Benefits of Incorporating Induction Furnace Slag in Concrete as Replacement of Cement: A Case Study of Pakistan

MOHAMMAD LAEEQUE AHMED*, MUHAMMAD AFZAL JAVED*, AND ABDUL SAMI QURESHI**

ABSTRACT

As Pakistan along with the rest of the world continues to develop, demand for limited natural resources continues to increase also. This demand for resources and subsequent waste that is generated has driven the idea of sustainability towards the forefront of modern day research. To achieve this goal, new and innovative ways are being developed to recycle waste materials that otherwise would end up in landfill sites. Slag, a by-product of steel manufacturing is one such waste material. Pakistan as being a developing country does not have proper facilities to insure safe disposal and recycling of slag. Hence, new and innovative ways for recycling slag are a necessity for Pakistan to move towards technological advancement. Current study focuses to explore the feasibility of using local induction furnace slag as partial substitute of OPC (Ordinary Portland Cement) in concrete as well as to check its performance against chloride and sulphate damage. The test results showed that 15% or more slag replacement will make the concrete immune to chloride and sulphate damage. However, results also indicate that with increase in slag replacement percentage there is a significant drop in compressive, flexural and split tensile strength of concrete. Keeping in view the loss of strength, immunity against chloride and sulphate damage, reduction in cost of making concrete and sustainability benefits; 15% slag replacement has been deemed optimum replacement value.

Key Words: Local Induction Furnace Slag, Sustainability, Recycle Waste Materials, Chloride and Sulphate Damage.

1. INTRODUCTION

Rapid population growth and depleting natural resources have brought the idea of sustainability in forefront of modern day research. Hence constant efforts are being made to introduce and improve sustainability in construction sector. To achieve this aim, the study of concrete has garnered focus of many researchers owing to its versatility and wide use as construction material.

Recently, attempts have been made to utilise refuse materials such as fly ash [1], silica fume [2] and recycled plastic fibre [3] etc. in concrete. The potential application of these industrial by-products as partial cement or aggregate replacement in concrete depends on their mechanical and chemical properties. Their utilization in concrete also comes from an environmental constraint i.e. safe disposal.

Authors Email: (laeeque.ahmad@ce.uol.edu.pk, mafzal.javed@ce.uol.edu.pk, sami.qureshi@faculty.muet.edu.pk)
* Department of Civil Engineering, The University of Lahore, Lahore.
** Department of Civil Engineering, Mehran University of Engineering & Technology, Jamshoro.

Steel slag is one such industry by-product, produced during steel smelting process. Roughly 0.2 ton of slag is generated when 1 ton of crude steel is produced [4]. Pakistan produced 2.89 million metric tons of crude steel [5] corresponding to 0.58 million tons of steel slag being generated. This huge quantity of slag generated each year is discarded as trash and put in landfills. That's why solid waste management of steel slag is one of the major environmental concerns for underdeveloped countries like Pakistan.

Steel industry of Pakistan can be split into two categories, public (government owned) and private sector. Pakistan Steel is the only pubic enterprise operational right now. It contains 2 blast furnace units with a production capacity of 1.1 million tons per annum of crude steel [6]. As by-product it produces granulated blast furnace slag. Remaining steel demand of the country is met by private sector. Private sector comprises of small scale 140 steel melting induction furnaces [7], which are spread throughout the different regions of Pakistan. Chemical composition of slag produced in these induction furnaces greatly vary from blast furnace slag.

Majority of previous researches related to using slag in concrete have been focused on incorporating blast furnace slag rather than induction furnace slag. GGBS (Ground Granulated Blast Furnace Slag) have been extensively used as fine aggregate replacement [8], coarse aggregate replacement [9] and also as partial cement replacement [10] in concrete. Other aspects of GGBS concrete like sustainability [11] as well as performance against creep and shrinkage [12] have already been evaluated also. Whereas incorporation of induction furnace slag in concrete have been mostly confined to aggregate replacement [13]. Attempts for cement replacement with induction furnaces slag have been very limited. This is due to the fact that induction furnace slag contains higher levels of iron oxide and lower levels of silica in comparison to GGBS. These factors reduce its potential of being used as cement replacement material in concrete as compared to GGBS. Therefore, current study aims to identify the benefits of partially replacing OPC content by locally available induction furnace slag in concrete.

2. MATERIALS USED

2.1 Cement

ASTM Type-I OPC [14] cement was used throughout the study. Basic properties of the selected cement were determined using ASTM standard procedures [14-15]. Outcome of these tests are mentioned in Table 1.

TABLE 1. OPC PROPERTIES

Properties	Lab Test Values	Manufacturer Values
Specific Gravity	3.02	-
Fineness	4.4%	< 10%
Initial Setting Time	43 min	> 30 min
Final Setting Time	270 min	< 600 min
Normal Consistency	33%	-
Compressive Strength of Cement: sand (1:3) Mortar		
3-Days	25.3 N/mm	28 N/mm
7-Days	36.7 N/mm	42 N/mm
28-Days	52.4 N/mm	54 N/mm

2.2 Aggregates

Local quarried fine and coarse aggregates were used in the study. Their material properties were determined using ASTM standard procedure [16]. Details of fine and coarse aggregate properties are shown in **Tables 2-3** respectively.

2.3 Steel Slag

Induction furnace slag was collected from a local steel mill located in Lahore. Slag Samples collected from the industry land filling site were gridded to 44 micron size (Sieve # 325 passing) as per the ASTM standard [17]. Then the powdered slag was (dry) mixed with cement as partial replacement of binder. The steel slag collection and grinding process is detailed in Fig. 1.

The replacement percentages were kept 0, 5, 10, 15 and 20% by weight respectively. Chemical Analysis was conducted in reference to the techniques mentioned in ASTM C 323. Chemical composition of selected steel slag sample and blast furnace slag from 'Pakistan Steel' are mentioned in Tables 4- 5 [18].

The results shown in Table 4 indicate that steel slag still contain high quantity of Hematite (Fe_2O_3). Lack of quality

control during smelting process is the main reason for such high quantity of ore being left un-reacted. Some lapses of quality control are documented in Figs. 2-5.
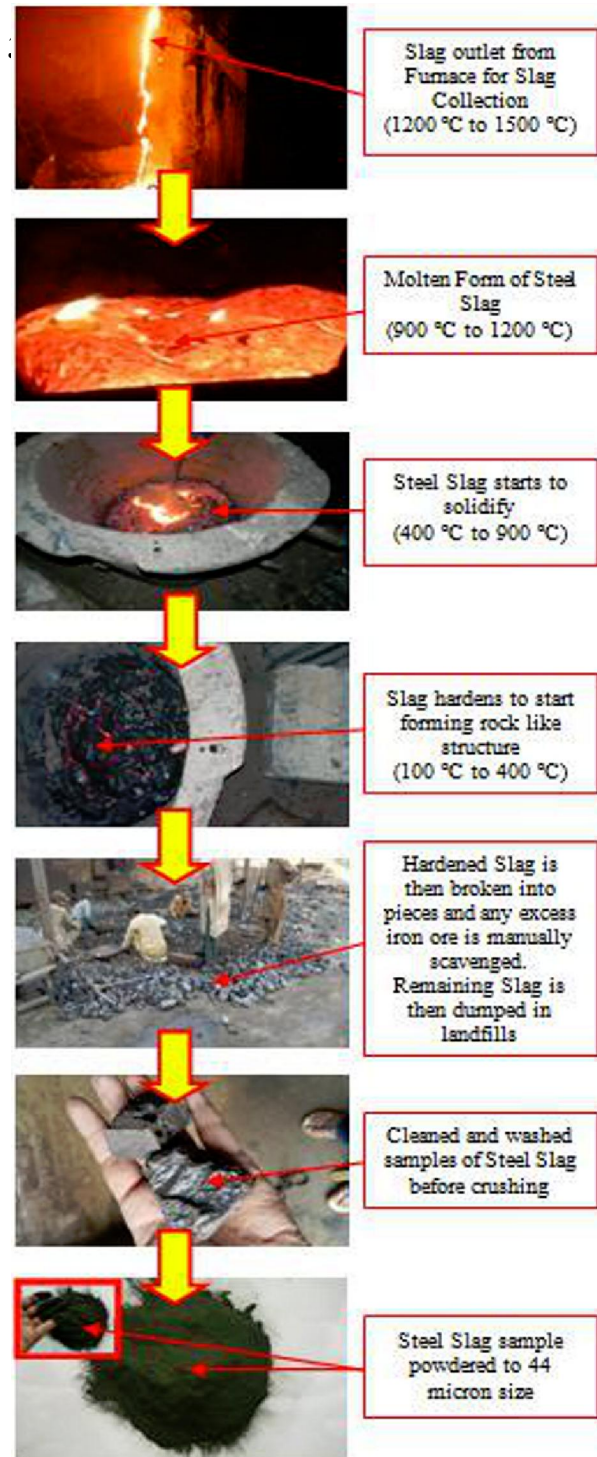

FIG. 1. STEEL SLAG COLLECTION AND GRINDING PROCESS

TABLE 2. PROPERTIES OF FINE AGGREGATES

Property	Value
Type	Natural
Fineness Modulus	2.4
Specific Gravity	2.69
Total Water Absorption	1.03%

TABLE 3. PROPERTIES OF COARSE AGGREGATES

Property	Value
Type	Natural (Crushed)
Fineness Modulus	7.4
Specific Gravity	2.75
Total Water Absorption	3.6%

Mehran University Research Journal of Engineering & Technology, Volume 37, No. 4, October, 2018 [p-ISSN: 0254-7821, e-ISSN: 2413-7219]

703

Following the ACI Mix Design Standard [19] requirements for compressive strength of 28 MPa, a mix ratio of 1:1.5:3 (binder: fine aggregate: coarse aggregate) and water to binder ratio value of 0.5 was set for the concrete samples to be tested. The water-to-binder ratio (w/(c + p)) remained constant throughout entire testing stage using weight equivalency technique [19] as cement was replaced by weight with different (0, 5, 10, 15 and 20%) percentages of steel slag.

TABLE 4. CHEMICAL ANALYSIS OF SELECTED SAMPLE

Chemical Composition	Percentages (%)
Loss on Ignition	0.08
Silica (SiO2)	13.12
Alumina (Al2O3)	4.88
Iron Oxide (Fe2O3)	37.54
Calcium Oxide (CaO)	39.50
Magnesium Oxide (MgO)	4.51
Sodium Oxide (Na2O)	0.32
Potassium Oxide (K2O)	0.04

TABLE 5. PAKISTAN STEEL'S BFS CHEMICAL ANALYSIS

Chemical Composition	Percentages (%)
Calcium Oxide	36-40%
Silica (SiO2)	36-39%
Alumina (Al2O3)	14-16%
Magnesium Oxide (MgO)	9% max
Manganese Oxide	1.3% max
Titanium Oxide	0.881% max
Iron Oxide	0.5% max
Sulphur	1.5% max

FIG. 2. NON-METALLIC ITEMS LEFT IN SCRAP METAL

4. DIFFERENT CURING MEDIUMS FOR CONCRETE TESTING

To better understand the sustainability and durability of concrete made with steel slag against chlorides and sulphate attacks. Test specimens were immersed and cured in three different curing mediums; namely water, chloride and sulphate medium. A study conducted by Jakhrani et. al. [20] on the seawater in the vicinity of Karachi harbour

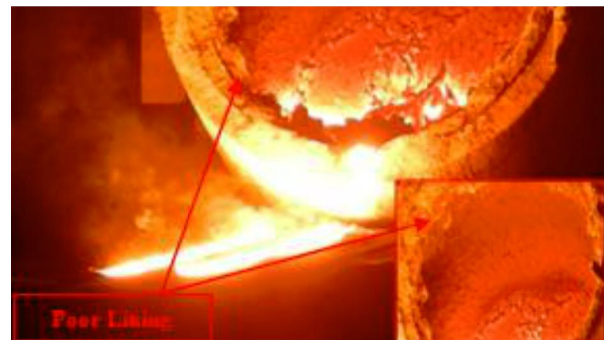*FIG. 3. PLASTIC BOTTLES BEING USED AS CHARGE*

FIG. 4. POOR FURNACE LINING WORKMANSHIP

FIG. 5. FLUX MATERIALS ARE LEFT EXPOSED TO NATURE

showed a maximum chloride concentration of 19800 ppm or 19.8 g/L and maximum sulphate concentration of 2949 ppm or 2.949 g/L respectively.

Considering the above mentioned findings and the prospect that pollution will keep on increasing in future, current study is carried out by taking 22000 ppm or 22 g/L of chloride concentration and 4000 ppm or 4 g/L of sulphate concentration for their respective curing mediums.

The curing guidelines mentioned in ASTM standard [21] were observed for all three mediums (water, chloride and sulphate). Water cured test specimens acted as control samples for test specimens cured in other two mediums (i.e. chloride and sulphate). Details of how each curing medium were prepared is mentioned as under:

Water Medium: Normal portable water having pH value from 6-8 was used. Fig. 6 shows cylinder and prism test specimens being cured in water medium.

Chloride Medium: 36.27 grams of sodium chloride (NaCl) was dissolved per litre of water to form the aqueous curing medium with the desired chloride concentration of 22 g/L. Fig. 7 shows cylinder and prism test specimens being cured in chloride medium.
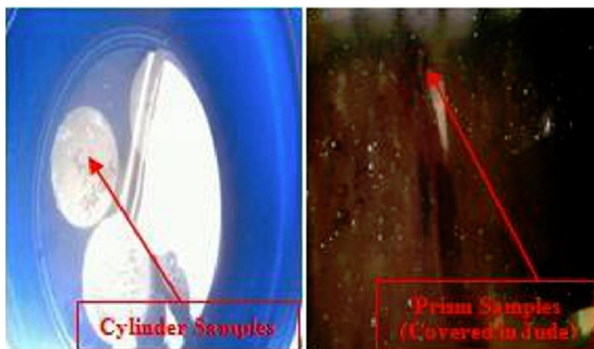

FIG. 6. TEST SPECIMENS CURED IN WATER MEDIUM

Sulphate Medium: 5.92 grams of sodium sulphate (NaSO$_4$) was dissolved per litre of water to form the aqueous curing medium with the desired sulphate concentration of 4 g/L. **Fig. 8** shows cylinder and prism test specimens being cured in sulphate medium.

5. BULK DRY DENSITY

Bulk dry density of samples was found before they were tested for compression, flexure or splitting tensile strength. The volumes of a cylinder and a prism are 0.0053 and 0.0112 m^3 respectively. To calculate the dry density of sample, each samples is first dried with a cloth (SSD Condition) and then weighed to the nearest 0.001 kilogram. Each sample is weighed and this weight is divided by the volume to find the bulk dry densities.

To insure accuracy of results, the bulk density of three samples of control concrete (having 0% slag) and three samples for each successive replacement of cement with

FIG. 7. TEST SPECIMENS CURED IN CHLORIDE MEDIUM

FIG. 8. TEST SPECIMENS CURED IN SULPHATE MEDIUM

steel slag in concrete (5, 10, 15 and 20%) were evaluated. Table 6 shows the results of bulk dry density tests against each percentage steel slag replacement of concrete.

Overall increase in dry density between control (0% slag) sample and 20% slag sample is just 1.73%, which is very minute increase. The graphical representation of results in Fig. 9 shows this slight increasing trend from 0-20% slag samples. The trend indicates that each successive increase from 0-20% have very minutely increased the density of concrete.

6.   SLUMP TEST

Slump is basically a measure of workability which is largely dependent of the value of water-cement ratio. If

TABLE 6. DRY DENSITY OF STEEL SLAG CONCRETE

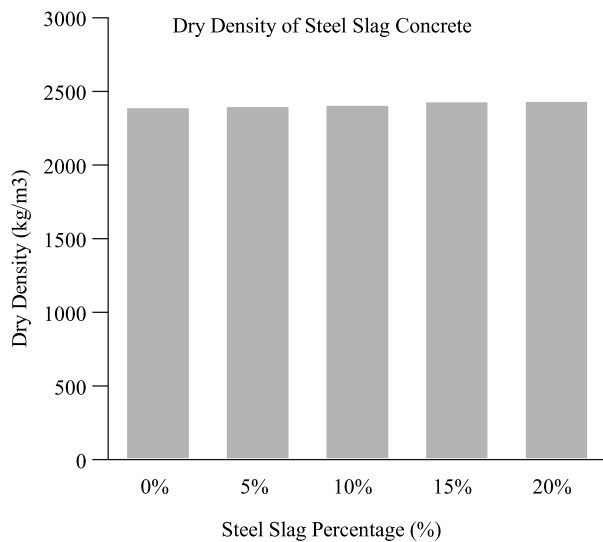| Slag Replacement (%)	Dry Density (Kg/m3)
0	2392
5	2401
10	2409
15	2432
20	2434

FIG. 9. GRAPH OF DRY DENSITY VS SLAG PERCENTAGE

more free water is accessible at the time of batching then more will be the fall of slump. Review of previous researches [22-23] indicate that hydration of slag occur much slower than compared to OPC. Therefore, as the percentage of cement replacement with steel slag increases the fall of slump should also increase. This trend was also observed in results of current study as shown in **Table 7**. Test was conducted as per ASTM standards [24].

7.   COMPRESSIVE STRENGTH

The compressive strength for different percentages (0,5,10,15 and 20%) of slag replaced concrete was measured after seven (7), fourteen (14) and twenty-eight (28) days. All the samples were tested using compressive strength testing machine (Fig. 10). The loading rate for testing was kept constant at 0.25 ± 0.05 MPa/s [25]. To improve the accuracy of results, three cylinders of each slag replacement for every individual curing medium (water, chloride and sulphate) were casted and the average of these samples was taken. The concrete cylinders were cured in each curing medium at room temperature ($25ºC \pm 5$). Compressive strength variations of samples cured in water, chloride and sulphate mediums are shown in Fig. 11 for 7 day strengths, Fig. 12 for 14 day strengths and Fig.13 for 28 day strengths respectively.

TABLE 7. SLUMP FOR DIFFERENT SLAG REPLACEMENTS

Slag Replacement (%)	Slump Values (mm)
0	58
5	65
10	78
15	89
20	102

The results clearly indicate sharp decrease of compressive strength after 15% replacement of cement with slag. At 28 days, the reduction in strength for each 5% replacement of slag between 0 and 15% was up to 1.5 MPa while more than 2.5 MPa decrease in
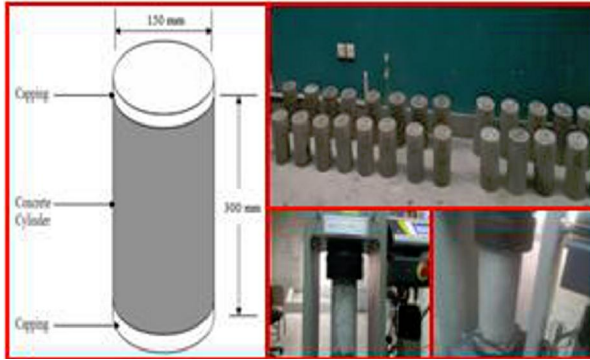

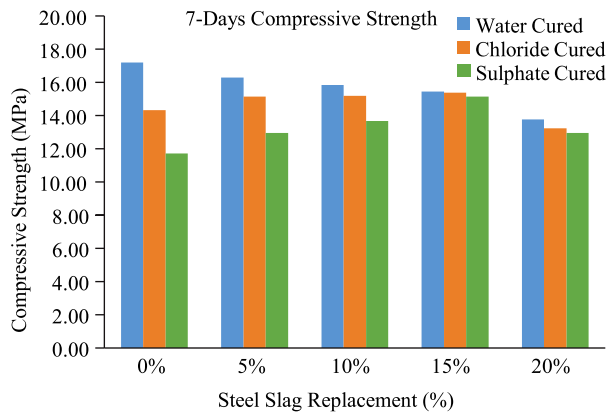*FIG. 10. CONCRETE CYLINDER COMPRESSIVE STRENGTH TEST*

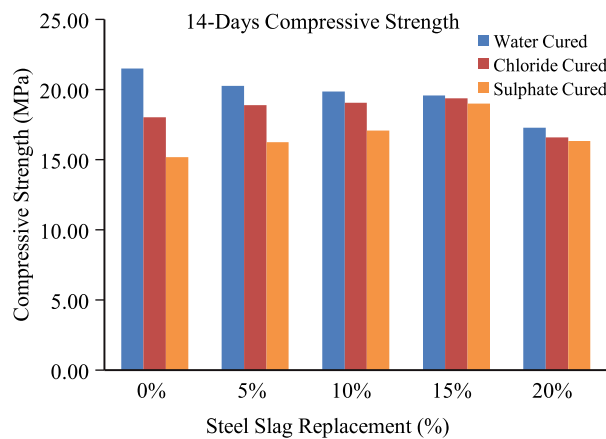*FIG. 11. COMPRESSIVE STRENGTH AT 7 DAYS*

FIG. 12. COMPRESSIVE STRENGTH AT 14 DAYS

compressive strength was observed in between 15-20% slag replacement. Same kind of trends was observed at 7 and 14 days as well. This reduction in compressive strength occurred due to the fact that normal OPC is composed almost 65% [14] of calcium oxide while the replacement slag only contained 39.50% (Table 4) calcium oxide, which is the essential for producing C_3S and C_2S binding compounds.

Another very important observation was that the results of 15 and 20% slag replacement yield almost identical strength in all curing mediums. This means that 15-20% steel slag replaced concrete will give almost same strength if cured in water, chloride or sulphate environment; greatly improving resistance of concrete against chloride and sulphate.

8. FLEXURAL STRENGTH

Flexural strength of different percentages (0,5,10,15 and 20%) of slag replaced concrete was measured after 28 and 56-days. All the prism samples (150x150x500mm) were tested using three point loading machine as per the guidelines mentioned in ASTM standards [26], shown in Fig. 14. Loading rate for testing was kept at 1.0 ± 0.05 MPa/min [26].
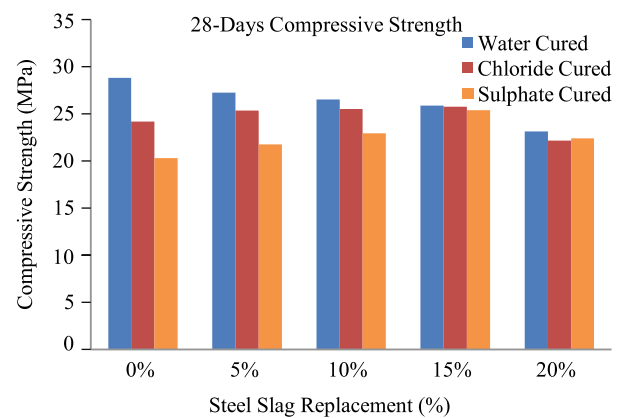

FIG. 13. COMPRESSIVE STRENGTH AT 28 DAYS

Mehran University Research Journal of Engineering & Technology, Volume 37, No. 4, October, 2018 [p-ISSN: 0254-7821, e-ISSN: 2413-7219]

707

To improve the accuracy of results, three prisms of each slag replacement for every individual curing medium (water, chloride and sulphate) were casted and the average of these samples was taken. The concrete prisms were cured in each curing medium at room temperature (25ºC ± 5). Flexural strength variations of samples cured in water, chloride and sulphate mediums are shown in Fig. 15 for 28-days strengths and Fig. 16 for 56 day strengths respectively.

Chloride medium cured prism showed highest flexural strength with 10 and 15% slag replacement at 28 and 56 days respectively. Sulphate medium cured prisms however indicated maximum flexural strength with 15% slag replacement on both 28 and 56 days testing.

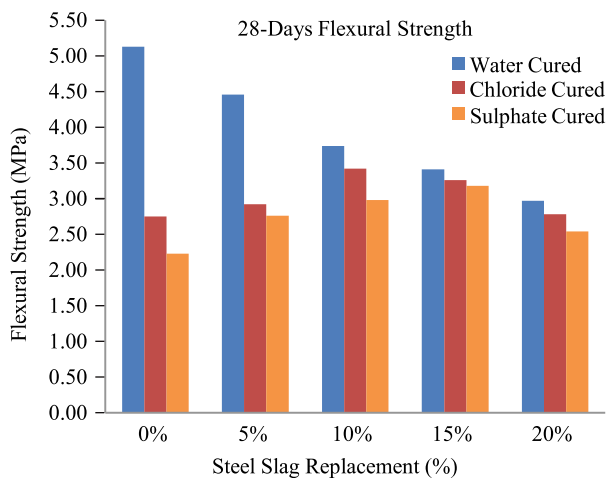*FIG. 14. FLEXURAL STRENGTH TEST OF CONCRETE PRISMS*

FIG. 15. FLEXURAL STRENGTH AT 28 DAYS

The results also indicate sharp decrease (up to 2.9 MPa on 28-days and up to 2.75 MPa on 56-days) in flexural strength of 0 and 5% slag replacement samples in chloride and sulphate curing medium as compared to water curing medium. The results of 15 and 20% slag replacement samples are almost the same in all curing mediums. Another important observation was that at 56 days testing; prisms cured in sulphate medium show higher strength than the prism cured in chloride. This indicates slightly improved resistance of slag concrete against sulphate in comparison to chloride in the long run.

9.   SPLITTING TENSILE STRENGTH

Since modulus of rupture discussed in section 8 is an indirect evaluation of tensile capabilities of the concrete. So splitting tensile strength of cylinder being more direct approach to determine tensile strength of concrete as specified by ASTM standard [27] was also performed. The splitting tensile strength of different percentages (0,5,10,15 and 20%) of steel slag replaced concrete was measured after twenty-eight (28) and fifty-six (56) days. All the cylinder samples (150mm diameter and 300 mm length) were tested using UTM (Universal Testing Machine) as shown in Fig. 17. And
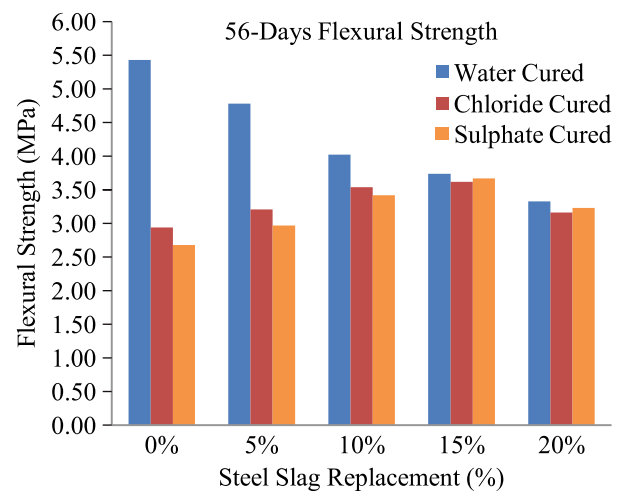

FIG. 16. FLEXURAL STRENGTH AT 56 DAYS

Mehran University Research Journal of Engineering & Technology, Volume 37, No. 4, October, 2018 [p-ISSN: 0254-7821, e-ISSN: 2413-7219]

708

loading rate during the testing was kept constant at 1.0 ± 0.05 MPa/min [28].

To improve the accuracy of results, three cylinders of each slag replacement for every individual curing medium (water, chloride and sulphate) were casted and the average of these samples was taken. The concrete cylinders were cured in each curing medium at room temperature ($25°C \pm 5$). The variations in splitting tensile strength of samples cured in water, chloride and sulphate mediums are shown in Fig.18 for 28 day strengths and Fig. 19 for 56 day strengths respectively.

The results of 56 days testing of 15 and 20% slag replacement samples have almost become identical. This is due to the fact that slag takes longer time to

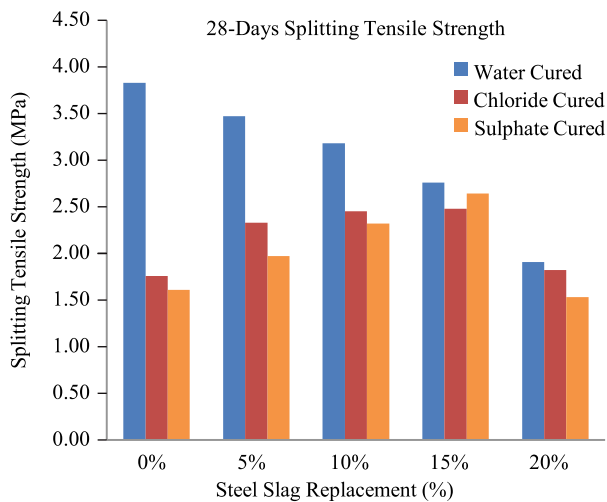*FIG. 17. SPLITTING TENSILE TEST ON CONCRETE CYLINDER*

FIG. 18. SPLITTING TENSILE STRENGTH AT 28 DAYS

hydrate as compared to OPC [27]. The delay in hydration and lack of calcining agent cause the reduction of splitting tensile strength but also provide longer duration of protection against chloride and sulphate damage.

10.   COST ANALYSIS

To understand the cost savings, it is essential to calculate the material quantities based on the mix ratio (1:1.5:3) used during the experimentation of this research. The calculations done for cost analysis are mentioned as under:

(i)   Bulk densities of cement (binder) = 1440 kg/m³, sand (fine aggregate) = 1770 kg/m³ and crush (course aggregate) = 1680 kg/m³ respectively.

(ii)   Specific gravities of cement = 3.02, sand = 2.69 and crush = 2.75 respectively.

(iii)   Percentage of air entrained is 2.5%.

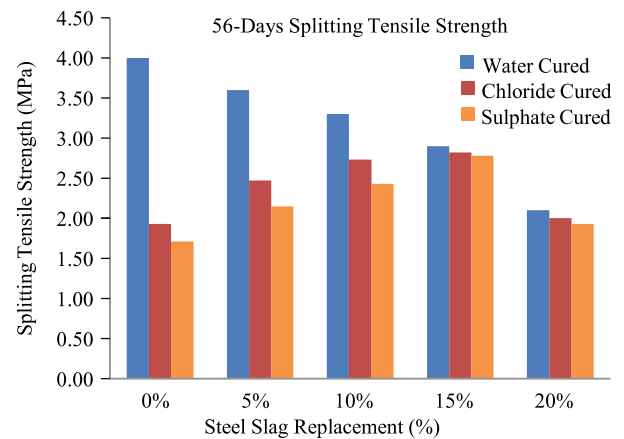(iv)   The mix proportioning of 1:1.5:3 of materials by dry volume can be expressed in terms of masses as:

FIG. 19. SPLITTING TENSILE STRENGTH AT 56 DAYS

OPC=1x1440=1440 kg

Sand=1.5x1770=2655 kg

Crush=3x1680=5040 kg

Therefore, ratio of masses of these materials with respect to OPC will be,

$$1 : \frac{2655}{1440} : \frac{5040}{1440} = 1 : 1.8 : 3.5$$

The water-to-binder ratio = 0.5

(v)   Using Absolute Volume Method to calculate the amount of concrete produced by one bag of cement (i.e. 50 kg cement).

$$V_c = \frac{0.5 \times 50}{1000} + \frac{1 \times 50}{1000 \times 3.02} + \frac{1.8 \times 50}{1000 \times 2.69} + \frac{3.5 \times 50}{1000 \times 2.75} = 0.13865 m^3$$

So one bag of cement (50kg) will produce 0.13865 m³ of concrete

(vi)   Since entrained air is considered to be 2.5%, so actual volume of concrete for 1 m³ of compacted concrete construction will be equal to 1- 0.025 = 0.975m³.

(vii)   The quantity of cement required for 1 cubic metre of concrete mix is equal to 0.975/0.13865 = 7.03 bags of cement.

(viii) Therefore, quantities of materials for 1m³ of concrete are:

Cement=7.03x50=351.5 kg

Sand=1.5x351.5=527.25 kg

Crush=3x351.5=1054.5 kg

As per the ACI Mix Design Standard the slag replacement was done using weight equivalency. For example, in a 15% slag replacement sample an absolute 15% weight of cement is being replaced by steel slag.

(ix)   The weight of cement replaced by samples containing 5,10,15 and 20% slag for 1m³ of concrete will become,

5% Slag Sample= 0.05x351.5 =17.575 kg

10% Slag Sample= 0.10x351.5=35.150 kg

15% Slag Sample= 0.15x351.5=52.725 kg

20% Slag Sample= 0.20x351.5=70.300 kg

After the material calculations the next step was to determine the cost of cement. For this study, DG Cement (ASTM Type I) has been used which cost 535 PKR per bag and 10.7 PKR per kg respectively (At the time of writing this paper). So cost of cement for each cubic metre of 1:1.5:3 mix is 351.5x10.7 = 3761 PKR.

(x)   Therefore, cost savings of producing 1 m³ concrete with 5,10,15 and 20% replacement respectively will be,

5% Slag Sample = 17.575x10.7=188.052PKR

10% Slag Sample = 35.150x10.7=376.105PKR

15% Slag Sample= 52.725x10.7=564.158 PKR

20% Slag Sample =70.300x10.7=752.210 PKR

(xi)   Cost of Grinding, Transportation and other miscellaneous expenditure per kg of Slag are estimated to be PKR 1.15

(xii)   Total cost savings for 1 m³ concrete mix containing 5, 10, 15 and 20% replacement respectively are:

5% Slag $= 188.052 - (17.575 \text{x} 1.15) \approx 167$ PKR

10% Slag $= 376.105 - (35.150 \text{x} 1.15) \approx 335$ PKR

15% Slag $= 564.158 - (52.725 \text{x} 1.15) \approx 503$ PKR

20% Slag $= 725.210 - (70.300 \text{x} 1.15) \approx 644$ PKR

(xiii)   Total cost reduction for 1 m^3 concrete mix containing 5,10,15 and 20% replacement respectively are:

5% Slag $= 100 - [\{(3761 - 167)/3761\} \text{x} 100] \approx 4.4\%$

10% Slag $= 100 - [\{(3761 - 335)/3761 \text{ x} 100] \approx 8.9\%$

15% Slag $= 100 - [\{(3761 - 503)/3761\} \text{x} 100] \approx 13.4\%$

20% Slag $= 100 - [\{(3761 - 644)/3761\} \text{x} 100] \approx 17.1\%$

11.   SUSTAINABILITY ANALYSIS

Ernst Worrell et al. [29] estimated that about 1 tonne of CO_2 and other GHG (Green House Gases) are produced on manufacturing each tonne of OPC. Considering these estimates, the calculation of CO_2 emissions are:

(i)   Each metre cube of 1:1.5:3 concrete mix contains 351.5 kg OPC

(ii)   Using Weight Equivalency per slag replacement is:

5% slag $= 17.575$ kg Slag per 1m^3 of concrete mix

10% slag $= 35.150$ kg Slag per 1m^3 of concrete mix

15% slag $= 52.725$ kg Slag per 1m^3 of concrete mix

20% slag $= 70.300$ kg Slag per 1m^3 of concrete mix

(iii)   Since for every 1000 kg OPC manufacture 1000 kg of CO_2 is produced.

(iv)   Therefore, reduction of CO_2 emission per 1m^3 of concrete mix will be,

5% slag replacement $= 17.575/1000 = 0.0177$ tonne

10% slag replacement $= 35.150/1000 = 0.0351$ tonne

15% slag replacement $= 52.725 1000 = 0.0527$ tonne

20% slag replacement $= 70.300/1000 = 0.0703$ tonne

(v)   And percentage reduction of CO_2 emission per 1m^3 of concrete mix will be,

5% slag replacement $= 0.0177 \text{x} 100 = 1.77\%$

10% slag replacement $= 0.0351 \text{x} 100 = 3.51\%$

15% slag replacement $= 0.0527 \text{x} 100 = 5.27\%$

20% slag replacement $= 0.0703 \text{x} 100 = 7.03\%$

12.   CONCLUSIONS

Following are the conclusions drawn from experimental results:

(i)   Induction furnace slag can be used as partial cement replacement in concrete.

(ii)   Concrete samples containing 15% and 20% slag content showed almost identical results in compression, flexure and splitting tensile strength for all three curing mediums

(iii)   Concrete samples containing 15% or more slag are almost completely immune to sulphate and chloride damage.

(iv)   20% slag replacement samples lost an average 20% compressive strength at 28 days, 39% flexural strength at 56 days and 47.5% splitting tensile strength at 56 days in sulphate and chloride mediums in comparison to control samples cured in water medium.

Mehran University Research Journal of Engineering & Technology, Volume 37, No. 4, October, 2018 [p-ISSN: 0254-7821, e-ISSN: 2413-7219]

711

(v)   15% slag replacement samples only lost an average 10% compressive strength at 28 days, 31% flexural strength at 56 days and 27.5% splitting tensile strength at 56 days in sulphate and chloride mediums in comparison to control samples cured in water medium.

(vi)   Considering the losses in strength with every increase in slag percentage and chloride-sulphate immunity in perspective, 15% slag replacement is deemed as the optimum partial replacement value.

13.   BENEFITS

The benefits of using optimum replacement (15% slag) in concrete are listed below:

(i)   Cost per meter cube of concrete will be reduced by 503 PKR or 13.4%.

(ii)   Carbon dioxide (CO_2) emissions will be reduced by 5.27%.

(iii)   Concrete will be immune against sulphate and chloride damage.

(iv)   31 mm slump increase will improve efficient mixing and workability of concrete mix.

(v)   1.64% increase in dry density will improve structural stability, acoustic and thermal insulation and water tightness of concrete.

(vi)   Improved workability, chemical damage immunity and better water tightness will also help in reducing repair and maintenance costs.

ACKNOWLEDGMENT

REFERENCES

[1]   Hamdy K.S., Ahmed, S.E., and Ahmed, M.W., "Mechanical Properties of Fly Ash Based Geopolymer Concrete with Fulland Partial Cement Replacement", Construction and Building Materials, Volume 126, pp. 56-565, 2016.

[2]   Pedro, D., de Brito,J., and Evangelista, L., "Evaluation of High-Performance Concrete with Recycled Aggregates: Use of Densified Silica Fume as Cement Replacement", Construction and Building Materials, Volume 147, pp. 803-814, 2017.

[3]   Pešiæ, N., Živanoviæ, S., Garcia, R., and Papastergiou, P., "Mechanical Properties of Concrete Reinforced with Recycled HDPE Plastic Fibres", Construction and Building Materials, Volume 115, pp. 362-370, 2016.

[4]   Hendrik, G.O., "Slag-Iron and Steel", US Geological Survey Minerals Yearbook, pp. 70.1-70.6, 2002.

[5]   Steel Statistical Yearbook, World Steel Association, pp. 6, 2016.

[6]   Some Fact about Pakistan Steel Mill, Pakistan Steel Melters Association, 2017, http://www.steelmelters.com/pakistan.htm

[7]   Steel Mills in Private Sector, Pakistan Steel Melters Association, 2017, http://www.steelmelters.com/pakistan.htm

[8]   Singh, G., Das, S., Ahmed, A.A., Saha, S., and Karmakar, S., "Study of Granulated Blast Furnace Slag as Fine Aggregates in Concrete for Sustainable Infrastructure", Procedia – Social and Behavioral Sciences, Volume 195, pp. 2272-2279, 2015.

Mehran University Research Journal of Engineering & Technology, Volume 37, No. 4, October, 2018 [p-ISSN: 0254-7821, e-ISSN: 2413-7219]

712

[9] Ozbakkaloglu, T., Gu, L., and Pour, A.F., "Normaland High-Strength Concretes Incorporating Air-Cooled Blast Furnace Slag Coarse Aggregates: Effect of Slag Size and Content on the Behavior", Construction and Building Materials, Volume 126,pp. 138-146, 2016.

[10] Aghaeipour, A., and Madhkhan, M., "Effect of Ground Granulated Blast Furnace Slag (GGBFS) on RCCP Durability", Construction and Building Materials, Volume 141, pp. 533-541, 2017.

[11] Khatib, J.M., and Hibbert, J.J., "Selected Engineering Properties of Concrete Incorporating Slag and Metakaolin", Construction and Building Materials, Volume 19, No. 6, pp. 460-472, 2005.

[12] Li, H., Wee, T.H., and Wong, S.F., "Early-Age Creep and Shrinkage of Blended Cement Concrete", Materials Journal, Volume 99, No. 1, pp. 3-10, 2002.

[13] Mohammed, T.U., Noor, M.A., Apurbo, S.A., Ahmed, M., Elahi, A., and Mazumder, M.H., "Utilization of Induction Furnace Slag in Concrete as Coarse Aggregate", 1st International Conference on Engineering Research and Practice, Dhaka, Bangladesh, 2017.

[14] ASTM C150/C150M-17, "Standard Specification for Portland Cement", ASTM International, West Conshohocken, PA, 2017.

[15] ASTM C430-17, "Standard Test Method for Fineness of Hydraulic Cement by the 45-mm (No. 325) Sieve", ASTM International, West Conshohocken, PA, 2017.

[16] ASTM C33/C33M-16e1, "Standard Specification for Concrete Aggregates", ASTM International, West Conshohocken, PA, 2016.

[17] ASTM C989/C989M-17, "Standard Specification for Slag Cement for Use in Concrete and Mortars", ASTM International, West Conshohocken, PA, 2017.

[18] Granulated Blast Furnace Slag, Pakistan Steel, Ministry of Industries & Production, Government of Pakistan, 2017, http://www.paksteel.com.pk product_gran_slag.html

[19] ACI 211.1-91, "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete", American Concrete Institute Committee, Volume 211, pp. 1-38, 2002.

[20] Jakhrani, A.Q., Samo, S.R., Sobuz, H.R., Uddin, M.A., Ahsan, M.J., and Hasan, M.S., "Assessment of Dissolved Salts Concentration of Seawater in the Vicinity of Karachi", International Journal of Structural and Civil Engineering, Volume 1, No. 2, pp. 61-69, 2012.

[21] ASTM C192/C192M-16, "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory", ASTM International, West Conshohocken, PA, 2016.

[22] Ramezanianpour, A.A., Atarodi, S., and Sami, M., "Durability of Concretes Containing Ground Granulated Blast Furnace GGBS Against Sulfate Attack", 3rdInternational Conference on Sustainable Construction Materials and Technologies, 2017, http://www.claisse.info/Proceedings.htm

[23] Arivalagn, S., "Sustainable Studies on Concrete with GGBS as a Replacement Material in Cement", Jordan Journal of Civil Engineering, Volume 8,No. No. 3, pp. 263-270, 2014.

[24] ASTM C143/C143M-15a, "Standard Test Method for Slump of Hydraulic-Cement Concrete", ASTM International, West Conshohocken, PA, 2015.

[25] ASTM C39/C39M-18, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens", ASTM International, West Conshohocken, PA, 2018.

[26] ASTM C78/C78M-18, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)", ASTM International, West Conshohocken, PA, 2018.

[27] Özbay, E., Erdemir, M., and Durmuº, H.I., "Utilization and Efficiency of Ground Granulated Blast Furnace Slag on Concrete Properties – A Review", Construction and Building Materials, Volume 105, pp. 423-434, 2016.

Mehran University Research Journal of Engineering & Technology, Volume 37, No. 4, October, 2018 [p-ISSN: 0254-7821, e-ISSN: 2413-7219]

713

[28]   ASTM C496/C496M-17, "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens", ASTM International, West Conshohocken, PA, 2017.

[29]   Worrell, E., Price, L., Martin, N., Hendriks, C., and Meida, L.O., "Carbon Dioxide Emissions from The Global Cement Industry", Annual Review of Energy and the Environment, Volume 26, pp. 303-329, 2001.