE STRENGTH AFTER ACID ATTACK

| S. No. | Mix | Trials | Area ($mm^2$) | Load (KN) | Compressive strength $N/mm^2$ | Average ($N/mm^2$) |
|---|---|---|---|---|---|---|
| 1 | | 1 | $22.5x10^3$ | 640 | 28.44 | |
| 2 | CC | 2 | $22.5x10^3$ | 550 | 24.44 | 26.44 |
| 3 | | 1 | $22.5x10^3$ | 620 | 27.56 | |
| 4 | SSC | 2 | $22.5x10^3$ | 750 | 33.33 | 30.45 |

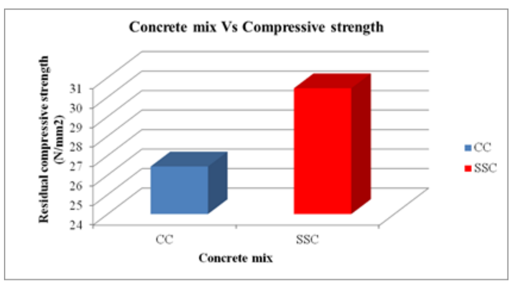


Fig. 4 Result of Acid Attack test

TABLE XIV WEIGHT LOSS AFTER ACID ATTACK

| S. No. | Mix | Weight before Acid attack Kg, ($W_1$) | Weight after Acid attack Kg, ($W_2$) | Weight loss (%) | Avg (%) |
|---|---|---|---|---|---|
| 1 | CC | 8.555 | 7.890 | 8.43 | 7.205 |
| 2 | | 8.915 | 8.412 | 5.98 | |
| 3 | SSC | 7.730 | 7.252 | 6.59 | 7.115 |
| 4 | | 7.735 | 7.186 | 7.64 | |

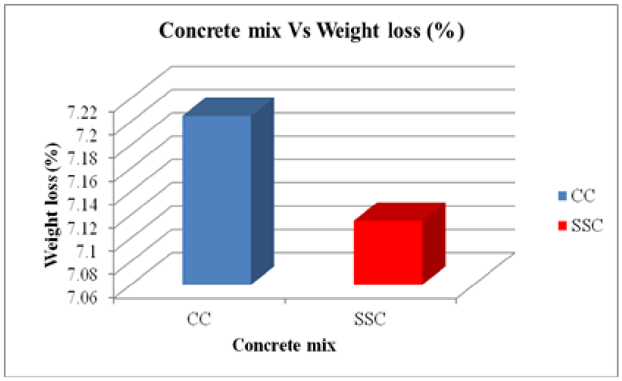


Fig. 5 Concrete mix vs weight loss

*Conclusion:* Residual compressive strength of steel slag after acid attack was found to be 15.15 %_higher than that of conventional concrete. Weight loss of Steel Slag Concrete is 1.24% lower than that Conventional Concrete.

### *E. Sulphate Attack Test*

After curing, the specimens were immersed in 5 % of $Na_2SO_4$ + 5 % of $MgSO_4$ + 90 % solution for 7 days. Durability of concrete against sulphate attack was calculated in terms of residual compressive strength and presented in Table 6.8 and Fig 6.

TABLE XV RESIDUAL COMPRESSIVE STRENGTH AFTER SULPHATE ATTACK TEST

| S. No. | Mix | Trials | Area ($mm^2$) | Load (KN) | Compressive Strength $N/mm^2$ | Average ($N/mm^2$) |
|---|---|---|---|---|---|---|
| 1 | CC | 1 | $22.5x10^3$ | 820 | 36.40 | 37.31 |
| 2 | | 2 | $22.5x10^3$ | 860 | 38.22 | |
| 3 | SSC | 1 | $22.5x10^3$ | 840 | 37.33 | 38.665 |
| 4 | | 2 | $22.5x10^3$ | 900 | 40.00 | |

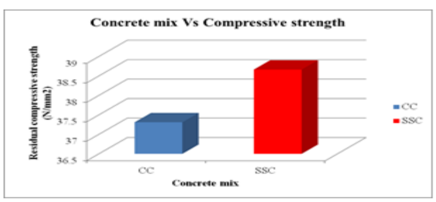


Fig. 6 Result of Sulphate Attack test

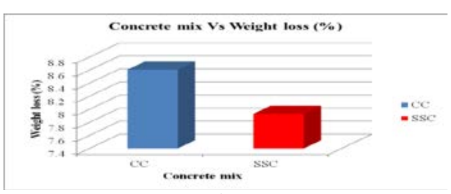


Fig. 7 Weight loss after Sulphte attack test

*Conclusion:* Residual compressive strength of steel slag concrete was found to be 3.66% higher than that of conventional concrete. Weight loss of Steel Slag Concrete is 8.50% lower than that Conventional Concrete.

### *F. Fire Resistance Test*

The dried specimen will be keep in the oven with 105®c in 24 hrs. And the cubes will be cooled in room temperature (27$^o$c) at 3 hrs. Fire resistance of concrete was calculated in terms of residual compressive strength and presented in Table

TABLE XVI RESIDUAL COMPRESSIVE STRENGTH AFTER FIRE RESISTANCE TEST

| S. No. | Mix | Trials | Area ($mm^2$) | Load (KN) | Compressive strength $N/mm^2$ | Average ($N/mm^2$) |
|---|---|---|---|---|---|---|
| 1 | CC | 1 | 4900 | 120 | 24.49 | 23.47 |
| 2 | | 2 | 4900 | 110 | 22.45 | |
| 3 | SSC | 1 | 4900 | 140 | 28.57 | 32.655 |
| 4 | | 2 | 4900 | 180 | 36.74 | |

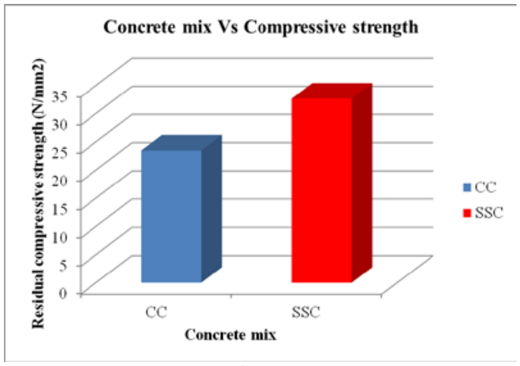


Fig. 8 Result of Fire resistance test

TABLE XVII WEIGHT LOSS AFTER FIRE RESISTANCE TEST

| S. No. | Mix | Weight before Fire resistance Kg, ($W_1$) | Weight after Fire resistance Kg, ($W_2$) | Weight loss (%) | Avg (%) |
|---|---|---|---|---|---|
| 1 | CC | 0.890 | 0.818 | 8.8 | 27.54 |
| 2 | | 0.880 | 0.823 | 6.9 | |
| 3 | SSC | 0.855 | 0.798 | 7.1 | 24.56 |
| 4 | | 0.850 | 0.804 | 5.7 | |

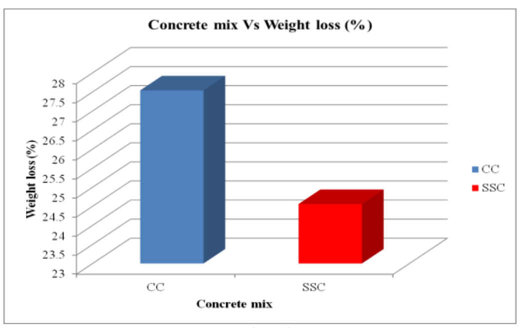


Fig 9 Weight loss after fire resistance test

*Conclusion:* Residual compressive strength of steel slag concrete was found to be 39.16% higher than that of conventional concrete. Weight loss of Steel Slag Concrete is 12.17% lower than that Conventional Concrete.

### *G. Exposure Conditions*

After the curing, the specimens were allowed to dry for about 24 hours, and will be kept in the Open natural atmosphere in 7 days. Durability of concrete against exposure conditions was calculated in terms of residual compressive strength and presented in Table

TABLE XVIII RESIDUAL COMPRESSIVE STRENGTH AFTER EXPOSURE CONDITIONS

| S. No. | Mix | Trials | Area ($mm^2$) | Load (KN) | Compressive strength($N/mm^2$) | Average ($N/mm^2$) |
|---|---|---|---|---|---|---|
| 1 | CC | 1 | $22.5x10^3$ | 850 | 37.78 | 34.89 |
| 2 | | 2 | $22.5x10^3$ | 720 | 32.00 | |
| 3 | SSC | 1 | $22.5x10^3$ | 780 | 34.67 | 35.555 |
| 4 | | 2 | $22.5x10^3$ | 820 | 36.44 | |

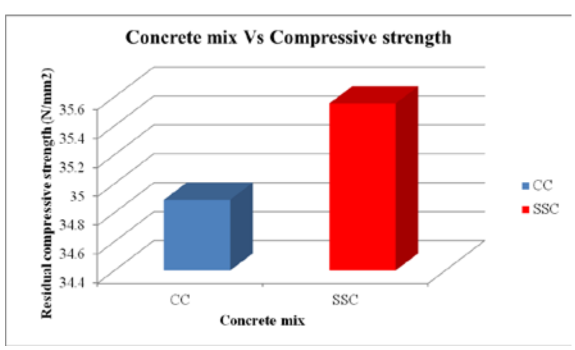


Fig. 10 Result of Exposure conditions

*Conclusion:* Residual compressive strength of steel slag concrete after exposure conditions was found to be 1.90% higher than that of conventional concrete.

*H. Cost Analysis and Comparison*

TABLE XIX PRESENT MATERIAL COST

| S. No. | MATERIALS | COST Rs | per | RATE (Rs/kg) |
|---|---|---|---|---|
| 1 | Cement | 350.00 | Bag | 7.00 |
| 2 | Fine aggregate | 7890.00 | Unit | 1.67 |
| 3 | Coarse aggregate (> 20mm) | 3230.00 | Unit | 0.65 |
| 4 | Steel Slag | - | - | - |
| 5 | Super Plasticizer | 750 | 5 lit | 150/lit |

TABLE XX COST OF THE SPECIMEN CASTING IN RUPEES FOR 1 $M^3$

| S. No. | Material | Conventional concrete | | Steel slag concrete | |
|---|---|---|---|---|---|
| | | Quantity (Kg) | Cost Rs p | Quantity (Kg) | Cost Rs p |
| 1 | Cement | 506.67 | 3546.69 | 506.67 | 3546.69 |
| 2 | Fine aggregate | 631.57 | 1054.72 | 631.57 | 1054.72 |
| 3 | Coarse aggregate | 1170.14 | 750.59 | 585.07 | 380.3 |
| 4 | Steel Slag | - | - | 585.07 | - |
| 5 | Super Plasticizer | 10.1 lit | 1515 | 10.1 lit | 1515 |
| Total cost | | Rs. 6867/$m^3$ | | Rs.6496.71/$m^3$ | |

Thus found out that, Cost of Steel Slag Concrete is found to be 5.6 % lower than that of Conventional Concrete.

## VIII. CONCLUSION

1. The impact value of SSA and NCA is 27.2% and 20.62% respectively. The impact resistance of SSA less than NCA. But it satisfies the requirement of IS specification.
2. The Compressive Strength of concrete increases with the increase in percentage of steel slag aggregate (SSA), which is 2.36% and 7.12% for 25% and 50% mixes respectively. And compressive strength decrease with further increase in percentage of steel slag aggregate, which is 7.14% and 15.3% for 75% and 100% mixes respectively when compared to control mix concrete 0% after 28 days curing. So the maximum compressive strength was achieved by 50% replacement of steel slag aggregate.
3. Water absorption of steel slag concrete was found to be 9.30 % lower than that conventional concrete.
4. Residual compressive strength of steel slag concrete sulphate attack was found to be 3.66% higher than that of conventional concrete. Weight loss of Steel Slag Concrete is 8.50% lower than that Conventional Concrete.
5. Residual compressive strength of steel slag concrete fire resistance was found to be 39.16% higher than that of conventional concrete. Weight loss of Steel Slag Concrete is 12.17% lower than that Conventional Concrete.
6. Residual compressive strength of steel slag concrete after exposure conditions was found to be 1.90% higher than that of conventional concrete. Weight loss of Steel Slag Concrete is 16.23% lower than that Conventional Concrete.
7. Cost of Steel Slag Concrete is found to be 5.6% lower than that of Conventional Concrete.

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