EFFECT OF GREEN CORROSION INHIBITORS ON THE CORROSION BEHAVIOUR OF REINFORCED CONCRETE

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Abstract:- *Reinforced concrete is widely used as a construction material and plays an important role worldwide due to its excellent properties. In spite of its advantages, there are some drawbacks with reinforced concrete; one among them is degradation of the steel reinforcement in concrete due to aggressive agents present in the surrounding environment, which affects the durability of the structures. This corrosion problem cannot be avoided but can be minimized by use of corrosion inhibitors. The organic molecules (green) inhibit corrosion by adsorption, forming a barrier between the metal and the environment. Corrosion behavior of reinforced concrete has been investigated for organic and inorganic inhibitors. The organic inhibitors were extracted from Azadirachta indica (neem) powder (G1) and dehydrated Aloe-vera powder (G2) and the inorganic inhibitor used was Calcium Nitrate (N). The inhibitors were added during mixing of concrete (2 % of weight of cement) and then the specimens were immersed in the Sodium chloride (NaCl) solution to induce corrosion. The corrosion resistance of the reinforcement was evaluated with the help of weight loss measurement and accelerated corrosion test. The results of inhibitors studied showed that Azadirachta indica has superior corrosion inhibition efficiency compared to Aloe-vera inhibitor. The chemical corrosion inhibitor showed good corrosion inhibition among all. The chemical corrosion inhibitor has better strength properties among all. But, at the same time green corrosion inhibitors have strength properties nearly same as conventional concrete. The addition of given green inhibitors do not significantly affect the hardened properties of concrete.*

Key words: ***Azadirachta indica, Corrosion inhibitors***

I. INTRODUCTION

Since twentieth century, the use of reinforced cement concrete (RCC) has become common practice due to its excellent properties compared to other construction like steel structures, bamboo, clay, mammoth ribs etc. RCC is relatively cheap and easy to maintain. This has led to the widespread use of reinforced and pre-stressed concrete in the construction of structure and infrastructure duo to its strength, fire resistance, durability etc. In spite of its advantages, there are some drawbacks with reinforced concrete; one among them is degradation of the reinforced concrete structures due to corrosion of reinforcement.

The process of corrosion involves two distinct periods namely initiation period and propagation period. The initiation period is the time taken to initiate corrosion which can be caused either by ingress of carbon dioxide or chloride ions. The factors which influence corrosion initiation are environment, optimum cover thickness, quality of concrete, type of steel, critical chloride, presence of cracks etc. after initiation of corrosion due to these above factors the propagation begins and this period has two distinct processes. One is that the corrosion follows an electrochemical process and other is the physical process due to which damage to concrete occurs.

There are many possible approaches adopted for reducing corrosion of concrete such as coating to reinforcement, galvanized reinforcement, improving metallurgy by adding chromium and copper, stainless steel reinforcement, corrosion inhibitors, nonferrous reinforcement, concrete coatings, cathodic protection and improving the concrete. One of the most economical and recently used techniques to control or delay the corrosion of reinforcement in concrete is the corrosion inhibitors.

The application of inhibitors to the reinforced concrete structure can be done during mixing of concrete or can be applied on the surface of already existing reinforced structure for repair works. Many researchers have carried out the behavior and efficiency of both organic and inorganic inhibitors in terms of its ability to reduce or delay corrosion process. Some of the published work has been briefly highlighted in the following paragraphs.

A.Torres-Acosta and Martınez [1] conducted a study State of the Art on Cactus Additions in Alkaline Media as Corrosion Inhibitors. the corrosion performance of reinforcing steel in alkaline media when two different dehydrated cacti (Opuntia ficus-indica-Nopal-and Aloe Vera) were used as additions in pH 12.5 and 13.3 solutions and in concrete. Aloe Vera did show also corrosion inhibiting improvements in some extent. The addition of such cactus led to an apparent formation of a denser and more packed oxide/hydroxide surface layer on the steel surface that decreased corrosion activity.

Akshatha.G and Jagadeesha Kumar [2] conducted a study on Effect of Corrosion Inhibitors in Reinforced Concrete. The organic inhibitors were extracted from Azadirachta indica (neem) and Ruta graveolens plants and the inorganic inhibitors used were Sodium Nitrate and Ethylene di amine tetra acetic disodium dihydrate. The results of inhibitors showed that Azadirachta indica has superior corrosion inhibition efficiency compared to the other inhibitors in acid and chloride solution.

So investigating the use of natural green organic inhibitors which is expected to be hydrophobic in nature, non-toxic and eco-friendly to improve the strength and prevent sulphate attack and chloride ingress to concrete is most apt and desirable.

II. MATERIALS AND METHODS

2.1Materials

The Ordinary Portland Cement 53 grade cement is used. The physical properties of the cement tested according to standard procedure conform to the requirement of IS 12269: 1989. Locally available river sand passing through 4.75mm sieve conforming to the recommendation of IS383-1970 was used. Locally available 10mm coarse aggregates conforming to the recommendation of IS 383-1970 was used. The water used for casting and curing purpose is free from organic impurities and its pH value lies between 6 and 8.

2.2 Method

2.2.1 Preparation of plant extract

The leaves were obtained from the plant in the neighborhood and thoroughly washed with water to remove unwanted materials and make it in the powdered form. The weighed amount of sample was put in the container; water was added in the proportion of (1:2). The mixture was left for 48 hours. The residue is collected by heating of mixture in oven. The major properties of constituent materials used in concrete mix as shown in Table 1. In this study concrete mix of M30 is designed as per IS: 10262-2009. Four mixes have been carried out and quantity of materials has shown in the Table 2.

Table - 1: Properties of Constituent materials of concrete

Materials	Properties	
Ordinary Portland cement (OPC) 53grade	Specific Gravity	3.14
Fine aggregate	Specific Gravity Fineness modulus Bulk Density Loose state Rodded state	2.65 2.72 1509 kg/m^3 1718.6 kg/m^3
Coarse aggregate	Specific Gravity Bulk Density Loose state Rodded state	2.76 1410 kg/m^3 1586 kg/m^3
Calcium nitrite	Specific Gravity	1.91
Azadirachta indica	Specific Gravity	1.72
Dehydrated Aloe-Vera powder	Specific Gravity	1.78

Table -2: Quantity of materials for 1 m^3 of concrete

Mix Designation	Calcium Nitrate	Neem Powder	Dehydrated Aloe-vera powder
C	0	0	0
N	9.53	0	0
G1	0	9.53	0
G2	0	0	9.53

The weight of cement, fine aggregates and coarse aggregates required remain same for the all mixes and the values are as follows,

Weight of cement = 476.1 kg/m^3
Weight of sand = 882.1 kg/m^3
Weight of coarse aggregates = 820.5 kg/m^3

The corrosion resistance of the reinforcement was evaluated with the help of weight loss measurement and accelerated corrosion test. Cement mortar cubes of 70.6 mm x 70.6 mm x 70.6 mm were casted for finding the compressive strength of the cement. Concrete cubes of 150 mm x 150 mm x 150 mm were casted for finding the compressive strength of concrete. Concrete cylinders of 300 mm length and 150 mm diameter were casted for finding the split tensile strength and modulus of elasticity of the concrete.

2.2.2Tests on Concrete

Four combinations of mixes were carried out such as C, N, G1 and G2 mixes. The concrete cylinder size of 150 mm length and 75 mm diameter were cast with HYSD steel bar of 16 mm diameter embedded centrally into it. (All quantities are in kg/m^3)

III.RESULTS AND DISCUSSIONS

3.1 Strength Tests

3.1.1Compressive strength of the cement

The standard consistency of OPC 53 grade cement has been measured with inhibitors and without inhibitors. The values of standard consistency have shown in the Table 3.

Table - 3: Standard consistency value of cement

S.No	Mix Designation	Standard consistency value (%)		
		2 %	5%	10 %
1	C	29.5	32	34.5
2	N	31	32.5	37
3	G1	31.5	34	39
4	G2	33	36	43

It is observed from Table 3. The percentage of inhibitors increases with increase of standard consistency value. Because of high standard consistency value, the w/c ratio is high and the strength of the concrete will get reduced. So, the addition of inhibitor is restricted up to 5 %. Based on the standard consistency value, the compressive strength of the cement mortar with 2 % and 5 % of the inhibitors has been measured at 3 days, 7 days and 28 days respectively and the test results are shown in Table 4 and Table 5.

Table - 4: Compressive strength of cement mortar for 2 % of inhibitors

S.No	Mix Designation	Average compressive strength (N/mm²)		
		3 days	7 days	28 days
1	C	33.6	46.2	57.34
2	N	30.5	41.7	56.98
3	G1	31.8	38.4	54.45
4	G2	26.9	37.1	53.5

Table- 5: Compressive strength of cement mortar for 5 % of inhibitors

S.No	Mix Designation	Average compressive strength (N/mm²)		
		3 days	7 days	28 days
1	C	33.6	46.2	57.34
2	N	26.5	36.5	49.25
3	G1	20.7	23.6	45.78
4	G2	16.7	20	40.15

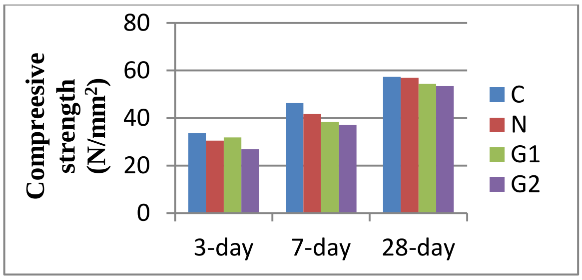

Chart -1: Compressive strength of cement mortar cubes for 2% of inhibitors

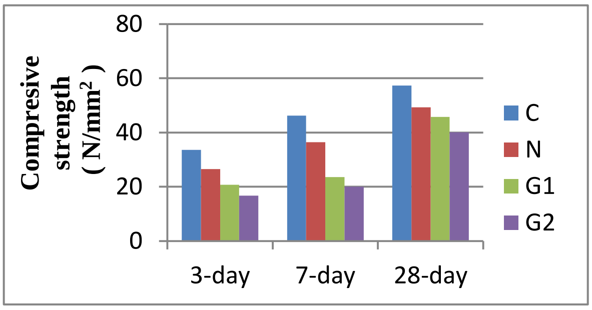

Chart -2: Compressive strength of cement mortar cubes for 5 % of inhibitors

It is observed from Figure 1 and Figure 2. The compressive strength of the cement mortar cubes of 2 % inhibitors are showed better results than the strength of the cement mortar cubes of 5 % inhibitors. But, at the same time the strength of cement mortar cubes of 5 % inhibitors is much less than the conventional cement mortar strength.

3.1.2 Compressive strength of the concrete

The compressive strength results after 28 days curing are shown in Table 6.

Table- 6: Compressive strength of concrete

S.No	Mix Designation	Average Compressive Strength (N/mm²) at 28th day
1	C	38.2
2	N	41.2
3	G1	37.7
4	G2	35.1

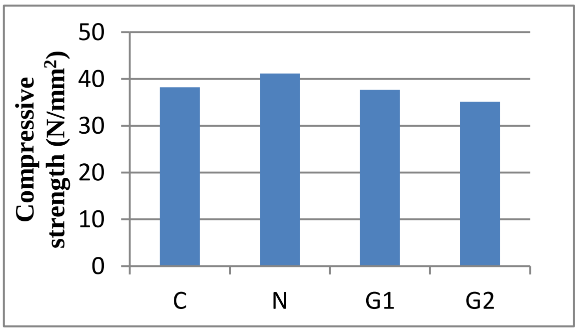

Chart -3: Compressive strength of concrete

From the Figure 3, the compressive strength of concrete with calcium nitrate inhibitor is increased by 7.85% than conventional concrete. At the same time, compressive strength of concrete with neem powder inhibitors is nearly same as conventional concrete.

3.1.3 Split tensile strength of concrete

The split tensile strength results after 28 days curing are shown in Table 7.

Table - 7: Split tensile strength of concrete

S.No	Mix Designation	Average Split tensile Strength (N/mm^2) at 28th day
1	C	2.48
2	N	2.76
3	G1	2.66
4	G2	2.22

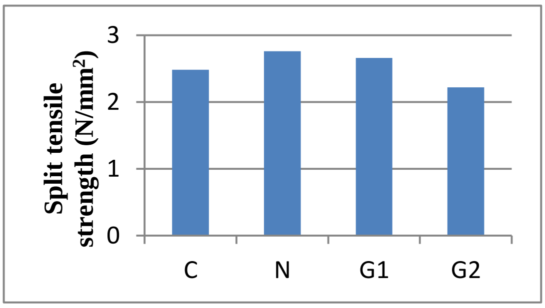

Chart -4: Split tensile strength of concrete

It is observed from Figure 4. The split tensile strength of concrete with calcium nitrate inhibitor is increased by 11.29% than conventional concrete. At the same time, Split tensile strength of concrete with neem powder inhibitors is increased by 7.29% than conventional concrete. But, in aloe vera inhibitor, 10.48% is reduced.

3.1.4 Flexural strength of concrete

The flexural strength results after 28 days curing are shown in Table 8.

Table - 8: Flexural strength of concrete

S.No	Mix Designation	Average Flexural Strength (N/mm^2) at 28th day
1	C	6.27
2	N	6.45
3	G1	5.87
4	G2	5.13

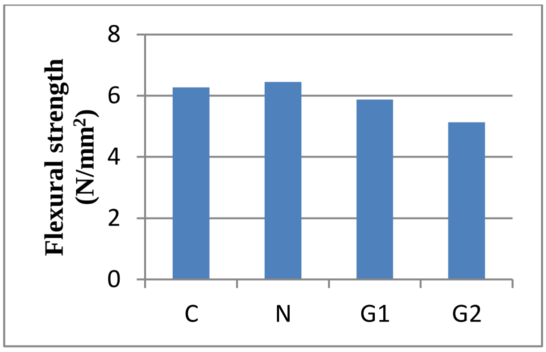

Chart -5: Flexural strength of concrete

It is observed from Figure 5. The flexural strength of concrete with calcium nitrate inhibitor is increased by 2.87% than conventional concrete. At the same time, Flexural strength of concrete with aloe-vera powder inhibitors is reduced by 18.14% than conventional concrete.

3.1.5 Stress – Strain curves

The cylinder was placed in compression testing machine with longitudinal compressometer used to measure the strain. The strain-stress curves for different concrete mixes have shown in the Figure 6.

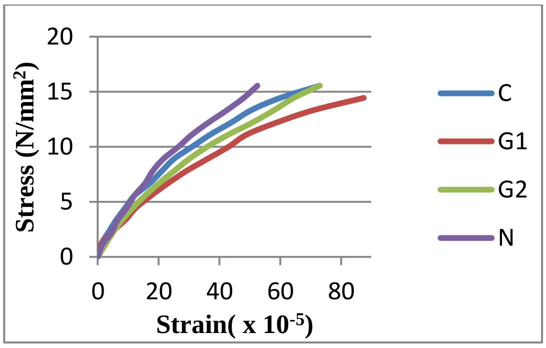

Chart -6: Stress-strain curves

From the Figure 6, the modulus of elasticity has calculated for different combinations.

Table- 9: Modulus of elasticity of the concrete

S.No	Mix Designation	Modulus of elasticity (N/mm^2) at 28th day
1	C	38420
2	N	39510
3	G1	36285
4	G2	32589

The modulus of elasticity of the different concrete mixes have shown in Table 9.The modulus of elasticity of concrete with calcium nitrate inhibitor is increased by 2.75 % than that of conventional concrete. But, at the same time modulus of elasticity of concrete with neem powder and aloe vera powder inhibitors are reduced by 5.56 % and 15.17 % respectively than the conventional concrete.

3.2Durability Tests

3.2.1 Accelerated corrosion test

Accelerated corrosion test is based on the electrochemical principle. The concrete cylinder of size 75 mm diameter and 150 mm length were cast with HYSD steel bar of 16 mm embedded centrally in to it. After 28 days curing, the specimen was immersed in the saline media (3% NaCl). The rebar projecting at the top is connected to the positive terminals of the power pack (anode) and the stainless steel plate is connected to the negative terminal (cathode). The test specimens were subjected to a constant voltage of 6 volts from D.C power pack. This setup forms an electrochemical cell. The applied voltage is kept constant continuously and the current response is monitored with respect to time. The current was taken to initiate corrosion in mA for different combinations. The corrosion initiation time of different concrete mixes have shown in Figure 7.

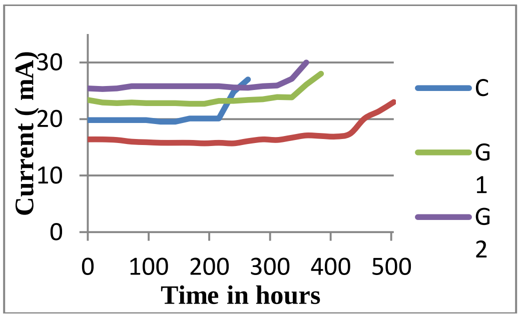

Chart -6: Accelerated corrosion test

From the Figure 7, we observed that the chemical inhibitors have high corrosion initiation time. But, at the same time the green corrosion inhibitors showed better results compared to convention concrete.

3.2.2 Gravimetric weight loss test

The initial weight of the rod was measured and embedded in the center of cylindrical concrete specimens of size 75 mm diameter and 150 mm long. The specimens were subjected to 28 days curing in fresh water. After the curing period was completed the cylinders were immersed in 3% NaCl solution under alternate wetting (3days) and drying (3days) conditions over a period of 60 days. At the end of 60days the cylinders were broke open and the final weight of the specimens was taken. Then the corrosion rate was measured in mm/y (millimeter/year) by using the expression [3]. The corrosion rate of different concrete mixes has shown in Table 10.

Table - 10: Gravimetric weight loss measurement

S.No	Mix Designation	Corrosion rate in mm/y
1	C	0.374
2	N	0.156
3	G1	0.128
4	G2	0.269

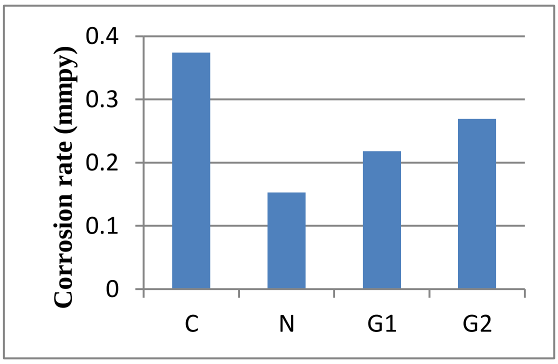

Chart -7: Gravimetric weight loss measurement

From Figure 8, it is inferred that the corrosion rate is high for the conventional concrete. The chemical inhibitor is showed better results among all. But, the green corrosion inhibitors are showed better results compared to conventional concrete.

Extracts of plant materials contain a wide variety of organic compounds. Most of them contain heteroatoms such as P, N, S, O. These atoms coordinate with the corroding metal atom (their ions), through their electrons. Hence protective films are formed on the metal surface and hence corrosion is prevented. The following is the trend observed on the basis of time taken for initiation of corrosion and reduction in corrosion rate: N > G1 > G2 > C

IV.CONCLUSIONS

The following conclusions can be stated based on both mechanical and corrosion test results of the reinforced concrete with inhibitors.

- The results of inhibitors studied showed that Azadirachta indica has superior corrosion inhibition efficiency compared to Aloe-vera inhibitor.
- The chemical corrosion inhibitor showed good corrosion inhibition among four combinations but its corrosion inhibition efficiency slightly more than the Azadirachta indica inhibitor.

- The results of inhibitors related to strength properties showed that, the chemical corrosion inhibitor has better strength properties among all.
- But, at the same time green corrosion inhibitors have strength properties nearly same as conventional concrete. The addition of given green inhibitors do not significantly affect the hardened properties of concrete.

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