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Use of Inhibitors for Corrosion Control in RC Structures – A Review

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Abstract: **-- Corrosion of steel rebar in exposed reinforced concrete (RC) structures located in the marine environment is one of the major problems in the construction industry. Corrosion can be described as the deterioration of a metal that results from an electrochemical or chemical reaction to its surrounding environment. The magnitude of reinforcement corrosion has a significant effect on flexural strength, deformational behavior, ductility, bond strength and mode of failure of the reinforced-concrete structures. Hence, from past two decades, researchers have developed various techniques which can be used for controlling corrosion of RC structures. Due to the cost associated with conventional techniques and some environmental issues related to them, the researchers started developing new cost-effective, environmentally friendly corrosion controlling technique. Corrosion effect can be minimized by providing proper cover or plastering with cement mortar, so that percolation of atmospheric agents can be minimized. Hence the use of corrosion inhibitors is motivated in the construction industry. The present paper reviews various types of admixtures which can be effectively used as the corrosion inhibitor for corrosion control of steel reinforced in concrete. The paper majorly focuses on use of green materials such as coconut shell ash (CSA), tamarinds pulp husk extract (TPHE) as a corrosion inhibitor in concrete.**

Index Terms**— Corrosion, Corrosion inhibitors, Concrete, Coconut shell ash (CSA), Tamarinds pulp husk extract (TPHE).**

I. INTRODUCTION

Steel Reinforced concrete is widely used in construction. The corrosion of the steel reinforcing bars in the concrete limits the life of concrete structure which is one of the main causes of deterioration of RCC structures and can be defined as an electrochemical process that causes the degradation (oxidation) of steel in concrete [1]. Steel embedded in concrete is normally in a passive state against corrosion due to a thin iron oxide layer that forms on the steel surface and remains stable in the high alkaline environment of the concrete. The initiation of corrosion, is due to breaking of protective film (depassivation) and this is mainly done in two ways: by the attack of chlorides on the steel (sea water, de-icing salt, unwashed sea sand, admixtures etc.) or by carbonation of the cover concrete due to the reaction with carbon dioxide, which causes reduction in the alkalinity of concrete. During corrosion process electrons are transferred from the anode to the cathode through the steel and hydroxide ions are transferred from the cathode to anode through the concrete pore solution. Thus the rate of corrosion is therefore controlled by one or more reactions [2].These reactions can be controlled by using corrosion inhibitors, which may be a good alternative to other protection methods or classical repair methods due to its lower cost and easy application. The corrosion inhibitors can be classified in different ways according to their application methods and mechanism of protection, or their content. The main application methods for corrosion inhibitors is addition to fresh concrete as an admixture and also applied on the hardened concrete surface, called penetrating corrosion inhibitor or migrating corrosion inhibitor or surface-applied corrosion inhibitor [2]. This review briefly addresses the various aspects of admixtures which can be used as corrosion inhibitors with added advantage of improvement in structural properties. This is followed by a brief overview of research work conducted on admixtures used as corrosion inhibitors.

II. INHIBITOR IN CONCRETE

Admixtures are solids or liquids that are added to a concrete mix to improve the properties of the resulting concrete. Admixtures that enhance the corrosion resistances of steel reinforced concrete include which primarily improves the structural properties of concrete. The latter are attractive due to their multifunctionality. The former are mostly inorganic

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chemicals (such as calcium nitrite, copper oxide, zinc oxide, sodium thiocyanate and alkaline earth silicate) that increase the alkalinity of the concrete, although they can be organic chemicals, such as banana juice. Admixtures that are used for structural property improvement can be solid particles, such as silica fume, fly ash and slag and solid particles dispersions, such as later [3]. However, for more than a decade, inorganic and synthetic chemical-based corrosion inhibitors such as chromate and nitrate based has been widely used in the industries and has led into a serious environmental deterioration and dreadful impact onto marine [4].These environmental issues regarding the use of the synthetic corrosion inhibitor have led into a rise in environment-friendly corrosion inhibitor has greatly increased the researcher's interest especially in the development of corrosion inhibitor derived from natural source, such as rich husk waste[5], coconut shell ash [9], tamarindus pulp husk extract[6]. Various pozzolanic materials used as corrosion inhibitors have different effect on properties of concrete. ASTM defines Pozzolans as siliceous or aluminous materials which possess little or no cementations properties but, in the presence of moisture, it will react with lime [Ca(OH)2] at ordinary temperature to form a compound with pozzolanic properties[9].Use of Silica fume, latex, methylcellulose as an admixture is particularly effective for improving the corrosion resistances of steel reinforced concrete by decreasing the water absorptivity (or permeability) and increasing the electrical resistivity of concrete. Carbon fibers decrease the corrosion resistances due to a decrease in the electrical resistances [3]. However, the negative effect of the carbon fibers can be compensated by adding either silica fume or latex which reduces the water absorptivity. In other words, carbon fiber reinforced concrete along with silica fume helps to improve corrosion resistances of resulting concrete than plan concrete [3]. Another widely used admixtures is Fly ash which is pozzolanic material used as admixture in concrete due to its multifunctional behavior. It have a beneficial effect on inhibiting the sulfate attack, reducing heat of hydration, increasing denseness and inhibiting alkali-aggregate reactivity[7].The addition of fly ash in concrete mixing stage can be done by either partially replacing the cement or as partial replacement to the fine aggregates[8].

As inorganic and synthetic chemical-baseded inhibitors have adverse effect on environment, uses of natural pozzolans have been motivated. Coconut shell ash (CSA) is the pozzolanic material which contains 38% SiO_2, 24% Al_2O_3, and 15.5% Fe_2O_3, thereby meeting the 70% ($SiO_2+Al_2O_3+Fe_2O_3$) requirement for pozzolana under ASTM C 618. Use of such materials can lead to increase in compressive and flexural strengths concrete [9]. Tamarindus Pulp Husk Extract (TPHE), has the chemical composition of amino acids, fatty acids, and minerals of tamarindus pulp husk. Fatty acid is commercially used in rubber compounds, synthetic rubber Polymerisation, paints, varnishes, plastics, cantles and surface coatings [10]. In case of concrete it is observed that these fatty acids helps to decreased water absorption capacity which is reduces the permeability. Differences in values found are likely to be due to differences in genetic strains, stages of maturity at which the plant parts were harvested, growing conditions, harvesting and handling techniques as well as to differences in analytical methodology [11].

III. STATE-OF-ART-OF USE OF CORROSION INHIBITOR

The primary goal of using corrosion inhibitors in concrete is to reduce the permeability and their by avoiding corrosion of steel rebar's. Various researchers have carried out work on use of different type of inhibitors such as organic or inorganic admixtures for corrosion control of structure. D.D.L.Chung[3] used silica fume, latex, methylcellulose and carbon fibers as corrosion inhibitors. In his study various combinations where made by using this admixtures and effect of these admixtures on corrosion potential (Ecorr, measured according to ASTM C876 using a high-impedance voltmeter and a saturated calomel electrode placed on the concrete surface; Ecorr that is more negative than -270 mV suggests 90% probability of active corrosion) and the corrosion current density (Icorr, determined by measuring the polarization resistance at a low scan rate of 0.167 mV/s) of steel reinforced concrete in both saturated $Ca(OH)_2$ and 0.5N NaCL solution were monitor. The saturated $Ca(OH)_2$ solution simulate the ordinary concrete environment; the NaCL represent high chloride environment[3].

M.Maslehuddin, H.Saricimen et al. carried out experimental study on addition of fly ash in concrete by considering three series of mix. In first series constant water cement ratio was kept and cement was replaced by zero to 20%. Where as in second series concrete mixes was designed to have a constant workability of 50 to 75 mm slump and the cement-replacement level with fly ash were the same as in series one. In third series two concrete mixes were cast. In the first mix, fly ash weighting 20% by weight of cement was added as an admixture, replacing equal quantity of sand. In the second mix, 20% cement was replaced with fly ash as in series one. A class Fly ash was used in all the fly ash concrete mix. Samples were immersed in 5% sodium chloride solution for more than 1000 days and

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corrosion resistance was evaluated by monitoring the half-cell potentials and measuring the corrosion rate of embedded steel using electrochemical techniques [7].

S.Carmel, S.Palanivel et al. monitored the performances of cement mortar in which partial replacement of fone aggregate(river sand) was done by using on shore marine sand with addition of CSA and TPHE as corrosion inhibitor. In order to prepare ash from raw coconuts, the coconut shell was sun dried for forty eight hours to remove moisture from it. It was then subjected to uncontrolled combustion by open air burning for three hours and was allowed to cool for about 12hours. The burnt ash was collected, ground into powder and sieved through a BS sieve of 75 micron [9].Then for preparation of inhibitor from tamarindus pulp husk, the freshly collected fruits were dried with exposure to sun for one week time period. After drying, they were ground to fine powder and were sieved through 600 micron sieve. The 50gm of dried fine powder of tamarindus pulp husk was weighed, and was then taken into a RB flask. In the RB flask, 300 ml of doubly distilled water was added with the fine powder and heated for 1hour at 50 degree centigrade. After one hour of heating, the particular specimen was allowed to cool for 1 hour. The cooled extract solution was clearly filtered without any solid particles. Initially the extract was filtered with ordinary filter paper twice and finally it was filtered through Watt man filter paper no.1 and the filtered inhibitor samples was stored in air tight containers properly and were kept in a dry cool place[6]. Then cement mortar (CM) were prepared using 1:3 mix proportion of cement and sand with w/c ratio of 0.4.Concrete with a lower water-cement ratio makes a stronger concrete than that with a higher ratio. Inhibitor extract TPHE was added at the rate of 0.5%, 1%, 1.5%, 2%, 2.5% by weight of cement and shore marine sand (MS) and CSA were added at the rate of 5%, 10%, 15%, 20, 25% and 0.5%, 1%, 1.5% and 2.0% respectively by weight of the river sand[6]. The specimens were cast using cast iron moulds of standard dimensions. After 24 hours, the specimens were removed from the moulds and were placed in clean water for curing [12]. The specimens were removed from the curing tank after 7, 28, 56 and 90 days and subjected to compressive, flexural, water absorption and change in length tests. For each mix,3 specimens were cast corresponding to each age. Compressive strength test was conducted using 50 mm mortar cubes, and the test was conducted at the ages of 7, 28, 56 and 90 days. Flexure test was conducted on mortar specimen of 75×75×250mm size. A two point flexure test was conducted at the ages of 7, 28, 56 and 90 days. The change in length was determined by testing of 25×25×285mm prison shore marine sand in accordance with ASTM C157-89 for the selected mixtures at the ages of 7 ,28 and 90 days after curing. The change in length was measured by using length.

Table –I. Effect of carbon fibers (F), methylcellulose (M), silica fume (SF), latex (L) on the corrosion resistance of steel rebar in concrete.

MIX	IN SATURATED Ca(OH)2 SOLUTION		IN 0.5 N NaCL SOLUTION	
	Ecorr(a) (-Mv, 5)	Icorr(a) ($\Omega A/cm^2$)	Ecorr(a) (-Mv, 5)	Icorr(a) ($\Omega A/cm^2$)
P	210	0.774	510	1.50
+M	220	0.73	—	—
+M+F	220	0.68	560	2.50
+M+SF	137	0.17	—	—
+M+F+SF	170	0.22	350	1.15
+SF	140	0.19	270	0.88
+L	180	0.36	360	1.05
+L+F	190	0.44	405	1.28
Note.: P+ plain; (a) Value at 25 weeks of corrosion testing.				

Compressor-meter satisfying the requirement of ASTM C900-00a.The water absorption test was undertaken using 50mm mortar cubes specimens, which were dried to a constant mass and one face of the prism is immersed in water for a specified time (0.5, 1, 24, 72 and 168 hours.) and the increase in mass was determined.

IV. RESULTS AND DISCUSSION

When inorganic admixture such as silica fume, methylcellulose, carbon fibers, latex were used as inhibitor following results where observed. Table I[3] shows that Silica fume improves the corrosion resistances of rebar concrete in both saturated Ca(OH)2 and 0.5N NaCL solution more effectively than any of the other admixtures, although latex is effective. Methylcellulose improves slightly the corrosion resistances of rebar concrete in saturated Ca(OH)2 solution. Carbon fibers decrease the corrosion resistances of rebar's in concrete, mainly because they decrease the electrical resistivity of concrete. The negative effect of fibers can be compensated for by either silica fume or latex [3].

Table –II Corrosion rate of steel in plain, cement, and sand-replaced fly ash concrete samples [3].

Particulars of concrete mixes	Corrosion rate (mpy)
Plain concrete.	1.94
20% cement replaced fly ash cement concrete.	0.93
20% sand replaced fly ash concrete.	0.16

Whereas when fly ash was used, the data on corrosion resistance characteristics of concrete samples monitored for more than 1000 days indicate that 20% cement replaced fly ash concrete sample perform better in resisting reinforcing bar corrosion compared to plan concrete samples. The concrete samples in which fly ash was used as an admixture replacing an equal quantity of sand perform better in inhibiting corrosion compared with plain and cement replaced fly ash concrete samples[7]. Effect on water absorption capacity when CSA, TPHE were used in cement mortar along with marine shore sand are presented in table 3. From the table, it is noted that, for the mix with MS up to 25 % replacement, there is considerable decrease in the percentage of absorption, but it is observed that replacement beyond 15% of MS affect the compressive and flexural strength. Hence for further testing, the mix CM+ MS15 was considered and optimum dose of 1.5% of CSA was out for this mix for decrease in water absorption. Addition of TPHE decreased further the absorption effect considerably, because of fatty acid content. The addition of TPHE up to 1.5% caused more decrease in percentage of absorption because of binding action created by TPHE, and beyond this percentage, there was no appreciable decrease in value, which was also observed at the end of other ages [6].

Table III- Water absorption at various hours [6].

No.	Description	Water absorption on percentage (hours)				
		0.5	1.0	24	72	168
1	CM	2.64	3.71	5.89	5.87	7.61
2	CM+MS5	1.71	2.97	4.56	5.15	5.76
3	CM+MS10	0.96	1.56	2.95	3.64	4.84
4	CM+MS15	0.91	1.32	2.74	3.35	4.15
5	CM+MS20	0.63	0.99	1.91	2.19	3.88
6	CM+MS25	0.55	0.73	1.69	2.07	3.64
7	CM+MS15+CSA0.5	0.83	1.19	2.65	3.23 2	3.99
8	CM+MS15+CSA1	0.68	1.07	2.50	2.89	3.93
9	CM+MS15+CSA1.5	0.56	0.96	2.34	2.74	3.82
10	CM+MS15+CSA2	2.44	3.07	4.76	5.01	5.66
11	CM+MS15+CSA2.5	4.50	4.96	6.64	7.38	7.42
12	CM+MS15+CSA1.5 +TPHE0.5	0.26	0.73	2.37	2.69	3.68
13	CM+MS15+CSA1.5 +TPHE1	0.26	0.65	2.19	2.71	3.16
14	CM+MS15+CSA1.5 +TPHE1.5	0.25	0.62	2.16	2.68	3.55
15	CM+MS15+CSA1.5 +TPHE2	0.24	0.62	2.17	2.69	3.53

V. SUMMARY AND COMMENTS

A brief review on use of various types of admixture as a corrosion inhibitor has been presented in this paper. Effects of organic, inorganic as well as environmental-friendly corrosion-inhibitors have been considered for discussion. By using electrochemical technique and water absorption capacity corrosion resistances were checked in consider work. The literature reveals that,

- Silica fume has better performances as corrosion inhibitor than any other inorganic admixtures.
- Use of fly ash as partial replacement of sand performs better in inhibiting corrosion compared with plain and cement replaced fly ash concrete samples.
- Addition of TPHE with MS 15% and CSA 1.5% decrease the water absorption of concrete with further increase in percentage of CSA and MS affects the compressive strength and flexural strength of concrete.

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