Experimental Investigation of Effect of Sulphates and Chlorides on Durability of Normal and Electromagnetic water M40 Grade concrete

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Abstract - *Electro-magnetic water concrete has been very recently developed by using electromagnetically treated water instead of potable water in concrete. The mix design, strength and durability of this electromagnetic water concrete is unimpeded. The presence of excessive sulphates and chlorides deteriorate the quality of concrete thereby affecting the strength and durability of concrete. Therefore the role of sulphates and chlorides and strength of normal and electromagnetic concrete with different mix designs and substitutions of cement with GGBS and Fly ash has been investigated in this paper. The durability aspects were studied pertaining to RCPT and WPT tests.*

***Key Words*: GGBS (Ground Granulated Blast Furnace Slag), FA (Fly ash), RCPT (Rapid Chloride Penetration test), WPT (Water Penetration test)**

1. INTRODUCTION

Concrete comprises of basically three ingredients: water, aggregates (rock, sand, or gravel) and cement. The water used in concrete plays a vital role in binding, workability and achieving strength of concrete. Electromagnetic water is water which is exposed to electromagnetic field. Electromagnetic water retains the same mechanical properties as that of water but the trajectory of the charged particles and radicals present changes. Exposure to electromagnetic field reorients the water molecule structure which increases the reactivity and solubility of water. Reduced viscosity and increased reactivity results in better mixing of ingredients of concrete. Electromagnetised water is found to increase the strength of concrete by 20 to 30% and helps in reducing the dosage of cement by 5%. In construction industry along with the strength of concrete, the durability of concrete is significantly important.

The presence of sulphates and chlorides hinders the achievement of strength. Sulphates and chlorides deteriorate the quality of concrete thereby affecting the durability of concrete.

The adoption of cement with supplementary materials such as fly ash, blast furnace slag and silica fume, is pretty common these days. The performance of the concrete with such substitutions pertaining to strength and durability with respect to content of chlorides and sulphates has been carried out in this research.

The content of sulphates and chlorides present in all concrete ingredients namely water, fine aggregates, coarse aggregates, cement, GGBS, Fly ash were considered. The strength of cubes of each of the samples was studied with respect to the content of sulphates and chloride content. Also the durability parameters were studied with reference to the sulphates and chloride content in concrete.

2. EXPERIMENTAL DETAILS:

2.1 Material Required:

2.1.1 Cement

Cement adopted in this experimental work is Ordinary Portland cement (Birla Super Shakti OPC grade 53). All properties of cement are tested using I.S. specifications for OPC.

Table 1: Properties of cement

Tests Conducted On Cement Brand: Birla Super Shakti, OPC 53 Grade	**Result**
Initial Setting Time	38 minutes
Final Setting Time	225 minutes
Soundness	7 mm
Specific Gravity Of Cement	3.05
Consistency	28%

2.1.2 Fine Aggregates

The fine aggregates adopted were crushed sand confirming to zone 1 and maximum size was 4.75mm and specific gravity 2.81. The testing of sand was done as per Indian Standard Specifications IS: 383-1970

2.1.3 Coarse Aggregates

Two types of aggregates were adopted for the experimental investigation viz. 10mm and 20mm. Sieve analysis was performed according to IS 383:1970-

specification and IS 2386:1977-Methods of tests for aggregates of concrete.

2.1.3 Water

Normal potable water and electromagnetic water which was extracted through the electromagnetic device was adopted. Varying water cement ratio for different samples was adopted.

2.1.5 GGBS (Ground Granulated Blast Furnace Slag)

The main components of blast furnace slag are CaO (30-50%), SiO_2 (28-38%), Al_2O_3 (8-24%), and MgO (1- 18%). GGBS of JSW cement was used. It is off-white in colour and substantially lighter than Portland cement. Addition of GGBS with OP Cement ensures higher durability of concrete avoids thermal cracking and improves workability. 30 to 50% by weight of cement was substituted with GGBS.

2.1.6 Fly Ash

Fly Ash of brand Ashcrete Class F was adopted. Fly Ash is a very fine grey amorphous powder. It is rich in silica and alumina. It is known to increase the ability of concrete to resist attack from sulphates in soil or ground water. Additionally, Class F fly ash has been proven to be highly effective in mitigating the deleterious effects of expansive alkali-silica reactions (ASR) in concrete.

2.1.7 Mix Design

The Indian Standard Mix Design procedure was adopted (i.e. IS: 10262-2009) for normal M40 grade concrete with different amount of substitutions of GGBS and Fly Ash with cement. Mix design for Electromagnetic concrete of M40 grade was derived through experimental analysis. The detailed mix design of M40 grade of concrete with GGBS is given below.

Table 2: Mix design of M40 grade of concrete with Fly Ash as substitute

Component	M40 (kg/m³)	M40 +20% Fly Ash (kg/m³)	M40 +30% Fly Ash (kg/m³)	M40 +40% Fly Ash (kg/m³)	M40 +50% Fly Ash (kg/m³)
Cement	450	360	315	270	225
Water	153	166.5	171	180	184.5
Fly Ash	-	90	135	180	225
Fine Aggregate	852	843.525	845.55	841.5	839.25
Coarse Aggregate 20 mm	624.8	567.036	568.39	565.67	564.125
10 mm	416.2	463.93	465.05	462.825	461.587
W/C Ratio	0.34	0.37	0.38	0.4	0.41
Admixture (Mid- Pc)	3.6	3.6	3.6	4.05	4.5

Table 3: Mix design of M40 grade of concrete with GGBS as substitute

Component	M40 +30% GGBS (Kg/m³)	M40 +40% GGBS (Kg/m³)	M40 +50% GGBS (Kg/m³)	M40 +60% GGBS (Kg/m³)
Cement	315	270	225	180
Water	171	184.5	193.5	207
GGBS	135	180	225	270
Fine Aggregate	850	851.45	841.5	837.45
Coarse Aggregate 20 Mm	570.72	572.33	565.67	562.95
10 Mm	467.28	468.27	462.82	463.07
W/C Ratio	0.38	0.41	0.43	0.46

2.1.8 Chloride Content calculation

For calculation of chloride content Volumetric analysis method was adopted. 10 mg of sample was dissolved in 100 ml of distilled water and allowed to dissolve on shake table. The sample was then filtered and the filtrate was extracted with the help of filter paper. The filtrate was then titrated against silver nitrate ($AgNO_3$) solution with potassium chromate as indicator. The end point of titration is the formation of reddish colour precipitate of silver chloride (AgCl).

$AgNO_3$ + filtrate sample + $K_2Cr_2O_4 \Longrightarrow AgCl$

2.1.8 Sulphate Content calculation

For calculation of sulphate content spectrophotometer method is adopted. Spectrophotometry is the quantitative measurement of the reflection or transmission spectrum of a material as a function of wavelength. Filtrates are extracted using the same procedure as that described in chloride content calculation. The filtrate is compared with a datum solution of barium chloride ($BaCl_2$) to give the sulphate content present in the filtrate.

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2.2 Methodology

Sulphate and chloride content is calculated for each of the ingredients of concrete. Mix design for M40 grade concrete with normal and electromagnetic water is evaluated. Also mix design for M40 concrete substituted with 30 to 60% GGBS and 20 to 50% Fly Ash with normal as well as electromagnetic water is prepared. The total sulphate and chloride content in each of the sample is calculated. Sample Cubes of 150mm x150mm x 150mm dimensions were cast and checked for strength after 7 and 28 days. The results of these tests of normal water and electromagnetic water samples are compared and analysed. The RCPT and WPT tests were carried out after 56 days. The sulphate and chloride content in eah of the mix designs and its effect on the results were analysed.

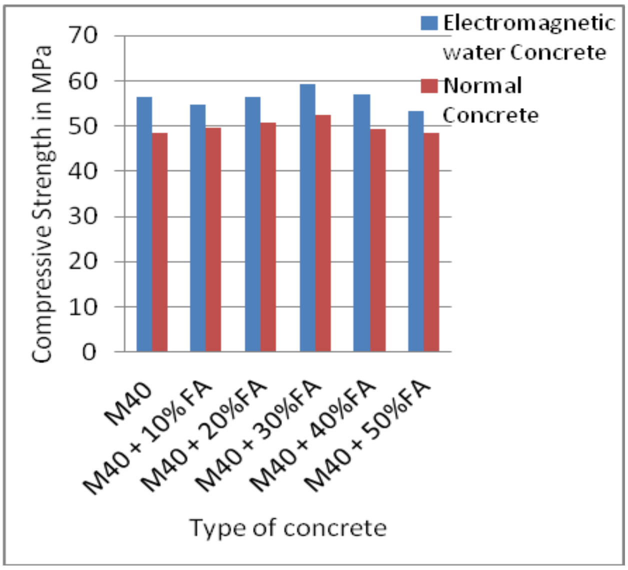
3. Results and Discussion:

3.1 The compressive strength of cubes with electromagnetic water and normal water with Fly Ash as additive is as shown in the table 4 below.

Table 4: Compressive strength of M40 concrete with fly ash as substitute.

Type of Concrete	28 days Electromagnetic water Concrete strength	28 days Normal Concrete strength
M40	58.88	48.44
M40 + 10% Fly Ash	54.66	49.77
M40 + 20%Fly Ash	56.44	50.66
M40 + 30%Fly Ash	59.33	52.44
M40 + 40%Fly Ash	57.11	49.33
M40 + 50%Fly Ash	53.22	48.44

The table shows the compressive strength of cubes with electromagnetic water is more than that of normal water concrete with Fly Ash as substitute.



Graph 1: Comparison of Electromagnetic and normal water concrete with Fly ash as substitute

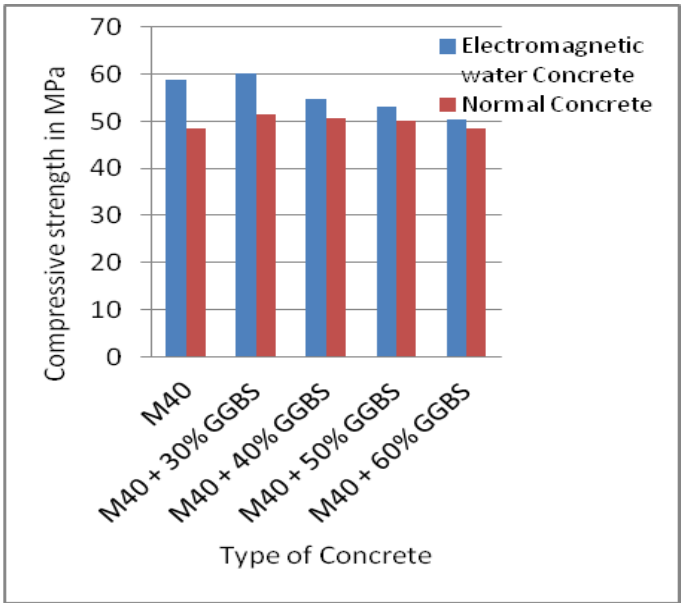
The graph shows the compressive strength of cubes with electromagnetic water was found to be more than that of normal water with Fly Ash as substitute in all the cases. And is optimum for M40+30% Fly Ash, which shows 13.13% increase in strength compared to that of normal water concrete.

3.2. The compressive strength of cubes with electromagnetic water and normal water with GGBS as additive is given in the following table.

Table 5: Compressive strength of M40 concrete with GGBS as substitute

Type of concrete	28 days Electromagnetic water Concrete strength	28 days Normal Concrete strength
M40	58.88	48.44
M40 + 30% GGBS	60.22	51.55
M40 + 40% GGBS	54.66	50.66
M40 + 50% GGBS	53.22	50.22
M40 + 60% GGBS	50.44	48.44

The table shows the compressive strength of cubes with electromagnetic water was found to be more than that of normal water with GGBS as substitute.



Graph 2: Comparison of Electromagnetic and normal water concrete with GGBS as substitute.

The graph shows the compressive strength of cubes with electromagnetic water was found to be more than that of normal water with GGBS as substitute in all the cases. It was found to be optimum for M40+30% GGBS, which shows 17.82% rise in strength of electromagnetic water concrete compared to normal water concrete.

3.3. The sulphates and chloride content present in each of the samples of concrete are as follows.

Table 6: Chloride and sulphate content present in concrete ingredients

Name	**Chloride content (ppm)**	**Sulphate content (ppm)**
Electromagnetic water	22.15	Nil
Normal water	78.2	47.28
Cement	174.44	6157
Fly ash	89.58	711.42
GGBS	37.71	1.862
Fine Aggregates	9.42	2.6
10 mm C.A	10.844	1.74
20 mm C.A	8.464	4.48

The table shows sulphates are predominantly present in cement and fly ash. Chlorides are in abundance in cement, normal water and fly ash.

3.4. The content of sulphates and chlorides present in normal water concrete with GGBS as cement substitute is as follows.

Table 7: Sulphate and chloride content present in each of the samples of M40 grade concrete with GGBS

Type of concrete	Total Chlorides (kg/m^3)	Total Sulphates (kg/m^3)	Compressive Strength (MPa)
M40	0.0737	1.9347	48.44
M40+30% GGBS	0.06601	1.3591	51.55
M40+40% GGBS	0.06289	1.1667	50.66
M40+50% GGBS	0.05934	0.9748	50.22
M40+60% GGBS	0.05494	0.7832	48.88

The table shows sulphates are in abundance in all the samples as compared to chlorides. Sulphates and chlorides are higher in normal M40 grade concrete and decrease with addition of GGBS with cement.

3.5. The content of sulphates and chlorides present in electromagnetic water concrete with GGBS as cement substitute is as follows.

Table 8: Sulphate and chloride content present in each of the samples of M40 grade concrete with GGBS

Type of concrete	Total Chlorides (kg/m^3)	Total Sulphates (kg/m^3)	Compressive Strength (MPa)
EM40	0.06485	1.92749	58.88
EM40+30% GGBS	0.05648	1.35043	60.22
EM40+40% GGBS	0.05283	1.15805	54.66
EM40+50% GGBS	0.04852	0.96572	53.22
EM40+60% GGBS	0.04334	0.77947	50.44

The table shows sulphates are in abundance in all the samples as compared to chlorides. Sulphates and chlorides are higher in normal water concrete than electromagnetic water M40 grade concrete and decrease with addition of GGBS with cement.

3.6. The content of sulphates and chlorides present in normal water concrete with Fly Ash as substitute is as follows

Table 9: Sulphate and chloride content present in each of the samples of M40 grade concrete with Fly ash

Type of concrete	Total Chlorides (kg/m³)	Total Sulphates (kg/m³)	Compressive Strength (MPa)
M40	0.0737	1.9347	48.44
M40+20% Fly Ash	0.1219	1.6408	50.66
M40+30% Fly Ash	0.1224	1.4869	52.44
M40+40% Fly Ash	0.1226	1.3371	49.33
M40+50% Fly Ash	0.1246	1.1876	48.44

The table shows sulphates are in abundance in all the samples as compared to chlorides. Sulphates and chlorides are higher in normal M40 grade concrete and sulphates decrease with addition of Fly ash with cement while chlorides increase.

3.7. The content of sulphates and chlorides present in electromagnetic water concrete with Fly Ash as substitute is as follows

Table 10: Sulphate and chloride content present in each of the samples of electromagnetic water M40 grade concrete with Fly ash

Type of concrete	Total Chlorides (kg/m³)	Total Sulphates (kg/m³)	Compressive Strength (MPa)
EM40	0.06485	1.92749	58.88
EM40+20% Fly Ash	0.11349	1.6329	56.44
EM40+30% Fly Ash	0.11371	1.4788	59.33
EM40+40% Fly Ash	0.11381	1.3286	57.11
EM40+50% Fly Ash	0.11397	1.1788	53.22

The table shows sulphates are in abundance in all the samples as compared to chlorides. Sulphates and chlorides are higher in normal water concrete than electromagnetic water M40 grade concrete and sulphates decrease with addition of Fly ash with cement while chlorides increase.

3.8. A comparison of the Rapid chloride penetration test results on all the samples is as follows

Table 11: RCPT results of normal and electromagnetic water concrete

Type of Concrete	Normal water concrete	Electromagnetic water concrete
Concrete without additives	1432.8	1313.1
20% Fly ash replacement	1395.9	1268.1
30% Fly ash replacement	1312.2	1233.9
40% Fly ash replacement	1137.6	1026.9
50% Fly ash replacement	1072.8	972.9
30% GGBS replacement	1206.9	1130.4
40% GGBS replacement	1085.4	1004.4
50% GGBS replacement	972.9	905.4
60% GGBS replacement	907.2	854.1

The table shows that the Chloride ion permeability decreases in case of electromagnetic concrete as compared to normal water concrete, which means increased durability of concrete. For M40 grade concrete without any additives, charge passing through concrete decreases from 1432.8 C to 1313.1 C because of use of electromagnetic water i.e. a decrease in 9.11%. In case of fly ash substitution, the charge passed through the concrete reduces by an average 13.55% in comparison with concrete without any replacement for normal water concrete and by 14.72% for electromagnetic water concrete.

The maximum reduction in current passed due to fly ash substitution was found out to be 25.12% in case of normal water concrete and 25.9% for electromagnetic concrete. In case of GGBS substitution for normal water concrete an average decrease in current flow by 27.2% was observed. And decrease in 25.96% for electromagnetic water concrete was observed. The maximum reduction due to replacement of 60% GGBS was found to be 36.68% for normal water concrete and 34.95% for electromagnetic concrete.

The reduction due to substitution of GGBS is more than the reduction observed for fly ash substitution. This means that the use of GGBS makes the concrete more durable than fly ash use; due to its micro structure bonding which restricts the flow of current through concrete. Therefore it can be seen that concrete with admixtures have increased durability and better RCPT results due to the dense micro structure of concrete caused because of the fineness of the admixtures.

3.9. A comparison of the WPT results of all the samples is as given below

Table 12: Comparison of WPT results of normal and electromagnetic water concrete

Concrete designation (replacement by weight of cement)	Normal water concrete (mm)	Electromagnetic water concrete (mm)	Change (mm)
M40 Concrete without additives	26.33	24.33	2
20% fly ash replacement	25.66	23.36	2.30
30% fly ash replacement	23.26	21.36	1.90
40% fly ash replacement	22.33	20.96	0.9
50% fly ash replacement	20.33	19.66	0.67
30% GGBS replacement	21.53	19.40	2.13
40% GGBS replacement	18.3	16.33	1.97
50% GGBS replacement	15.33	13.50	1.83
60% GGBS replacement	14.46	12.93	1.53

The table shows that electromagnetic concrete allows lesser penetration of water than compared to normal concrete. For M40 concrete without any substitution the penetration of water decreases from 26.33 mm to 24.33 mm due to use of electromagnetic water which is a 8.22% decrease. For substitution of fly ash there is a decrease in 13.04% on an average whereas in case of GGBS as substitution there is an average decrease in 12.30%. In case of normal concrete the water penetration depth decreases on an average by 12.30% due to addition of fly ash and decreases by average 13.40% in case of electromagnetic concrete. For normal concrete the water penetration decreases on an average by 33.89% due to addition of GGBS whereas in case of electromagnetic concrete with GGBS it decreases by 34.30%. In case of optimum content of fly ash the water penetration decreases by 19.19% compared to the control mix without any additives for normal concrete and by 22.78% for electromagnetic concrete. In case of optimum content of GGBS water penetration reduces by 30.49% for normal concrete and 32.88% for electromagnetic concrete. The reduction in water penetration is more in case of GGBS substitution than that of Fly ash substitution.

4. CONCLUSION

1. The optimum replacement of fly ash was found to be 30% by weight of cement.

2. The optimum replacement of GGBS was found to be 30% by weight of cement.

3. For optimum content of fly ash in electromagnetic concrete,

a. Chlorides are 7.65% less and sulphates are 1.15% less as compared to normal concrete.
b. Compressive strength increases by 8.25% compared to normal concrete.
c. Chloride ion permeability reduces by 6.345% compared to normal concrete.
d. Water penetration depth decreases by 8.89% as compared to normal concrete.

4. For optimum content of GGBS in electromagnetic concrete

a. Chloride content reduces by 14.43% and sulphates by 0.67% compared to normal concrete.
b. Compressive strength increases by 5.17% as compared to normal concrete.
c. Chloride ion permeability decreases by 6.76% as compared to normal concrete.
d. Water penetration depth reduces by 9.89% as compared to normal concrete.

5. GGBS substitution yields lesser chloride ion permeability than fly ash replacement.

6. Chloride ion permeability reduces by 9.11% due to use of electromagnetic water. Therefore electromagnetic water is more durable than normal concrete.

7. GGBS substitution causes lesser water penetration depth as compared to fly ash substitution.

8. Water penetration decreases 8.22% due to use of electromagnetic water. Therefore electromagnetic water is more durable than normal concrete.

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