Significance of Ethanolamines in Enhancing Corrosion Resistance of Fly Ash Blended Concrete

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Abstract

Fly ash is an inexpensive supplementary cementious material used in concrete, while it actually improves strength, durability and ease of pumping of the concrete. Corrosion of steel bars in the concrete has become one of the menacing problems on durability aspects which influence the service life of structures. The objective of this study is to access the corrosion protection effectiveness of two organic inhibitors namely Diethanolamine and Triethanolamine in fly ash blended concrete and determine the optimum percentage of inhibitor to be added for obtaining maximum strength and durability. Also, to compare the performances of the two organic inhibitors and to study the further enhancement in durability due to the addition of the inhibitors that had excelled in its performance

KEYWORDS – Concrete, Fly ash, Inhibitor, strength, Durability, Corrosion resistance

I. Introduction

Fly ash is an industrial byproduct that has refocused and rekindled the interests of scientists and engineers on the material and structural implications of incorporating it as an essential cementitious component of concrete. Among various remedies, use of supplementary cementitious material such as flyash in concrete is an economical and efficient method to control corrosion[1]. Flyash blended cements have received considerable attention due to their significantly better durability performance in severe exposure conditions[2]. In addition to the cost saving by partial replacement of cement, it also reduces CO2 emission during the manufacture of Portland cement[3,4]. Corrosion is defined as the destruction or deterioration of materials due to chemical or electrochemical reaction with the environment and also the loss of steel due to the formation of rust[5-9]. The performance of concrete to protect re-bar can be enhanced by various methods. Corrosion resistant coatings in reinforcing bar, cathodic protection and addition of inhibitors are some of the methods to control corrosion [10-13]. These inhibitors function by reinforcing the passive layer or by forming oxide layer and preventing chloride ions reacting from it [14-15]. Numerous studies were carried out to determine the optimum percentage of addition of fly ash to replace cement. Study of literatures indicated that compared with the control mix, the concrete with 20 to 50 percent cement replacement with fly ash show substantial increase in compressive strength, split tensile strength and flexural strength. This paper is intended on the study of corrosion resisting organic inhibitors Diethanolamine and Triethanolamine , which are added during casting of concrete in fly ash blended concrete in which cement is replaced by 25% of fly ash.

II. MATERIALS

Ordinary Portland Cement (43 Grade) was used throughout the investigation. In this experiment, river sand with fineness modulus of medium sand equal to 2.06 conforming to grading zone III of IS 383-1970 was used as fine aggregate. Locally available well-graded granite aggregates of normal size greater than 4.75 mm and less than 16 mm having fineness modulus of 2.72 was used as coarse aggregates. Potable water has been used for casting concrete specimen. High yield strength cold twisted deformed bar of Fe 415 graded conforming to IS 1786 has been used. Mechanical properties are, yield strength of 475 N/mm, ultimate tensile strength of 582 N/mm, % of elongation on 30 cm gauge length is 11%. Fly ash was obtained from Mettur thermal power plant in Tamilnadu. In this study, 25% by weight of cement is replaced by class C fly ash. The grade of concrete used is M20 having mix proportion of 1:1.464:3.21 with water cement ratio 0.50.Organic inhibitors Diethanolamine – DE, Triethanolamine – TE were used in this study. Application of these admixtures in reinforced concrete was possible by adding it to the mixing water during concrete preparation. The inhibitors were added at the dosage of 1%, 2% and 3% by weight of cement

III.EXPERIMENTAL PROGRAM

Experiments were conducted on concrete specimens to study strength and micro structural properties. Strength tests include compressive strength, split tensile strength, flexural strength and bond strength. The micro structural properties studied were percentage of water absorption, percentage of permeable voids and bulk density. To study the migration and dispersion of the organic inhibitors Scanning Electron Microscope (SEM), Linear polarization resistance technique, impressed voltage measurement and gravimetric weight loss tests were performed.

IV. RESULTS AND DISCUSSION

4.1. Strength test results

Table-1 Strength test results with Triethanolomine

Sl. No	Identification	Compressive strength in N/mm2		Split tensile strength in N/mm2		Flexural strength in N/mm2		Bond strength in N/mm2	
		28 Days	90 Days	28Days	90 Days	28Days	90 Days	28Days	90 Days
1	F25	25.91	32.49	2.74	4.65	4.4	9.2	4.22	5.19
2	1% TE	23.32	33.51	2.58	4.78	4	9.8	3.98	5.29
3	2% TE	22.83	34.62	2.55	4.95	4	10.2	3.76	5.12
4	3% TE	22.24	33.13	2.5	4.6	3.9	9.8	3.47	5.02

Table 1 presents the test values on the 28thand 90th day of compressive, split tensile, flexural and bond strengths for various percentages of tri-ethanolamine inhibitor added.

Table-2 Strength test results with Diethanolomine

Sl. No	Identification	Compressive strength in N/mm2		Split tensile strength in N/mm2		Flexural strength in N/mm2		Bond strength in N/mm2	
		28 Days	90 Days	28Days	90 Days	28Days	90 Days	28 Days	90 Days
1	F25	25.91	32.35	2.74	4.65	4.40	9.20	4.22	5.19
2	1% DE	23.24	32.65	2.50	4.71	3.80	9.30	3.93	5.24
3	2% DE	22.51	33.87	2.15	4.75	3.70	9.40	3.74	5.20
4	3% DE	21.96	31.64	2.04	4.58	3.50	9.10	3.46	5.08

Table 2 presents the test values on the 28th and 90th day of compressive, split tensile, flexural and bond strengths for various percentages of di-ethanolamine inhibitor added. Except bond strength result, for the other three mechanical tests, tri-ethanolamine inhibitor performed well. It enhanced the compressive, split tensile and flexural strengths of the fly ash blended cement concrete. Even in the case of bond strength result, there was only a marginal drop in the value of specimens cast with tri-ethanolamine inhibitor when compared with the control and other inhibitor and still it was much higher than the permissible limits.

4.2 Micro structural properties

The values obtained from the various micro structural properties tests performed on the hardened concrete specimens with 25% fly ash and with various percentages of the two organic inhibitors are tabulated below.

Table 3 Micro structural test values

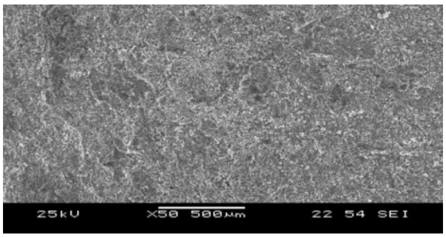
S. No.	Identification	Coefficient of water absorption x 10-10 m2/sec		Percentage of voids (%)		Effective porosity (%)		Bulk density Kg/m^3	
		TE	DE	TE	DE	TE	DE	TE	DE
1	FA 25	0.96		0.66		10.06		2404	
2	1.0%	0.78	0.88	0.58	0.61	9.85	9.96	2435	2420
3	2.0%	0.48	0.74	0.55	0.58	9.69	9.89	2443	2428
4	3.0%	0.29	0.56	0.54	0.57	9.63	9.82	2447	2432

Table 3 presents the test values for various percentages of inhibitors added.There was appreciable reduction in the porosity and water absorption values for the specimens cast with tri-ethanolamine inhibitor. This was evident from the picture taken using Scanning Electron Microscope (SEM) shown in Figure. Tri-ethanolamine has migrated effectively through the pores in the concrete, making it impermeable to a larger extent for any foreign element to ingress through it.

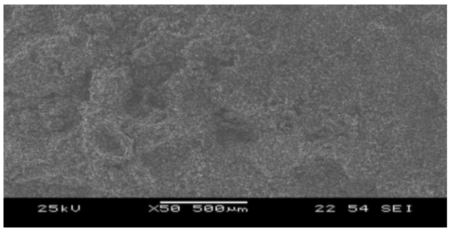
4.3 Scanning Electron Microscopic analysis

From the following photographs of the scanning electron microscope taken for different dosages of the four organic inhibitors it is obviously seen that tri-ethanolamine inhibitor had effectively diffused through the pores of concrete comparatively and had formed compounds that reduce the permeability and porosity upto 2% of dosage.

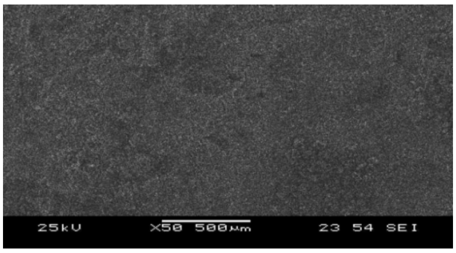
Figure 1. SEM Photographs



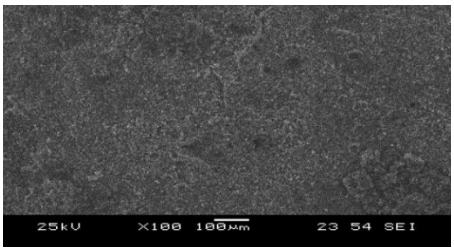
F25 Control – without inhibitor



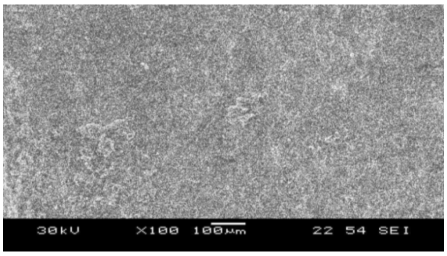
TE -1%



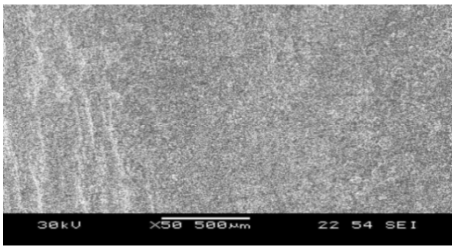
TE – 2%



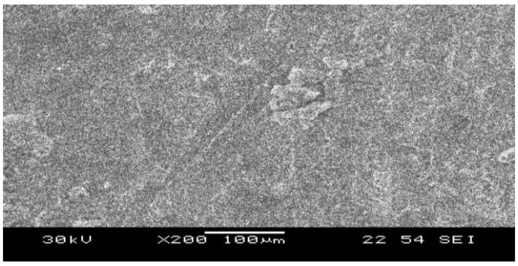
TE – 3%



DE – 1.0 %



DE – 2.0



DE – 3.0 %

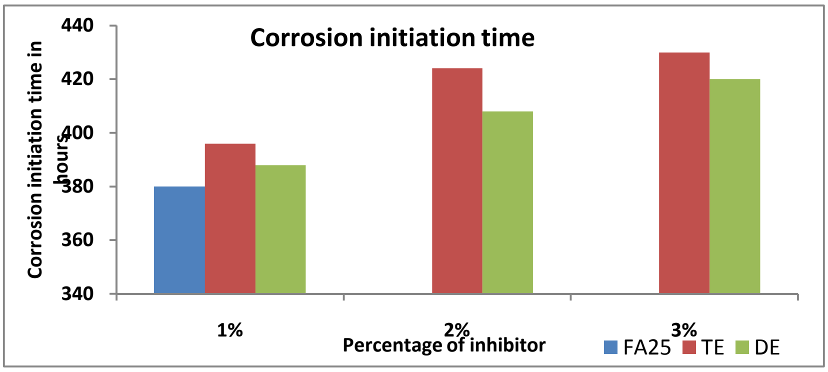
When the dosage of the inhibitors was increased to 3%, the pictures show that these compounds are not effective. They create pore pressure within concrete and due to that the mechanical strengths dropped down and the drop in values was still more pronounced with addition of 3% of inhibitors. Also the analysis result of Fourier Transform Infra-Red spectroscopy(Figure 2) shows that the elements that inhibit corrosion are dominant in tri-ethanolamine by their peak values shown in figure.

4.4. Impressed Voltage Test

As carried out earlier, similar specimens were cast with different dosages of the two organic inhibitors and the test was performed. On applying a constant impressed voltage from a D.C. source, the variation of current was recorded with respect to time. A sharp rise in current indicated the onset of corrosion and cracking of the concrete was usually visible thereafter.

The time taken for initiation of first crack was considered as a measure of their relative resistance against chloride permeability and reinforcement corrosion (Figure 3).

Figure 3 Impressed voltage test results



4.5.Linear Polarization Resistance (LPR) Technique

The procedure was repeated for the specimens with 2% percentage of the two organic inhibitors. The calomel electrode, metal cathode and rebar embedded in concrete were connected to the LPR meter. 20 mV of direct voltage was applied to the rebar and direct current was measured. The polarization resistance R_p was obtained by dividing the direct voltage by direct current. From R_p values, the corrosion currents i_{corr} were calculated and the corresponding corrosion rates in mmpy were obtained and presented in Table 4. .

Table 4 Linear Polarization measurements

S. No.	Identification	Polarization resistance R_p in Ohms	Corrosion current i_{corr}A/cm^2	Corrosion rate mmpy
1	FA 25	12.093×10^6	4.300×10^{-6}	0.0516
2	TETA – 2%	17.931×10^6	2.900×10^{-6}	0.0348
3	DETA – 2%	13.684×10^6	3.800×10^{-6}	0.0456

4.6.Gravimetric Weight Loss Method

The tested specimens with 2% of the two organic inhibitors were broken and the corroded rebars were again immersed in pickling solution, cleaned and weighed. The difference between the initial and final weights were taken as the weight loss of the specimen and it was converted into reduction in thickness and expressed as loss in thickness in mm per year (mmpy). Table 5 shows the corrosion rate of the specimen.

Table 5 Weight loss measurements

S. No.	Identification	Corrosion rate in mmpy
1	FA 25	0.0542
2	TETA – 2%	0.0312
3	DETA – 2%	0.0448

4.7 .Discussion on test results

All the above durability tests performed reveal that due the decrease in the permeability and porosity of the fly ash blended concrete with increase in dosages of the inhibitors, the ingress of chlorides through the dense concrete medium took more time and hence the corrosion initiation times were increased. With increase in percentage of inhibitors, the corrosion initiation time accordingly increased in the impressed voltage test. The same trend was observed in LPR techniques. The corroded rods which were initially weighed before testing were again weighed after corrosion test by breaking open the concrete specimen and after thorough cleaning of the cement paste stuck over the embedded surface of the rods. The weight loss measurements observed was converted to its equivalent loss in mmpy and this result also validated the earlier concept.

V.CONCLUSION

It was determined that 2% tri-ethanolamine inhibitor added specimens performed well when compared with other inhibitor of the same percentage and increased the corrosion initiation time by 20% and at the same time rendered the mechanical and micro-structural properties to the optimum. 3% of organic inhibitors though enhanced the corrosion resistance proved inferior in mechanical strengths. Hence 2% has been validated as the optimal dosage for all the two organic inhibitors and of the two, tri-ethanolamine has excelled others in overall performance with respect to strength and durability.

REFERENCES

[1] Ampadu K.O. et al (1999), 'Beneficial effect of fly ash on chloride diffusivity of hardened cement paste' Elsevier – Science Direct, Cement and Concrete Research, 1999, 29 : 585-590.

[2]. ASTM C 618-03, 'Standard specification for coal fly ash and raw or calcined natural pozzolan for use as a mineral admixture in concrete'. Annual book of ASTM standards, V.4.02, American Society for Testing and Materials, Philadelphia, PA; 2003.

[3]. Balouch S.U. et al (2010), 'Surface corrosion of steel fibre reinforced concrete' Elsevier – Science Direct, Cement and Concrete Research 40 (2010) 410-414.

[4]. Behera J.P. et al (2000), 'Investigations on the development of blended cements using activated fly ash' Indian Concrete Journal 2000, 74: 260-263.

[5]. Bjegovic D et al (1999), 'Migrating corrosion inhibitor protection of concrete' Mater. Perform 11 (1999) 52-56.

[6]. Nmai C.K. (2004), 'Multi-functional organic corrosion inhibitor' Elsevier – Science Direct, Cement & Concrete Composites 26 (2004) 199-207.

[7]. Ormellese et al (2006), 'Corrosion inhibitors for chlorides induced corrosion in reinforced concrete structures' Elsevier – Science Direct, Cement and Concrete Research, No. 36, pp. 536-547.

[8]. Pengfei Huang et al (2005), 'Influence of HCl corrosion on the mechanical properties of concrete' Elsevier – Science Direct, Cement and Concrete Research 35 (2005) 584-589.

[9] .Phanasgaonkar A et al (1997), 'Corrosion inhibiting properties of organic amines in simulated concrete environment: Mechanism, International Conference on Understanding Corrosion Mechanism in Concrete: a key to improve infrastructure durability, Cambridge, 1997.

[10].Santhakumar A.R. (2010), 'Concrete Technology', Oxford University Press, India.

[11]. Saraswathy V et al (2001), 'Evaluation of a composite corrosion-inhibiting admixture and its performance in concrete under macrocell corrosion conditions' Elsevier – Science Direct, Cement and Concrete Research 31 (2001) 789-794.

[12]. Scott A. Civjan et al (2005), 'Effectiveness of corrosion inhibiting admixture combinations in structural concrete' Elsevier – Science Direct, Cement & Concrete Composites, No. 27, pp. 688-703.
[13]. The Electrochemical Society of India (1998), 'Corrosion handbook', Associate (Data) Publishers Pvt. Ltd., India.
[14].Trepanier S.M. et al (2001), 'Corrosion inhibitors in concrete: Part III. Effect on time to chloride-induced corrosion initiation and subsequent corrosion rates of steel in mortar' Elsevier – Science Direct, Cement and Concrete Research 31 (2001) 713-718.
[15]. Tae-Hyun Ha et al (2005), 'Accelerated short-term techniques to evaluate the corrosion performance of steel in fly ash blended concrete' Elsevier - Science Direct, Building and Environment, August 2005.